

EVALUATION OF THE PROBABLE SUSCEPTIBILITY TO LANDSLIDE IN THE MUNICIPALITY OF BAI MARE (MARAMUREȘ COUNTY)

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ABSTRACT. - Evaluation of the probable susceptibility to landslide in the municipality of Baia Mare (Maramureș County). The General Urban Plan of the municipality of Baia Mare needs a study of the probable susceptibility to landslide in order to organize the infrastructure corresponding to the requirements of sustainable development. The complexity and diversity of local geographical factors, strongly influenced by human interference, favor the release and spread of elevation processes in the piedmontan and montane areas of the municipality. In order to prevent major unbalance there is a need for implementation of proper measures based on thorough studies.

Key words: susceptibility to landslide, landform energy, digital terrain model.

1. General considerations

Romania's Accession Protocol to the European Union, Appendix VI-Environment Section (March 31st, 2005, Bruxelles), stipulates firm obligations and strict deadlines concerning the air and water quality, waste management, industrial and agricultural pollution and risk management.

In accordance with these terms, but also before accession, Romanian legislation has focused on these matters (Law 124/1995, HGR 124/1995, Law 575/2001, HGR 382/2003, HGR 447/2003, Ord. MLPAT/MAPL 62/N/1998 etc together with specific urban planning regulations, construction location, designing and authorization of projects, as well as measures taken in order to diminish destructive effects)

Of all these, HGR 447/2002 refers explicitly to *The Methodological Norms and the Content of Maps for Natural Risk to Landslide and Flooding*. The law

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stipulates in chapter I, article 3 (2) that *the natural risk map of landslide is the document which lays at the foundation of a county council's decision to declare an area as exposed to the risk of landslide*". while art. 4 mentions that on the basis of these maps, "*local public authorities declare, monitor and ensure the management of crisis situations caused by landslide, establishing measures to prevent and diminish the natural risk of landslide, as well as the conditions which need to be met in order for constructions to be authorized in such areas.*"

2. Methodology

The drafting of the landslide susceptibility map, both for the territorial and administrative division of Baia Mare and for the incorporated area, had at its basis the two methodologies: HGR 447/2003 concerning *The methodological norms for drafting and the content of the maps of natural risk of landslide and flooding*, materialized in the *Writing Guide of risk maps to flank landslide in order to ensure the stability of constructions- Indices GT-019-98*, and an improved methodology, tested and used by the Geography Institute of the Romanian Academy. Both take into consideration the most significant natural and anthropic indices which contribute to the landslide phenomenon; in both cases, component quantization and analysis according to the respective relations, have led to the creation of qualitative classes concerning the susceptibility to landslide.

In order to process geographical data, the methodology presented in this paper has used geographical modeling techniques, in which the maps expressed as raster layers, are treated as part of algebraic equations which allow for the derivation of new maps. The software used to develop the model of susceptibility to landslide is the suite of programs ESRI (Map Algebra from ArcGIS Spatial Analyst)

In order to obtain the map of susceptibility to landslide, we calculated the indices of susceptibility, taking into consideration six factors which generate landslides: lithology, elevation, landform energy, land use, precipitation and seismicity, according to the following formula:

$$LSI = (F1 \times 35 + F2 \times 25 + F3 \times 15 + F4 \times 10 + F5 \times 10 + F6 \times 5) / 100$$

These six factors have been selected based on two criteria: accessibility and spatial resolution of the data.

The data source for the variables elevation and landform energy is constituted by the Digital Terrain Model obtained on the basis of topographic information from the maps 1: 25.000. The pixel resolution of DTM is 10 meters. While the GIS program generates automatically the data on the elevation parameter from the DEM, the landform energy, defined as the difference between the maximum and the minimum altitude, has been generated as extra information in relation to the elevation.

The land use parameter has been processed from the Corine Land Cover 2000 database (*Coordination of Information on the Environment*), at the level registered in the year 2000. This set of European reference data contains 44 classes of land coverage, grouped in three hierarchical levels.

The lithology has been obtained using geological maps at the scale of 1:200 000, drafted by the Romanian Institute of Geology (1968-1970). The attributes derived from this map are mainly the chronostratigraphic units and their lithological description.

The data layer concerning seismicity has been derived from the Romanian Standard SR 11100/1-93, drafted after the serious earthquake of 1977, which differentiates 4 classes of MSK intensity, representing the intensity values of probable earthquakes for a time frame of 100 years.

The map of maxim precipitations per 24 h is based on the recorded quantities (1872-2005) and differentiates among 4 classes: <100 mm, 100-150 mm, 150-200 mm and >200 mm (Dragotă, 2006).

The Landslide Susceptibility Indices (LSI) has been calculated using ArcGIS and a series of functions from Spatial Analyst. It was presumed that landslides cannot appear on surfaces with the lowest elevation (0-2°), and neither can they happen on water surfaces, water courses and marshes. For these surfaces, the LSI value will be 0, regardless of the values of landform energy, seismicity or precipitations. The LSI calculated through the integration of the above mentioned factors may have values ranging between 0 and 10. These values have been grouped in five classes of susceptibility: no susceptibility (0-2), low susceptibility (2-4), average (4-6), high (6-7) and extremely high (7-10).

3. The drafting of thematic maps

The Digital Terrain Model (3D). The altitudinal deviation of the territorial and administrative division of Baia Mare is situated between 180 m (The Săsar riverbed) and 1 306, 6 m (Igniș mountain top). With a north-south orientation and having as main axes the Firizei Valley and the Săsar Valley, the amphitheatre-shaped landform of the area contains the Săsar fen and terraces, the hilly piedmont and the hillocks of Baia Mare, culminating at the Firizei and its tributaries spring, with volcanic mountain peaks of over 1100, belonging to the Igniș and Oaș Mountains (fig. 1). The altitudinal layered mountainous and depression climate, with strong west and north-west influences has as a correspondent, the altitudinal succession of vegetal layers (mainly wood), the presence of the comestible chestnut being characteristic due to the climatic shelter of the depression.

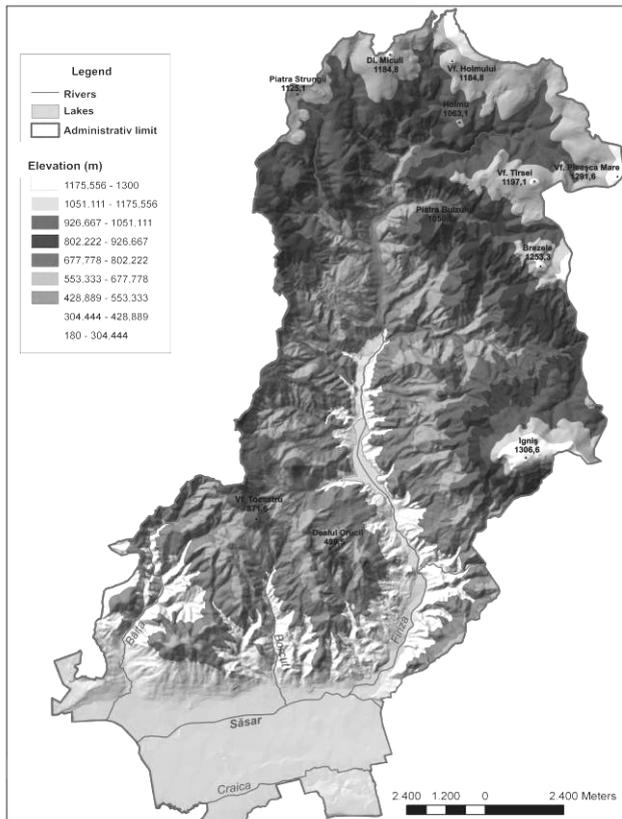


Figure 1. The 3D model of the Baia Mare territorial and administrative division.

The elevation map of the territorial and administrative division of Baia Mare, having a gradient of 1° , has allowed for the drawing of an image which is very similar to the reality (fig. 2).

Obviously, almost horizontal terrains ($0-0.72^\circ$) are characteristic first and foremost for fens and valleys; but, because the surface of a pixel is of 100 m^2 , such elevations are also present on inter-fluvial peaks, even belonging to volcanic hummocks. The greatest part of flat surfaces belongs to the Săsar fen and terraces, situated on both sides of the river.

All of these surfaces are stable, but due to the lithologic conditions specific to terraces, occasional flooding, water stagnation or stailment.

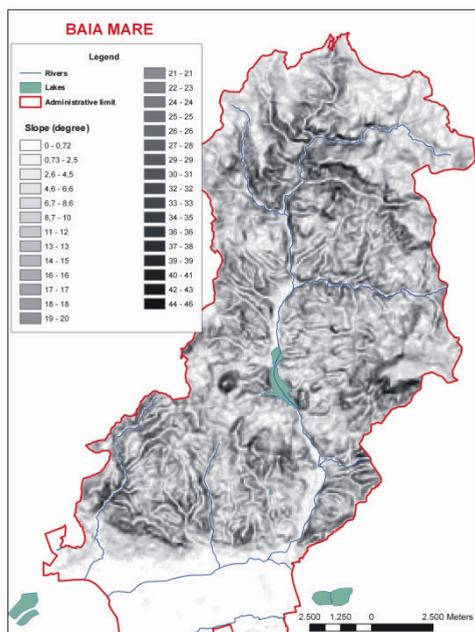


Figure 2. The Elevation Map in the territorial and administrative division of Baia Mare.

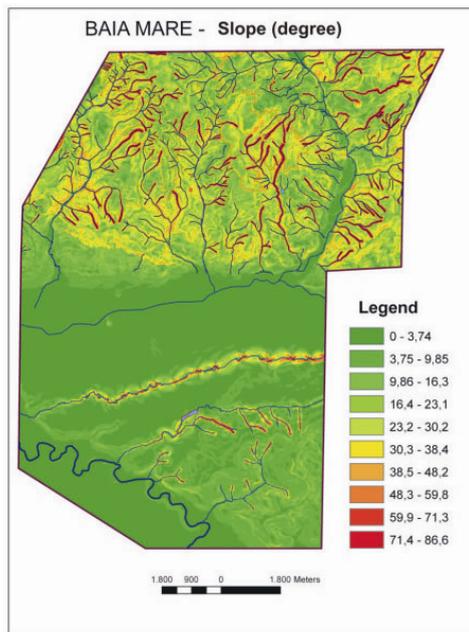


Figure 3. The Elevation Map of the incorporated areas of Baia Mare.

Greater elevation values of above 30° or even 40° are characteristic for the superior hollow of the Firiza and to the slopes of the volcanic hummocks. The presence of hard and compact andesite confers, however, stability to these slopes.

The *elevation map of the incorporated areas of Baia Mare*. The greatest part of the incorporated areas has an elevation level between $0-1^\circ$, corresponding to the Săsar spring. Here we include the 4-5 m terrace on the right and left side of the river, the 20-25 m terrace to the Cărbuneasa Valley; towards the Lăpus fen the 20-25 m terrace is distinct with an elevation of $10-20^\circ$ (fig. 3).

These surfaces are characterized by high stability, but can be easily flooded due to the lack of regularization and maintenance of riverbeds. This the case of the Craica river, a meandering course, for the greater part without dams; if on the superior reach and on the medium riverbed, although characterized by a meandered belt, it has 1-3 m banks with an elevation of up to $30-50^\circ$, in the lower reach, towards the confluence with the river Lăpuș, the valley is a little fixed-edge, the elevation of the banks not exceeding $10-15^\circ$.

The piedmontan strip between the Borcut and the Usturoi Valley, which narrows itself from west to east, is characterized by an elevation of $15-25^\circ$, the contact with the mountain area (elevation of $30-40^\circ$) being trenchant. Actually, the

greatest number of landslides (old, fossilized, reactivated or new) has been reported here. Among the conditions that favour landslides here, we can mention: the abundance of argyle formations in piedmontan deposits, the input of surface and phreatic outflow from the nearby mountain area and the sometimes inappropriate land usage, including through construction. *It can be deduced that this area is the most vulnerable to geomorphologic processes (landslides) and it requires close monitoring.*

The piedmontan sector between the Usturoi and Firiza Valley, with the same elevation value, it is narrower and as a consequence, susceptibility to landslide is lower, only manifesting itself on small surfaces. The montane area, in which elevations of 30-40° predominate, is characterized by short and deep valleys (elevations of 50-70°) and, thus, by erosion processes. Taking into consideration the increase in frequency lately of strong and short rainfall in the small watershed areas, we can expect the intensification of surface erosion and solid discharge; the protection of forest vegetation being the best prevention.

The map of landform energy. This geomorphologic index is extremely important in establishing the altimetric “potential” of a sample surface. Practically, it represents the difference between the maximum and the minimum altitude related to 1 km² (m/km²). It constitutes simultaneously one of the necessary factors/components for the estimation of the susceptibility index. Drawing the landform energy map for the territorial and administrative division and incorporated areas of Baia Mare, has been done using modules from the software suite ArcGis 9.2 (fig. 4).

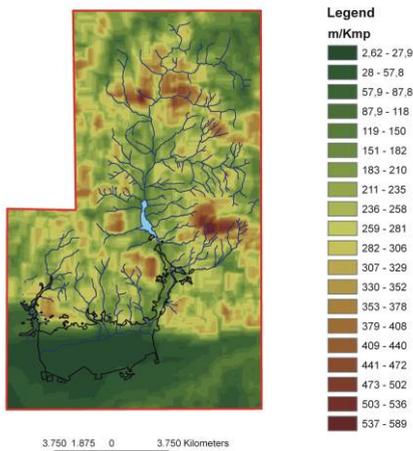


Figure 4. The landform energy map in the territorial and administrative division of Baia Mare.

As expected, in the incorporated areas, the minimum values (2,62-27,9 m/ km²) can be found in the Săsar fen and on the 4-5 m terraces on its left side, where the altitudinal differences per surface unit is low. On the corresponding terrace from the right side of the river, the landform energy increases gradually reaching values of 260-280 m/km² close to the Usturoi Valley and between the St. Ioan and Vicleanul Mare valleys, to the northern limit of the incorporated areas. Punctually, in a few isolated areas of the incorporated areas on the left of side of the Borcut valley, values of 454-502 m/km² can be found. These high values create special difficulties when it comes to construction and infrastructure elements (access roads, sewers, water, gas

and electricity distribution systems), while also increasing the landslide vulnerability index. The highest values of landform energy in the territorial and administrative division of Baia Mare, 500-600 m/km² can be found in the high mountainous areas, at the Firiza spring and in the surroundings of the Igniş peak. In the territorial and administrative division of Baia Mare, the low and medium classes predominate in the mountainous areas. The stable surfaces, where the possibility of landslide is low or inexistent, are to be found concentrated around the Săsar river and in particular places around the compact and wooded volcanic peaks. A high susceptibility to landslide is characteristic for the piedmontan level, which although presents a medium declivity, it is full of adobe and water deposits in which marl-argyle have an important role. The validity of the methodology used also resides from the presence of different types of landslide which have been identified and mapped here.

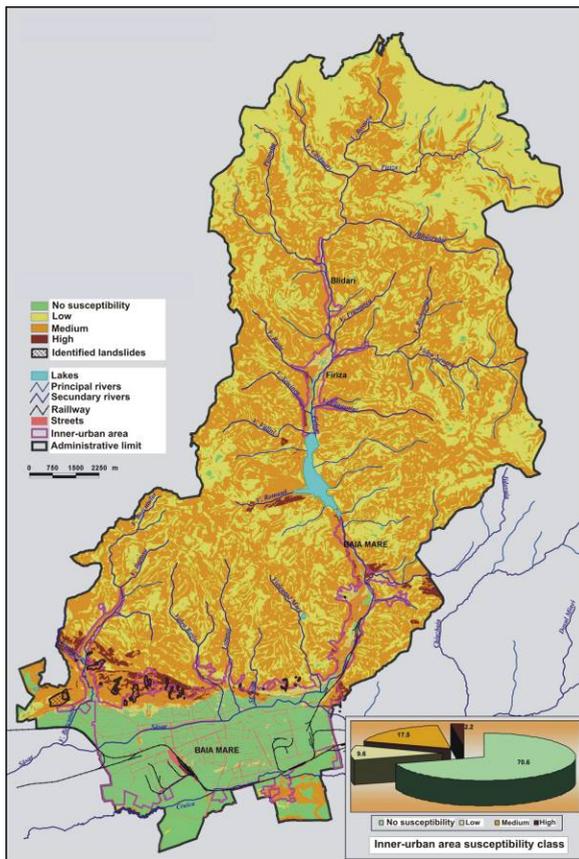


Figure 5. The probable susceptibility to landslide in the territorial and administrative division of Baia Mare.

The expansion of the residential areas of Baia Mare municipality happens specifically along the Săsar piedmont and in the Baia Mare- Seine direction, which is precisely in those areas where such an expansion is not recommended from a geo-technical point of view. This is due to the semi-consolidated materials present from the nearby volcanic area such as gravel and ballast, in which argyle predominates. Taking into consideration the elevation given (generally 6-17°), these have a high susceptibility to fluvatile-denudational processes (cloughs and gushes) and to landslide.

The northern piedmontan sector of the incorporated area can be separated in several sectors:

The V. Roşie and

Usturoi Valley. Even if they have pronounced elevations, they both have a lower morpho-dynamic potential, due to the hard andesine rocks that can be found in the sedimentary sub-layer.

The Florilor Hill Sector has a medium morpho-dynamic potential, the extension of the sedimentary rocks in the sub-layer being relatively reduced.

The Crucii Hill Sector has a medium morpho-dynamic potential, attenuated by the presence of stable andesine pumice rocks.

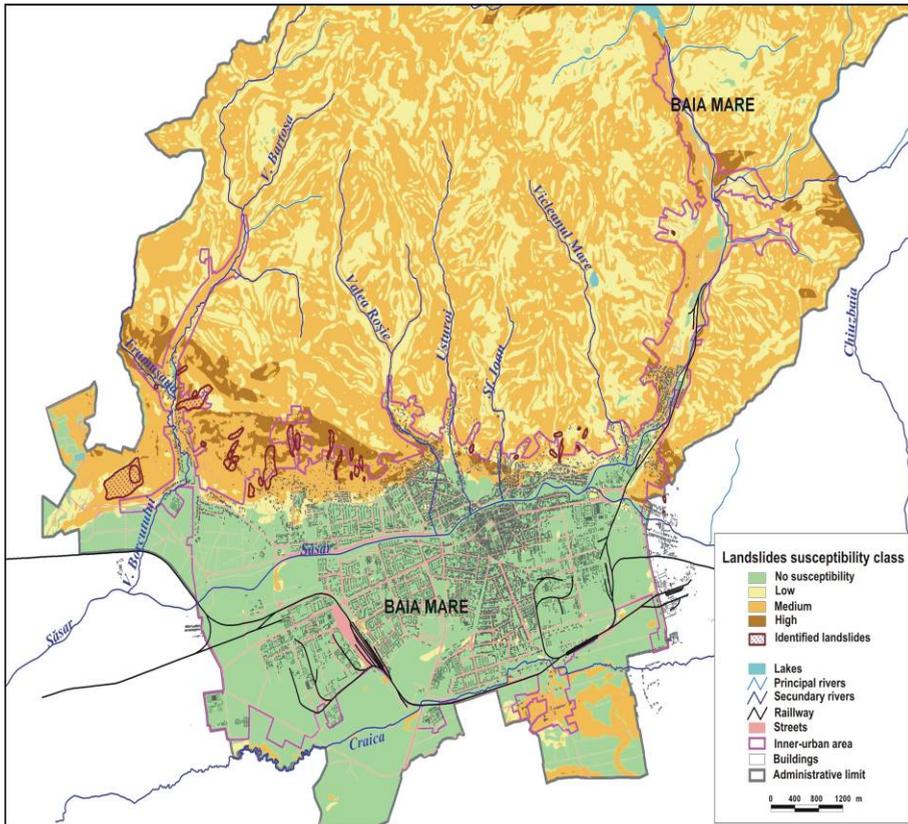


Figure 6. The probable susceptibility to landslide in the inner-urban areas of Baia Mare.

The Amada and Firiza Valley Sector. Here we can find a vast development of colluvial and alluvial deposits, and to the east, stable eruptive rocks appear to the bottom of the glacis. The pronounced elevation and the great extension of pannonian sedimentary rocks in the quaternary deposits sub-layer, determines a high morpho-dynamic potential.

The Firiza Valley up-river Sector presents an alternation between pannonian and quaternary deposits. A genetic complexity of the glacis can be noticed. The piedmontan deposits have been removed through erosion from the area between the Săsar River and the volcanic formations, and at the bottom of the erosion glacis formed on the sedimentary formations, a colluvial-alluvial glacis has formed. The erosive sector is characterized by an 8-15° elevation, while the accumulative sector has elevations lower than 8°.

The incorporated areas susceptibility to landslide map (fig. 5) outlines that 71% of its surface is stable, not exposed to landslide; however, right in its center we can notice small areas with low and medium susceptibility values (especially on the left side of the Craica Valley). 2,2 % of the incorporated areas has a high susceptibility to landslide, particularly in the piedmontan stretch between the Borcut and Roșiei Valley, *thus needing appropriate measures concerning land use and the design and execution of any constructions* (fig. 6).

4. Conclusions and recommendations

The territorial and administrative division of Baia Mare and its incorporated areas is situated on several landform levels, each having its particular characteristics, clearly differentiated (lithologic, geologic, structural, climatic, pedological, bio-geographic, hydrologic, and hydro-geologic), a fact which is reflected in the land use methods.

The joint dynamics of natural factors, corroborated with a more and more intense human intervention, sometimes delayed and in contradiction with the natural evolution, imposes the need for appropriate strategies which will not lead to the release/ intensification of imbalances, but will actually lead to a sustainable and efficient development.

The current geomorphic processes present in the territorial and administrative division of Baia Mare and in its incorporated areas especially concern: the stability of slopes/surfaces and of minor riverbeds; the stability and regularization of minor riverbeds. The stability of the 4-5 m surfaces of the Săsar river fen and terraces does not cause special issues, but the need to respect the current regulations in the case of any construction work is still present.

The area with the greatest number of active current processes (landslides) corresponds to the piedmontan level on the right of the Săsar River, parasitized at the contact with the terraces by the dejected cones from the affluents (Borcutul, Roșie Valley, Usturoi, St Ioan Valley). Old, reactivated and new landslides, have been identified here. Taking into considerations the ample presence of new constructions it is strongly necessary to respect specific regulations; where it's necessary, there is a need for drainage works and the consolidation of slopes.

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