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SLOPE SUSCEPTIBILITY TO LANDSLIDES IN THE TARNAVA MARE CORRIDOR, BETWEEN MEDIAS AND BLAJ (ROMANIA)

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Slope susceptibility to landslides in the Târnava Mare corridor, between Mediaş and Blaj (Romania).

Marius Paisa, Florina Grecu, Raluca Alexandru

Slope susceptibility to landslides in the Târnava Mare corridor, between Mediaş and Blaj. Un certain nombre de modèles et de méthodes qualitatifs et quantitatifs sont disponibles pour le calcul des cartes de risques de glissements de terrain et de susceptibilité. Le zonage de susceptibilité aux glissements de terrain implique un certain degré d'interprétation. L'évaluation de la susceptibilité aux glissements de terrain est nécessaire pour éviter la dégradation du terrain et l'évaluation de la susceptibilité aux glissements de terrain nécessite de comprendre les facteurs qui influencent l'instabilité des pentes. Même si les glissements de terrain sont principalement associés aux zones de montagne, ils peuvent aussi se développer dans les zones de basse altitude, comme c'est le cas d'interventions anthropiques directes (excavation de talus, déforestation, routes improvisées, etc.). Les cartes de susceptibilité issues de cette étude expriment les conditions du terrain et ont une utilité pratique pour identifier les zones de glissements de terrain dans le corridor. La distribution spatiale et la classification des unités de terrain en fonction de la propension à produire des glissements de terrain dépendent de la topographie, de la géologie, des propriétés géotechniques, du climat, de la végétation et de facteurs anthropiques tels que le développement et la déforestation intensive.

Mots clés: susceptibilité, danger, bassin hydrographique de Târnava Mare, glissements de terrain.

Slope susceptibility to landslides in the Târnava Mare corridor, between Mediaş and Blaj. A number of qualitative and quantitative models and methods are available for computing landslide-hazard and susceptibility maps. Landslide susceptibility zoning involves a degree of interpretation. The landslide susceptibility assessment is necessary to prevent terrain degradation and the evaluation of landslide susceptibility requires understanding the factors that influence slope instability. Even though landslides are mainly associated with mountain areas, they can also develop at lower altitude areas, such is our case where they are caused by direct anthropogenic intervention (through slope excavation, deforestation, improvised roads, etc.). The susceptibility maps that resulted from this study express the terrain conditions and have practical use for identifying the landslide areas within the corridor. The spatial distribution and rating of the terrain units according to the propensity to produce landslides is dependent on the topography, geology, geotechnical properties, climate, vegetation and anthropic factors such as development and intensive deforestation.

Key words: susceptibility, hazard, Târnava Mare river basin, landslides.

1. INTRODUCTION

In the specialized literature the terms of susceptibility and landslide hazard are often used interchangeably, although they are different concepts (Guzzetti, 2005). Landslide susceptibility is the probability that a landslide will occur in an area characterized by certain environmental conditions (Brabb, 1984) and it reffers to the degree to which a surface can be affected by slip processes. In contrast, the hazard is the probability that a landslide of a certain magnitude will occur in a particular time and in a certain area. In addition to prediction of where the sliding will occur, landslide hazard forecasts "when" or "how often" it will occur and "how much" will it be (Grecu, 2006). Thus, susceptibility is the spatial component to landslides hazard.

In Romania, the necessity of creating hazard maps was first explored by Petre Coteţ (1978). Eventually, risk assessment maps were developed, especially in doctorate thesis, without following a consistent methodology. Significant contributions to this domain were added by: Bălteanu (1983, 1992), Bălteanu et al. (1989, 1994), Grecu (1994, 1996, 1997, 2001, 2002), Cioaca (2002), Sandu (1994, 1997), Florea (1998), Grecu, Comănescu (1997, 1998), Brânduş, Grozavu (2001), Urdea (2000), Voiculescu (2002), Armaş et al. (2003), Sorocovschi (2002, 2003) etc.

In recent decades we've seen an increasing information base aimed at in-depth knowledge of the process of sliding. This information is mainly based on interdisciplinary studies, used in the development of numerous policies relating to weather phenomenon and determining areas susceptible to landslides, large-scale studies justified by natural disasters around the globe, some of which are influenced in a growing share by the high human impact (Cătescu et al., 2012).

In Romania, the geomorphological literature, assessments and methodological references on landslide susceptibility were made by Bălteanu et al. (1989), Rădoane et al. (1993), Cioacă (1996), Grecu (1997, 2002), Armaş (2003, 2006), Prefac et al. (2008) etc.

By combining the successive stages of the spatial distribution maps of the factors responsible for landslide processes (the degree to which they contribute to the destabilization of the slope), resulted in the sliding susceptibility zoning map (Montgomery et al., 1991; Pachauri, Pant, 1992; Rădoane et al., 1993; Mejia-Navarro et al., 1994; Grecu, 1997; 2002; Pachauri et al., 1998; Moreiras, 2005 etc.).

Recently, numerous studies have focused on evaluating the landslide susceptibility based on probabilistic computing models such as Bayes theory, known as the "Weight of Evidence" (Bonham-Carter, 1991; Lee et al., 2002; Armaş et al., 2003), likelihood ratio

(Chung, Fabbri, 2003, 2005; Fabbri et al., 2003; Lee, 2004), certainty factors (Chung, Fabbri, 1993, 1999; Binaghi et al., 1998) etc.

2. METHODOLOGY

2.1. Studied area

The Târnava Mare hydrographic basin is located in the central part of Romania, as a part of the Mures hydrographic basin. The Târnava Mare river springs out of the volcanic chain of the Eastern Carpathians (south-eastern part of the Gurghiu mountains, at 1441 m), crossing the Transylvanian Sub-Carpathians and the Târnavelor Plateau until Blaj, where it meets the Târnava Mică river, temporarily creating the united Târnava, flowing into Mureş, downstream of Mihalţ village.

The Târnava Mare hydrographic basin has a surface of 3606 km^2 and the main stream has a length of 223 km, the absolute fall from spring to shedding is 1202 (Konecsny, 2006). The studied corridor is located between Mediaş and Blaj, occupying a surface of 739,33 km^2, being framed by the geographical coordinates 23°49'12" and 24°22'04" eastern longitude and 46°15'14" şi 45°59'30" northern latitude (Figure 1).

The geology of the studied area is relatively simple as it overlaps a Neogene sedimentary package belonging to Sarmatian and Pannonian deposits, uncemented rocks (sands and gravels) or weakly cemented rocks (friable sandstone, thin horizons of conglomerates, clays and marls).

2.2. Materials and methods

The landslide susceptibility map was developed in alignment with the 575/2001 Law, 124/1995 Law, HGR 382 and 4447/2003 and Ord. MLPAT/MAPL 62/N/1995/1998, following the "Guidelines for drafting slope sliding risk assessment maps for assuring construction stability " – Indicative GT-019-98.

The slopes susceptibility to landslides was evaluated by combining the following methods: the *HG 447/2003* methodology (semi-quantitative) and the *„weight of evidence"* method (quantitative method). The susceptibility map was obtained by weighting factors based on field observations and the frequency of landslides calculated for each class of each factor considered preliminary.

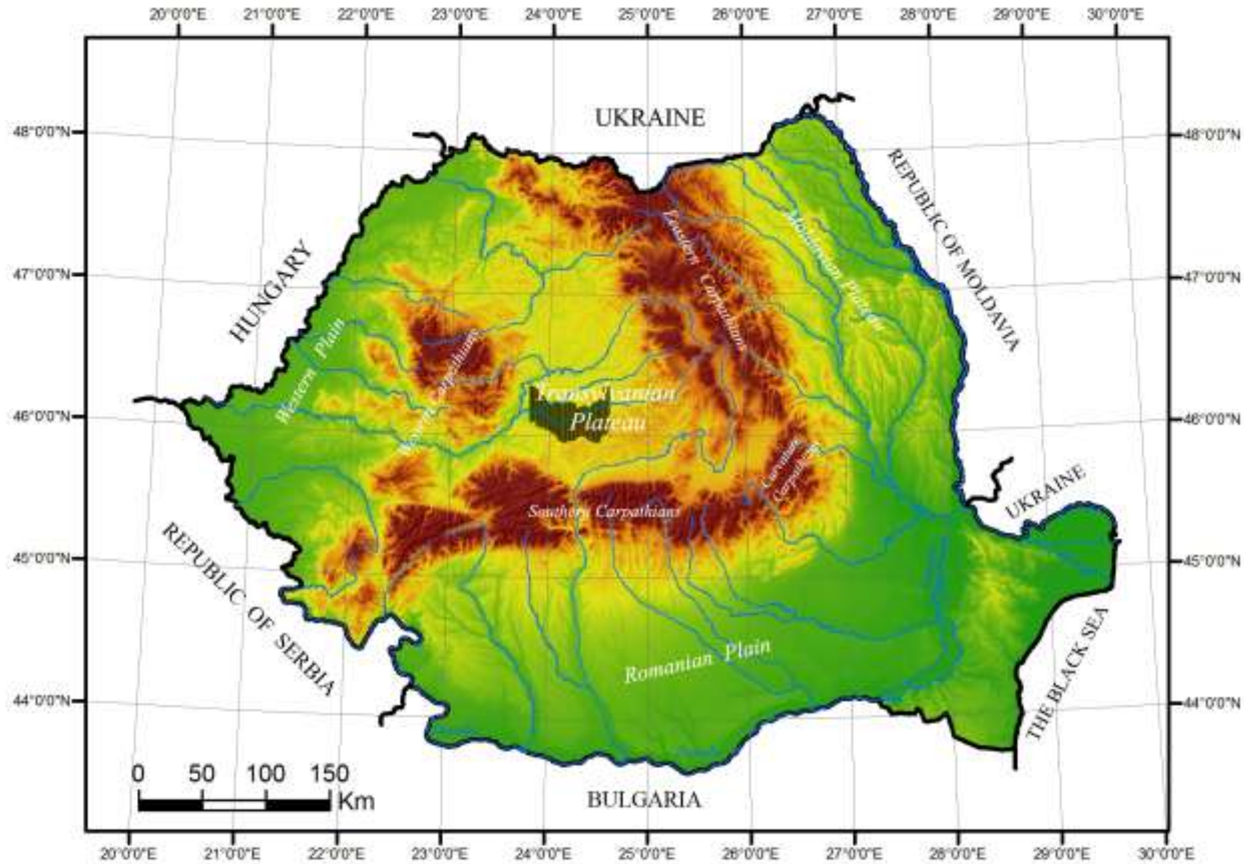


Figure 1. The location of The Târnava Mare corridor, between Mediaş and Blaj, within Romania

The hazard/susceptibility map according to *HG 447/2003* was developed by estimating the importance of each class of the eight factors involved and calculating average coefficient hazard (Km), taking into account the specifications in Annex C.

The susceptibility map achieved by using the *"weight of evidence"* method consisted in probabilistic calculation of weights which are assigned to each class of each factor used. Based on positive and negative weights (computed for each class), resulting contrast values which were used, by summation, in the spatialisation classes of landslide susceptibility.

The validation of susceptibility map achieved through the method weight of evidence indicates a good correlation between susceptibility classes and active landslides. Although it has a good degree of correlation, this method has a tendency to overestimate or underestimate the importance of classes, but it can be limited by field observations.

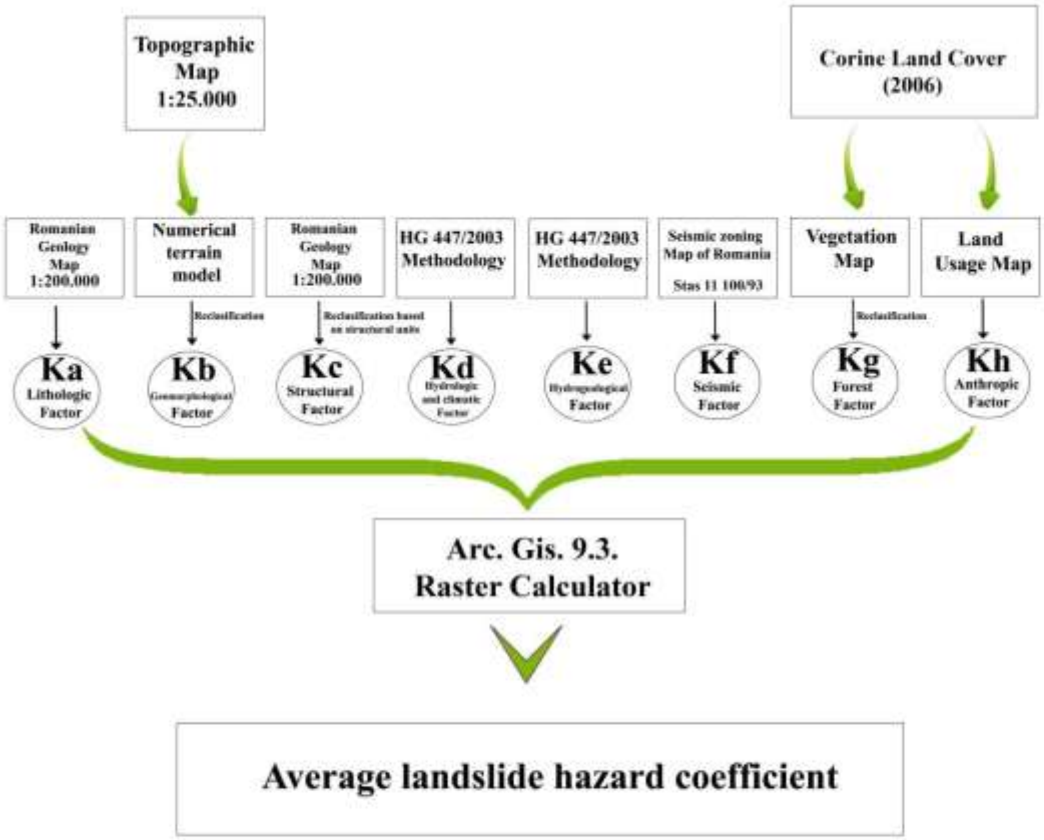


Figure 2. The elaboration layout of the Average landslide hazard coefficient using GIS techniques.

For the developing of the The average coefficient hazard maps for the studied corridor, the following materials were considered and used: Topographic map of Romania, scale 1:25.000; Geological map of Romania, scale 1:200.000; Romania's Soil map, scale 1:200.000; Seismicity zoning map scale MSK (SR-11100-93); orthophotoplans (obtained with Global Mapper 13) and Corine Land Cover data set (2006) which was the base for developing the vegetation and land usage Maps. For the study area these coefficients were calculated at pixel level, for the 20m resolution model. The calculation of the Km coefficient was made with the Spatial Analyst and Map Calculator functions from ArcGIS 9.3. program.

The results were validated by correlating the *Km coefficient* with the landslides mapped in the field using a GPS receiver. The following levels of the potential to cause landslides (low, medium, high) were established according to the Km coefficient (Table 1).

Table 1. Landslide occurrence potential (Driga et. al., 2007)

Landslide occurrence potential					
Low		Medium		High	
Landslide occurrence probability (P%) and the corresponding risk potential (Km)					
Zero	Low	Medium	Medium - High	High	Very High
0	<10	30-Oct	31 - 50	51 - 80	> 80

In order to carry out the analysis of the *GT-019-98 Indicative*, the following formula was used (Driga et. al., 2007):

Km=(Ka*Kb)/6*(Kc+Kd+Ke+Kf+Kg+Kh),

where

Ka= lithologic criterion;

Kb= geomorphological criterion;

Kc= structural criterion;

Kd= hydrological and climate criteria;

Ke= hydrogeological criterion;

Kf= seismic criterion;

Kg= forestry criterion;

Kh= anthropogenic criterion.

The Lithologic criterion (Ka) is based on the classification of geological formations, starting from the average values of superficial formations (diluvium, colluvium, proluvium) or from the basic rocks (shale, marl, limestone) and reaching very high values for uncemented or poorly cemented sedimentary rocks (sands, breccia). Based on the Romanian geological map, the lithological factor in the corridor area was classified as follows: *Ka= 0.5* was assigned to Quaternary (Holocene), composed from gravel and sand; *Ka= 0.7* is assigned to the Sarmatian which overlaps on marl, sand, gravel and tuff formations; *Ka= 0.9* refers to the Pannonian with gravel, sand and clay-marls.

The Geomorphological criterion (Kb) refers to the classification of the study area in the macro-relief units (hills and mountains, plateaus, plains). According to this assignment a classification regarding slope values is emerging (interval values are directly proportional with slope values). Thus, for the study area, these intervals have been defined based on slope gradient: *Kb= 0.1* is for slopes with an angle smaller than 3^{o}; *Kb= 0.3* contains slope values between 3º- 5º; *Kb= 0.4* represents the slope values between 5º-10º; *Kb= 0.6* refers to the slopes with 10º-15º values; *Kb= 0. 8* goes to the slope values of 15º-25º, *Kb= 0.9* with slopes that surpass 25º.

The Structural criterion (Kc) in the Târnava Mare corridor is represented by the class *Kc=0.5* which is assigned entirely to the Transylvanian Depression.

The hydrological and climate criteria (Kd) refers to delimitation of areas depending on the amount of precipitation and erosion potential of the river, amid climate types in our country. Therefore, the *Kd = 0.1* value is assigned for the hill climate encountered in the study area.

The hydrogeological criterion (Ke) is difficult to approach due to lack of hydrogeological maps, which would determine with greater precision the depth at which groundwater lies. Consequently, the criterion values were estimated using the *HG 447/2003 methodology*.

The medium-high values *Ke= 0.5* were assigned to the areas where groundwater flow occurs at high values of the hydraulic gradients, causing pressure filtration. Very small values such as *Ke= 0.1*, were assigned to groundwater with a very low hydraulic gradient (filtration forces are reduced).

The seismic criterion (Kf) was determined by seismic zoning map of Romania, scale MSK (SR -11100-93), which indicates the intensity of earthquakes, in Annex 2 - "Guidelines for drafting slope sliding risk assessment maps for assuring construction stability " – Indicative GT-019-98. The Târnava Mare corridor falls within the values of seismic intensity of 7 (degrees MSK), with the coefficient Kf = 0.75.

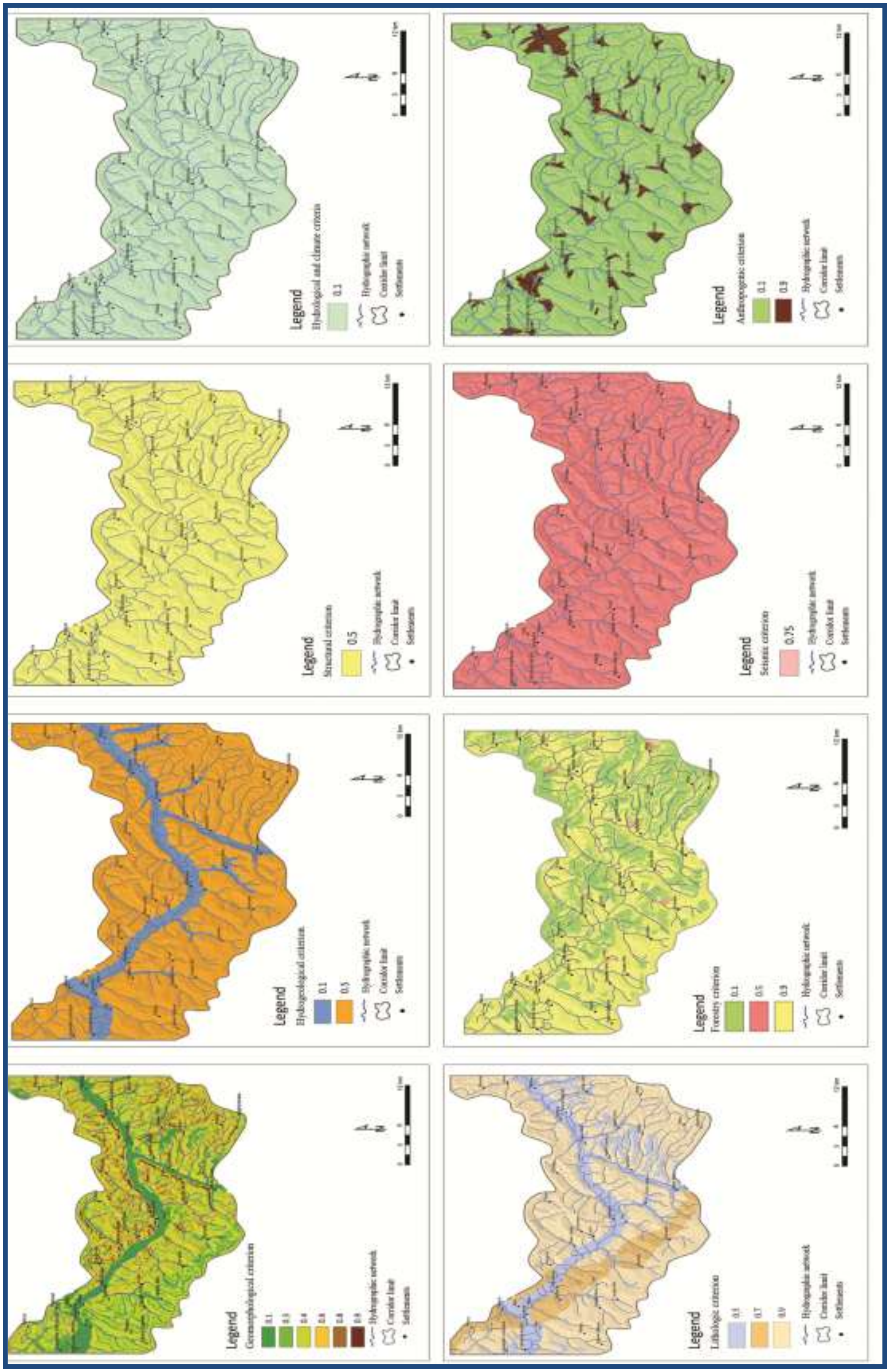
The forestry criterion (Kg) was developed from the Land usage Map, taking into account the vegetation coverage degree. The values for this factor vary from *Kg= 0.1* to *Kg= 0.9* as follows: *Kg= 0.1* for forests, *Kg= 0.5* for orchards and Kg= 0.9 for pastures, hayfields and meadows.

The anthropogenic criterion (Kh) shows very high values, namely *Kh = 0.9*, for the Târnava Mare corridor.

3. RESULTATS ET DISCUSSION

Following the completion of average coefficient landslide hazard map, five classes of values were obtained within the Târnava Mare corridor between Mediaş and Blaj.

The ***zero vulnerability class (0-0.03)*** corresponds to the surfaces with no sliding risk (Târnava Mare valley, Visa valley).


Legend
Geomorphological criterion
Hydrographic network
Corridor limit
Settlements
Legend
Hydrogeological criterion
0.1
0.5
Hydrographic network
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Structural criterion
0.5
Hydrographic network
Corridor limit
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Legend
Hydrological and climate criteria
0.1
Hydrographic network
Corridor limit
Settlements
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Lithologic criterion
Hydrographic network
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Settlements
Legend
Forestry criterion
0.1
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0.9
Hydrographic network
Corridor limit
Settlements
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Seismic criterion
0.75
Hydrographic network
Corridor limit
Settlements
Legend
Anthropogenic criterion
0.1
0.9
Hydrographic network
Corridor limit
Settlements

↑ Figure. 3. The criteria used to develop the avergae landslide hazard coefficient

Low vulnerability class (0.03-0.10) *it is visible on the valley interfluves, especially in the southern, south-western part of the corridor.*

Medium vulnerability class (0.11-0.30), it's the most wide-spread within the corridor, occupying 400, 42 km^2 out of the total of 739, 33 km^2 and it corresponds to the meadow, hayfields covered surfaces, with slopes varying from 10^o to 15^o. With a substrate made of Pannonian and Sarmatian deposits, this class is visible on the Târnava Mare Cuesta, on the slopes adjacent to the Glogoveţ, Valea Lungă, Lodroman, Chesler, Păucea valleys and in the south-eastern part of the corridor, on the slopes adjacent to the Soroştin, Visa, Vorumloc, Ighis valleys.

Medium - high vulnerability class (0.31- 0.50) occupies 16% out of the total surface of the corridor (115, 63 km^2), unevenly distributed within the study area, however it has an emphasized concentration in the central-northern and south-eastern parts of the corridor. In this class there are present steep slopes (> 20^o), with sandy-clayey, and clay formations within the Panonian. This class is generally visible on the slopes adjacent to the Tur, Cergău, Glogoveț, Valea Lungă, Lodroman, Chesler, Soroștin, Șeica, Visa, Vorumloc, Ighiș valleys.

High vulnerability class (0.51- 0.60) occupies narrow surfaces within the corridor, around 6 km^2(1%). These values overlap with very abrupt slopes (inclination higher than 25^o), being visible in the central-northern and central-southern parts of the corridor. This class is generally visible on the slopes adjacent to the Valea Lungă, Chesler, Soroștin, Visa, Pârâul Popii, Râpa, Vorumloc valleys.

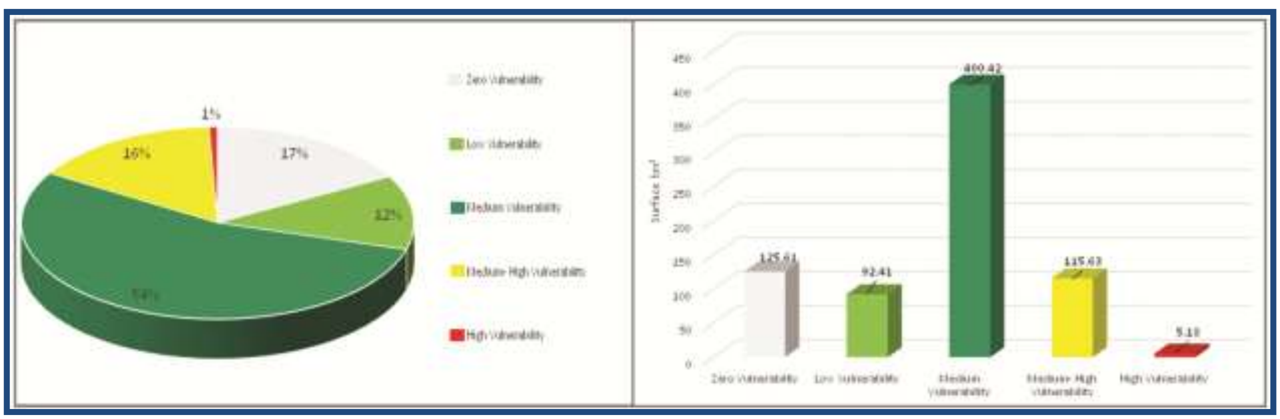

Figure 4. Graphic representations of the Average landslide hazard coefficient for the Târnava Mare corridor

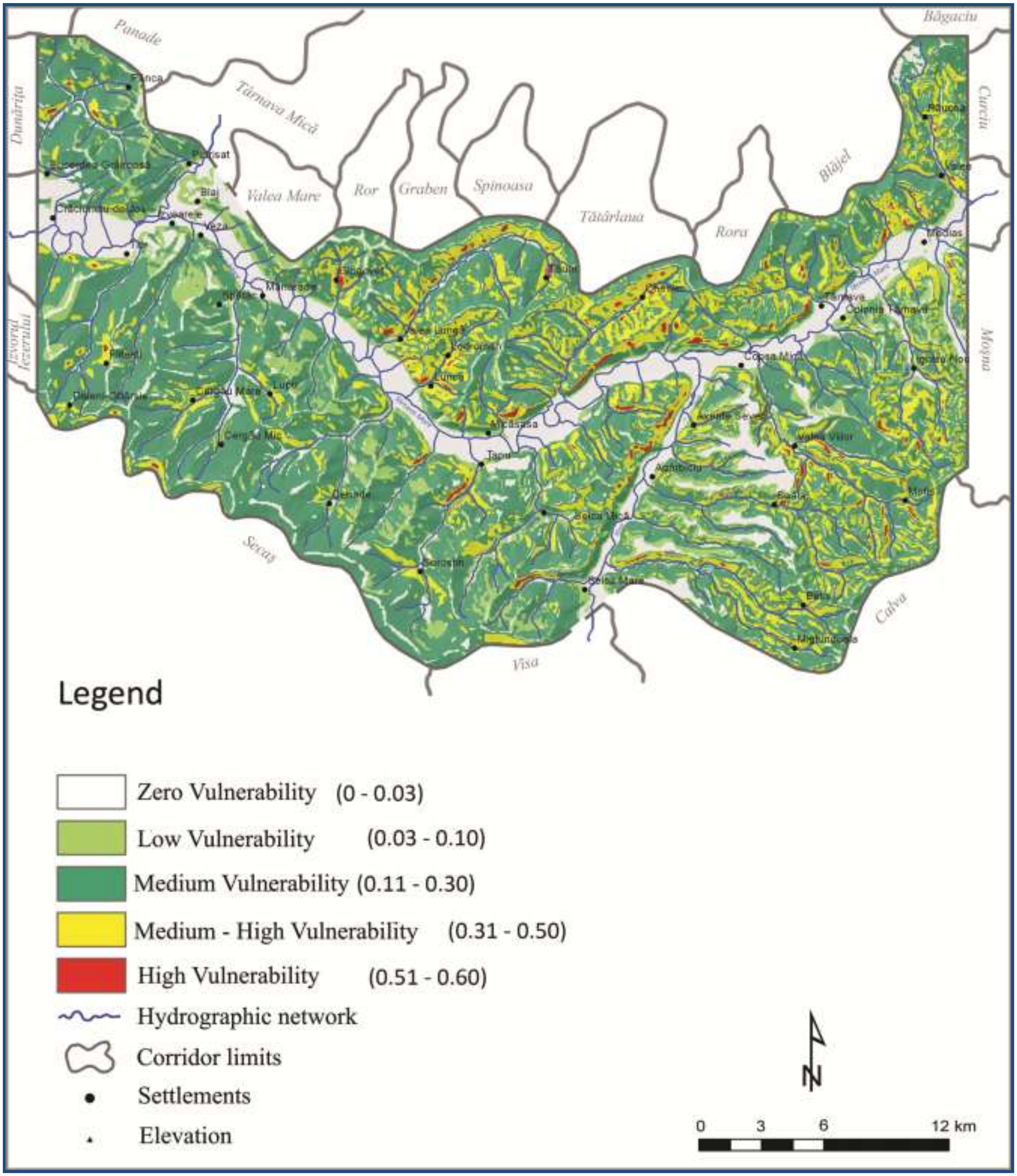

Figure 5. The Average lanslide hazard coefficient map within the Târnava Mare corridor (Mediaş –Blaj)

4. CONCLUSION

The resulting map cannot accurately indicate the moment when landslides may occur because such estimates require permanent monitoring of factors involved in the making of landslides (lithological, geomorphologic, structural, hydrological and climatic, hydrogeological, seismic, forestry and anthropic), but the map is the reference point in the elaboration of plans to combat landslides and can be used as a tool for identifying the areas suitable for urban development by establishing a potential sliding risk, (Cătescu, Alexandru, Paisa, Grecu 2012).

An analysis such as the one presented in this study, can capture the environmental influences on human activities and their intervention on the dynamics and destabilization of slopes by deforestation, inappropriate land usage and construction. A landslide hazard map can be used as a tool to help identify land areas best suited for development by examining the potential risk of land sliding. Though even with detailed investigation and monitoring, it is extremely difficult to predict landslide hazards in absolute terms.

As measures to counteract the instability of the slopes, consideration may be given to: *re-terracing* by adding material to the base area of the slopes (berms, fillings) and sloping; *surface drainage* to prevent infiltration of water in the sliding area, *drainage wells* or *drainage galleries*; *support structures* via gabions, gravity support walls or reinforced earth, pilots, columns, trunks, anchored nets.

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