Comparative evaluation of landslide susceptibility in hill catchments (Săsăuş and Mislea), using GIS techniques

Georgian CĂTESCU, Raluca ALEXANDRU, Marius PAISA, Florina GRECU

Abstract: A number of qualitative and quantitative models and methods are available for computing landslide-hazard and susceptibility maps. Though the susceptibility map has usually incorporated the estimated frequency of land sliding in a qualitative sense rather than quantitatively. 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.

The susceptibility maps that resulted form this study reflect the terrain conditions and are really useful for identifying the landslide areas within the basins. 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, Săsăuş river basin, Mislea river basin.

Introduction

In the geomorphic literature the terms of susceptibility and landslide hazard are often used interchangeably, although they are different concepts (Guzzetti, 2005). Landslide susceptibility is the probability for a landslide to occur in an area characterized by certain environmental conditions (Brabb, 1984) reffering 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 field research was initially sporadic, and was based mostly on small relief units and approaching different methodologies. The necessity of creating hazard maps was first underlined by Petre Coteț (1978). In time, risk assessment maps were developed, especially in units studied in detail as doctorate thesis, without following a consistent methodology. Significant contributions to this domain were: Schreiber (1980), Bălteanu (1983,1992), Bălteanu and colab. (1989, 1994), Grecu (1994, 1996, 1997, 2001, 2002), Cioacă (2002), Sandu (1994, 1997), Constantin (1999), Grecu, Comănescu (1997, 1998), Branduş, Grozavu (2001), Armaş and colab. (2003), Sorocovschi (2002, 2003), etc. In recent decades there is a wealth of information aimed at in-depth knowledge of the process of sliding, information 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.

Latest trend since the 1990s, is to develop susceptibility maps for landslides, which are the synthesis of quantitative and qualitative analysis of the area studied, reclassification and interpretation of results (Carrara, 1983; Brabb, 1984; Varnes and IAEG Commission on Landslides and other Mass-Movements, 1984, Crozier, 1986; Carrara and colab., 1995; van Westen, 2008; Chung and Fabbri, 1999; Crozier and Glade, 2005; Glade and Crozier, 2005; Guzzetti and colab., 2005, etc.).

In Romanian geomorphic literature, assessment and methodological references on landslide susceptibility were made by Bălteanu and colab. (1989), Rădoane and colab. (1993), Cioacă (1996), Grecu (1997, 2002), Armaş (2003, 2006), etc.

The sliding susceptibility zoning map was obtained by combining the successive stages of the spatial distribution maps of the factors responsible for landslide processes, namely the degree to which they contribute to the destabilization of the slope (Montgomery and colab., 1991; Pachauri and Pant, 1992; Rădoane and colab., 1993; Mejia-Navarro and colab., 1994; Grecu, 1997; 2002; Pachauri and colab., 1998; Moreiras, 2005, etc.).

Also, in recent years, numerous studies have emerged to evaluate susceptibility of landslide based on probabilistic computing models such as Bayes theory, known as the "Weight of Evidence" (Bonham-Carter, 1991; Lee and colab., 2002; Armaş and colab., 2003), likelihood ratio (Chung and Fabbri, 2003, 2005; Fabbri and colab., 2003; Lee, 2004), certainty factors (Chung and Fabbri, 1993, 1999; Binaghi and colab., 1998) etc.

Studied areas

This paper aims to evaluate the slope landslide susceptibility of two river basins (Mislea and Sasăuş) located in different landscape units: the Curvature Sub-Carpathians, a unit of Orogen with hilly terrain and an active neotectonic manifested by an accentuated morphodynamic and Transylvanian Depression, also an Orogen unit all but a with a plateau terrain. The catchments have many similarities in morphology, despite being located in different morpho-structural units. Săsăuş morpho-hydrographic basin is situated within the Romanian territory, in the southern part of Hârtibaciu Plateau, a subunit of the Transylvanian Depression, and it is framed by the geographical coordinates 24°49'23" and 24°32'14" Eastern longitude and 45°56'51" and 45°47'54" Northern latitude (Figure 1).

Săsăuş river basin is bordered in the North, Northwest and West by Hârtibaciu River basin, in the East by Cincu River basin and in the South by Olt River basin and it occupies a total surface of 232,21 km^2. The geology of the basin area is relatively simple as it overlaps a Neogene sedimentary package belonging to Sarmatian and Badenian, uncemented rocks (sands and gravels) or weakly cemented rocks (friable sandstone, thin horizons of conglomerates, clays and marls).

Mislea morpho-hydrographic basin is located in the South-Eastern part of Romania, at the contact of the Curvature Sub-Carpathians with the Romanian Plain, framed by the geographical coordinates 45°11'25" and 45°03'12" Northern latitude, 25°46'19" and 25°59'48" Eastern longitude (Figure 1).

Mislea river basin is a tributary to Teleajen river basin and has a total surface of 175km^2. The basin is bordered in the North and East side by Vărbilău River basin, by Doftana basin in the East and Dâmbu basin in the South. The geology of Mislea River basin is more complex as it overlaps the following structural units: Carpathian Molasses, consisting of sandstones, marls, clays, marl-limestone of Mio-Pliocene age and Tarcău nappe consisting of Oligocene and Eocene age formations (sandstones, shales, marls, breccias).

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.

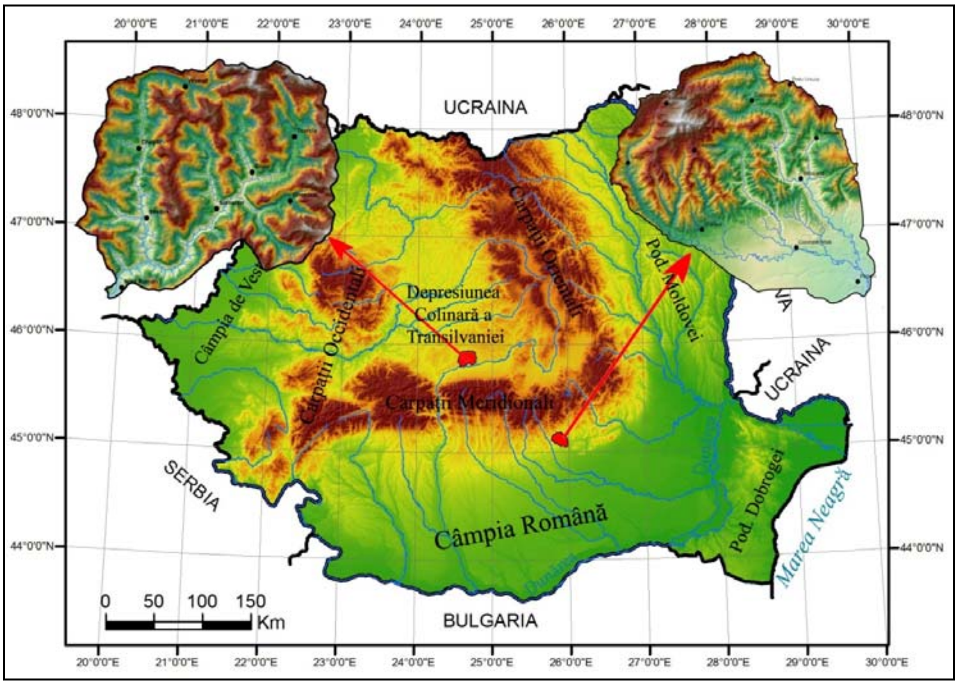

Figure 1. The location of Săsăuş and Mislea River catchments within Romania

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), (Agterberg, Cheng, 2002). 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.

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 (K_m), taking into account the specifications in Annex C.

Due to overestimation or underestimation of the importance of classes and many of the introduced errors by using factors whose mapping is difficult (hydro-climatic, hydrogeological, structural factors), the validation of the obtained map indicates a weak correlation between the susceptibility classes, respectively of the average coefficient hazard and active landslides.

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 spatialization classes of of landslide susceptibility.

The validation of susceptibility map achieved through the weight of evidence method 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 this can be limited by field observations.

In order to develop “the average coefficient susceptibility” maps for Săsăuş and Mislea basins, 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); orthophotos (A.N.C.P.I.) 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 K_m coefficient was done with the Spatial Analyst and Map Calculator functions from ArcGIS 9.3. program.

The results were validated by correlating the K_m *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 no. 1*).

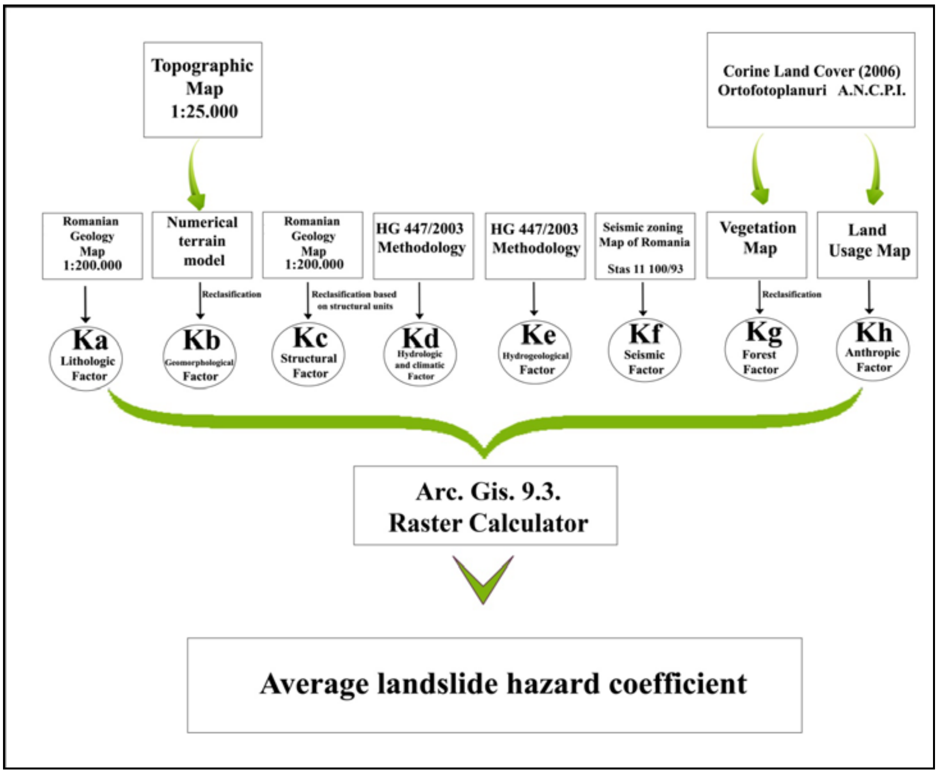

Figure 2. The elaboration scheme of the Average lanslide hazard coefficient using GIS techniques (Alexandru, Cătescu, 2012)

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

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

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

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

K_a= lithologic criterion;

K_b= geomorphological criterion;

K_c= structural criterion;

K_d= hydrological and climatic criteria;

K_e= hydrogeologic criterion;

K_f= seismic criterion;

K_g= forest criterion;

K_h= anthropogenic criterion.

Aiming for the implementation of landslide susceptibility maps it is necessary that the above criteria and their association to be taken into consideration: K_a *(lithologic criterion),* K_b *(geomorphological criterion),* K_c *(structural criterion),* K_d *(hydrological and climatic criteria),* K_e *(hydrogeologic criterion),* K_f *(seismic criterion),* K_g *(forest criterion),* K_h *(anthropogenic criterion).*

The Lithologic criterion (K_a) is based on the classification of geological formations, starting from the average values of superficial formations (dilivium, 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 from Săsăuş basin was classified as follows: K_a= *0.5* was assigned to Quaternary (Holocene), composed from gravel and sand; K_a= *0.7* is assigned to the Sarmatian which overlaps on marl, sand, gravel and tuff formations; K_a= *0.9* refers to the Pannonian with gravel, sand and clay-marls.

Taking into account the geographic position and the geological base, Mislea river basin presents more values of this criteria than Săsăuş river basin. Thus, the following classes are present: K_a= *0.5* is attributed to the Quaternary (Pleistocene and Holocene), consisted from gravel, sand and sandy-clay; K_a=*0.6* represents the Romanian and Dacian with clay, sand, marl, and charcoal formations; K_a=*0.7* is assigned to the Oligocene and Eocene with clay, marl, breccia, marl-clayish shale formations (Pucioasa Layer), sandstone (Fusaru and Kliwa Layers), flysch (Şotrile), clay-flysch (Plopu); K_a=*0.75* represents the Pontian and Helvetian with marl, clay, gravel, charcoal, sandstone, gypsum and conglomerate layers; K_a= *0.8* corresponds to the Meotian with gravel, sandstone, clay and marl formations; K_a= *0.9* refers to the Sarmatian with an under layer of marl, clay, sand and limestone formations; K_a= *0.95* is identified as being part of the Tortonian, Aquitanian and Burdigalian with marl, clay-shale, breccia, tuff, salt, gypsum and sandstone.

The Geomorphological criterion (K_b) refers to the classification of the study area in the macro-relief units (hills and mountains, plateaus, plains). According to this assignment (Săsăuş basin in the plateau unit and Mislea in the hill unit) a classification regarding slope values is emerging (interval values are directly proportional with slope values). Thus, for both basins, these intervals have been defined based on slope gradient: K_b= *0.1* is for slopes with an angle smaller than 3^0; K_b= *0.3* contains slope values between 3^0- 5^0; K_b= *0.4* represents the slope values between 5^0-10^0; K_b= *0.6* refers to the slopes with 10^0-15^0 values; K_b= *0. 8* goes to the slope values of 15^0-25^0. Due to steeper slopes found in Mislea basin, a new slope value class is added to the K_b criterion, respectively K_b= *0.9* with slopes that surpass 25^0.

The Structural criterion (K_c) in Săsăuş river basin is represented by the class K_c=*0.5* which is totally assigned to the Transylvanian Depression, meanwhile within Mislea basin we encounter two classes as follows: K_c= *0.8* refers to Tarcău Nappe and K_c= *0.9* for the molasse formations.

The hydrological and climatic criteria (K_d) refers to the demarcation of areas depending on the amount of precipitation and erosion potential of the river, amid climate types in our country. Therefore, the K_d = *0.7* value is assigned for the hill climate found in both basins, the K_d = *0.5* value is assigned to plain transition climate, encountered only in Mislea basin at the contact of the Subcarpathians with the Romanian Plain.

The hydrogeologic criterion (K_e) 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*.

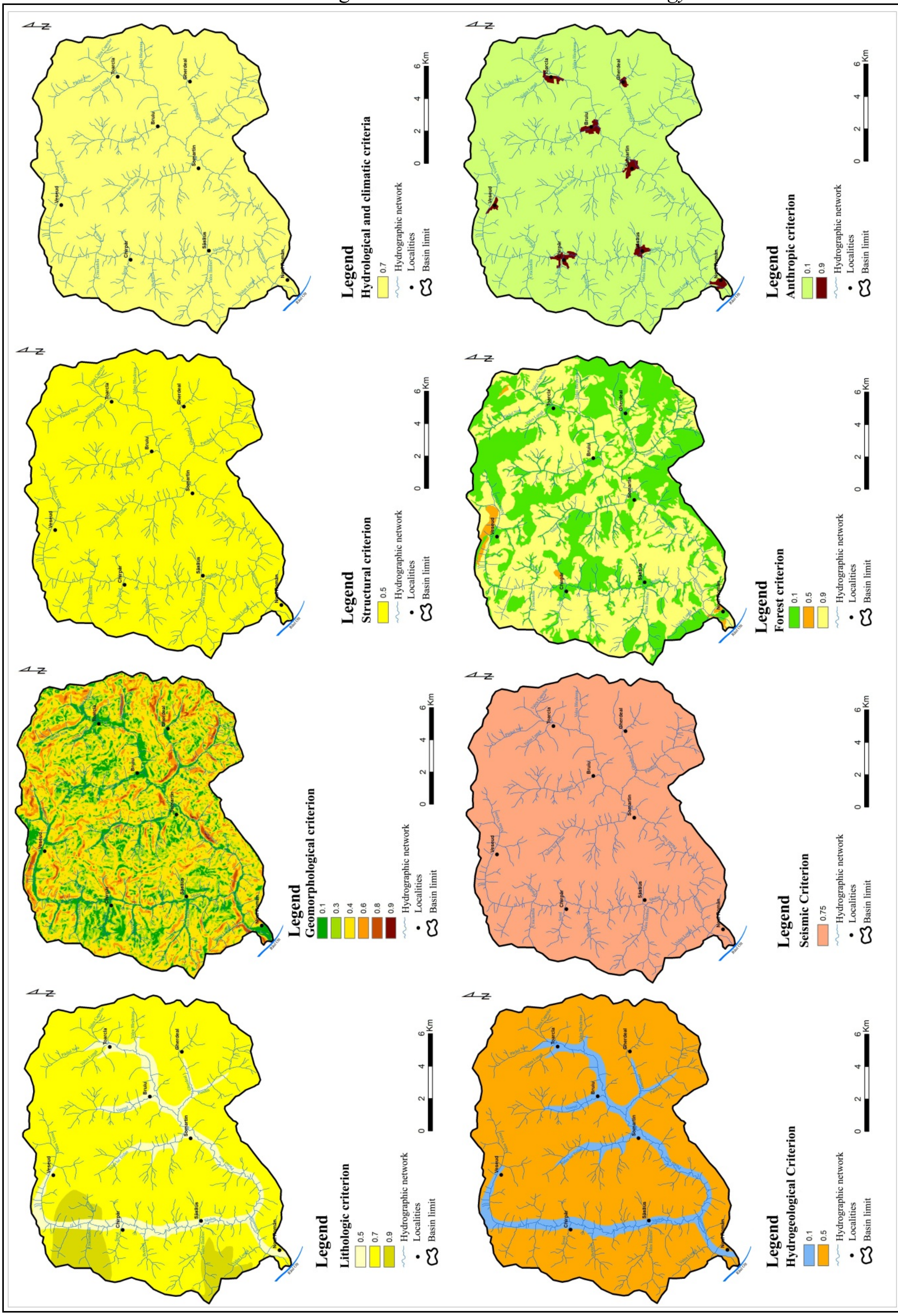

Fig. no. 3 - Criteria used in developing of the Average Landslide Hazard Coefficient Map within Săsăuş river basin

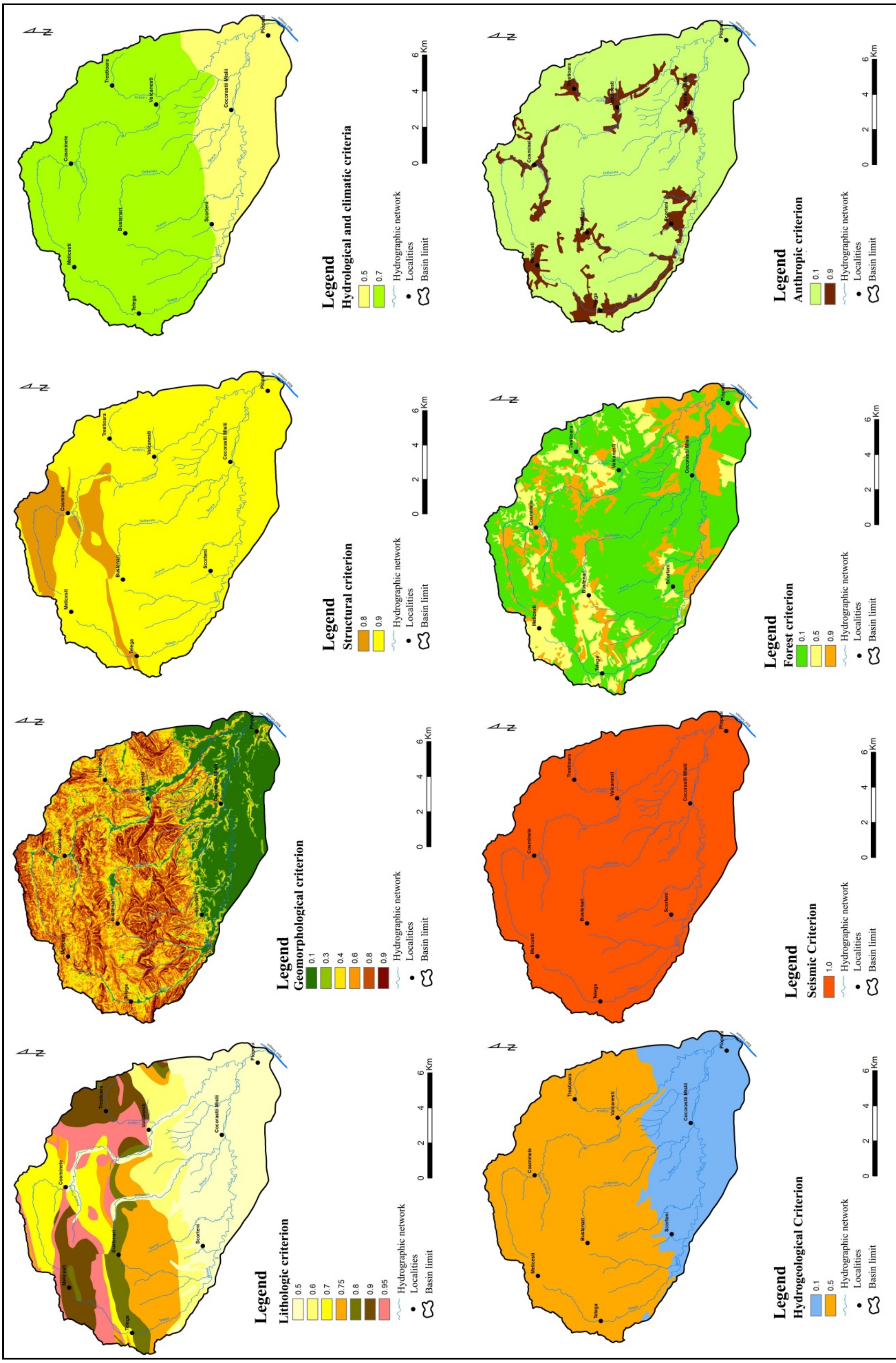

Fig. no. 4 - Criteria used in developing of the Average Landslide Hazard Coefficient Map within Mislea river basin

The medium-high values $K_e = 0.5$ were assigned to the areas where groundwater flow occurs at high values of the hydraulic gradients, causing pressure filtration.Very small values such as $K_e = 0.1$, were assigned to groundwater with a very low hydraulic gradient (filtration forces are reduced). The lowest values encountered within Săsăuş basin are concentrated along the main river valleys, while within Mislea basin these values are present in the Mislea Depression.

The seismic criterion (K_f) was determined by seismic zoning map of Romania, scale MSK (SR - 11100-93), which indicates the intensity of earthquakes. Săsăuş basin area falls within the values of seismic intensity of 7 (degrees MSK), with the coefficient $K_f = 0.75$, while Mislea basin corresponds to values of seismic intensity 9 (MSK degrees), with the coefficient $K_f = 0.9$.

The forest criterion (K_g) was developed from the Land usage Map, taking into account the vegetation coverage percentage. The values for this factor vary from $K_g = 0.1$ to $K_g = 0.9$ as follows: $K_g = 0.1$ for forests, $K_g = 0.5$ for orchards and Kg= 0.9 for pastures, hayfields and meadows. In Săsăuş river basin, the coefficient $K_g = 0.1$ is evenly distributed over the entire basin, mainly in its Eastern half. The coefficient assigned to orchards occupies small areas, concentrating mainly in Northern basin, on Vizina Valley, near villages Chirpăr, Toarcla and Noul Român. The coefficient $K_g = 0.9$ is the most widespread within the basin, homogeneously distributed on the slopes of the main river valleys Săsăuş, Pârâul Nou, Valea lui Trifan, Gherdeal, Panda, Valea Lungă, Veseud. Regarding Mislea basin the forests *($K_g = 0.1$)* show the highest widespread.

The orchards occupy a larger area compared to Săsăuş basin, being most common in the northern and southern parts of the basin, near the villages of Cosminele, Trestioara, Cocorăştii Mislii and Plopeni. The $K_g = 0.5$ coefficient which indicates the distribution of pastures, hayfields and meadows, has a smaller distribution compared to Săsăuş (encountered mostly on the valley slopes of Telega, Poiana Trestia, Lupăria and Runcu).

The anthropogenic criterion (K_h) shows very high values, namely $K_h = 0.9$, for both basins for settlements located valley slopes of Săsăuş, Pârâul Nou, Şomartin, Telega, Doftănet, Mislea and Cosmina.

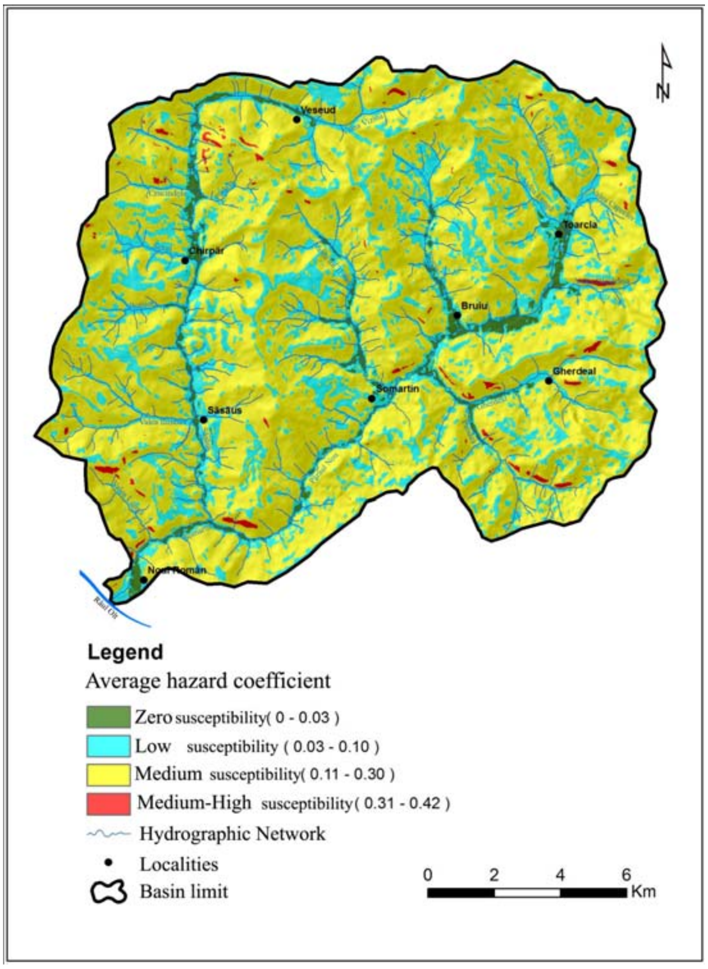

Figure 5. The Average lanslide hazard coefficient map within Săsăuş river basin

Results and discussions

Following the completion of average coefficient landslide hazard map, four respectively five classes of values were obtained within the Săsăuş and Mislea river basins. The *zero susceptibility class (0-0.03)* corresponds to the surfaces with no sliding risk (Săsăuş, Valea lui Trifan, Pârâul Nou and Mislea Depression).

Class of reduced susceptibility (0.03-0.10) is mostly found in Săsăuş basin on the interfluves of Săsăuş, Valea lui Trifan, Valea Vizina, Gherdeal, Veseud valleys, whereas within Mislea basin it is present in Mislea depression along the main river valleys.

Medium susceptibility class (0.11- 0.30) has the largest expansion of Săsăuş basin (175 km^2 of the total of 232 km^2) and corresponds to areas occupied by pastures, hayfields and meadows (with slopes ranging from 10^0-15^0, presenting an average inclination, most of this range overlapping Panonian and Sarmatian formations). However, regarding Mislea basin, this class is present in the central-southern on the valley slopes of Cosmina, Telega, Doftăneţ, which mostly correspond to areas covered by forest with under layers of marl and sand Pliocene formations.

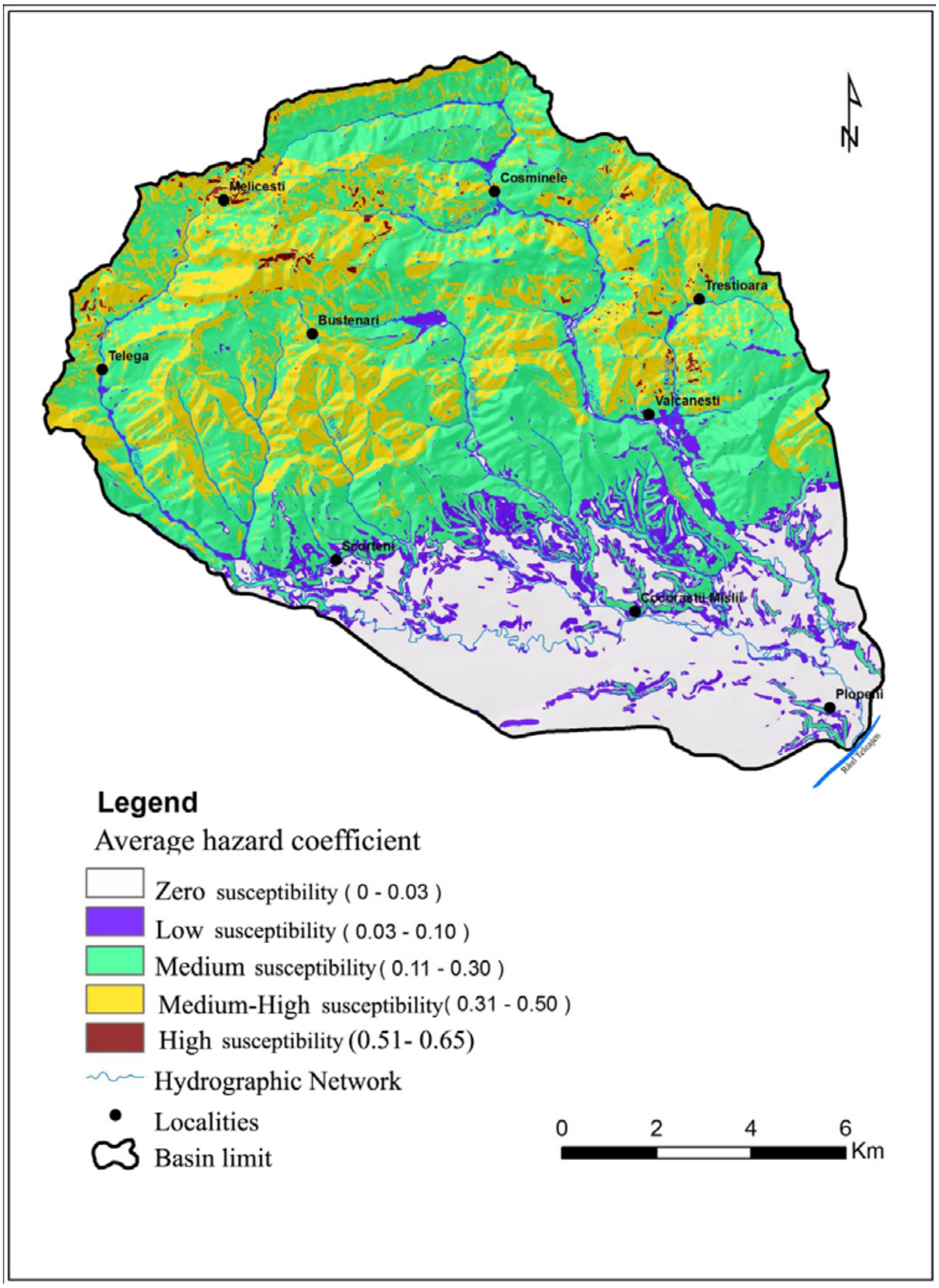

Figure 6. The Average lanslide hazard coefficient map within Mislea river basin

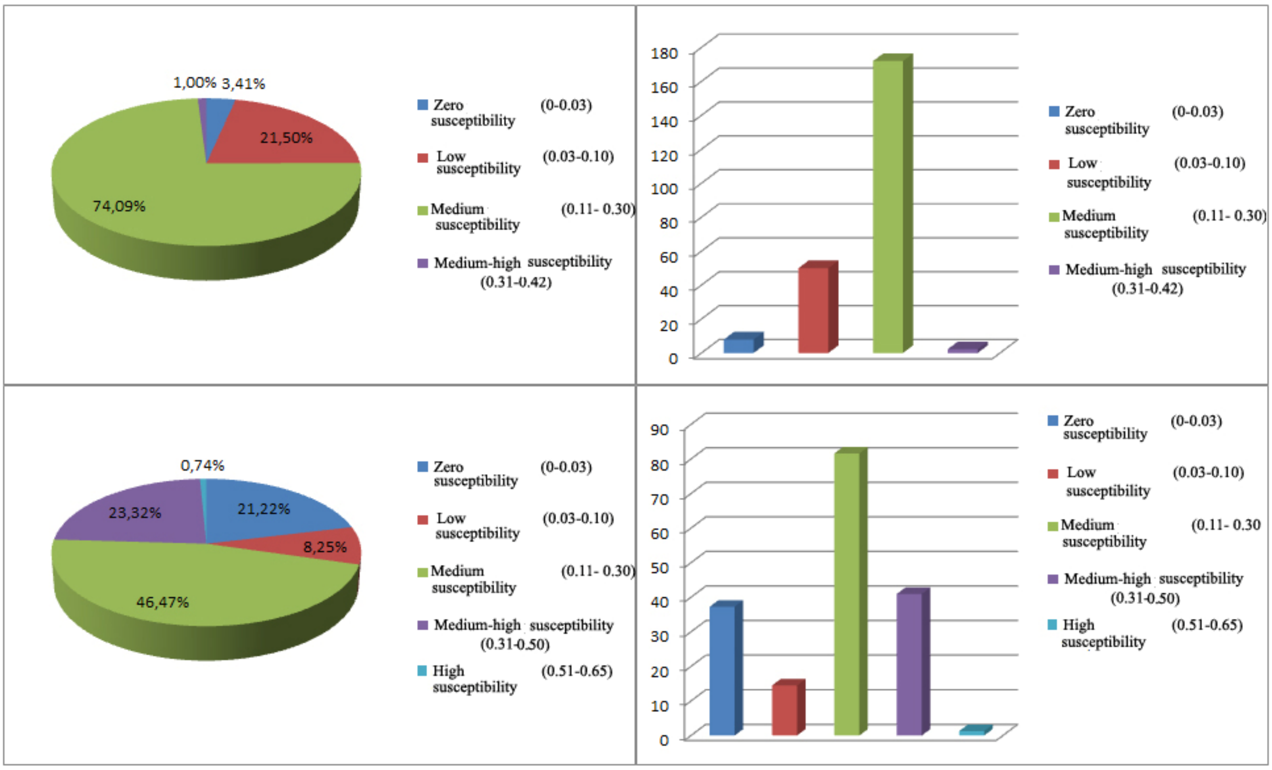

Figure 7. The cyclogram and hystogram of the Average lanslide hazard coefficient for Săsăuş (above) and Mislea (below) river basins

The *medium-high susceptibility class (0.31-0.42)* occupies the smallest area, unevenly distributed on the basin surface, in the Northern Sector of Vizina Valley, South-West on Săsăus Valley and East on the left side of the Pârâului Nou, Gherdeal, Pandea, Valea Caprelor,Valea Bleşăraua and Valea Lungă valleys. This class is associated with grasslands areas, hayfields and meadows, with Sarmatian and Quaternary substrate deposits (gravel, sand and marls).

The *medium-high susceptibility class (0.31-0.50)* within Mislea basin corresponds to forest covered surfaces belonging to Vâlcăneşti, Cosminele, Telega and Buştenari depressions. The landslides framed in the *medium-high and high* classes overlap with areas occupied by orchards, pastures, hayfields and meadows. This class is superimposed on reactivated old slides encountered in torrential valley slopes in the upper Sector of the Cosmina, Poiana Trestia, Lupăria and Telega Rivers.

Most areas in the medium to high and high categories fall in the range of slopes between 15^0 – 20^0 (steep), represented by sandy-clay and marly-clay formations and salt deposits found especially in the north-west part of the basin (upper sectors of Telega, Mislea, Doftăneț and Poiana Trestia valleys). Regarding the high susceptibility class (0.51- 0.65), it is only present in Mislea basin due to slopes with values higher than those in Săsăuş basin, which favors the probability of landslides to occur. The representative areas for this class are adjacent to Trestioara, Vâlcăneşti and Cosminele settlements.

Conclusions

Resulting maps cannot pinpoint when the landslide may occur because such estimates require continuous monitoring of the factors involved in producing landslides (lithological, geomorphological, structural, hydrologic and climatic, seismic, forestry and anthropic factors).

However, the maps may be viewed as an essential instrument for the development of landslide susceptibility maps. Such an analysis 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 landsliding.Though even with detailed investigation and monitoring, it is extremely difficult to predict landslide hazards in absolute terms.

Figure 8. The validation of the Average lanslide susceptibility coefficient Maps with the help of spatial images for Săsauş (above) and Mislea (below) river basins

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