“BABEȘ-BOLYAI“ UNIVERSITY
CLUJ-NAPOCA
FACULTY OF GEOGRAPHY
DOCTORAL SCHOOL OF GEOGRAPHY

LANDSLIDE RISK

IN THE BAIA MARE DEPRESSION

PhD THESIS
- Summary -

Scientific coordinator:

Prof. univ. dr. IOAN-AUREL IRIMUȘ

PhD candidate:

FLAVIA-LUANA MĂGUȚ (căs. MARIAN)

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TABLE OF CONTENTS

Keywords: landslides, susceptibility, risk, logistic regression, Baia Mare.

1. INTRODUCTION

The following paper aims at identifying the landslide susceptible areas from the Baia Mare Depression and at determining the risk level associated to the built-up elements from this territory. In order to fulfil this aim, a qualitative approach based on the methodology included in the Romanian legislation was used, together with quantitative applications at catchment and local level. The main work stages are being detailed by the following objectives:

- identification of factors influencing landslide occurrence at depression, catchment and local level;
- identification of the landslides from the study area and of their main characteristics;
- landslide susceptibility assessment in the study area;
- description of landslide temporal occurrence in the Baia Mare Depression and of the damages which have occurred until present;
- assessment of landslide risk associated to built-up areas, main roads and high electricity poles in the Baia Mare Depression;
- the use of alternative methods in determining the landslide susceptibility for risk estimation, presented as case studies;
- description of risk mitigation methods in the study area.

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2. LANDSLIDE RISK – THEORETICAL AND METHODOLOGICAL ASPECTS

2.1. Concepts used in risk research

The interest for risk research can be identified both at international and national level, in numerous fields of study, which implies at a linguistic and methodological level the existence of a variety of concepts and specific methods for risk assessment. In the present paper these are used according to the official theoretical and methodological standards.

Thus, the risk represents ”the combination of the probability of an event and its negative consequences” (UNISDR, 2009, p. 25) and can be quantified through the product of hazard (H) and vulnerability (V): R=HxV (Varnes, 1984).

Among the risk associated concepts (hazard, susceptibility, temporal probability, vulnerability, elements at risk, sensitivity, resilience), the term ”susceptibility” has only recently started to be used in the Romanian studies and stands for the spatial probability of a process in a particular area, where certain factors are present (Brabb, 1984; Crozier și Glade, 2005).

2.2. General methodological aspects of landslide risk research

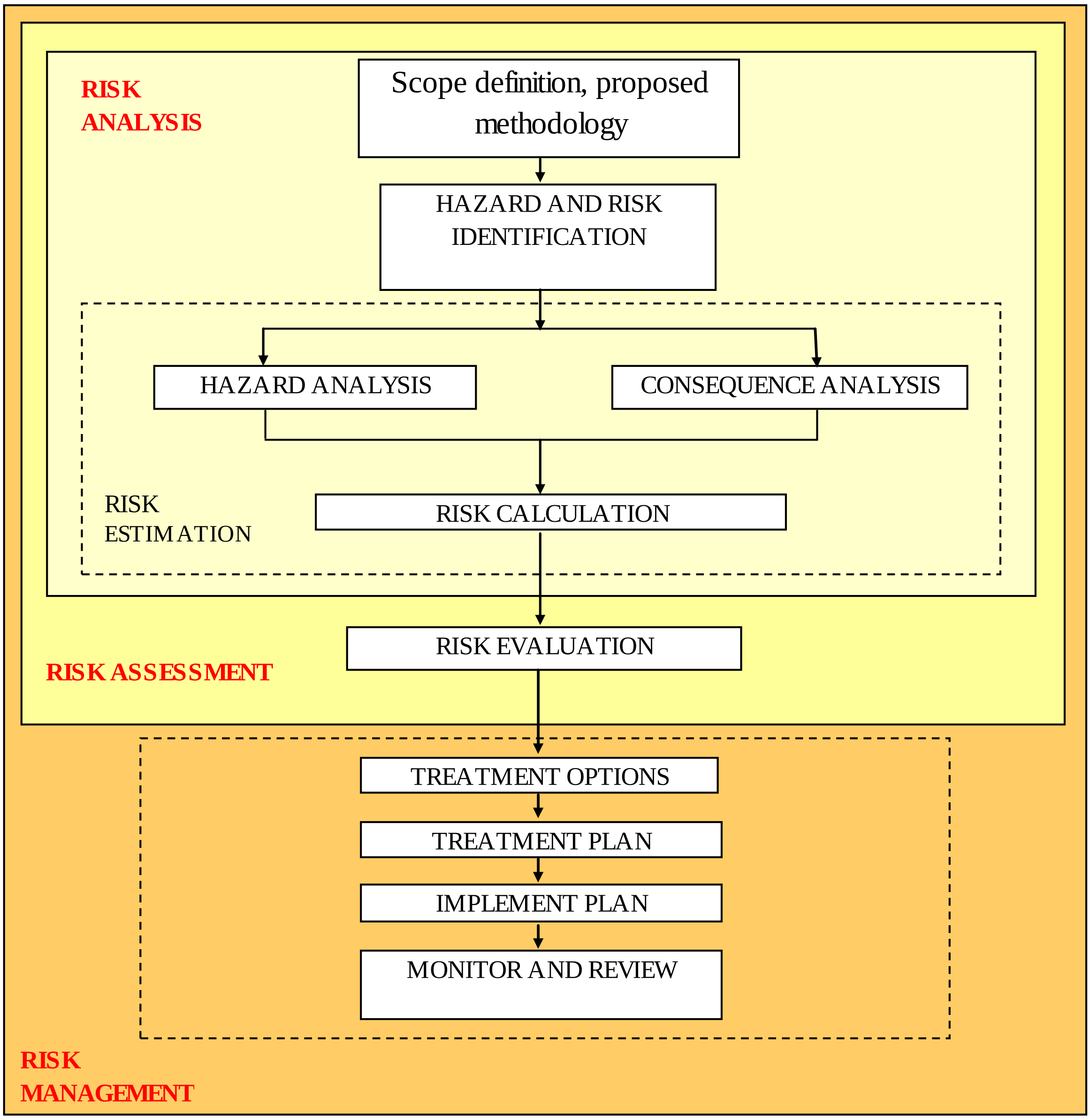


Fig. 2.2. Stages of risk management and the relationships among them (after Crozier and Glade, 2005; Australian Geomechanics Society, 2000).

In the broader field of risk management there is a series of interdependent stages, illustrated in the chart 2.2., and at each of these stages the methods used can be either qualitative, quantitative or semi-quantitative, according to the data availability, the scale and the purpose of the study (table 2.1.).

Table 2.1. Scale of analysis and the qualitative and quantitative approaches in landslide risk analysis.

SCALE	QUALITATIVE METHODS		QUANTITATIVE METHODS	
	Inventory	Heuristic analysis	Statistical analysis	Process-based and numerical analysis
<1:10 000	YES	YES	YES	YES
1:10 000-1:100 000	YES	YES	YES	Probable
1:100 000-1:500 000	YES	YES	Probable	NO
>1:750 000	YES	YES	NO	NO

(Source: after Glade and Crozier, 2005, pg. 87, modified after Soeters and van Westen, 1996).

2.3. Landslides – definition, classification, characteristics

The object of the present study is represented by landslides, a mass movement process which takes place under the influence of gravity, on a sliding surface or surface of rupture characterised by intense driving forces (Cruden și Varnes, 1996; Surdeanu, 1998; Rădoane et al., 2001 ș.a.).

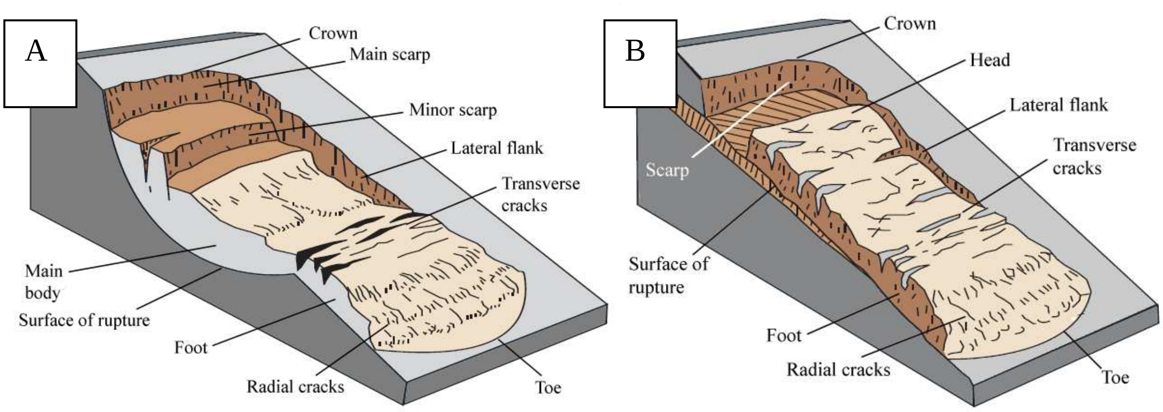


Fig. 2.3. Schematic of a rotational – A and translational – B landslide
(Highland and Bobrowsky, 2008, p. 11 and 13, after Cruden and Varnes, 1996).

Cruden și Varnes (1996) classify these processes according to the **degree of activity** in: active, reactivated, suspended, inactive (latent, abandoned, stabilised, relict) and according to the **complexity of the process** in singular, multiple and successive, while Varnes (1978) uses the **shape of the sliding surface** as the main criterion in differentiating between rotational (concave surface of rupture) and translational (planar surface of rupture) landslides (fig. 2.3.), as well as complex landslides with combined characteristics of the first two.

Regarding the age of the landslides, Posea (2005) mentions the postvillafranchian uplifts as the period of landslide initiation, in the periglacial climate of Würm and postglacial period (around 9000-7000 years ago), followed by the Atlantic period (around 500-3000 years ago). For the historical time interval, the probable periods are identified through the specific human activities and the climatic characteristics: the middle of the 18th century, the period after 1829, the first decades of the 20th century, with a maximum in the interval 1938-1942 characterised by high precipitation, the deforestation period after the World War II, the 1969-

1973 interval and the intense deforestation period after 1989 (Surdeanu, 1998; Posea, 2005), a more recent cycle of activity being the one from the interval 2004 - 2011.

2.4. Methodological aspects of landslide risk research in the Baia Mare Depression

Taking into consideration the general instructions for susceptibility, hazard and risk studies of the Australian Geomechanics Society (2000, 2007a), the type of analysis which is necessary and most efficient is directly dependent on the scale of analysis, the extension of the territory and the costs associated with the project. Thus, the 600 km^2 of the Baia Mare Depression at a scale of 1:25 000, correspond to the 10-1000 km^2 interval and the 1:25000-1:5000 scale interval to which an appropriate approach includes a landslide inventory, a susceptibility and hazard zonation and a preliminary risk zonation.

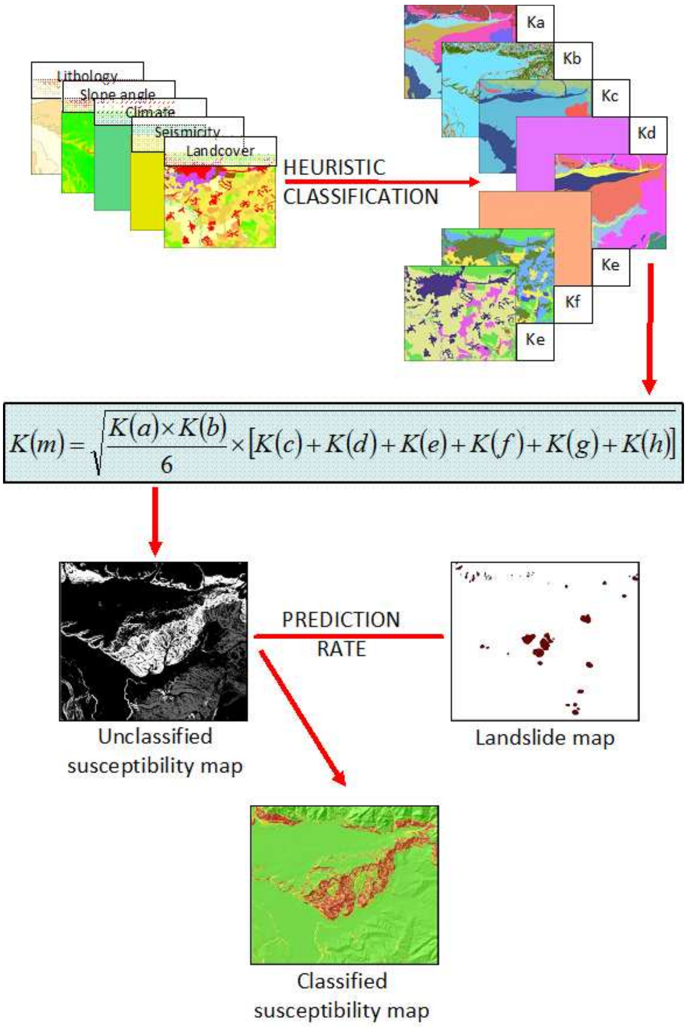


Fig. 2.5. The main stages of applying the legislative method using GIS techniques.

2.4.2. Landslide risk analysis

2.4.2.1. Qualitative approach

The landslide risk estimation for the built-up areas, the main roads and the high electricity poles of the electricity line Iernut-Baia Mare includes a series of work stages:

1. landslide susceptibility assessment using the semi-quantitative method described in the Governmental Decision 447/2003 (fig. 2.5.);

2. validation of the susceptibility map using mapped landslides from the study area;

3. transformation of the susceptibility classes into hazard classes using linguistic descriptors correspondent to the probability classes described by Fell et al. (2005) after AGS (Australian Geomechanics Society, 2000);

4. estimation of vulnerability and consequence classes for each type of elements at risk (Fell et al., 2005; AGS 2000, AGS 2007);

5. the risk estimation is based on a matrix of qualitative combinations between the probability of landsliding (hazard) and the probable consequences related to each type of elements at risk (Fell et al., 2005; AGS 2000, AGS 2007).

2.4.2.2. Quantitative approach

In order to use a quantitative method in the assessment of landslide susceptibility, a reduced study area was analysed (the Chechiș catchment, 100 km^2) where a landslide inventory was created through field investigations. The selected method is represented by the *statistical model of logistic regression* (fig. 2.6.), one of the methods most often used in landslide susceptibility assessment both internationally (Dai and Lee, 2002; Lee, 2004; Ayalew et al., 2005; Brenning, 2005; Chauhan et al., 2010 etc.), and in Romania (Micu and Bălteanu, 2009; Bălteanu et al., 2010; Armaș, 2011; Șandric et al., 2011; Mărgărint et al., 2011; Armaș, 2012; Grozavu et al., 2012 Mărgărint et al., 2013 ș.a.).

The method is based on the assumption that a specific combination of factors which led to landsliding in the past will function in a similar way in the future (Crozier și Glade, 2005). Thus, the probable location of future landslide occurrence is statistically determined using an inventory of present landslides from the study area and the terrain characteristics where these events occured (Carrara et al., 1995).

In applying the logistic regression an important role is played by the softwares ArcGis 9.3, R and RSAGA, a series of factors included in the analysis as independent variables and the landslide inventory as dependent variable. The validation of the results is based on an independent set of landslides extracted from the original inventory and the methods AUROC (Burt and Barber, 1996; Hosmer and Lemeshow, 2000; Guzzetti et al., 2006), success and prediction rate (Chung and Fabbri, 1999, 2003, 2008; Van Westen et al., 2003; Remondo et al., 2003).

The general formula of the logistic regression is represented by the natural logarithm of the odds ratio, or *logit*:

$$\ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots \beta_k x_k, \quad \textbf{(2.3.)}$$

$$p = P(y=1|x) \quad \textbf{(2.4.)}$$

where p is the probability that the depdendent variable has the value 1 (landslides occur), conditioned by the values of the independent variables x_1, x_2... x_k; $\beta_1, \beta_2, ...\beta_k$ are the regression coefficients which describe the contribution of each factor x to explaining the probability of landslide occurrence (y=1) and describe the transformation which keeps the linear relationship between the independent and dependent variables using the natural logarithm (fig. 2.7.); β_0 is the intercept or the control value for which x=0 (Hilbe, 2009; Burt and Barber, 1996).

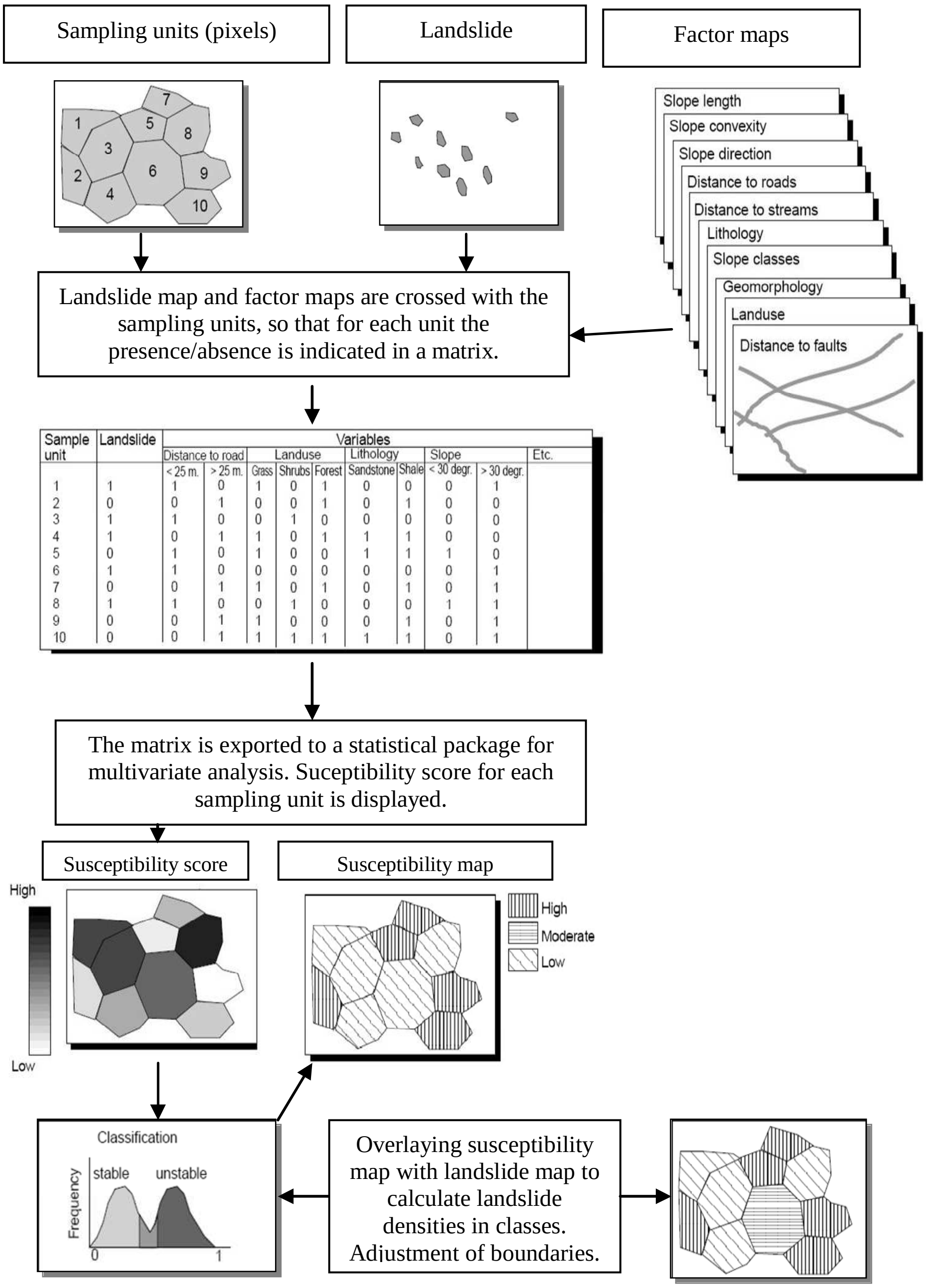


Fig. 2.6. Stages of applying the logistic regression model for landslide susceptibility assessment.

Further on, the results of the logistic regression can be included in a quantitative risk analysis in the Chechiș catchment, as soon as the data for a quantitative vulnerability estimation of the elements at risk are available. In this paper such an estimation was done only for the three landslides from the Baia Sprie – Dănești area which are investigated in more detail in chapter 7.

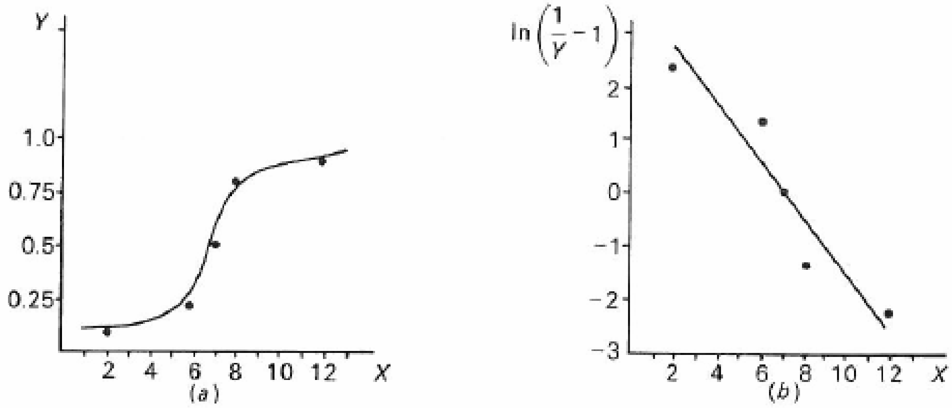


Fig. 2.7. (a) The logistic function and (b) its linear transformation (Burt and Barber, 1996, p. 496).

3. THE BAIA MARE DEPRESSION – GEOGRAPHIC IDENTITY AND PREMISES OF RELIEF FORMATION

3.1. Location and limits

The Baia Mare Depression is located at the contact with the volcanic mountains of the northern sector of Eastern Carpathians and is included as a geographic unit in the Crișana Hills, the subunit of Silvano-Someșene Hills (Geografia României, vol.IV 1992). It is being differentiated from the surrounding units (fig. 3.1.) on lithologic and morphologic criteria.

3.2. Geological premises of relief formation

After the Baia Mare basin was tectonically individualised through the alpine movements (Paucă, 1964), the processes of sedimentation continued the geologic evolution of the area, doubled by volcanic activity. After the retreat of the Pannonian Sea, the erosion and accumulation processes intensified, resulting in large piedmontal deposits (Ghiurcă, 1969; Posea, 1962) and started the incision of the hidrographic network in the depression deposits. Hundreds of meters of Miocene sediments were eroded until the rivers reached the prepliocene rocks (Paucă, 1977; Coteț, 1973). The fluvial processes continue, the most recent sedimentary deposit being the Cuaternary, which can be identified on terraces and flood plains, as well as on hill tops, where a yellow, deluvial clay was deposited from the surrounding volcanic and cristaline units (Paucă, 1964). As a result of all these processes, the most important lithologic units in the study area are the Sarmatian, the Pannonian and the Cuaternary.

3.3 Meteo-climatic and hydrographic premises of relief formation

The Baia Mare Depression is located in the north-western Romania, under the influence of western air masses and near the Gutâi Mountains. As a result, the average annual precipitation at the Baia Mare meteorological station has a value of 894.8 mm/year (for the interval 1961-2011), a value which varies spatially from west (600-700 mm/year) to south and east (1000 mm/an) (Atlasul climatologic al R.S.R, 1966; Covaci, 2005).

The study area is characterised by a moderate continental climate with mild winters and lower temperatures in the summer months. Thus, the annual average temperature (1971-2000) at the Baia Mare station is of 9.7 °C (PUG Baia Mare, 2011). The western winds are predominant (12.5%) in the warm half of the year, while the eastern winds take 11.9% of the cold interval.

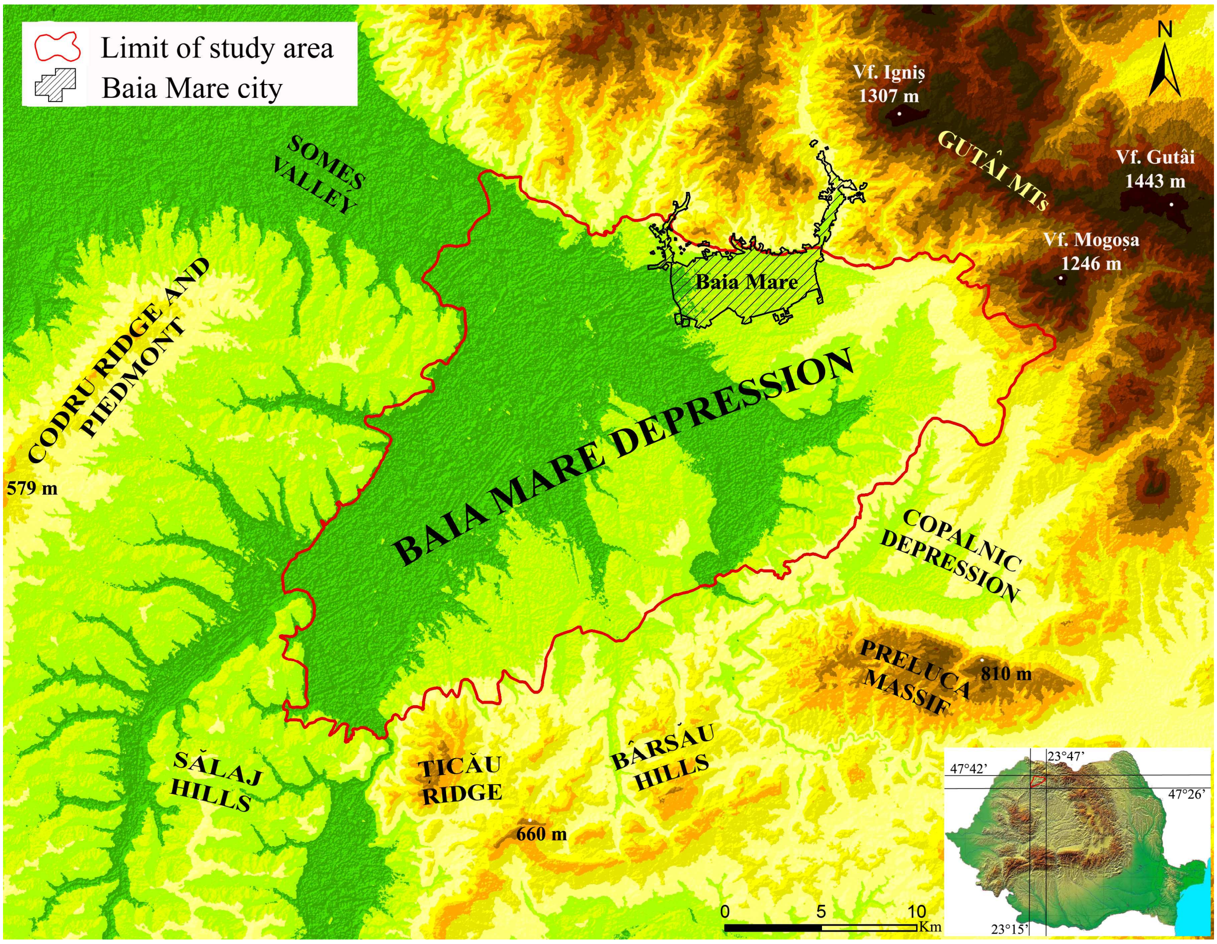


Fig. 3.1. Geographic location of the study area and the relation to neighbouring units.

The climatic characteristics of the study area determine a flow regime of the main rivers specific to the western Carpathians, characterised by early spring high waters (March-

April), while the source for the permanent and temporal flow is divided among 47% rain, 50% rain and snow melt and 3% snow (Ujvari, 1972). The hydrographic network is rich in water courses, its main rivers being: Someș, Bârsău, Lăpuș, Săsar and their tributaries.

3.4. Biopedogeographic premises of relief formation

In the altitude interval of 300-700 m in the Baia Mare Depression the forests include mainly oak species and beech, in association with different grains and other grass species, growing on eutricambosols or luvosols (Filip, 2008; Coman, 2006). The forests of mixed broadleaf species develop on the sunny slopes of the piedmontal hills and on the high terrases, between 250 and 400 m, the soils specific to this level being the luvosols, while on the low terraces and in the flood plain (150-250 m) the forest vegetation is scarce, most of the surface being dominated by grass species. Along the water courses willows and poplar trees grow on hydrisols.

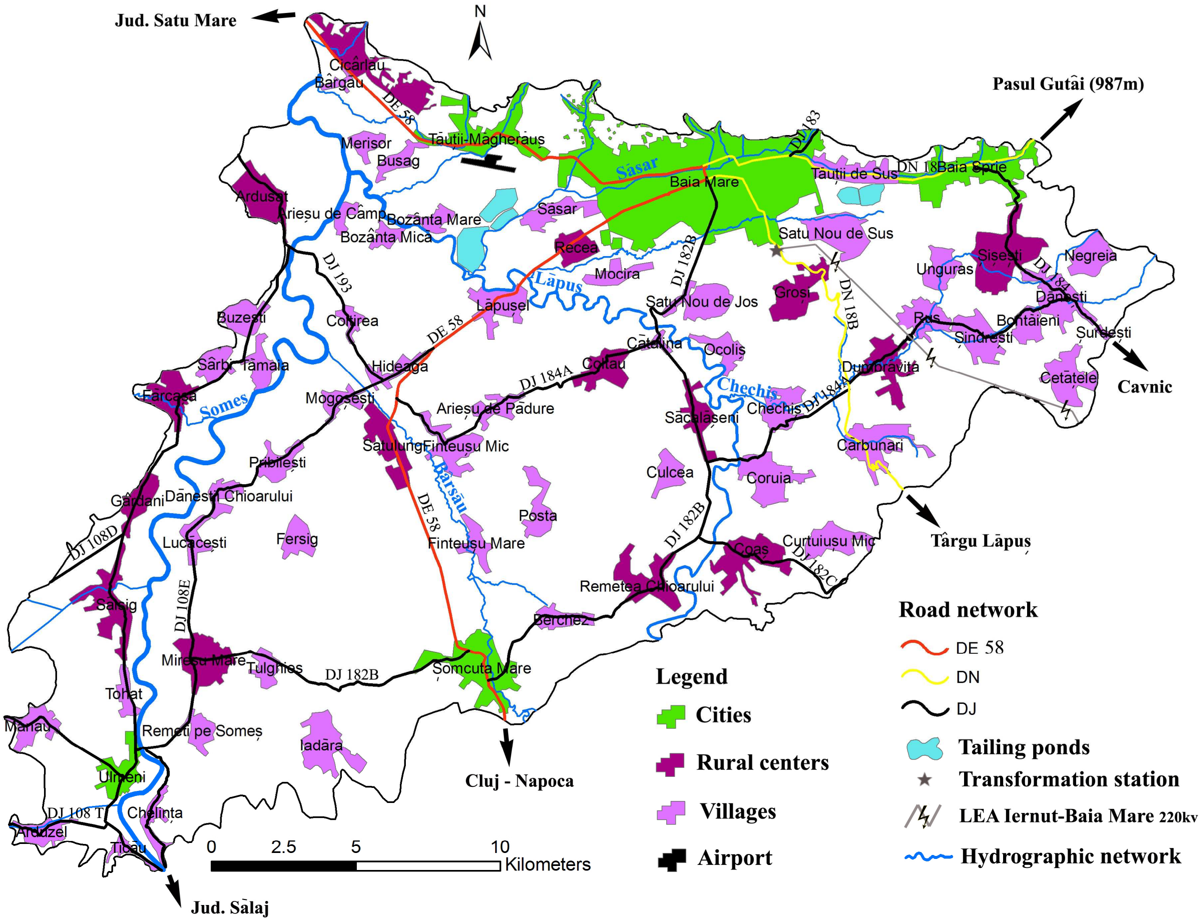


Fig. 3.10. Map of the main anthropic elements from the Baia Mare Depression.

3.5. Anthropic premises of relief formation

The Baia Mare Depression is a well populated territory, the anthropic surfaces representing aproximatively 15% of the 600 km^2, including the territories of 16 communes and 5 urban administrative units (fig. 3.10.), representing a total of 70 settlements, out of which 5 cities: Baia Mare – 123 738 loc., Baia Sprie – 15 476 loc., Șomcuta Mare – 7 565 loc., Ulmeni – 7 270 loc., Tăuții-Măgherăuș - 7 136 loc. (Recensământul populației, 2011).

4. THE RELIEF OF BAIA MARE DEPRESSION

4.1. Morphologic characteristics

From a geomorphological point of view, in the Baia Mare Depression there are three main morphogenetic levels: the low plain with the inferior terraces and flood plains, corresponding to the hydrographic convergence area (below the altitude of 200 m); the piedmontal glacis developed as a narrow strip at the contact with the Igniș Mountains (photo 4.3.), the piedmonts and hills; the high plain of the middle and superior terraces and the intefluvial surfaces between the main rivers: Săsar, Lăpuș, Bârsău and Someș (Geografia României, vol.IV 1992; Posea et al., 1980).

Photo 4.3. The upper limit of the Baia Mare glacis (dotted line; 2013).

4.2. Morphometric characteristics

The palaeogeographic evolution of the studied area was dominated by sedimentary processes followed by the modelling action of rivers which determines a decrease in altitude from est to west and from south to north, reaching the lowest altitude (142 m) in the hydrographic convergence area of the Lăpuș and Someș rivers. The highest altitude (723 m) is recorded in the north-eastern part of the depression, at the contact with the mountain area.

The geodeclivity map in figure 4.3. shows the spatial distribution of steep slopes (5-15°) in the internal hills and the Baia Mare glacis, 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 the shaded and sunny slopes, the latter being more extended in the northern half of the depression, the piedmont and the Baia Mare glacis.

The thematic maps of profile and planar curvature, generated using GIS techniques and the digital elevation model, allow the identification of slope types and, indirectly, of their influence on the slope processes and on the convergent or divergent flow direction, respectively.

Interfluvial surfaces are outlined through the fragmentation density of the relief, the most extended ones being on the surface of the Posta Piedmont, the Curtuiuș Hills and the northern slope of the Baia Mare Piedmont. These areas are characterised by the minimal values of this indicator (0-1 km/km^2). At the same time, the fragmentation depth is an indicator of the relief energy which influences the slope processes, the maximal values from the Baia Mare Depression (250-366 m/km^2) characterising the northern and the north-eastern areas of the depression, the Baia Mare glacis and the Negreia Piedmont.

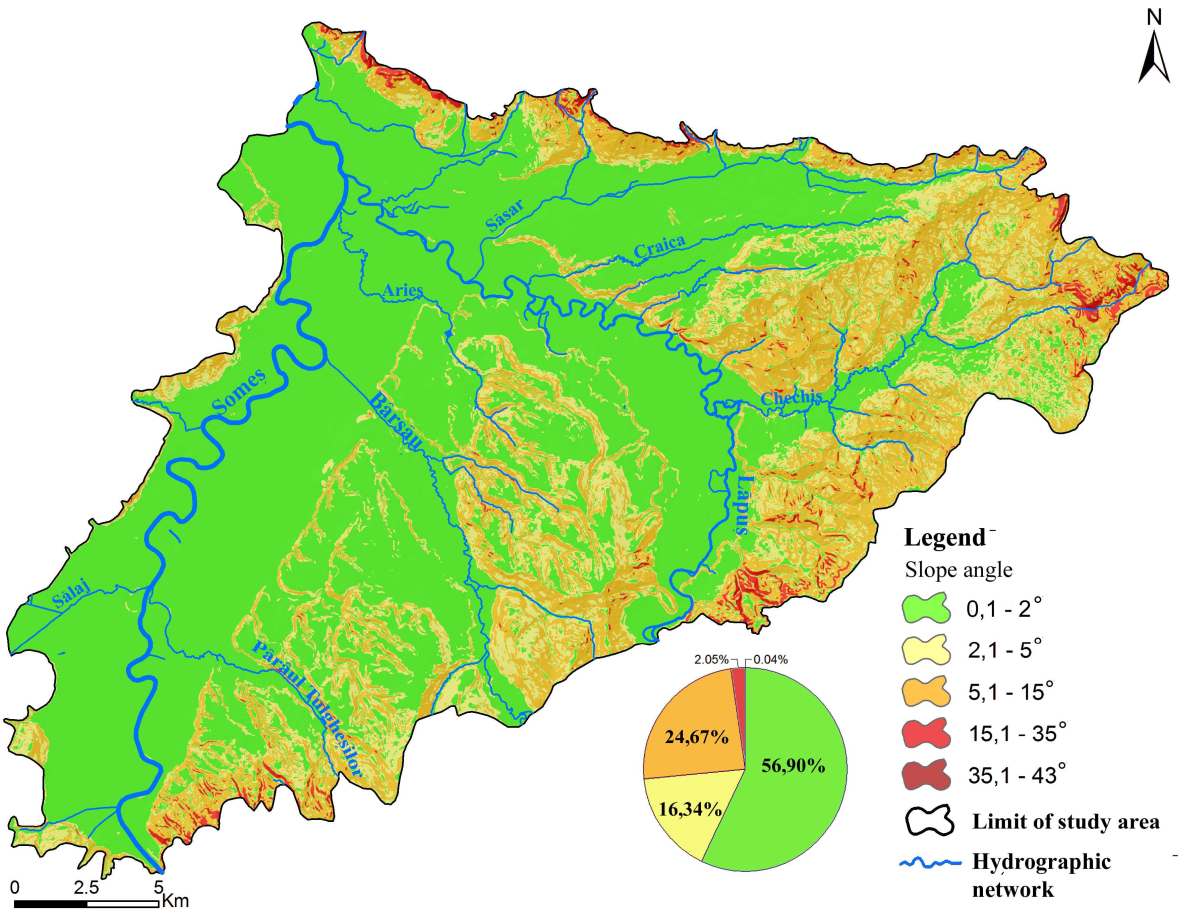


Fig. 4.3. Slope cathegory map of the Baia Mare Depression (0,1-2º cvasi horizontal and slightly sloped; 2,1-5º moderately sloped; 5,1-15º steep; 15,1-35º steeper; 35,1-43º very steep).

4.3. Present processes of relief formation

The present slope processes from the Baia Mare Depression are represented by torrential erosion, landslides and falls, which affect especially the Pliocene and Miocene deposits in the Iadăra, Șomcuta, Groși and Șișești hills and outside the depression, in the Urmeniș hills. In addition to these areas, which were identified in 1973 by Coteț, the Baia Mare glacis is another landslide affected area where the increase in anthropic pressure leads to an increase in landslide activity. On the other hand, in the flood plains the lateral erosion processes continuously reshape the morphology of the river courses affecting the bank stability and the adjiacent slopes.

Photo 4.4. Cuaternary silty and contractive clays (Groși, 2010).

4.4. The landslides from the Baia Mare Depression

In the Baia Mare Depression, landslides are usually associated with the Pannonian deposits (Miocene-Pliocene), represented by marly clays and with covering Cuaternary deposits, 4-5 m thick, represented by silty and contractive clays, in a consequent structure (Zaharia and Driga, 2009; PUG Baia Mare, 2011; Zaharia, 2012).

Photo 4.5. Marly clays covered by silty and contractive clays
(Dumbrăvita; foto: S. Zaharia, 2008).

The characteristics of the Quaternary contractive clays (photo 4.4.) make it difficult to identify the exact conditions of landslide activation. Beside the accumulation of water inside the deposits during prolonged rainfall events, leading at a certain point to slope failure, there are many situations when these conditions are not enough for landslide occurrence. Thus, drought periods can lead to the formation of cracks which, during the eventual rainy periods, enable water to reach the impermeable layers underneath in a short time. In addition to this, the presence of sandy

Photo 4.6. Rotational landslide in Groși (2012).

deposits can play a similar role in the water transfer to the upper surface of the impermeable marly clays (photo 4.5.) or to impermeable layers inside the Cuaternary deposits, generating slip surfaces (PUG Baia Mare, 2011; Zaharia, 2012).

The morphology of most of the landslides from the Baia Mare Depression is characteristic to rotational movements (photo 4.6), according to Varnes (1978), the landslide body being generally uplifted, causing the formation of a reversed slope, drainage disruption (Crozier, 1984) and the emergence of springs among the bodies of landslides (Varnes, 1978).

The translational landslides from the study area are generally smaller and represent the outcome of new or reactivated processes on older landslide bodies (photo 4.7). In addition to these there are many situations with successive scarps on the same slope, which can be described as multiple landslides with several slip surfaces connected to a main surface of rupture (Buma și van Asch, 1996). A similar morphology but with smaller depths and individual slip surfaces charcaterise the successive landslides (Hutchinson, 1988). Unfortunately, a clear separation between these two types is difficult when no data related to the exact position of the slip surfaces is available.

Photo 4.7. Recent translational landslide on an old landslide body (Dănești, 2013).

5. QUALITATIVE ANALYSIS OF LANDSLIDE RISK IN THE BAIA MARE DEPRESSION

5.1. Landslide susceptibility in the Baia Mare Depression

Using the method described in the G.D. 447/2003 the average susceptibility coefficient for the Baia Mare Depression was calculated using the following factors:

Ka = lithologic;
Kb = geomorphologic;
Kc = structural;
Kd = hydrologic and climatic;
Ke = hydrogeologic;
Kf = seismic;
Kg = sylvic;
Kh = anthropic.

Table 5.1. illustrates the coefficient values for the **lithologic (Ka), structural (Kc) and hydrogeologic (Ke) factors** which were estimated using the geologic 1:200 000 (sheet

no. 3 Baia Mare, 1967) The **geomorphologic** coefficient **(Kb)** was determined using the correspondence between the slope value intervals and the probability classes described in the legislative document (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) (G. D. 447/2003; Marchidanu, 2005), while the **hydrologic and climatic coefficient (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 use, soil texture and slope angle (Bilaşco, 2008). Last but not least, **the seismic coefficient** (**Kf**) is given the value 0,50 corresponding to a potential seismic intensity of 6 on the M.S.K. scale (G. D. 447/2003; Marchidanu, 2005), and the Corine land cover classes (2006) were used to heuristically determine the values of the sylvic (**Kg**) and anthropic (**Kh**) factors.

Table 5.1. Heuristically estimated coefficients of the factors Ka-lithologic, Kc-structural and Ke- hydrogeologic using the main lithologic units.

Lithologic unit	Ka	Kc	Ke
Crystalline schist (Precambrian),	0,50	0,50	0,30
Priabonian (Eocene),	0,10	0,50	0,50
Lattorfian (Oligocene)	0,40	0,50	0,50
Chattian – Burdigalian (Oligocene)	0,60	0,50	0,50
Badenian (Miocene)	0,50	0,50	0,50
Sarmatian / Volhinian + Bessarabian (Miocene)	0,60	0,85	0,70
Pannonian (Upper Miocene -Pliocene)	1,00	1,00	0,70
Andesites (Lower Sarmatian)	0,05	0,05	0,15
Dacites of Dăneşti	0,00	0,00	0,10
Cuaternary – Upper Holocene	0,40	0,05	0,40
- Lower Holocene	0,40	0,05	0,50
- Upper Pleistocene	0,90	0,80	0,90
- Lower Pleistocene	0,85	0,80	0,90

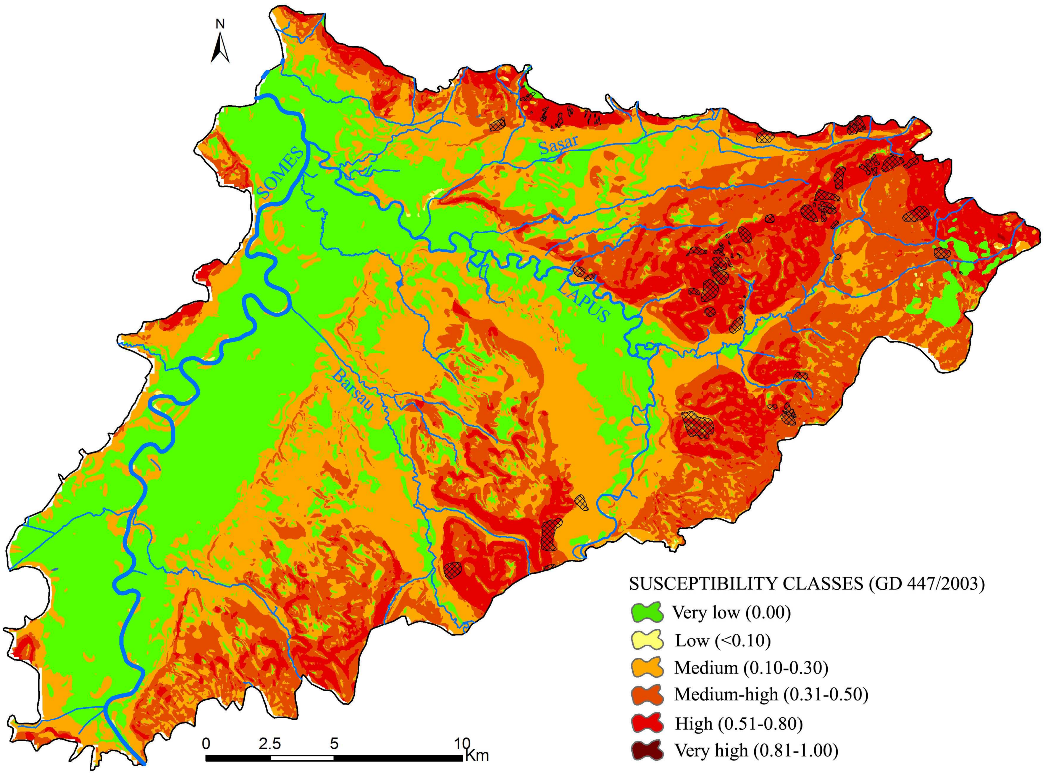
The values of the eight factors are used to automatically classify each factor map with the help of ArcGis 9.3 creating eight corresponding rasters with 20 m resolution. The average susceptibility coefficient and its corresponding map are the results of applying the following formula using MapAlgebra:

$$K(m)=\sqrt{\frac{K(a)\times K(b)}{6}\times[K(c)+K(d)+K(e)+K(f)+K(g)+K(h)]} \qquad \textbf{(5.2.)}$$

where:

K(m) = average susceptibility coefficient (GT 006-97; G.D. 447/2003; Marchidanu, 2005).

The validation of the susceptibility map was done by overlaying it with the mapped landslides from the Baia Mare Depression and by determining the prediction rate (Chung şi Fabbri, 2003). As a result, 10% of the study area having the highest susceptibility values corresponds to 62% of the mapped landslides. Thus, most of the landslides previously mapped overlay high susceptibility values (Chung şi Fabbri, 2005), which accounts for a very good prediction capacity of the resulting map. The susceptibility classes have been determined using the susceptibility intervals proposed by the G.D. 447/2003 (fig. 5.3.), and the class validation (fig. 5.4.) shows that 70% of the mapped landslides are included in the high susceptibility class.



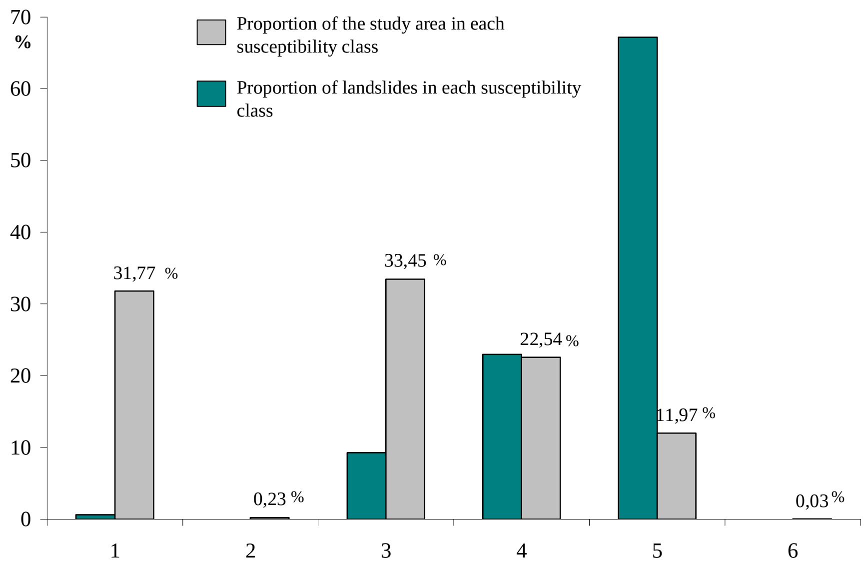


Fig. 5.4. Proportion of landslides in each susceptibility class

(1- zero, 2-reduced, 3-medium, 4-medium-high, 5-high, 6-very high; G.D. 447/2003).

5.2. Hazard analysis

The hazard classes can be determined using the susceptibility map on the basis of a qualitative correspondence illustrated in table 5.6.

5.3. Vulnerability analysis

Depending on the data available at this point, five classes were used to describe the possible consequences to landslides associated to the built-up areas and the main roads in the Baia Mare Depression. These take into account the vulnerability of these elements (the factors which offer information on their resilience and exposure) and the general value of the direct and indirect damages. These classes were defined by Fell et al. (2005) after AGS (2000) and by AGS (2007a) using qualitative descriptors of the estimated damages and have been related to semi-quantitative examples from the Baia Mare Depression (table 5.7).

Tabelul 5.6. Correspondence of susceptibility, probability and hazard classes.

Nr.	Susceptibility classes	Probability classes	Hazard classes
1	Zero	Not credible	Very low
2	Reduced	Rare	Low
3	Medium	Unlikely	Medium
4	Medium-high	Possible	Medium-high
5	High	Likely	High
6	Very high	Almost certain	Very high

Source: after Fell et al. (2005); AGS (2000); AGS, 2007a.

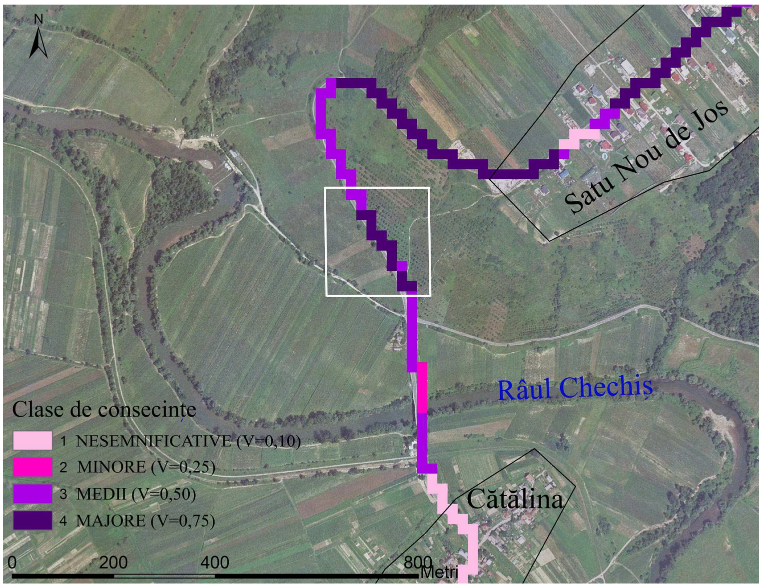


Fig. 5.8. Estimated road consequence classes – example from the DJ 182B between Cătălina and Satu Nou de Jos (white square shows the location of photo 5.1.).

The possible consequence classes (table 5.7.) for the main roads in case of landslide occurence were attributed using the matrix from table 5.8., by applying the overlay technique. The roads raster („*drum_012*“) was combined with the landslide susceptibility raster („*km*“), using a formula for spatial analysis developed with logic conditions (CON):

„road_consequences“ = con([drum_012] == 0 & [km] == 1, 0, con([drum_012] == 0 & [km] == 2, 0, … con([drum_012] == 1 & [km] == 1, 1, con([drum_012] == 1 & [km] == 2, 2, … con([drum_012] == 2 & [km] == 1, 1, con([drum_012] == 2 & [km] == 2, 1, … con([drum_012] == 2 & [km] == 6, 4, 0)))))))))))))))))) **(5.4.)**

Table 5.7. Consequence classes (adapted after Fell et al., 2005 and AGS, 2000), **estimative vulnerability value** (V) **and examples from the Baia Mare Depression.**

Nr	**Consequence descriptor**	**Description**	**Examples from Baia Mare Depression**	**Magnitude or occurence particularities of recorded landslides**
V	**Catastrophic** ***V = 1***	structure completely destroyed or large scale damage requiring major engineering works	deformation and house collapse, requiring evacuation; overturning of poles, fracturing and collapse of entire road width	sudden landslide occurence with high speed (e.g. Groși, 13.05.1977 – 12m in 6h), >2m depth; Cărbunar, March 1999; Chelința, 19.01.2011).
IV	**Major** ***V = 0,75***	extensive damage to most of structure, or extending beyond site boundaries requiring significant stabilisation works	cracks and deformation of houses, pole tilting, cracks and deformation of roads, road collapse on one way;	sudden or slow landslidin frequent reactivations; (e.g. Groși, Remetea Chioarului, Chelința, Ulmeni – local reactivations);
III	**Medium** ***V = 0,50***	moderate damage to some of structure, or significant part of site requiring large stabilisation works	cracks in the walls of houses and smaller constructions, slight pole tilting, deformation and fracture of roads;	slow landsliding with sudden reactivation of low magnitudine (movement is visible only through damages) (e.g. Unguraș, Dănești, Cărbunar, Satu Nou de Jos – 5-30 cm deformation of the road);
II	**Minor** ***V = 0,25***	limited damage to part of structure, or part of site requiring some reinstatement/ stabilisation work	cracks which do not destabilise houses and other construction, slight pole tilting, deformation of centimeters of roads;	slow landsliding, small, superficial reactivations, (e.g. <5 cm deformations of roads, superficial cracks on walls);
I	**Insignificant** ***V = 0,10***	little damage	minor cracks.	very slow movements or lack of any movement.

Validation of results was done heuristically by comparing the results with observations from the field. Thus, the 182B road sector illustrated in figure 5.8. is known for the frequent landslides on the right side of the Chechiș river, determining deformations of tens of centimetres in the road cover (fig.5.8. and foto 5.1.). This situation confirms the results which have included this road sector in the major consequence class.

Table 5.8. The matrix of susceptibility-consequence correspondence for the county (DJ), national (DN) and european roads (E58).

ROAD	**Km - 1**	**Km - 2**	**Km - 3**	**Km - 4**	**Km - 5**	**Km - 6**
1 – DJ și DN	I	II	III	IV	IV	V
2 – E 58	I	I	II	III	III	IV

Photo 5.1. The county road DJ 182B frequently repaired due to landslide deformations (in the background, Cătălina; the present drainage system proves itself inefficient (2013).

By considering a series of factors in the vulnerability estimation of the built-up areas, without quantifying them at this point, four cathegories of human settlements were considered and were included in consequence classes, according to table 5.8. As a result a raster was created using Map Algebra and a formula similar to (5.4.).

The resulting vulnerability map (fig. 5.9.) identifies in the medium and major classes of consequences (vulnerability interval 0,50-0,75) the main settlements

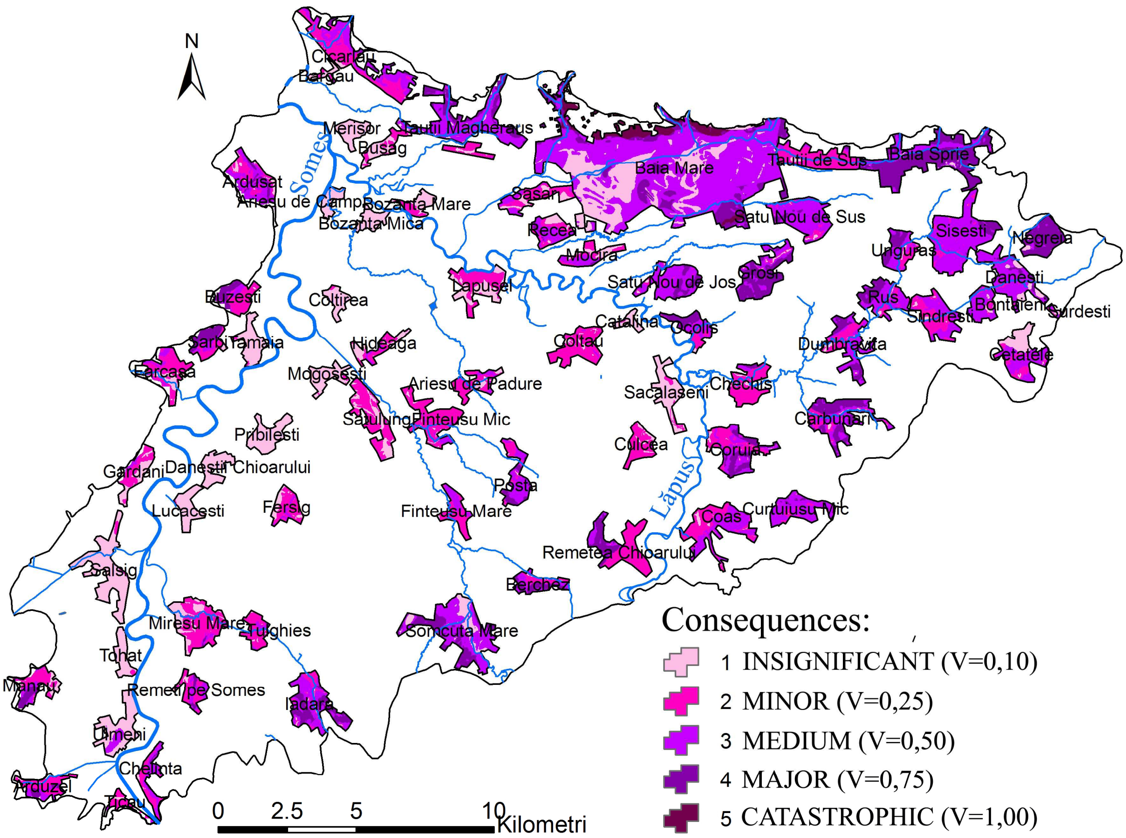


Fig. 5.9. Vulnerability map (vulnerability intervals –V – are represented through possible consequence classes for the built-up areas in the Baia Mare Depression).

mentioned in the official reports as being affected by landslides, with damages to houses and smaller constructions, farm land or orchards located near households.

Table 5.9. The matrix of susceptibility-consequence correspondence for the built-up areas.

Built-up area	Km - 1	Km - 2	Km - 3	Km - 4	Km – 5	Km - 6
1 – Baia Mare municipality	I	II	III	IV	V	V
2 – cities	I	II	III	IV	IV	V
3 – rural centers	I	I	II	III	IV	V
4 – villages	I	I	II	III	IV	IV

A similar analysis was performed for the high tension electricity poles included in the aerial line Iernut - Baia Mare (220kv) which crosses the study area in the Chechiș catchment. In order to determine the vulnerability classes, a raster for the Euclidian distance around the poles was generated at 0-20 m, 20-40 m, 40-60 m intervals, resulting in three distance classes to which three vulnerability intervals were related: 0,5 (medium consequences for the 0-20 m distance), 0,25 (minor consequences for the 20-40 m distance) and 0,10 (insignificant consequences for the 40-60 m distance).

5.4. Risk analysis

The landslide risk estimation was performed separately for the three elements at risk analysed using adapted formulas with logic conditions based on the matrix illustrated in table 5.10.

Table 5.10. Matrix of qualitative risk estimation using the landslide probability and the consequence level.

Probability	Consequences				
	Catastrophic - V	Major - IV	Medium - III	Minor - II	Insignificant- I
Almost certain - 6	**VH**	**VH**	**H**	**H**	**M**
Likely - 5	**VH**	**H**	**H**	**M**	**L -M**
Possible - 4	**H**	**H**	**M**	**L -M**	**VL - L**
Unlikely – 3	**M- H**	**M**	**L -M**	**VL - L**	**VL**
Rare – 2	**M-L**	**L -M**	**VL - L**	**VL**	**VL**
Not credible -1	**VL**	**VL**	**VL**	**VL**	**VL**

VH – very high, H – high, M – medium, L – low, VL – very low.
(The lowest value was selected when two classeThe results indicate a series of s of risk occur; after Fell et al., 2005 and AGS 2002).

The results indicate a series of settlements where sectors of the built-up areas are included in the class of potential major consequences: Iadăra, Șomcuta Mare, Berchez, Remetea Chioarului, Posta, Coruia, Sârbi, Buzești, Cărbunari, Ocoliș, Groși, Satu Nou de Jos, Dumbrăvița, Rus, Unguraș, Șișești, Negreia, Baia Sprie, Baia Mare (fig. 5.17.). The past events with recorded damages confirm these results and motivate the zoning of these areas as having a high landslide risk level, unacceptable without detailed studies and mitigation measures.

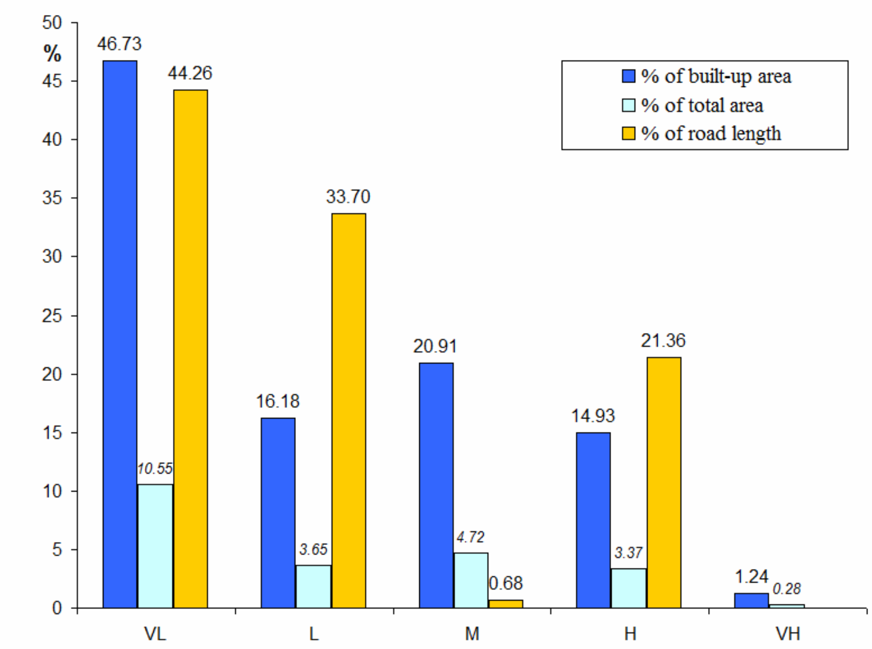


Fig. 5.12. Proportion of each risk class

The road sectors most exposed to landslide risk include the natioanl road 18B between Cărbunari and Baia Mare and the county road 182B between Tulghieș and Remetea Chioarului. These have been repeatedly affected by major landslides and are currently marked

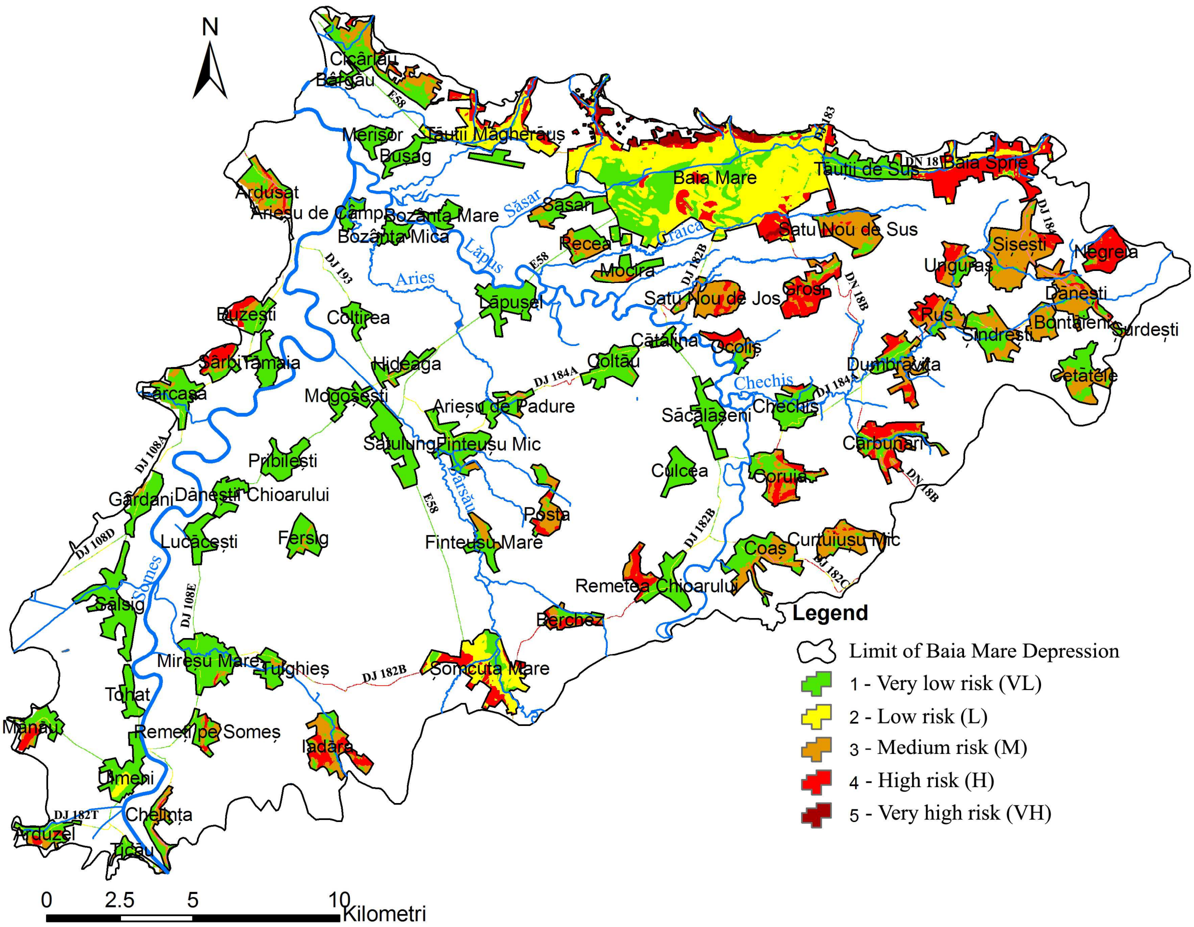


Fig. 5.17. Landslide risk levels for built-up areas and roads in the Baia Mare Depression.

by active landslide processes, thus validating the risk analysis results which include them in the high risk class, unacceptable without specialised intervention.

Out of the total built-up area, aproximately 15% represent high risk areas, while from the total road length, 21% are included in this class (fig. 5.12.). In the Baia Mare Depression these values represent an area of 20,5 km^2 included in the high risk zone and 1,7 km^2 in the very high risk zone (in the north of the Baia Mare municipality), as well as 48 km of road in the high risk class. In the case of the high voltage poles, the results indicate that five poles are included in the landslide risk classes ranging from low to high risk, while the rest are characterised by low and very low risk levels.

6. QUANTITATIVE ANALYSIS OF LANDSLIDE SUSCEPTIBILITY – CASE STUDY IN THE CHECHIȘ CATCHMENT

In order to use a cuantitative method to determine the landslide susceptibility, a smaller area of analysis was selected, represented by the Chechiș catchment. The landslide inventory created in the 2011-2013 interval through field mapping is used to determine the landslide susceptibility of the area by means of the *logistic regression model*.

6.1. The landslides from the Chechiș catchment

The preliminary analysis of the landslides identified in the Chechiș catchment illustrates the main factors which determine the landslide occurence and the main geomorphologic characteristics needed in the hazard analysis.

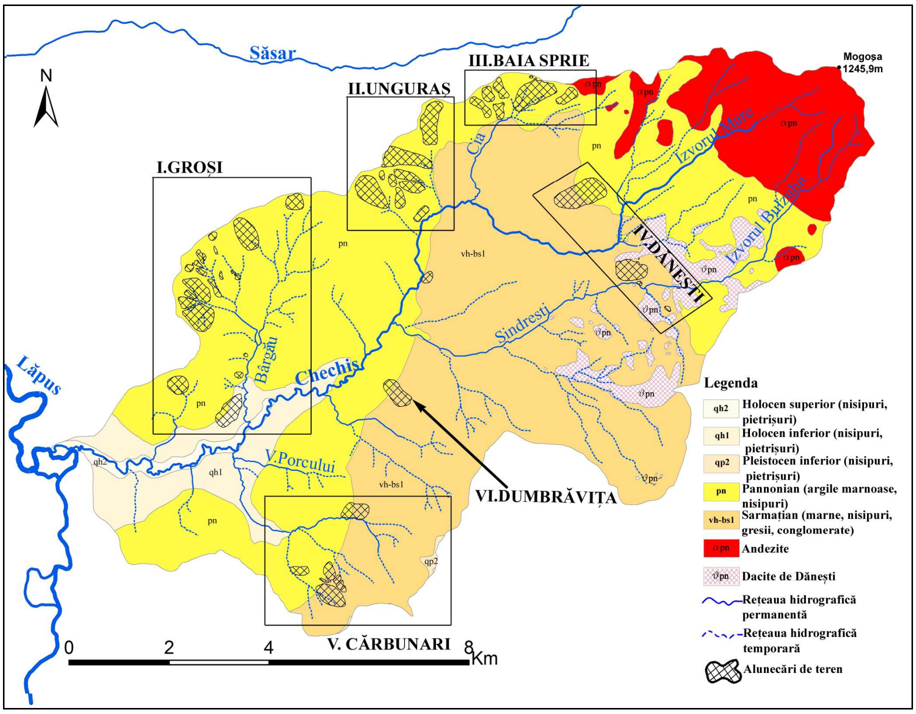


Fig. 6.2. The landslides from the Chechiș catchment.

56 landslides were identified in six areas extensively affected by landsliding (fig. 6.2.): **I-Groși, II-**

Unguraș, **III-Baia Sprie, IV-Dănești**, **V-Cărbunari** și **VI-Dumbrăvița**. The preliminary results of the field observations and mapping have been published by Măguț et al., 2013.

The 30-year cycle of recurrence for the climatic conditions favourable to landslide occurrence (Surdeanu, 1998) is confirmed in the studied area by the still visible damages caused by landslides from the early 70s or by reactivations of older landslides, from the 40s and 50s (photo 6.1.) and the recent activity suggested by fresh scarps.

Photo 6.1. Overturned fountain in Groși

(water level at <1 m from ground surface, 2012; source: Măguț et al., 2013).

Using the available geologic data, (fig. 6.2.) and local sources of information (ing. dr. Zaharia Sorin, s.c. Geoproiect s.r.l., Baia Mare), a series of morphological profiles were completed with schematical lithologic information. Two exceptions are represented by the Dumbrăvița and Baia Sprie-Dănești areas where geotechnical investigations were available for the validation of the results and the lithological and structural information was based on drilling data (chapter 7). This led to the identification of the general landslide occurrence conditions in the Chechiș catchement:

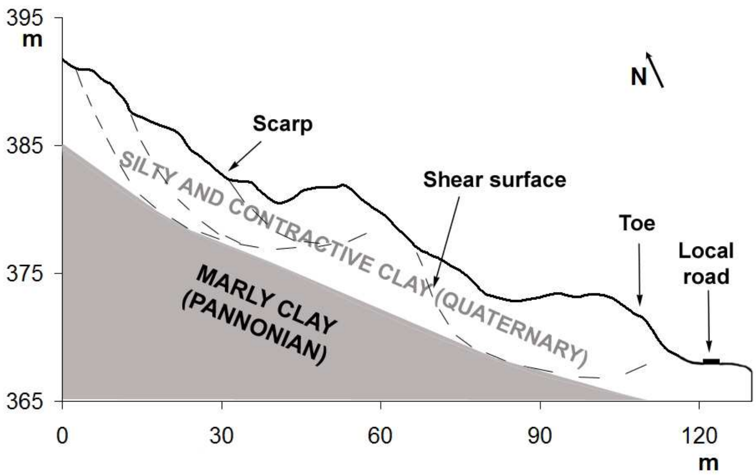


Fig. 6.4. Geomorphologic profile in the Unguraș area

(after Măguț et al., 2013).

- most landslides (including recent reactivations) have a surface of rupture in the Quaternary deposits consisting of silty and contractive clays, in association with the hydrostatic level and the local drainage conditions;

- the landslides with a surface of rupture at the interface between the Quaternary deposits and the

Pannonian marly clays can occur in addition with the situation presented above, if the triggering conditions include prolonged rainfall, rainfall which follows dry periods when deep cracks form in the covering deposits (Zaharia, 2012), or local conditions which allow the water to descent to the Pannonian deposits. These slip surfaces can be individual or can form in time through the intersection of several slip surfaces through repeated reactivations or lateral enlargements of the landslide area.

6.2. Landslide susceptibility assessment using logistic regression

In the Chechis catchment a series of factors were in order to establish their influence on landslide occurrence by means of the logistic regression model: lithology, relief energy, slope angle, aspect, plan curvature, profile curvature, fragmentation density, distance to roads, distance to streams and topographic wetness index. Statistically, these factors represent the independent variables included in the model, while the mapped landslides represent the dependent, binary variable, with two values (Hair et al., 1992; Hilbe, 2009): 0-landslide absence, 1-landslide presence.

In preparing the independent variables using ArcGis 9.3 the raster and vector data available for each factor were used to generate a series of dummy variables which are necessary in representing qualitative, discrete variables (Hardy, 1993; Garavaglia și Sharma, 1996; Dai și Lee, 2002; Hilbe, 2009): **litology** (seven classes – seven dummy variables), **aspect** (eight classes), **profile curvature** (three classes), **plan curvature** (three classes), **distance to streams** (seven classes), **distance to roads** (six classes), **topographic wetness index** (three classes), **digital elevation model** (nine classes). Together with the factors included as continuous variables (**slope angle, fragmentation density**), they totalise 48 variables intersected using Hawths Tools in ArcGis 9.3 with a series of points generated using the landslide layer. The script used in this stage and the logistic regression performed in the following stages has been developed by Helene Petschko from the ENGAGE research group led by Prof. Thomas Glade (University of Vienna), together with Prof. Alexander Brenning (Waterloo University, Ontario).

The statistical correlation of the mapped landslides with their causing factors is assessed using the multivariate analysis model of logistic regression, with the help of the statistical software R and the RSAGA platform. By applying the logistic regression formula (6.1.), the combination of factors with the closest results to reality is selected using the Akaike criterion, and the stepwise variable selection (Allison, 2001). As a result, the final model included eight variables, their coefficients being illustrated in table 6.3.

glm(formula = *landslide ~ slope + dem_2 + dem_3 + lit_pn + dens_fr + cpr_ccv + ...*, family = binomial, data = *model_dataframe*) **(6.1.)**

Table 6.3. Coefficients of the final logistic regression model.

VARIABLES		COEFFICIENT
Lithology:	Pannonian (lit_pn)	19.26702
	Sarmatian (lit_sm)	17.73916
Slope angle	(slope)	0.29864
Aspect:	NV (aspect_nv)	-1.07024
	SV (aspect_sv)	0.73423
	S (aspect_s)	0.83124
Altitude intervals:	201-300m (dem_2)	3.69364
	301-400m (dem_3)	4.87467
	401-500m (dem_4)	3.99033
Distance to streams:	100-200m (dist_ape_2)	-0.66913
	201-300m (dist_ape_3)	-1.20730
	301-400m (dist_ape_4)	-1.90681
	401-600m (dist_ape_5)	-2.07179
Distance to roads:	201-400m (dist_drum_3)	-0.65639
	401-800m (dist_drum_4)	-1.04064
Fragmentation density	(dens_fr)	-0.30774
Topographic wetness index with values close to 0 (twi_0)		-0.40802

Based on these coefficients, the landslide occurrence in the Chechiș catchment is explained by a combination of favourable factors (Pannonian and Sarmatian lithology, slope angle in the altitude interval of 201-500 m, southern and south-western aspect) with a series of factors which are not associated to landslide occurrence and can be considered as restrictive: north-western aspect, distance to streams larger than 100 m, up to 600 m from where its influence is no longer significant, 201-800 m distance to roads, fragmentation density and the topographic wetness index with values close to 0, correspondent to the interfluvial surfaces of the study area.

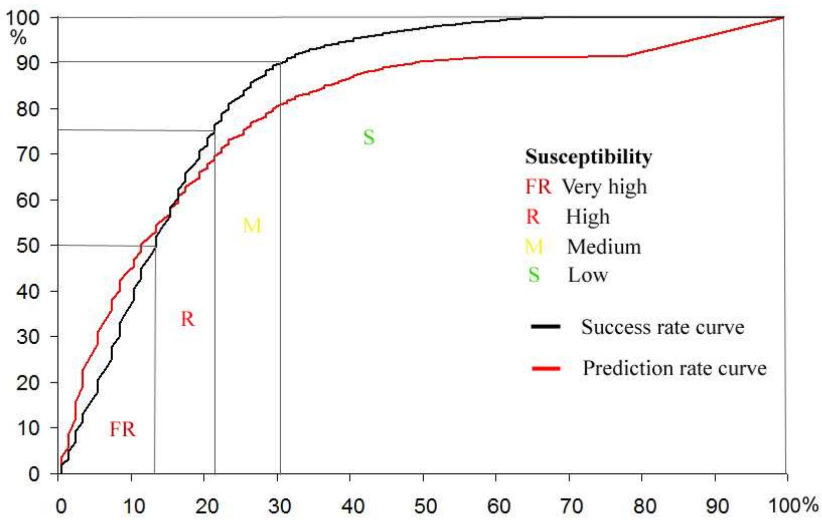


Fig. 6.11. The success rate and prediction rate curvesfor the susceptibility model used in the Chechiș catchment (x axis– cumulative % of the total study area fo each susceptibility value; y axis – cumulative % of landslides for each susceptibility value).

The regression coefficients are used for determining the spatial probability of landslide occurrence, represented by the map in figure 6.14. In order to make a solid classification of the resulting map, the success rate was used to determine the susceptibility intervals defining each class (Chung și Fabbri, 1999, 2003, 2008; Van Westen et al., 2003; Remondo et al., 2003) (fig. 6.11.).

The areas included in the very high susceptibility class on the map from figure 6.14. represent almost the entire southern sector of the Baia Mare Piedmont, a series of slopes from the Cărbunari area and the Negreia Piedmont, corresponding to 14% of the studied area (14 km^2). The high and medium susceptibility classes surround these areas, covering a total of 30.45% (30.45 km^2) of the catchment area. Almost all the landslide areas mapped in the field correspond to a high and very high level of landslide susceptibility, one of the few exceptions being the anthropically triggered landslide from Dumbrăvița. These results confirm the model's capacity of explaining the occurrence of past landslide and the prediction of future landslide areas where similar characteristics are present.

The model validation is based on the interpretation of the success and prediction rates (fig. 6.11.), as well as of the area under the ROC curve. Thus, the 0.80 value of the AUROC (Area Under the Receiver Operating Characteristic Curve) which resulted after validating the model with the independent landslides from the Chechiș cathcment, underlines the good prediction capacity of the model applied, its accuracy being 80%. In addition to this, when ananlysing the proportion of independent validation landslides in each susceptibility class (fig. 6.13.), one can notice that in the first 10% of the studied area characterised by the highest susceptibility values, 47.10% of the landslides are correctly predicted. The first tenth of the area has the highest efficiency and relevance in the validation of results (Chung și Fabbri, 2003), thus the results show a good prediction capacity of the model.

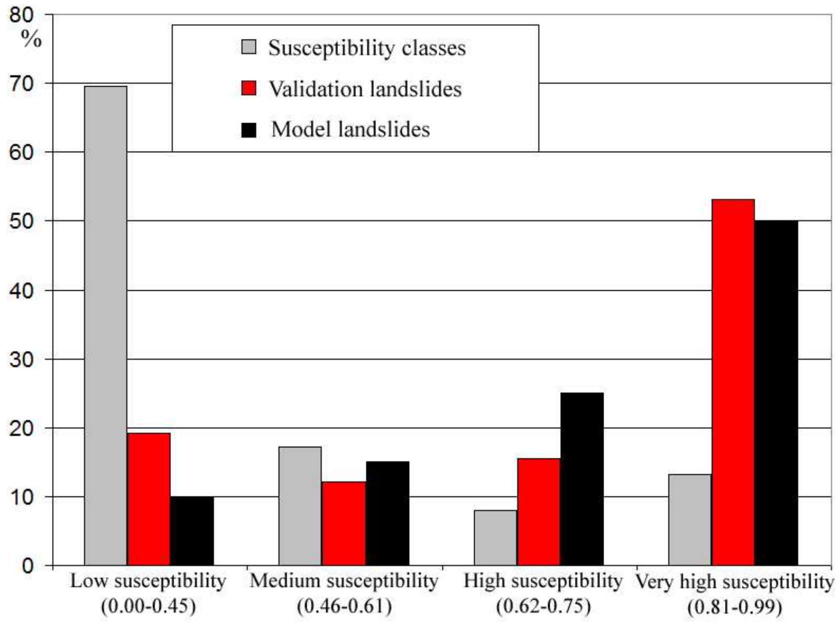


Fig. 6.13. Landslide proportion in each susceptibility class.

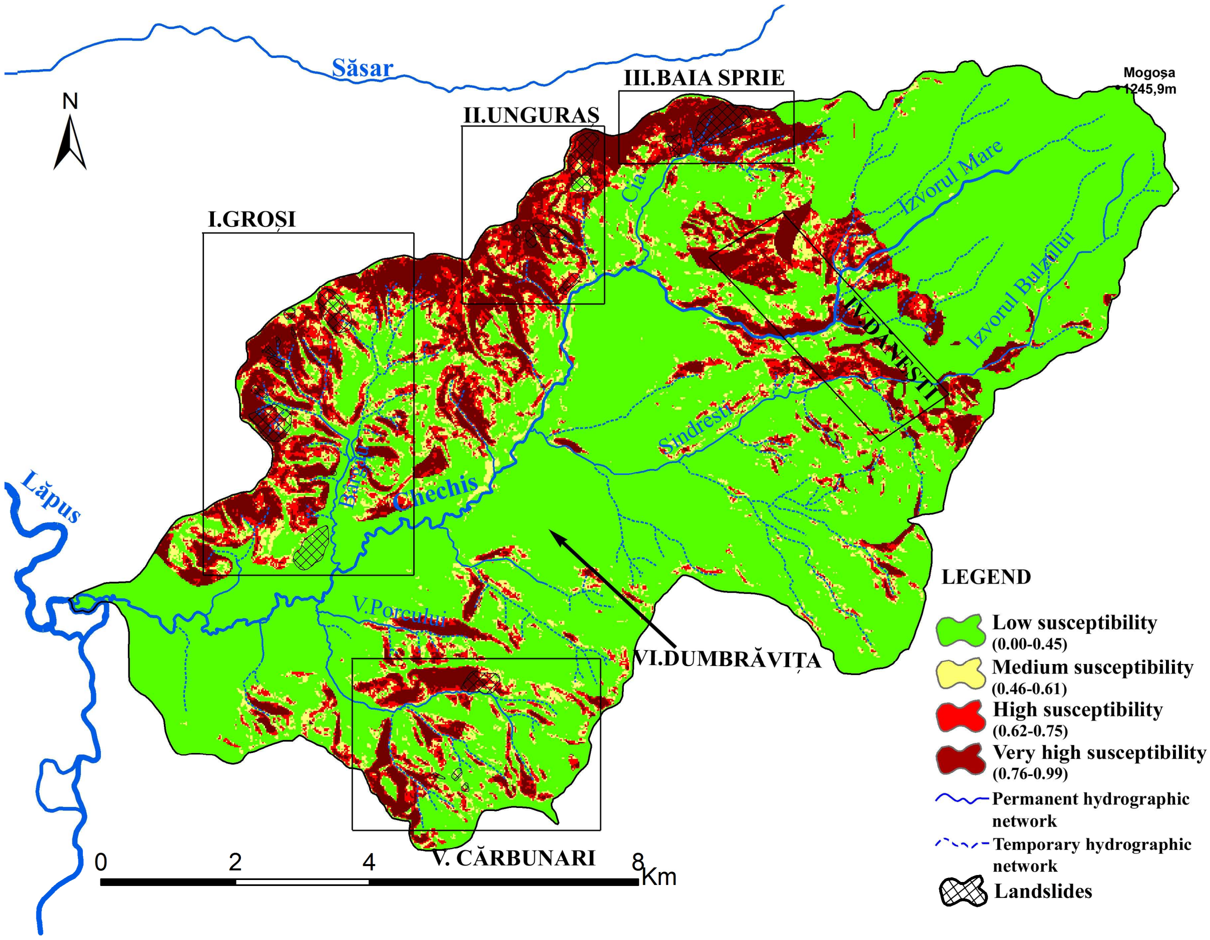


Fig. 6.14. Reclassified map of landslide susceptibility in the Chechiș catchment.

6.3. Landslide hazard estimation in the Chechiș catchment

The hazard estimation from the final part of chapter 6 makes use of the precipitation data available at the meteorological station Baia Mare, known occurrence dates of landslides and field observations.

Two general classes of magnitude have been defined using the movement speed of the active landslides from the study area: 3m/sec.-1.5m/month and 1.5m/month-0.3m/5 years. The frequency of occurrence for each magnitude interval is difficult to determine because of incomplete data, however by comparing the landslide occurrence dates with the mutiannual precipitation regime (fig. 6.16.), one can notice that landslide activity is associated to rainy years following dry years, or to more consecutive rainy years (above the multiannual average). The probability that the first set of conditions is fulfilled has been heuristically determined using the annual precipitation series from the Baia Mare station and the available landslide occurrence dates and has the value of 20%, corresponding to a 0.2 annual probability. It is estimated, without any present possibility to validate the results at this point, that this value corresponds to the first class of magnitude, while the probability that slow landslides occur is undoubtedly higher.

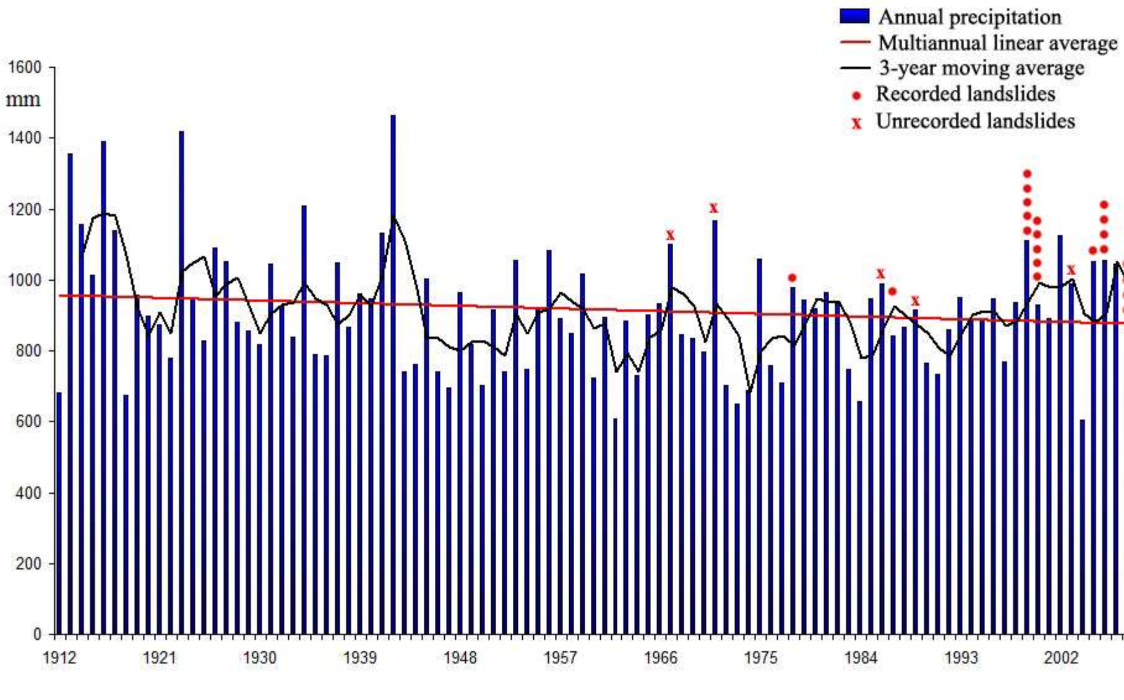


Fig. 6.16. Annual precipitation at the Baia Mare meteorological station (1911-2011) **and the recorded and unrecorded landslides from the Baia Mare Depression** (Precipitation data source:: 1908-1970 www.eca.knmi.nl; 1971-2007 PUG Baia Mare; 2008-2011 ANM).

7. LANDSLIDE RISK ASSESSMENT – CASE STUDY IN THE BAIA SPRIE – DĂNEȘTI AREA, THE COUNTY ROAD 184

The direct involvement in the geotechnical study required by the project ”Rehabilitation of the county road Baia Sprie (DN18) - Cavnic (DJ 184) - Ocna Șugatag (DJ 109F) - Călineşti (DJ185) - Bârsana (DJ185)” (beneficiary s.c. SEARCH CORPORATION s.r.l. BUCUREŞTI), which was made in February-March 2013 in the Chechiș catchment has allowed the direct observation of the research stages and provided an important data source for a local detailed risk evaluation. The personal contribution to the study has included field observations, mapping of landslides, generating the general and detailed cartographic material and geomorphological interpretations of data.

The three landslides directly affecting the road sector between kilometre 1 and 9, between Baia Sprie and Dănești (fig. 7.2), are located on the Negreia Piedmont, at the foot of the volcanic masif Mogoşa (Posea, 1962). From a lithological point of view, the studied area is located at the contact of Sarmatian and Pannonian sedimentary deposits with the volcanic dacites of Dănești. The slope aspect is predominantly western and the slope value ranges between 4 and 20 degrees, the maximum values characterising the scarp areas.

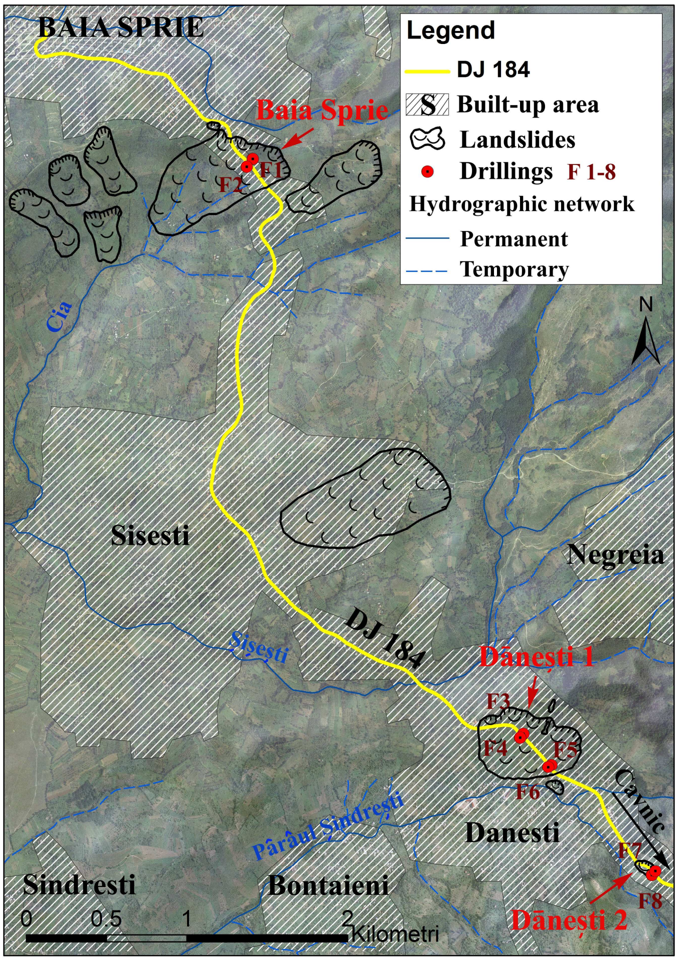


Fig.7.2. Location of the landslides affecting the county road 184, inside the limits of the Baia Mare Depression.

The field investigations included observations, identifying the main elements of the landslides and mapping them with a GPS (Garmin eTrex 3.0), measuring geometrical characteristics of landslides, eight geotechnical drillings and eight investigations using a dynamic penetrometer.

Photo 7.5. Recent reactivations of landslides below (left) and above DJ 184 (right) (2013).

By analysing the present profile of the slope crossed by the 184 road one can notice that both at the Baia Sprie and Dănești I landslide the road intersects and cuts through rotational landslide bodies. The recent reactivations (photo 7.5.) of these landslides are generally triggered by rainfall, snow melt and sometimes by human intervention. The drillings performed on the three landslides enabled the firm s.c. GEOPROIECT s.r.l. to create also a series of four geotechnical profiles, and the previously created profiles for different slopes in the Chechiș catchment were finally validated and completed with detailed lithologic data (fig. 7.6.).

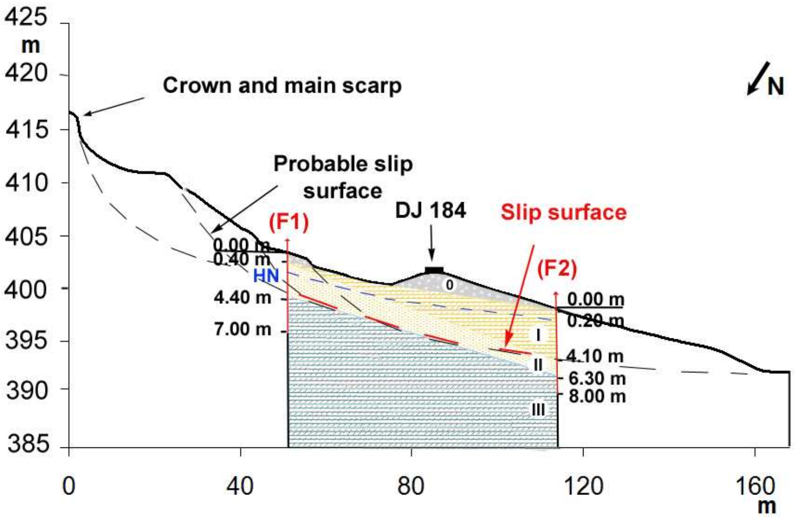


Fig. 7.6. Geomorphologic profile made by combining the previous topographic profile PT with the geotechnical profile P1 (Baia Sprie landslide; 0 – earth fill, I- silty, brown-green, very consistent clay, II- silty, brown-grey, consistent clay, III- silty, grey-blue, very consistent, marly clay).

The firm s.c. PROIECT BIHOR s.a. used for two of the profiles the Bishop method in order to determine the slope stability based on the limit equilibrium and the factor of safety (Rădoane et al., 2001). The results of this analysis as well as the geotechnical characteristics determined through the eight drillings were used to identify the depth of the surfaces of rupture for the three landslides. Thus, for the Baia Sprie landslide, the minimum value of the factor of safety (F = 0.89) corresponds to an average depth of 3-4 m and 5.8 m under the road foundation which can also be differentiated based on the smallest cohesion (10 kPa), the smallest value of the internal friction angle ($8^{\circ}\ 10^{'}$ - $8^{\circ}\ 50^{'}$) and the smallest value of the upper plasticity limit (W_L = 59,78%) recorded in the drilling results.

Foto 7.3. Polygonal cracks up to 10 cm wide, caused by the constraction of the silty clay (Baia Sprie, November 2012).

In the case of the Dănești I landslide, the minimum value of cohesion (10-19 kPa) in the 1^{st} made of average and large sand, redish-brown silty clay, with gravels explains the shallow reactivations observed on the upper slope (fig. 7.8.). The geotechnical characteristics include an angle of internal friction ranging from 8° 10' to 11° 10' and a slope angle of the profile between 2 and 7-7.8 degrees, up to 12 degrees on the upper slope. In addition to this, on the 3^{rd} profile, a surface corresponding to the minimal value of the factor of safety (F = 0,405) can be identified at a depth of 3 m, confimed by the low cohesion value of the layers I and I/L (15-20 kPa and 10 kPa) and in the presence of a freatic layer found underneath. The probability that these unstable deluvial deposits would slide on the lower, silty and very consistent clay layer (50 kPa in the layer II) is very high, therefore the Dănești I landslide has been recommended for monitoring of the landslide movements, beside several stabilising measures (Studiu geotehnic - Proiect nr.2800-2013). The smaller Dănești II landslide requires similar intervention methods as the other two landslides affecting the 184 road, including water drainage, drilled columns and the use of preventive actions.

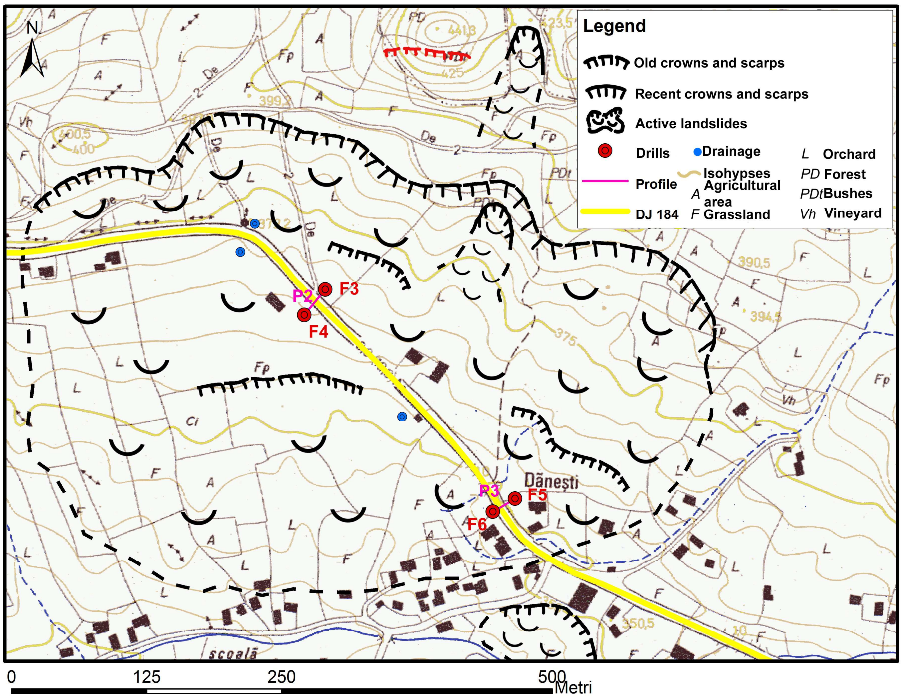


Fig. 7.8. Dănești I landslide (source of cartographic backgound 1:5000: National Agency of Cadastre and Estate Publicity, Baia Mare; F3-F6 – geotechnic drills, P2-P3 – geotechnic profiles, old scarp in volcanic area – dotted red line).

7.4. Landslide risk assessment in the Baia Sprie-Dănești area

On the surface of the analysed landslides and in their close proximity, there are numerous constructions and local roads. By overlaying these elements on the two susceptibility maps created in the previous chapters the comparative landslide exposure can be visualised.

Taking into consideration the two general landslide scenarios presented in chapter 6, (sudden activation of landslides and slow landslide processes), it is estimated that the vulnerability of the elements at risk takes two possible values, V=1 for the complete destruction of the elements and V = 0.5 for damages caused in time by slow movements.

As a consequence, if no risk mitigation measures are taken (especially the drainage of excessive water from the slopes), the landslide risk represented by complete destruction of the elements is possible. When considering the slow movements, it is estimated that, in time, they can cause damages of up to half the value of the analysed elements at risk (table 7.11.). In the present, this type of movements causes cracks in the walls of the buildings, deformations of the local roads as well as tilting of electricity poles.

Table 7.11. Estimated landslide risk of buildings and roads on the surface of landslides Baia Sprie, Dănești I and II.

Elements at risk	**Number of buildings; length of the road exposed to high and very high risk**	**Estimated value for area and length unit**	**Estimated value of potential damages**	
			V = 1 (rapid landslide movements)	V = 0,5 (slow landslide movements)
Buildings	87 (10319 m^2)	200 €/m^2	2.063.800 €	1.031.900 €
DJ 184	1149 m	750.000 €/km	861.750 €	430.875 €
Local roads	896 m	100.000 €/km	89.600 €	44.800 €

8. LANDSLIDE RISK MANAGEMENT IN THE BAIA MARE DEPRESSION

Evaluating the landslide risk in the study area, there are many administrative units which must plan the expansion of its built-up area by responsibly implementing prevention measures through detailed landslide risk studies, stabilising measures and building restriction where the risk level is unacceptable. At the same time, the ongoing rehabilitation of the county and national roads must include landslide stabilising measures like the ones described for DJ 184.

CONCLUSION

In the Baia Mare Depression, the landslide risk is a reality faced by many communities and as a consequence, it should not be underestimated or ignored. The detailed further investigation of the regional and local situations presented in this study would enable the future prevention of negative effects by applying mitigation methods adapted to local conditions. The realistic and responsible management of the landslide risk is highly dependent on the correct information and awareness of the inhabitants, as well as of the responsible authorities, of the role they have in amplifying or reducing the risk level from the inhabited areas. In this respect we hope the present study will represent a useful instrument.

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