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LARGE LANDSLIDE RISK ASSESSMENT IN HILLY AREAS. A CASE STUDY OF HUŞI TOWN REGION (NORTH-EAST OF ROMANIA)

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ABSTRACT

Large landslides are a common geomorphological characteristic of the Moldavian Plateau (Romania), their presence and manifestation being favored mainly by geological and climatic conditions. In numerous cases, the spatial pattern of the large landslides is under the form of amphitheatres, with impressive dimensions, reaching sizes of hundreds of hectares. Due to their defensive characteristics, these landforms often constituted sites for settlements location during the Middle Ages. The constant growing of the human pressure (19th, 20th century) had led to the settlements extension in areas of high slope instability. A representative case of settlements location on these landforms is the Huşi town, with a population of 25.000 inhabitants, situated in the central part of the Moldavian Plateau. The landslide risk assessment for the Huşi town area (approximately 79 km^2) was performed on the basis of landslide susceptibility and exposed elements maps. Landslide susceptibility was assessed using the logistic regression approach, taking into account ten quantitative and qualitative factors. The cartographic base was represented by topographic maps at scale 1:5.000 and the high resolution orthorectified aerial image (2010). The elements exposed to risk were digitized from the same primary cartographic materials and the General Urban Plan provided by local administration. The results indicate high level of landslide susceptibility on the southern side of the Huşi town and this should be seriously considered by the decision makers in the land planning projects.

***Key words**: landslides susceptibility assessment, logistic regression, elements at risk, Huşi town, Romania.*

INTRODUCTION

Landslides are landscape modeling processes, often with risk character and important potential ecological and economic consequences. Their occurrence is controlled both by a series of favoring factors (e.g. geological, climatic, hydro-geological characteristics, geomorphometry) and triggering factors (neotectonics, heavy rainfalls, human activities).

In the last three decades, landslides investigations have passed from qualitative to quantitative approaches and from purely geological or geomorphological investigations to hazard and risk assessment (Varnes, 1984) at different time or spatial scales. Although there are some landslide susceptibility and hazard studies since the 1970s years (Fell *et alii*, 2008), the scientific approach still faces many methodological difficulties especially for quantifying and multi-scale landslide risk mapping (Van Westen *et alii*, 2006). Therefore, new techniques and methods have been developed and continuously improved on various conceptual and methodological frameworks: geophysical models to assess slope stability and landslide dynamics (Bogoslovsky & Ogilvy, 1977; Gallipoli *et alii,* 2000; Jongmans & Garambois, 2007); susceptibility and hazard prediction (Guzzetti *et alii*, 2005; Brenning, 2005; Guzzetti *et alii,* 2006; Günther *et alii*, 2012); vulnerability assessment (Glade, 2003; Uzielli *et alii*, 2008; Kaynia *et alii,* 2008; Pascale *et alii*, 2010); complex approaches intended to quantify landslide risk (Guzetti, 2000; Dai *et alii,* 2002; Ko ko *et alii*, 2003; Bell & Glade, 2004; Crozier & Glade, 2005).

The last direction became increasingly important aiming to meet the needs of the present-day society that records important financial, material and even human losses caused by these geomorphological processes. In landslide risk assessment, risk is most often viewed as a product between hazard, exposure and vulnerability. Due to the high conceptual complexity, it is not surprising that there many points of view, with some overlapping between hazard and risk or with understanding of exposure either as element of hazard or as part of vulnerability. Susceptibility is seen as the probability of landslide occurrence in a given area, taking into account all preparatory conditions and any triggering factor, whose action is considered permanently acting. It still remains unknown and aleatory (the hazard) the moment of landslide triggering, its dynamics and spreading or the release rate (Glade *et alii*, 2005). The exposure reflects a spatial dimension of human structures (peoples, dwellings and utilities, road or special networks, other social and economic objectives) and identifies their presence in areas that may be affected by the considered probable landslides. Vulnerability is perhaps the most differently defined component in risk assessment, varying from the limitations to exposure or the simply value and percentage of the economic losses to exposure, preparedness and prevention, coping ability, adaptive capacity and recovering (Stângă & Grozavu, 2012). These different meanings evolved over time, the role of the intrinsic characteristics of the society being widely recognized (Haque & Burton, 2005), but the disciplinary context seems to be decisive, since the physical scientist have a clear preference for a hazard-based point of view, while the social scientists and human geographers rather adopt a structural and human-centered perspective (Smith & Petley, 2008).

To counter the landslide risk in urban areas, four approaches have been employed by landslide managers and urban planners: (1) restricting development in landslide-prone areas; (2) implementing and enforcing excavation, grading, and construction codes; (3) protecting existing developments by physical mitigation measures and (4) developing and installing monitoring and warning systems (Schuster & Highland, 2007).

In Romania, during the last years, several studies and modern approaches can be mentioned, including applications of GIS techniques and statistical analysis methods, evaluation and mapping of the inherent risk associated with these geomorphological processes and of landslide susceptibility, in particular (Micu & Bălteanu 2009; Bălteanu *et alii*, 2010; Grozavu *et alii,* 2010, 2012; Mărgărint *et alii*, 2011; Şandric *et alii*, 2011; Armaş, 2011, 2012; Nicorici *et alii*, 2012).

The current study aims to assess the landslide risk in terms of susceptibility and exposure appraisal, without considering the temporal variability of landslides or the economic or functional dimension of vulnerability. The analysis is applied to the southern part of Huşi town territory, situated within the Moldavian Plateau, where landslides represent defining geomorphological feature. Landslide susceptibility assessment constitutes a mandatory step for landslide hazard and risk evaluation (Cardinali *et alii,* 2002; Guzzetti *et alii,* 2008), the prognosis and mapping of future landslide locations being possible only through a better understanding and evaluation of the importance of favoring and triggering factors.

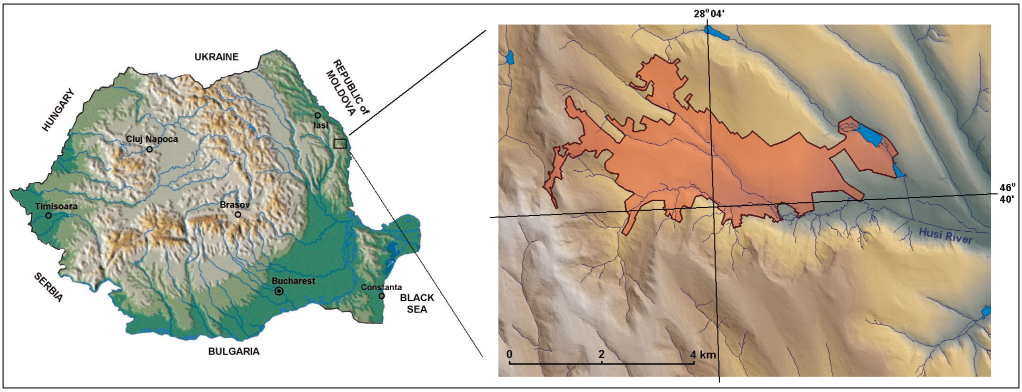

Fig. 1 - Geographical position of study area. The relief, hydrography and the limit of Huşi town

STUDY AREA

Huşi town is situated in North-East of Romania (46°40'30"N, 28°03'30"E), in the central-eastern part of the Moldavian Plateau (Fig. 1). This is a platform region, in which the sedimentary layers display a faint inclination (4-7 m/km) from NNW to SSE. The town is located in the southern part of a depression area developed along the right side of Prut River, which marks the border between Romania and the Republic of Moldova. The elevation ranges from 35 m a.s.l., in the valley of the Huşi River (tributary to Prut River) to 365 m a.s.l., on top of the hills from the south-western part of the area.

GEOMORPHOLOGICAL SETTING

The overall morphology is characterized by the dominance of monocline relief, with north facing cuesta escarpments and south facing dip slopes, consequences of river network adaptation to geological structure. Along the escarpments, landslides present an almost continuous distribution. In the southern part of Huşi town, along the right side of the homonym river, several large, semicircular shaped landslides are developed (Fig. 2). These landslide basins formed through a succession of deep, rotational landslides. In fact, within the Moldavian Plateau, there are many cases with landslides having the aspect of large amphitheaters, with impressive dimensions, reaching sizes of hundreds of hectares. Due to their defensive characteristics, these landforms often constituted sites for settlements location during the Middle Ages. The constant augmentation of human pressure (19th, 20th century) has led to the extension of settlements in areas of high slope instability.

The landslides recognition is facilitated by their general morphology, their evident scarps, and the rolling aspect of slope deposits. Still, only about 15% of the slopes presents evidences of active landslides. These activations of deluviums are closely related to the multiannual and annual precipitations regime and also to some rainfall events when the precipitations are concentrated during the spring or summer months (Pujină, 2003). In the study area, the mean multiannual precipitations are about 500 mm/year, the altitude induced variations ranging from 460 to 560 mm/year. About 70% of the annual quantities fal between April and September (Irimia *et alii,* 2011).

In the larger area of the Moldavian Plateau, a series of periods were identified, for the last 50 years,

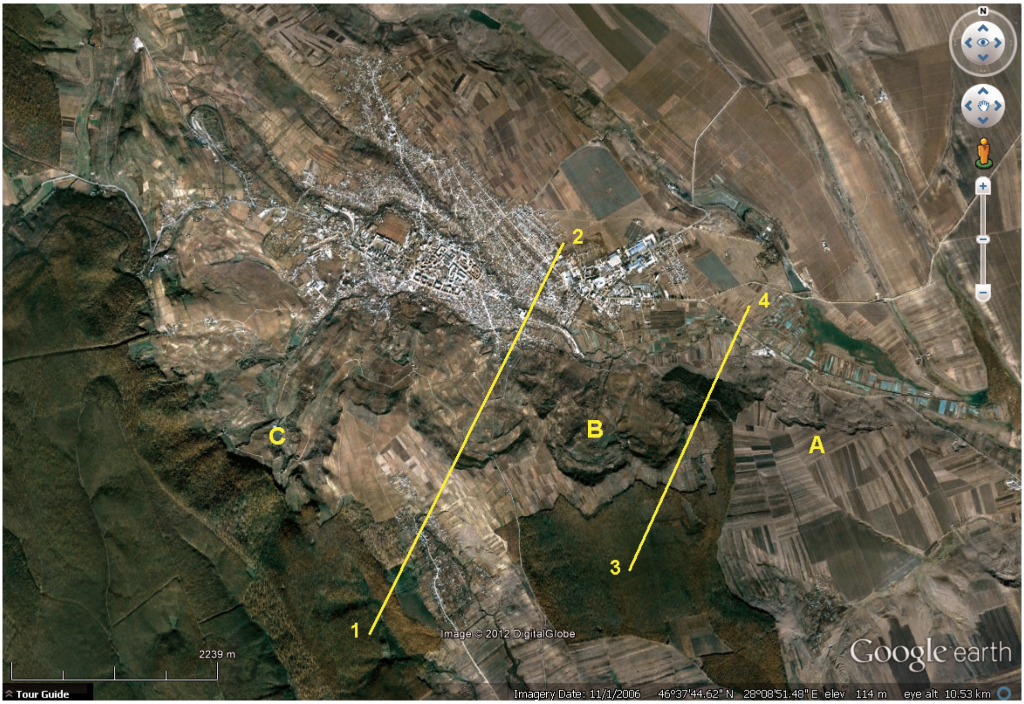

Fig. 2 - Satellite image (Google Earth®) of Huşi town: 1-2 and 3-4 represent the directions of geological profiles described in Fig. 4; A, B, C are the different evolution stages of landslide basins

when landslides activity increased for at least 2 consecutive years with precipitation excess (1968-1972, 1978-1980, 1996-1998 etc.), but also for single years, such as 1991 (Stângă, 2012). These were the periods when landslide activation was recorded in Huşi area as well.

Another characteristic of this slope is that the development degree of landslide basins is more and more evident from East towards West (A, B and C in Fig. 2). Along this direction a gradual decrease of landslides activity is noticed. This situation is in relation with the different evolution stages of the area, with the base level and with the development of the hydrographic network (Montgomery & Dietrich, 1988).

Generally, it should be noticed that the landslide processes have almost a permanent character, aligning in the normal evolution of this cuesta escarpment. The occurrence and intensity of periods with excessive rainfall, the rapid snow melting or the earthquakes play a vital role in the activation of old deluviums.

SOCIO-ECONOMIC FEATURES

Huşi Depression is predominantly an agricultural area, in which the arable lands occupy about 50% of the region. The western half is dominated by orchards, while the southern part (the study area) in mostly covered by vineyards (Fig. 3). The region of Huşi represents one of the main vineyards centres form eastern Romania, with a total surface of about 2130 ha. The relief soil and climate conditions are suitable especially for white wines production (Irimia *et alii*, 2011). The population of Huşi town has evolved from 500-600 inhabitants, in the 16th century, to approximately 2800 inhabitants, at the beginning of the 19th century, 13,400 in 1899, 15,000 in 1946 and 18,400 in 1956 (Gugiuman, 1959). In 2004, the town had 29,510 inhabitants, while the preliminary data of 2011 census points out a significant falling down to 25,000 inhabitants.

Initially extended over a low declivity perimeter, without landslides, the town grew constantly during the 20th century and occupied gradually

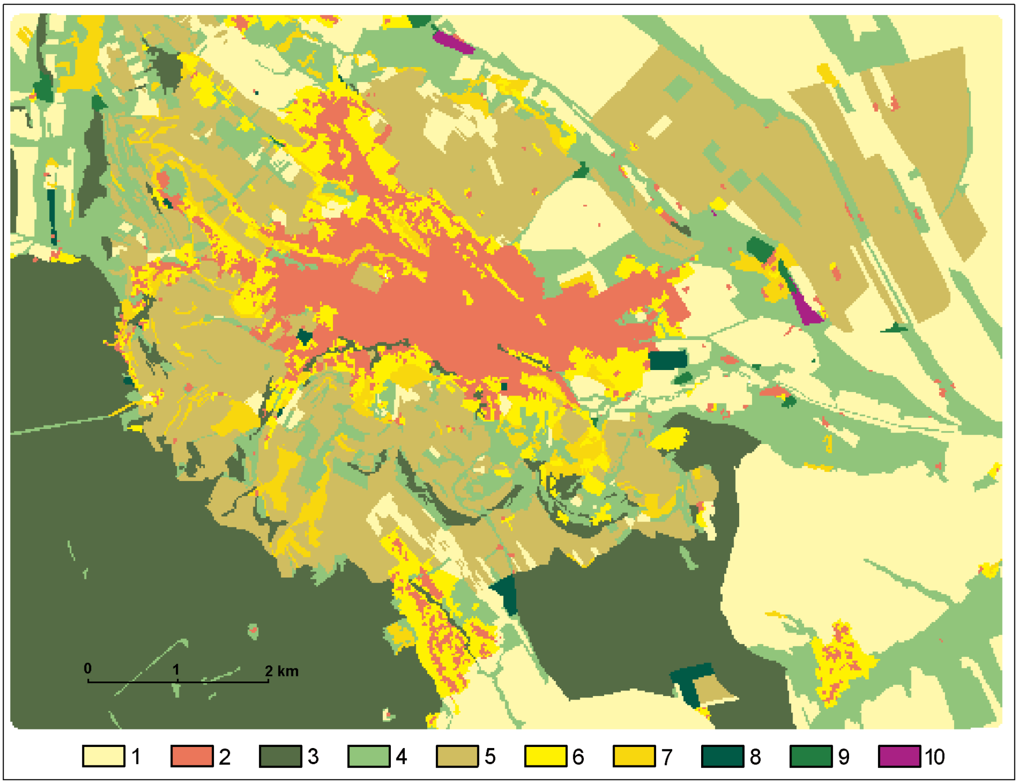

Fig. 3 - Land use in Huşi region: 1 - arable land; 2 - built area; 3 - forest; 4 - pastures; 5 - vineyards; 6 - complex (arable, gardens, vineyards and orchards); 7 - complex (forest and pastures); 8 - orchards; 9 - other categories; 10 - lakes

more and more instable terrains, which is a common evolution pattern for other settlements within the Moldavian Plateau as well (Mărgărint *et alii*, 2010). Currently, the infrastructure is relatively scarce both in terms of roads and railways (the town being located at the end of Crasna-Huşi trail). Nevertheless, the development potential is high, the town being situated along the IX European route, connecting Bucharest and Chişinău capitals, along which the construction of a highway is foreseen.

GEOLOGICAL SETTING

Geologically, the region belongs to the south-eastern part of the East-European Platform. For the Romanian territory, this morphostructural unit is known as the Moldavian Platform.

The geological description of the study area is based on the data provided by Gugiuman (1959), Jeanrenaud (1971), Ionesi & Ionesi (1994), Ionesi *et alii* (2005), Pohrib *et alii* (2012) and also on the data obtained from our own observation in the southern part of the Huşi Depression. The granofacial classification of the geological deposits was done according to the ternary diagram and the Romanian Standard STAS 1243-83. The granulometric analyzes were performed in the laboratory of geotechnical research within the Faculty of Engineering of "Gh. Asachi" Technical University in Iaşi).

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The lithological peculiarities were determined by the eustatic sea level variations recorded in the Late Bessarabian in the East-Carpathian platform domain (Ionesi *et alii,* 2005; Pohrib *et alii*, 2012). Thus, the stratigraphic column reveals the lithological products of three sedimentogenetic phases: in the first phase (Middle Bessarabian), a sedimentary epiclastic sequence accumulated; the second one (Middle-Late Bessarabian) was defined by a mixt sedimentation, predominantly carbonate with epiclastic episodes; in the third phase, the epiclastic sedimentation was again generalized (Fig. 4).

The sedimentary succession of the Middle Bessarabian (Bârnova-Muntele Formation) outcrops bellow the altitude of 90 m in the western part of the area and below 80 meters in the eastern part. It begins with amalgamated sedimentary bodies with lutites, siltic lutites and siltites. In the upper levels, there is an alternation of sandy bodies with subordinated intercalations of lutites and siltites, the succession being finalized by a silto-lutitic body. Lutites in the bottom of the succession were intercepted with geotechnical drilling, while the middle and upper strata outcrop in the southern part of the area.

The sedimentary deposits accumulated in the Middle-Upper Bessarabian (Şcheia Formation) outcrop in the southern part of Huşi Depression, between the altitudes of 90-240 m in the West and 80-150 m in the East. From the bottom of the suite, the severe erosion exposed the oolitic limestone and sandstone stratified deposits with sands intercalations, having a thickness of 20-25 m in the western part and 3-5 m in the eastern one (Pietrăria Member). Above these, there is a prograding sedimentary succession (Muncelu Member), consisting of a sequence of sandy-siltic and sandy bodies with intercalations of lumachelle limestone. After their accumulation, in the Late Bessarabian, an interruption of sedimentation allowed the formation of the IInd Moldovalah paleorelief (Ionesi & Ionesi, 1994; Ionesi *et alii*, 2005). This paleorelief was confirmed by the sands with silicified wood scraps, found at 240 m in the western part of the area (Gugiuman, 1959), and by the exogenous clays of the O-Bt horizon, mentioned by Pohrib *et alii* (2012) to the south of the Voloşeni-Rusca alignment. Above the IInd Moldovalah discordance, the Khersonian-Meotian epiclastic sequence formed, consisting of Huşi Formation and Nuţaşca-Ruseni cinerites. This sequence is predominantly sandy with some intercalations of sandstones, siltites and lutites. The Meotian cinerites and sands end the lithological column of the area.

METHODOLOGY

The starting point of this study was the drawing up of landslide inventory based on the high resolution orthorectified aerial image (2010 edition, pixel size: 0.5 x 0.5 meters), high resolution images available from Google Earth®, completed with field surveys and mapping. Because of some shortcomings as the lack of multitemporal data and dating or the ambiguities in defining the landslide age (Guzzetti *et alii,* 2012), in this approach, there were mapped and analyzed all landslides, regardless the age and the type.

The next phase aimed to realize the landslide susceptibility map for a region that includes the Huşi town territory, delineated based on a rectangular cutout of 10.5 x 7.5 km (Fig. 1). Methodologically, there was chosen one of the statistical methods frequently used in the international scientific literature, including for landslide study: logistic regression (Atkinson & Massari, 1998; Ayalew & Yamagishi, 2005; Brenning, 2005; Meusburger & Allewell, 2009; Akgün, 2012). This method has some important advantages: it offers a greater computational simplicity (Falaschi *et alii*, 2009), GIS software having implemented different facilities for this kind of analysis (Dai & Lee, 2002); it gives freedom to integrate the variables which can be either continuous or discrete (categorical), or any combination of both types, and they do not necessarily have normal distributions (Gorsevski *et alii*, 2000; Mathew *et alii*, 2007); it has the capability to eliminate unrelated causative factors and to evaluate the significance of the related ones, providing more detailed and reliable outcome (Yesilnacar & Topal, 2005; Falaschi, 2009; Chauhan *et alii*, 2010; Ghosh *et alii*, 2011); it offers the possibility to realize models based on a

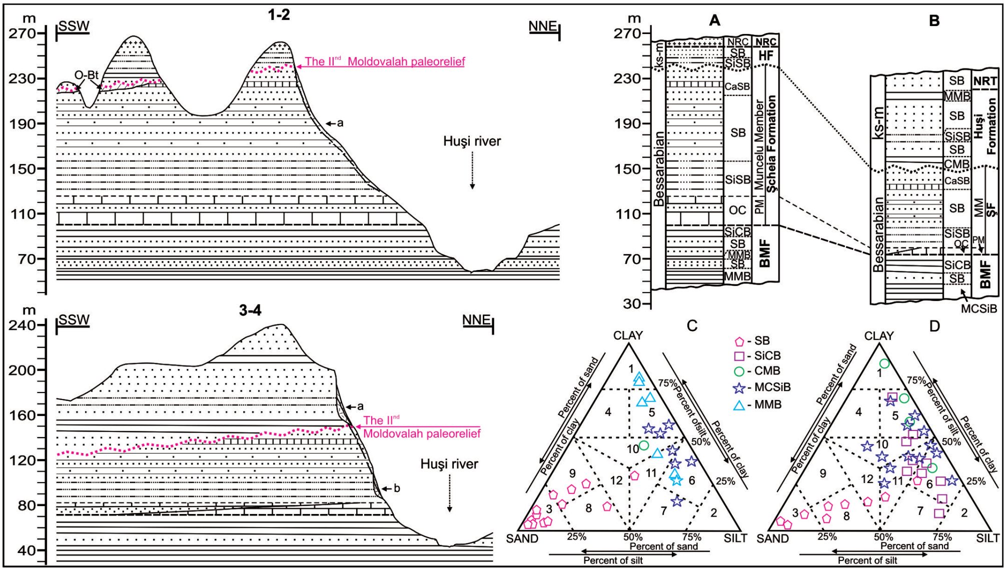


Fig. 4 - The architecture of sedimentary bodies separated on granofacial criteria. 1-2 and 3-4 – geological section, according to Fig. 2. O-Bt - deposits with aspect of Bt illuvial soil horizon, a and b – slidings and slumps; A and B - lithological column (corresponding to 1-2 and 3-4 sections respectively): ks-m - Chersonian-Meotian epiclastic cover, BMF - Bârnova-Muncelu Formation, ŞF - Şcheia Formation (PM - Pietrăria Member, MM - Muncelu Member), HF – Huşi Formation, NRC - Nuţaşca-Ruseni Cinerites, SB - sandy body with reduced intercalations of siltic sands and clayey sands, SiSB - sandy silt, CaSB - sandy with lumashelic limestone, CSiB - clayey silt body, with transitions towards siltic clays, MCSiB - mixed silt clayey body, with transitions from clayey silts to siltic clays and siltic mud, CMB - clayey mud body, MMB - mixed mud body with transitions towards siltic mud and clayey mud, OC - oolithic limestones, lumashelic limestone, with sandstones and sands; C - the granulometric projection sedimentary bodies of lithological column A and D - of lithological column B (according to BOGGS, 2009; grain size distribution % according to STAS 1913-5-85): 1 - clay (claystone) (C); 2 - silt (siltstone) (Si); 3 - sand (sandstone) (Sa); 4 - sandy clay (sandy claystone) (SaC); 5 - silty clay (silty claystone) (SiC); 6 - clayey silt (clayey silstone) (CSi); 7 - sandy silt (sandy silstone) (SaSi); 8 - silty sand (silty sandstone) (SiSa); 9 - clayey sand (clayey sandstone) (CSa); 10 - clayey mud (clayey mudstone) (CM); 11 - silty mud (silty mudstone) (SiM); 12 - sandy mud (sandy mudstone) (SaM)

limited dataset (Van Den Eeckhaut *et alii*, 2012) and gives possibility to evaluate predictive accuracy (Gorsevski *et alii,* 2006). In literature, this method was considered even the most useful for landslide susceptibility assessment at regional scale (Ohlmacher & Davis, 2003; Chau & Chan, 2005).

Logistic regression links the presence or the absence of landslides to a set of quantitative or qualitative variables, generating a continuous spatial probability model:

$$P = \frac{1}{1 + e^{-z}}$$

(which varies from 0 to 1 on a shaped curve), computed on the basis of a linear combination (z) of independent variables (x_1, x_2 … x_n): $z = b_0 + b_1x_1 + b_2x_2 + \ldots + b_nx_n$, where b_o is the intercept of the model and b_1, b_2 … bn are the regression coefficients.

In order to extract predictors' values from a raster layer, a total number of 2483 equally distanced grid points were generated for the landslide and landslide-free areas. To preserve the relative equality of the two points' samples, required by the nature of the statistical analysis, the density of points inside the landslide area is markedly higher than in the landslide-free area (Grozavu *et alii*, 2010).

Landslide causative factor database consists of several environmental data layers. As qualitative variable was considered the land use (Fig. 3) and as quantitative continuous variables were considered topographical parameters (terrain altitude, slope angle, mean curvature, plan curvature, profile curvature and slope height, obtained from the digital elevation model - DEM - with 10 x 10 m resolution, derived from 1:5,000 Romanian topographic plans in stereographic projection), distance to the drainage network and mean annual precipitations. The classified slope aspect (horizontal, N, E, S, W) and land use were converted into quantitative variables by computing the respective landslide densities.

To obtain the elements exposed to landslide risk, we used the General Urban Plan (GUP), at 1:5,000 scale, 1996 edition, provided by local administration. The reconstitution of Huşi town extending during the 1920s was made on the basis of the Shooting Directory Plans in the Lambert-Cholenski conic projection at 1:20,000 scale (Crăciunescu, 2010).

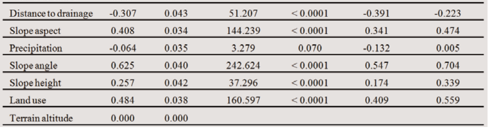
The data integration was accomplished in the georeferenced environment provided by TNTMips 7.3, ArcGIG 9.3 and SAGA 2.0.8 software packages while the statistical analysis was performed using Excel 2003 and XLSTAT 2010 trial version.

RESULTS AND DISCUSSIONS

The logistic regression generated the landslide susceptibility map, as a graphical output materialized by continuous values between zero and one. Fig. 5 shows classified landslide susceptibility map performed on the basis of natural breaks method (Jenks), which identifies the class breaks that best group similar values and maximizes the differences between classes. According to the standardized regression coefficients (Tab. 1), landslides occurrence is best explained by slope inclination, land use and slope aspect classes, similar outcomes with other obtained in Moldavian Plateau, using the same method (Grozavu *et alii,* 2010, 2012; Mărgărint *et alii,* 2011). Secondary positions are occupied by distance to drainage network, slope height and plan curvature. The influence of mean annual precipitations is less significant (error probability equals 0.07) and more uncertain, since the upper bound of the standardized coefficient is positive, while the lower bound and the coefficient in itself are negative (Tab. 1). The stepwise procedure of the logistic regression method eliminated 3 variables from the analysis: terrain altitude, mean and profile curvature.

The model validation was realized through the ROC (Receiver Operating Characteristic) analysis, a very useful method for evaluating the predictive accuracy of the logistic regression model (Gorsevski *et alii*, 2006). For the cut-off value of 0.5, the area under the ROC curve has the value of 0.891, which means a high degree of accuracy (Fig. 6). In addition, 84.6% of the landslide area was correctly classified by the logistic regression model, the overall accuracy being of 81.64%.

Over the landslide susceptibility map, there were



Parameter	Value	Standard error	Wald Chi-Square	Pr > Chi2	Wald Lower bound (95%)	Wald Upper bound (95%)
Mean curvature	0.000	0.000				
Plan curvature	-0.204	0.034	35.373	< 0.0001	-0.272	-0.137
Profile curvature	0.000	0.000				
Distance to drainage	-0.307	0.043	51.207	< 0.0001	-0.391	-0.223
Slope aspect	0.408	0.034	144.239	< 0.0001	0.341	0.474
Precipitation	-0.064	0.035	3.279	0.070	-0.132	0.005
Slope angle	0.625	0.040	242.624	< 0.0001	0.547	0.704
Slope height	0.257	0.042	37.296	< 0.0001	0.174	0.339
Land use	0.484	0.038	160.597	< 0.0001	0.409	0.559
Terrain altitude	0.000	0.000				

Tab. 1 - Standard regression coefficients of the logistic regression model

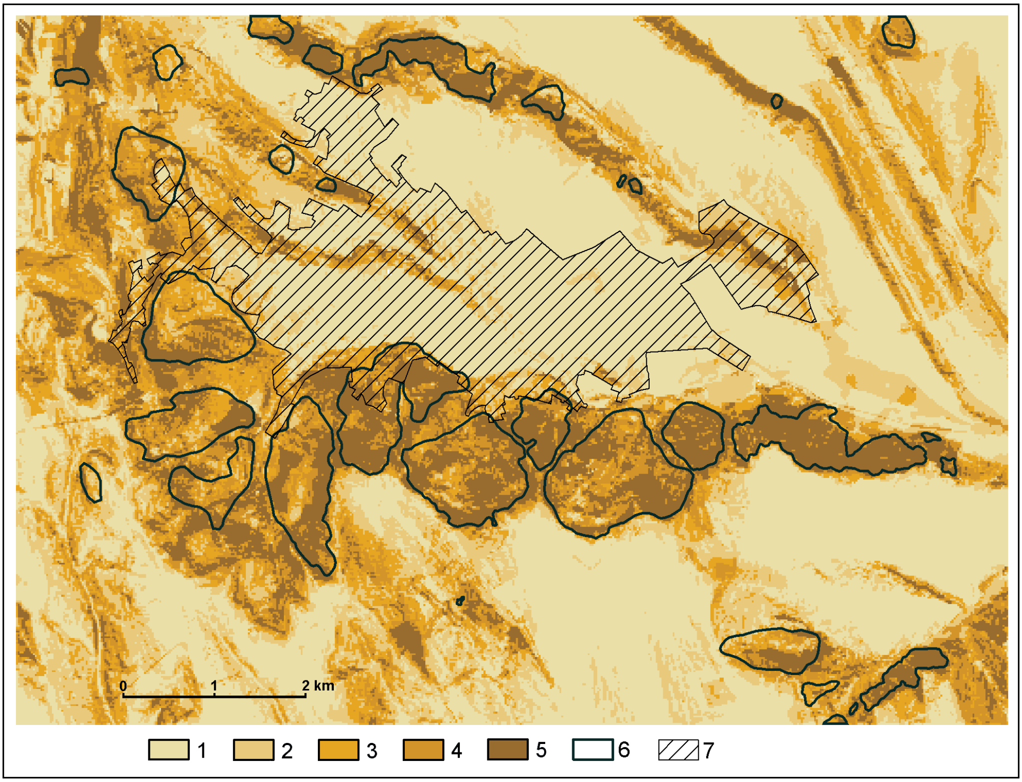


Fig. 5 - Landslide susceptibility classes (Jenks method) in Huşi town area: 1 - very low; 2 - low; 3 - medium; 4 - high and 5 - very high class. 6 - landslides bodies. 7 - Huşi town

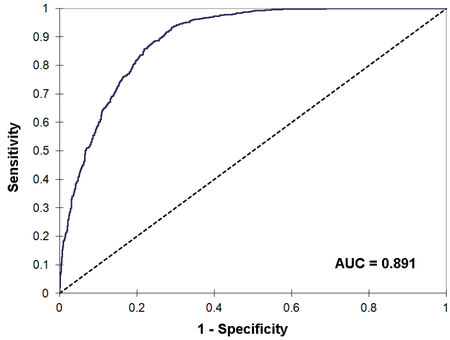
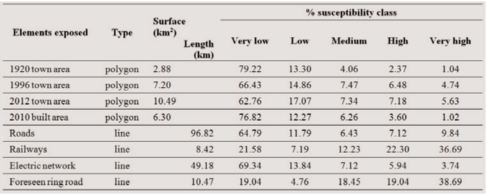


Fig. 6 - ROC curve and area under de curve value



Elements exposed	Type	Surface (km²)	Length (km)	% susceptibility class				
				Very low	Low	Medium	High	Very high
1920 town area	polygon	2.88		79.22	13.30	4.06	2.37	1.04
1996 town area	polygon	7.20		66.43	14.86	7.47	6.48	4.74
2012 town area	polygon	10.49		62.76	17.07	7.34	7.18	5.63
2010 built area	polygon	6.30		76.82	12.27	6.26	3.60	1.02
Roads	line		96.82	64.79	11.79	6.43	7.12	9.84
Railways	line		8.42	21.58	7.19	12.23	22.30	36.69
Electric network	line		49.18	69.34	13.84	7.12	5.94	3.74
Foreseen ring road	line		10.47	19.04	4.76	18.45	19.04	38.69

Tab. 2 - Elements exposed to the landslide risk in Huşi town. The weight within the susceptibility classes

overlapped the exposed elements, initially acquired in vector format and subsequently converted in raster format: the intravilan area (according to the General Urban Plan for 1996 and 2012), the area occupied with buildings and gardens in 1920 (according to the Shooting Directory Plans), the current built area (based on the orthorectified aerial image of 2010). Also, several linear vector elements were added and analyzed: roads, railways, aerial and underground electrical network, the city ring road project (Tab. 2)

Analyzing the exposed elements and their weight on susceptibility classes reveals that the town extended continuously on lands with an increasingly higher risk to landslides. While in 1920, only 3.4% of the town corresponded to the classes with high and very high landslide susceptibility, in 1996, the summed weight of the two classes rises to 11.2% and reaches today 13%. It can be clearly noted that only the very low susceptibility class recorded decreasing percentage, while all the other four classes had an ascending trend.

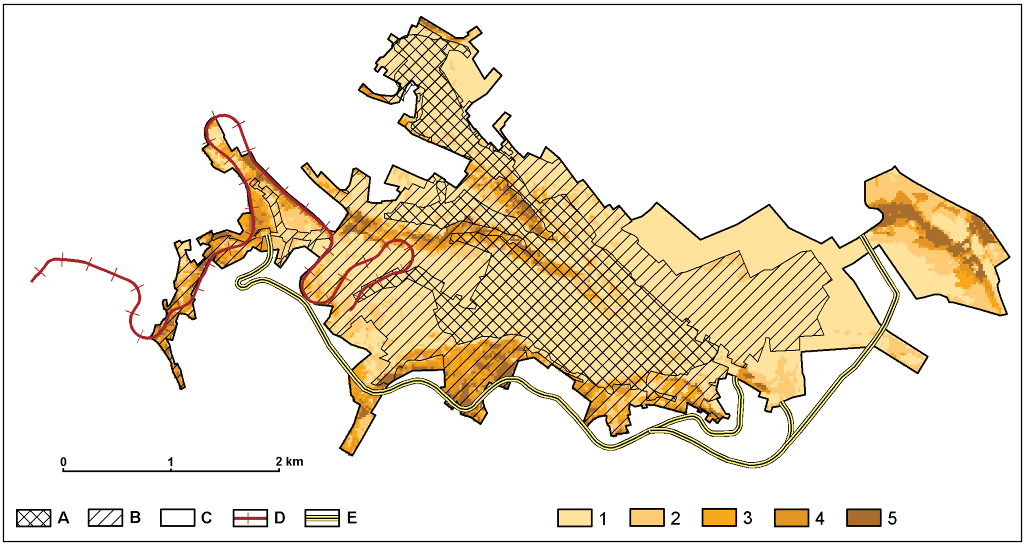


Fig. 7 - Territorial evolution of Huşi town and some exposed elements to landslide risk, overlapped to the landslide susceptibility classes. (A - town limit in 1920; B - town limit in 1996; C - town limit in 2012; D - railways; E - ring road project. Susceptibility classes: 1 - very low; 2 - low; 3 - medium; 4 - high; 5 - very high)

Between 1920 and 1996, the town extended both to East and West, through districts with industrial and transport function, on lands with low susceptibility and to the southern slope with high susceptibility (Fig. 7). There have been built here especially individual houses at a time when, generally, there was no legal interdiction (the legislation vacuum during the 1990s years). Also here, in the same period, there have been established some winemaking units. In the eastern extremity of the town, on lands with high susceptibility to landslides, there have been designed recreational areas, but without important technical urban facilities.

After 1996, the intravilan extending was regulated by adopting in 1999 the General Urban Plan. The layer with the built area in 2010 (including both the construction itself and the courtyards) reveals that only 4.6% of them overlap the classes of high and very high susceptibility.

In the case of linear elements, there are some contrasting situations. The less exposed are the electrical networks (51% of the 20kV underground lines, in the central town) and the roads (regardless the level of importance or modernization).

A special situation is the one of the railway that connects Huşi to the national railway system. It was originally constructed with narrow gauge of 1000 m and became operational in 1890. Extended to a standard gauge in 1940, the line does not benefited from major investment and it follows sinuously the fragmented land with radii up to 120 m and slope gradients of 30 m/km. Along this line, the classes with high and very high landslide susceptibility totalize 59% (Fig. 7).

Much more relevant are the landslide susceptibility values for the lands along the future ring road that should deflect the heavy traffic (Fig. 7). This foreseen ring road would insinuate along the southern slope of the city, dominated by large landslides: our results show that 58% of the projected road pass through areas that fall within the classes of high and very high susceptibility. Therefore, we consider that the route of this objective to be realized must be carefully redesigned and moved on the northern part of the city. This is the appropriate solution in long term, regardless the higher momentary economic costs of lands.

CONCLUSIONS

The example of the Huşi town reveals once more that the growing trend of landslide risk is largely related to the expansion of human structures (peoples, dwellings and utilities, road or special networks, other social and economic objectives) in areas that may be affected by the landslides.

Assessing the probability of landslide occurrence in some places (landslide susceptibility) and, implicitly, identifying the exposed elements that could be affected are mandatory phase for an adequate landslide risk management.

Identifying the significant factors that favor or trigger the sliding processes is the most important for a correct assessment of landslide susceptibility. In this context, the logistic regression proves to be a useful method and a tool that guarantee the objectivity of the evaluation.

The identification of susceptible areas and of the exposed elements can serve to decision makers for a sustainable territory planning. This current regional approach must be continued and completed at a much higher detail level, including with the estimation of the potential socio-economic and environmental costs.

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