

LANDSLIDE SUSCEPTIBILITY ASSESSMENT IN THE BRĂIEȘTI-SINEȘTI SECTOR OF IAȘI CUESTA

Adrian GROZAVU¹, Mihai Ciprian MĂRGĂRINT¹ & Cristian Valeriu PATRICHE¹

¹“Alexandru Ioan Cuza” University of Iași, Faculty of Geography and Geology, Geography Department, Romania, email: adriangrozavu@yahoo.com, margarint.ciprian@yahoo.com, email: pvcristi@yahoo.com

Abstract: In order to evaluate the landslide susceptibility in a sector of Iași Cuesta from the Moldavian Plateau, which constitutes one of the Romanian’s regions particularly susceptible to landslides, the logistic regression method was applied. The first stage consisted in the preparation of a landslide inventory by mapping their spatial distribution. Next, the construction of a GIS database including known factors controlling the landslide activity (slope angle, slope height, slope aspect, mean curvature, plan curvature, profile curvature, distance to drainage network, mean annual precipitations and land use), along with the statistical analysis of the data by using the logistic regression, led to the identification of the prevailing factors for the landslide occurrence in the region: terrain slope, land use and mean annual precipitations. Finally, a relevant landslide susceptibility map was achieved, showing that the terrains displaying high and very high susceptibility represent about 29% of the region’s area. Compared to landslide area (3082 ha), these terrains cover a significantly greater surface (5675 ha), resulting that 2593 ha from the landslide free area has a great potential for landsliding. The comparison with other regions with similar morphoclimatic conditions may constitute a validation of the obtained results.

Keywords: landslide susceptibility assessment, GIS, logistic regression, Iași Cuesta

1. INTRODUCTION

Analysis and assessment of landslide risk, as well as other risk phenomena menacing humans and their activities, are challenging tasks. The studies devoted to such extreme events are numerous, seeking the continuous improvement of the possible approaches and implicitly of the results. In this context, it becomes imperative, at least at European level, the harmonisation of mapping approaches and models, of the input data, of the levels and scales used for representing landslide susceptibility, hazard and risk (here, we may mention some initiatives, such as the ones of Hervás et al., 2007, Fell et al., 2008).

It is generally recognised that the methodological framework for landslides includes mapping landslide distribution (i.e. inventorying) and susceptibility (basically *where* landslides may occur in the future), as well as the assessment of hazard (basically *where and when* or *how often*) and risk (potential damage or losses).

Regarding landslide susceptibility assessment, among the used methods - qualitative, quantitative

and hybrid - the statistical ones (bivariate or multivariate) are considered to be more suitable because they reduce the subjectiveness and provide good results, especially at medium scales 1:25,000-1:50,000 (Van Westen et al., 2006; Thiery et al., 2007). As a matter of fact, Guzzetti et al. (1999), Demoulin & Chung (2007), Cascini (2008) debate on how important is to relate the level of zoning to the required out-comes and to the scale of zoning. The studies applying the logistic regression method for landslide susceptibility assessment are more and more numerous (Atkinson & Massari, 1998; Aleotti & Chowdhury, 1999; Dai et al., 2001; Lee & Min, 2001; Süzen & Doyuran, 2004; Nefeslioglu et al., 2008; Bai et al., 2010, and others), therefore proving its usefulness in this area of research.

Because in Romania there are important areas affected by landslides it is imperative to deepen the knowledge about this risk phenomenon, to carry out a scientific inventory, to improve the foreseeing and prognoses of landsliding process and the mapping methodology. Surdeanu (1997) provides a critically synthesis of the scientific literature from our country regarding these geomorphologic processes. During

recent years we notice the emergence of studies attempting to apply new methods and techniques such as matrix cube approach (Rădoane et al., 1993), field survey (Mac et al., 1997, Moldovan et al., 2010, Grecu et al., 2010), estimation and monitoring by means of satellite images (Abdellaoui et al., 2004), geotechnical lab analyses and computer-based investigations (Armaş et al., 2004). Also, the Ministry of Local Public Administration proposed a methodology for elaboration of landslide risk maps (the latest version being the one from 2003). Several recent studies seek application of quantitative and qualitative methods to develop landslide susceptibility assessment and appropriate mapping, at large and medium scale (Driga & Ciupitu, 2007; Micu & Bălteanu, 2009; Grozavu et al., 2010), or at the scale of the entire country (Bălteanu et al., 2010).

Moldavian Plateau represents one of the regions in Romania particularly susceptible to landsliding, mostly agricultural land, but also human settlements and infrastructure being affected. The studies carried out up to the present moment, have tried to explain aspects regarding the relations between surface geology and landslide distribution, the ways of manifestation, the typology and the age of landslides. The establishment of a correlation between the recurrence of the landsliding process and some of the triggering factors (such as the precipitations regime) was pursued by Pujină and Ioniță (1996). Analysing the historical documents for a period of 170 years concerning the Bârlad Plateau, the authors conclude that new landslides generally occur once in 40 years and that there is a 15-years recurrence interval for landslides reactivation. At the scale of the entire country, Bălteanu (2003) argues that the rise in torrential rainfall over 1962-2000 period, alongside deforestation, may have favoured a more frequent occurrence of landslides.

This paper focuses on the landslide susceptibility evaluation according to Fell et al. (2008), by applying the logistic regression to a sector of Iași Cuesta, where there is a significant frequency of these geomorphologic processes.

2. THE STUDY AREA

The study area is situated in the North-East of Romania and it comprises three administrative unities (Brăiești, Lungani and Sinești communes) from Iași County, with a surface of 196.27 km², covering, in part, a sector of Iași Cuesta which constitutes the transition from Central Moldavian Plateau to Moldavian Plain (Fig. 1).

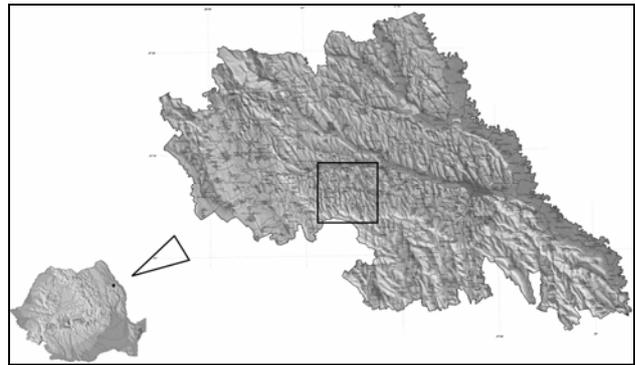


Figure 1. Location of the study area

Natural conditions (geology, relief, climate) along with the human influence (deforestation, intensive pasturing etc.) constitute a favourable context for landsliding. The lithology is represented by an alternating sequence of Sarmatian marls, clays, sandstone and sand complexes.

From the geomorphological point of view, the region is characterized by a significant relief fragmentation, which is made up of hills with narrow interfluves. It is noticeable the asymmetry of the relief, caused by the monocline structure characteristic to the entire plateau.

The rivers network, tributary to Bahlui River, evolved through numerous local lateral captures, favoured by the remarkable manifestation (especially during Pleistocene) of landsliding.

The climate, characterized by mean annual precipitations ranging from 550mm to 700mm, favours the manifestation of some excessive continentalism traits (high temperature variations, uneven precipitation regime and frequent droughts).

3. MATERIALS AND METHODS

In the present article, landslide susceptibility is defined as a quantitative and qualitative assessment of the classification, volume (or area) and spatial distribution of landslides which exist or potentially may occur in an area (Fell et al., 2008).

Consequently, the first step in our analysis was to create an inventory of active and potentially active landslides, performed using orthophotoimages (2006), topographical maps (1:25,000, 1:5000, 1984 edition) and terrain verifications. We identified 149 landslides with a total surface of 3082 ha, representing 15.7% of the study area, occurring especially on cuesta fronts and being in different evolution stages. Most of landslides are detrusive, inconsistent, with depths between 2-10m and the relatively stabilized ones are predominant, affected on discontinuous areas by active landslides.

Stability or instability of slopes are caused by a

number of factors, acting together or alone (Farrokhzad et al., 2011), the change in the foothill slope being considered the factor which is more effective towards mass movement (Asadian et al., 2010). The next step of our study consisted in the construction of a GIS-based landslide causative factors database, using TNTmips 6.9 and ArcGIS 9.3 software packages, including the following thematic layers:

- *Digital Elevation Model (DEM)*, derived at a spatial resolution of 20x20m, on the basis of 1:25,000 topographic maps;

- *Geomorphometrical parameters* derived from DEM (slope angle, slope height, slope aspect, mean curvature, plan curvature, profile curvature, distance to drainage network);

- *Mean annual precipitations*;

- *Land use*, the only categorical predictor in our analysis, was transformed into a quantitative predictor by computing the *landslide density* for this parameter (Bai et al., 2010);

Being relatively uniform throughout the region, surface lithology was not included in our analysis. The statistical analysis of the data was performed using the Logistic Regression module from XLSTAT 2010 software (Table 1).

The analysis of landslide susceptibility is based on the application of the logistic regression model (Atkinson & Massari, 1998; Dai et al., 2001; Grozavu et al., 2010). This method links the presence / absence of a phenomenon to a set of quantitative or qualitative variables, generating a continuous spatial probability model:

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

where P is the probability of an event (landslide) to occur, which varies from 0 to 1 on an S-shaped

curve, computed on the basis of a linear combination (z) of predictors ($x_1 \dots x_n$):

$$z = b_0 + \sum_{i=1}^n b_i \cdot x_i \quad (2)$$

where, b_0 is the intercept of the model and b_i are the regression coefficients.

A total number of 3012 equally distanced grid points was generated for the landslide and landslide free areas (Fig. 2). It is generally recommended that the number of points inside and outside landslide area should be fairly equal (Nefeslioglu et al., 2008; Bai et al., 2010). For this reason, the points' density is higher in the landslide area.

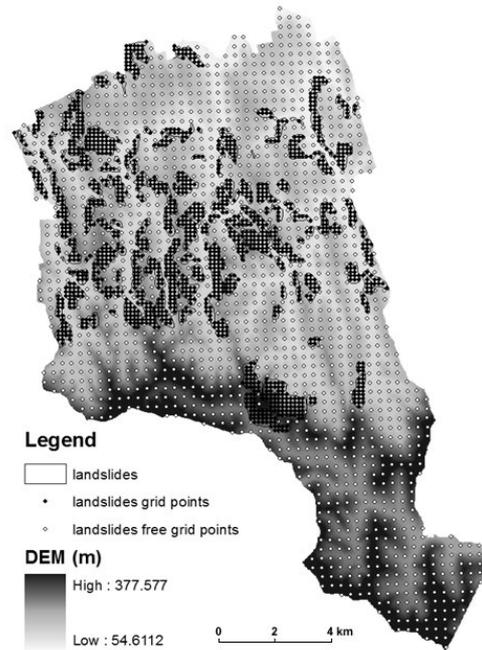


Figure 2. Locations of grid points inside and outside the landslide area

Table 1. Descriptive statistics for landslide area and potential predictors

Variable	Minimum	Maximum	Mean	Std. deviation
DEM (m)	58.629	363.554	148.768	50.861
Slope (degrees)	0.000	19.000	7.968	3.521
Slope height (m)	1.701	147.867	18.733	15.098
Aspect (degrees)	-1.000	360.000	165.262	102.857
Distance from drainage network (m)	0.141	1037.569	171.405	130.510
Mean annual precipitations (mm/year)	478.797	618.966	527.175	25.343
Mean curvature (rad./m)	-1.198	0.909	-0.009	0.181
Plan curvature (rad./m)	-0.591	0.699	-0.001	0.103
Profile curvature (rad./m)	-0.843	1.316	0.008	0.125
Land use (weighted landslide density)	0.059	2.568	1.333	0.958

4. RESULTS AND DISCUSSION

Table 2 shows the linear correlation coefficients matrix for the considered potential predictors. We notice that there are some significant correlations among these variables, which require their selection. This selection was performed using a forward stepwise procedure implemented in the logistic regression module from XLSTAT 2010.

The standardized regression coefficients show that landslide occurrence is best explained by slope angle, land use and precipitations and secondary by distance from drainage network, plan curvature (Fig. 3).

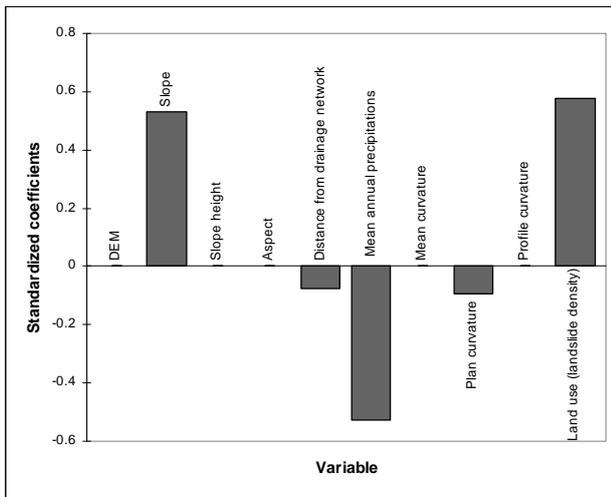


Figure 3. Standardized logistic regression coefficients

The spatial distributions of continuous and classified landslide susceptibility are given in figures 4 and 5. We notice that indeed the terrain slope plays a major role in explaining the landslides spatial distribution. The landslide susceptibility index for the study region is characterized by a mean value of 0.359 and a standard deviation of 0.303.

The regression coefficients show that the spatial probability of landslides occurrence is higher on steeper slopes, on bare soils and pastures, on terrains closer to the drainage network (Table 3). The inverse relation between landslides and mean annual precipitations is explained by the fact that most of the active and potentially active landslides occur at mid-altitudes, under lower precipitations conditions, those from the southern part of the region, developed under forests, at higher altitudes, being predominantly stabilized. The probabilistic model achieved by means of logistic regression can be qualified as good, which is revealed by the values of the regression quality parameters displayed in table 4.

Table 4. Quality parameters of logistic regression model

Quality parameters	Values
-2 Log(Likelihood)	2688.711
R ² (McFadden)	0.352
R ² (Cox and Snell)	0.386
R ² (Nagelkerke)	0.515
Area under ROC curve	0.869
RMSE	0.383

Table 2. Pearson correlation matrix for potential predictors

Variables	DEM	Slope	Slope height	Aspect	Distance from drainage network	Mean annual precipitations	Mean curvature	Plan curvature	Profile curvature	Land use (landslide density)
DEM	1	0.151	0.517	-0.055	0.428	0.826	0.179	0.042	-0.224	-0.088
Slope	0.151	1	0.187	0.119	0.087	0.013	0.034	0.049	-0.010	0.377
Slope height	0.517	0.187	1	-0.027	0.631	0.332	0.481	0.338	-0.417	0.005
Aspect	-0.055	0.119	-0.027	1	-0.050	-0.181	0.009	0.021	0.005	0.030
Distance from drainage network	0.428	0.087	0.631	-0.050	1	0.324	0.295	0.202	-0.261	-0.036
Mean annual precipitations	0.826	0.013	0.332	-0.181	0.324	1	0.069	-0.011	-0.109	-0.136
Mean curvature	0.179	0.034	0.481	0.009	0.295	0.069	1	0.742	-0.837	-0.040
Plan curvature	0.042	0.049	0.338	0.021	0.202	-0.011	0.742	1	-0.254	-0.026
Profile curvature	-0.224	-0.010	-0.417	0.005	-0.261	-0.109	-0.837	-0.254	1	0.037
Land use (landslide density)	-0.088	0.377	0.005	0.030	-0.036	-0.136	-0.040	-0.026	0.037	1

Values in bold are different from 0 with a significance level $\alpha=0.05$

Table 3. Logistic regression coefficients

Intercept / predictors	Regression coefficients	Standard error	Wald Chi-Square	Pr > Chi2
Intercept	16.418	1.216	182.254	< 0.0001
DEM	0.000	0.000		
Slope	0.273	0.016	280.487	< 0.0001
Slope height	0.000	0.000		
Aspect	0.000	0.000		
Distance from drainage network	-0.001	0.000	5.929	0.015
Mean annual precipitations	-0.038	0.002	245.401	< 0.0001
Mean curvature	0.000	0.000		
Plan curvature	-1.629	0.476	11.740	0.001
Profile curvature	0.000	0.000		
Land use (landslide density)	1.093	0.056	382.847	< 0.0001

Variables marked with bold were selected for computing the landslide susceptibility index

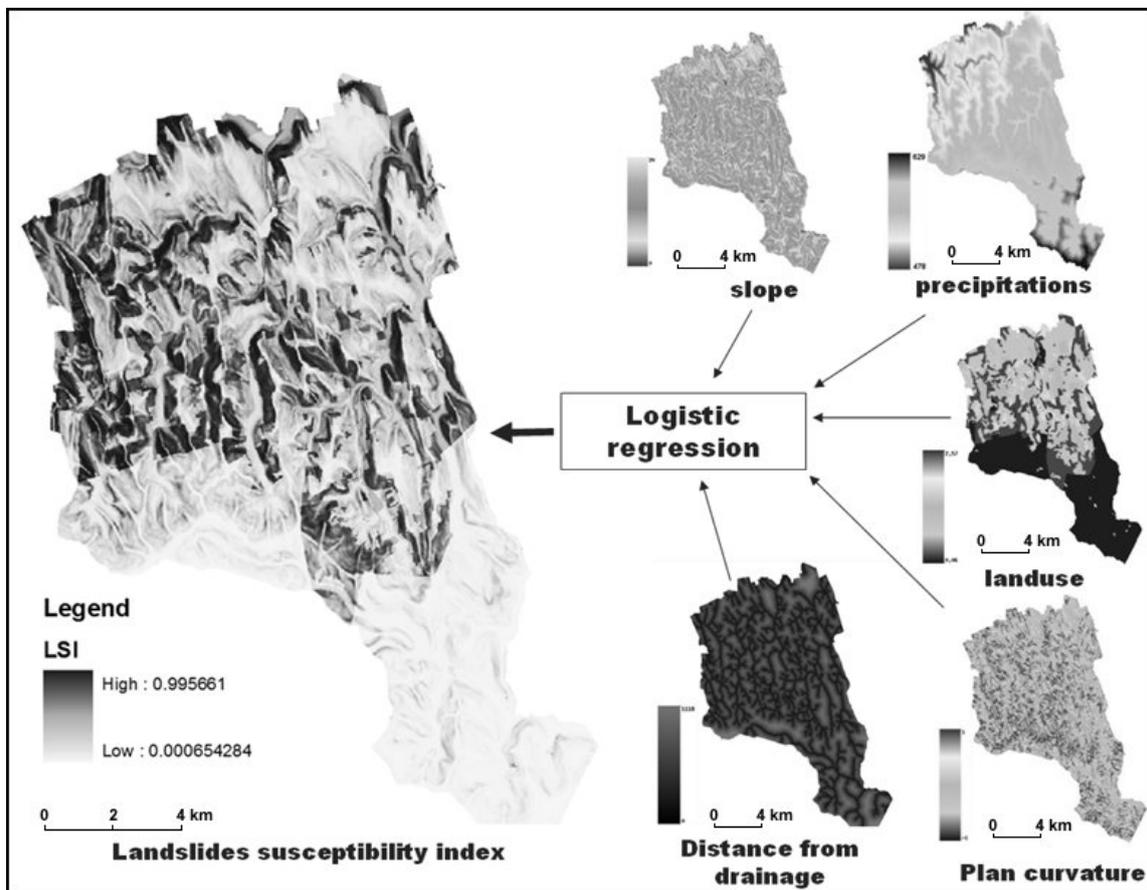


Figure 4. Computation of landslide susceptibility index on the basis of 5 selected parameters

Table 5. Numbers and percentages of correctly classified points

from \ to	0	1	Total	% correct
0	1129	362	1491	75.72%
1	290	1214	1504	80.72%
Total	1419	1576	2995	78.23%

This is also proved by the fact that 80.72% of the points situated inside landslide area and 75.72% of the points situated in the landslide-free area were classified correctly (Table 5).

The landslide susceptibility classes were derived using the natural breaks algorithm (Jenks),

implemented in ArcGIS, which performs the classification by grouping similar values while maximizing the differences between classes.

More than half of our region is characterized by very low and low landslide susceptibility, while the terrains displaying high and very high susceptibility represent about 29% of its surface (Fig. 5).

Inside the landslide area, 75% of its surface was correctly classified as displaying high and very high landslide susceptibility values. However, 10% of this area was included in low and very low landslide susceptibility classes, denoting therefore that the model should be further improved.

Compared to landslide area (3082 ha), the terrains displaying high and very high landslide susceptibility values cover a significantly greater surface (5675 ha), resulting that 2593 ha from the landslide free area has a great potential for landsliding.

5. CONCLUSIONS

Landslide susceptibility analysis and mapping can provide useful information for evaluating the

economical and ecological consequences of these geomorphological processes and assist in the development of guidelines for sustainable land use planning.

Our study proves the usefulness of the logistic regression method for evaluating the landslide susceptibility, having the advantages of being objective and quantitative and allowing the researcher to assess the quality of the results.

For our particular region and for the scale of the approach, the main factors explaining the landslide occurrences are terrain slope, land use and mean annual precipitations.

It can be stated that logistic regression constitutes an adequate method for predicting the instability of slopes, within an analysis carried out at large and medium scales, with an acceptable level of confidence.

The model can be a starting basis for evaluating the landslide susceptibility of the entire Moldavian Plateau, and also in making comparisons with other regions with similar morphoclimatic conditions.

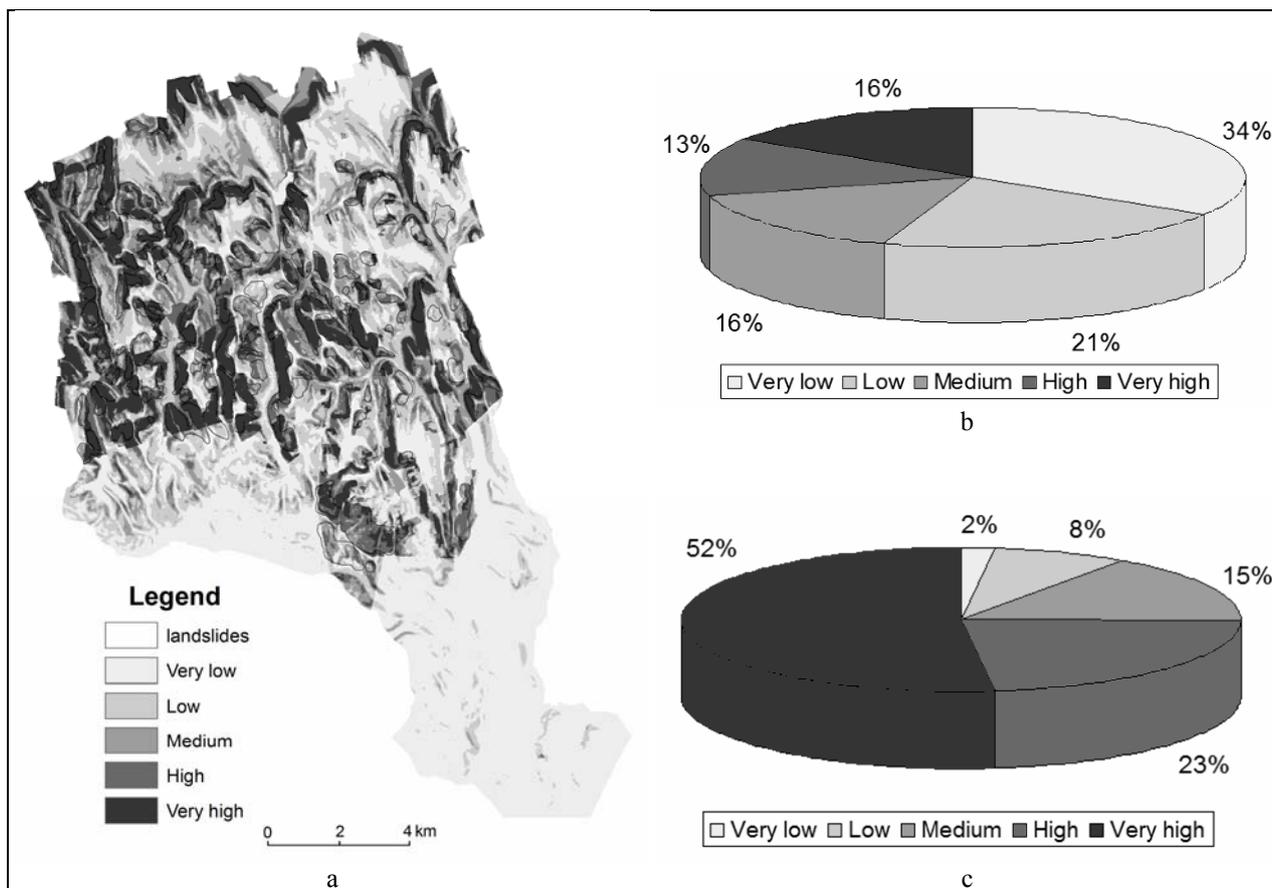


Figure 5. Classified landslide susceptibility (a), percentages of landslide susceptibility classes for the entire region (b) and for the landslide area (c)

Acknowledgments. This study was carried out with financial support from project POSDRU / 89 / 1.5 / S / 49944, co-ordinated by “Al. I. Cuza” University of Iași.

REFERENCES

- Abdelaoui, A., Ozer, A., Pătru, I. & Ielenicz, M.,** 2004, *Imagerie satellitale et suivi du risque naturel en Roumanie: glissement de terrain sur la vallée de Prahova*. Revista de Geomorfologie, 6, 53-59.
- Aleotti, P. & Chowdhury, R.,** 1999, *Landslide hazard assessment: summary review and new perspectives*. Bulletin of Engineering Geology and the Environment, 58, 21-44.
- Armaș, I., Damian, R. & Șandric, I.,** 2004, *Landslides in the M. Caproiu St. – Eternității St. perimeter, town of Breaza*. Revista de Geomorfologie, 6, 61-70.
- Asadian, F., Arzjani, Z. & Varavipour, M.,** 2010, *Changes of microenvironment in Gilan City due to landslides*. Carpathian Journal of Earth and Environmental Sciences, 5(1), 93 – 102.
- Atkinson, P.M & Massari, R.,** 1998, *Generalized linear modeling of susceptibility to landsliding in the central Apennines, Italy*. Computers and Geosciences, 24(4), 373-385.
- Bai, S.B., Wang J., Lü, G.N., Zhou, P.G., Hou, S.S. & Xu, S.N.,** 2010, *GIS-based logistic regression for landslide susceptibility mapping of the Zhongxian segment in the Three Gorges area, China*. Geomorphology, 115, 23-31.
- Bălțeanu, D.,** 2003, *Environmental change and sustainable development in the Romanian Carpathians*. The Journal of the Geographical Society of Hosei University, 35, 7-12.
- Bălțeanu, D., Chendeș, V., Sima, M. & Enciu, P.,** 2010, *A country level spatial assessment of landslide susceptibility in Romania*. Geomorphology, doi:10.1016/j.geomorph.2010.03.005
- Cascini, L.,** 2008, *Applicability of landslide susceptibility and hazard zoning at different scales*. Engineering Geology, 102, 164–167.
- Dai, F.C., Lee, C.F. & Xu, Z.W.,** 2001, *Assessment of landslide susceptibility on the natural terrain of Lantau Island, Hong Kong*. Environmental Geology, 40(3), 381–391.
- Demoulin, A. & Chung, C.J.F.,** 2007, *Mapping landslide susceptibility from small datasets: A case study in the Pays de Herve (E Belgium)*. Geomorphology, 89, 391-401.
- Driga, B. & Ciupitu, D.,** 2007, *Vulnerability assessment of Turț basin (Satu Mare County) to natural and anthropic risks*. In: Deak, S., Deak, G. (Eds.), Capacity building on the economic principle, Proc. of the 2nd International Seminar, Ecomining, Sovata, October 2007, 245-256.
- Farrokhzad, F., Choobasti, A.J., Barari, A. & Ibsen, L.B.,** 2011, *Assessing landslide hazard using artificial neural network: case study of Mazandaran, Iran*. Carpathian Journal of Earth and Environmental Sciences, 6(1), 251 – 261.
- Fell, R., Corominas, J., Bonnard, C., Cascini, L., Leroy, E. & Savage, W.Z.,** 2008, *Guidelines for landslide susceptibility, hazard and risk zoning for land use planning*. Engineering Geology, 102, 85-98.
- Greco, F., Comănescu, L. Toroimac, G., Dobre, R., Săcrieru, R. & Mărculeț, C.,** 2010, *Slope dynamics – precipitation interrelation in the Curvature Subcarpathians (Romania)*. Revista de Geomorfologie, 12, 45-52.
- Grozavu, A., Mărgărint, M.C. & Patriche, C.V.,** 2010, *GIS applications for landslide susceptibility assessment: A case study in Iași County (Moldavian Plateau, Romania)*. In: Brebbia, C.A. (Ed.), Risk Analysis, VII, 393-404.
- Guzzetti, F., Carrara, A., Cardinali, M. & Reichenbach, P.,** 1999, *Landslide hazard evaluation: a review of current techniques and their application in a multi-scale study, Central Italy*. Geomorphology, 31, 181-216.
- Hervás, J. & Montanarella, L.,** 2007, *Main issues on landslide mapping harmonisation in EU member states in the framework of European Commission soil policy*. In: Hervás, J. (Ed.), *Guidelines for Mapping Areas at Risk of Landslides in Europe*, Proc. Experts Meeting, JRC, Ispra, Italy, 23-24 October 2007. JRC Report EUR 23093 EN, Office for Official Publications of the European Communities, Luxembourg, 7-10.
- Lee, S. & Min, K.,** 2001, *Statistical analysis of landslide susceptibility at Yongin, Korea*. Environmental Geology, 40, 1095-1113.
- Mac, I., Irimuş, I.A. & Râpeanu, M.,** 1997, *Structural and Lithological Premises in the Genesis of Landslides in the Transylvanian Basin*. Studia Univ. „Babes-Bolyai”, Seria Geographia, XLII, 1-2.
- Micu, M. & Bălțeanu, D.,** 2009, *Landslide hazard assessment in the Bend Carpathians and Subcarpathians, Romania*. Z. Geomorphol., 53 (3), 49-64.
- Moldovan, M., Pandia, I., Rus, I., Simea, I. & Surdeanu, V.,** 2010, *Spatial relations in the recent evolution of the deep-seated landslide from Cheia (Cluj County)*. Revista de Geomorfologie, 12, 53-58.
- Nefeslioglu, H.A., Duman, T.Y. & Durmaz, S.,** 2008, *Landslide susceptibility mapping for a part of tectonic Kelkit Valley (Eastern Black Sea region of Turkey)*. Geomorphology, 94, 410-418.
- Pujinã, I. & Ioniță, I.,** 1996, *Present-day variability and intensity of the sliding processes in the Barlad Tableland*. Proc. of International Conference on Disaster and Mitigation, Madras, India, A4, 35-40.
- Rădoane, M., Rădoane, N. & Ichim, I.,** 1993, *Using the cube matrix method for landslide susceptibility assessment. Case study: Neamț Department* (in

- Romanian). Studii și Cercetări GGG, seria Geografie, XL, 111-118.
- Surdeanu, V.**, 1997, *The study of landslides*. Revista de Geomorfologie, 1, 97-102.
- Süzen, M.L. & Doyuran, V.**, 2004, *A comparison of the GIS based landslide susceptibility assessment methods: multivariate versus bivariate*. Environmental Geology, 45, 665-679.
- Thiery, Y., Malet, J.P., Sterlacchini, S., Puissant, A. & Maquaire, O.**, 2007, *Landslide susceptibility assessment by bivariate methods at large scales: Application to a complex mountainous environment*. Geomorphology, 92, 38-59.
- Van Westen, C.J., Van Asch, T.W.J. & Soeters, R.**, 2006, *Landslide hazard and risk zonation: why is it still so difficult?*. Bulletin of Engineering Geology and the Environment, 65, 167-184.
- *** *ArcGIS Desktop 9.3 Help*, Environmental Systems Research Institute (ESRI), <http://webhelp.esri.com/arcgisdesktop/9.3/>
- *** *Reference Manual for the TNT products V6.4*, Lincoln, MicroImages Inc., 2000.
- *** *XLSTAT Tutorial*, <http://www.xlstat.com/en/support/tutorials/>

Received at: 18. 01. 2011
 Revised at: 29. 08. 2011
 Accepted for publication: 14. 09. 2011
 Published online: 17. 09. 2011