# A LANDSLIDE SUSCEPTIBILITY ANALYSIS FOR BUZAU COUNTY, ROMANIA

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*Key-words*: susceptibility, shallow landslides, weights of evidence.

Landslides are one of the most common hazards in the Romanian Curvature Carpathians and Subcarpathians, covering a wide range of geomorphic mass wasting forms and processes. The purpose of this paper is to present a susceptibility analysis at regional scale for the Buzau County (Romania), focusing on shallow and medium-seated (*sensu* Bălteanu 1983) landslides. The susceptibility map was obtained using the weights-of-evidence modeling technique that allows understanding the significance of predisposing factors of shallow and medium-seated failures. The model was run considering eight environmental factors: slope, altitude, internal relief, planar and profile curvature, aspect, soil, land-use. A landslide inventory derived from archive data, literature review, field mapping and aerial imagery interpretation was divided into a training and a prediction set and was used to prepare and validate the model. The model performance was evaluated using the area under the ROC and the success rate curve. The susceptibility map represents an important step for landslide hazard and risk assessment, crucial components for the definition of adequate risk management strategies.

## 1. INTRODUCTION

The interest in studying landslides distribution and impact is rising for two principal reasons: an increasing awareness of their socio-economic significance on the one hand, and on the other hand the growing pressure of development and urbanization on the natural environment. As development expands on sloping urban areas, a higher incidence of slope instability and landsliding is reported (Aleotti & Chowdhury, 1999).

Landslides are one of the most widespread geomorphological processes of the mountainous and hilly areas of Buzău County that represents a sector of the Curvature area of the Romanian Carpathians. The region, formed by Neogene molasse deposits and by Cretaceous and Paleogene flysch (Bălteanu et al., 2012), is intensely modeled by a wide variety of slope and valley processes, resulting from the association of numerous favorability, preparedness and triggering factors (Badea & Bălteanu, 1977; Bălteanu & Micu, 2009). To evaluate the landslide risk it is important to estimate landslide susceptibility, defined as the propensity of an area to be affected by mass movements. Landslide susceptibility is function of morphometric (as slope, aspect, internal relief, etc.) as well as terrain characteristics (as indicated also by the factor of safety or excess strength) combined with the triggering factors, capable of reducing excess strength and generating slope movement (Glade & Crozier, 2005). Landslide susceptibility can be evaluated exploiting statistically-based analysis, assuming that the conditions under which the present and past landslides occurred will be the same for future

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movements. In this paper, we present a landslide susceptibility zonation for the Buzau County prepared using the weights of evidence modeling technique (Bonham-Carter et al. 1988; Agterberg et al.1989).

## 2. STUDY AREA

The susceptibility zonation was prepared for a study area that extends for about 3 000 km$^2$ and is located in the mountainous and hilly region of the Buzau County (Fig. 1). The county presents very different morphologic, morphometric and morphodynamic patterns in the northern and in the southern part: the first part is located in the mountainous terrain of the Carpathians and Subcarpathians regions, while the second part is represented by the Romanian Plain. The Carpathian Mountains, composed by flysch formations, have altitudes ranging from 900/1000 to 1700 m, a relative relief of 500–800 meters, and slope angles ranging between 20 and 45 degrees.

The Subcarpathians, shaped on molasse deposits dominated by schistose marls and clays, present elevation up to 900 m, a relative relief of about 300–500 m and slope angle usually below 20 degree. The area is affected by neotectonic movements, more intense along the Carpathians and Subcarpathians belt where the uplift rate reaches 3–5 mm/year causing subsiding phenomena of about l–2 mm/year along the frontal lowlands (Zugrăvescu et al., 1998). The mountains sector is part of the Romanian Curvature Carpathians corresponding to the Vrancea Seismic Region. The area is affected by several natural hazards, that cause severe damages mainly in their outer part, in the zones of long-lasting and intense habitation (Micu & Bălteanu, 2009).

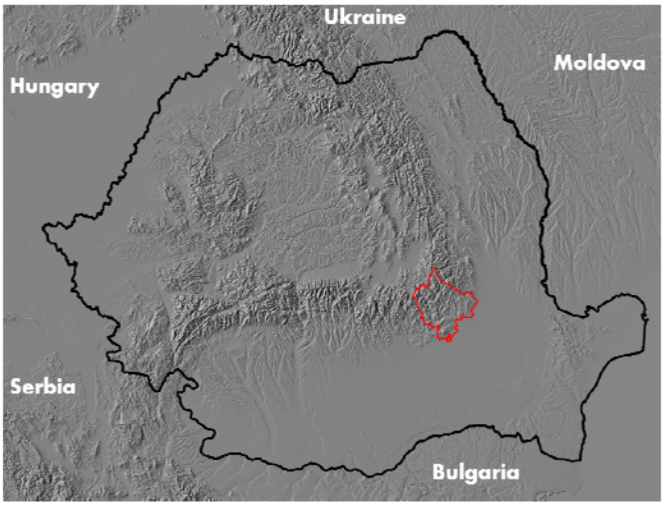


Fig. 1 – In the map the red line shows the mountainous and hilly area of the Buzau County. Romanian borders are reported in black.

The area is affected by climatic hazards that include intense precipitation events, droughts and strong winds (foehn). The rainfall regime is highly controlled by the Romania's position in the south-east Europe, characterized by the presence of the Carpathian arch and dominated by the western circulation of air masses. In the Subcarpathians area, argillaceous Neogene molasse with high content of montmorillonite and illite crops out and landslides have an important influence on slope evolution. Shallow translational slides, moderate to deep-seated rotational slides, and mudflows, are common (Bălteanu et al., 2012). In the period between 2005 and 2010 different landslide events have been recorded in the area. Single landslide or multiple-landslide events were reported in May 2005, August–September 2005, April 2006, June 2006, and February 2010. High intensity rainy periods were recorded in 1910–1919, 1932–1941, 1966–1975, 1976–1995, 1986–1995, 2005–2010 and numerous landslides were reported

(Dragota, 2006; Surdeanu, 1998; Topor, 1964) in the Subcarpathians (mainly as shallow-medium seated) and in the Carpathians (mainly deep-seated).

Several social and human factors influence and control the occurrence, nature and severity of natural hazards. In fact, the excessive pressure on the environment through deforestation, improper land use and unsuitable location of industrial activities makes the territory more prone to natural disasters, while afforestation, careful land management, drainage, irrigation and embankments locally reduce the risk related to the impact of natural events (Bălteanu, 1997).

## 3. METHODOLOGY AND DATA

The landslide susceptibility zonation was prepared using the weights-of-evidence modeling technique (WofE). The WofE approach is a statistical technique widely applied in many scientific fields and proved to be suitable to prepare landslide susceptibility maps (Lee & Choi 2004; Süzen & Doyuran 2004; Neuhäuser & Terhorst 2007; Thiery et al. 2007; Regmi et al. 2010; Ozdemir & Altural 2013, among many others).

WofE is a log-linear form of the data-driven Bayesian probability model that uses known occurrences as training datasets to derive a predictive output (response theme). This latter is generated from multiple, weighted evidences (evidential themes representing explanatory variables), influencing the spatial distribution of the occurrences in the study area (Raines, 1999).

The method is based on the calculation of positive and negative weights (W + and W −) by which the degree of spatial association among training points and each explanatory variable class may be modeled. If the class is positively correlated, W + is positive and W − is negative. If the class is negatively correlated, W − is positive and W + is negative. If the class is uncorrelated with an occurrence, then W + = W − =0. The posterior probability would equal the prior probability, and the probability of an occurrence would be unaffected by the presence or absence of the variable class (Sterlacchini et al., 2011).

To run the WofE analysis, explanatory variables were selected and thematic maps were prepared. Eight factors were used for the susceptibility zonation: DEM derivates (altitude, aspect, planar curvature, profile curvature, slope and internal relief), soil and land use maps. The DEM (25 × 25m) was obtained by interpolating the contour lines of the topographic maps available at a 1:25,000 scale (edition 1984). Morphometric indexes are important to identify and characterize different topography, to evaluate evolution tendencies and to outline terrain evolution stages denoted by different-intensities slope processes. They allow outlining mountainous or hilly ridges separated by valleys or depressions, and give information on landslide morphology. The land-use map was obtained based on aerial photos interpretation (1:5,000, 2005, source ANCPI). The soil map represents an improved version of the Soil Maps of Romania (1:200,000 sheets; 1963–1994; source ICPA). We chose to use the soil map, to represent the characteristics of the materials involved in the failures (mainly shallow to medium seated landslides) instead of the lithological map that is more representative of the bedrock. In some tests, where the soil map was replaced by the lithological map, the model success and prediction rate decreased significantly, suggesting that the variable "soil" explains better the landslide distribution.

*Table 1*

Type of classification and number of classes used per each thematic layer introduced in the susceptibility analysis.

| Evidential theme | Type of classification | Number of classes |
|---|---|---|
| Altitude | Quantile | 10 |
| Planar curvature | Quantile | 10 |
| Profile curvature | Quantile | 10 |
| Slope angle | Quantile | 10 |
| Internal relief | Quantile | 10 |
| Aspect | Manual (compass direction plus flat area) | 9 |
| Soil | Expert based | 11 |
| Land-use | Expert based | 9 |

To run the WofE model, the morphometric variables derived from the DEM were reclassified in 10 classes using quantiles, except for the aspect which was reclassified in 9 classes according to the main compass directions plus one class showing the flat areas; the soil and the land-use maps were reclassified, based on expert judgment, in terms of slope stability (Table 1). The usage of the quantile classification for the DEM derived variables may cause important consequences if data distribution is extremely skewed. The usage could make it possible to better explore the behavior of the factors with respect to the landslide occurrence, because the rank-ordered variables are equally distributed (Blahut et al., 2010). The landslide inventory, derived from archive data (Institute of Geography, Romanian Academy, Buzău County Inspectorate for Emergency Situations) is composed by 1 613 failures. The inventory shows higher information in the Subcarpathian area where shallow and medium-seated landslides are more common. The greater number of failures reported is related to the higher concentration of urban settlements that made the mass movements more important to the authority that compiled the inventory because of the possible consequences. For the model, landslides were represented as the centroid point of the scarp area and the points were split into a training and a prediction set, with the same number of points randomly sampled using a random selection (ArcGIS 9.3 tool).

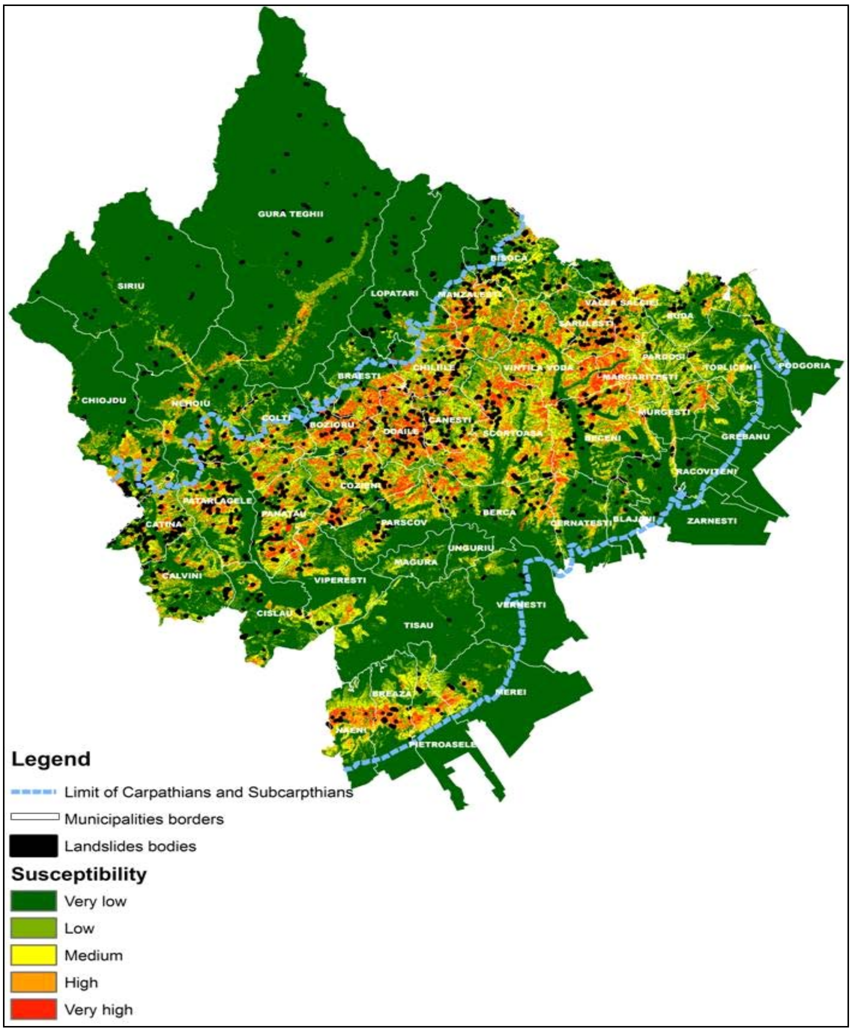


Fig. 2 – Landslide susceptibility map reclassified in five classes from very low to very high. In black are reported the landslide polygons used for the analysis, in white the communes administrative borders and in dashed blue the morphological limit between the Carpathians (North) and the Subcarpathians (South).

In order to construct and validate the prediction capability of the model the success rate curve and the Prediction Rate curve were performed respectively Chung and Fabbri (1999, 2003, 2008). The success rate curve (SRC) is obtained by plotting the cumulative percentage of the susceptible area against the cumulative percentage of events included in the analysis as training set; the steeper is the curve, the larger is the number of events falling into the most susceptible classes. The prediction rate curve (PRC) is similar to the SRC but is defined using the subset of landslides not used in the model definition (predictive subset). In order to test the goodness of the susceptibility model we exploited the Receiver Operating Curve (ROC) which plots the true positive (landslide area classified as susceptible) and false positives (non-landslide area classified as susceptible) (Sterlacchini et al., 2011).

#### 4. RESULTS AND DISCUSSION

The susceptibility map computed for the northern portion of the Buzău County, corresponding to the mountains and hills areas, is shown in Figure 2. The susceptibility map was reclassified in 5 classes, from very low to very high, using a quantile distribution. The goodness of the model was estimated through the SRC, PRC, and the ROC curves obtaining the following values: SRC 79.73 %, PRC 78.90 %, ROC 79.49% (Fig. 3a and b).These values were considered satisfactory considering the detail and the accuracy of the data used in the analysis.

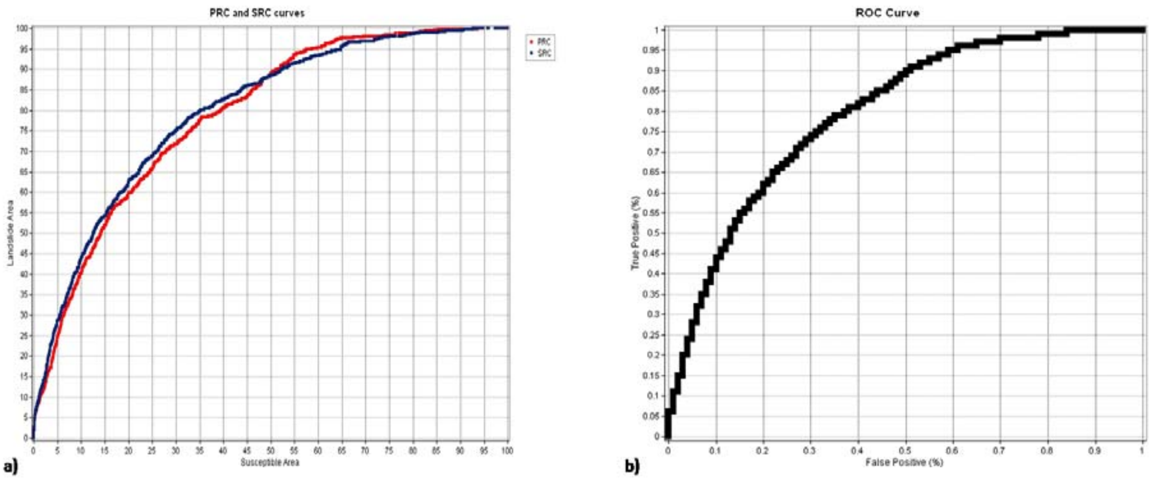


Fig. 3 – PRC and SRC curves on the left (a) and ROC curve on the right (b).

The area classified as high susceptible (high and very high classes) represents almost 10% (588.03 $km^2$) of the total: only 1.6% of the Carpathian region is classified as highly susceptible, while 17 % of the Subcarpathian sector is in the high classes.

We have computed the distribution of the susceptibility classes in each Municipality and we have noticed that some have around one third of their territory classified in the most susceptible classes, as is the case of Bozioru, Cozieni, Margaritesti, Odăile, Sarulesti and Vintilă Vodă (see Fig. 4). This result was also confirmed by the field observations, and the information given from the municipality local authorities. The analysis of the classified susceptibility map highlights a major difference between the Carpathians in the North and the Subcarpathians in the South. This difference is mainly related to the geo-environmental characteristics of the two sectors (geology, geomorphology, land-cover) that influence the occurrence of the different landslide types. In fact, the Subcarpathian relief is characterized by shallow and medium-seated landslide whereas the Carpathian sector by deep seated-failures (Fig. 5). In our analysis we have addressed mainly shallow and medium-seated landslides, and the high susceptible areas in the Subcarpathian sector can be explained by a major propensity of the sector to be affected by these types of phenomena.

In addition, based on local knowledge, we do not exclude a possible underestimation of the susceptibility values in the Carpathian sector due to the incompleteness of the landslide dataset that presents a greater number of information in the Subcarpathian area than in the northern half of the study area.

| Most susceptible area in % | Most susceptible area in sqkm | Municipality |
|---|---|---|
| 21.01 | 16.06 | Beceni |
| 10.60 | 7.88 | Berca |
| 6.85 | 4.98 | Bisoca |
| 1.96 | 0.45 | Blajani |
| 31.50 | 11.56 | Bozioru |
| 18.84 | 8.79 | Braesti |
| 11.53 | 5.77 | Breaza |
| 9.38 | 4.13 | Buda |
| 6.70 | 3.97 | Calvini |
| 22.77 | 7.06 | Canesti |
| 15.28 | 5.79 | Catina |
| 5.79 | 2.92 | Cernatesti |
| 25.16 | 8.97 | Chilile |
| 6.73 | 8.63 | Chiojdu |
| 4.25 | 2.59 | Cislau |
| 9.59 | 3.35 | Colti |
| 32.16 | 17.87 | Cozieni |
| 1.07 | 0.61 | Grebanu |
| 0.55 | 2.52 | Gurateghi |
| 4.25 | 4.39 | Lopatari |
| 0.77 | 0.21 | Magura |
| 16.47 | 15.61 | Manzalesti |
| 43.24 | 9.93 | Margaritesti |
| 2.92 | 2.91 | Merei |
| 14.19 | 4.19 | Murgesti |
| 16.55 | 7.31 | Naeni |
| 7.53 | 8.49 | Nehoiu |
| 49.35 | 17.75 | Odale |
| 22.88 | 11.60 | Panatau |
| 11.68 | 2.64 | Pardosi |
| 9.75 | 5.66 | Parscov |
| 17.50 | 14.05 | Patarlagele |
| 7.10 | 3.97 | Pietroasele |
| 3.76 | 1.94 | Podgoria |
| 0.59 | 0.19 | Racoviteni |
| 33.91 | 11.42 | Sarulesti |
| 28.79 | 27.63 | Scortoasa |
| 0.23 | 0.51 | Siriu |
| 0.08 | 0.08 | Tisau |
| 2.99 | 2.01 | Topliceni |
| 1.15 | 0.19 | Unguriu |
| 26.78 | 8.70 | Valeasalcieni |
| 0.24 | 0.22 | Vernesti |
| 32.57 | 22.21 | Vintilavoda |
| 10.02 | 6.63 | Viperesti |
| 0.90 | 0.71 | Zarnesti |

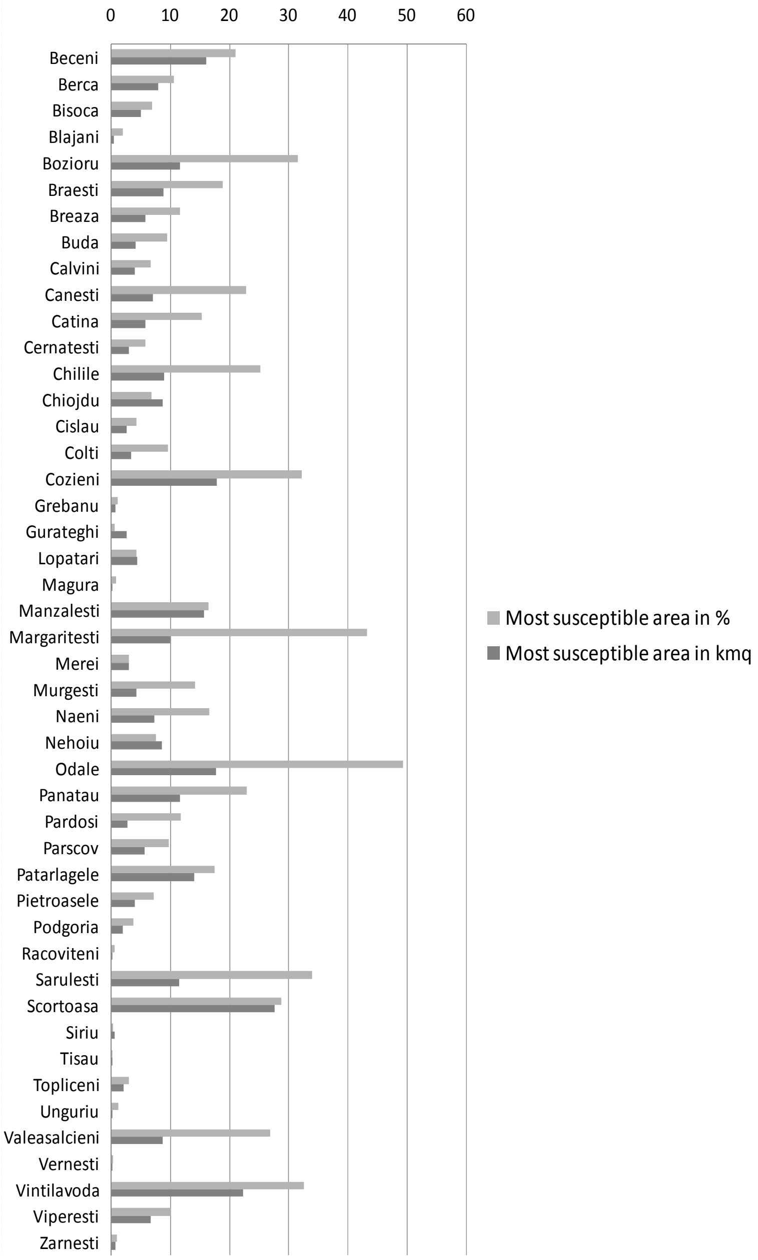


Fig. 4 – Extent of the most susceptible areas expressed as percentage (%) and km$^2$ for each Municipality (in alphabetic order). Values are reported in table on the left and with histogram on the right.

Fig. 5 – Examples of landslides in the Subcarpathians (on the left) and in the Carpathians (on the right).

**5. CONCLUSIONS**

This study is focused on assessing the spatial probability of landslide occurrence in the hilly and mountainous part of the Buzău County (Romania). The susceptibility assessment, based on a statistic-probabilistic approach, allowed us to identify the most susceptible areas. The County exhibits a medium potential to be affected by shallow and medium-depth seated landslides since around 10% of the total area is classified in the high and very high susceptible classes. This value increases in the inner Subcarpathians, where some municipalities have about 30–40% of their territory classified as highly unstable. The municipalities classified as more unstable, are located in the inner sector of the Subcarpathians, corresponding mainly to the Miocene molasse formations, very rich in schistose marls and clays heterogeneously mixed with tuffs, gypsum and salt. Slope instability in this sector is also increased by piping and dissolution processes that are weakening the already loose, folded and often faulted strata. The high slope instability is also directly related to the land-use pattern. In fact, most of the terrains are covered by an association of sparse trees and poorly-managed orchards heterogeneously mixed with pastures that provide overall weak slope stabilization.

The susceptibility zonation can be considered a valid instrument for the local authorities to understand the landslide distribution of the County. It also represents an important step to a possible hazard and risk assessment that are necessary evaluations for adequate risk management strategies. The landslide susceptibility map provides a probability of the future spatial distribution of shallow and medium seated landslides. Therefore, it is important to underline that additional analysis are needed for a complete understanding of the severity of the area especially in terms of possible consequences, as, for instance, a further completion of the landslide inventory which could improve the predictive capacity of the model, enhancing its reliability. To obtain a more reliable zonation, a large amount of data needs to be permanently collected, updated and analyzed, involving an increasing effort of multiple actors participating to this field. Further analysis aimed to evaluate the temporal probability, the exposure and the landslide risk in the Buzău County will be carried out in the framework of the ongoing European Project FP-7 "CHANGES" (Grant Agreement No. 263953), that also financed the presented work.

## REFERENCES


Agterberg, F.P., Bonham-Carter, G.F., Wright, D.F., 1989. *Weights of Evidence modelling: a new approach to mapping mineral potential.* In: Agterberg, F.P., Bonham-Carter, G.F. (Eds.), Statistical Applications in the Earth Sciences. Geological Survey of Canada, Paper 89–9, 171–183.

Aleotti, P. and Chowdhury, R., (1999). *Landslide hazard assessment: summary review and new perspectives*, Bull. Eng. Geol. Environ., 58(1), 21–44.

Badea, L. and Bălteanu, D., (1977). *The terraces in the Subcarpathian Valley of Buzău River*, SCGGG-Geog., Bucharest.

Bălteanu, D.,(1983). *Field experiment in geomorphology*, Edit. Academiei, Bucharest.

Bălteanu, D.,(1997). *Geomorphological Hazards in Romania*, in Geomorphological Hazards of Europe, edited by Embleton C., pp. 409–420, Elsevier, Amsterdam.

Bălteanu, D., Jurchescu, M., Surdeanu, V., Ioniţa, I., Goran, C., Urdea, P., Rădoane, M., Rădoane, N. and Sima, M., (2012). *Recent Landform Evolution in the Romanian Carpathians and Pericarpathian Regions*, in Recent Landform Evolution, edited by D. Lóczy, M. Stankoviansky, and A. Kotarba, pp. 249–286, Springer Netherlands.

Bălteanu, D. and Micu, M., (2009). *Landslide investigation: from morphodynamic mapping to hazard assessment. A case-study in the Romanian Subcarpathians: Muscel Catchment*, CERG Editi., edited by T. (Eds. Malet, J.-P., Remaitre, A., Bodgaard, Strasbourg, France.

Bonham-Carter, G.F., Agterberg, F.P., Wright, D.F., 1988. Integration of geological datasets for gold exploration in Nova Scotia. Photogrammetric Engineering 54, 1585–1592.

Blahut, J., van Westen, C. J. and Sterlacchini, S.,( 2010). *Analysis of landslide inventories for accurate prediction of debris-flow source areas*, Geomorphology, 119(1–2), 36–51.

Chung, C. and Fabbri, A.,( 1999). *Probabilistic prediction models for landslide hazard mapping*, Photogramm. Eng Remote Sen, 65(12), 1388–1399.

Chung, C.-J. F. and Fabbri, A. G.,( 2003). *Validation of Spatial Prediction Models for Landslide Hazard Mapping*, Nat. Hazards, 30(3), 451–472.

Chung, C. and Fabbri, A. G.,( 2008). *Predicting landslides for risk analysis — Spatial models tested by a cross-validation technique*, , 94, 438–452.

Dragotă, C., (2006). *Heavy precipitation in Romania*, Edit. Acad Rom, Bucharest.

Ielenicz, M., (1984). *The Ciucaş-Buzău Mountains. Geomorphic Study*, Edit. Academiei, Bucharest.

Lee, S. and Choi, J., (2004). *Landslide susceptibility mapping using GIS and the weight-of-evidence model*, Int. J. Geogr. Inf. Sci., 18(8), 789–814.

Micu, M. and Bălteanu, D., (2009). *Landslide hazard assessment in the Curvature Carpathians and Subcarpathians, Romania*, Zeitschrift für Geomorphol. Suppl., 53(2), 31–47.

Neuhäuser, B. and Terhorst, B., (2007). *Landslide susceptibility assessment using "weights-of-evidence" applied to a study area at the Jurassic escarpment (SW-Germany)*, Geomorphology, 86(1–2), 12–24.

Ozdemir, A. and Altural, T., (2013). *A comparative study of frequency ratio, weights of evidence and logistic regression methods for landslide susceptibility mapping: Sultan Mountains, {SW} Turkey*, J. Asian Earth Sci., 64(0), 180–197.

Raines, G., (1999). *Evaluation of Weights of Evidence to Predict Epithermal-Gold Deposits in the Great Basin of the Western United States*, Nat. Resour. Res., 8(4), 257–276.

Regmi, N. R., Giardino, J. R. and Vitek, J. D., (2010). *Modeling susceptibility to landslides using the weight of evidence approach: Western Colorado, {USA}*, Geomorphology, 115(1–2), 172–187.

Sterlacchini, S., Ballabio, C., Blahut, J., Masetti, M. and Sorichetta, A., (2011). *Spatial agreement of predicted patterns in landslide susceptibility maps*, Geomorphology, 125(1), 51–61.

Surdeanu, V., (1998). *The geography of degraded lands*, Presa Univ., Cluj-Napoca.

Süzen, M. and Doyuran, V., (2004). *A comparison of the GIS based landslide susceptibility assessment methods: multivariate versus bivariate*, Environ. Geol., 45(5), 665–679.

Thiery, Y., Malet, J.-P., Sterlacchini, S., Puissant, A. and Maquaire, O., (2007). *Landslide susceptibility assessment by bivariate methods at large scales: Application to a complex mountainous environment*, Geomorphology, 92(1–2), 38–59.

Topor, N., (1964). *Dry and rainy years in Romania, Meteo.*, Inst CSA, Bucharest.


Received 12 March, 2014.