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ASSESSMENT OF LANDSLIDE SUSCEPTIBILITY USING THE CERTAINTY FACTOR MODEL: RĂŞCUŢA CATCHMENT (CURVATURE SUBCARPATHIANS) CASE STUDY

Zoia PREFAC[1], Sorina DUMITRU[2], Viorel CHENDEȘ[3], Igor SÎRODOEV[1,4] & George CRACU[1]

[1]Ovidius University of Constanța, Faculty of Natural and Agricultural Sciences, 124 Mamaia Blvd., 900527, Constanța, Romania, e-mail: zoiaprefac@yahoo.co.uk; george.marius.cracu@univ-ovidius.ro
[2]National Research and Development Institute for Soil Science, Agrochemistry and Environment, 61 Mărăști, 71331, Bucharest, Romania, e-mail: sorina_dumitru@yahoo.com
[3]National Institute of Hydrology and Water Management, Şos. București-Ploiești 97, sector 1, 013686, Bucharest, Romania, e-mail: viorel.chendes@hidro.ro
[4]University of Bucharest, Interdisciplinary Center for Advanced Research on Territorial Dynamics, 4-12, Regina Elisabeta Blvd., 030018, Bucharest, Romania, e-mail: igor.sirodoev@univ-ovidius.ro

Abstract: Landslides are related to slope instability phenomena, frequently responsible for considerable losses of both goods and lives. The severity of the landslide problem worsens with increased settlement development and change in land use. The aim of this paper is to assess landslide susceptibility of a hilly area located in the Subcarpathian sector of the Râmna River, namely Rășcuța catchment, by specific geomorphological and geological data and procedures (field survey, large scale mapping). The landslide susceptibility map was developed using GIS techniques and statistical analysis of a set of lithological, morphological and land use information, using a bivariate model, namely certainty factor. The resulted map shows that the Strâmba catchment and the lower catchments of Rășcuța and Peletic Rivers are the most critical areas, with high and very high susceptibility; these areas summarize up to 46% out of the entire study area. On the opposite, the areas having the lowest susceptibility are located in the upper part of Rășcuța and Peletic catchments, covering about 16% of the study area.

Keywords: quantitative assessment**,** landslide susceptibility, GIS, certainty factor, Subcarpathian basin of Râmna, Rășcuța catchment

1. INTRODUCTION

Among the slope processes landslides have the greatest impact on human communities, being responsible for significant economic losses and even casualties. In addition, they can seriously influence land use and urban planning. In this context, during the last decades, the interest in this topic has been strongly increasing worldwide: many studies have been focused on landslides mapping, landslide susceptibility zoning, landslide hazard assessment and landslide risk evaluation.

Landslide susceptibility is the likelihood of a landslide occurring in an area on the basis of local terrain conditions (Brabb, 1984) or, in a mathematical form, the probability of landslide spatial occurrence based on known slope failures, given a set of geoenvironmental conditions (Guzzetti et al., 2005).

A review of the literature regarding landslide susceptibility and hazard assessment (Varnes, 1984; Soeters & Van Westen, 1996; Aleotti & Chowdhury, 1999; Guzzetti et al., 1999; 2000; Chacon et al., 2006; Fell et al., 2008) reveals that landslide susceptibility can be evaluated through various methods, which can be grouped into two broad categories: qualitative methods, based entirely on the expert judgment (e.g., Montgomery et al., 1991; Pachauri & Pant, 1992; Mejia-Navarro et al., 1994; Pachauri et al., 1998; Moreiras, 2005) and quantitative methods, which themselves are classified into statistical and deterministic (physically-based) methods. The last ones are based on numerical modelling and calculation of the safety factor (Montgomery & Dietrich, 1994; Dietrich et al., 1995; Pack et al., 1998). Statistical methods can be either bivariate (see Chung & Fabbri, 1993; Van Westen, 1994; Binaghi et al., 1998; Lee, 2004) or multivariate (Carrara, 1983; Gorsevski et al., 2000; Ercanoglu & Gokceoglu, 2002; Ayalew & Yamagishi, 2005; Gorsevski et al., 2006, Lee et al., 2006).

In Romania, the lack of a strong legislation in the post-socialist period has led to an increase in natural hazards impact on the society, especially due to massive deforestation (Bălteanu et al., 2004).

Nowadays, Romania as an EU member country has a well-defined legal framework, largely harmonized with EU requirements for protection against natural disasters. Nevertheless, implementation of the strategy for civil protection and environmental safety has shortcomings. For example, the National Territorial Planning Plan (PATN) (approved by the Law no. 575/2001) – The Fifth Section – Areas of Natural Hazards, foresees risk maps for every settlement located in the natural risk areas to be included in the General Urban Plans (PUG). However, due to lack of funds risk maps still remain at the stage of desideratum (Armaș et al., 2003). Moreover, the methodology of risk map development, provided by the Ministry of Local Public Administration in 1998, 2001 and 2003, is subjective and difficult to apply (Șandric et al., 2011), particularly, due to the uncertainties and different interpretations that may occur in assigning weights to various landslide controlling factors.

If in the 1990s and the early 2000s, the qualitative approaches prevailed in the estimation of landslide susceptibility in Romania, (Rădoane et al., 1993; Grecu, 2002), in the last decade, the number of quantitative ones has risen steeply (Micu & Bălteanu, 2009; Armaș, 2011, 2012; Constantin et al., 2011; Șandric et al., 2011; Grozavu et al., 2012; Armaș et al., 2013, Petrea et al., 2014, Marian et al., 2016). A medium-scale (1:200,000) country-wide assessment of landslide susceptibility was done by Bălteanu et al., (2010). The authors used a qualitative method (Landslide Susceptibility Index), taking into consideration six factors that control the spatial distribution of landslides (lithology, slope gradient, maximum rainfall in 24 hrs, land use, seismicity and local relief).

The aim of this paper is to make a large-scale landslide susceptibility assessment using bivariate statistical analysis and GIS modelling. The method was applied in the Răscuța catchment, which is a part of Subcarpathian Basin of Râmna River.

2. THE STUDY AREA

In Romania, landslides are the most specific to Subcarpathians, especially to Curvature Subcarpathians, due to the local lithological composition, in which clays with a high content in montmorillonite and illite prevail, due to rainfall regime and the proximity to the Vrancea seismic region, which plays a major role in activating deep-seated slides, rock-falls and debris flows (Bălteanu et al., 2012).

The study area overlaps the Răşcuţa catchment, which is tributary to the Subcarpathian sector of Râmna River. The study area covers 68.4 square kilometers and is located outside the Romanian Carpathian Bend, within the Curvature Subcarpathians, overlapping Inner Subcarpathian hills and Râmna hilly depression.

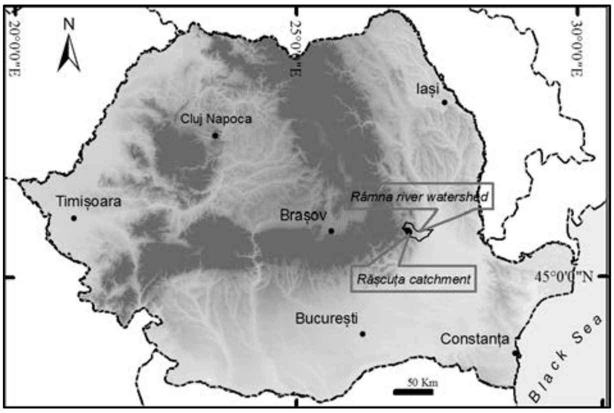

Figure 1. Location of the study area

The landforms within the study area are the result of a relatively recent evolution, being a consequence of the petrographic facies and active tectonics that characterize the outer part of the Carpathian geosyncline.

The sedimentary succession consists of Upper Miocene – Pliocene deposits (molasse-type sediments), with a wide range of cyclic sequences of sandstones, marls and clays. Upper Pliocene (Romanian) deposits are made up of alternations of clays, sandy clays, clayey sands, medium and fine sands that are poorly consolidated. These rocks are associated in different proportions that alternate rhythmically, but there can be noticed the predominance of the clays or sands with a thickness of 0.1-1.5 m up to 3 m. At the same time, the regular alternation of permeable and impermeable layers justifies the great frequency of landslides. Structurally, the study area belongs to the homocline of the external flank of the Carpathian foredeep, favouring the development of cuestas. The structural disposition of the region was completed at the end of

Early Pleistocene, when there were intense tectonic uplift movements.

The study area is affected by neotectonic uplift movements, with rates of 1-2 mm per year (Zugrăvescu et al., 1998). Another cause, which explains the abundance of landslides within the Rășcuța catchment, is its location within an area with maximum seismic activity.

The morphology of the region displays a strong structural character. The cuestas are specific for this area being developed as parallel, dense, clearly visible chains, on a North-South direction approximately.

The elevation ranges from 165 m to 773 m above sea level, with an average value of 389 m (standard deviation – 107 m). Terrain inclination gradient ranges from 0.06° to 49.8°, with a mean value of 13.6° and a standard deviation of 6.1°. The drainage density varies between 0 and 6.5 km/km^2 with a mean value of 3.7 km/km^2. The highest values are quite normal if taking into account the development of the torrents induced by the lithology of the region.

Analysis of the land use types highlights the large area covered by forest (54.2% of the study area), with a significant contribution to increase slope stability as a moderator of the amplitude of climatic variables and regulator of soil water balance. This class covers mainly the upper and middle sectors of the Rășcuța Valley, and its tributary, Peletic. The agricultural areas cover 32.2%, out of which 12.3% are orchards, 12.2% are pastures, the other areas being covered by agricultural land mixed with natural vegetation and areas with complex cultures. The settlements occupy 7.7% of the river catchment area.

The study area is characterized by the alternation of dry and rainy periods, which enhances the generally - low cohesion of the rocks. The mean amount of precipitation ranges between 550 and 700 mm/year, the highest amounts being registered frequently in the summer (June-August). The driest period usually occurs in winter, but also at the end of fall, or even during the springtime (Prefac & Urdea, 2012). The rainy years, in which the precipitation amount exceeded the normal mean by about 20 percent, were: 1971, 1972, 1984, 1991, 1995, 1998 and 2005. Thus, in these years, the landslide intensity increased.

In Rășcuța catchment, landslides are abundant, and range in age and type from ancient (dormant), partly eroded, large and deep-seated slides to young, active, shallow slides and flows.

In conclusion, one of the main features of the landforms in the study area is the intense slope dynamics caused by slope processes, which are favoured by natural factors and amplified by the man-made ones (Prefac, 2006).

3. DATA AND METHODS

In order to assess landslide susceptibility in the study area, the first stage consists in developing the landslide inventory, based on topographical maps (at scale 1:25,000, 1981 edition), colour aerial photos (at scale 1: 5,000, 2005 edition) and on field surveys in 2005-2008. The inventory resulted in identification of 169 shallow and medium landslides, covering an area of 13.03 km^2, which represents about 19% of the entire study area. Almost all landslides are translational, affecting the soil layer and the upper regolith. Planar slip surfaces of these slides are located below the topographical surface generally from 0.5 m to 3 m. The entire landslide inventory was randomly divided into two data-sets: training data-set – 7.8 km^2, which represents 60% of all landslides and validation data-set – 5.2 km^2, 40% of all landslides (Fig. 2).

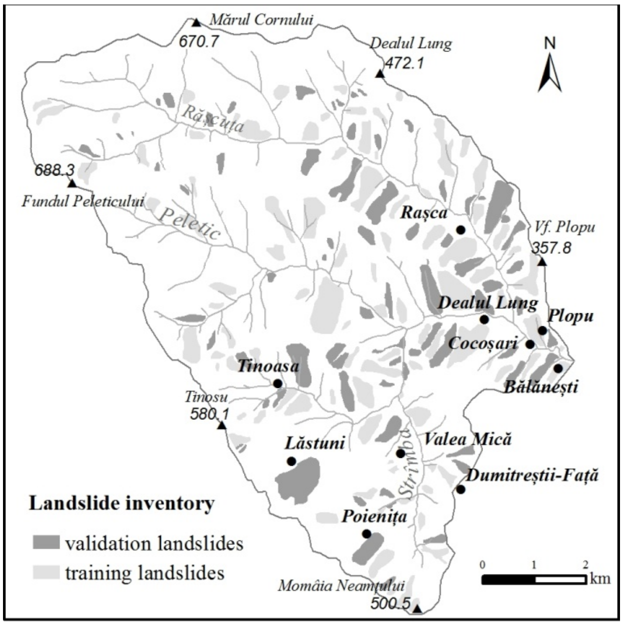

Figure 2. Landslide inventory

In the next stage, six categories among the most used landslide controlling factors (Hasekioğulları & Ercanoglu, 2012) are selected and defined, as following: lithology, land use, slope angle, slope aspect, depth of fragmentation and topographic wetness index (TWI). Each category was divided into different classes. A GIS-based database of landslide controlling factors was created using ArcGIS 9.3 and SAGA – GIS. 2.0.0. The database includes the following thematic layers:

- the lithology data layer, derived from the

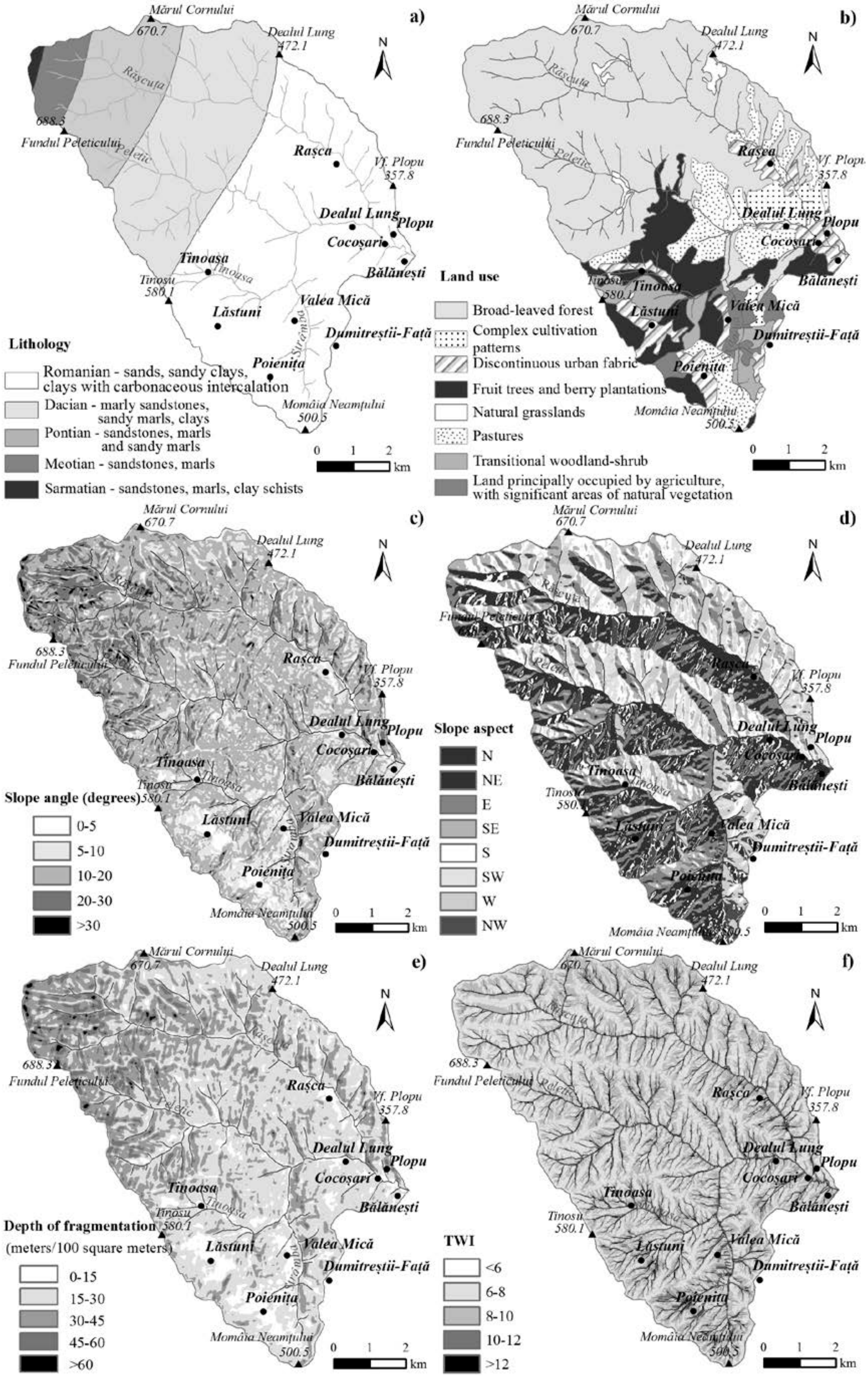

Figure 3. Landslide controlling factors: (a) lithology, (b) land use types, (c) slope angles, (d) slope aspect, (e) depth of fragmentation and (f) topographic wetness index (TWI).

- geological map published by Geological Institute of Romania (at scale 1:200,000, 1970 edition, Covasna sheet) (Fig. 3a);

- land use data layer, processed from Corine Land Cover 2000 database (Coordination of Information on the Environment); for the study area, this European reference dataset was reduced to eight land cover classes grouped at the third hierarchical level (Fig. 3b);

- Digital Elevation Model (DEM), generated by digitization of contours on topographic maps (at scale 1:25,000); interpolation was done using Topo to Raster function, resulting a DEM at a spatial resolution of 12.5 x12.5 m;

- slope angle, slope aspect, depth of fragmentation and topographic wetness index (TWI) were derived from DEM (Fig. 3c, 3d, 3e, 3f);

Among the statistical methods widely used in landside susceptibility assessments, in combination with GIS models, the certainty factor model (CF) (Chung & Fabbri, 1993; Binaghi et al.,1998; Luzi & Pergalani, 1999; Lan et al., 2004; Su et al., 2010; Kanungo et al., 2011; Devkota et al., 2012; Pourghasemi et al., 2013, Wang et al., 2015, Pineda et al., 2016), that was selected for the study area, is used for managing uncertainty in rule-based systems.

The CF method was developed by Shortliffe & Buchanan (1975) for MYCIN project and was later modified by Heckerman (1986).

The method uses the assumption that landslide susceptibility can be determined by statistical relationships between past landslides and several spatial data sets (i.e. geology, slope, aspect, vegetation etc.), identified as the main instability factors of landsliding.

This approach was applied in slope instability zonation by Binaghi et al., (1998), who described in detail the calculation of CF values. Certainty factor approach is defined as a function of probability to solve the problem of combining heterogeneous data (Chung & Fabbri, 1993).

CF is expressed by the following relations:

$$CF = \begin{cases} \dfrac{pp_a - pp_s}{pp_a(1 - pp_s)}, if\ pp_a \geq pp_s \\ \dfrac{pp_a - pp_s}{pp_s(1 - pp_a)}, if\ pp_a < pp_s \end{cases} \qquad (1)$$

where pp_a is the conditional probability of having a number of events (landslides) occurring in class a and pp_s is the prior probability of having the total number of events occurring in the study area.

The CF values vary from -1 to 1. A positive value means an increasing certainty in landslide occurrence, while negative value corresponds to a decreasing certainty in landslide occurrence. A value close to 0 means that the prior probability is very similar to the conditional one and, it is difficult to give any indication about the certainty of the landslide occurrence (Kanungo et al., 2011).

Conditional and prior probability values were obtained by calculating the landslide frequency in the training dataset in each class of each controlling factor. This was achieved by overlapping the corresponding training inventory layer over the thematic layer for each landslide controlling factor (i.e. slope angle, slope aspect, depth of fragmentation, TWI, lithology and land use). Then, for each class of each controlling factor, the CF values were calculated using the equation (1) and the corresponding CF layers were obtained. In order to model the landslide susceptibility, the CF layers were combined pairwise, according to the CF integration rules described by Chung and Fabbri (1993) and Binaghi et al., (1998). Finally, the combination of the CF values (x and y), as a result of two different data layers, is expressed as $\mathcal{Z}$ score according to the following equation:

$$\mathcal{Z} = \begin{cases} x + y - xy, & x, y \geq 0 \\ \dfrac{x + y}{1 - min(|x|, |y|)}, & x, y\ opposite\ signs \\ x + y + xy, & x, y < 0 \end{cases} \qquad (2)$$

For an easier interpretation of the results, the resulted values were grouped into susceptibility classes to create landslide susceptibility zonation map for the study area using natural breaks (Jenks) algorithm.

4. RESULTS AND DISCUSSION

From the analysis of the CF values obtained for each class of conditioning factor, it can be noticed that the suitable class for landslide occurrence and development are the Romanian deposits (0.26), consisting of alternating strong contractile clays, sandy clays, clayey sands, medium and fine poorly consolidated sands, which facilitate land sliding processes. At the opposite, the Sarmatian deposits, consisting of marls alternating with thick packages of hard rocks, such as sandstones and conglomerates, have the lowest CF values (-0.97).

Among the land use classes, the most favourable are the areas with complex crops (with the maximum CF value 0.54), followed by pastures, transitional woodland-shrub and settlements (with high CF values, between 0.1 and 0.33); orchards showed a high favourability for landslides too.

In terms of slope angles, the highest values are found in two classes: one with the angles ranging from 5 to 10 degrees, and the other from 10 to 20 degrees. Other slope classes have negative CF values, which point at the low probability of landslides occurrence (Fig. 4). In the Rășcuța catchment, slopes with shady aspect (northern and north-eastern), representing 33% of the study area, have high CF.

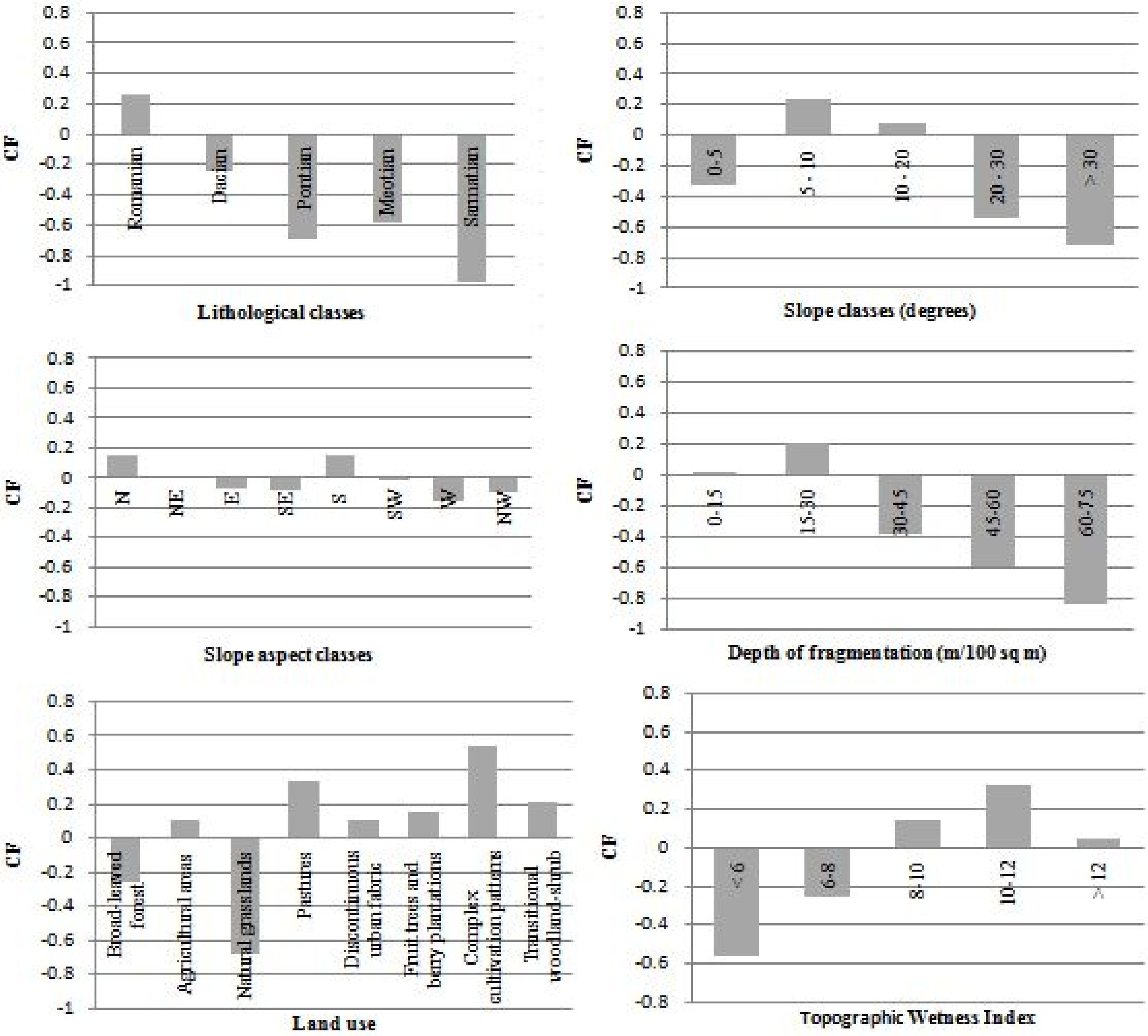

Figure 4. Certainty factor values for each controlling factor

These values are explained by lower temperatures at ground level and by high humidity, which favours the landslides. The highest CF value for the aspect classes is owned by northern slopes (CF = 0.15). Also, the southern slopes show a high CF value (CF = 0.12). This value could be explained by the strong deepening of the drainage network, finally leading to the undermining of the slope and by the fact that these slopes are covered mostly by pastures.

CF values for depth of fragmentation are positive for 0-15 and 15-30 m/100 m^2 classes, the highest value being obtained by 15-30 m/100 m^2 class (CF = 0.20). TWI shows positive values for the classes 8 – 10, 10 – 12 and >12, with the maximum CF value (0.33) for 10 – 12 class.

The results of the analysis show that lithology, land use and slope angle are the most significant factors for landsliding in the study area, among the considered ones.

Subsequently, the combination of raster layers corresponding to CF values calculated for each thematic layer in accordance with CF integration rules of equation (2) led to the development of the landslide susceptibility map (Fig. 5). In order to facilitate the interpretation of the results, the outcomes have been classified using natural breaks in five landslide susceptibility classes. Large area is occupied by slopes with low and very low susceptibility (30% and 16%, respectively) (Fig. 6), which is found in the upper and middle sectors of the Răşcuța and Peletic catchments. These areas are mostly forested and constituted by Sarmatian, Meotian, Pontian, and Dacian deposits, composed of marls alternating with sandstones and conglomerates.

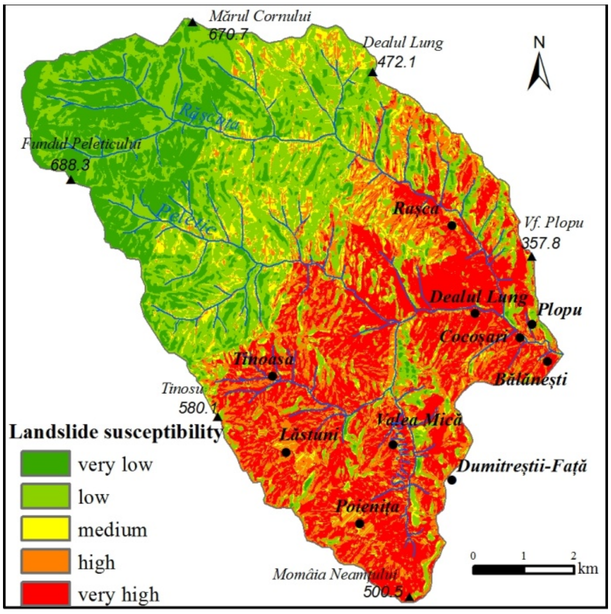

Figure 5. Landslide susceptibility map

The classes 4 and 5, meaning high and very high landslide susceptibility, cover 46% of the area, being distributed in the Râmna hilly depression, on Romanian deposits and being used as agricultural lands. The areas falling in medium susceptibility class have a low share in the study area, approximately 8%.

Validation of the results was made by overlapping the validation data set over the landslide susceptibility map to get the landslide frequency within each class of susceptibility. The results are presented in figure 7. Most of the validation landslides are in the fifth and fourth classes, about 74%, highlighting a high susceptibility. The outcomes of validation are comparable with other landslide susceptibility models (Bednarik et al., 2010).

5. CONCLUSIONS

The landslide susceptibility assessment in the Răşcuţa catchment realized using CF model provides quantitative estimation on landslides occurrence, useful in identifying areas prone to future landslides.

Our outcomes show that land use types, slope angle and lithological composition are the main controlling factors, which explain landslides occurrence. Among them, agricultural surfaces, slopes ranging between 5° to 20°, and the Romanian deposits, consisting of alternating sands, clayey sands, clays and sandy clays have the most important contribution to landslide occurrence. At the same time, both depth of fragmentation and slope aspect have less significant impact on landslides.

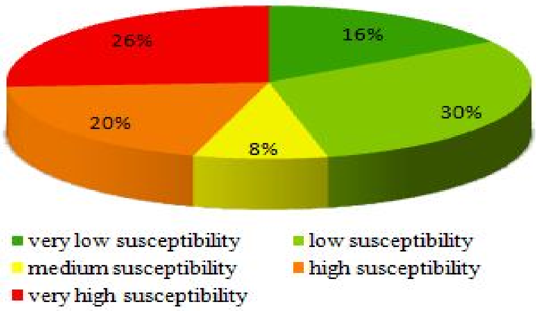

Figure 6. Shares of landslide susceptibility classes within the study area

The landslide susceptibility map shows that the most critical area, with high instability is represented by the Strâmba catchment and the lower catchment of Răşcuța and Peletic rivers. The upper parts of Răşcuța and Peletic catchments are characterized by high stability.

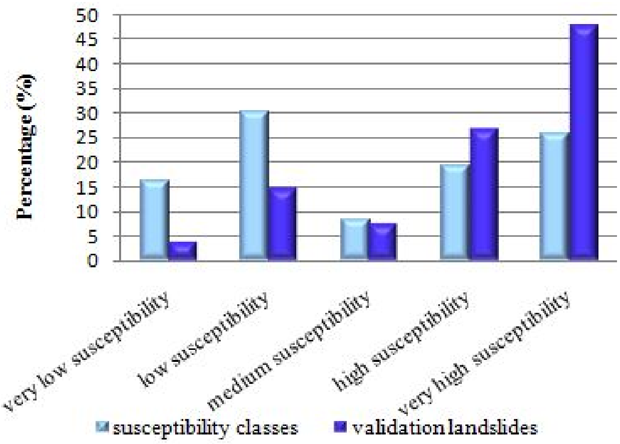

Figure 7. The occurrence of validation landslides in each class of susceptibility

From the results obtained by overlapping the validation landslide layer and the landslide susceptibility layer, one can see that the highest frequency (82%) of validation landslides occurrence and development are recorded in medium, high and very high susceptibility classes (74% cases belong to the latter two).

The landslide susceptibility map generated in this study constitutes a useful tool for the local authorities involved in territorial and land use planning.

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