STATISTICAL MODEL USING GIS FOR THE ASSESSMENT OF LANDSLIDE SUSCEPTIBILITY. CASE-STUDY: THE SOMEŞ PLATEAU

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Key-words: landslide susceptibility, statistical approach, database, GIS analysis, the Someş Plateau.

GIS-statistisches Modell zur Bewertung der Gebietsverwundbarkeit für Erdrutschen.Fallstudie Someş Hochebene. Die Erdrutschen sind eine der wichtigsten Problemen, die in der Zeit die Veränderung von morphometrischen Merkmalen bestimmen und die lokalen und regionalen menschlichen Aktivitäten beeinflüssen. Dieses Modell stellt einen konzeptionellen, probabilistischen Ansatz mit Hilfe von GIS Methodologie dar, die die verwundbaren Bereiche der Erdrutschen bestimmt. Das benützte Verfahren basiert sich auf einer statistischen Wahrscheinlichkeitsanalyse, die auf einem digitalen Vektor-und Rasterdaten GIS entwickelt wird, bearbeitet durch räumliche Formeln mit Hilfe von mathematischen und logischen Kenntnissen. Die Eingangsdatenbank ins Modell wird von Schichten im Rasterformat, vertretend die morphometrischen Merkmale der Landschaft (Neigung, Höhe, usw.), ebenso Schichten im Vektorformat (Identifizierung der Massenbewegungsprozessen von Grundstücken, Geologie, Landnutzung usw.) repräsentiert. Um die endgültige Karte der Gebietsverwundbarkeit für Erdrutsche zu verwirklichen, haben wir statistisch das Gewicht der betroffenen Gebieten für jedes Element aus der Datenbank analysiert und haben eine Neueinstufung in fünf Klassen dargestellt. Ebenfalls organisieren wir eine Bestätigung des Modells im Feld und stellen in graphischer Form der Prozentsatz jeder Klasse auch fur die gesamte analysierte Oberfläche aber auch fur die geographischen Untereinheiten vor.

1. INTRODUCTION

The changes in the slope morphometric elements and partially the land use changes are mainly determined by the presence of some mass movement processes (landslides, falling and rolling processes etc.), as they induce to their manifestation areas a certain degree of exposure. The increasing human pressure contributes to the above mentioned phenomena, with significant impact on residential areas, communication infrastructure and agricultural land use. The assessment of landslide impact on human settlements is extremely important, as well as its quantification.

In order to work out the landslide susceptibility map, we used a combined GIS – statistical analysis methodology with the help of which we integrated the field data into the susceptibility determination model, the implementation area, the Someş Plateau, being an extremely complex one from the morphometric and morphographic point of view.

The majority of the studies on landslides in Romania (Bălteanu 1983; Surdeanu 1998) were based on the classical investigation methodologies, in 2009 Micu & Bălteanu and also Chitu & Şandric used the statistical approach. The landslide susceptible areas analysis using GIS models is more and more frequent worldwide, first of all, because of its facile applicability (Chung *et al.* 1995; Nagrajan *et al.* 1998; Dhakal *et al.* 2000; Saha *et. al.* 2002; Sarkar, Kanungo 2004; Surdeanu *et. al.* 2006; Sarkar *et. al.* 2006; Filip 2008; Bălteanu *et. al.* 2010).

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Rev. Roum. Géogr./Rom. Journ. Geogr., **55**, (2), p. 91–101, 2011, Bucureşti.

1.1. The Someş Plateau

Integrative part of the Transylvanian Plateau, the studied region represents its north – north-western compartment, being the most complex and extended unit among the Transylvanian Plateau's three major subdivisions.

From the regional point of view, there are four major subdivisions: the Purcăreț-Boiu Mare Plateau, the Someş Corridor, the Simişna Sălătruc Hills and the Cluj and Dej Hills, each being polarized by some urban centers or important rural areas (Fig. 1.). The main polarizing centers are the cities of Cluj-Napoca, Gherla and Dej for the Cluj and Dej Hills, and the commune centers of Ileanda and Gâlgău for the Simişna-Sălătruc Hills and the Boiu Mare Plateau. The unit's total area is of 2,625 km^2.

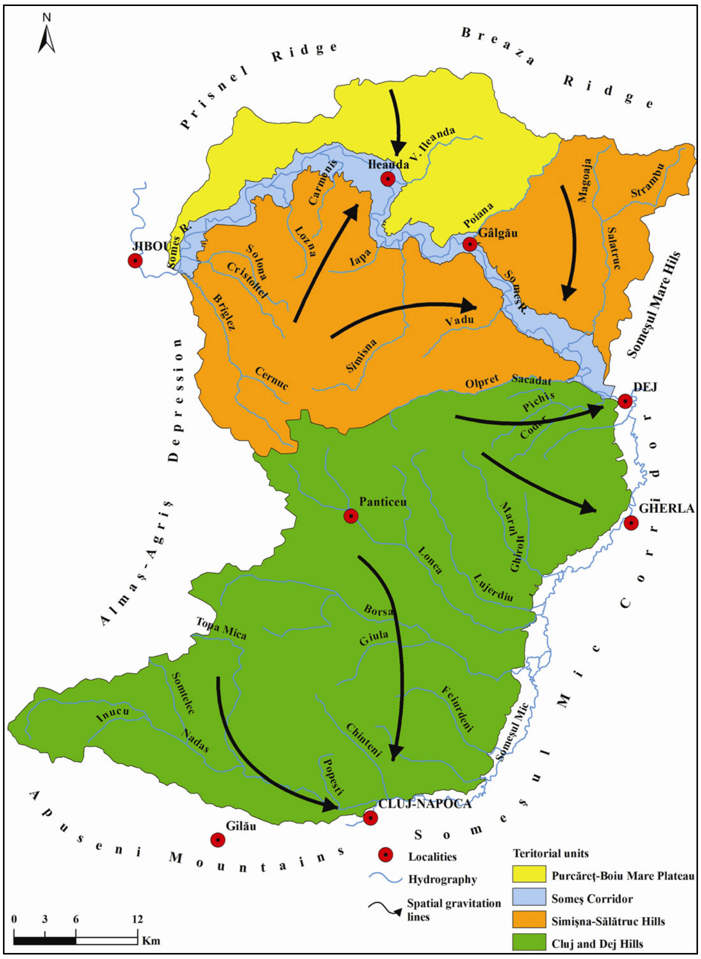

Fig. 1 – The Someş Plateau. Limits and regional subdivisions.

2. GIS METHODOLOGY

GIS software allows complex spatial analyses using a wide range of data, represented mainly by spatialized geographic elements (vector or raster layers), each one quantified with the help of specific attributes. In working out the susceptibility model, we used a specific GIS database consisting of both vector (landslides inventory, land use, vegetation, geology, contour lines) and raster layers (precipitation distribution, slope angle, slope aspect, drainage depth and density, landforms' altitudinal distribution)

(Table 1). According to their utilization in the model, the databases were differentiated into three categories: primary, derived and modeled.

Table 1

Database structure

Nr. crt.	Name	Type	Structure	Attribute	Origin
1	Contour lines	Vector	Line	Elevation	Primary
2	Landslide	Vector	Polygon	Area	Primary
3	Land cover	Vector	Polygon	Cover type	Primary
4	Vegetation	Vector	Polygon	Vegetation type	Derivate
5	Geology	Vector	Polygon	Lithology	Primary
6	Precipitations	Raster	Grid	Mean value	Primary
7	Slope angle	Raster	Grid	Slope degree	Derivate
8	Digital elevation model	Raster	Grid	Elevation	Modeled
9	Aspect	Raster	Grid	Aspect type	Derivate
10	Drainage depth	Raster	Grid	Elevation difference in m	Derivate
11	Drainage density	Raster	Grid	km/km^2	Derivate
12	Area susceptibility	Raster	Grid	Class	Modeled

In order to develop the spatial analysis model, we used the statistic GIS technique based on the bivariate probability analysis equation proposed by Yin & Yan 1988 and Jade & Sarkar 1993, and which is based on the assumption that the prediction of an analyzed phenomenon should start from the spatial distribution of the existing ones, for each of their activating factor and then statistical values are computed for each characteristic interval of the analyzed variable (the activating factor), ranging from negative to positive values, the closer to the positive values, the greater the susceptibility is and vice versa.

$$I_i = \log \frac{S_i / N_i}{S / N} \quad (1)$$

Where:

I_i – statistical value of the *i* factor

S_i – area with identified landslides within each considered variable

N_i – area of the analyzed variable category within the studied territory

S – total area affected by landslides within the studied territory

N – the studied area in km^2.

The most significant element in the spatial analysis is represented by the existing landslides (Fig. 2). They were identified by field research trips and topographic maps (scale 1:25,000), aerial photos and satellite images. Thus, a total area of 55.104 km^2 was identified to be affected by landslides, with higher density and increased manifestation in south and south-east, while in the northern and western part landslide density is quite low.

2.1. Database processing

The large number of variables taken into consideration in determining the susceptibility (land use, vegetation, geology, precipitation, slope angle, slope aspect, drainage depth and density, relief distribution, elevation), as well as the complexity of the model, require several characteristic steps to be performed.

The first step in the spatial analysis process is the statistical and probabilistic processing of the primary and derived database Table 1 by using the spatial analysis GIS functions (ArcGIS software, Tabulate Area Function) that helped us to identify the areas affected by landslides and then to input them into the equation (1), for each variable, with the purpose to assess its statistical value (Table 2).

The second step consists in analyzing the influence of each individual variable on the way landslides occur and evolve.

Elevation

The way in which elevation or rather the differences in elevations may contribute to landslides occurrence refer in particular to the difference in height between the upper and the lower slope sectors. The landforms induced by landslides will develop in accordance to these relative heights and will also determine the slope length.

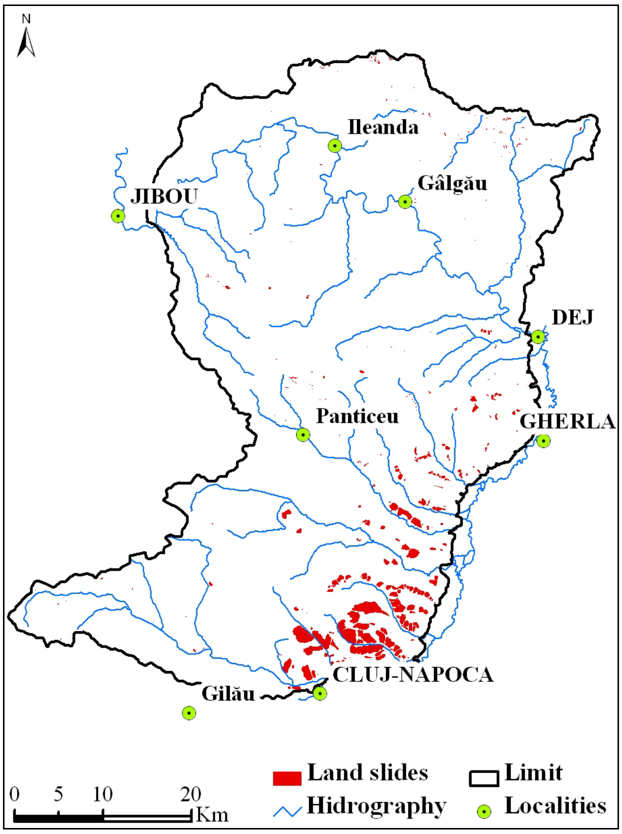

Fig. 2 – Landslides distribution.

The statistical analysis of the elevation Grid database reveals a high statistical value – 0.14 (Fig. 3) on the elevation interval between 401 and 500 m, with an area of 28.4 km^2 from the total 982.7 km^2 that correspond to this elevation interval. At the same time, large areas are not affected by landslides (31.98 km^2), most of them corresponding to the elevation intervals of 101–200 m, 701–800 m, 801–900 m, 901–1,000 m situated in the Someşul Corridor and in the flat areas of the plateau's hills.

Slope angle

A requirement in landslide occurrence is the existence of a minimum slope angle to enable sliding. Without it, the unstable deposits might be affected only by subsidence and resetting. At the same time, as the slope angle increases, landslides are replaced by rolling and falling processes.

Declivity, a direct reflection of the morphogenesis, is ranked among the most important variables influencing the dynamics of the down-slope movement. It also reflects the environmental conditions under which the relief is modeled.

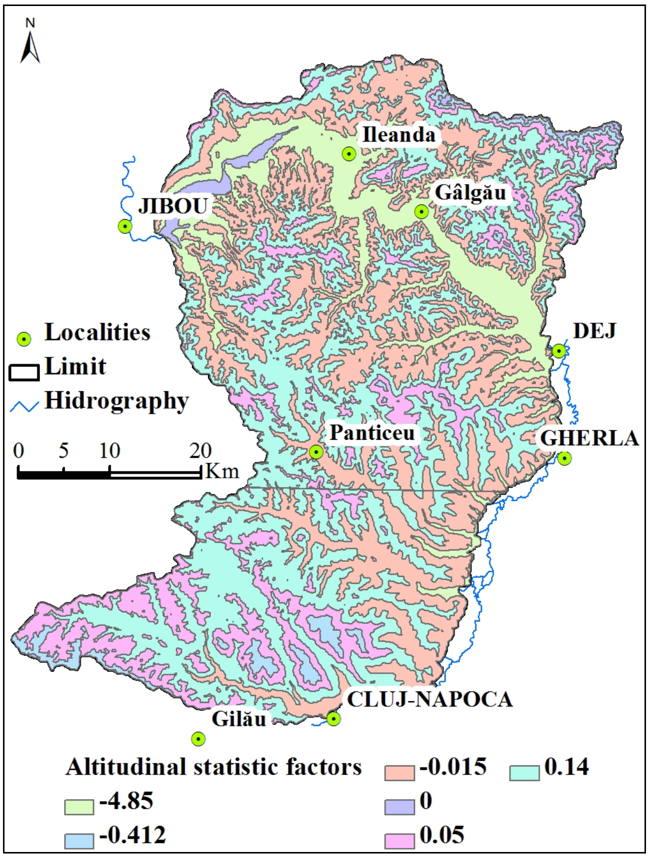

Fig. 3 – Altitudinal statistic factor.

In general, geodeclivity is typical to plateau relief with relatively small slopes, the largest area, representing 1754.9 km^2, they are covered by slopes with an inclination ranging between 5 and 15 degrees, and share 66.78 % of the total Someş Plateau, and they are correlated with the maximum landslide area extension, 47.62 km^2 being affected by landslide with a computed statistical value of -2.88 (Table 2).

We also underline that on slopes with an angle over 35 degrees, no landslides were identified. This might be explained also by the smaller manifestation area from this slope interval, of only 0.084 km^2.

Geology

Among the variables considered in the development of the landslide susceptibility model, geology, represented by the lithological and structural features, is among the one that induces the process type and dimension. These types of geomorphological processes occur mainly on sedimentary rocks, such as clays, marls, and poorly consolidated sands or on substrates in which these rocks are disposed in alternation. An example in this respect is the behavior of clay that in the presence of water expands and in the lack of a solid base triggers down-slope movements.

In order to achieve the analysis and determine the statistical value (Fig. 4, Table 2) for the geological substrate, we used the lithological characteristics of different periods, statistical values between -0.50 and -0.90 being computed.

Precipitations

Precipitations influence the down-slope movement processes mainly by their rate and temporal distribution. Landslide occurrence is favored by significant rainfalls that follow a drought period when the existing fissures enable water penetration.

For the study area there were analyzed precipitation records from the Cluj-Napoca meteorological station and seven other pluviometrical gauges. With this data the average multiannual precipitation map was created using the characteristic curves method. The highest average annual precipitation values were identified between the elevations of 650 and 800 m, representing 77% of the total precipitation volume.

Slope aspect

Landslide distribution is also correlated to the slope exposure, this variable standing between the fundamental ones, influencing the geomorphologic processes sense and direction.

The most significant differences are registered between the slopes exposed to south and south-west, receiving increased solar energy and having a computed statistical value (Table 2) of 0.328, respectively of 0.324 and sharing 54.73% of the total areas affected by landslides and those exposed to north, much more shaded, with a statistical value of 0.213 and sharing only 7.6 % from the landslide affected areas.

Table 2

Computed statistical values for the GIS model variables.

Variable	Characteristic intervals	Statistic value	Variable	Characteristic intervals	Statistic value
Elevation	182–200 201–300 301–400 401–500 501–600 601–700 700–800 801–900	0 -4.850 -0.015 0.140 0.050 0.412 0 0	Precipitation	500–550 550–600 600–650 650–700 700–750 750–800 800–850 850–900 900–1000 1000–1050	-1.358 -1.141 0.380 0.298 -0.124 -0.620 -2.673 0.000 0.000 0.000
Slope angle	0–2 degrees 2.1–5 degrees 5.1–15 degrees 15.1–21 degrees 21.1–35 degrees > 35 degrees	-3.914 -3.154 -2.888 -3.664 -3.788 0	Land cover	Broad-leaved forest Agricultural areas Pastures Complex cultivation patterns Fruit trees and berry plantations Artificial surfaces Arable land Transitional woodland-shrub Mineral extraction sites Coniferous forest	-0.204 0.537 -0.333 -0.656 0.406 0.599 -0.850 -3.142 0.478 0.608
Geology	gravel, sand sand, clay clays marl marl, clay	-0.907 -0.723 -0.508 0.550 -0.837	Drainage depth	0–50 50.1–100 101–150 151–200 201–250 251–300	-1.625 -0.096 0.077 -0.034 -0.302 0.000
Drainage density	0.1–1 1.1–2 2.1–3 3.1–4	0.131 -0.412 -0.669 -1.719			

The explanation of these differences is explained by the fact that on the southern slopes the freeze-thaw and the wetting drying processes occur daily, especially in the transition seasons and this together with the land cover management of these slopes contributes to the substrate instability and the triggering of down-slope movements.

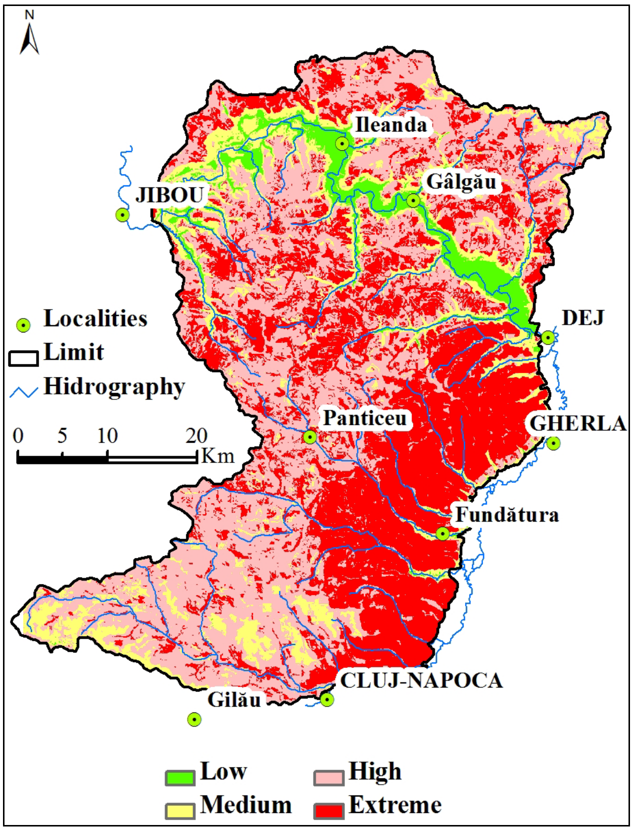

Fig. 4 – Landslide susceptibility map.

Land cover

Land use in these very fragmented hilly regions reflects the human interventions, which is then reflected in the rate of the geomorphologic processes on slopes.

The most significant changes in the natural landscape occurred mainly as a result of the vegetation cover change. The vegetation type has gradually changed during time through deforestation or grubbing, forests were replaced by arable fields, meadows, grasslands or orchards. These changes didn't come with any direct consequence, but they induced slope instability and interfered in the geomorphological processes dynamics.

Within a context of general increase in the landslide affected areas, knowing the evolution tendencies of the geomorphological processes, with all the informational support which is provided, it should represent a real support in the prevention and control of these phenomena and their destructive effects on human plans.

At the same time, the splitting of the agricultural lands in plots of only 0.5 on 0.5 ha and the lack of coherent measures to prevent and control erosion, leads to a decreased land stability, which, at its turn, favors the occurrence of landslides.

The database used in the spatial analysis and in the extraction of the statistical values was derived from the vector structures of CORINE land cover 2006.

Drainage depth

The depth of drainage, as it expresses the relative altitudinal differences between the watershed and thalweg, influences landslide formation in a quite similar manner as the elevation does. As higher is the drainage depth the greater is the mass movement processes likelihood of occurrence.

We identified large surfaces affected by landslides in areas that correspond to the drainage depth interval of 101–150 m (Table 2), interval that covers the most extended area in the Someş Plateau, respectively 44.3%.

Drainage density

The degree of horizontal fragmentation in a territory (by permanent and temporary channels) expresses the drainage density (Table 2). It influences landslide formation in a very specific way, as the more fragmented a territory is, the more inclined slopes it has, which at their turn are exposed to the above mentioned processes. The computed statistical values for this variable ranges between 0.131 and 1.719.

2.2. Spatial analysis

The outcome of this study, the landslide susceptibility map (Fig. 4), was achieved through a multiple spatial overlay analysis. This analysis was performed with the ESRI ArcGIS geoinformation software, analysis module “Spatial analyst”, the Raster Calculator function that makes possible the integration of mathematic equations into GIS (Bilaşco *et al.* 2009).

Applying the mathematical identifier "+" to the database, representing the input variables having as numerical attributes the computed statistical values, total statistical values from - 0.498, representing low susceptibility, to - 16,678, representing high susceptibility, were obtained. The resulted values were grouped into four classes (Table 3) by using the “Natural Breaks” (Jenks) classification available in ArcGis, this method identifies break points by selecting the class breaks that best represent the similar values and maximizes the differences between classes, after that, the features are divided into different classes whose limits are set where there are relatively significant differences in the data series. As a result we divided the values into classes with set maximum and minimum values, each value corresponding to a particular susceptibility class. Usually, the value classes are established by identifying significant gaps between values in the value series.

2.3. Model validation

The model validation was achieved by field trips meant to identify by direct observation or by using a GPS in some areas affected by landslides and then we compared the results with the modeled database.

In this way, we identified two areas: the first one, with extremely increased susceptibility, in the north-western part of the locality of Fundătura (Fig. 5) and which fits in a proportion of 97% in the modeled high susceptibility class, and the second, in the south-eastern part of the locality of Ileanda that corresponds totally to the modeled results for that area.

Table 3

Susceptibility classes

Susceptibility classes	Statistic Value
Low	-16.67 … -9.95
Medium	-9.96 … -6.33
High	-6.34 … -3.86
Extreme	-3.87 … -0.49

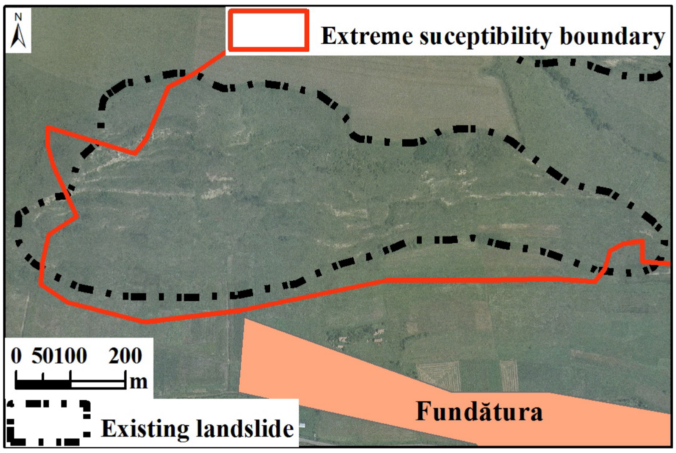

Fig. 5 – Model validation.

3. RESULTS AND DISCUSSIONS

The analysis of the susceptibility map, as well as that of its adjacent grid and numeric database (Fig. 6), mirrors at the level of the total studied area an increased incidence of the areas with high susceptibility (43.2%), located mainly in the northern part of the plateau, followed by the areas with extreme susceptibility (38.5%), located especially in the eastern and south-eastern sector, in the hills bordering the Someşul Mic Corridor.

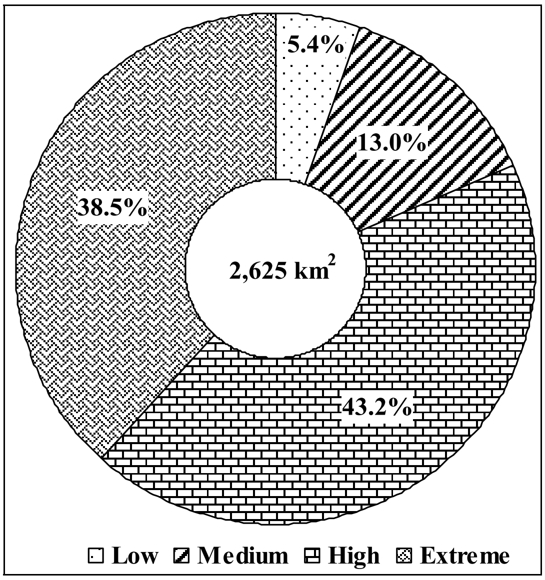

Fig. 6 – Weight of areas with different susceptibility.

As regarding the areas included into the classes with average and small susceptibility, they are much less extended in comparison to the total studied area.

The two categories share together 18.4 %, the corresponding areas are situated mainly on interfluves (those in the first category) or in the Someşul Mare Corridor and in the river channels that converge towards one of the two main corridors in the region (the areas in the second category).

In order to highlight the susceptibility areas and their impact on human communities, we also analyzed the susceptibility categories on the regional subdivisions of the plateau (Fig. 7).

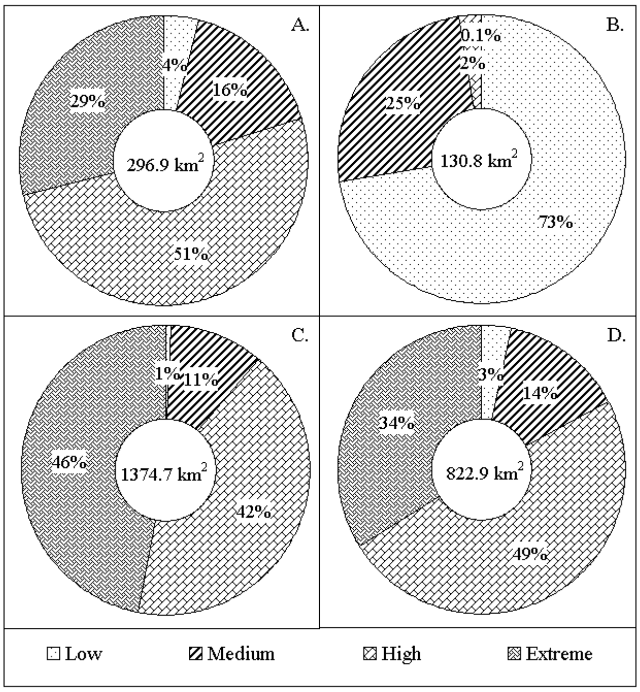

Fig. 7 – Someş Plateau regional subdivisions. Weight of the areas with different susceptibility levels (A. Purcăreț-Boiu Mare Plateau, B. Someş Corridor, C. Cluj and Dej Hills, D. Simişna-Sălătruc Hills).

So, it can be noted that the high and extreme susceptibility classes are well represented in the Purcăreț – Boiu Mare Plateau (A), Cluj and Dej Hills (C) and Simişna-Sălătruc Hills (D) regional units, as a direct result of the morphometric diversity and of the relatively high declivity (with average values ranging between 5.1 and 15 degrees):.

The areas with average and low susceptibility are generally less extended in the above mentioned regional units, while they are better represented in the Someşul Mare Corridor, as a result of the large extension of the Someş channel and river plains.

It is also worth to be mentioned that the areas with average susceptibility are also less represented, sharing between 13 and 16 % from the territory of all the regional subunits, appearing mainly in the Someşul Mare Corridor, in the mean sectors of the river channels draining the Someş Plateau or at the contact between slopes and the Someş river plain.

4. CONCLUSIONS

Through its diverse morphologic features, its specific land use and human activities, the Someş Plateau constitutes an area that favors the occurrence of landslides.

The proposed model points out the increased landslide susceptibility in this regional unit, as the most part of its surface (81.7%) corresponds to the extreme and high susceptibility classes.

The complexity of the GIS spatial analysis model, the results' accuracy and its good validation prove its significant utility for the practical research in the field and supports its extrapolation to other territories.

ACKNOWLEDGEMENTS: The present work was supported by CNCSIS – UEFISCSU, project number PNII – IDEI 2549/2008.

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Received June 7, 2011