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LANDSLIDE SUSCEPTIBILITY ASSESSMENT IN THE CODRULUI HILLS (NORTH-WESTERN PART OF ROMANIA)

Corina ARGHIUŞ[1], Viorel-Ilie ARGHIUŞ[2], Alexandru OZUNU[2], Liviu-Octavian MUNTEAN[2] & Radu MIHĂIESCU[2]

[1]"Gh. Lazăr"National Pedagogical College, 55 Al. Vaida Voevod Street, Cluj-Napoca, Romania, e-mail: corinarghius@yahoo.com

[2]Babeş-Bolyai University, Faculty of Environmental Sciences and Engineering, 30 Fântânele Street, 400294 Cluj-Napoca, Romania, e-mail: arghius.viorel@ubbcluj.ro

Abstract: The implementation of GIS spatial analysis was aimed in order to determine the landslide susceptibility in The Codrului Hills. The methodology for assess landslide susceptibility is based on the premise that the processes will occur under the same geological, geomorphologic and climatic conditions as in the past. The analysis of the landslide susceptibility data showed that the most susceptible areas are the ones with 6-17° slope angles, facing on southwest, with a high drainage density of 4-6 km/km², overlapping Pannonian deposits, covered by pasture and an amount of precipitation in the cold season between 225 and 250 mm. Finally, the landslide susceptibility map was tested using current landslide distribution. The test results showed satisfactory agreement between the landslide susceptibility index and the landslide inventory data. Thus, 92.41% of the current landslides fit the areas characterized by moderate and high susceptibility and only 0.14% of the contemporary landslides are located in the very low susceptibility area. The GIS analysis of the landslide susceptibility revealed that most of the study region is stable from this point of view (68.65%), mainly due to the prevalence of the low slope angles and good vegetation coverage.

Keywords*:* landslide, susceptibility, frequency ratio model, GIS, Codrului Hills

1. INTRODUCTION

GIS techniques give, nowadays, the possibility of rapid and accurate geomorphological investigations. In this study, GIS spatial analysis was employed in order to assess the landslide susceptibility (landslide hazard) in the Codrului Hills.

Landslides, as mass movements, occur in a variety of geological materials, on different scales, and are found in almost any environment where slopes are present (Dufresne & Davies, 2009).

In Romania, the geomorphological literature which approach mass movements is vast and many studies are focused on their spatial analysis, morphology and morphodynamics, earthquake-induces landslides, land use changes and landslides dynamics, the correlation between rainfalls and landslide occurrence, mapping and classification and landslide typology (Surdeanu, 1998, Vespremeanu-Stroe et al., 2006, Grecu et al., 2010, Arghiuş et al., 2011). The studies focused on the issue of landslide susceptibility assessment are recent and relatively scarce (Rădoane et al., 1995, Bălteanu et al., 2010, Bilaşco et al., 2011, Grozavu et al., 2012, Nicorici et al., 2012, Constantin et al., 2012) .

The concept of landslide susceptibility is generally seen as expressing the likelihood of a landslide occurring in an area on the basis of local terrain conditions (Brabb, 1984, Soeters & van Westen, 1996).

The available methods to assess the landslide susceptibility can be divided into qualitative (mainly include heuristic methods) and quantitative approaches (deterministic and statistic methods). The deterministic and statistical methods are based on numerical expressions of the relationship between controlling factors and landslides (Zhu & Huang, 2006). The most commonly used quantitative methods are Logistic Regression

(Guzzetti et al., 1999, Bai et al., 2010), Discriminant Analysis (Carrara et al., 1995, Baeza & Corominas, 2001), Artificial Neural Networks (Lee & Evangelista, 2006, Ermini et al., 2005), Certainty Factor (Lan et al., 2004), Factor of Safety (Günther & Thiel, 2009), Frequency Ratio (Lee & Sambath, 2006), Landslide Index Method (Gunther & Thiel, 2009).

2. THE STUDY AREA

Located in the North-Western part of Romania, the Codrului Hills covers 966 km^2 (Fig. 1), being characterized by a generally mild topography. Altitudes range from 580 m a.s.l. in the Codrului Ridge to 125 m a.s.l. in the western. The major part of the region is occupied by sedimentary rocks (sandy-clay, clay, sand, marl, gravel) excepting Codrului Ridge which is predominantly metamorphic. The largest areas are covered by forest (37.5%) and farm land (35.8%). Average annual precipitation amount varies from 540 mm in South-West to 817 mm in North-West, near the mountain area, much of it beeing concentrated within the warm season (Arghiuş, et al., 2011).

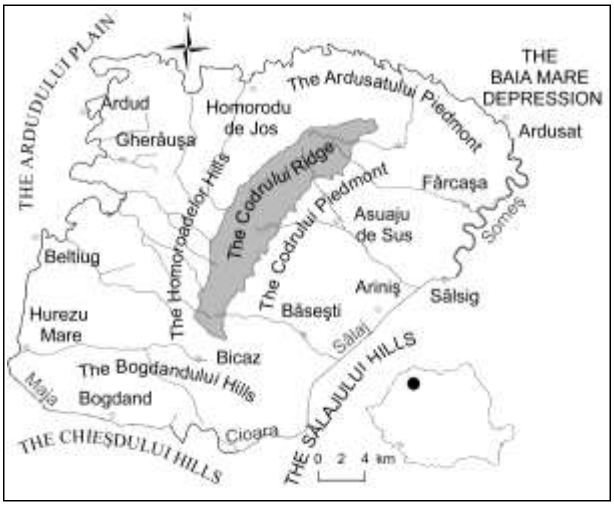

Figure 1. Location of the study area

Previous works on landslides in the Codrului Hills are very sparse. Only, the western part of this area has been the subject of landslide investigation (Driga et al., 2007), but a comprehensive investigation of the landslide susceptibility of the Codrului Hills has not previously been performed.

The Codrului Hills do not present proper conditions for triggering large landslides, which can directly affect population's households or critical infrastructure (Fig. 2). However, by the change of the land use they have indirect, economic consequences and constitute a potentially costly risk for human life and the built environment (Chen & Lee, 2003, Arghiuş, et al., 2011).

Figure 2. Hillslopes shaped by landslides in the study region

3. DATA AND METHODOLOGY

The methodology for determining the landslide susceptibility is based on the statement that landslides are more likely to occur in the presence of the same lithological, topographical, climatic and land-use conditions as in the past, (Varnes, 1984, Carrara et al., 1995, Guzetti et al., 1999, Ermini et al., 2005, Lee & Pradhan, 2006, Vergari, et al., 2011). Therefore, mapping past and recent slope movements, together with the identification and mapping of the conditioning or preparatory factors of slope instability, are the keys in predicting future landslides (Carrara et al., 1998, Zêzere, 2002).

Data used in the analysis of landslides susceptibility were derived from several sources (Table 1).

Table 1. GIS Database

Data type	Layers	GIS Data Type	Scale/ Resolution
Field data	Areas affected by landslides	GPS	0.5 m
DEM	Slope angle	GRID	10 m
	Slope aspect	GRID	10 m
	Relative elevation	GRID	10 m
	Drainage density	GRID	10 m
Aerial images	Aerial photos	SID (2005)	0.5 m
Map data	Topographic map	Polyline/ polygon	1:25 000
	Lithology	Polygon	1: 200 000
Corine Land Cover (2000)	Land use	Polygon	30 m
Climatic data	Precipitation	1970-2002	-

The landslide susceptibility map was performed by applying a semi-quantitative model.

The investigation methodology followed the steps mentioned below (Fig. 3):

- development of spatial database, including landslide inventory map (made on mapping of aerial photos and with GPS) and factor's maps supposedly involved directly or indirectly in the stability of slopes. For landslide susceptibility assessment of the Codrului Hills seven factors were selected: slope angle, slope aspect, relative elevation, drainage density, lithology, land use, and cold season precipitations;

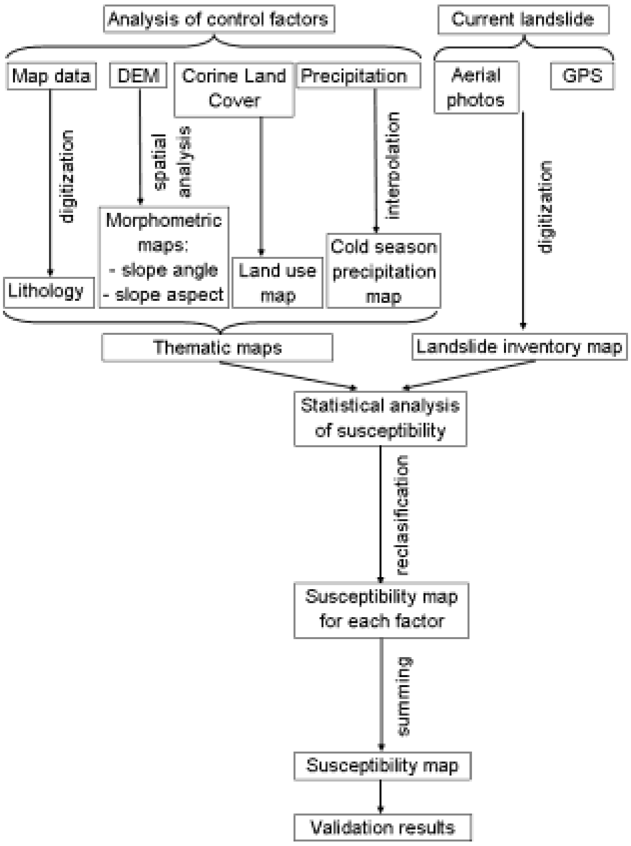

Figure 3. Flow-chart of landslide susceptibility investigation

- assessment of the relation between control variables and landslides using Frequency Ratio Model, based on the observed relation between current landslide distribution and spatial characteristics of control factors. This model was successfully used in the analysis of the landslide susceptibility by Lee & Pradhan, 2006, Lee & Sambath, 2006, Lee & Pradhan, 2007, Jadda et al., 2009.

Correlation is expressed by frequency ratio index, which is the ratio between the percentage of the area affected by the landslide for a given parameter (a class of slopes, a type of rock, slope aspect or use land) and the percentage of that parameter in the entire study region. If the index value > 1 means that there is a strong correlation and thus, a high probability of developing landslides, and if the index value <1 the correlation is weak and thus a low probability;

- thematic maps reclassification according to indices achieved;

-summing up the thematic maps in raster system, using GIS methodology - Raster Calculator tool package ArcGIS 9.2. The landslide susceptibility index *(LSI)* was calculated by summation of each factor's ratings (F_r) using equation (1):

$$LSI = \sum F_r \quad \text{(Lee \& Pradhan, 2006)} \qquad (1)$$

- reclassification of the landslide susceptibility index into four descriptive levels (Barredo et al., 2000), in order to generate maps that are easy to understand by policy makers and other stakeholders:

- very low - in these areas no destructive landslides are expected to occur within the coming years;

- low - in these areas no destructive landslides are expected to occur within the coming years, assuming that the land use situation remains the same. Inadequate construction of infrastructure or buildings may lead to problems, however;

- moderate - in these areas there is a moderate probability that destructive phenomena that could damage infrastructure or buildings will occur within the coming years. However, the damage is expected to be localised and can be prevented by relatively simple and inexpensive stabilisation measures;

- high -in these areas there is a high probability that destructive phenomena will occur within the coming years. These events are expected to damage infrastructure or buildings considerably. Construction of new infrastructure or buildings is not recommended in these areas, at least not until a detailed study has been performed.

- validation of the obtained results by overlapping and comparison of landslide susceptibility map with the current landslide map.

4. RESULTS

Creating the landslide inventory is fundamental for landslide susceptibility assessment based on GIS. Inherently, this step involves a certain level of uncertainty (Crozier, 1995, Carrara et al., 1992, Zêzere, 2002). To reduce these uncertainties, the landslide mapping (Fig. 4) was performed using GPS terrain data and aerial photos with high spatial resolution (0.5 meters).

Using ArcGIS 9.2 software the landslide areas were identified and mapped and using XTools extension the main morphometric parameters of the landslides were calculated. The obtained data sets were analyzed, resulting the following remarks:

- the landslides are mostly shallow, with small and medium surface extension, because the hill slopes, through their morphometric features (slope angle, in particular) are less likely sensitive to such processes;

- a number of 238 landslides were identified, covering a total area of 171.9 ha, which represent 0.18 % of the study area (Arghiuş, et al., 2011).

Figure 4. Inventory landslide map

The results obtained on the landslide frequency ratio, presented in Table 2 were illustrated in graphical forms and mapping, to reveal the influence of control factors on landslide susceptibility. Thematic maps related to variables included in the model have been reclassified in accordance with the obtained indices, setting 4 susceptibility classes (very low, low, moderate, high).

The slope angle is one of the most important factor involved in landslide genesis and evolution. The analysis of the relation between the slope angle and the current landslide distribution reveal the fact that the most sensitive areas are the ones with moderate slopes, with a slope angle of 6-17º (Fr=1.97). This slope angle class is considered by Surdeanu, 1998, to be most prone to landslide processes (Fig. 5). Mild slopes (0-3º) have a very low frequency of landslides because of the generally lower shear stresses associated with low gradients (Fr=0.06).

The lack of landslides on steep natural slopes (over 17º) in the study area, can be explained by the unfavorable lithology, this area beeing represented by the outcropping bedrock of Codrului Ridge.

In the case of the slope aspect, southwest-, east- and south-facing slopes, less covered with forests, are highly susceptible to landslides (Fr > 1). The lowest susceptible slopes were the ones facing on northeast and northwest, with ratio < 0.8 (Fig. 6). The high values of drainage density and relative elevation lead to a high morphodynamic potential.

Table 2. Frequency ratio (Fr) - relation between landslides and related factors

Factor	Clases	Area (km²)	Land slide area (km²)	% from total land slide area	Fr
lope angle	0-3º	312	0.035	2.01	0.06
	3-6º	376	0.713	41.5	1.06
	6-17º	276	0.971	56.5	1.97
	17-32º	1.44	0	0	0
Slope aspect	N	129	0.221	12.8	0.95
	NE	142	0.175	10.2	0.69
	E	121	0.217	12.6	1.00
	SE	106	0.185	10.7	0.98
	S	115	0.239	13.9	1.16
	SW	121	0.353	20.5	1.64
	W	115	0.172	10.0	0.84
	NW	112	0.158	9.20	0.79
Relative elevatio n	<50 m	270	0.152	8.81	0.31
	50-100 m	605	1.54	89.7	1.43
	100-150 m	82.8	0.026	1.51	0.17
	>150 m	8.60	0	0	0
Drainag e density	<2 km/km²	314	0.343	20.0	0.61
	2-4 km/km²	620	1.22	71.0	1.10
	4-6 km/km²	31.7	0.155	9.04	2.75
	> 6 km/km²	0.57	0	0	0
Cold season precipitatio	<225 mm	0.289	0	0	0
	225-250 mm	92.1	0.052	3.02	0.31
	250-275 mm	401	0.830	48.3	1.16
	275-300 mm	434	0.827	48.1	1.07
	>300 mm	39.0	0.010	0.59	0.14
Lithology*	1	0.682	0	0	0
	2	82.3	0	0	0
	3	187	0.03	1.85	0.09
	4	12.7	0.04	2.57	1.94
	5	89.0	0.01	0.74	0.07
	6	25.9	0.02	1.57	0.58
	7	17.1	0	0	0
	8	491	1.57	91.4	1.79
	9	60.7	0.03	1.88	0.30
Land-use	Coniferous forest	1.83	0	0	0
	Broad-leaved forest	336	0.070	4.06	0.11
	Shrubland	24.2	0.054	3.13	1.25
	Arable and fallow land	70.3	0.153	8.87	1.21
	Pasture	142	1.28	74.7	5.08
	Orchard	21.2	0.007	0.43	0.19
	Vineyard	31.4	0.012	0.69	0.21
	Arable land	276	0.123	7.13	0.24
	Artificial surfaces	58.5	0.018	1.04	0.17
	Water bodies	5.35	0	0	0

*1 - Igneous rocks; 2 – Metamorphic rocks; 3 - Holocene sands and gravels; 4 - Early Pleistocene sands and gravels; 5 - Late Pleistocene sands, gravels and clays; 6 - Pleistocene deluvial deposits; 7 - Quaternary colluvial and deluvial deposits; 8 - Pannonian marly-clays and sands; 9 - Sarmatian marls, sands, sandstone and conglomerates

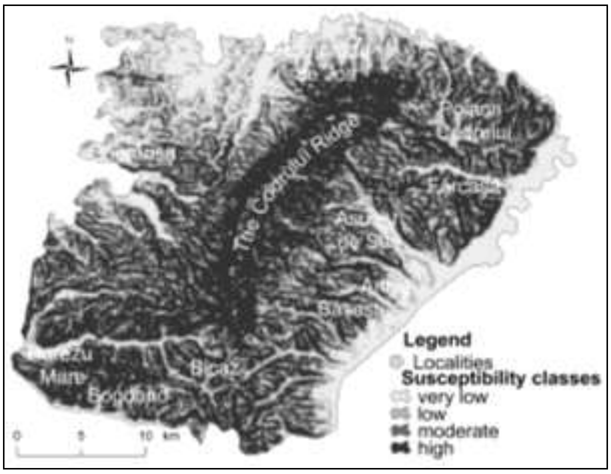

Figure 5. The susceptibility of slopes to landslide (slope angle factor)

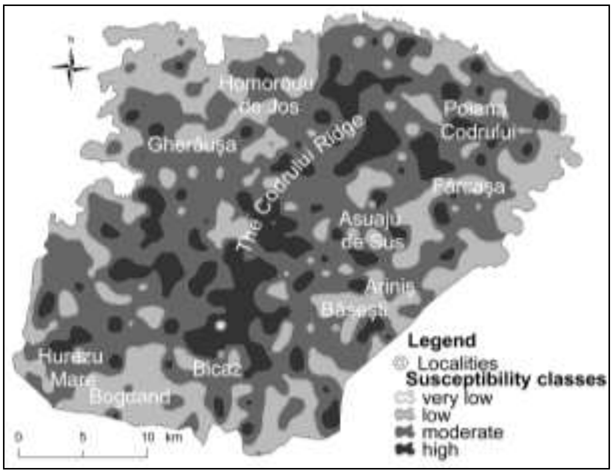

Figure 7. The susceptibility of slopes to landslide (drainage density)

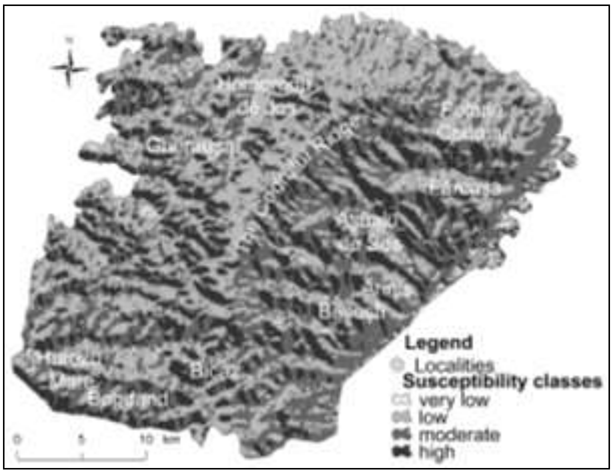

Figure 6. The susceptibility of slopes to landslide (slope aspect)

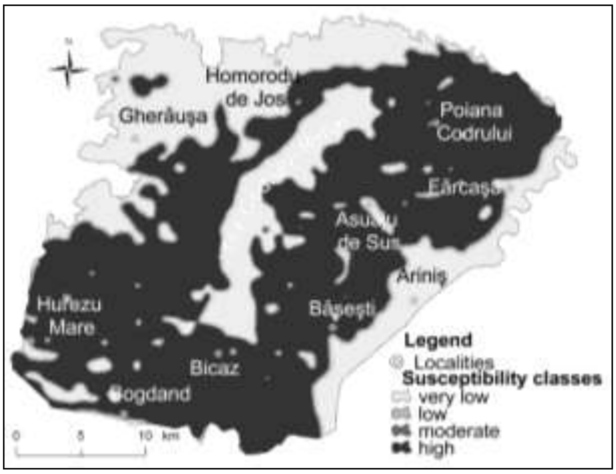

Figure 8. The susceptibility of slopes to landslide (relative elevation)

Thus, an increase in the landslide susceptibility occurs, along with the increase of the drainage density, except the areas with high drainage density (over 6 km/km²). However, these areas represent a small percent of the area (0.05 %), thus not influencing the regional landslide susceptibility analysis (Fig. 7).

In the case of relative elevation, the most susceptible class of values is the 50-100 m one, with the Fr=1.43. The highest values (>100 m) generally belong to the Codrului Hills, dominantly composed of metamorphic rocks, unaltered by landslide processes (Fig. 8).

Regarding the lithological factor, it was found that the frequency ratio is higher (Fr=1.79) in Pannonian deposits (marly-clays), and lower in alluvium and metamorphic rock areas (Fig. 9).

In the Codrului Hills region, the most important factor that could lead to trigger landslides is related with precipitation conditions.

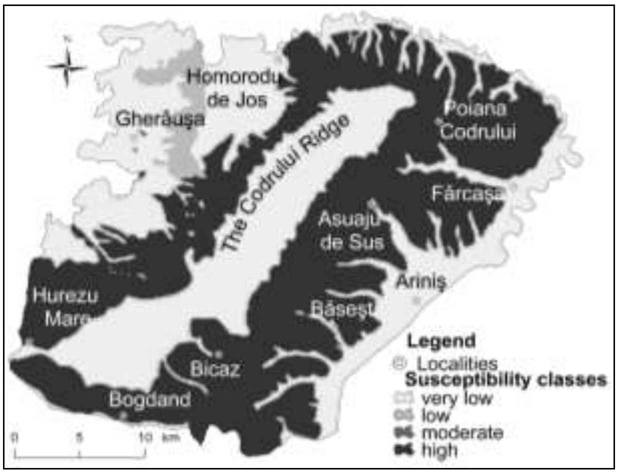

Figure 9. The susceptibility of slopes to landslide (lithology)

The research conducted in the study area showed that the new landslides and the reactivation of the old ones are mainly the result of a favourable combination between a high amount of precipitations in winter and a long duration and medium-heavy rainfalls early in the spring. Consequently, most of them have occurred in the late winter and early spring period (Arghius et al., 2011). This pattern has been reported by other researchers in similar climatic region conditions (Szabo, 2003, Dragicevic, et al., 2012). In this context, the climatic parameter used in the analysis of the landslide susceptibility was the precipitation amount from November to April. The most susceptible areas are the ones with precipitation amount between 250-275 mm, with a frequency ratio of 1.16. The areas with lower susceptibility (Fr<0.35) are in Codrului Ridge, the villages Ardusat and Sălsig and the northwestern part of Homoroadelor Hills (Fig. 10).

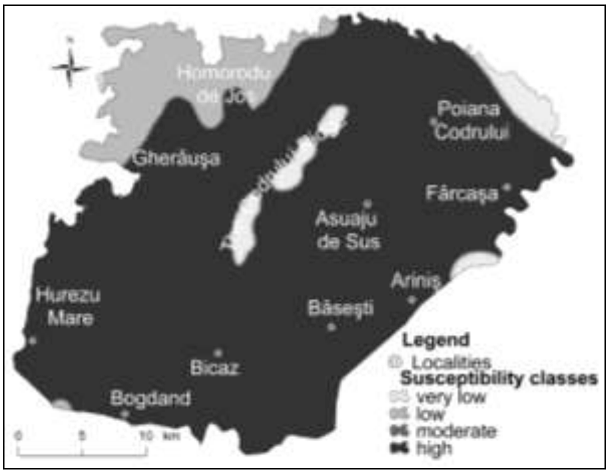

Figure 10. The susceptibility of slopes to landslide (precipitation factor)

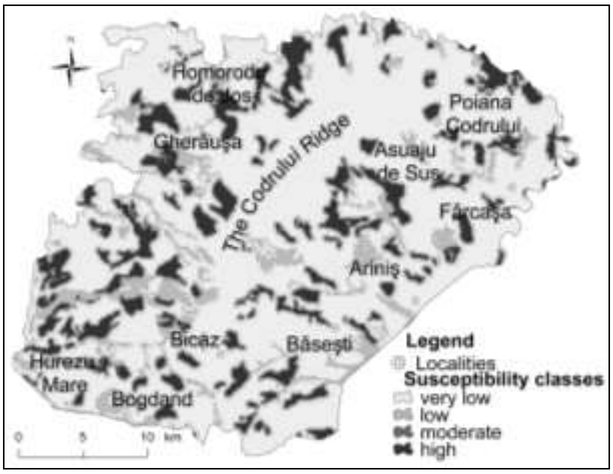

Figure 11. The susceptibility of slopes to landslide (land use)

The land use induces a high influence on the initiation and evolution of the landslides. Naturally, the lowest probability of landslides is found in forest areas (Fr= 0.11), while the most susceptible areas are the pastures (Fr=5.08); a high probability of landslides (Fr>1) is specific, also, to scrublands, developed mainly on cleared and fallow lands (Fig. 11).

In the study region, LSI (Landslide Susceptibility Index) had a minimum value of 1.39, and a maximum value of 14.41, with an average value of 6.95 and a standard deviation of 2.52. The index was grouped into 4 equal susceptibility clases (according to Barredo et al., 2000) (Table 3).

Table 3. The percentage of landslide susceptibility classes

Susceptibility classes	Fr values	Area (km²)	% from total area
Very low	<4.64	185.623	19.21
low	4.64-7.90	477.730	49.44
moderate	7.90-11.16	216.544	22.41
high	>11.16	86.385	8.94

From the landslide susceptibility map the following categories result (Fig. 12):

- Very low susceptibility (19.21 % of the total area), specific to the Codrului Ridge, Someş and Sălaj river flood plain and to the mild slopes from the northwest part of the region;
- Low susceptibility (49.44 % of the total area), mainly distributed on the interstream areas;
- Moderate susceptibility, representing 22.41 % of the total surface;
- High susceptibility, with a high probability of landslides occurring in the near future. This area is represented by old landslide deluvial deposits, with a high probability of reactivation. 8.94 % of the area is included in this class, mainly near the Asuaju de Sus, Gârdani, Beltiug, Băseşti and Socond villages.

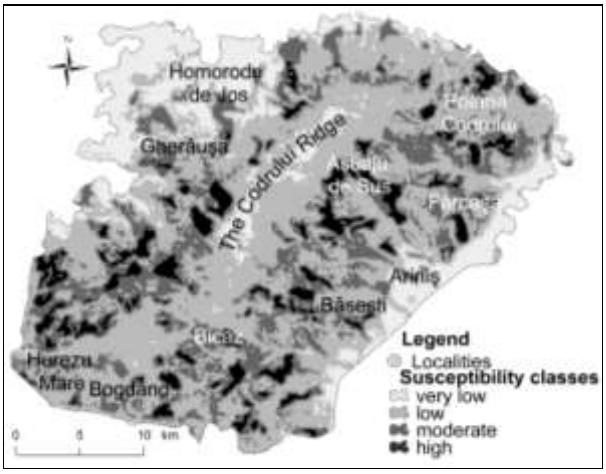

Figure 12. Landslide susceptibility map

The analysis of obtained data showed that the most susceptible areas are the ones with 6-17°slope angles, facing on southwest, with a high drainage density of 4-6km/km², overlapping Pannonian deposits mainly consist of marly-clay deposits, covered by pasture and an amount of precipitation in the cold season between 225 and 250 mm.

Finally, the landslide susceptibility map was tested using current landslide distribution. The test results showed satisfactory agreement between the landslide susceptibility index and the landslide inventory data. Thus, 92.41% of the current landslides fit the areas characterized by moderate and high susceptibility and only 0.14% of the contemporary landslides are located in the very low susceptibility area (Fig. 13).

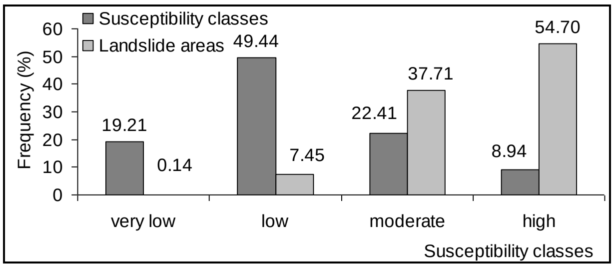

Figure 13. Verification of landslide susceptibility

5. CONCLUSIONS AND RECOMMENDATIONS

The landslide susceptibility of the Codrului Hills was performed through Frequency Ratio Model, which is based on the observed relation between current landslide distribution and spatial characteristics of control factors. Then, the landslide susceptibility index generated by this model was reclassified into four descriptive levels in order to generate a landslide hazard map that is easy to understand and apply by decision makers.

The GIS analysis of the landslide susceptibility revealed that most of the study region is stable from this point of view (68.65%), mainly due to the prevalence of the low slope angles and good vegetation coverage. Nevertheless, these unstable conditions can be easily unbalanced by deforestation or improper agricultural techniques which could trigger new landslides.

The test results showed satisfactory agreement between the landslide susceptibility index and the current landslide distribution. Beside of this, for the future, attention should be focused on improving of the predictions by increasing the spatial resolution of the factors taken into account.

Although, the landslides are often difficult to predict, the landslide susceptibility can be assessed and the related landslide risk properly managed. In this context, this landslide susceptibility map is easy to understand and a very useful tool for decision makers in land use planning strategies and development of the most appropriate measures to mitigation of landslide risk.

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