Assessment of the susceptibility degree to landslides within Ciulucurilor Hills by Method of Frequency Rate

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ABSTRACT: Landslide susceptibility map for Ciulucurilor Hills was carried out using frequency ratio method. Its calculation is performed by the ratio of the percentage of landslide areas for each factor taken into account (lithology, elevation, drainage depth, slope, exposition, land use, distance from river and drainage network density) and the percentage of the total area corresponding to each factor. Very low susceptibility land occupies 10.1% of the region surface and is the most common in the south-west and the Big Ciuluc and the Middle Ciuluc river valleys. There is 25.8% of the built surface on this area. Low susceptibility land occupies 40.3% of the territory, being the largest class of susceptibility. It holds 56.2% of the arable land and 47.6% of the built surface. The average susceptibility is recorded on 22.9% of the territory and has a more compact distribution in Soloneţ basin. This land holds 38.8% of the pasture surface and 28.5% of the perennial plantations. The land with high and very high susceptibility occupies 26.7% of the territory, with a high frequency in the south-west of the region, on interfluve between the Big Ciuluc and the Middle Ciuluc rivers. These classes have 81.9% of forest surface and only 12.6% of the arable land. The length of the roads located on the land with high and very high susceptibility is 164.5 km.

KEY WORDS: landslides, susceptibility, the Method of Frequency Rate, Ciulucurilor Hills

1. Introduction

Landslides can be recorded throughout the Republic of Moldova territory. However, these processes occur more frequently in hilly areas and plateaus, mainly in the central part of the country. Within this region, frequency of landslides is now 40-50 slidings/100 km^2. Landslides annually cause considerable material damages, destroying houses, roads, industrial units, agricultural lands, etc.

The purpose of this paper is to develop susceptibility map to landslides from limits of Ciulucurilor Hills, using the method of frequency rate. Actuality of this study is due to lack of recent researches, the latest inventory of landslides in the area were carried out in the early 90s of the twentieth century.

2. Study methods

Susceptibility map of land to landslides for Ciulucurilor Hills was performed with the Method of Frequency Rate (Frequency Ratio Model) in ArcGIS (ESRI) (Fig. 1). This represents the probability of landslides. Its calculation is the percentage ratio of area occupied by landslides for each factor considered and percentage of total area corresponding to each factor. If the ratio is higher than 1, the probability of developing landslides is high, and below 1- this decreases, relation between that factor and sliding being not very important or even negligible (Goţiu D., Surdeanu V., 2008). Cartographic pattern was developed on the basis of eight factors (Lithology, Elevation, Fragmentation depth, Slope, Exposition, Land use, Distance from the rivers and Density of drainage network), adding to the inventory of landslides. For each factor was calculated of frequency rate based on overlap with landslide inventory (Lee, Evangelista, 2005; Lee, Pradhan, 2006). Finally, it was realized landslide susceptibility map, by summing the maps with listed factors.

Ciulucurilor Hills are located in the north-central part of the country, limited to the south with Codrii Plateau, from east - Dniester Plateau, to the west - Middle Prut Plain and to the north - Plain Cubolta. Delimitation physical-geographical subregion was performed by Laboratory of Landscape Ecology (Boboc N., 2009). Study area, according to regionalization, has a total area of 1723 km2, and within its limits there are active landslides 71.2 km^2 or about 4.13%.

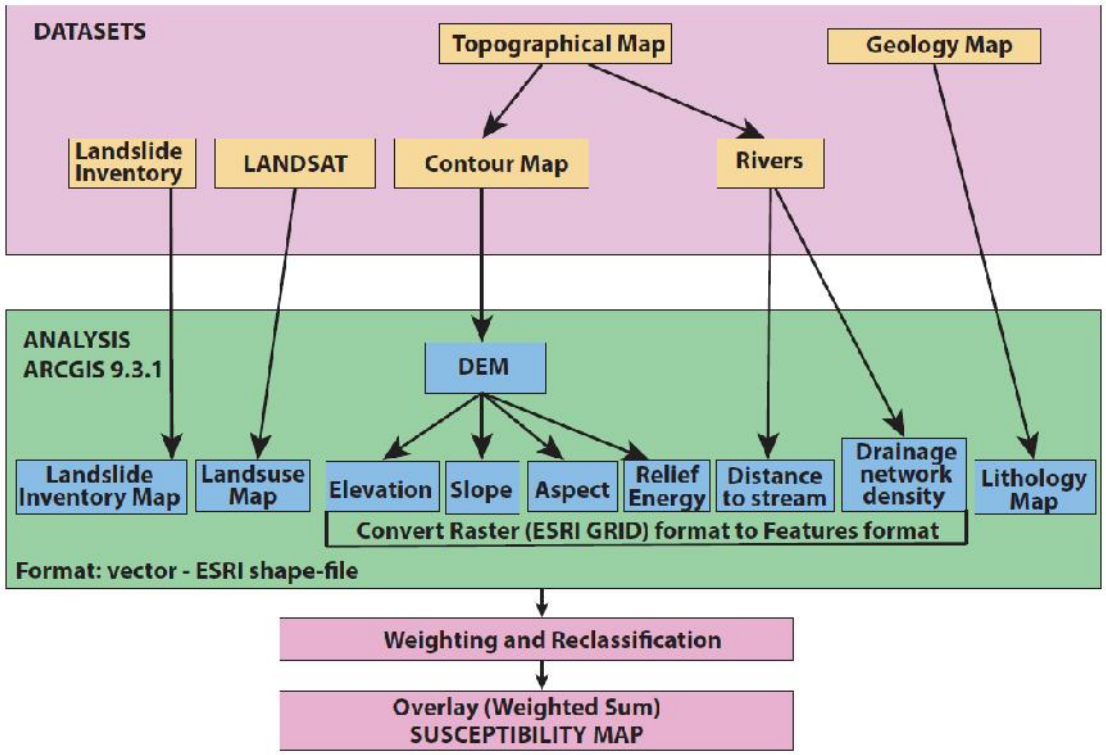

Figure 1. Analysis methodology for landslides susceptibility by Frequency Rate Method.

3. Results and discussion

In the development of sliding process in the study area a special role has the geological (lithology), topographic and the land use specifics.

The geological structure. Relief and specific landscape at present from Ciulucurilor Hills generally were formed in Neogene deposits. The oldest rocks, organogenic limestones, clastic and chemogene (oolitic limestone) of the Inferior Sarmatian (volanian horizont) appear at the surface in the eastern part, in the valley of Raut River and partly in the north, in the lower slope of the valley sectors, latitudinally of Raut (Balti-Floreşti) (Fig. 2). The geological structure in the river valleys predominate clays of Inferior Bassarabian and slope surfaces are composed from clays attributed to Early Bassarabian covered by clays alternating with silty and sands accumulated during Medium Bassarabian. Interfluvial peaks consist of sands alternating with clays of Late Bassarabian and in the south-east - from sands of Hersonian and Meotoan. Younger deposits, represented by sands and gravels of age Pliocene, appear episodically in the north and east of the country, oval on top of the hills more prominent.

Most of landslides can be found throughout areas in which they are alternating with silty clays and sand, the rate of frequency having the value of 1.23. A key feature of these deposits is their relatively low resistance. This is due to the poor physical contact between the mineral particles. Under the influence of water, clay structures, strong in the dry state, changes its consistency - from solid to liquid. Therefore, widespread clayey-sandy deposits, their presence in the structure of the majority of the slopes are one of the basic conditions of the territories prone to landslides. Highest stability is recorded on calcareous structures.

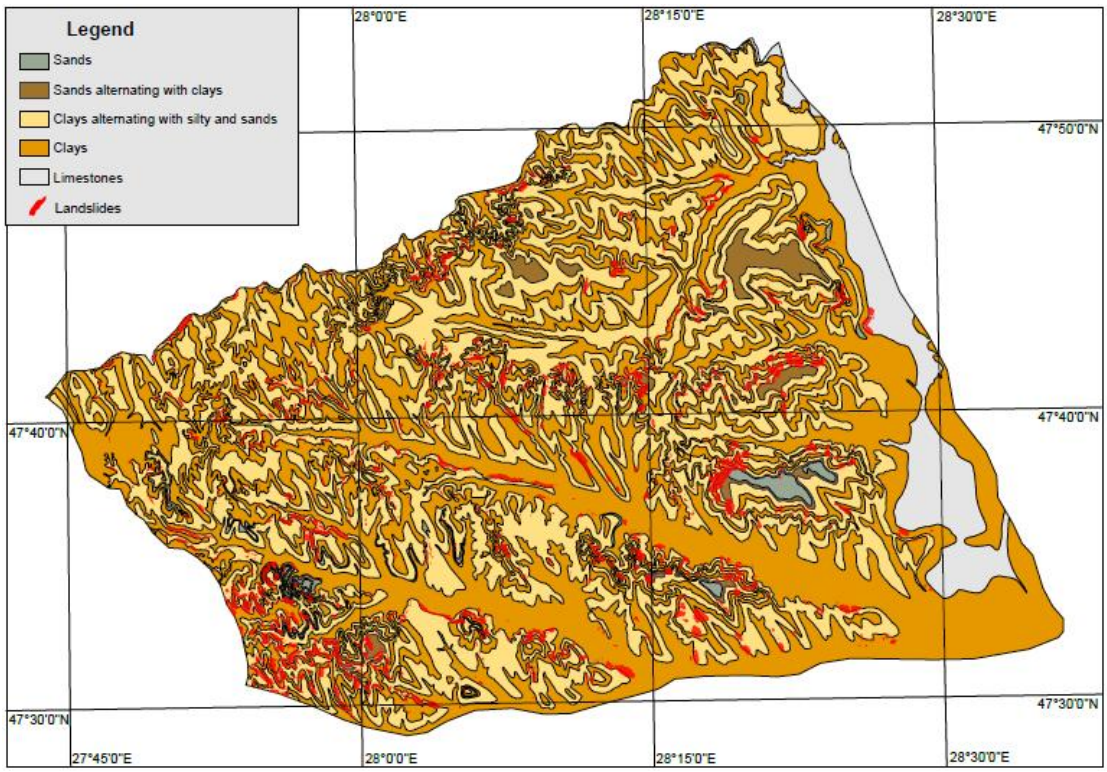

Figure 2. Lithological structure.

Elevation. Over 67% of the region surface it is within altimetric step between 100-200m and is represented by the interfluvial slopes and peaks with a uniform distribution on the investigated area. Altitudinal steps of less than 50m and that included between 50-100m holds shares of 3.5% and 16.8%. They occupy river valleys of Raut River, Ciulucul Mare, Ciulucul Mijlociu, Ciulucul Mic and meadows from the lower courses of the rivers: Solonet, Chiva, Iligaci (Fig. 3). The top of slopes, hills of 200-250m, occupy 9.2% of the total area. Areas of distribution of this relief step are greatly restricted in the southern and extend more in the northeast of study area. The areas with an altitude higher than 250m occupy an area of 3.4%, predominantly in the north-eastern part of region (Titu P., 2011).

Landslides with a frequencies rate of 1.75 at the step of 200-250 m and 1.24 at the step of 150-200 m. On the lands with altitude less than 100 m share of landslides is 6.08%.

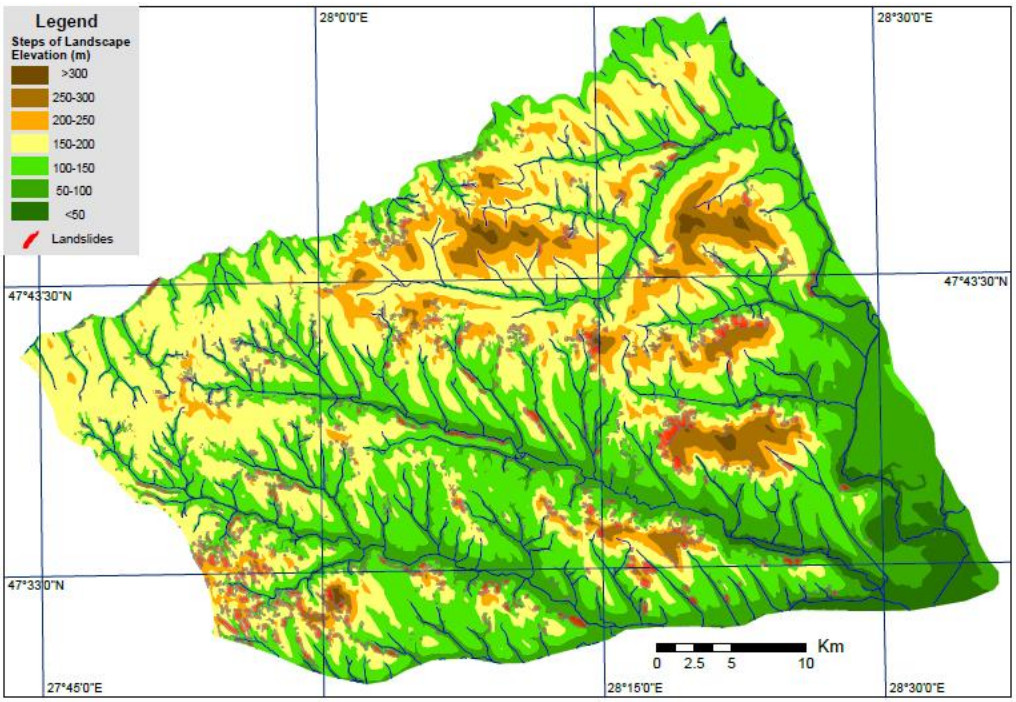

Figure 3. Hypsometry

Slope is the best indicator that estimates the action of gravity, being the way that this controls drain water and mobility of materials. It is therefore particularly important for landslides that may accelerate or diminish depending on the particular values of threshold slope.

The slopes of less than 2° have 16.8% of the total area, being found mainly in large river meadows, in the upper parts of the slopes, in contact with the interfluvial peaks (Fig. 4). The slopes with values of of 2-5 ° have the largest surface, with a share of 42.5%, comprising fluvial terraces, connections between meadows and slopes, some low angle slopes and connections between the peaks and slopes interfluvial. The slopes of 5-7 ° values, have a smaller area as to the previous class, with a share of 17.8%, and occupy the same aerials as the previous class. The slopes with values of 7-15 ° hold 76.1% from landslides and 21.4% of the region. The slopes with angle of inclination higher than 15 ° are most likely to landslides, with the values of the frequency ratio of 3.75. So with the increased levels of slope increases the rate of frequency values the probability that above mentioned geomorphological processes to occur is higher.

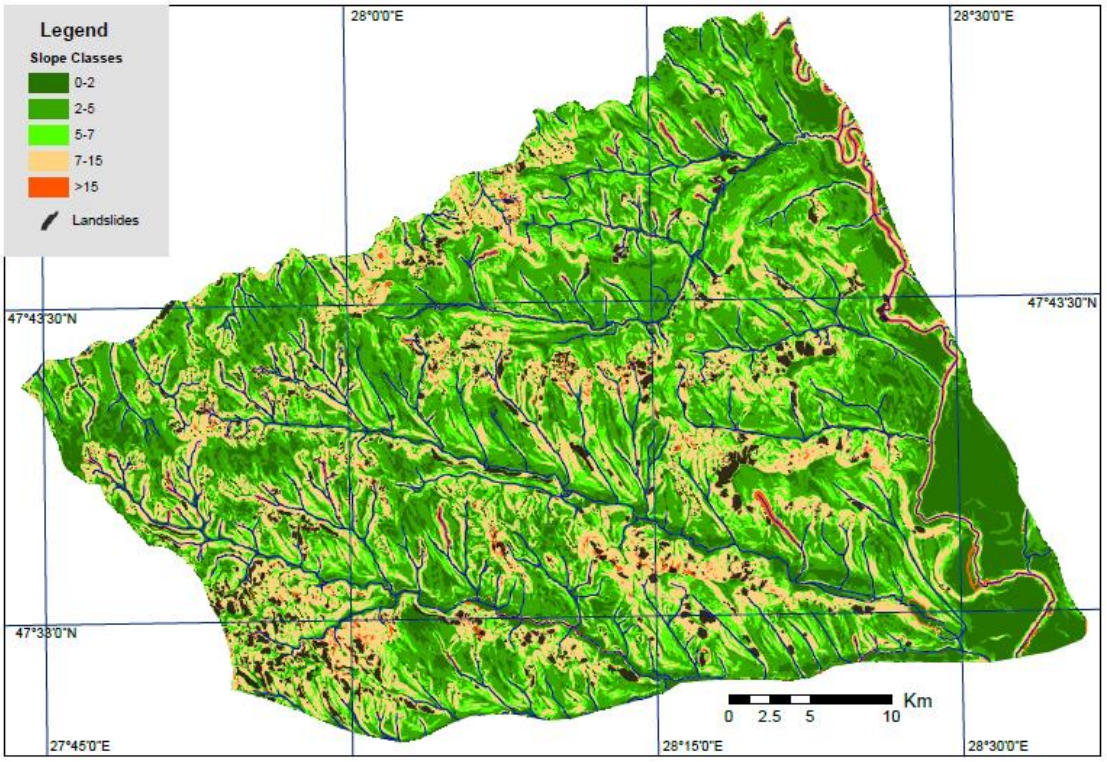

Figure 4. Slopes.

Exposition. As well as the slope, appearance or slope orientation plays a very important role in the way of geomorphological processes evolution. Sloping surfaces orientation, in relation to the duration of isolation, conditions to distribution of thermal regime, rainfall, air and soil moisture, boosting the different morphodynamic processes.

Distribution of slopes with different orientations within Ciulucurilor Hills is heterogeneous, resulting in a "jigsaw puzzle" of areas with small surfaces (Fig. 5). The highest percentage have slopes facing south-west (17.9%), north-east (16.5%), Eastern (13.1%) and Southern (12%). The lowest percentages have north-west-facing slopes (6.8%) and North (9%).

Most of landslides overlap the slopes with northern exposition, north-eastern, western and north-western which have high and very high susceptibility (Table 1). This is because these slopes have the capacity to hold moisture in the soil.

Landscape Fragmentation Density has an important role in starting landslides because the increasing numbers of collectors (trenches and torrents) increase incision per unit surface area. It is therefore recommended directing them to a collector at the base of the slope. (Surdeanu V. et al., 2006).

In the entire region, fragmentation density values ranging from very low, below 0.5 km / km ² to over 2 km / km ² (Fig. 6), grouped by morphological units, conditioned mainly by lithological and structural features of the substrate. Most landslides are located in cells with values between 1.5-2 km/km^2. Very low susceptibility of land fragmentation density with the values higher than 2 km/km^2 is the fact that they are located in areas of valleys confluence.

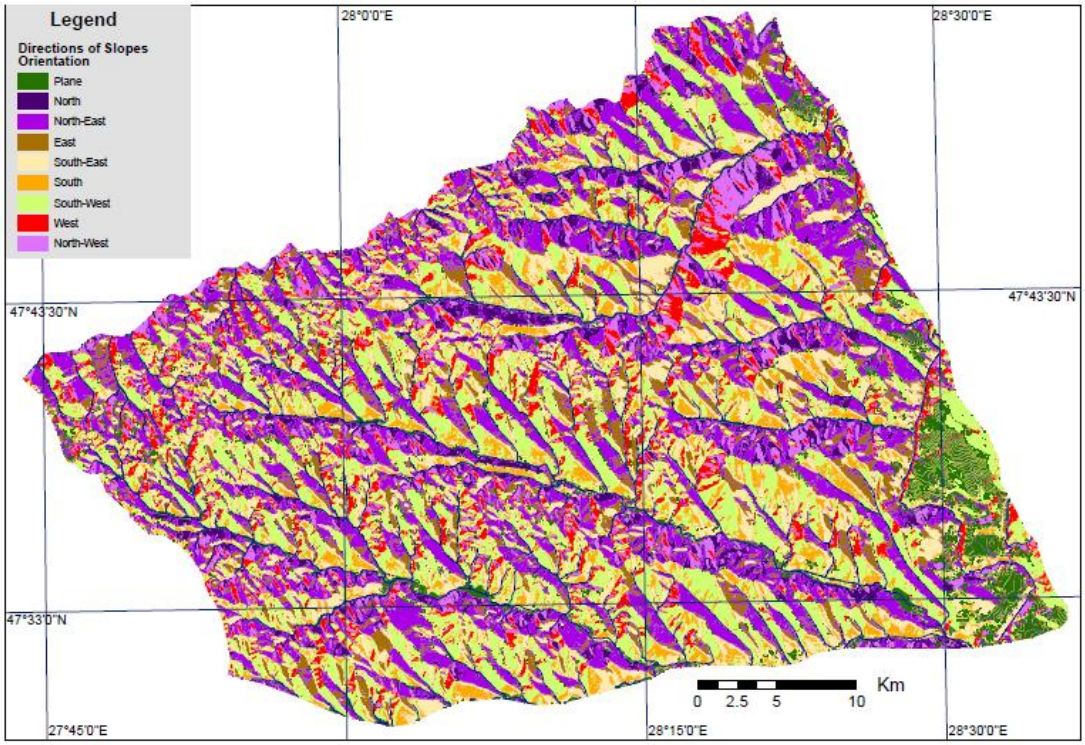

Figure 5. Exposition.

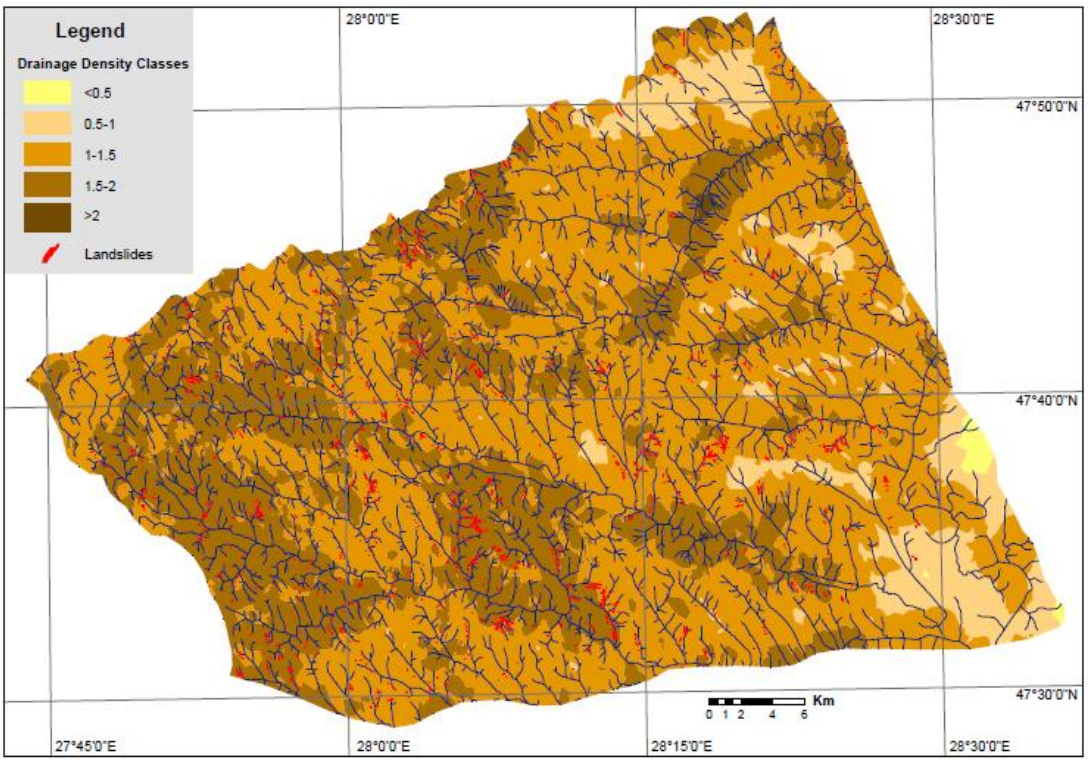

Figure 6. The relief fragmentation density.

Land usage and vegetation represents one of the key factors in stabilizing landslides. Hydrological factors and those associated mechanical of plants increase the stability of slopes. Effect of vegetation on slope stability should be seen not only as natural system of anchoring the stratum surface that it covers, but the role of climate regimes as moderator and regulator of water balance in the soil (Prefac Z., 2008).

The large share of agricultural land, approximately 85% (Fig. 7), of which more than half is arable lands (53.9%), reflects the fact that the study region has an agricultural specialization, which is reflected upon the stability of slopes. Almost half of landslides bodies are used as pasture lands, they have the highest values and frequency rate, 2.44. According to the calculations presented in Table 1 forestlands are most susceptible to landslides. This situation is explained by the fact that forests are secondary, as a result of planting land affected by these geomorphologic processes. Therefore these categories of land were assigned conventional a null frequency rate.

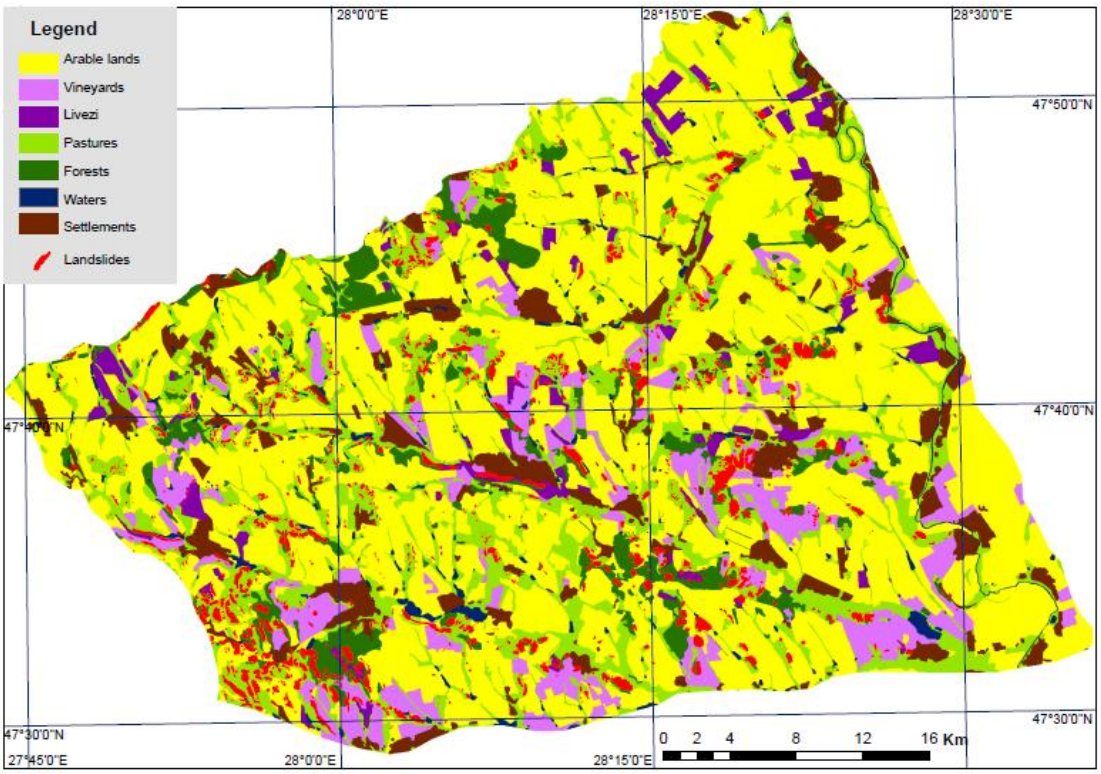

Figure 7. Land usage.

The calculation of Landslide Susceptibility Index - LSI is based on summation of frequency rate (Fr) of the 8-factors (Table 1), according to the equation below.

LSI = (Fr (Elevation) + Fr (Exposition) + Fr (Slope) + Fr (Relief energy) + Fr (Lithology) + Fr (Relief fragmentation density) + Fr (Distance from rivers) + Fr (Land Usage)) / 8)

Table 1. Factorial calculation of Landslide Frequency Rate

Elevation			
Factor	**The share of the total area of the region (%)**	**The share of the total landslides (%)**	**Frequency Rate**
<50	3.55	0.04	0.01
50-100	16.80	6.04	0.36
100-150	36.39	36.44	1.00
150-200	30.66	37.95	1.24
200-250	9.22	16.14	1.75
250-300	3.07	3.28	1.07
>300	0.32	0.11	0.33

The slope			
Factor	**The share of the total area of the region (%)**	**The share of the total landslides (%)**	**Frequency Rate**
0-2	16.85	0.73	0.04
2-5	42.53	5.27	0.12
5-7	17.84	12.86	0.72
7-15	21.44	76.10	3.55
>15	1.35	5.05	3.74

Exposition			
Factor	**The share of the total area of the region (%)**	**The share of the total landslides (%)**	**Frequency Rate**
Plane	3.32	0.04	0.01
North	8.97	17.96	2.00
North-East	16.51	24.20	1.47
East	13.11	9.14	0.70
South-East	10.16	4.19	0.41
South	12.05	4.89	0.41
South-West	17.87	13.20	0.74
West	11.26	16.60	1.47
North-West	6.75	9.78	1.45

Fragmentation density (km/km^2)			
Factor	**The share of the total area of the region (%)**	**The share of the total landslides (%)**	**Frequency Rate**
<0.5	0.36	0.07	0.21
0.5-1.0	8.05	1.73	0.21
1.0-1.5	57.35	54.66	0.95
1.5-2.0	34.10	43.45	1.27
>2.0	0.15	0.09	0.61

The fragmentation depth			
Factor	**The share of the total area of the region (%)**	**The share of the total landslides (%)**	**Frequency Rate**
<50	13.23	0.97	0.07
50-100	72.99	59.54	0.82
100-150	13.23	37.55	2.84
150-200	0.55	1.95	3.54
>200	0.01	0.00	0.00

Land use			
Factor	**The share of the total area of the region (%)**	**The share of the total landslides (%)**	**Frequency Rate**
Waters	1.57	0.00	0.00
Forests	6.07	16.59	2.73
Pastures	19.79	48.23	2.44
Arable land	53.91	21.49	0.40
Orchards	2.73	3.54	1.30
Vineyards	8.25	8.11	0.98
Settlements	7.68	2.04	0.27

Lithology			
Factor	**The share of the total area of the region (%)**	**The share of the total landslides (%)**	**Frequency Rate**
Clays	49.33	44.09	0.89
Clays alternating with silty and sands	43.27	53.26	1.23
Limestones	4.94	0.00	0.00
Sands	0.88	0.90	1.02
Sands alternating with clays	1.59	1.75	1.11

The distance from the rivers, m			
Factor	**The share of the total area of the region (%)**	**The share of the total landslides (%)**	**Frequency Rate**
<250	26,68	22,24	0,83
250-500	23,88	23,14	0,97
500-750	19,06	16,41	0,86
750-1000	13,13	12,86	0,98
1000-1250	8,20	9,84	1,20
1250-1500	4,65	8,00	1,72
1500-1750	2,27	4,19	1,84
1750-2000	1,02	2,05	2,01
2000-2250	0,44	0,88	1,97
2250-2500	0,21	0,30	1,45
>2500	0,46	0,09	0,20

Susceptibility map of land to landslides. Based on factorial analysis the susceptibility to landslides was performed a synthesis map of susceptibility to landslides (Fig. 8).

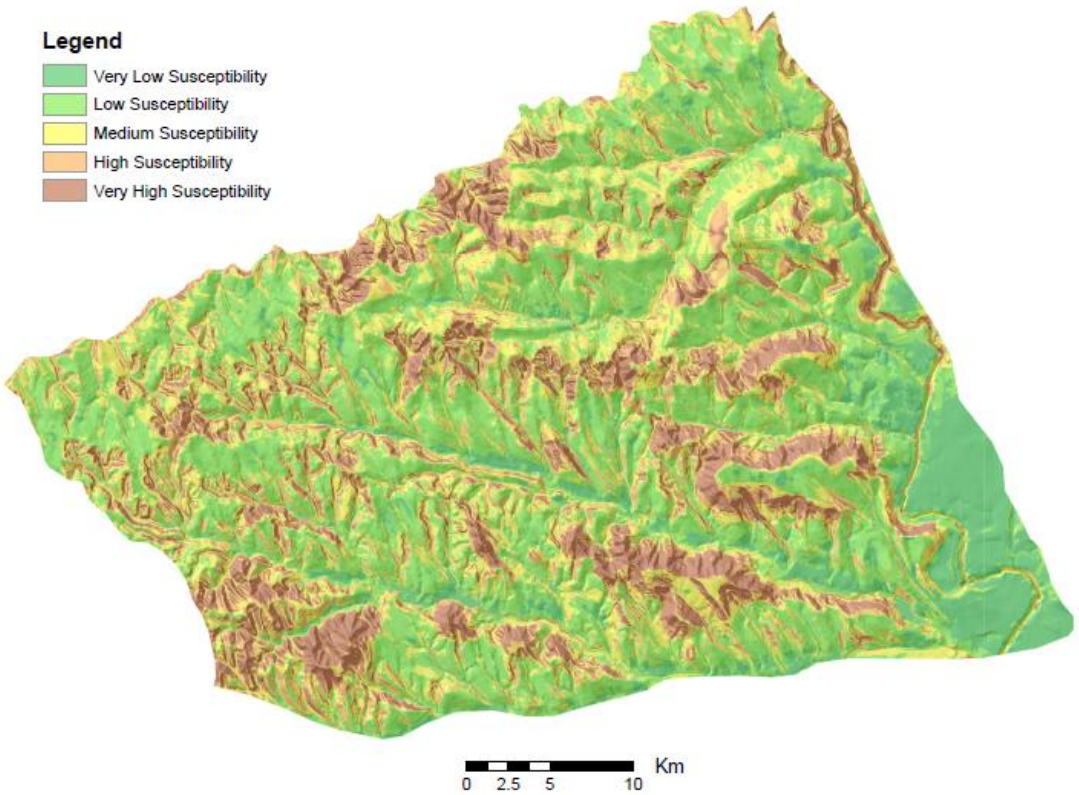

Figure 8. The susceptibility of land to landslides.

Lands with very low susceptibility occupy 10.1% (Fig. 9) of the region surface and are more frequent in the south-west and in river valleys: Ciulucul Mare and Ciulucul Mijlociu. These lands are 25.8% from urban area.

Lands with low susceptibility occupy 40.3% of the territory, being the largest class of susceptibility. They hold 56.2% of the arable land and 47.6% from urban area.

The average susceptibility is recorded in 22.9% of the territory and has a more compact a distribution in Solonet river basin. These lands have 38.8% of the pastures' area and 28.5% of perennial plantations.

Lands with high and very high susceptibility occupy 26.7% of the territory (13.3% and 13.4%, respectively) with a high frequency in the southern -western part of the region, the interfluves between rivers Ciulucul Mare and Ciulucul Mijlociu, between settlement Petropavlovca and the road linking the village Bănesti with city Telenesti; the interfluves of the Ciulucul Mare River with rivers Iligaci and Soloneţ.

These classes have 81.9% of the forests' area and only 12.6% of that are arable lands. Length of roads located on land with high and very high susceptibility constitutes 164.5 km.

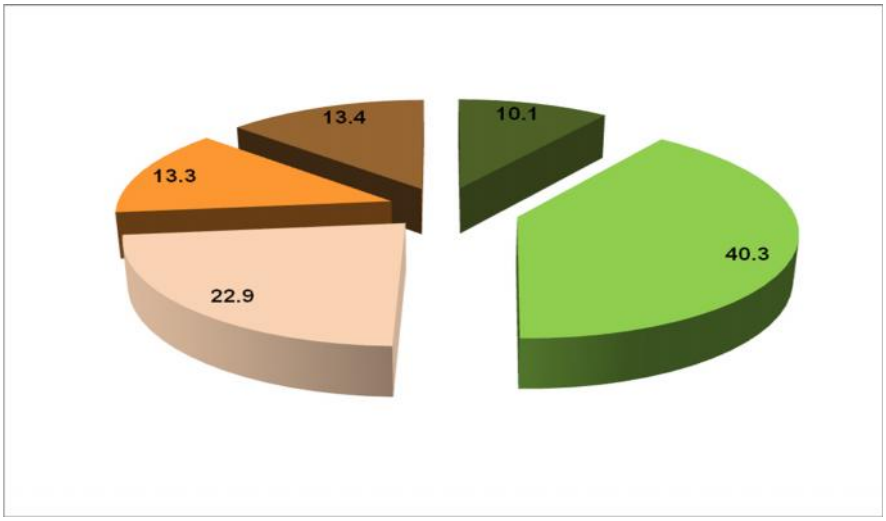

Figure 9. Share of land with different susceptibility grades within Ciulucurilor Hills.

In a last stage we had passed the results validation, which were performed by overlapping thematic layer of susceptibility classes' representation with the landslides layer in order to obtain frequency within each class of susceptibility. The results were represented graphically in Figure 10 and show that the highest incidence of landslides records fifth grade, that signifying high susceptibility. Frequency of landslides in this class is 64.2%. A high frequency is recorded and within the class with the high susceptibility (24.4%).

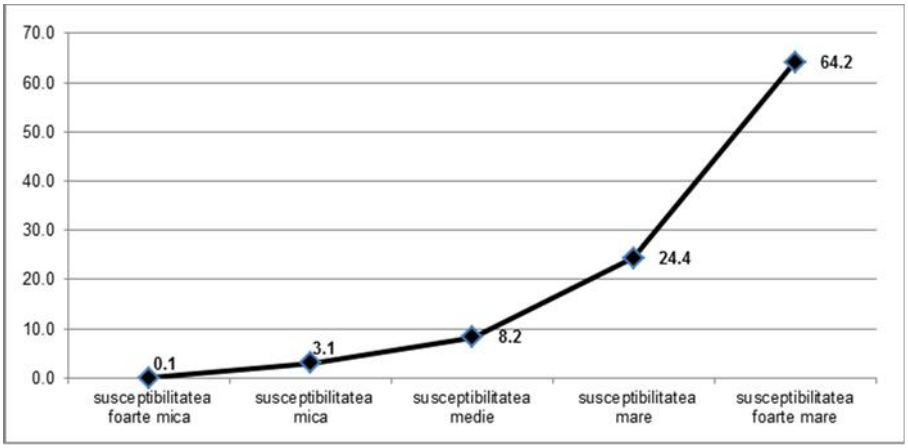

Figure 10. Share of landslides on land with different levels of susceptibility.

4. Conclusions

In conclusion, it can be noted that the evaluation of slopes susceptibility to landslides, performed using statistical method, which is based on determining the rate of landslides frequency in the

classes of each thematic layer, provides the opportunity to identify areas prone to landslides. However, this type of analysis involves rather a large degree of uncertainty due to the limitations of the used data. In addition, the accuracy of the analysis is reduced in case of process analysis as a whole and not as individually.

Analysis of slopes susceptibility to landslides reveals the high percentage of land with the low sensitivity (40.3%), they may however be unbalanced by deforestation, over-pasture and poor farming practice techniques that lead to the emergence of new land landslides or destabilization of those existing.

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