LANDSLIDE SUSCEPTIBILITY EVALUATION BY GIS SPATIAL ANALYSIS: GIURGEU MOUNTAINS, ORIENTAL CARPATHIANS, ROMANIA

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Abstract

Landslides and lands affected by landslides are still an essential problem in Romania due to their huge negative economic effects. Landslides cause property damage, affect a variety of resources, such as forests, roadways, water supplies. The prediction of all these can be done by using geotechnical studies, engineering projects or using a GIS spatial analysis model. Over the years, different methods were elaborated to evaluate the landslide occurrence probability, including the methodology adopted by Romanian Governmental Decision no. 447/2003. The new era of technological development has driven the boundaries of environmental research to a rich expansion regarding the specialized remote sensing or GIS methods and techniques on the entire globe. Although the primary driving force for a landslide to occur is the action of gravity, there are other essential factors which affect the original slope stability. These factors (hypsometry, slope, slope aspect, fragmentation density, fragmentation depth, stream power index and wetness index) were included in a complex model to determine the landslide occurrence probability using GIS spatial analysis in the Giurgeu Mountains, Oriental Carpathians, Romania. Only land morphometric characteristics were chosen to be integrated in the study, thus obtaining in the final step of the study a susceptibility map for the study area.

Key words: landslide, GIS spatial analysis, morphometric characteristics, probability, susceptibility

INTRODUCTION

Landslide is the movement of a mass of rock, debris or earth down a slope (Cruden, 1991). Landslides represent one of the major natural hazards in all relief units on Romanian territory, the differences being related to the role played by several factors. Landslides have a high prevalence in areas with rugged terrain (Pleşa et al, 1980).

The aim of this study was to present the land morphometric characteristics and their role regarding the landslide occurrence probability. In other words, the purpose was to prepare a susceptibility map, using an optimal combination of landslide morphometric causing factors. Landslides can be studied in nature or in the laboratory and the landslide susceptibility study can be based on geomorphologic mapping, heuristic analysis, analysis of inventories, statistical modeling or process based (conceptual) (Gunther, 2007). On the other hand, it is well known that it can be determined by a mathematical formula which expresses the relationship between the factors which contribute to landslide occurrence. The study was conducted for the Giurgeu Mountains (Fig. 1), located in Moldavian-Transylvanian

Carpathians, Romania and was designed to use the deterministic quantitative analysis which is based on a formula that includes in this study seven parameters.

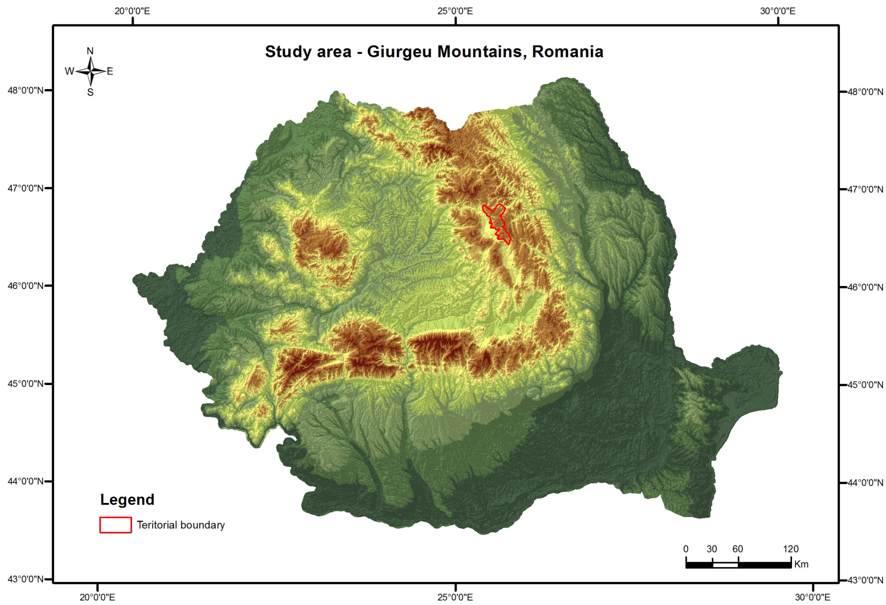

Fig.1. Geographical position of the study area (original map)

The Giurgeu Mountains can be divided into three units: the Raven Mountains, the Prisaca Mountain and the Black Mountain, but because these units have almost the same morphometric characteristics, the study presents the results for the entire area defined by the Giurgeu Mountains boundary. Through GIS spatial analysis, we can answer in the end to the question „Where could landslides occur?".

MATERIAL AND METHOD

In order to obtain good results, the GIS spatial quantitative deterministic analysis model used in this study is based on a few steps. The first one is represented by a database that must be created, and that has to include all the structures, modeled databases and derived databases. The modeled database, the support for factors that will be included in the final equation is represented by the Digital Elevation Model with a 25 m resolution. The other data needed, such as the hydrological network or the territorial boundary was provided from specialized sites (www.geofabrick.de, www.geo-spatial.org). The final formula will include seven parameters. Their probability values were obtained based on Romanian Governmental Decision no. 447/2003, values presented in Table 1.

Table 1

Statistical value and probability related

Value	Probability
< 0.1	Low
0.1-0.3	Medium
0.31-0.5	Medium- High
0.51-0.8	High
> 0.8	Very High

Based on the table above, a database was created taking into consideration the territorial extension for each characteristic interval, which will be presented in the following seven tables (Results and discussion).

RESULTS AND DISCUSSION

The present methodology for the determination of landslide occurrence probability includes the following major steps: creating a raster database, area proportion identification, assigning probability values, reclassification, and conversion – obtaining a compact database, equation implementation. Due to the fact that the probability for a landslide to occur on a territory is directly proportional to its spatial extension, it was necessary to calculate the value of the interval probability coefficient (vp) with the following formulas:

$$(x * y) / 100 = z \qquad (1)$$

$$x = vp_{max} - vp_{min} \qquad (2)$$

$$vp = a + z \qquad (3),$$ where

x – the value of the probability interval; y – the interval area of spatial extension, as percentage; z – the value of the probability coefficient depending on the area; vp_{max}, vp_{min} - the maximum and the minimum value of the probability interval; vp – the probability value; a – the basic value of the probability interval; z – the value of the probability coefficient depending on the area (Bilașco et al, 2014).

Table 2 illustrates the steps for the calculation of probability values for the intervals of the slope aspect factor.

Table 2

Values and probability classes (Slope aspect)

Intervals	Probability	x	y	z	vp
plan	Low	0.1	0.15	(0.1 * 0.15) / 100 = 0.00015	0 + 0.00015 = 0
N NE	Medium	0.2	22.88	(0.2 * 22.88) / 100 = 0.05	0.1 + 0.05= 0.15
E NW	Medium- High	0.19	24.56	(0.19 * 24.56)/ 100 = 0.05	0.31 + 0.05 = 0.36
SE S	High	0.29	25.24	(0.29 *25.24) / 100 = 0.07	0.51 + 0.07 = 0.58
SW W	Very High	0.2	27.16	(0.2 * 27.16) / 100 = 0.05	0.80 + 0.05 = 0.85

Hypsometry (Fh). The hypsometric analysis for the study area. The Giurgeu Mountains reveals a high altitudine area extension, the areas with low and average landslide occurrence probability having no weight. The medium-high, high and very high probability cover the entire area, with weights of 0.02%, 83.61% and 16.37%, high probability covering an area of 490.09 km^2 (Table 3).

Using the methodology and the steps presented above, the DEM raster was classified (Fig. 2) based on the hypsometric intervals presented in Table 3. The result of the procedure based on the determination of the value of the probability coefficient specific, for the extension area of the probability interval and the calculation of the interval probability coefficient (1, 2, 3) is presented in Fig 2, which contains the study area in probability values for hypsometric factor.

Table 3

Values and probability classes (Hypsometry)

Intervals	**Probability**	**Probability Value**	**Area (km^2)**
165-400 m	Low	-	-
401-500 m	Medium	-	-
501-700 m	Medium- High	0.31	0.12
901-1800 m	High	0.75	490.09
701-900 m	Very High	0.83	95.95

Slope angle (Fs). It is well known that a high value of slope (expressed in degrees) presents high susceptibility for landslides. The database derived from the DEM and the first two columns from table 4 which allow following the steps of the model, reveal the spatial extension of the probability. With a weight of 44.23%, the area is included in the medium probability class, followed by the medium-high, low, high classes (40.13%, 6.99% respectively 6.92%), only 1.73% out of the total area being covered by very high probability class.

Table 4

Values and probability classes (Slope angle)

Intervals	**Probability**	**Probability Value**	**Area (km^2)**
0 - 5^0	Low	0.007	40.97
5.1^0 - 15^0	Medium	0.19	259.26
15.1^0 - 25^0	Medium-High	0.39	235.23
25.1^0 - 30^0; > 35^0	High	0.53	40.56
30.1^0 - 35^0	Very High	0.8	10.14

Slope Aspect (Fa). When the terrain is flat, there is no slope. This means that there is no aspect. But in the mountains, there are slopes in all directions (www.gisgeography.com). The compass direction that the slope faces is slope aspect. As table 5 shows, there are *north*-facing, *west*-facing, *south*-facing and *east*-facing slopes.

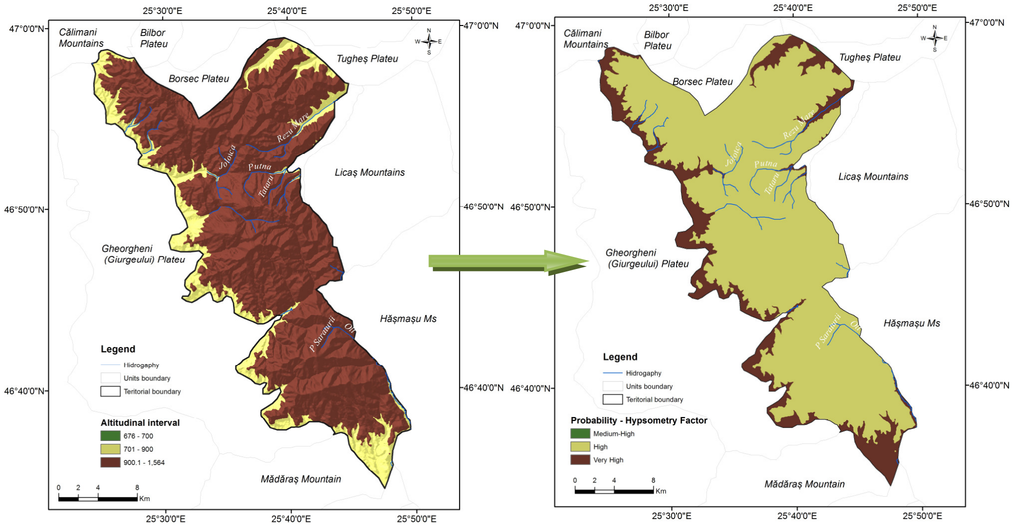

Fig. 2. Probability values map for hypsometry (original maps)

According to the probability values presented below and the reclassification of the aspect (obtained from the DEM), statistically, the largest area SV, V with 159.26 km^2 (27.16%) is included in the very high probability interval, followed by S, SE 25.24% (high probability) E, NV 24.56% (medium-high probability) and N, NE 22.88% (medium probability). The share of flat surfaces is 0.15% of the total.

Table 5

Values and probability classes (Slope aspect)

Intervals	Probability	Probability Value	Area (km^2)
plan	Low	0.0002	0.88
N NE	Medium	0.15	134.11
E NW	Medium-High	0.36	143.96
SE S	High	0.58	147.95
SW W	Very High	0.85	159.26

The depth of fragmentation (Fda). The depth of fragmentation is the expression difference of altitude between the lowest and the highest level on a standard area (in this study 1 km*1 km). According to Neamțu, 1996, the higher the altitude difference is, the greater the degree of inclination of the slope and length and thus will risk triggering erosion and gravitational processes (Vlad and Alexandru, 2012). The largest part of the study area, respectively 48.87% presents values of the depth of fragmentation between 301 and 400 m. Also, the analysis of the depth of fragmentation values map shows that most of the area register values contained in the medium and low probability classes (33%, respectively 3.42%), followed by high and very high probability classes with the following weights: 13.68% and 1.03%.

Table 6

Values and probability classes (Depth of fragmentation)

Intervals	**Probability**	**Probability Value**	**Area (km^2)**
0 - 100 m	Low	0.003	23.47
100.1 - 200 m	Medium	0.17	226.47
200.1 - 300 m	Medium-High	0.40	335.39
300.1 - 400 m	High	0.55	93.88
> 400 m	Very High	0.8	7.07

The density of fragmentation (Fdd). The drainage density and landscape fragmentation is an area ratio of the length (measured in km) and unit area (calculated km^2) and expresses the degree of horizontal fragmentation of the landscape (Rodica Joldiș, 2014). It is a parameter indicating the hydrographic network density in relation to the area occupied by slopes. According to Mac, 1986, at high values of drainage so when there a dense network of valleys and narrow interfluves, there is a large extension of surface slopes with potential for triggering slope processes (Vlad and Alexandru, 2012).

At high values, this indicator determines a high instability of slope, so it is very important in determining the landslide occurrence probability. The most of the area is covered by low probability, followed by medium, medium-high and high probability classes.

Table 7

Values and probability classes (Density of fragmentation)

Intervals	**Probability**	**Probability Value**	**Area (km^2)**
0 - 0.5 m/km^2	Low	0.01	75.08; 567.35 (Value 0)
0.5 - 1 m/km^2			
1 - 1.5 m/km^2	Medium	0.11	36.92
1.5 - 2 m/km^2	Medium-High	0.31	5.76
2 - 2.5 m/km^2	High	0.51	1.17
> 2.5 m/km^2	Very High	-	-

Wetness Index (Fwi). It is also known as topographic wetness index and it is related to the degree of water accumulation on certain areas. WI was developed by Beven and Kirkby (1979), being calculated with the following formula (where "accumulation" is represented by flow accumulation, "625" represents the area in m^2 of the DEM cell and the "slope" is represented by the slope in radians):

*Ln (("accumulation"*625)/Tan("slope"))* (4).

The study area has low degree of water saturation, 83.39% of the total being included in the low landslide probability.

Table 8

Values and probability classes (Wetness Index)

Intervals	Probability	Probability Value	Area (km^2)
0 - 14	Low	0.08	574.00
14 - 16	Medium	0.10	8.56
16 - 18	Medium- High	0.31	3.58
18 - 20	High	0.51	0.01
> 20	Very High	0.80	0.01

Stream Power Index (Fspi). SPI was developed by Moore et al (1991), being calculated with the following formula (where "accumulation" is represented by flow accumulation and the "slope" is represented by the slope in radians):

Ln(("accumulation"+0.001)("slope"/100+0.001))* (5).

Almost the entire area with a weight of 98.21% and with negative values of the SPI has a low landslide occurrence probability. The other probability classes have very small weights (medium 1.06%, medium- high 0.16%, high 0.14%, respectively very high 0.41%).

Table 9

Values and probability classes (Stream Power Index)

Intervals	Probability	Probability Value	Area (km^2)
< 0	Low	0.09	575.67
0 - 1	Medium	0.10	6.21
1.1 - 1.2	Medium- High	0.31	1.00
1.21 -1.4	High	0.5	0.88
> 1.4	Very High	0.80	2.40

Based on the seven factors presented above, the occurrence probability for every pixel of the study area was determined (fig. 3) and the model was executed by using the formula (6) presented below with the Raster

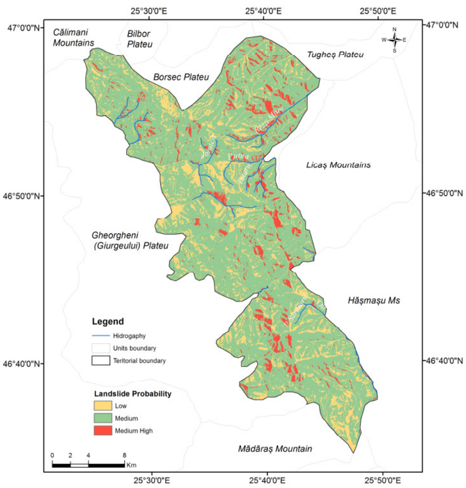

Fig. 3. Landslide probability map of the study area (original map)

Calculator function. All the raster databases, both modeled and derived, were included in the model.

SquareRoot((“Fa”“Fs”)/5* (“Fh”+“Fda”+“Fdd”+“Fwi”+“Fspi”)* (6)

Figure 3 reveals that in a proportion of 76.99%, the study area is included in medium landslide occurrence probability, following by low landslide probability with a weight of 16.82% and medium-high probability with a weight of 6.19%.

CONCLUSIONS

Based on the conducted study, it can be concluded that every morphometric characteristic influences the appearance of landslides with a different weight. The land morphometric characteristics with the greatest weight are the slope angle and the slope aspect. G.I.S. spatial analysis allows visualizing on a map the zones most prone to landslides.

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