GIS FOR SPATIAL LANDSLIDE DISTRIBUTION ANALYSIS IN THE TRANSYLVANIAN DEPRESSION

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Abstract: - **GIS for spatial landslide distribution analysis in the Transylvanian Depression**. Landslides represent one of the most important hazardous geomorphic phenomena in the Transylvanian Depression, the vast depressional area inside the Carpathian Mountains. For the landslide's distribution analysis, we used five criteria: geology, slope, altitude, exposition and the 3rd order administrative units. This type of studies are a must, on one hand to find out how the current landslides are distributed, and on the other hand to identify the areas which are prone to this type of hazardous geomorphic phenomena. By investigating the study area's ortophotoplans and topographic maps, 13.157 landslides were vectorized to create a landslide inventory map. The study shows that lithologic conditions (the presence of friable rocks such as marls, clays, sand) and the land use (mostly agricultural lands) are the most defining factors for landslide development, it is believed that in the future landslides will appear on similar slope, orientation and geological conditions. In this situation, to know the susceptible areas to landslides it will represent a valuable information for the territorial planning and also to avoid the building and expanding of other civil engineering constructions on lands which are prone to landslides.

Key words: landslides, spatial statistics, spatial distribution, GIS.

1. INTRODUCTION

One of the key hazardous geomorphic processes from the Transylvanian Depression are represented by landslides. The Transylvanian Depression is located within the Carpathian Arc, on the territory of Romania (Figure 1) (Bilaşco et al., 2011; Petrea et al., 2014). On its 2465125 ha surface there were identified 13157 landslides, which represent in total 96761 ha.

This is, on one side the result of the characteristic geological substrates, and on the other side the result of the land use which is significantly influenced by the anthropic activities. Under lithological aspect it is especially noticeable the

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presence of friable rocks like marls, clays, gritstone etc., as the result of sedimentation of eroded materials from the Carpathian Mountains, which delimitate the Transylvanian Basin (Sanders et al., 2002; Krezsek and Filipescu, 2005; Krezsek and Bally, 2006). We must mention that even if it is a depressionary space, it has the hilly aspect, which is the direct effect of fluvial modelling of the mentioned lithological formations.

The original forest's place, which had also a slope retaining role, was initially taken by the grasslands (they were used as a meadows), and afterwards, as mechanization took over agriculture, these were transformed mostly in arable lands. Given these land use changes and considering also the friable lithology, landslides did not take long to occur (Roşian et al., 2010).

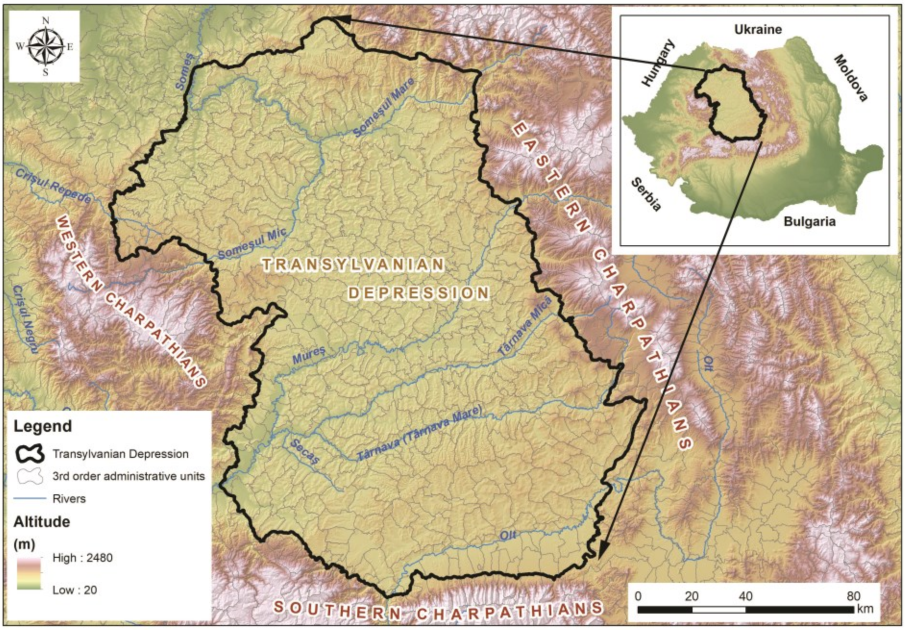

Fig. 1. Localization of the study area

Thus, the Transylvanian Depression landslides distribution statistical analysis proves to be extremely useful, given the fact that the causes and triggering factors of these geomorphic processes are still the same nowadays. Therefore, we present the current distribution of landslide as well as data about possible areas that in the future might be affected by such processes.

2. METHODS AND RESOURCES

A spatial analysis methodology was used in order to identify the landslide distribution within Transylvanian Depression based on five criteria (geology, altitude, slope, slope orientation and administrative units), taking into consideration also field Global Positioning System (GPS) observations (Roșian et al., 2016a).

Landslide identification was made using 1:5000 orthophotos, based on which, using a GIS software (ArcMap 10.2), landslides were vectorized using its Editor function. Also, field observations were made and where landslide delimitation was not possible by ortophotoplans, the GPS method was applied; the information from field observations were then downloaded and introduced into a GIS in order for them to be processed (Roșian et al., 2016b).

Subsequently, based on the classes of each criterion, (geological age, altitude intervals, slope values, orientation type etc.) the landslides were analyzed to identify their distribution and extension. For this purpose, we identified the areas exposed to landslides by using Esri's ArcGIS toolbox Spatial Analyst tools/Zonal/Tabulate Area tool which computes the areas for each class defined by the analysis, it uses the classes as defined zones and computes the area which is affected by the studied phenomena. We also analysed the number of slides in each class, this was accomplished by identifying the gravitational point of every vectorised landslide polygon, and this point was used to compute density (Roșian et al., 2016a).

3. RESULTS AND DISCUSSIONS

After vectorizations of landslides from orthophotos, the statistics say that in the Transylvanian Depression, there are 13157 landslides which represent 96761 ha. Given that the geographic unit surface is of 2465125 ha, it results that 3.92% of its surface is affected by landslides.

From a landslide distribution perspective, starting from the five criteria taken into consideration, we reached the following results.

From a geological point of view, Burdigalian (sandstones, clammy clays), Badenian (clays, marls), Sarmatian (marls, sands) and Pannonian deposits (clays, sands, poorly cemented sandstones) prevail along with the Quaternary deposits (Pleistocene and Holocene). As it results from Figure 2 and Table 1, landslides mostly affect the areas belonging to the Pannonian era.

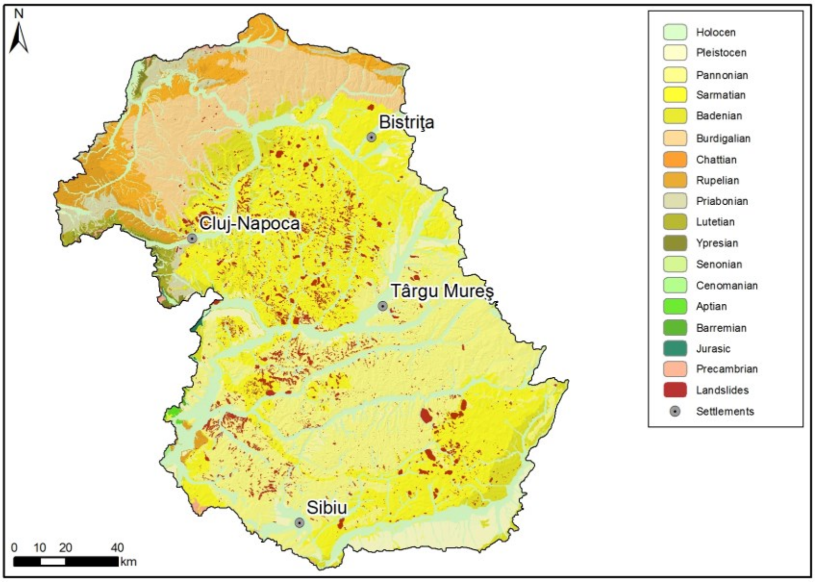

Fig. 2. Geological map

Table 1. Landslide distribution based on geological deposits

Geological deposits	Landslide no.	Landslide surface (ha)	Percentage (%)
Holocen	541	4228	4,2
Pleistocen	149	873	1
Pannonian	4169	32279	33
Sarmațian	6032	55174	57
Badenian	506	2602	2,6
Burdigalian	870	898	1
Chattian-Acvitanian	354	133	0,1
Rupelian	119	180	0,2
Priabonian	355	311	0,3
Luteţian-Bartonian	40	52	0,1
Ypresian	11	25	0,1
Senonian	0	0	0
Cenomanian	0	1	0,1
Apţian-Albian	1	2	0,1
Barremian	0	0	0
Jurasic	1	1	0,1
Precambrian	9	2	0,1
Total	13157	96761	100

In order to observe landslide distribution from an altitude perspective, six altitude classes were chosen: 166 - 300 m, 300 – 400 m, 400 – 500 m, 500 – 600 m, 600 - 700 şi 700 – 1175 m (Figure 3). As it results from Table 2, the majority of landslides belong to the altitude range 300 – 400 m and the largest surface is also specific to the 300 – 400 m range.

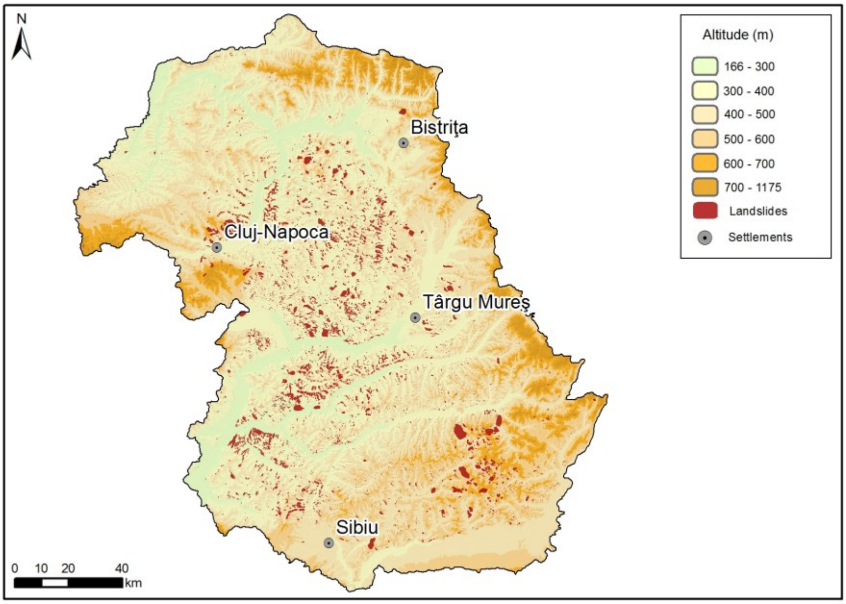

Fig. 3. The map of altitude range

Table 2. Landslide distribution based on altitude range

Altitude range (m)	Landslide number	Landslide surface (ha)	Percentage (%)
166 - 300	402	3751	4
300 - 400	6189	40058	41
400 – 500	4600	36624	38
500 – 600	1563	11568	12
600 – 700	358	2605	3
700 - 1175	45	2155	2
Total	13157	96761	100

Another indicator of landslide distribution is represented by slope. Starting from the previous field classifications depending on slope, for the Transylvanian Depression seven classes were chosen: 0 – 2^{o}, 2 – 5^{o}, 5 – 7^{o}, 7 – 12^{o}, 12 – 17^{o}, 17 –

22^o şi 22 – 49^o (Figure 4). As it can be noticed on Table 3, the majority of landslides belong to the 7^o – 12^o slope category and the largest surface is specific to the same range.

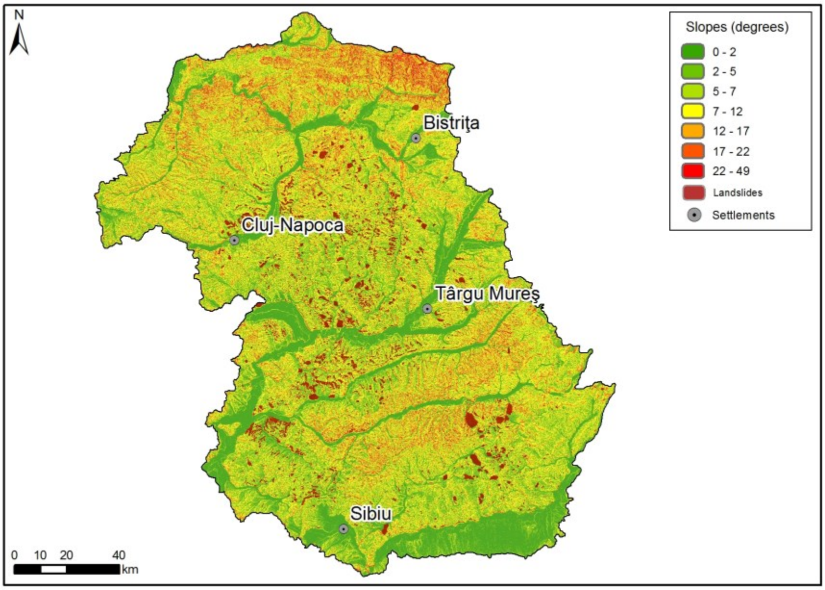

Fig. 4. Slope map

Table 3. Landslide distribution based on slope categories

Slope category (^{o})	Landslide number	Landslide surface (ha)	Percentage (%)
0 - 2	58	2237	2
2 - 5	635	16879	17
5 - 7	1209	17692	18
7 – 12	5503	42478	44
12 - 17	3967	14138	15
17 - 22	1421	2768	3
22 – 49	364	569	1
Total	13157	96761	100

An important criterion taken into consideration to observe landslide distribution is represented by slope orientation (Figure 5). The exposure to the sun energy decisively determines the heat condition, soil and humidity, it influences the freezing-melting processes, the type and nature of the superficial deposits on the slopes and leads to qualitative differences in the ongoing processes preceding erosion (Jakab, 1979). In Table 4, one can notice that the surfaces that have a southwest orientation are the mostly affected slopes by landslides. Also, from a surface perspective, the highest values are specific to western slopes. This means that on the southwest slopes are more landslides but they have smaller surfaces compared to those with a western exposure (less numerically, but have larger surfaces).

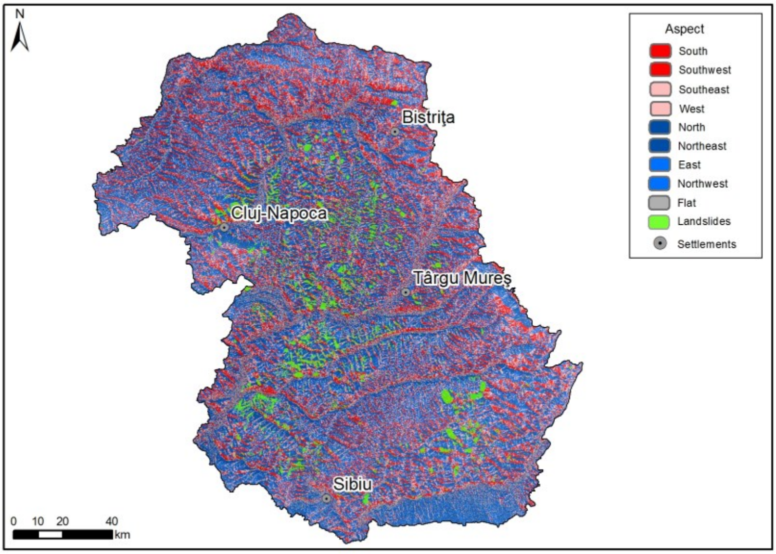

Fig. 5. Landform exposure map

Table 4. Landslide distribution based on exposure

Exposure towards to the sun	Exposure towards Compass directions	Landslide number	Landslide surfaces (ha)	Percentage (%)
Sunny	South	2420	15884	16
	South-West	3181	19086	20
Partial sunny	South-East	1413	11543	12
	West	2273	15829	16
Shady	North	957	8004	8
	North-East	644	6382	7
Partial shady	East	793	8243	9
	North-West	1476	11790	12
Flat (unexposed)		0	0	0
Total		**13157**	**96761**	**100**

In regards to landslide distribution we took into consideration also the local 3rd order administrative units, for the Transylvanian Depression. We considered this subdivision because al territorial planning and future interventions, with national or international budgets, are limited by the administrative hierarchy and so it represents a must in the present situation landslide and erosion analysis and statistics.

So, the following situation unfolded: there are 414 administrative units of which 346 are affected by landslides. The situation of the ten most affected administrative divisions from the landslide extent and number is shown in the tables 5 and 6.

Table 5. Landslide distribution at the administrative units level by affected areas

Name	Studied territory surface (ha)	Landslide surface (ha)	Percentage of the affected surface (%)	Number of landslide
Șona	10566	2673	25	112
Apold	12536	2648	21	47
Cluj-Napoca	17922	2542	14	85
Saschiz	9785	1853	19	45
Șoarș	17247	1767	10	124
Loamneș	9903	1351	14	104
Fărău	7984	1334	17	140
Blaj	9887	1304	13	86
Iacobeni	10326	1256	12	48
Jidvei	10495	1168	11	69

Tabelul 6. Administrative units landslide distribution by landslide number

Name	Studied territory surface (ha)	Number of landslide	Landslide surface (ha)	Percentage of the affected surface (%)
Chiuiești	11249	309	70	1
Vima Mică	6294	263	73	1
Ceanu Mare	9607	254	890	9
Moldovenești	10734	218	559	5
Jibert	16481	188	1107	8
Cojocna	13906	173	800	6
Unirea	9846	170	522	5
Sâncel	5171	166	354	7
Viișoara	5762	164	510	9
Alma	3423	163	111	3

The values showed in table 6 suggest that even if for some of the administrative units there are a high number of landslides, their surface is relatively small.

In regards to landslide type, in most of the cases, these are of a superficial and of medium depth according to Varnes classification (Varnes, 1978). Their large number is tightly bound, along with the land use, also to the geological characteristics. They are Miocene age formations that belong to Burdigalian, Badenian, Sarmatian and Pannonian ages. For Burdigalian sandstone and clammy clays are typical, for Badenian marls, for Sarmatian marly clays, sand and tuff and for Pannonian clays, sands and poorly cemented sandstones. These clays have in their composition montmorillonite, illite and beidellite minerals which can retain water. Taking into consideration that it is a hilly area made of the mentioned lithology, there is a highly susceptibility to landslides.

Hence, from the perspective of a spatial distribution analysis, the conclusions that can be drawn are, that the most affected by landslides are the areas overlapped with Sarmatian deposits, those on an altitude range of 300 - 400 m and those which have a slope between 7-12 degrees, but also those with a western orientation. At the administrative units' level, the most affected are: Şona, Fărău, Jidvei, Adămuş, Bichiş, Aţintiş, Gorneşti, Iernut, Târnăveni, Suplac etc.

4. CONCLUSIONS

When all the observed landslide triggering factors come together we need to take actions because the susceptibility to these type of phenomena within the area of the Transylvanian Depression are high. Considering also the susceptibility of the area to other type of hazardous geomorphologic phenomena, along with the combative measures, preventive measures are also necessary.

It is recommended, in this regard, the change of the used agricultural techniques, by preventing slopes hydric oversaturation and helping a quick drainage of precipitation, rivers or groundwaters.

Given the number of landslides and the areas affected by them, in the Transylvanian Depression, it is necessary to extend the research method to all the other regional units of Romania, trying to illicit information regarding all the factors affecting the landslide phenomena and to construct a general spatial GIS model for the area's susceptibility.

REFERENCES

1. Bilașco, Ș., Horvath, Cs., Roșian, Gh., Filip, S., Keller, I.E., (2011), *Statistical model using GIS for the assessment of landslide susceptibility. Case study: The Someş plateau*, Romanian Journal of Geography, Romanian Academy Publisher, Bucharest, pp 91-101.
2. Jakab, S.,(1979), *Slope asymmetry in the Târnava Mică and Niraj Hills*, Trav. Station „Stejarul", Seria Geologie-Geografie, Nr. 7, pp. 23-33. [in Romanian]
3. Krézsek, C., Filipescu, S.,(200)„ *Middleto late Miocene sequence stratigraphy of the Transylvanian Basin (Romania),* Tectonophysics, vol. 410 (1-4), pp. 437-463.
4. Krézsek, C., Bally, W.A.(2006), *The Transylvanian Basin (Romania) and its relation to the Carpathian fold and thrustbelt:* Insights in the gravitational salt tectonics, Marine and Petroleum Geology, vol. 23 (4), pp. 405-442.
5. Petrea, D., Bilașco, Ș., Roşca, S., Fodorean, I., Vescan, I.,(2014), *The determination of the Landslide occurrence probability by spatial analysis of the Land Morphometric characteristics (case study: the Transylvanian Plateau),* Carpath J Environ Sci, pp 91-110.
6. Roşian, G., Rusu, R., Tahâş, S.,(2010)„ *The Degree of Finishing of the Drainage Basins of the Transylvanian Depression,* Studia Universitatis Babeş-Bolyai, Cluj-Napoca, Seria Geographia, vol. 58, pp. 69-76.
7. Roşian, G., Horváth, Cs., Muntean, L., Mihăiescu, R., Arghiuş, V., Maloş, C., Baciu, N., Măcicășan, V., Mihăiescu, T. (2016a), *Analysing landslides spatial distribution Using GIS. Case study: Transylvanian Plain*, Proenvironment, Nr. 9, p. 366-372.
8. Roșian G., Horváth Cs.; Réti K.-O.; Boţan C.-N.; Gavrilă I. G.(2016b)*, Assessing landslide vulnerability using bivariate statistical analysis and the frequency ratio model. Case study: Transylvanian Plain (Romania),* Zeitschrift für Geomorphologie, NF Volume 60 Issue 4 (2016), p. 359 – 371.
9. Sanders, C., Huismans, R., Vanwees, J.D., Andriessen, P.,(2002), *The Neogene history of the Transylvanian basin in relation to its surrounding mountains,* European Geosciences Union, Stephan Mueller Special Publication Series, vol. 3, pp. 121-133.
10. Varnes, D.J (1978)*, Slope movement types and processes, In Landslides, Analysis and Control,* Special Report 176, Transportation Research Board, Washington, p. 11-33.