STUDIA UBB AMBIENTUM, LXIV, 1, 2019, pp. 69-79
(RECOMMENDED CITATION)
DOI:10.24193/subbambientum.2019.1.05

SPATIAL ANALYSIS OF LANDSLIDES USING GIS. CASE STUDY: TÂRNAVELOR PLATEAU

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ABSTRACT. Landslides represent one of the most important hazardous geomorphological phenomena in the Târnavelor Plateau. Geographically this unit is positioned on the southern part of the Transylvanian Depression. For the landslides distribution analysis, we used five criteria: geology, slope, altitude, exposition and the local administrative units. This type of studies is 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 geomorphological phenomena. By investigating the study area's ortophotoplans and topographic maps, 5797 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 to develop, it is believed that in the future landslides will appear on similar slope, orientation and geological conditions etc. In this situation, knowing the susceptible areas to landslides is beneficial for the territorial planning actions and also to avoid the building and expanding other civil engineering constructions on lands which are prone to landslides.

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

INTRODUCTION

One of the main hazardous geomorphological processes from the Târnavelor Plateau are represented by landslides. The Târnavelor Plateau is placed in the southern part of the Transylvanian Depression (figure 1) (Bilașco et al., 2011; Petrea et al., 2014). On its 780.916 ha surface there were identified 5797 landslides, which represent in total 47.930 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 presence of friable rocks like marls, clays, clay marl, gritstone etc., as the result of sedimentation of eroded materials from the Carpathian Mountains, which delimitate the Transylvanian Basin (Sanders et al., 2002; Krézsek and Filipescu, 2005; Krézsek 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 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 type geomorphological processes did not take long to occur (Roşian et al., 2010).

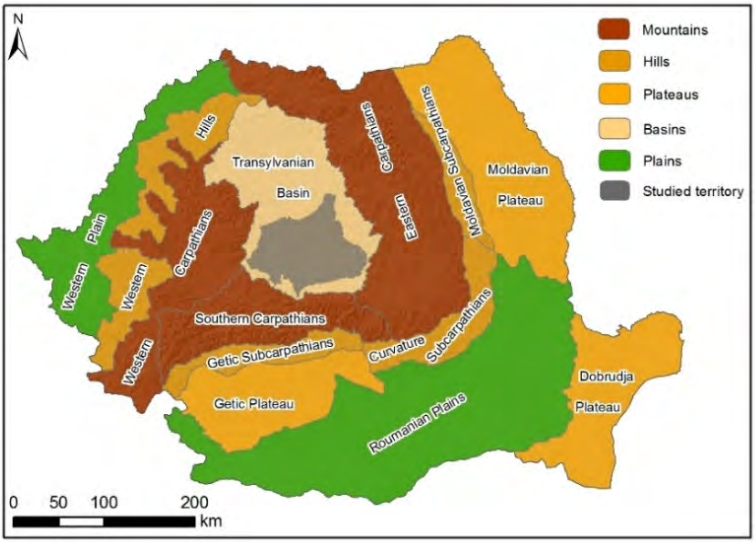

Fig. 1. Localization of the study area

Thus, the Târnavelor Plateau landslides distribution statistical analysis proves to be extremely useful, given the fact that the causes and triggering factors of these geomorphological 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.

METHODS AND RESOURCES

A spatial analysis methodology was used in order to identify the landslide distribution within Târnavelor Plateau 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 analyzed 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).

RESULTS AND DISCUSSIONS

After vectorizations of landslides from orthophotos, the statistics say that in the Târnavelor Plateau, there are 5.797 landslides which represent 47.930 ha. Given that the geographic unit surface is of 78.0916 ha, it results that 6,13% 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, Badenian (marls), Sarmatian (marl clay) and Pannonian deposits (clays) 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.

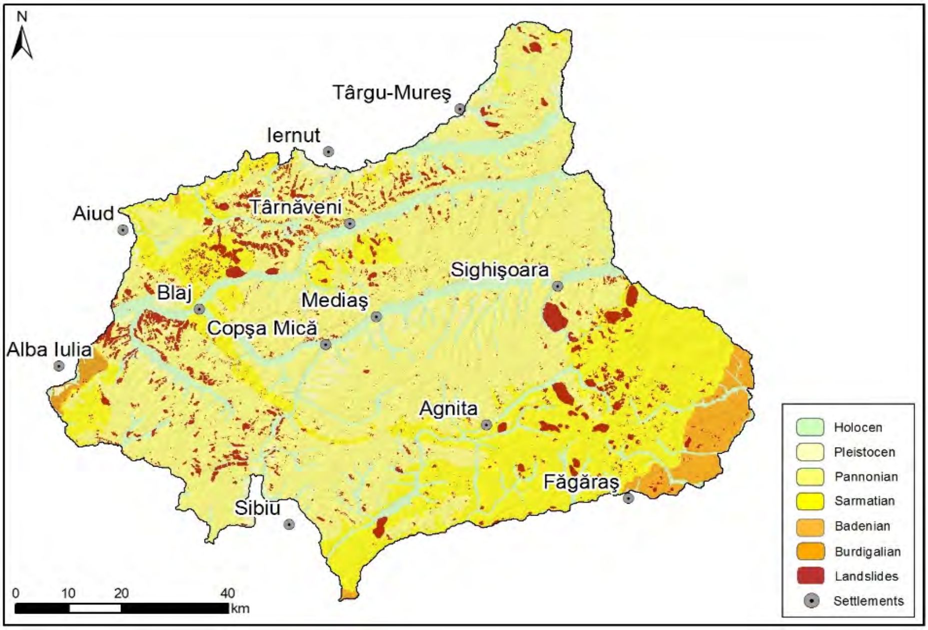

Fig. 2. Târnavelor Plateau Geological map

Table 1. Landslide distribution based on geological deposits

Geological deposits	Landslide number	Landslides area (ha)	Percentage (%)
Holocene	259	2228	6
Pleistocene	67	345	1
Pannonian	3765	29548	61
Sarmatian	1613	15110	30
Badenian	76	660	1
Burdigalian	17	39	1
Total	5797	47930	100

In order to observe landslide distribution from an altitude perspective, six altitude classes were chosen: 216 - 300 m, 300 – 400 m, 400 – 500 m, 500 – 600 m, 600 - 700 and 700 – 808 m (figure 3). As it results from table 2, the majority of landslides belong to the altitude range 400 – 500 m and the largest surface is also specific to the 400 – 500 m range.

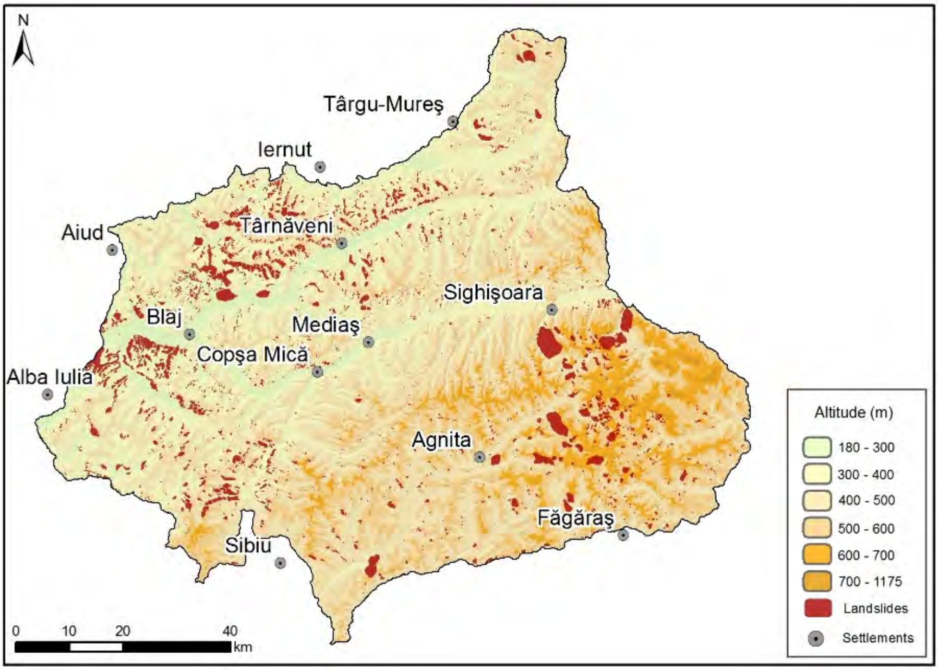

Fig. 3. The map of altitude range

Table 2. Landslide distribution based on altitude range

Altitude range (m)	Landslide number	Landslide surface (ha)	Percentage (%)
216 - 300	216	3070	6
300 - 400	2243	16493	34
400 – 500	2230	17593	37
500 – 600	973	9014	19
600 – 700	135	1760	4
700 - 808	0	0	0
Total	5797	47930	100

Another indicator of landslide distribution is represented by slope. Starting from the previous field classifications depending on slope, for the Târnavelor Plateau seven classes were chosen: 0 – 2°, 2 – 5°, 5 – 7°, 7 – 12°, 12 – 17°, 17 – 22° şi 22 – 45° (figure 4). As it can be noticed on table 3, the majority of landslides belong to the 7° – 12° slope category and the largest surface is specific to the same range.

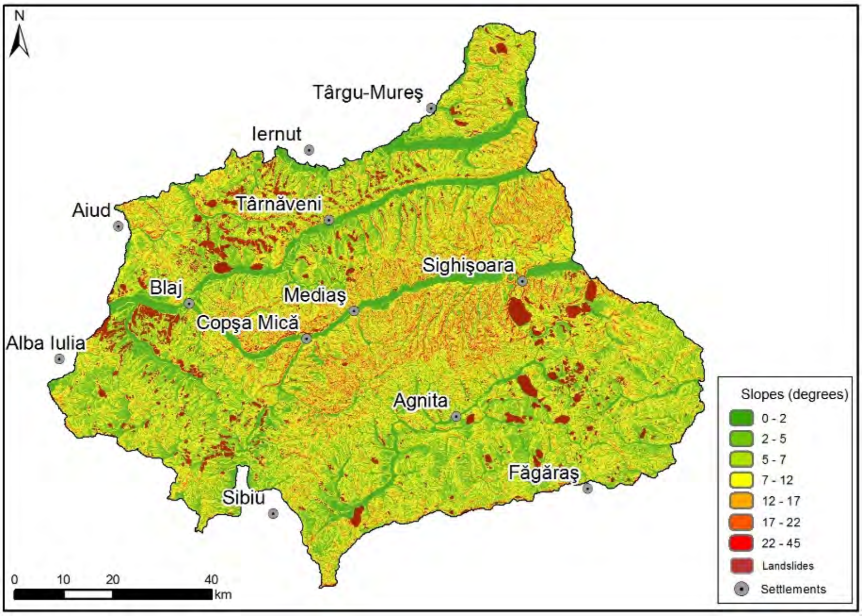

Fig. 4. Slope map

Table 3. Landslide distribution based on slope categories

Slope category (°)	**Landslide number**	**Landslide surface (ha)**	**Percentage (%)**
0 - 2	15	910	2
2 - 5	254	8,835	18
5 - 7	634	9,769	20
7 – 12	2,476	21,041	44
12 - 17	1,622	5,876	12
17 - 22	620	1,126	3
22 – 45	176	373	1
Total	5,797	47,930	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).

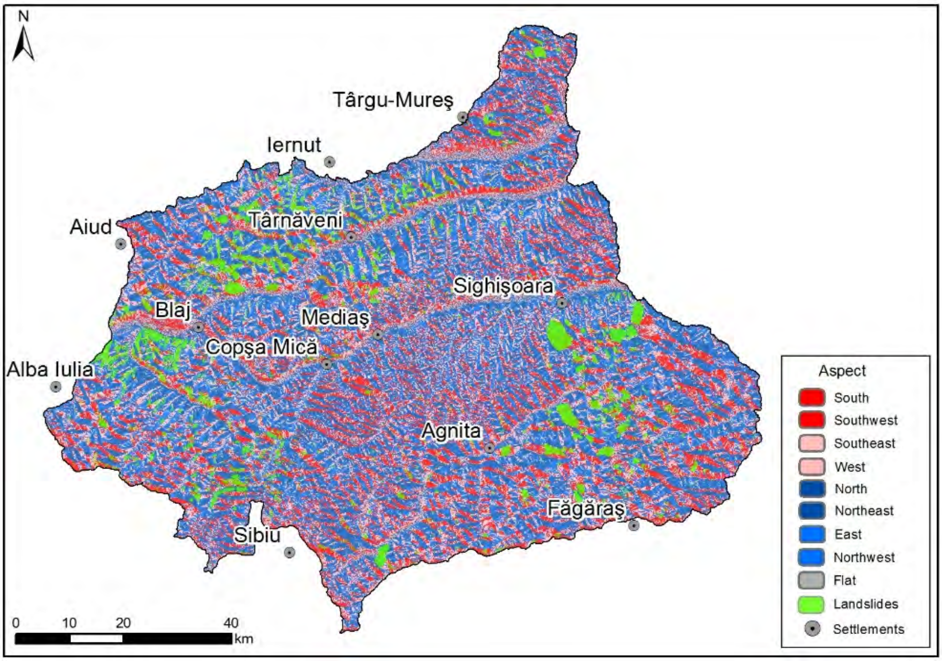

Fig. 5. Landform exposure map

In regards to landslide distribution we took into consideration also the local administrative units, for the Târnavelor Plateau. 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.

Table 4. Landslide distribution based on exposure

Exposure towards to the sun	Exposure towards compass directions	Landslide number	Landslide surface (ha)	Percentage (%)
Sunny	South	953	7,163	15
	South-West	1,243	8,837	18
Partial sunny	South-East	644	5,326	11
	West	1,103	9,380	21
Shady	North	396	3,720	8
	North-East	299	2,538	5
Partial shady	East	415	3,675	7
	North-West	744	7,291	15
Flat (unexposed)		0	0	0
Total		5,797	47,930	100

So, the following situation unfolded: there are 168 administrative units of which 149 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 local administrative units level by affected areas

Name	Studied territory surface (ha)	Landslide surface (ha)	Percentage of the affected surface (%)	Number of landslide
Şona	10,566	2,673	25	112
Apold	12,536	2,648	21	47
Saschiz	9,785	1,853	19	45
Şoarş	17,247	1,767	10	124
Loamneş	9,903	1,351	14	104
Fărău	7,984	1,334	17	140
Blaj	8,340	1,304	16	85
Iacobeni	10,326	1,256	12	48
Jidvei	10,495	1,168	11	69
Brădeni	8,156	1,150	14	60

Table 6. Local administrative units landslide distribution by landslide number

Name	Studied territory surface (ha)	Number of lanslide	Landslide surface (ha)	Percentage of the affected surface (%)
Jibert	16,481	188	1,107	8
Sâncel	5,171	166	354	7
Alma	3,423	163	111	3
Micăsasa	8,897	156	362	4
Fărău	7,984	140	1,334	17
Lopadea Nouă	9,226	133	396	4
Şoarş	17,247	124	1,767	10
Bîrghiş	9,986	114	206	2
Şona	10,566	112	2,673	25
Adămuş	8,115	112	1,119	14

The values showed in table 6 suggest that even if for some of the territorial-administrative divisions 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 Badenian, Sarmatian and Pannonian. For Badenian marls are typical, 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 mineral 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 Pannonian deposits, those on an altitude range of 400 - 500 m and those which have an angle of inclination of 7-12 degrees, but also those with a west orientation. At the administrative units level the most affected are: Șona, Apold, Saschiz, Șoarș, Loamneș, Fărău, Blaj, Iacobeni, Jidvei, Brădeni, Jibert, Sâncel, Alma, Micăsasa, Lopadea Nouă, Bîrghiș, Adămuș etc.

CONCLUSIONS

When all the observed landslide aggravation factors come together we need to take actions against landslides within the area of the Târnavelor Plateau. 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 technique, by preventing slopes hydric oversaturation with 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 subunits of Transylvania, trying to illicit information regarding all the factors affecting the landslide phenomena and to construct a general spatial GIS model for the areas susceptibility.

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