GEOGRAPHIC ANALYSIS OF THE LANDSLIDES OCCURRENCE USING ArcGIS

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ABSTRACT. Geographic analysis of the landslides occurrence, Satu Mare county, Romania, using ArcGIS. This multidisciplinary study is aimed at analyzing the natural and anthropic causes that favour the occurrence or reactivation of landslides, which have negative consequences (destruction/serious damages to houses, roads, power supply network, agricultural lands). The research was conducted by experts from the Institute of Geography of the Romanian Academy, Geoproiect Baia Mare. The case study is focused on the Bogdand commune area, located in Satu Mare County.

Key-words: landslides, geomorphology, slope map, surface draining, flowing potential.

1. Introduction

Located in the south-eastern extremity of Satu Mare County, Bogdand commune lies along the valleys of the Maja and the Cerna (tributaries of the Crasna), which flow through the Codru Hills. The Bogdand commune has four villages: Bogdand, Corund, Ser and Babţa (Fig. 1).

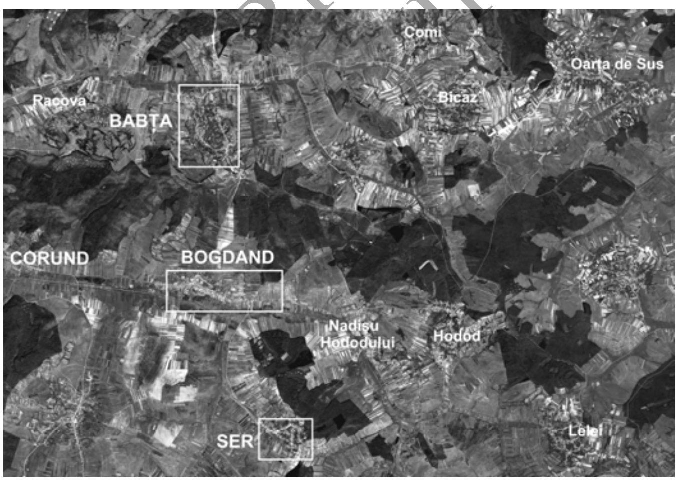


***Figure 1**. Commune Bogdand - The aerial view*

The territory of Bogdand commune lies in a geological subunit with hills that belongs to the northern Somes Platform, called by some authors "the marginal Salaj Platform", (Ciupitu et al., 2006). This is the lowest subunit of the northern Somes Platform (with altitudes of 150-320 m) and has the lowest relief energy (60 - 160 m). The relief in this region includes hills and is typical of the western peri-Carpathian Hills, (Driga, 2007).

2. Geology

On the surface, *Pontian* sedimentary deposits can be found with appreciable depth, and deep into the ground *Pannonian* sedimentary formations can be identified as well. The *Quaternary* deposits that cover them are quite deep in the depression passages of the main valleys. The *Pannonian* deposits were found in a number of drillings, but they also appear on the surface through the shore detrital facies made up of sandstones and sands. The *Pontian* layer includes alternations of clayish or sandy marls, marl clays, fine clays, clays and coaly sands. The *Quaternary* layer is represented by deluvial and alluvial deposits. The deluvial deposits grow deeper and deeper towards the bottom of the slope, being created through the erosion of the sand-clay-sandstone complex formations, with depths of 4 to 6 m. The alluvial deposits can be found along the main valleys and are made up of grayish-yellowish alluvial clays, sometimes sandy, with depths of 8 to 13 m at Babta and 12 m at Bogdand.

Actually the landslides on the territory of Bogdand commune occur and are favoured by the very specific features of the deluvial and alluvial deposits to be found here. Structurally we note the presence of a syncline with a deep fold northwards. The western side of this syncline borders a fault, with amplitudes of 30 to 50 m.

3. Geomorphology

The general aspect of the relief includes bevel, monoclinal hills covered by forests at the top, with altitudes of 250 to 300 m, this altitude increasing towards the south. The parallel peaks are fragmented by streams in sequences bordered by cuestas, which are tributary to the right side to the Maja şi Cerna streams, the main draining streams that flow into the Crasna. The valley of the Crasna is bordered by the following hills: Dl. Morii (301.5 m), Dl. Dumbrava (328.1 m), Dl. Făgetul Brusturilor (343.0 m), etc., whereas the valley of the Maja is bordered by Dl. Mare (284.0 m), Dl. cu Pădure, Dl. Capul Dealului (282.17 m), etc. The majority of the valleys, including the draining axes of the Crasna and Cerna are typical torrential valleys, being favoured by the lithological structure of the soil and by the fact that the slopes frequently exceed 15^0 and the relief energy is quite high (frequently over

75 m). The slopes, having various inclinations, have been affected by landslides, some stabilized, others reactivated, with various intensities and sizes.

4. Hydrology

The surface waters represented by the two main streams (the Cerna and the Maja) and their tributaries are highly torrential. The Maja has 28 km in length; its draining basin is 244 km^2, with an average altitude of 237 m. The Cerna springs from the southern slope of Culmea Codru, and flows from the east to the west; its length is 18 km and its draining basin 112 km^2, with an average altitude of 231 m.

Although the slope of the majority of the streams is steep, their peculiar lithology and the non-periodic variation of the rainfalls in the region confers them a highly torrential character. Due to the fact that the water flows down the slopes, a draining network was formed, tending to become permanent. The water table lies at the basis of the deluvial and alluvial deposits, which include small gravels and sands with medium and fine granulation, and at the top dusty sands to sandy clays. The depth of the water table ranges from 2 to 5 m. The permanent variation of this level, which sometimes lies very close to the topographic surface, makes the sedimentary deposits excessively wet (above their capacity of absorption) and consequently favours the occurrence of landslides.

The deep underground waters have three aquifer levels: the first, at +160 to +140 m, has a very low flow (4 m^3/day); the second, at +100 to +60 m, has a flow of 43-69 m^3/day; the third aquifer is situated at depths of +30 to +50 m and its flows are not homogenous throughout the territory (43-691 m^3/day).

5. Climate

On a background of a moderate temperate climate, Bogdand commune is also under the influence of western (oceanic) air masses, which are wet and generate moderate variations of the air temperature between winter and summer. The average annual temperature of the air ranges from 9-10ºC in the meadows of the Crasna and Cerna to 7-8ºC on the hill tops. In January the average temperature drops, depending on the altitude, from -2. -3ºC to < -6ºC. The most important dynamic factor in the occurrence of the landslides are the rainfalls. The main characteristic of the atmospheric precipitations is their high variation and discontinuity in both time and space. The average annual quantity in the analysed period (1968-2007) was 700.5 mm; the lowest annual quantity was 377.6 mm (2000), while the highest was 910.4 mm (2001).

The evolution of the monthly quantities range is between 94.6 mm in June, which is the rainiest month of the year, and 40.0 mm in February, the driest month.

The maximum rainfall quantity averages in a period of 24 hours (1968-2000) ranges between 29.4 mm in June and 10.6 mm in March.

6. Soil and Vegetation

The oak and beech forests grow in this massif only at the top of the hills, while the majority of the hill slopes are barren at the bottom, leaving room for pastures, hay fields and in some places orchards, vineyards and various crops. Predominant are the illuvial clay *podzolic soils*, pseudogleic or pseudogleised, luvosoils and albic stagnosoils (stagnic albic stagnosoils), with a low humus content; their physical and mechanical features are favourable to the temporary stagnation of the water from precipitations, to overmoisturing and finally to the occurrence of landslides.

7. Land use

The local natural geographic conditions influence the use of the land here. There are equal areas of arable lands and forests; the latter have been highly affected by human actions in the last years. Unfortunately many agricultural works are made down the slopes and generate the formation of streams. Besides the lots of land covered of vineyards and orchards, there are many pastries and hay fields. A special category includes the fields where shrubs grow; these fields are not suitable for farming, but they play an important role in stopping or preventing the occurrence of landslides. Within the village limits some dwelling houses and annex buildings (chiefly in Babţa village) were affected by landslides and had to be evacuated; also some sectors of the roads and of the electricity system have been damaged.

8. Methodology

The research conducted on the territory of Bogdand commune aimed at establishing the geographic premises that lead to the occurrence of slope processes, particularly landslides.

8.1. Field research

The field research phase, scheduled in a few stages, aimed at identifying, selecting and mapping the natural and man-generated processes that affect the stability of the land in the respective areas. The topographic studies were made with the Sokia Total station; drillings and samplings were made up to below the sliding bed.

8.2. Laboratory research

The objective of the laboratory analysis was to process both the bibliographic information and the field observations. Gauss projection maps 1:25,000 (geo-referenced), ortho-photoplans, geological and hydrogeological maps, topographic studies (AutoCad), drilling charts, and physical and mechanical tests were used for the drawing up of the themed mapping materials. The 3D model for Babta village was made based on the ARcView 3.2 software; the 1:500, 1:1,000 or 1:2,000 plans were made using modules ArcMap and ArcScene from the ArcGis 9.2 software.

For each of the studied areas were made up and analysed, at one of the mentioned scales, the following: the contour lines plan, with an equidistance of 0.5 m or 1 m (based on the topographic studies), the slopes map (in degrees), a map showing the direction of surface draining and a map indicating the surfaces with a high potential for water flowing.

9. Case study

Babţa is the village that is the most affected by the landslides on the territory of Bogdand commune. This village lies in the shape of long amphitheatre, oriented North – South, chiefly along the two interfluves starting from Făgetul Brusturilor hill (343 m), from which waters are drained towards the inside by the

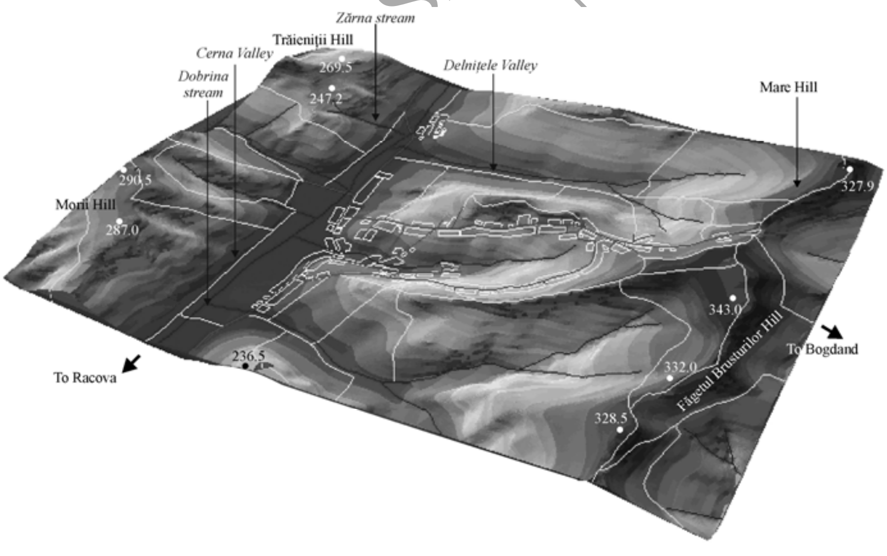


Figure 2. *3D model of Babţa village*

Boierului Stream, and towards the outside by the Delnițelor Stream and the Dobrina Stream, all these flowing into the Cerna Stream from the left (Fig. 2).

The large meadow of the Cerna, with altitudes of 170 m, excess humidity and barren beds, is the main axis of drainage (both surface and underground).

In the area of Babta village six regions were identified and studied, Tab. 1. They have particularly unfavourable consequences upon the inhabitants of the village and are caused chiefly by the landslides, Fig. 3.

Table 1. Regions of the Babta village

Area	Perimeter (m)	Surface (m^2)
Sector B1	1,094.49	39,592
Sector B2	324.16	6,395
Sector B3	910.46	31,035
Sector B5	1068.31	27,708
Sector B6	499.40	14,646

Sector B1 is located at the limit of the village on the road from Bogdand, a road that has been damaged by the landslides crossing it.

Sector B2 corresponds, together with Sector B3, to a vast landslide, partially reactivated, that in the past damaged many dwelling houses and agricultural lands. It is the sector with the highest landslide potential and risk.

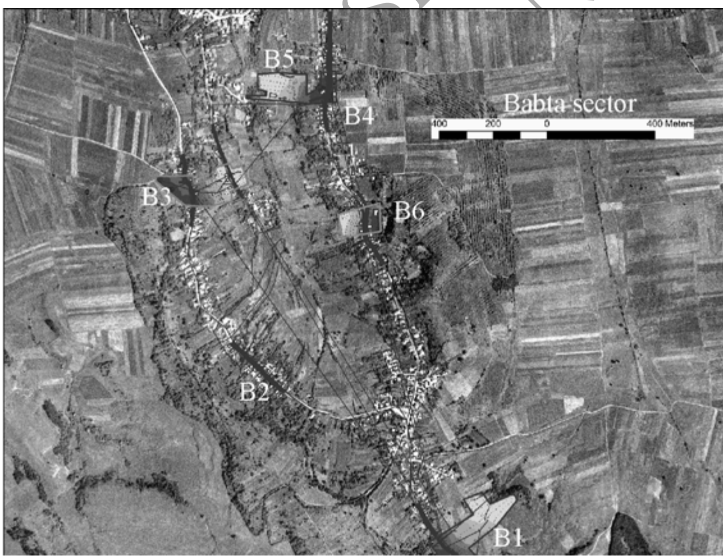


Figure 3*. Affected areas by landslides in Babța*

Sectors B4 and B5 correspond to the right slope of the Boierului Stream, including dwelling houses, the village church, streets, the electrical system, the telephone network and farming land.

Sector B6, situated on the same slope includes dwelling houses, streets, the power supply system, the telephone network and farming land.

9.1. Sector B1 analysis

Analysing sector B1 from Bogdand to Babta village, it can be noticed the road was affected by an old landslide, reactivated at the origin. The analysed surface (39,592 m^2) covers the biggest part of the slide. The level map reflects the gradual decrease of the altitudes from 287 m (the highest point of the slide) to 246 m (the bottom of the slide), Fig. 4. The almost continual fall is interrupted by a number of mounds rising above the general plan by 4 to 6 m, one of which is situated right on the road. The configuration of the level lines reveals small surface water draining axes.

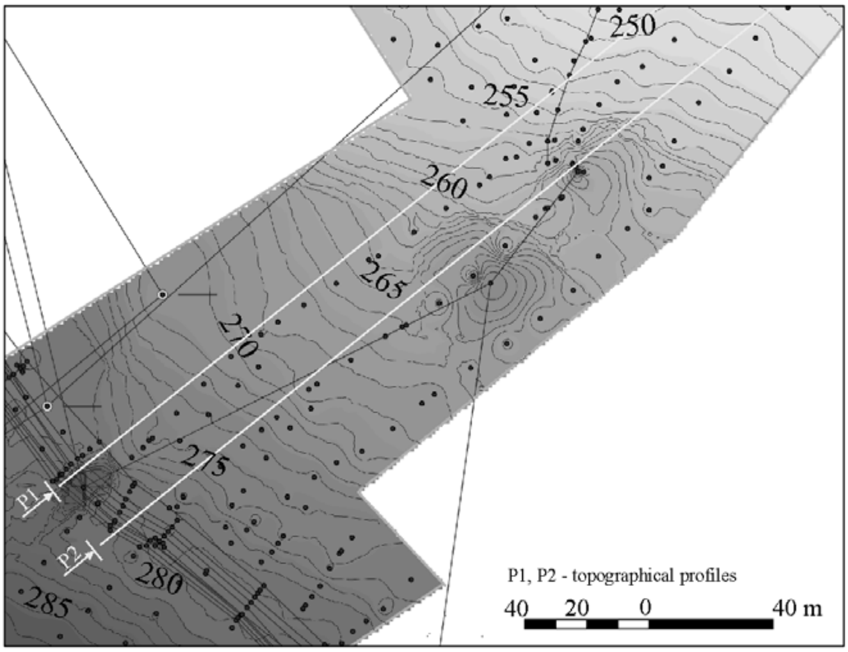


***Figure 4**. Level map of Sector B1 (P1, P2 – profiles)*

Profile P1, executed along the slide, reveals the existence of a number of sliding steps which, although they seem to be stabilized, stand in a fragile balance and are likely to reactivate in the future. For the first step the breaking ravines must be levelled; at the other steps, besides the execution of surface drains, all farming (arable) works must stop.

Profile P2, executed in the same conditions east of the first profile, includes drillings F1, F2 and F3; based on the data obtained from these drillings, the water table lies at a depth of 2.70 m, increasing slightly downhill. Based on the information obtained from the same drillings, it can be estimated that the slide bed lies at depths of 4 to 4.5 m.

The slope map includes the majority of the surface analysed from 0 to 17^0; steeper slopes, up to 60^0, are present around the mounds mentioned above, Fig. 5. The road is in the highest section of the interval 0-9^0, but uphill and downhill from it there are steps with slopes of 17-24^0, here and there 30^0, with excess moisture at their bases.

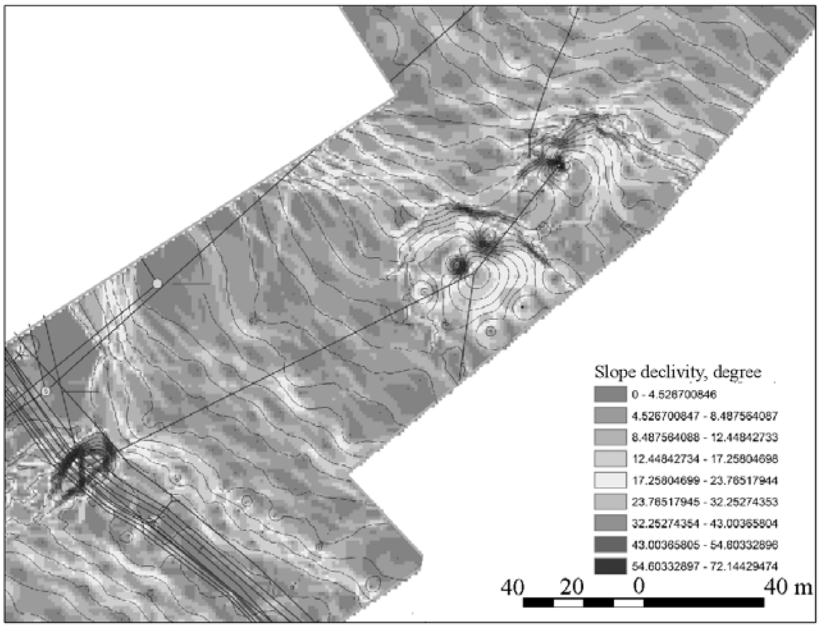


***Figure 5**. Slope map of Sector B1*

9.1.1. Directions of the natural surface draining

Using the hydrological module of the ArcGis 9.2 application, the authors determined the main natural draining directions, Fig. 6. It can be noted that the sliding step located uphill from the road generates, through the water that is discharged at its basis, potential flowing arteries which cross the road. Downhill from the road, the sliding steps supply quantities of water that tend to be drained chiefly towards the northern limit of the slide, generating at least two main axes.

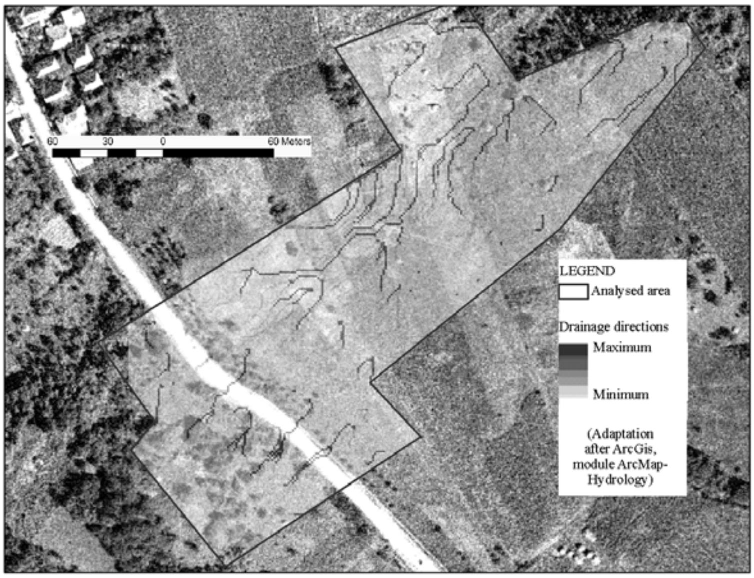


***Figure 6**. Drainage directions*

9.1.2. Areas with high flowing potential

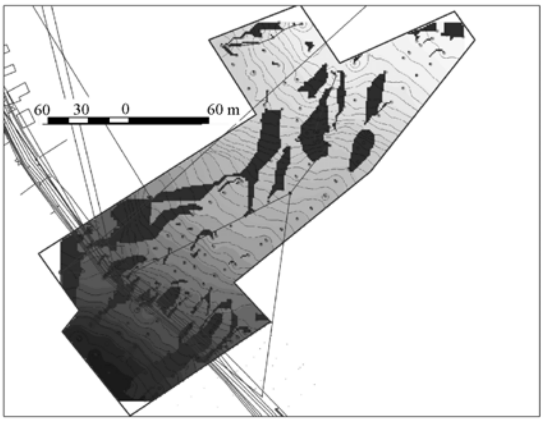


***Figure 7.** Water flowing potential, Sector 1*

Using the same module, as well as the level map, the slope map and the information about the rainfalls, the authors determined the main areas with a high water flowing potential, Fig. 7.

In the rainiest year of the last four decades (2001), the analysed surface received 36,036 m^3 water from rainfalls; in the rainiest month (June) the quantity was 3,762 m^3, whereas in an interval of 24 hours 1,148 m^3 rain fell over the same surface. Depending on the physical and mechanical properties of the aquifers' horizon down to the sliding bed, a part of these quantities of water could fill the aquifer up to its saturation level, and another part flow randomly on the surface.

It can be notice that the road was damaged by the surface water flowing generated by the sliding step uphill and also that there is an almost continual area with high draining potential along the central axis of the sliding.

9. 2. Sector B3 analysis

Sector B3 was the most seriously affected by landslides in Bogdand commune from the point of view of the size, the dynamics and destructive consequences of these landslides. This sector is situated also on the left slope of the valley called Valea Boierului and it includes a perimeter of 910,46 m with a surface of 31,035 m^2.

There are two roads on this sector, as well as farming land and dwelling houses and annexes. When the old slide was reactivated a number of houses were destroyed, others were badly damaged, together with the streets and the farming land, Fig. 8.

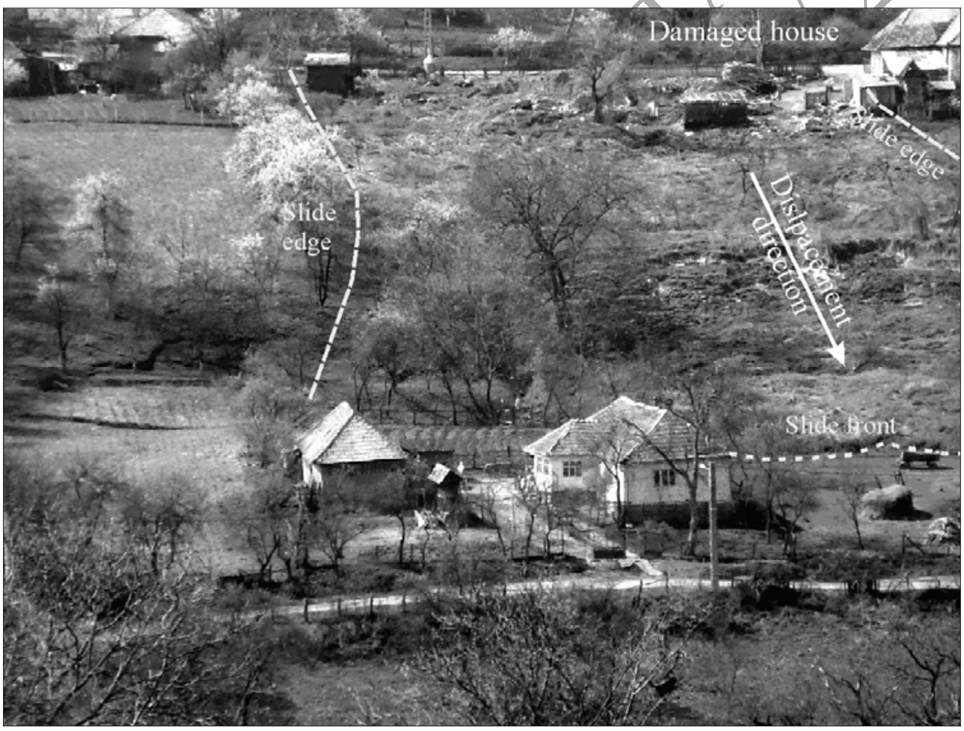


Figure 8. *Active landslide with destroyed dwelling houses and land*

The main road, the power supply system and the telephone network seen not to be yet affected by the landslide, but the surrounding houses and annexes were destroyed or can not be used anymore.

The main body of the slide, which is in some sectors well defined by lateral breaking planes, is highly instable and is broken in a succession of steps and overturned furrows with small temporary lakes and portions that are over moistened.

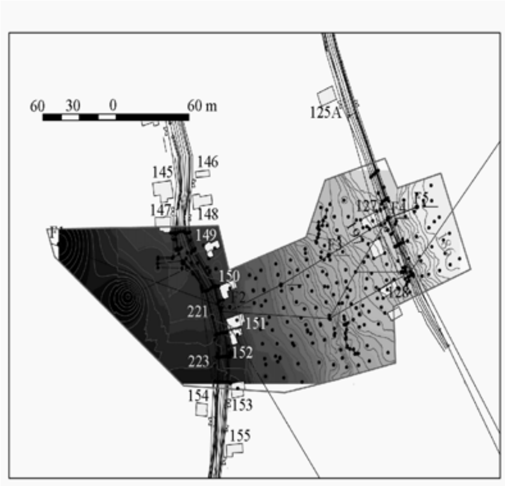


Figure 9. *Level map of sector b3*

The fronts of the sliding steps evolve rapidly, regressively, supplying permanently and destroying the cohesion of the slid material; the tendency of lateral expansion of the main slide by undermining the areas not yet affected is evident.

Without a rapid intervention the reactivated sliding sectors can merge and damage the entire left slope of Valea Boierului. The arable fields, the orchards, the houses and the annexes along the secondary road are endangered by the front of the slope; a series of houses and dependencies have already been destroyed. The distance between the altitudes ranges from 185 to 230 m; the configuration of the level lines indicates the main body of the reactivated landslide and a few sliding steps, Fig. 9.

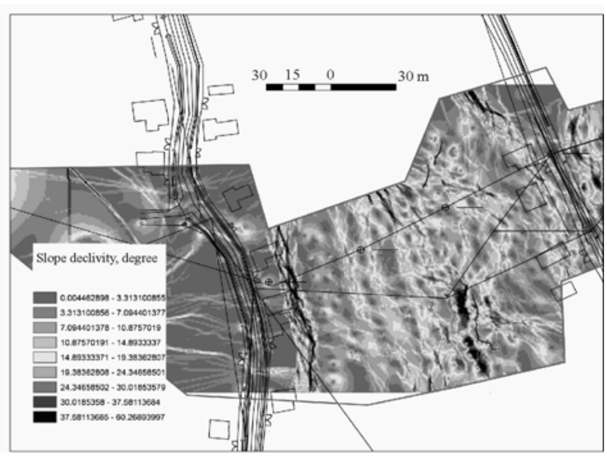


Figure 10*. Slope map of Sector B3*

The slope map shows, through differences and value distribution, the actual situation of the main body of the slide, Fig. 10.

Thus, whereas the main road and the dwelling houses and annexes situated on the right of the road lie on slopes of 0-7^0, in their close vicinity the first sliding step has slides of over 40^0; as a result of the rapid regression of the step, the dwelling houses were seriously damaged and were evacuated.

After the succession of the sliding steps, the terminal frontal part of the slide, which is swollen towards the direction of the maximum flowing speed, pushes hard the secondary road and the adjoining houses and annexes. It is unlikely that these will not be irremediably affected shortly. Longitudinal profiles were made along the body of the slide, and these reflect the existence of sliding steps.

9.2.1. Directions of the natural surface draining

Although they are short, the draining directions are changing permanently and damage both the roads and the buildings, Fig. 11.

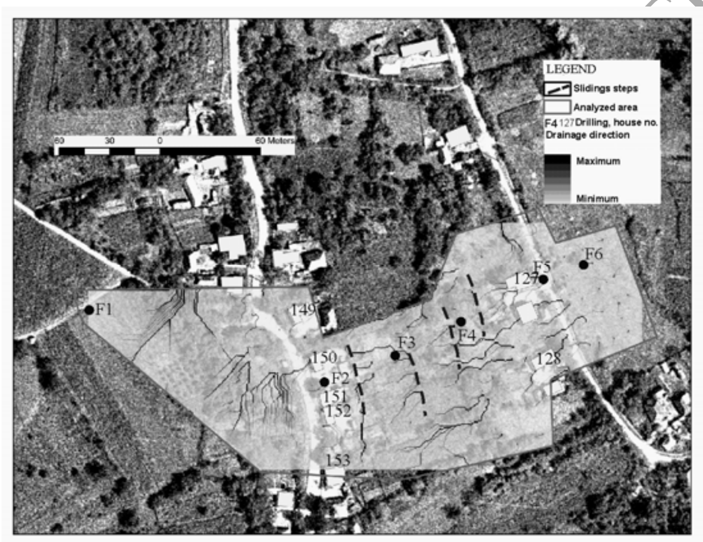
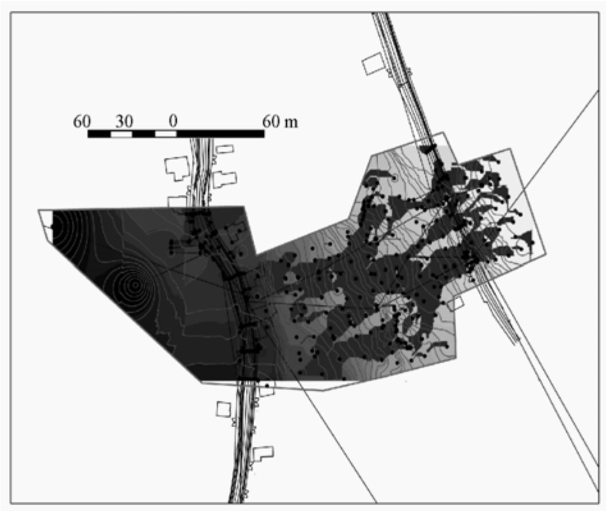


Figure 11. *Water flowing potential, Sector 3*

9.2.2. Areas with high flowing potential

Considering the facts shown above, the studied region is a potential water reservoir. While the main road, due to its milder slope, favours the collection of small quantities of water, the body of the main landslide temporarily collects and then releases, both underground and through the surface flowing, important quantities of water, Fig. 12.

The surface flowing is not regulated or permanent, and is originates especially from the water accumulated in the slid mass. Due to the high fragmentation of the sliding deposits, the biggest part of the water from rainfalls accumulates in this material. The maximum annual quantity of atmospheric precipitations received by sector B3 was 28,242 m3; in the rainiest day 2,950 m3 water were collected, and in 24 hours the maximum quantity recorded was 900 m3. Also to note is that the secondary road and the dwelling houses and annexes in its vicinity suffer, besides the physical pressure of the slide front, the almost continuous impact of the waters flowing from the mass of the slide front.



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The remediation of this situation is extremely difficult. Before attempting to stabilize the slide mass, an well devised system must be implemented in order to drain the excess water from the sliding mass (along the entire left slope of the valley there is one single drainage, that is old and has not been properly maintained). At the same time the main slide and the neighbouring areas must be monitored geomorphologically.

10. Conclusions

The investigations and research study results of the natural and anthropic causes that favour the occurrence or reactivation of landslides, which have negative consequences on the Bogdand village area are presented in this paper. The interest of the local authorities is to have a real image of the area in order to elaborate the territorially improvement plans against the sliding risk of the landslides.

The data base was developed based on the surveying, geomorphological mapping, physical and mechanical analysis of the boring-samples, geo-electrical profiles and hydro-metheorological information. Specialised tools were used for data processing, as statistical analysis, several ArcView and ArcGIS 9.2 modulus.

The most important results of the landslide risk analysis of Bogdand village area are: the land model (generated with ArcMap, 3D Analyst and ArcScene software applications), slope maps and water drainage preferential direction maps. Their interpretation represented the data base for further planning actions in Bogdana village.

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