Some aspects of making landslide hazard map in Romania

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Abstract:- This article aims to a comparative study on the implementation of landslides hazard maps In this regard, base layers of spatial data such as topography, land cover, geology and soil were considered. Factors influencing landslides were extracted from existing data for the area under consideration, supplemented by the field investigations of landslides. Landslide susceptibility indices were computed using the current methodology under the laws of Romania on the implementation of landslides hazard maps and using LSI - Landslide Susceptibility Index, used in different international projects and papers.

Keywords: Landslide susceptibility, hazard map, analysis of landslide potential.

1. Introduction

Landslides are complex phenomena involving the movement of earth masses located in slope due to their moisture, under the action of gravitational forces. Landslides complexity is given by the multiplicity of causes that can cause the conduct of the process, the nature of the affected layers and their development in time and space.

The causes of landslides are a consequence of long-term actions caused by external factors, which may be natural or anthropogenic. The landslide often occurs due to aggregation effects on the mass of the earth. Meteorological climatic factors are represented by precipitation, temperature, freeze-thaw phenomenon, the wind, etc.. Rainfall phenomena play a role in the onset and evolution of landslides.

The assumption that is generally made in identifying landslide hazard susceptibility regions is that occurrence of landslides follows past history in the region depending on geological, geomorphologic, hydro geological and climatic conditions.

Landslides are divided into: active landslides, stabilizes landslides and inactive landslides. Active landslides are phenomena that are currently running trigger due to a primary landslide, while reactivated landslides are triggered after periods of stability. Landslides are considered stabilized, although they slipped once, they found a temporary equilibrium. The inactive landslides are considered those that are older than one year, although time is questionable.

Therefore, the development stages of landslides are ([1], [3]):

The pre-sliding - refers to the case where the massive is still strengthened and intact. In this case, displacements grows progressively and shear strength is mobilized at values lower than peak.

In the second development stage, called landslide stage itself, the stage of the slide itself, the deformation increase and surface discontinuity develops in turn. This phenomenon is controlled by peak shear strength parameters in the area where the surface of the discontinuity is progressively developed.

Further, the next step is to include the post-landslide movements of large masses of earth or rock whose balance has changed as a result of slipping. The last stage is the stage of reactivation, the masses of earth or rock slides along some preexisting failure surfaces, occasionally or continuously, the phenomenon is controlled only by the parameters of the residual shear strength.

The classification in one of the stages listed above, however, is difficult because of the lack of clear indications. It involves the following steps ([2], [4]):

1. *Identify and research potential of landslides areas*

This is done by various methods such as drilling, mining, geological mapping. All methods aim delimitation of the mass of slippery rocks, determining the physic-mechanical and hydro

Within acceptable limits, steady state of a slope can be evaluated by estimating the stability factor Fs, whose physical significance factor is the ratio of

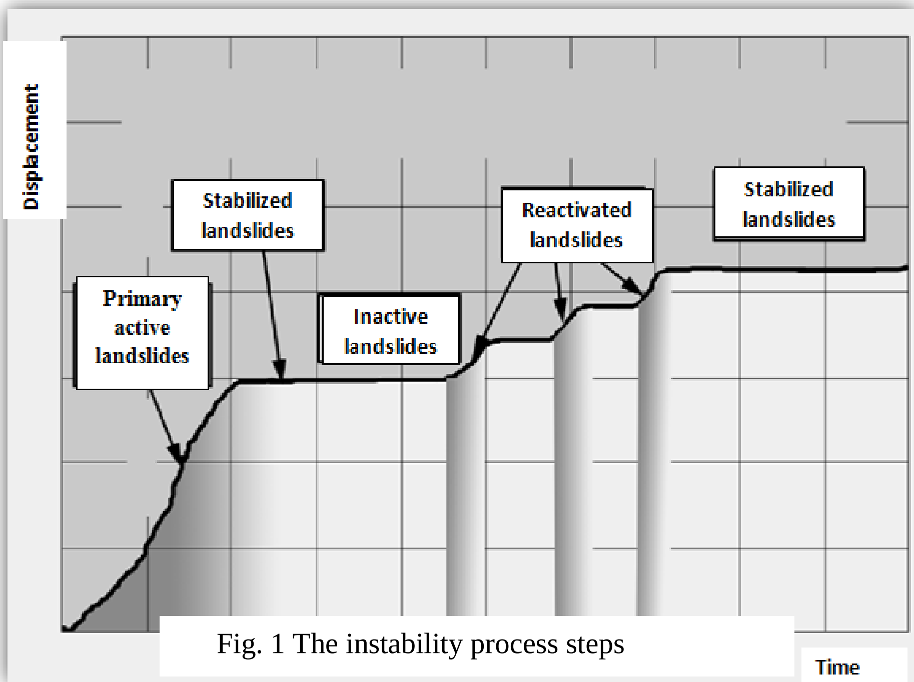

Fig. 1 The instability process steps

geological characteristics. It is very important to know these factors to help predict the evolution of land sliding.

2. *Identify potential landslides areas.*

The remedy for an already produced landslide is an action to recover only affected land, it is very important to identify and direct correlation with how operates the shear strength on the primary landslide. The pre-landslide, first landslide and landslide reactivation are specific to cliff instability, rotational and translational landslides and landslides with side extension. The rotational and translational landslides are most common in Romania.

2. Making of landslide hazard maps

Synonymous with landslide instability map or the potential for landslides, landslide hazard map is a location plan at an appropriate chosen scale, corresponding to an area of land, divided into polygons, characterized by the same degree of instability at sliding. Landslide hazard maps are determined based on consideration of the interaction of several factors which, by their joint action can influence steady state slopes.

the shear strength of rock in the most probable slip surfaces (τ_f) and shear forces acting on the same level (τ):

$$F_S = \frac{\tau_f}{\tau} \qquad (1)$$

The stability factor can vary between the critical value (Fs = 1), the minimum value which marks the stable balance limit and high value, theoretically infinite (Fs = ∞), situations in which the slope is stable.

The formula used in drawing up the hazard map is:

$$K_m = \frac{1}{F_S} \qquad (2)$$

Physical significance of Km factor is a measure of the degree of instability at sliding, or, within acceptable limits, the measure of landslide potential.

This relationship has been adopted in order to limit the variation of the sliding instability Km in the range between 0 and 1.

In relation (2) we can see that at the limit equilibrium of slope when Fs = 1, the sliding instability factor is Km = 1 or, expressed as a percentage, the sliding instability is 100%. For larger values of factor Fs, the level of slip

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instability decreases and becomes zero when the stability factor is theoretically very high.

In order to describe the possibility of producing landslides have to be taken into account as many as possible natural and anthropogenic factors, which act independently or simultaneously on the steady state of slopes [5].

The methodology used to produce landslide hazard maps under the laws of Romania is based on the evaluation of the probability of landslide considering the eight factors of influence: a) – lithology; b) – geomorphologic; c) - structure; d) - hydrological and climatic; e) – hydro geological; f) – seismic; g) – forestry; h) - anthropogenic.

The influence of each factor on the equilibrium state of the slope is expressed as a coefficient Ki (i = a ... h), whose value ranges between 0 and 1. The considered influencing factors do not act with the same intensity on the stability of slopes. Of these, two are seen as having a key role: lithological factor Ka and Kb geomorphologic factor, the other six factors having a secondary influence.

To calculate the degree of the sliding instability the empirical formula was adopted:

$$K_m = \sqrt{\frac{K_a \cdot K_b \left(K_c + K_d + K_e + K_f + K_g + K_h\right)}{6}}$$

or

$$K_m = 0{,}408\sqrt{K_a \cdot K_b \sum_{i=c}^{h} K_i} \qquad (3)$$

Evaluation of coefficients Ka ... Kh, corresponding to the eight factors influencing slope stability, is based on analysis of existing documentation and information materials are obtained through field recognition. More accurate assessment of these factors is essential to the quality of the hazard map.

The calculation formula can be applied to large areas on condition that they are divided into squares. The formula allows the integration of data into a GIS. Instability factor Km is a form of estimating the potential for landslide, whose values are not the result of a mathematical calculation based on probabilistic statistical processing of data, but based on qualitative analysis and interpretation of the action of natural and anthropogenic factors influencing state equilibrium slopes. The accuracy and reliability of values assignable influence coefficients Ka ... Kh, are dependent on the level of training and experience of specialists that prepare such mapping documentation.

For making of landslide hazard maps do not take into account the geological work carried out for this purpose, but using all the existing geological, geotechnical, geomorphologic, hydro geological data etc., only performing geological recognition on the ground. Geotechnical investigations by field and laboratory work will be conducted only in areas with high instability to assess the risk associated with landslides that could trigger and affect important economic and social areas.

The second methodology considered in this article is used in various international projects and articles ([1], [2], [3], [4]).

In this case, to obtain a landslide hazard map, an index was calculated taking into account six factors that control the landslides. These six factors are: lithology, slope of terrain, topography of the area, land use, precipitation and seismicity.

It was assumed that each factor has a different impact on the landslide probability in the table below:

Factor	Code	Influence (%)
Lithology	F_1	35
Slope of terrain	F_2	25
Precipitation	F_3	15
Land use	F_4	10
Seismicity	F_5	10
Local relief	F_6	5

Table 1. The influence of different factors

Landslide Susceptibility Index (LSI) was calculated using the following formula:

LSI = (F1 • 35 + F2 • 25 + F3 • 15 + F4 • 10 + F5 • 10 + F6 • 5) / 100

It is assumed that there is no landslide in the area where the slope factor is less than 2°. LSI factor in these areas should be 0, regardless of the local relief, the seismicity and rainfall.

3. The case study

The case study was carried out for an area in the northern part of Romania, known in particular due to the presence of layers of coal, which is located on the Moldavian Platform.

Geological map of the study area was obtained from maps prepared by the Romanian Institute of Geology, during 1968 - 1970.

The study area is located in the Siret hydrographic Basin, Moldova river, cadastral code XII.1.40 XII. Surface water network has a branched, consisting of streams (Moişa, Săcuţa, Mihăileasa, Ploştina streams) which flows into the Moldova river.

From a climate perspective, the study area falls within an area with temperate - continental and Baltic influences. Average yearly temperature (50 years) is around 8.1 ° C. Historical minimum temperature was -26.40 ° C on 28 December 1996 and a maximum of 36.70 ° C on 22 August 2000.

Rainfall in the study area are directly proportional to temperature, the origin of air masses and their dynamics, orography and geographical location, due to moderate persistent continental east air masses, but rainfalls shall be recorded and producing flood.

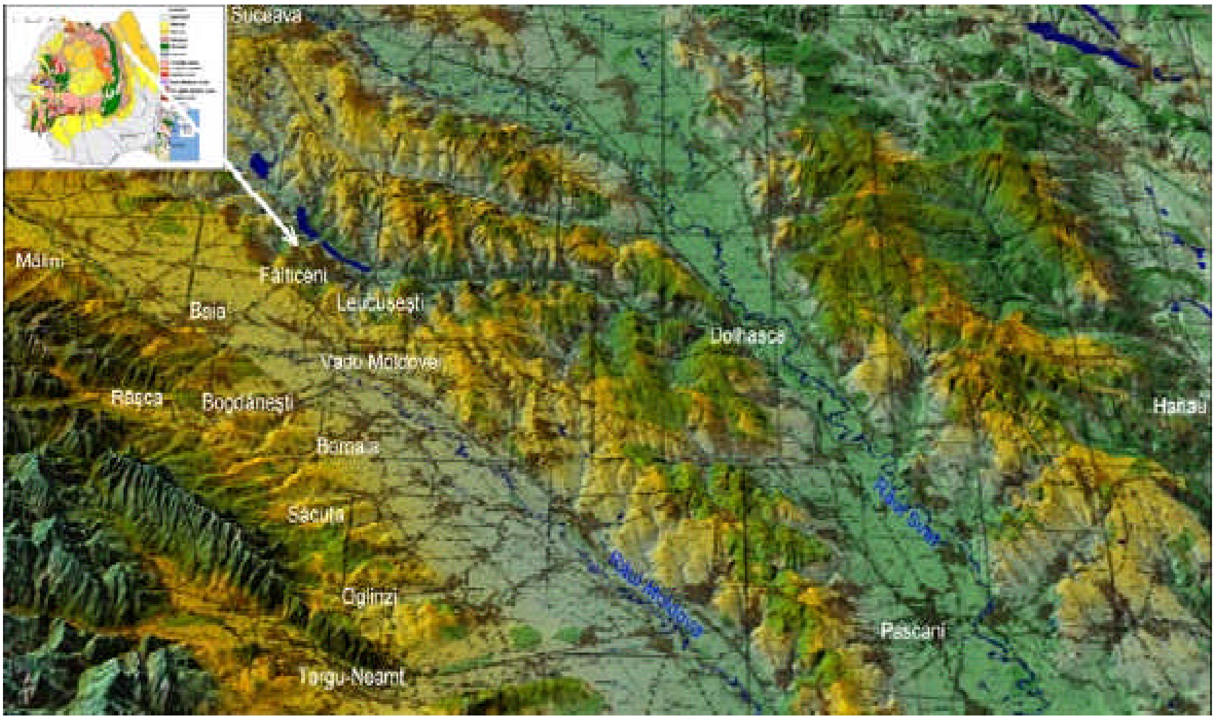

Fig. 2. The relief in the study area (Boroaia,

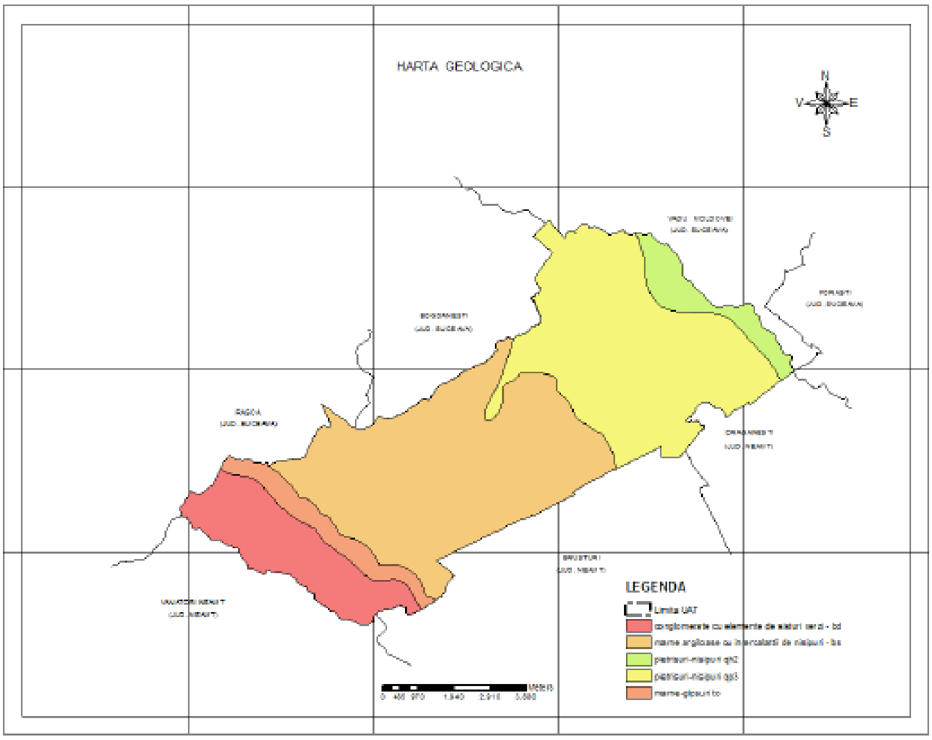

Fig. 3. The geological map in the study area

The average annual rainfall is 621 mm and the thickness of the snow has annual average of 7.8 cm.

In present, in Romania, seismic hazard for a given area or site is established under seismic zoning

In present, in Romania, seismic hazard for a given area or site is established under seismic zoning map, adapted from SR 11100/1-1993 standard, which was conducted by adapting to international regulations in force. According to the classification in the studied area, the seismic representation identifies two areas of seismic intensity of 6 or 7.1 MSK scale.

Due to favourable climatic conditions, spontaneous vegetation cover was replaced mostly by crops (potato, wheat, corn), some of them underlie the development of the livestock sector.

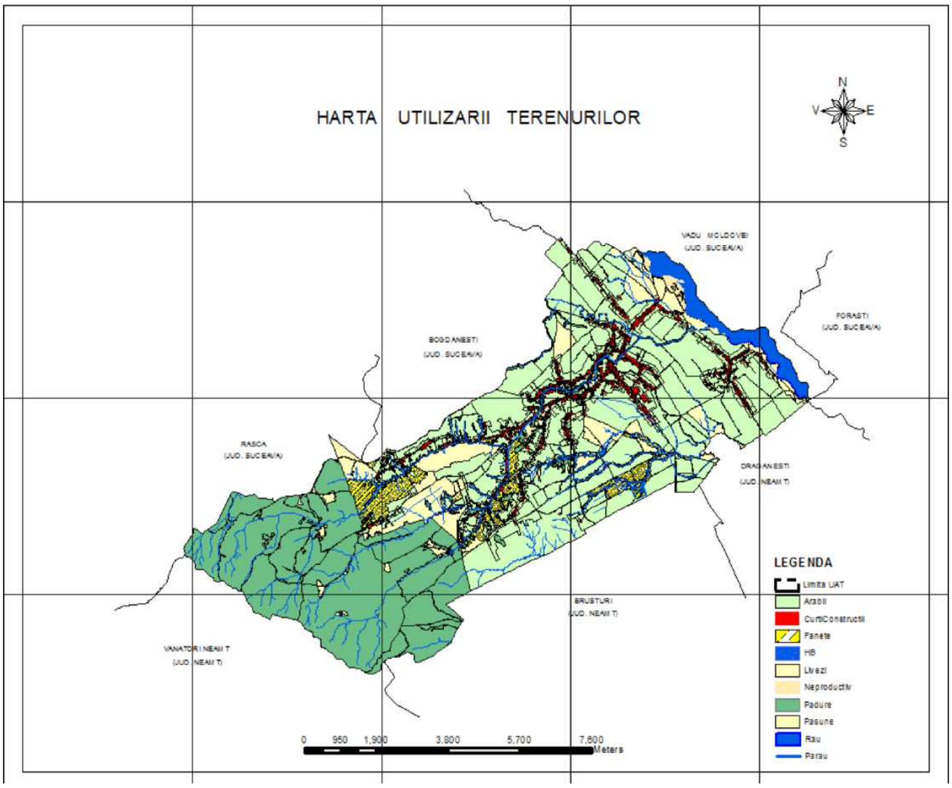

Fig. 4. Map of land use in the study area.

The study area includes Boroaia commune with six other villages. The population density is 65 inhabitants per km^2, the population density is 18.5 inhabitants lower than the county average.

Being among medium municipalities, Boroaia has a population of about 5500 people. In terms of structure, Boroaia villages are scattered and took place along the valleys and roads, and in terms of form are linear villages.

The study area is characterized in terms of flora in a particular variety of species, due to the layout of the village in the vegetation change from forest to meadow. Woody vegetation consists mostly of hardwood (beech, hornbeam, oak, maple) but we also encounter Whitewood (fir, spruce).

1. Analysis of landslide potential.

Watching the two methodologies proposed for the case study were calculated two values of the average coefficient of influence: the instability factor Km and Landslide Susceptibility Index (LSI). The study area was divided into five specific areas, the values of each factor was calculated for each area of study.

Landslide Susceptibility Index (LSI) was determined taking into account six parameters: lithology, slope, rainfall, land use, seismicity and local relief. It was assumed that each parameter is assigned a different weight in the calculation of landslide potential.

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Nr. Crt	Area	Lanslide potential (p)	Litho logy	Slope	Rainfall	Land use	Seismicity	Local relief	LSI
			F1	F2	F3	F4	F5	F6	LSI
1	Zone I	low	0.5	0.1	0.7	0.1	0.3	0.1	0.35
2	Zone II	low	0.5	0.1	0.7	0.2	0.3	0.1	0.36
3	Zone III	medium	0.6	0.3	0.7	0.2	0.3	0.2	0.45
4	Zone IV	high	0.8	0.4	0.7	0.3	0.3	0.3	0.56
5	Zone V	medium	0.7	0.2	0.7	0.2	0.3	0.2	0.46

Table 2. Landslide Susceptibility Index (LSI) calculation

Five areas with different landslide potential were revealed: low potential, medium potential and high potential.

Calculation of the average coefficient Km, as required by law in Romania, considered the eight parameters: lithology, geomorphological, structural, hydrologic-climatic, hydrological, seismic, forestry and anthropogenic.

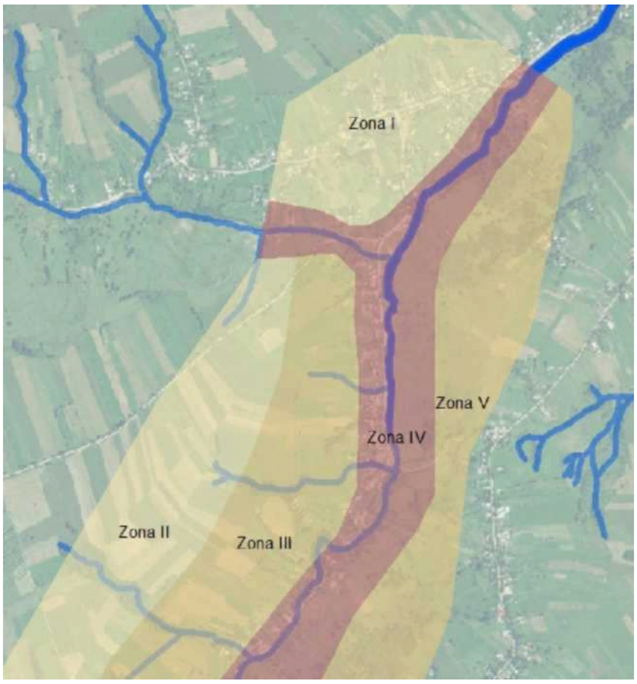

Fig. 5. Representation of landslide potential areas

Fig. 6. Images of land affected by landslide

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Nr. Crt	Area	Landslide potential (p)	Coefficients								
			Litho-logy	Geo-morfological	Struc-tural	Hidrologic climatic	Hydro-geologic	Seis-mic	Forestry	Anthro-pogenic.	Average coefficient
			Ka	Kb	Kc	Kd	Ke	Kf	Kg	Kh	Km
1	Zone I	low	0.5	0.4	0.5	0.7	0.6	0.3	0.5	0.4	0.32
2	Zone II	low	0.5	0.5	0.6	0.7	0.6	0.3	0.3	0.2	0.34
3	Zone III	medium	0.6	0.6	0.5	0.7	0.8	0.3	0.5	0.3	0.43
4	Zone IV	high	0.8	0.6	0.6	0.7	1	0.3	0.4	0.8	0.55
5	Zone V	medium	0.7	0.5	0.5	0.7	0.8	0.3	0.5	0.5	0.44

Table 3. Calculation of average coefficient Km accordance with the law in Romania

Nr. Crt	Area	Landslide potential (p)	Land Ssusceptiblity Index	Average coefficient
			LSI	**Km**
1	Zone I	low	**0.35**	**0.32**
2	Zone II	low	**0.36**	**0.34**
3	Zone III	medium	**0.45**	**0.43**
4	Zone IV	high	**0.56**	**0.55**
5	Zone V	medium	**0.46**	**0.44**

Table 4. Comparison of average coefficients of landslide susceptibility

A comparative analysis is shown in Table 4, where for each area under study is observed that the values calculated for the two landslides susceptibility indexes are close.

1. Conclusions

Preparations of landslide hazard maps under the two methodologies presented are similar in terms of results, but also in terms of factors used to calculate the potential occurrence of landslides. The factors with the greatest influence are lithology and topography (slope, geomorphology)

Making landslide hazard maps requires the development of interdisciplinary studies. Integrating these studies in a hazard map is achieving by using them in a GIS. ([6], [7], [8]).

In the methodology used in international projects and articles, the number of parameters to be introduced in the calculation is lower, it is easier to implement, and the study conducted in this article indicates that the final results produced by the two methodologies are similar.

How these data will be implemented locally to achieve hazard maps is up to local authorities and the number of specialists available that integrate all this data.

Hazard landslide map can be an important documentation of Local Government to inform the public about the expansion of dwellings in areas affected by possible landslides, to consolidate operations and embankment of slopes, to adopt escape strategies of and to help the people affected by these phenomena.

Upon completion of landslide hazard map can be proposed following preventive measures ([9], [10], [11], [12]):

- Restrict uncontrolled deforestation in areas with high landslide hazard land;
- A forestation water species rooted deep in the soil (willow, locust) both drinking water and erosion protection of deforestation slopes;
- Avoid overloading of slopes by any kind of building in perimeters classified as having high probability of landslide occurrence.
- Establish a monitoring system for landslides to updating forecasting and warning systems in areas with high risk of landslides and execution sewers waters from precipitation;
- Execution of cleaning and maintenance of drainage collection systems;
- Avoiding pollution with products that can lead to soil degradation;
- Making plans in case of disaster;
- Train population on the possible occurrence of landslides in the area.

The practical importance of these cartographic products is recognized for all users. A landslide susceptibility map would be useful for the Government and other development agencies to implement appropriate mitigation measures to reduce hazards.

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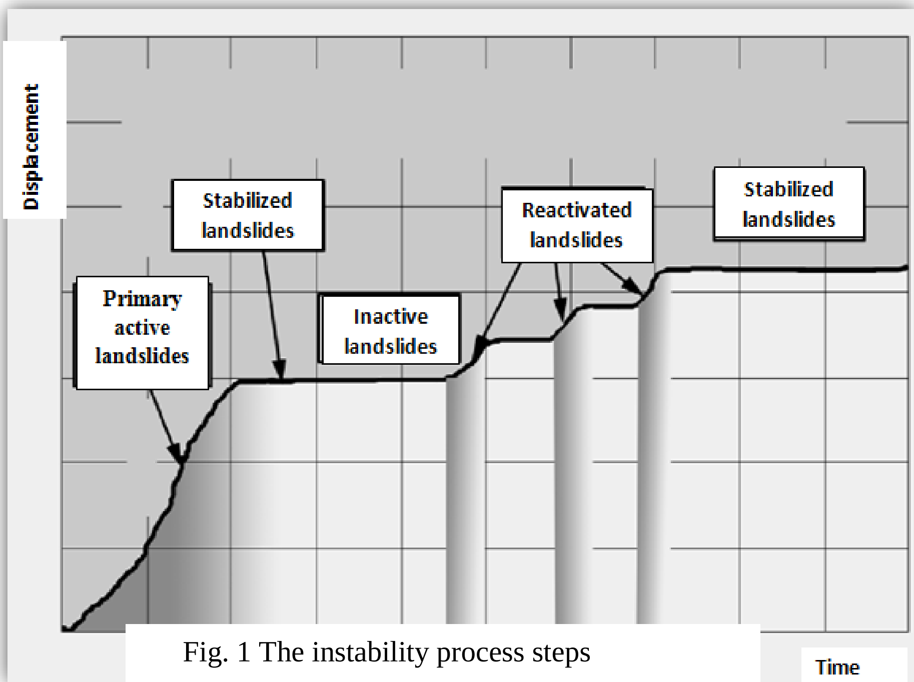

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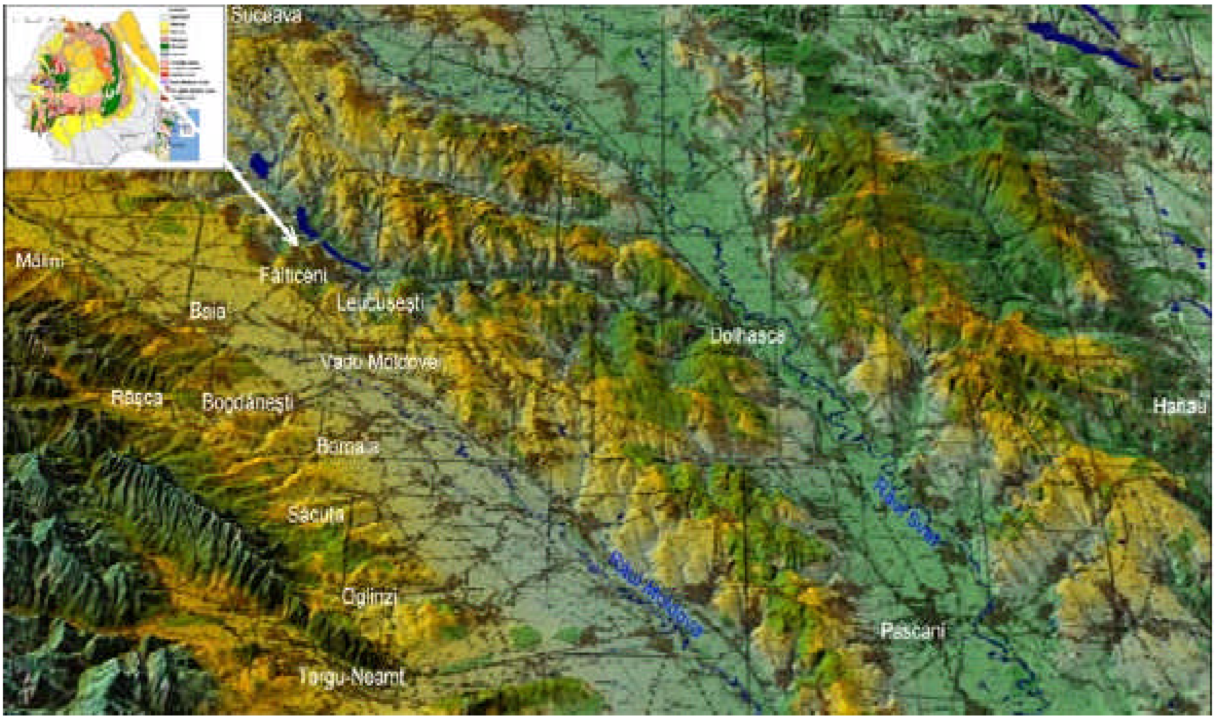

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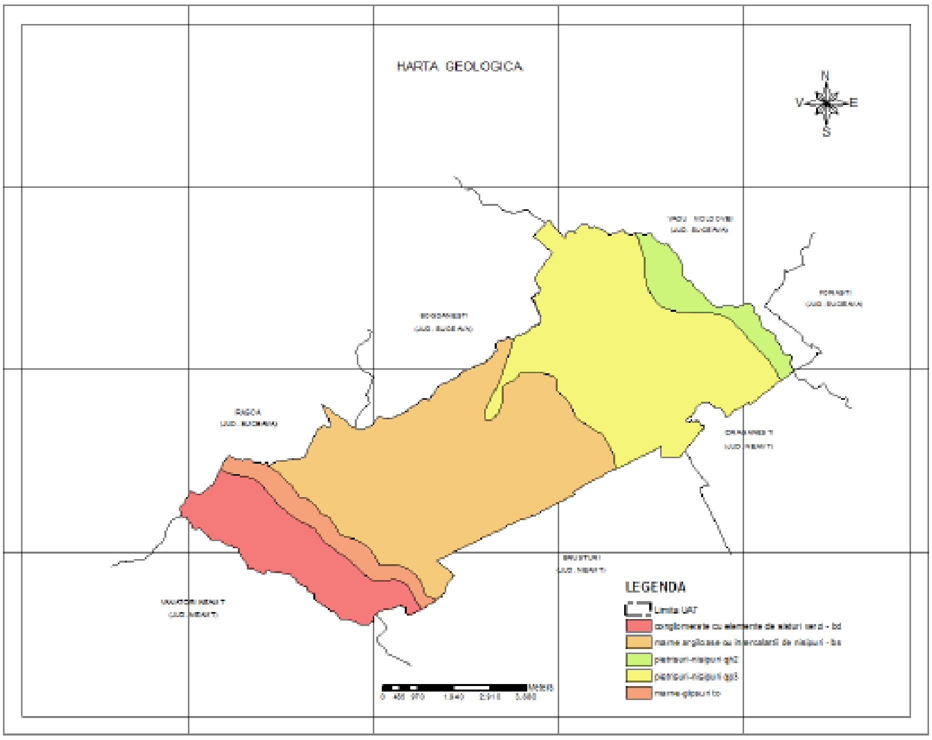


Fig. 3. The geological map in the study area

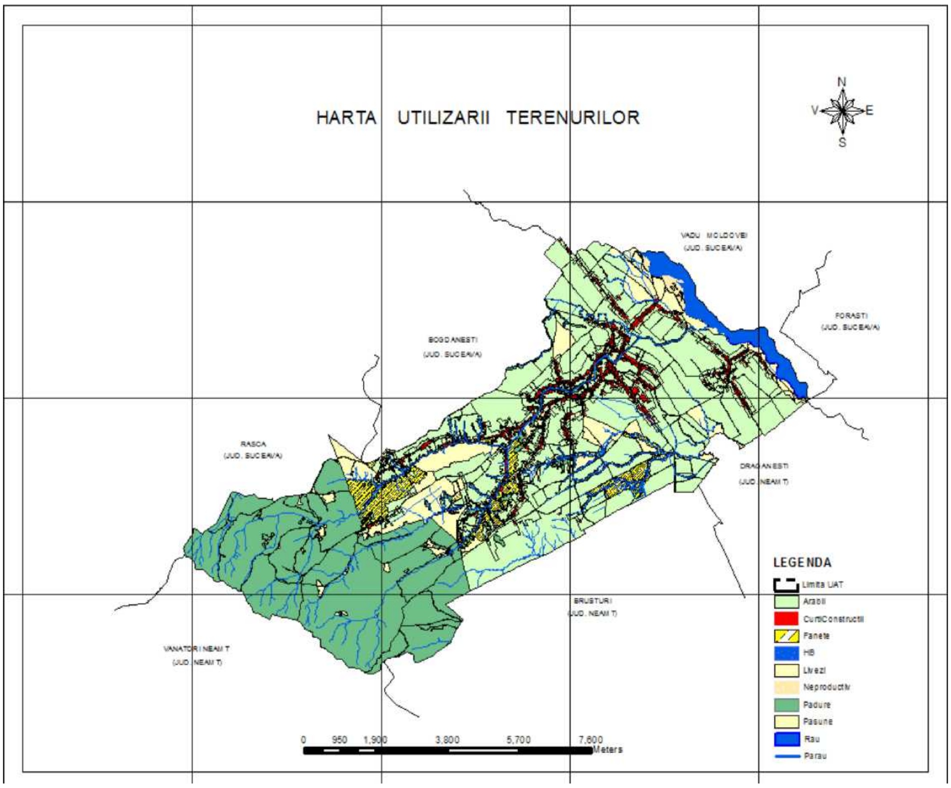
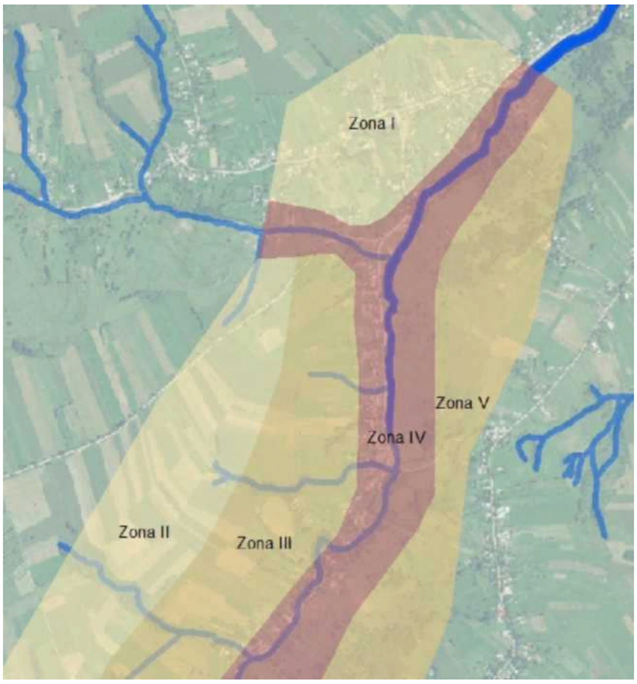


Fig. 4. Map of land use in the study area.



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