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A Scientific Network for Earthquake, Landslide and Flood Hazard Prevention – *SciNet NatHazPrev*

Landslide Hazard Assessment Methodologies in Romania

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- In the literature the terms of ***susceptibility*** and ***landslide hazard*** are often used as synonyms, although they are different concepts (Guzzetti, 2005).
- ***Landslides susceptibility*** is the probability that a landslide to occur in an area characterized by certain environmental conditions (Brabb, 1984). Is the degree which a surface can be affected by the landslide process.
- In contrast, ***landslide hazard*** is the probability that a landslide of a given magnitude will occur in a given period of time and in a given area. In addition to prediction of where the landslide will occur, landslide hazard forecast "when" or "how frequently" it will produce and "how large" it will be (Guzzetti et al., 2005).
- Thus, susceptibility is the space component of landslide hazard.

Methods for landslide susceptibility evaluation

Qualitative methods

- Geomorphological mapping;
- Direct mapping method;
- Multi-class weighting method;
- Spatial multi-criteria analysis;
- Analytical hierarchy process;
- Fuzzy logic approach

Quantitative methods

Statistical methods

Bivariate methods:

- Weights of evidence;
- Certainty factors;
- Dempster-Shafer method;
- Fuzzy logic.

Multivariate methods :

- Discriminant analysis;
- Logistic regression analysis;
- Multiple regression analysis.

Deterministic methods

- Static infinite slope modeling;
- Dynamic infinite slope modeling with rainfall trigger;
- Earthquake induced infinite slope modeling.

- In Romania, landslides are among the most widespread geomorphological processes in the hilly regions built of Neogene molasse deposits, as well as in the mountainous regions developed on Cretaceous and Paleogene flysch.
- During the ’90s and early 2000s, in the estimation of landslide susceptibility was used especially qualitative approaches.
- The number of quantitative ones has risen steeply in the last years (Micu & Bălteanu, 2009; Armaș, 2011, 2012; Constantin et al., 2011; Șandric et al., 2011; Grozavu et al., 2012; Armaș et al., 2013).

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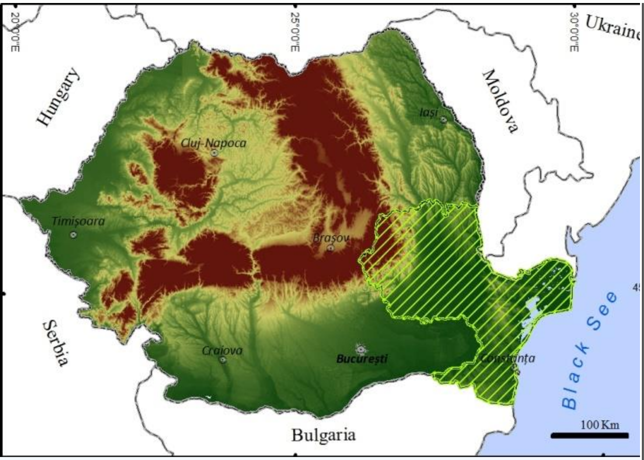
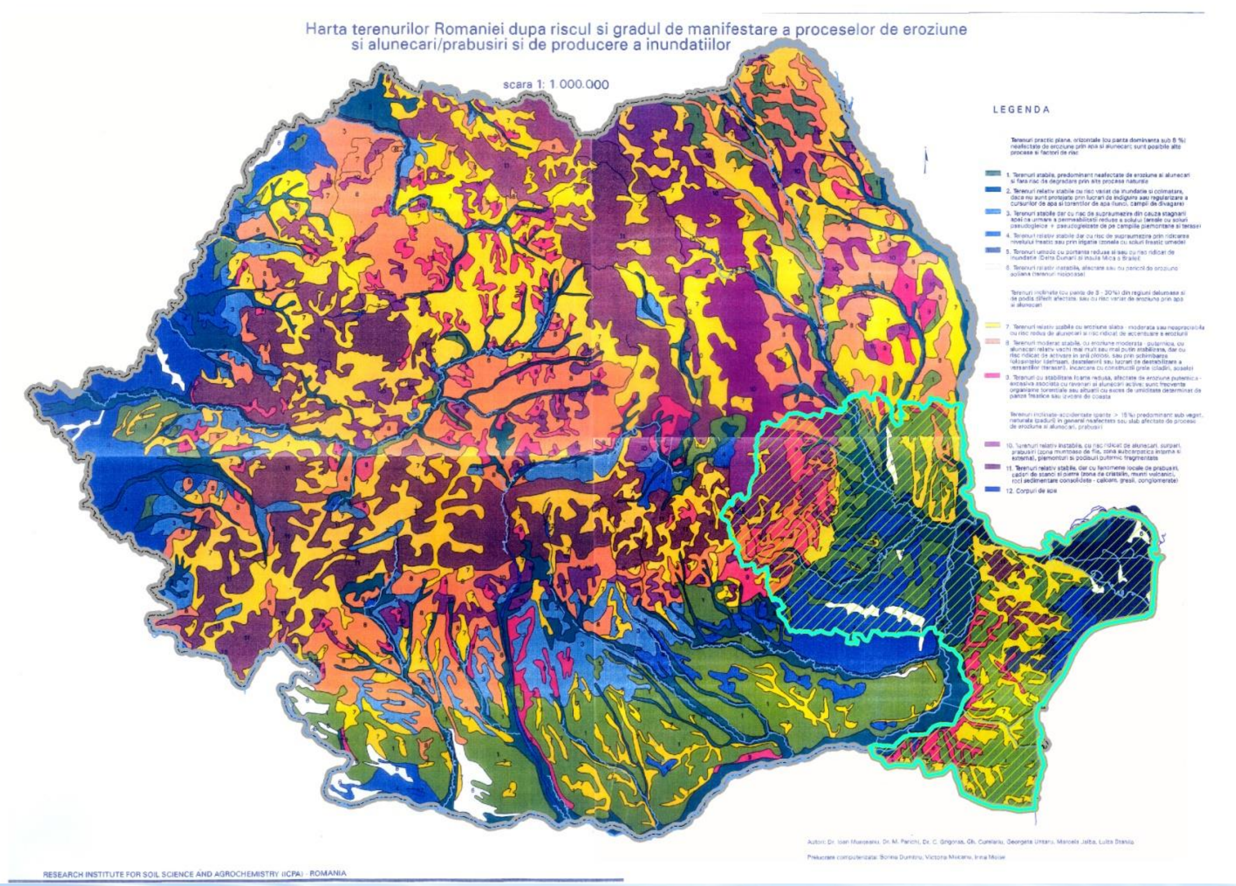


Position of Study area
Area = 35737 sq. kms.



Romania’s land zoning in terms of potential for erosion, landslides / falls and floods

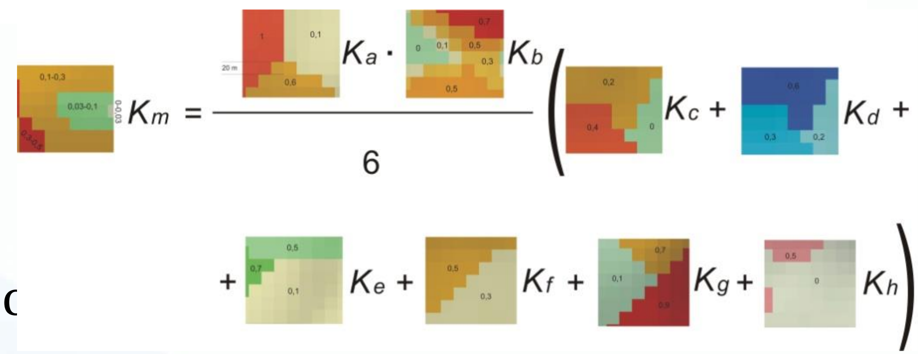
- A series of normative acts published in several stages, such as:
  - Law 575/2001,
  - Law 124/1995,
  - Government Decision 382 and 447/2003,
  - Common Order of the Ministry of Public Works and Territorial Planning, of the Chief of Department for Local Public Administration and Ministry of Waters and Environmental Protection no. 62/N-19.0/288-1.955/1998, based on the *Writing guide for landslides risk maps to ensure construction durability – Indicative GT-019-98*

set the methodological norms regarding *elaboration way and content of the landslides hazard maps* based on calculating of the average **coefficient of hazard K(m) .**

For drawing the map of landslide hazard are required the following steps:

- dividing the territory for which the hazard map is elaborated in bounded polygonal surfaces to represent as homogeneous lithologic and structural deposits ;
- estimating the weights and geographical distribution of “risk coefficients” K(a-h) depending on the criterion presented in Table 1;
- calculating the average hazard coefficient K(m) corresponding to each analyzed polygonal surface by using a specified formula (1); :
- determining the degree of potential (low , medium, high) associated with a certain probability of landslides occurrence (practically zero, low, medium , medium -high , high and very high) .

$$K_{(m)} = \sqrt{\frac{K_a \times K_b}{6}\left(K_c + K_d + K_e + K_f + K_g + K_h\right)} \quad (1)$$



Where:

- K_a = lithologic criterion;
- K_b = geomorphological criteri
- K_c = structural criterion;
- K_d = hydrological and climatic criterion;
- K_e = hydrogeological criterion;
- K_f = seismic criterion;
- K_g = forest cover criterion;
- K_h = anthropogenous criterion,

expressed through a scale from 0 to 1

- Among the landslide affecting factors, **lithology** and **geomorphology** are considered the most important.
- Depending on the K(m) coefficient’s value, are establish landslide occurrence potential:
  - low potential, K(m) < 0.1
  - medium potential, K(m) = 0.1 to 0.3
  - medium-high potential, K(m) = 0.3 to 0.5
  - high potential, , K(m) = 0.5 to 0.8
  - high-very high potential, K(m) are above 0.8.

Legend:

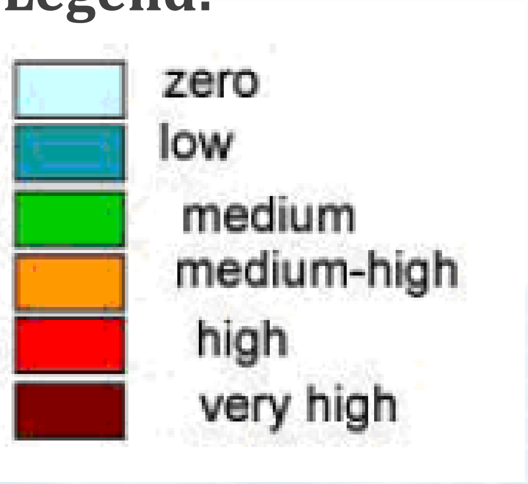


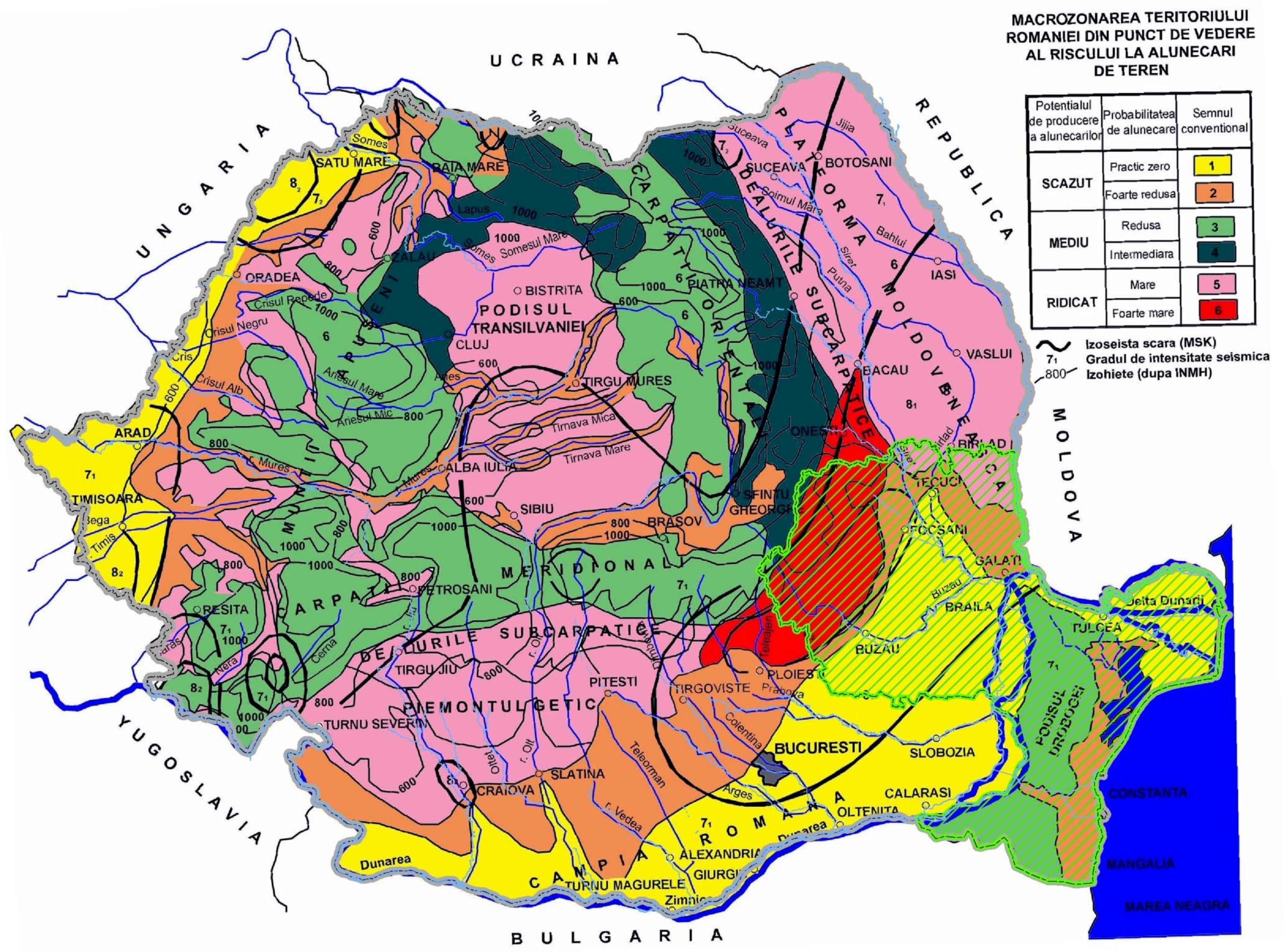
Table 1. Rating -Criterion for landslide potential and probability occurrence assessment

Crt. No.	Symbol	Criterion	Landslide occurrence potential (p)					
			Low		Medium		High	
			Landslide probability occurrence (p) and the corresponding risk coefficient (K)					
			Practically zero	**Low**	**Medium**	**Medium-high**	**High**	**Very high**
			0	**< 0,1**	**0,1-0,3**	**0,31-0,5**	**0,51-0,8**	**> 0,8**
0	1	2	3	4	5	6	7	8
1	a	Lithologic	Solid, massive, compacted or fissured unweathered rocks		Sedimentary rocks of overlaying formations (deluvial, coluvial and proluvial deposits) and pelitic stratified rocks (clay slate, marls, calcareous marl, chalk); metamorphic rocks (especially epizone and less mesozone schists, highly weathered and exfoliated); some weathered igneous rocks		Detrital sedimentary rocks (unconsolidated – saturated, plastic clays, with high expansive and contractile capacity); montmorillonitic clays; small or medium grain sized loose silt and sand; salt breccia	
2	b	Geomor-phologic	Plain relief (hydrographic network integrates mature valleys)		Hilly relief representative for piedmont and plateau areas, edged by medium height slopes with, generally, medium and high declivity		Hilly and mountainous relief, highly fragmented by a dense network of young valleys (most of them, subsequent valleys) with steep and height slopes	
3	c	Structural	Massive igneous rocks; stratified sedimentary rocks with horizontal bedding; metamorphic rocks with horizontal schistosity planes		Most of folded and faulted geological structures affected by cleavage and fissuring; diapir structures; overthrust sheet forehead		Geological structures representative for geosynclines areas in flysch facies and molasse formations from marginal depressions; stratified geological structures highly folded and dislocated, affected by a dense cleavage, fissuring and stratification network	

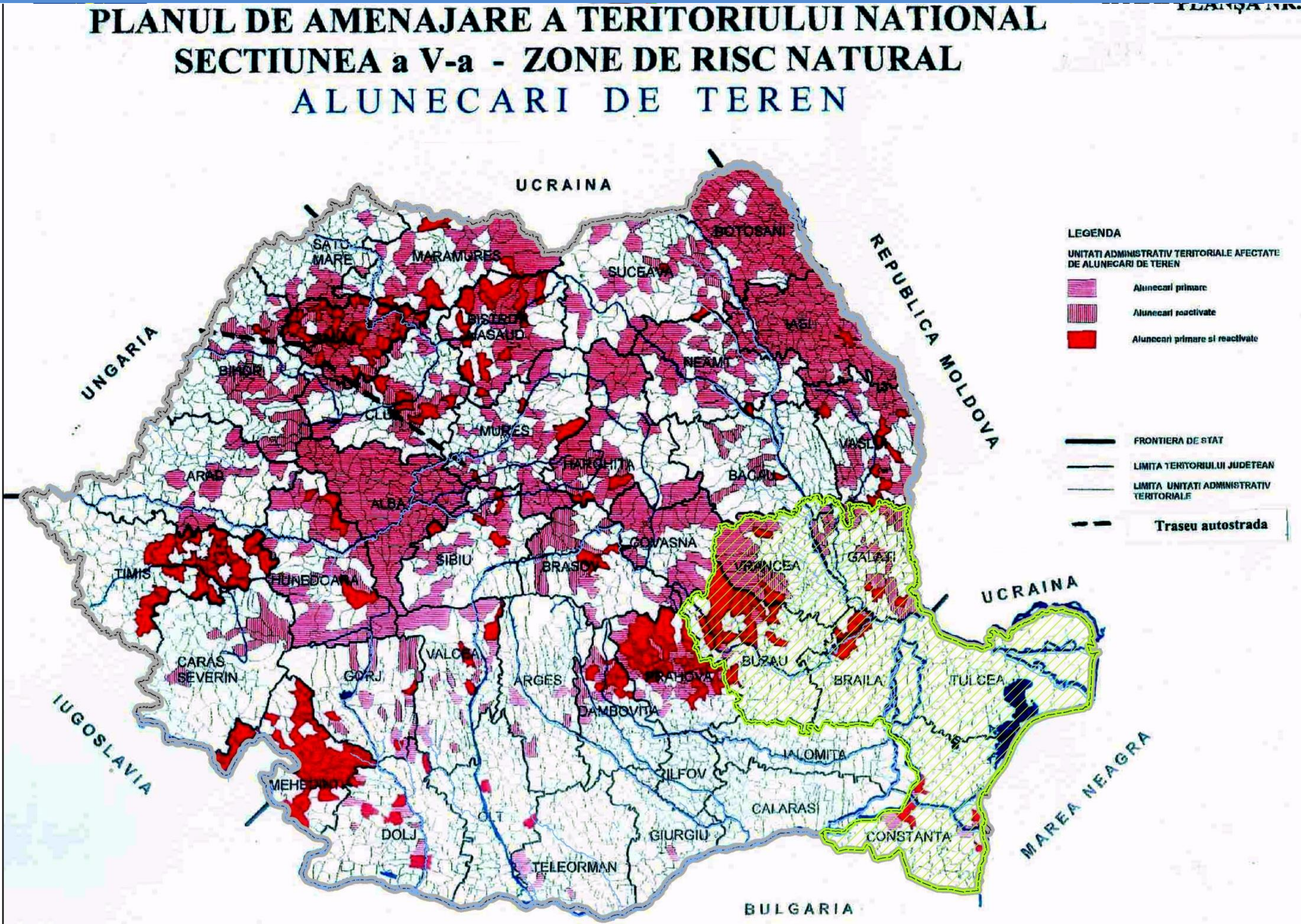
Crt. No.	Symbol	Criterion	Landslide occurrence potential (p)					
			Low		Medium		High	
			Landslide probability occurrence (p) and the corresponding risk coefficient (K)					
			Practically zero	Low	Medium	Medium-high	High	Very high
			0	< 0,1	0,1-0,3	0,31-0,5	0,51-0,8	> 0,8
0	1	2	3	4	5	6	7	8
4	d	Hydrologic and climatic	Generally dry areas with reduced average annual rainfall; the debit flow is strictly conditioned on the precipitation amount; on the river bed, deposition exceeds erosion (lateral erosion only on floods)		Moderate amount of rainfall; the hydrographic network is composed by mature primary valleys, meanwhile, the tributaries are young valleys. During floods, lateral and linear erosion along with important transport and solid discharge are being observed		Long slow rainfall conducive to water infiltration; heavy rainfall with important overflows and solid discharge transport; predominant process: linear erosion	
5	e	Hydrogeo-logic	Ground water flow at low hydraulic gradients; filtration forces are negligible; confined ground water at great depths		Moderate hydraulic gradients; the equilibrium state of the slope responds to the filtration forces values; phreatic water is situated above 5 m depth		Ground water flow at high hydraulic gradients; water sources are located at the base of the slopes; ground water flow direction is outwards; filtration forces can act as a landslide trigger	
6	f	Seismic	Seismic intensity on M.S.K* scale < 6th degree		6 – 7th degree of seismic intensity		Seismic intensity on M.S.K scale > 7th degree	
7	g	Forestry	Timbering covering > 80%; extended deciduous forests		Timbering covering between 20% – 80%; deciduous and coniferous forests of various age and width		Timbering covering < 20%	
8	h	Anthropic	No important constructions on the slopes; water reservoirs are absent		A number of construction works (road platforms and railroads, coast channels, quarries etc) with limited extension with adequate slope protective measures		Overloaded slopes (dense water supply network and sewerage, roads, railroads, coast channels, quarries, dumps etc; water reservoirs.	

*Medvedev – Sponheuer – Karnik seismic intensity scale (MSK 64)

Macro-zoning map of induced landslides risk in Romania



Map of landslides types - Romania



COMMENTS:

- In the absence of chronological information on the occurrence of landslides, spatial–temporal probabilities cannot be calculated and consequently predictions must be restricted to the spatial distribution of future landslides; that is susceptibility (Bălteanu et al., 2010).
- There is no information regarding the differentiation between landslide types in the present methodology.

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ADVANTAGES:

- gives an overview relatively suggestive of areas with different landslide potential;
- integrates data generally easier to find;
- can be used in case of lack information about the existence of landslides (obtained from inventory using different sources).

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Hazard Risk Mitigation And Emergency Preparedness Project In Romania (2008-2012)

- World Bank Project on natural disasters study in Romania, coordinated by RMSI (Risk Management Solutions India).

- **Main goals:**

- execution of geological and geotechnical studies on two pilot areas for the design and implementation of an “in situ” monitoring system (including installation of monitoring equipment);
- data collection and processing for elaboration of a model for landslides anticipation;
- elaboration of a monitoring manual including elements of an early warning system;
- design and implementation of a training program for local authorities.

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- More recent, Bălteanu et al., in 2010, have developed a landslide susceptibility model for the whole country applying a scoring system to a set of conditioning factors based on expert judgement (heuristic model).
- This research was carried out due to a World Bank project on losses and insurance costs relating to disasters in Romania, and aims to provide a unitary basis for addressing landslide susceptibility in the country.

- It takes into account the most important triggering factors, as well as settlements and infrastructure affected by landslides.
- It also forms the basis for elaboration of a landslide-hazard risk map in an attempt to quantify all potential losses related to this process.

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Triggering Factors

- Was used a **Landslide Susceptibility Index (LSI)** method based on quantitatively defined weighted values.
- Expert analysis, combined with a long history of landslide mapping and assessment and field experiments, play an important role in this method.
- The expert judgement involved a large number of studies and assessments undertaken at different scales, and geomorphological mapping of Romanian territory at the scale of 1:200,000.

- In computing a GIS landslide-susceptibility map of Romania six major triggering factors were considered:
  - lithology,
  - height difference,
  - slope angle,
  - land use,
  - rainfall
  - seismicity.
- Each factor was classified under sub-classes carrying a rating from 0 to 10 according to its relevance for landslide susceptibility.
- Further, each factor was considered to have a differential influence on such susceptibility, named ‘assigned weight’.

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- The results were compared with different assessments from several countries.
- To validate the methodology, besides expert judgement, repeated geomorphic mapping over a long period, as well as field observations and measurements in the most affected regions, were used.

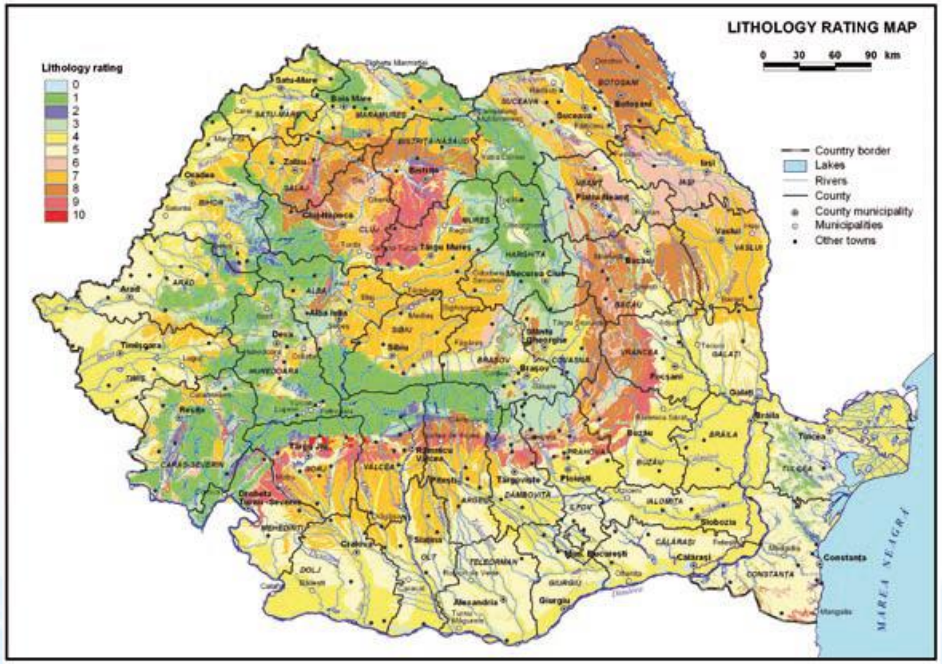

Figure shows an example of a lithology rating map based on 1:200,000 scale map elaborated by the Institute of Geology, Romania.

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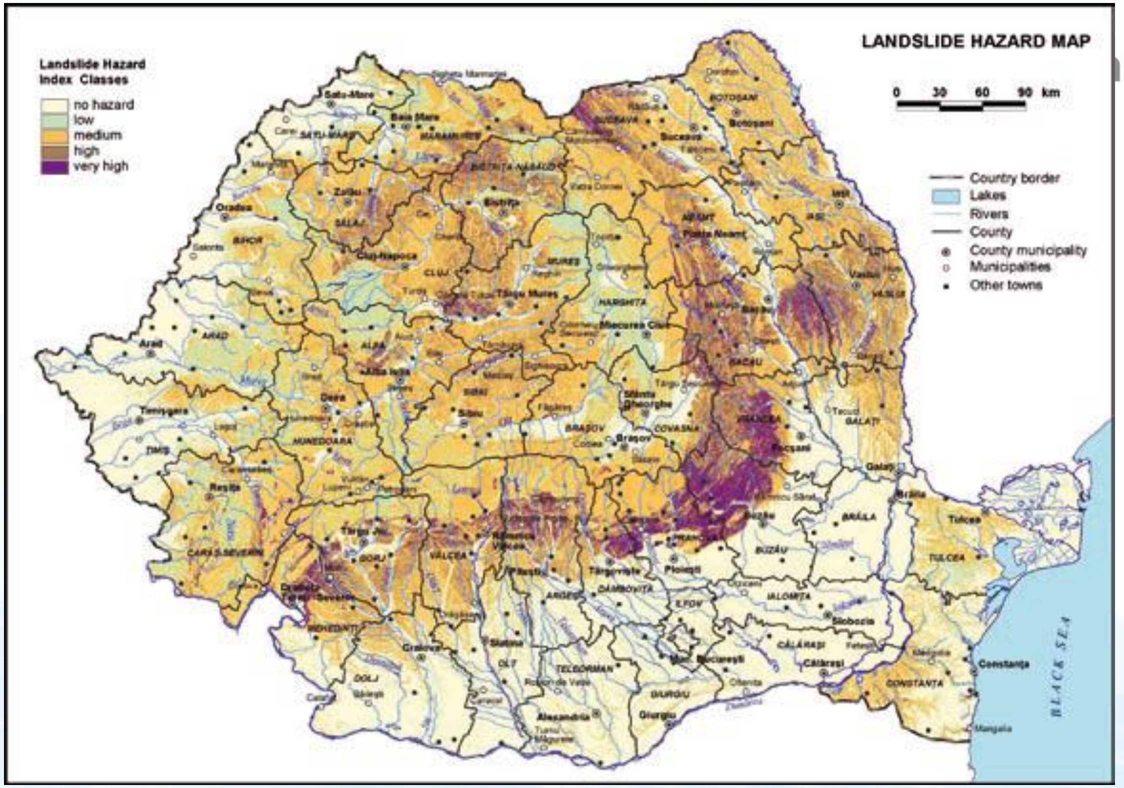

Susceptibility Classes

- The LSI was further classified under **five hazard classes**; each category based on correlation of expert judgement and existing geomorphological maps of the whole of Romania.

- The established classes are:
  - ‘no susceptibility’, represents around 39% of Romania (plains and low hills),
  - ‘low’, 10%,
  - ‘medium’, 38.3%,
  - ‘high’ and ‘very high’ susceptibility, classes around 10% (mostly in the Subcarpathian region).

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IncREO - Increasing Resilience through Earth Observation

http://www.increo-fp7.eu/

(Jan. '13 – Dec. '14).

Project Structure

WP 101: European/national legislation and existing GMES/Copernicus solutions
WP 102: Three level assets mapping concept (national, regional, local)
WP 103: Assets mapping specifications and production
WP 201: Dam failure (Use case: Hungary)
WP 202: Wind, waves and storm surges (Use cases: France and Bulgaria)
WP 203: Flooding (Use case: Albania)
WP 204: Landslide (Use case: Romania)
WP 205: Multi-risk evaluation, hot spot identification and mapping (Use case: Italy)
WP 206: Community networking and end-user facilitation
WP 301: Geo-information atlas "Assets and natural hazards"
WP 302: Global risk and vulnerability modelling and mapping
WP 303: Multi-hazard atlas and risk analyser
WP 402: Communication and dissemination
WP 403: Scientific and technical coordination
WP 401: Financial and contractual management of the consortium

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IncREO project aims to:

- analyze legislation, existing strategies and prevention capabilities in priority regions (EU Floods Directive, the Danube Strategy);
- analysis of priority areas in terms of climate and hydrology using Earth observation satellite data;
- application of methods based on Earth Observation satellite data to study the impact of human intervention on the land use and land cover and increased incidence of natural disasters;
- defining and carrying out case studies for each type of hazard (earthquakes, landslides, fires, floods);
- recommendations on prioritizing of interventions in geographic regions prone to natural disasters.
- The objective of the work package which includes Romanian Space Agency –ROSA, is to assess and map in a detailed manner the risk and vulnerability of areas in Romania highly prone to landslides in the Buzau County.

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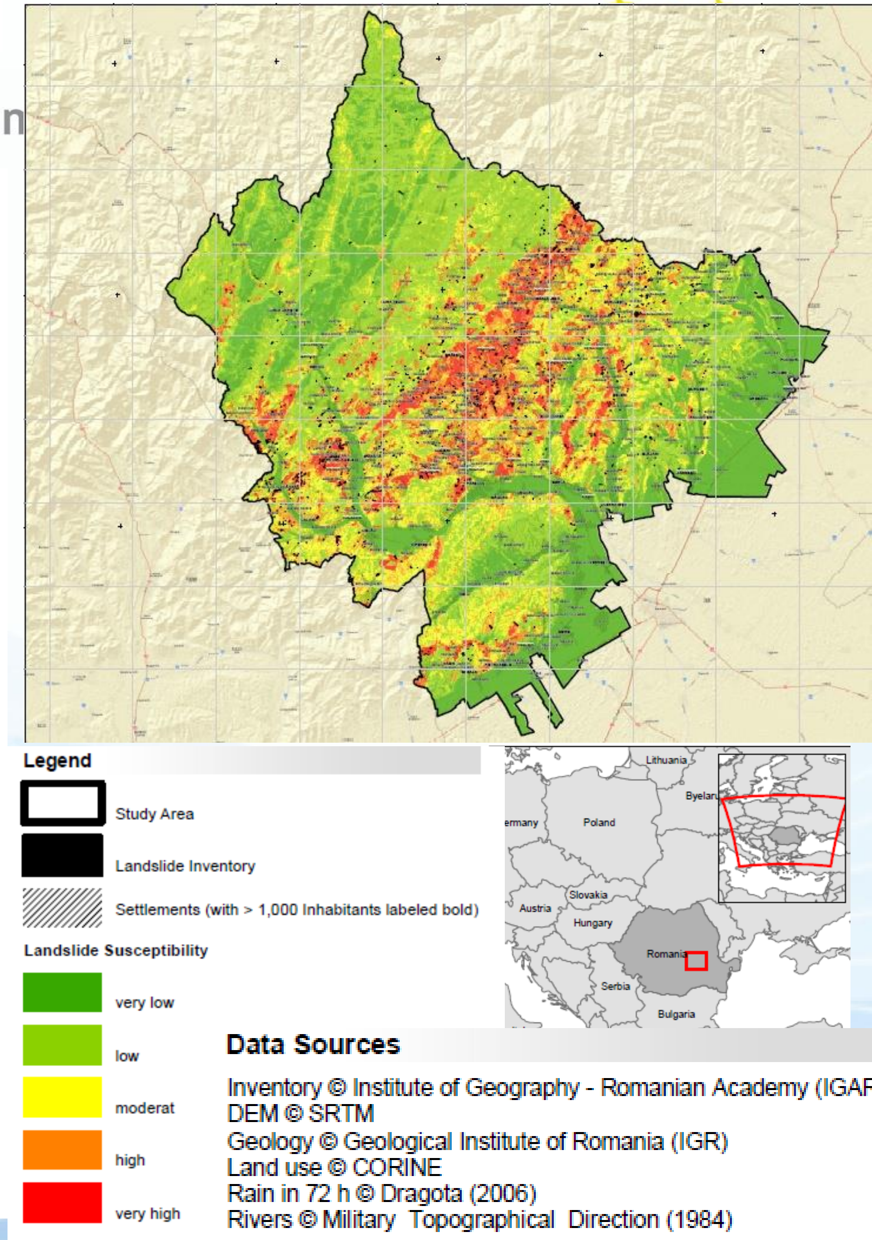
- The map shows the landslide susceptibility of Buzau County, Romania.
- For assessing the susceptibility of landslide prone areas a quantitative inventory-based probabilistic method with the approach of **“Weight of Evidence” (WofE)** was chosen.
- The following inputs were used:
    - Landslide inventory (kindly provided by the **FP7 CHANGES project**),
    - DEM (slope, aspect, relative relief),
    - geology,
    - land use,
    - max. rainfall in 72 h,
    - distance to drainage network.
- It is assumed that the landslide inventory is complete



CONCLUSIONS

- The methodology provided by the Ministry of Local Public Administration in 1998, 2001 and 2003 it is subjective and difficult to apply (Șandric et al., 2011), due to the uncertainties and different interpretations of the specialists that may occur in assigning weights to various landslide controlling factors in assessing susceptibility.
- Presently, there is no coherence and cohesion in decisions and actions taken by the research institutes and government institutions involved, at local or regional scale in systematic investigation, or a strategy for inventorying and monitoring of landslide affected areas, at national scale.
- Moreover, although a general trend of unification between the Romanian and the international terminology regarding landslide susceptibility, hazard and risk has been observed in recent years, the present methodological requirements underlying the legal framework are not updated.