STUDIA UBB GEOGRAPHIA, LVII, 2, 2012, pp. 37-50
(RECOMMENDED CITATION)

APPLIED LEGISLATIVE METHODOLOGY IN THE ANALYSIS OF LANDSLIDE HAZARD. CASE STUDY FROM MARAMUREŞ COUNTY

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ABSTRACT. – Applied Legislative Methodology in the Analysis of Landslide Hazard. Case Study from Maramureş County. Within the context of Romania's adhering process to the E.U., several legal instruments were created in order to reduce the impact of natural hazards. In the field of landslide risk, the Governmental Decision 447/2003 establishes "*The mapping methodology and the content of landslide and flood risk maps*", describing the criteria used to determine the sliding potential in a certain area. The case study applying the method described in this Governmental Decision focuses on the administrative unit of Groşi, from Maramureş County, which is characterized by high values of annual precipitation and a lithology dominated by contractive clays and marl. With the help of the ArcGis 9.3 software a susceptibility coefficient was computed and reclassified into three categories: low, medium and high. The validation of the results was based on previously mapped landslides. Another analysis of landslide susceptibility was also performed using statistical methodology. Both the advantages and disadvantages which resulted from this comparative analysis are thoroughly presented and discussed. Nevertheless, the overall results point to a medium landslide susceptibility of most of the study area and high landslide susceptibility in the area affected by active and partially stabilized landslides. In order to evaluate the landslide hazard, the frequency and magnitude of the sliding processes was also estimated by heuristically establishing the return periods of rainfall-triggered landslides and the volume of material displaced during past events.

Keywords: *Maramureş, landslide hazard, legislative methodology, multivariate statistic analysis.*

1. INTRODUCTION

In the evolution of geographic systems, natural hazards are thresholds which can shift the whole system to a new state of equilibrium. When the human component is also involved, they can cause damage and casualties, which define a state of risk. Nevertheless, hazards are an association of causing factors, or legally binding circumstances, which determine a perfectly natural energy outburst (I. Mac, D. Petrea, 2002).

Knowing this association of factors, one can establish the spatial coordinates of almost any natural hazard. However, the etymology of the concept suggests there is a large amount of uncertainty related to the fulfilment of its potential. Therefore, defining the temporal coordinates of a hazard is done with greater difficulty, especially due to the lack of sufficient data. Considering these aspects, a hazard can be ideally characterized by the answers to the questions "what", "where", "when", "how strong" and "how often" (M. J. Crozier, T. Glade, 2005).

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The answer to the first question is represented in this study by landslides, a process which shapes the slope profile under the gravity impulse, on a sliding surface (V. Surdeanu, 1998), included in the larger category of mass movements.

The answer to the question "where" is given by two sets of results generated by applying the method approved by the Romanian legislation and the statistical multivariate method in a study area located near the Baia Mare municipality, in Maramureș County.

In order to complete the hazard analysis with the answer to the last questions, the probability of occurrence of a landslide with a particular magnitude must also be determined. In order to achieve this, the date of occurrence of past landslides, when known, was correlated with the climatic circumstances from the respective periods, in order to approximately determine the return periods and the magnitude of potential landslides, using the landslide triggering rainfall cyclicity.

Several GIS techniques were used in defining the data base, the mapping process and spatial analysis performed. These were completed with field observations and a rich experience of applying the legislative methodology in civil engineering projects, which helped adapting the models in order to represent reality as effectively as possible.

2. SUSCEPTIBILITY ANALYSIS AND GIS TECHNIQUES

When considering landslides as natural hazards, spatial analysis is being often used in mapping susceptibility, a measure of an areas' predisposition to landslides, based on the presence of some known causing factors or on the history of events which affected a particular slope (M. J. Crozier, T. Glade, 2005). Using GIS techniques in combining these factors provides a higher accuracy and time economy, the effort and human resources needed being also considerably reduced (D. E. Alexander, 2008).

In addition to this, combining spatial data by means of GIS techniques allows the production of a multitude of models. However, choosing the most appropriate one cannot be accurately done without the experienced opinions of geomorphologists and geologists who know the real behaviour of the natural process. Therefore, the best results in hazard zonation are given by the combination of heuristic reasoning and computer-assisted models (C. J. van Westen et al., 2006). The two methods presented in the next section combine these two elements in different proportions and thus, the results vary accordingly.

2. 1. Legislative methodology

"*The mapping methodology and the content of landslide and flood risk maps*", established by the Governmental Decision 447/2003, acts in our country as the main legislative basis for the administrative actions of local and regional authorities. The landslide risk map, made accordingly to the instructions described in this decision, represents the legal act used by the county council to declare a landslide risk zone (G.D. 447/2003, chapter 1, art. 3 (2)), to establish the actions needed for risk prevention and mitigation, as well as to authorise the conditions for building in those specific areas (G.D. 447/2003, chapter 1, art. 4).

From the perspective of applied geomorphology, it is useful to know the variety of methods found in the scientific literature which are used for mapping landslide risk, but not sufficient, as only legislation can ensure the financial support needed by a practitioner in order to put into practice a prevention and mitigation project.

This is the reason why the first method used to establish the landslide susceptibility for the study area is represented by the method described in the Romanian legislation. The combination of factors considered for determining the sliding potential is achieved by means the following mathematical expression, originally found in the technical regulation GT-019-98 ("Ghid de redactare a hărților de risc la alunecare a versanților pentru asigurarea stabilității construcțiilor", 1998).

$$K(m) = \sqrt{\frac{K(a) \times K(b)}{6} \times [K(c) + K(d) + K(e) + K(f) + K(g) + K(h)]}$$

in which: *K(m)* = average susceptibility coefficient; *Ka* = lithologic coefficient; *Kb* = geomorphologic coefficient; *Kc* = structural coefficient; *Kd* = hydrologic and climatic coefficient; *Ke* = hydrogeologic coefficient; *Kf* = seismic coefficient; *Kg* = forest coverage coefficent; *Kh* = anthropic coefficient.

For each of these eight factors their classes of susceptibility are determined heuristically by means of a general description, which allows the selection of a value between 0 and 1 for each factor. The susceptibility classes are defined as follows: zero (0), reduced (< 0.10), medium (0.10-0.30), medium-high (0.31-0.50), high (0.51-0.80) and very high (>0.80). Eventually they are reclassified in three classes: low (< 0.10), medium (0.10-0.50) and high (0.51-1) (G.D. 447/2003).

2. 2. Statistical analysis

Although in our country the legislative method is mostly a heuristic one, the most commonly used method for determining landslide susceptibility in recent studies, especially at a large and medium scale (<1:10.000 – 1:100.000) (T. Glade, M. J. Crozier, 2005), is statistical analysis (e.g. C. J. F. Chung, A. G. Fabbri, 2008, N. R. Regmi et al., 2010). Already in 2006, F. Guzzetti et al. counted, for the previous six years, over 40 such studies published in major international journals and their ever rising number is a proof of the method's efficiency, when properly validated (C. J. F. Chung et al., 2003, F. Guzzeti et al., 2006).

Starting from the assumption that a certain combination of factors, which have previously caused a landslide, will similarly act in the future, this quantitative method establishes statistical relationships between the factors and the distribution of mapped landslides, seen as dependent variable. These relations are then applied to the whole study area in order to classify it according to the factors' influence on landslide susceptibility (M. J. Crozier, T. Glade, 2005).

In order to include more than two factors which act as variables, as it is the case for landslide occurrence, the model usually used is that of multivariate analysis (Maria Rădoane et al., 1996), which is basically a set of techniques for data analysis. One of these techniques is represented by the linear probability model of the logit type, also called *logistic regression*, which uses one or more variables to determine a single, nominal, dependent variable (J. R. Hair et al., 1992), in this case, the presence or absence of landslides. The result will be a map (fig. 1) in which for each pixel, the landslide susceptibility is represented by a value included in the interval 0-1 (0-100%).

The relation between landslides and the factors contributing to their occurrence in the area of study is described by a set of coefficients which were generated by the logistic regression performed with the help of the free statistical software R, available at http://www.r-project.org.

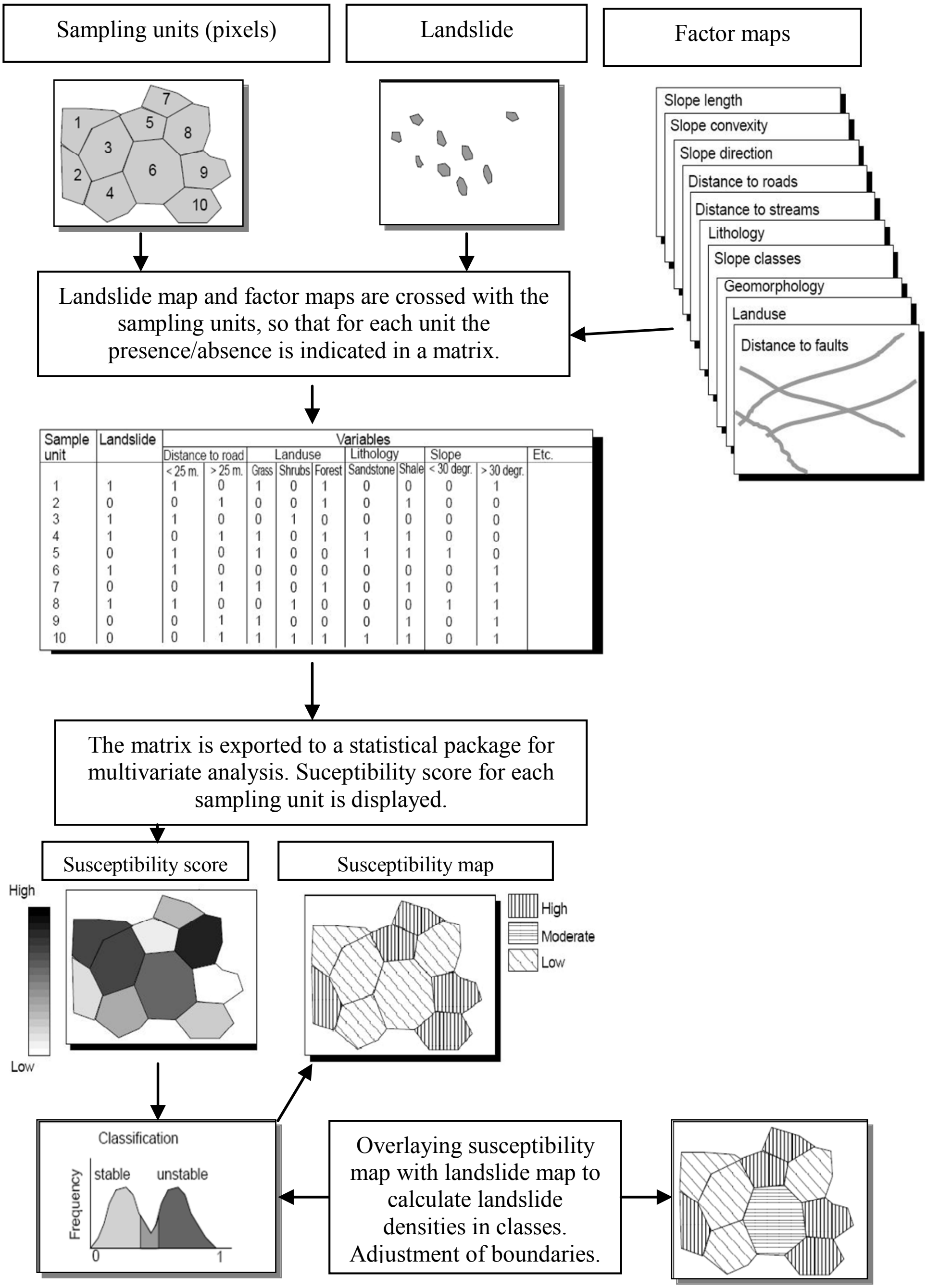

Fig. 1. GIS application in multivariate statistical analysis of landslide susceptibility (after C. J. van Westen et al., 1997).

A positive coefficient increases the probability of landslide occurrence, whereas a negative one diminishes it (J. R. Hair et al., 1992). As illustrated in fig. 1, the susceptibility of the whole area was computed using the Map Algebra functions and the following expression which multiplies the regression coefficients (*a0, a1, a2, a3*) and the independent grids used to derive them (x1, x2, x3):

prediction = 1 div (1 + (exp (- (a0 + a1x1 + a2x2 + a3x3 + ...))))[1].

2. 3. Validation

For the first method, the validation is performed by comparing the spatial distribution of the mapped landslides with the susceptibility map generated. The percentage of the surface affected by landslides which coincides with the area with high susceptibility will give the goodness of the model.

For the statistical method, the validation stage is based on the cross-validation technique (e.g. C. J. F. Chung et al., 2003, C. J. F. Chung, A. G. Fabbri, 2005, 2008, R. Bell, T. Glade, 2004, M. J. Crozier, T. Glade, 2005) which uses a training data set and a test data set, the first one used for building the model and the second for validating it (A. Brenning, 2005) and estimating its ability to predict future landslides (F. Guzzetti et al., 2006).

The goodness of the model is given, as for the first method, by the percentage of landslide surface which matches the highest susceptibility classes. In order to compare the results of the two methods, the classes employed were determined using the same value intervals: low (<0.10), medium (0.10-0.50) and high (0.51-1), as specified in the legislation.

3. PROBABILITY OF LANDSLIDE OCCURRENCE

Estimating landslide hazard usually includes two stages: determining the susceptibility of the territory to the process and estimating the probability that a triggering factor might activate or reactivate a landslide. The latter consists of the relationship established between the magnitude and the return period of landslide occurrence under the influence of a particular triggering factor (C. J. van Westen et al., 2003).

As the seismic factor does not act as a trigger in the study area, the most important influence upon landslide activation and reactivation is manifested by rainfall. The lithology of the area is dominated by covering contractile clay deposits. During the years with low precipitation, deep fractures develop, reaching the underlying marl. When rainfall eventually occurs, these fractures, which can be up to 20 cm wide, enable rain water to rapidly reach this level and create a sliding surface on the marl deposits, located at a depth of approximatively 2-4 m.

The lag time between heavy rainfall and landslide occurrence, as well as specific rainfall thresholds depending on the water already infiltrated, require a detailed analysis, which is still lacking at this point. Therefore, the only way to establish a general relationship between past landslide events and rainfall is heuristically, taking into consideration the average annual rainfall in order to determine the rainy years (more than multiannual average rainfall) which have a correspondence in landslide activity, preferably following a sequence of 2-3 years with low precipitation, which favour the occurrence of fractures into the covering deposits.

[1] *http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Regression_analysis*

The volume of each landslide was then approximatively estimated and was used to heuristically determine the magnitude classes which characterise the Groşi area. The return periods established for the years with landslide potential were used to determine the return periods of landslides with different magnitudes, inferred from the surface affected and the displaced volume.

Validating these results is very difficult, due to the lack of complete temporal information for each of the mapped landslides. Therefore, the results are considered as a general estimation which could eventually be used in a more accurate and detailed landslide probability analysis.

4. THE GROŞI STUDY AREA

The study area includes an administrative unit from Maramureş County, situated 5 km south from the Baia Mare municipality and is represented by a former piedmontal unit from the foot of the volcanic mountains Gutâi (P. Coteț, 1973), fragmented by the Săsar and Chechiş rivers, in the northern part of the Baia Mare Depression.

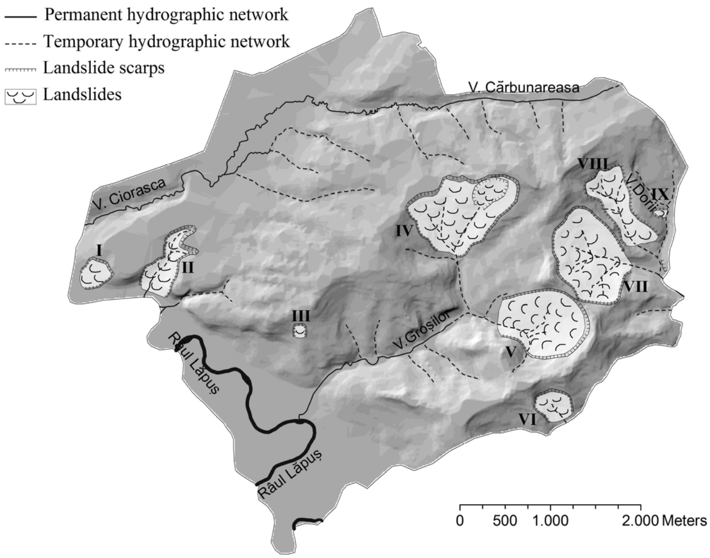

Fig. 2. Mapped landslides in the Groşi study area: I-DJ 182B, II-DC 79, III-Ocoliş, IV-Dâmbeni, V-La groape, VI-Habra, VII-Strujereilor, VIII-Bulbuc, IX-DN 18B.

The lithology of the Groşi area is represented by Quaternary deposits (up to 20 m thickness), above a much thicker layer (more than 800 m) of Pannonian marl (Miocene - Pliocene). The covering deposits, which are affected by mass - movements, consist mostly of contractive clays, with a high water - retentive capacity (values of the retention coefficient range between 150 and 250, according to the NE 00196 normative[1]) and the sliding surface is generally found at their basis, on the marl deposits.

The climate is characterized by an average annual temperature of 9.7°C and an average rainfall of 890.8 mm/year (1971-2007), due to the orographic convection of the western air masses. The hydrographic network consists of two permanent streams, Cărbunăreasa and Groşilor Valley, which are collected by Lăpuş River, and some temporary streams, collected by Chechiş River. 47% of the runoff comes from rainfall, 50% from rainfall and snow melt and 3% from snow melt (I. Ujvari, 1972).

[1] *P.U.C.M. (1978) - Instrucțiuni tehnice pentru proiectarea şi executarea construcțiilor fundate pe pământuri cu umflări şi contracții mari, Institutul central de cercetare, proiectare şi directivare în construcții, Bucureşti.*

The land use reflects the main activities, fruit cultivation and raising animals. Thus, 45% of the territory is used as grassland and 21% as pastures, while the southern and south-western slopes are cultivated with fruit trees (9%). The arable land occupies 25% of the area and only 1.78% is represented by forests[1].

5. RESULTS OF THE SUSCEPTIBILITY ASSESSMENT

In assessing the landslide susceptibility of the Groşi area, two methods were tested, as previously presented. The spatial data used in both cases consisted of a landslide map and several other maps illustrating the spatial distribution of each factor considered. Fig. 2 illustrates the 9 main landslides mapped in the study area. They are generally historical landslides which had periods of activity in the past and incorporate smaller reactivated landslides (fig. 3). The covering deposits are generally 2 m thick, including them in the category of shallow landslides (V. Surdeanu, 1998), but some reactivated portions accumulated thicker deposits of up to 4m.

5. 1. Applied legislative methodology

According to the legislative methodology used to generate the landslide susceptibility map (GT-019-98 normative), 8 factors were included in the final calculation, which was performed with Map Algebra, included in the ArcGis 9.3 software:

Fig. 3. Toe of a more recently reactivated landslide body on the DC 79 landslide.

Ka **-** the lithologic factor consists of 4 lithologic units, for which the susceptibility coefficient was heuristically appreciated. Thus, most of the study area (74%) is characterised by Quaternary covering deposits with an average thickness of 2-4 m, occasionally reaching up to 20 m, consisting of unconsolidated sedimentary rocks (contractive clays), over a more than 800m thick deposit of Pannonian marl (fig. 3). The northern sector, represented by the medium level of fluvial terraces (9%), is also covered with contractive clays on a layer of Pleistocene sediments. For both of these areas, the landslide susceptibility was considered as very high, therefore the corresponding coefficient, Ka, has the value 0.8. The south-western and western sector, corresponding to the fluvial plane of the Lăpuş River, consists of alluvial deposits (13.5%), while the fourth lithological unit characterises the interfluvial sector with colluvium (3.5%). For both units, the susceptibility coefficient was appreciated at 0.25 (medium susceptibility);

Kb **-** The geomorphologic factor is represented by a combination of slope (I. A. Irimuş, 1997), drainage density and relative relief. Each of these parameters was classified according to their influence upon landslide susceptibility (table 1);

[1] *Strategia de dezvoltare socio-economică a comunei Groşi*, Judeţul Maramureş, 2009, http://subm.ro/.

Classification of geomorphologic parameters used to determine the susceptibility coefficient Kb

Table 1

Kb	Slope (°)	Drainage density (km/km²)	Relative relief (m/km²)
0	0	0	0
0.05	1-2	0-0.5	0-10
0.10	2-3	0.5-1	10-20
0.20	3-4		20-40
0.30	4-5	1-1.5	40-60
0.40	5-6		60-80
0.50	6-7	1.5-2	80-100
0.60	7-8		100-110
0.70	8-9	2-2.5	110-120
0.80	9-32	2.5-3.5	120-140

Kc **-** The structural factor is considered to have a corresponding coefficient of 0.10, unitary for the whole study area, characterised by rather horizontal lithologic bands;

Kd **-** The hydrologic and climatic coefficient was considered given the hydrologic and climatic characteristics of the study area and it was appreciated to have a very high influence upon landslides, both as a conditioning and triggering factor. Thus, it has a homogenous value of 0.85;

Ke **-** The hydrogeologic factor is represented by a general phreatic depth of less than 5m, with frequent springs at slope toe and on the slope surface. This corresponds to a high level of influence upon landslide susceptibility, with a 0.70 value of the Kb coefficient for the entire area;

Kf - The seismic factor has a 0.5 value of the corresponding coefficient. This was given by the 6 seismic intensity degree (MSK[1]), characteristic for Maramureş County;

Kg - The forest coverage factor was determined using the land use map, by taking into consideration the percentage of forest vegetation. Thus, a specific coefficient was determined for each of the 9 Corine Land Cover (CLC) categories identified in the study area, as presented in table 2. The special situation of the fruit trees plantations, which are frequent in the study area, was considered from the stability point of view;

Land cover classes and the corresponding Kg coefficient

Table 2

CLC code	Forest vegetation (%)	Kg values
2	<20	0.80
3	<20	0.80
8	<20	0.80
12	<20	0.70
16	20-80	0.55
18	<20	0.85
20	<20	0.70
23	>80	0.10
40	-	0

2 = Discontinuous urban fabric; 3 = Industrial and commercial units; 8 = Dump sites; 12 = Non-irrigated arable land; 16 = Fruit trees; 18 = Pastures; 20 = Complex cultivation patterns; 23 = Broad-leaved forests; 40 = Water courses.

Kh - The anthropic factor influences the landslide susceptibility by specific constructions which determine the overburden pressure on the slopes, change the slopes profiles or the ground water level. As this is the case especially on the quasi-levelled terrace surfaces, while the transport network spreads on the slopes, the value of the coefficient was appreciated separately for built areas at 0.30 (CLC 2, 3, 8) and un-built area at 0.20 (CLC 12, 16, 18, 20, 23, see table 2).

With the expression previously presented, the 8 classified factor maps were combined in order to determine the average

[1] *Medvedev-Sponheuer-Karnik seismic intensity scale (MSK-64).*

susceptibility coefficient (Km). The resulting susceptibility map was then reclassified into three susceptibility classes, according to the Km value: low (<0.10), medium (0.10-0.30) and high (0.51-1). As a result, 11.1% of the area is included in the lowest susceptibility class, 85.8% in the medium susceptibility class and 3.1% in the high susceptibility class. The highest value of the average susceptibility coefficient was 0.57. As most of the study area was classified as medium susceptible to landslides, a better illustration of the susceptibility variation is obtained by using the more detailed classes, as shown in fig. 4.

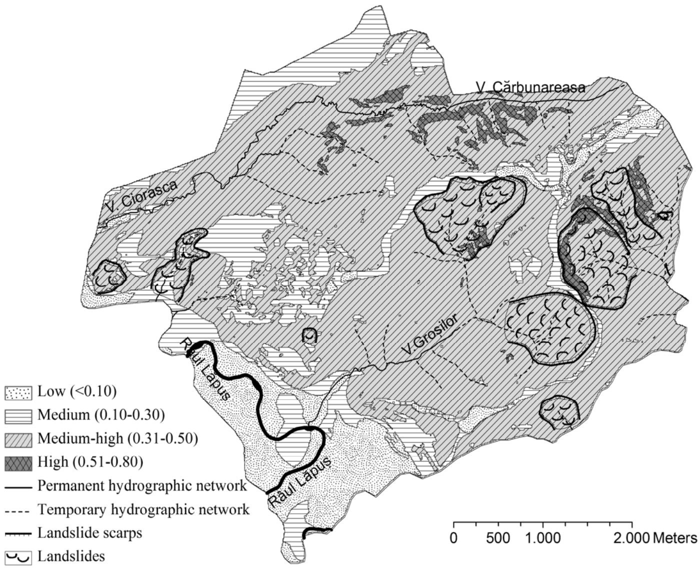

Fig. 4. Landslide susceptibility map of the Groşi area, generated by applying the legislative methodology.

The validation of the results included 89.8% of the mapped landslides in the medium-high susceptibility class (Km between 0.31-0.50) and 6.6% in the high susceptibility class (Km between 0.51-0.80). Taking into consideration the fact that the very high susceptibility class (Km> 0.80) is usually attributed in practice to active, massive landslides, which is not the case in the study area, the absence of such a class is seen as a valid result. In addition to this, the fluvial plain and the most extended interfluvial sectors were correctly classified in the low landslide susceptibility class. Therefore, the overall susceptibility map was considered as satisfactory and realistic.

5. 2. Applied statistical methodology

The landslides used to generate the susceptibility map of the Groşi area were represented by the landslides DJ 182B (I), Ocoliş (III), Dâmbeni (IV), Habra (VI), Strujereilor (VII), and the test set used for validation included landslides DC 79 (II), La groape (V), Bulbuc (VIII) and DN 18B (IX) (fig. 2).

The factors selected for the multivariate statistical analysis were the Digital Elevation Model, slope, aspect and drainage density derived from the DEM, a geology grid and a land use grid. The latter two included the same lithology and land use classes used in the previous section (table 2).

The landslide and factor layers were transformed into grids with 10 m resolution. Based on a reclassified landslide grid with the value 0 for non-landslide pixels and 1 for landslide pixels, 400 randomly generated pixels were selected and used to extract 400 pixels as samples from each factor grid.

These were eventually used to determine the coefficients of the logistic regression.

The susceptibility map (fig. 5) was generated using the Map Algebra included in the ArcGis9.3 software, multiplying each original grid by its respective coefficient, thus, applying the results of the logistic regression to the whole study area. Reclassifying the results according to the susceptibility classes previously employed in the legislative method, 20.0% of the study area was included in the low susceptibility class, 53.6% in the medium susceptibility class and 26.4% in the high susceptibility class.

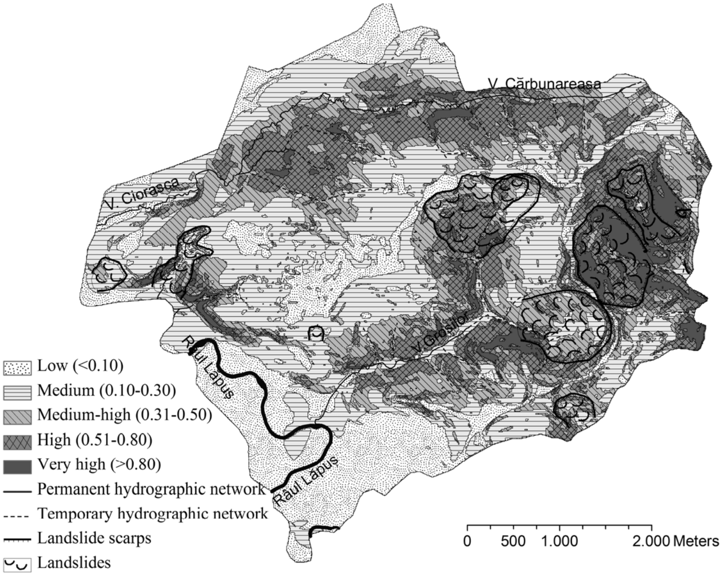

Fig. 5. Landslide susceptibility map of the Groşi area, generated by statistical analysis.

In order to validate the capacity of the statistical model to predict future landslides, the testing set of landslides was transformed into a grid and using Map Algebra it was statistically

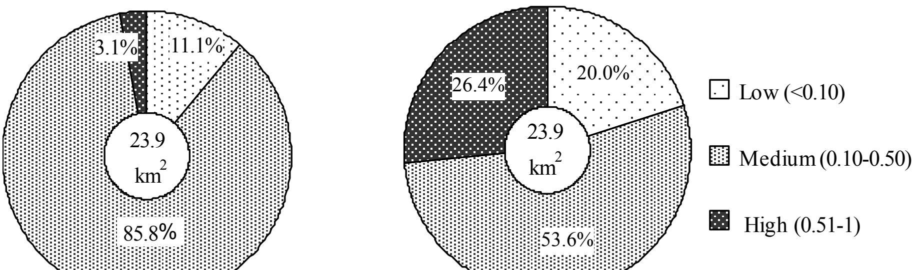

Fig. 6. Percentage of the study area classified in the three susceptibility classes, according to the legislative method (left) and statistical method (right).

compared to the susceptibility grid, already classified into the 5 detailed susceptibility classes (fig. 5). Thus, only 2.2% of the mapped landslides were included in the low susceptibility class, 19.0% in the medium class, 34.8% in the medium-high class, 27.3% in the high class and 16.7% in the very high susceptibility class, indicating a good validation of the model.

Fig. 6 illustrates the percentage of the study area included in the three susceptibility classes from the two sets of results. At first sight, the statistical method seems to overestimate the class of high susceptibility (26.4%), although this is validated by 44% of the mapped landslides and also by past landslides with dramatic activity, like the Dâmbeni landslide (fig. 2) which on May 13th 1977, moved on a distance of up to 12 m and required the evacuation of several families.

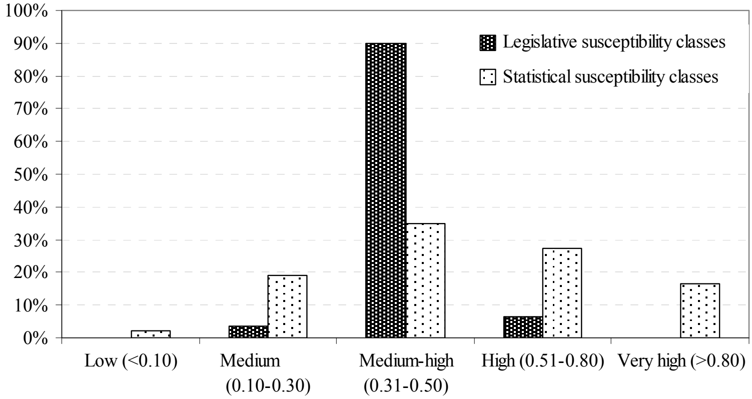

Fig. 7. Percentage of test landslides mapped in each susceptibility class.

On the other hand, only 6.6% of the mapped landslides (fig. 7) are included in this category by the legislative susceptibility map. Based on field experience and the observation of recent reactivations inside past landslides, the results of the statistical method are closer to reality than those of the legislative one.

In what concerns the medium susceptibility class, the legislative results suggest a general condition of the Groşi area as susceptible to shallow landslides. The statistical results indicate the same tendency, but to a lesser extend, nevertheless, characterising more than half of the study area (fig. 6).

The areas with low susceptibility generally coincide for both sets of results. Thus, the interfluvial sector and the fluvial plain of the Lăpuş River were mapped in this category. Nevertheless, the stability of the interfluvial band depends of the time scale used for its analysis, as some narrower sectors are already being affected by a regressive evolution of the landslide scarps, determined by mud flows and slumps. Eventually, this would damage the local roads which generally follow the intefluvial surface.

Finally, both susceptibility maps indicate the Cărbunăreasa Valley as highly susceptible to landslides, although there are no visible traces of landslide activity. A possible explanation for this result would be the influence of the drainage density which has rather high values in this area. However, excluding this factor would reduce the level of susceptibility from the southern slope which is highly affected by landslides. Further analysis of this aspect is still required.

6. PROBABILITY OF LANDSLIDE OCCURRENCE IN THE GROŞI AREA

Landslide data related to the moment of occurrence and intensity of the past events is available only for recent activations and reactivations (for the last 40 years). Thus, the years with known landslide activity were: 1970, 1977 (with the particular activation of Dâmbeni landslide on May 13th), 1985, 1988, 2002, 2005, 2007 and 2010. Knowing the variation of annual rainfall for the 1908-2007 interval (fig. 8), it was possible to compare the years with landslide activity with those of higher than average rainfall.

What is easily noticeable is that the years with known landslide activity generally have an annual rainfall of 950-1150 mm, following a period of 2-3 years with rainfall values between 600-800 mm/year. This situation has an average return period of 1/7 years. Another landslide triggering condition is a succession of several years with annual rainfall above the multiannual average (900 mm/year), which is the case for the landslide reactivations which took place in 2002.

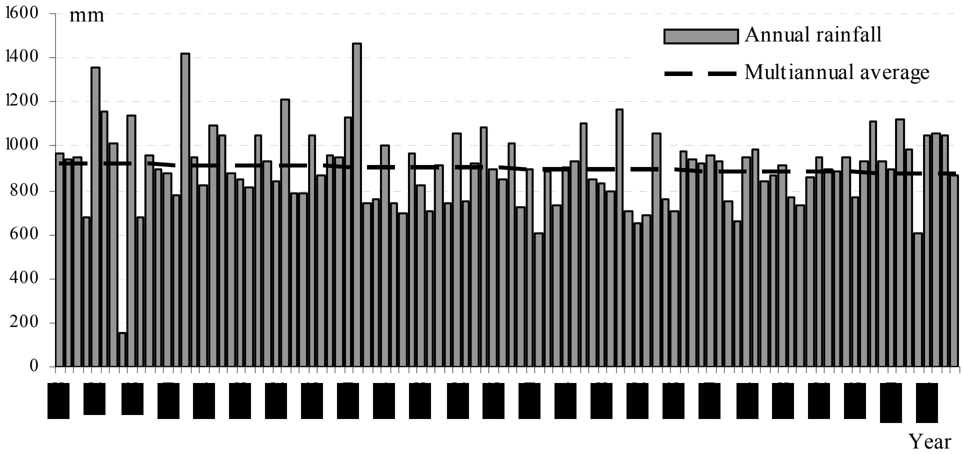

Fig. 8. Annual rainfall variation at Baia Mare meteorological station (1908-2007) (Data sources: 1908-1970 http://www.ncdc.noaa.gov/ghcnm/, 1971-2007 PUG Baia Mare (2010).

The landslide volumes differ according to the mapped surfaces of the affected areas, but a specific characteristic of the Groşi area is the occurrence of several adjacent smaller landslides which eventually converge, forming a larger surface. The situations when larger failures take place at once are less frequent. Therefore, an average magnitude of 40000 m^3 was inferred from the estimated landslide volumes, which generally characterises the most frequent events (comparable to landslide DN 18B, see fig. 2) and corresponds to a return period of 1/7 years or less. An average volume of 600000 m^3 characterises larger events (May 13th, 1977, Dâmbeni landslide) for which the return period is estimated at 1/30 years.

7. CONCLUSIONS

Using two different methods which combine heuristic reasoning with computer-assisted models, the landslide susceptibility estimated for the area of study indicates in both cases a general condition for most of the territory of medium and medium-high susceptibility, given by high annual rainfall and the presence of contractile clays as covering deposits.

The areas mapped as high and very high susceptible to landslides differ to a great extent between the two models, 3.11% in the case of the legislative model and 26.40% for the statistical analysis. This is not necessarily considered an error, because the two methods use different principles.

When considering the legislative methodology, the most important problem is the process of establishing the value of each coefficient, which depends to a great extend on the experience and field knowledge of the specialist who analyses the hazard, therefore it is a rather subjective endeavour which needs a more detailed description of factor classes, especially with quantitative specifications. This limitation might be the cause for mapping the Cărbunăreasa Valley as highly susceptible to landslides, although no past landslides were identified there.

As local authorities use the legislative methodology to define hazard and risk areas, comparing the results with those of an alternative method, like the statistical analysis, could correct subjective errors and would give a better understanding of the local processes.

Although it requires further information and analysis, a general estimation of the landslide probability was also determined for the Groşi area, characterised by landslides with an average magnitude of 40000 m^3 and a return period of 1/7 years, and not so frequent (1/30 years), larger and potentially more damaging landslides of 600000 m^3.

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Note: *This work was possible with the financial support of the Sectoral Operational Programme for Human Resources Development 2007-2013, co-financed by the European Social Fund, under the project number POSDRU/107/1.5/S/76841 with the title "Modern Doctoral Studies: Internationalization and Interdisciplinarity".*