Forum geografic. Studii și cercetări de geografie și protecția mediului
Volume 10, Issue 1 / June 2011, pp. 70-77
(www.forumgeografic.ro) **DOI**: 10.5775/fg.2067-4635.2011.021.i

Landslide assessment: from field mapping to risk management. A case-study in the Buzău Subcarpathians

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Received on <December 30, 2010>, revised on <February 12, 2011>, accepted on <April 25, 2011>

Abstract

Landslide risk management represent the final steps within a long process of evaluation that starts with detailed field observation. Based on geomorphological field mapping and the additional support offered by other methods and devices (aerial photos or remote sensing images, GPS and total station surveys, statistical analysis, numerical modelling etc.), landslide susceptibility and hazard assessments offers compulsory information for risk mapping. Unfortunately, there are still papers and even legislative initiatives which skip these important steps, offering results which can be at least severely arguable. The present paper is focusing on highlighting a proper methodology for landslide risk management, having as a case-study a small catchment typical for the Romanian Curvature Carpathians-Subcarpathians contact (Muscel Valley). Within this space of 19.6 km^2, the risk management assessment started with detailed geomorphological mapping, providing information for landslide inventory. Based on this inventory, statistical analysis allowed the susceptibility assessment, and through additional information like landslide frequency and magnitude, triggering threshold and its recurrence interval, landslide hazard assessment and mapping were performed. Finally, risk analysis, assessment and management, outlined by a risk map, finished the procedure, aiming to provide useful information for risk governance.

Keywords: *landslide risk, mapping, small catchment, the Subcarpathians.*

Rezumat. Evaluarea alunecărilor de teren: de la cartarea pe teren la managementul riscului. Studiu de caz în Subcarpații Buzăului

Managementul riscului la alunecări de teren reprezintă etapa finală a unui proces de evaluare de lungă durată, care începe cu observaţii de teren detaliate. Pe baza cartărilor geomorfologice de teren şi a suportului adiţional oferit de alte metode şi mijloace tehnice (aerofotograme şi imagini satelitare, ridicări GPS sau cu staţii totale, modelare numerică etc.), evaluarea susceptibilităţii şi hazardului la alunecări de teren oferă informaţii obligatorii pentru cartarea riscului. Din nefericire, încă mai există lucrări şi chiar iniţiative legislative care fac abstracţie de aceste etape importante, oferind rezultate care pot fi considerate cel puţin discutabile. Lucrarea de faţă urmăreşte să descrie o metodologie adecvată managementului riscului la alunecări de teren, având ca studiu de caz un bazin hidrografic mic, tipic pentru contactul Carpaţilor şi Subcarpaţilor de la Curbură (bazinul Muscelului). În cadrul acestui spaţiu de 19.6 km^2, managementul riscului a debutat printr-o cartare geomorfologică de detaliu care a furnizat informaţii pentru realizarea unei inventarieri a acestora. Pe baza acestei inventarieri, analiza statistică a permis evaluarea susceptibilităţii iar cu ajutorul informaţiilor precum corelaţia frecvenţă-magnitudine, praguri de declanşare şi interval de recurenţă, s-a realizat evaluarea şi reprezentarea grafică a hazardului la alunecări. În final, analiza, evaluarea şi managementul riscului au dus la schiţarea hărţii de risc, care a finalizat procedura şi care urmează să furnizeze informaţii utile pentru guvernarea acestuia.

Cuvinte-cheie: *risc la alunecare, cartare, bazin mic, Subcarpaţi.*

INTRODUCTION

The Buzău Subcarpathians, as a part of the Curvature Subcarpathians, and especially their inner sector, represents an area severely affected by a wide range of landslides. Their morphological, morphometrical and morphodynamic complexity represents the combined result of numerous favouring (heterogeneous and predominantly poor-consolidated sediments), preparedness (long-lasting autumn rains, rains overlapping snowmelt, summer torrential rainfalls) and triggering (certain values within the above-mentioned rainfalls, certain earthquakes) factors.

The main purpose of this paper is to gather all the requested data for obtaining a risk map, constituting also an example of methodological approach, in which the risk is regarded as the logic product of the inventory-susceptibility-hazard assessment and mapping succession. We have considered only those landslides triggered by precipitation, the earthquakes not being taken into consideration in this application as triggering factor. The case-study is represented by Muscel, a small catchment situated on the border of the Buzău Subcarpathians and Carpathians.

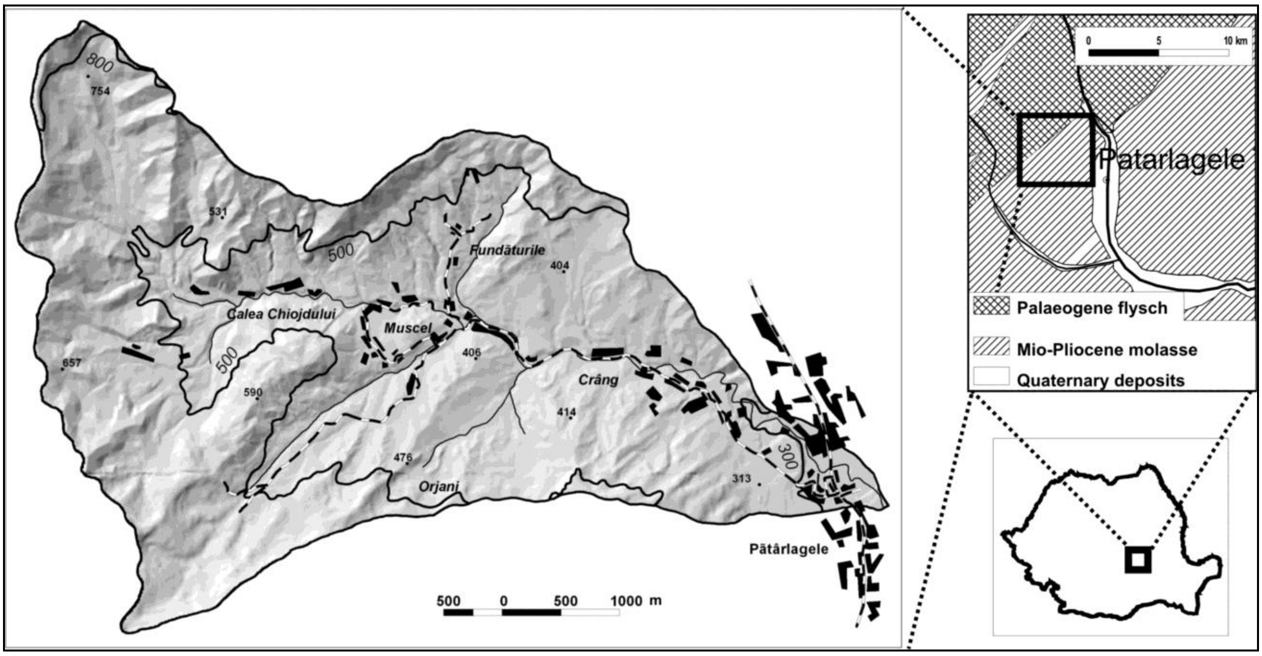

Fig. 1 Study area

STUDY AREA

The main reason for picking-up the Muscel Catchment (Fig. 1) as study area is due to the fact that it represents a typical Curvature Carpathians-Subcarpathians basin from several points of view: an almost equal distribution of Paleogene flysch - Mio-Pliocene molasse – Quaternary deposits; petrographic and structural-controlled relief morphology and morphometry; land-cover and land-use; settlements distribution and structure.

Covering an area of 19.6 km^2, Muscel Catchment is carved in the east-facing slope of Manta-Muscel Hill and it extends on an altitude of 629 m, between Pătârlagele Peak (909 m) and the Buzău Valley (280 m). There is a clear correlation between the relief and the lithological background: the upper sector of the catchment, developed on schistose flysch formations, is characterized by steep slopes (affected mainly by sheet wash, gully erosion and rarely by rock falls), narrow valleys, high summits (Pătârlagele Peak, 909 m), 6-6.5 km/km^2 fragmentation density, 30-50° average slope and a 300-350 m relief energy. The middle sector, corresponding to Mio-Pliocene schistose and marly-clay formations, features rounded ridges, slopes affected by superficial slides and flows, wider valleys, lower values of fragmentation density (3-4 km/km^2) and depth (50-100 m) and average slopes of 5-30°. The lower sector, built on the Quaternary terrace deposits of the Buzău river, shows depleted slopes (under 5°) and lower values of fragmentation density (2-2.5 km/km^2) and depth (10-20 m) (Bălteanu & Micu, 2009).

Among the climatic features, the rainfalls are showing maximum implications in slope modeling, either as long-lasting autumn rains or concentrated episodes of summer heavy rains (177,8 mm in 24 hours, on the 2nd of July, 1975). The temperatures may be considered as landslide preparing factors only in spring, when the snowmelt may be overlapped by spring showers. The annual precipitation regime registers means of 630-700 mm, with a minimum of 350 mm and a maximum of 1 200 mm.

The main land cover class is represented by forests (41.5%); 33% is covered by grasslands and pastures and 12.3% by old, almost destroyed orchards, which are used in present mainly as hayfields, resulting large areas prone to landslides.

DATA AND METHODS

In order to obtain a landslide risk map, several steps should be followed, always taking into consideration the quantity and especially the quality of the input data on one hand, and the working scale-adapted methodology, on the other hand. The methodologies for obtaining such maps are largely described in the actual international literature (ALARM FP5, MountainRISKS FP6 - related). Among some of the (many) new examples are: Castellanos Abella & vanWesten (2008), Gulla et al. (2008), Melchiorre et. al. (2008), vanWesten et al. (2008) (susceptibility); Brunettil et al. (2010),

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Crozier (2005), Holub & Fuchs (2009), Hungr et al. (2008), Pasuto et al. (2004)(hazard); Castellanos Abella & vanWesten, (2007), Chung and Fabri (2008), Remondo et al. (2008), Zezere et al. (2008).

The risk map is based on the hazard map, which is realized taking into account the susceptibility map (Glade et al, 2005, Lee & Jones, 2004). On each step, one may take into consideration the above-mentioned relationship. Based on that, a certain approach, either qualitative or quantitative (Micu, 2008) should be used for reliable results. If a transition from a quantitative method to a qualitative one may be used based on data depletion, the other way around (from qualitative to quantitative) may induce a lot of potentially propagating uncertainties, especially if used at the beginning of the process.

Therefore, adapted for a data-scarce environment, employed a combination of approaches, starting with quantitative methods but finishing with a qualitative one, transition conditioned by the quality of the available data.

The GIS, built under ArcView 3.2, contains topographical maps 1:10000, geological map 1:100000, improved with terrain-based geological sketches (i.e. superficial formations map, Institute of Geography archive) and aerial photos from 2005, based on which it was developed a 10x10 m/pixel DEM and also the land-cover map. The landslide inventory was based on field mapping, aerial photo interpretation, DGPS measurements (Thales Mobile Mapper) and total station surveys (Sokkia E 610).

The landslide susceptibility map was based on bivariate statistical analysis (*joint conditional probability*) and completed with a frequency-magnitude relationship analysis, was useful for a quantitative hazard map.

Vulnerability and risk were assessed in a qualitative manner, based on an expert judgment analysis.

RESULTS AND DISCUSSIONS

Landslide inventory

In Muscel catchment, the landslides are very well represented, and their typology (age, movement type, depth, structure, form, direction) is the result of the lithological favourability combined with poor-quality forest coverage.

The majority of the landslides are being single-patterned, shallow and translational. Along the main rivers (Muscel, Balosin, Saramura, Maloteasa) are characteristic rotational displacement, superficial (1-2 m deep) caused by river erosion (slope undercut). They are showing 20-500 m lengths, rarely exceeding 20-30 m in width. Their displacement rates (from 3 mm/min to 13 m/month) rank them as moderate to rapid (Cruden and Varnes, 1996). Generally, the shallow slides with an elongated profile (length/width ratio above unity) characterize steep slopes (>15°), while an ellipsoidal shape (length/width ratio under unity) is characteristic of more gentle slopes (<15°) (Bălteanu & Micu, 2009).

The landslide inventory (Fig. 2) includes (2008) 147 cases of active landslides (79 ha total surface) and also very large areas (31.5% of the entire catchment) corresponding to dormant landslides (605 ha). Their seasonal and annual dynamics are showing an increased activity interval between March-July (0.20-1.50 m retreats of main scarps), caused by spring showers sometimes overlapping snow-melt. Subsequently, the slides become almost generally covered by grass, but keep a reactivation potential over the following years.

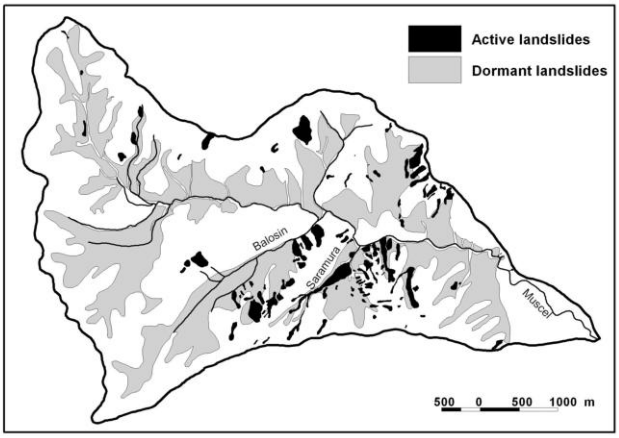

Fig. 2 Landslide inventory

Landslide susceptibility

Based on the previously-obtained inventory, landslide susceptibility, defined as the space component of occurrence probability, was assessed using a quantitative approach, based on bivariate statistical analysis.

The method, applied and described in detail by Bălteanu and Micu in 2009, followed several major steps:

- defining independent variables: simple data, rather easy to obtain like slope, aspect, lithology, land cover;
- determining landslide distribution on each class of each previously-considered parameter and each parameter;
- obtaining a non-classified susceptibility map (values from 0 to 1, representing a future landslide occurrence probability based on the prior probability for each variable and on all of their conditional probabilities) (Fig. 3);

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- classifying the previous map (splitting the data-set into training/ estimation and validation landslides);
- obtaining the classified landslide susceptibility map (Fig. 3), based on the prediction/ validation curves (Fig. 4);
- susceptibility map validation, using 2005 landslides, not included in the initial landslide inventory.

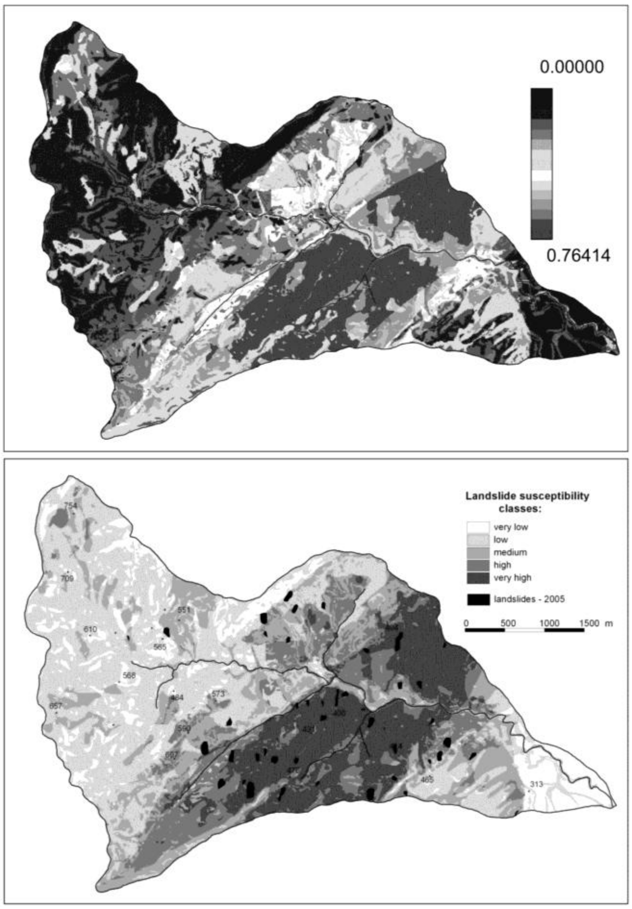

Fig. 3 Landslide susceptibility map (unclassified - above, classified - below)

The landslide susceptibility map shows clearly the mid sector of the catchment, corresponding to loose formations belonging to Mio-Pliocene molasse formations, as being the most landslide- prone from the point of view of space occurrence probability.

Landslide hazard

The first information concerning landslide hazard, regarded as the probability of occurrence in space and time, was given by the first morphodynamic maps (Bălteanu, 1975; Bălteanu & Micu, 2009). Along 4 years (1969-1972), an area of 10.12 km^2 situated in the middle catchment, was mapped periodically, the result being an assessment of spring and summer as the seasons marked by the most intense landslide activity.

Based on that assumption, a further and more detailed assessment of the most landslide-prone months was done using Angot Pluvial Index (Dragotă et. al., 2008; Bălteanu & Micu, 2009). Based on this assessment, the summer proved to be the season showing the highest favourability for landslide, while June represents the month marked by most landslides occurrence, followed by May and September.

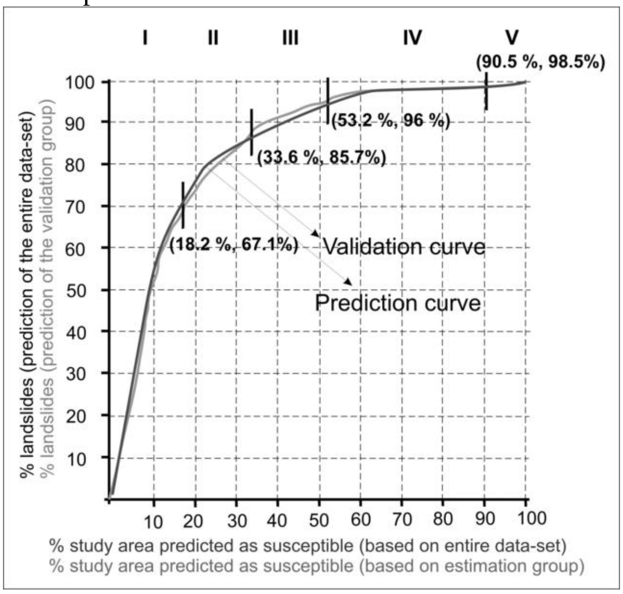

Fig. 4 Prediction-validation curves

A quantitative hazard assessment should mean the completion of the susceptibility map with information concerning: landslide frequency-magnitude relationship, typology of existing landslides, presumed landslides typology, occurrence factor and occurrence threshold, and also the recurrence interval of that particular threshold. Hazard assessment is based on the following assumption: a certain combination of precipitation quantity-duration, evaluated in present as producing landslides of a certain magnitude (a certain scenario), will have the same effect (from the point of view of landslide typology and affected surface), each time it will occur in the future. Knowing the recurrence interval of that particular threshold (determined using Gumble function), one can model corresponding scenarios.

The probability that a pixel can be affected by a landslide, within each scenario, is given by the formula (Zezere, 2004):

$$P = 1 - \left(1 - \frac{S_T}{S_{Sc}} \times pred\right)$$

where:

S_T – total surface affected by landslides within a certain scenario; S_{Sc} – total surface of a particular susceptibility class; Pred – prediction value of that particular susceptibility class.

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During 2005, a year of maximum rain activity (the second ever recorded, after 1975, with four months - May, July, September and October - marked by mean monthly values above 130 mm), the landslides occurred in Muscel Catchment (mainly shallow, between 0.3 – 1.5 ha) were mapped after each rainy episodes. This helped, on one hand, on validating the landslide susceptibility map (near values of occurred and predicted landslides; Bălteanu & Micu, 2009) and on the other hand, outlined several landslide-generating rainfall thresholds. Combined with the subsequent field mappings (2006-2009), at least two thresholds may be taken into account: 30 mm in 24h and 50 mm in 48h. For Pătârlagele weather station (very close to the confluence of Muscel and Buzău, therefore considered representative), the recurrence interval for maximum precipitation in 24 and 48 hours are 52.4 and 63.3 mm (for 20% probability) (Micu et al, 2010), and values of 30 mm/24 h and 50 mm/48 h may occur annually. Taking into consideration the landslides caused by 30 mm/24 h, a landslide hazard map, based on the previous formula, was obtained (Fig. 5). This is the way in which, fulfilling all the previous requirements, one may model all the scenarios needed.

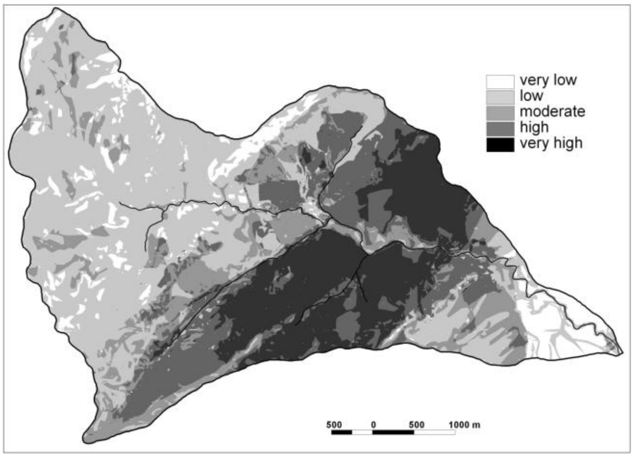

Fig.5. Landslide hazard map for 30mm/24h scenario

Landslide risk

Based on the information provided by susceptibility and hazard, one may go one step forward and obtain a landslide risk map. In order to do that, it is required a vulnerability assessment.

Vulnerability and its components represent a rather delicate problem, especially due to the social, economical and political framework of today's Romania, and subsequently, of our study-area.

An objective assessment of vulnerability should contain (Weichselgartner, 2001) exposure, preparedness, prevention and response analysis. If exposure, regarded as identifying, inventory and assessment of infrastructure, properties or individuals through direct or indirect consequences, may be rather easily achieved, the vulnerability assessment gets complicated when dealing with preparedness, prevention and their means, and also with the measures for coping or mitigating the potential social or economical losses.

For today's Romania, some elements on which vulnerability assessment should be based on are quite difficult to quantify. Issus like Government or EU subventions, insurance market trends are often considered as highly confidential. This aspect may be related with resilience, as the society's (on all its levels) response capacity in the framework of EU joining (regarded as a "risk" by a lot of people).

This is the moment in which a change from a quantitative assessment to a qualitative one has been done. The attempt to quantify a maximum loss potential through monetary units (humans being excluded as elements at risk due to the absence of previous victims and landslide typology) proved to be difficult, caused by the lack of information derived from the confidential status of the insurance policies and submitted subvention files.

Therefore, it was considered more reliable a qualitative risk assessment, the elements at risk and vulnerability being ranked through attributes varying from "*no damages/interruptions*" to "*quas-itotal damage/interruption*", reflecting a particular potential damage level. Through primarily estimations of the presence/absence of insurances or subventions and a parallel analysis of building/maintenance and salary/income, seven classes of elements at risk have been established (some with sub-classes), each one with its correspondent vulnerability class (Table 1).

The result was a vulnerability map (Fig.6) showing that the majority of Muscel Catchment corresponds to medium vulnerability class, followed by high vulnerability. Very low and low values are corresponding to the reinforced concrete houses or facilities built in the lower sector of the catchment, on Buzau River terraces. Also, in these classes were included the insured orchards who benefits also by governmental and EU subventions.

The next step is the risk map (Fig. 7) which is represented by the overlay of hazard and vulnerability maps, through the combination of the specific classes (Table 2).

Risk analysis – highlights the level of threat; landslide magnitude (very low-to-medium) compensates their high frequency (yearly in case of shallow slides) but they cover very large areas, including the entire catchment in medium-high risk.

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Risk evaluation – regarded as a cost-benefit analysis, is rather difficult to be performed. The costs directed to prevention measurements (drainage systems, retention walls, reforestations) are considered by the local authorities as subsidiary to more pressing problems, like transportation infrastructure improvement, water supply, domestic waste disposal, educational infrastructure improvement. Within acceptable risk may be included those areas for which the owner considers that potential damages are not important and therefore the damages are accepted without almost any interventions.

This category includes the pastures and grasslands situated at long distance to households and the forests from the upper catchment. Tolerable risk (meaning that the owner is aware of the potential damages but considers them inexpensive compared with the income and easy to mitigate with a certain cost that is willing to assume) includes the pastures and meadows situated in the villages vicinity, old orchards (more than 20-30 years old) or the shelters in the upper-middle catchment used for seasonal harvesting (Orjani, Fundături, Maloteasa, Balosin, Murătoarea).

Intolerable risk (the owner is well aware of the potential damages, and he is willing to invest any funds required by the coping and mitigation strategies) gathers the households (houses, annexes, gardens or other agricultural fields) from the Saramura-Muscel confluence or Crâng village, and also the productive, young orchards from Crâng, Muscel or Fundăturile villages.

Table 1 Elements at risk and their vulnerability

Elements at risk		Score	Vulnerability	Explanation (damage type)
Buildings	Reinforced concrete	0.1	Very low	Weakly affected structure, unaffected stability, damages at the construction joints.
	Concrete, masonry	0.3	Low	Small cracks, unaffected stability, repairs that can be postponed.
	Wood, masonry	0.5	Medium	Heavily deformed, resistance structure affected, evacuation needed.
	Wood, clay	0.8	High	Partially destruction, evacuation needed.
	Clay	0.9	Very high	Almost entire destruction, evacuation needed, full reconstruction.
Roads	Paths	0.1	Very low	Minor damages, access undisturbed.
	Stone	0.5	Medium	Repairs that implies tens-hundreds cubic meters of rough material.
	Asphalt	0.8	Large	Repairs that implies tens-hundreds cubic meters of rough and fine materials.
Electricity network		0.6	Large	Ruptures of electricity cables, pillar foundations affected, immediate repairs.
Agricultural fields	With subventions, insured	0.2	Low	Seasonal character of potential damages can be easily covered by subventions and insurances.
	Without ubvention, not insured	0.5	Medium	Seasonal character of potential damages, acceptable costs.
Orchards	With subventions, insured	0.2	Low	Production suffers seasonal losses, recovering costs are acceptable and covered by insurances.
	Without subvention, not insured	0.7	Medium	Production suffers seasonal losses; damages are transmitted from one year to another, but with acceptable repairing costs.
Pastures, grasslands	With subventions, insured	0.2	Low	Production suffers seasonal losses, recovery costs are covered and they are not urgent and don't imply the stop of other production activities.
	Without subvention, not insured	0.6	Medium	Production suffers seasonal losses, recovery costs are not covered but they are not urgent and don't imply the stop of other production activities
Forests	With subventions, insured	0.2	Low	Reduced magnitude damages, which are covered by insurance and by selling the resulted material (wood).
	Without subvention, not insured	0.4	medium	Reduced magnitude damages, which are covered only by the selling of resulted material (wood).

Risk management – represents the most difficult aspect within risk studies, because it suppose the implementation of prevention and mitigation policies based sometimes on tough, correctional

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measurements. It is a vital moment because the entire scientific process described before should result in convincing the authorities to accept and implement certain requirements. For Muscel Catchment, such measurements should be taken in order to reduce the potential damages caused by landslides: river banks consolidation along sectors affected by lateral erosion, causing retrogressive slides (Saramura - Muscel confluence); reducing flowing speed by building thalweg steps (Muscel, Calea Chiojdului); gabion reconstructions; stop the remove of buckthorn bushes for fence-building; rejuvenation of plum orchards; stop the construction of buildings in very high risk areas and adapt the destination of land-use in high risk areas.

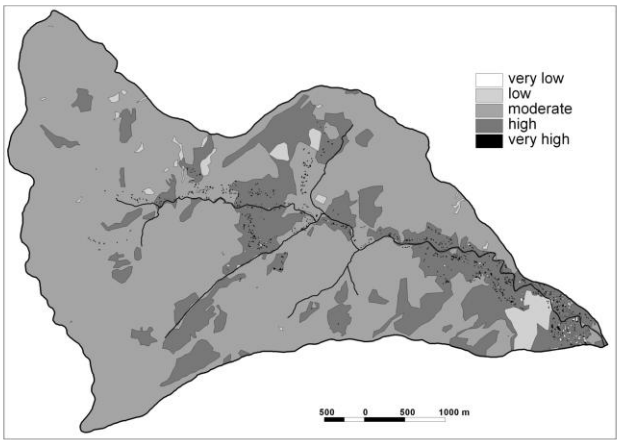

Fig. 6 Vulnerability map

Table 2 Risk matrix

Hazard	Vulnerability				
	Very low	Low	Medium	High	Very high
V. low					
Low					
Medium					
High					
V. high					

Source: after Bell, 2007

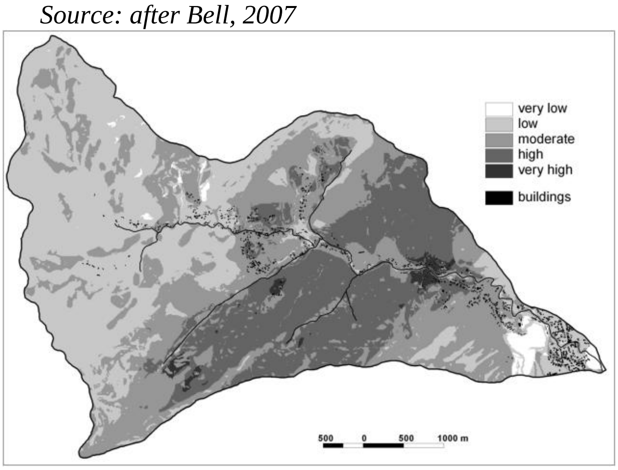

Fig. 7 Landslide risk map

CONCLUSION

The risk assessment and mapping is the final step of a complex procedure, which starts with susceptibility and hazard assessment (and for sure, not the other way around). Along this succession of activities, one may realize the importance of making a correlation of the working scale with the proper methodology. Likewise, it is strongly required a correlation between the quantity and especially the quality of the data and the proper methodology. The two approaches have both advantages and draw-backs: a quantitative approach gives indeed good and objective results, but it requires a lot of data, maybe not all the time available; qualitative approach requires more easy to obtain data, but due to their more general content, it may give good results only if carefully handled, because its rather subjective estimations, based on the expert's knowledge or judgement.

As for Muscel Catchment, taking into account the presence of large areas belonging to high risk classes, it implies a more active involvement of local authorities in realizing a common landslide data set used for a proper risk assessment, vital in establishing local development plans.

REFERENCES

Bălteanu, D., (1975). *A morphodynamic map in the Buzău Subcarpathians*, in *Proceedings of the Applied Geomorphology and Geomorphological Cartography Workshop*, Iaşi (*in Romanian*)

Bălteanu, D & Micu, M., (2009). *Landslide investigation: from morphodynamic mapping to hazard assessment. A case-study in the Romanian Subcarpathians: Muscel Catchment*, in *Landslide processes: from geomorphologic mapping to dynamic modeling*, CERG Editions, Strasbourg, France.

Bell, R., (2007). *Lokale und regionale Gefahren- und Risikoanalyse gravitativer assenbewegungen an der Schwäbischen Alb*, Erlangung des Doktorgrades (Dr. rer. nat.), Unib. Bonn

Brunetti, M. T., Peruccacci, S., Rossi, M., Luciani, S., Valigi, D., Guzzetti, F., (2010). *Rainfall thresholds for the possible occurrence of landslides in Italy*, Nat. Hazards Earth Syst. Sci., 10, pp. 447–458.

Castellanos Abella, E. A., van Westen, C. J., (2007). *Generation of a landslide risk index map for Cuba using spatial multi-criteria evaluation.*, Landslides: journal of the International Consortium on Landslides, 4, pp. 311-325

  DOI: 10.5775/fg.2067-4635.2011.021.i

Castellanos Abella, E.A., Van Westen, C. J., (2008). *Qualitative landslide susceptibility assessment bymulticriteria analysis: A case study from San Antonio del Sur, Guantánamo, Cuba*, Geomorphology 94, Elsevier, Netherlands, pp. 453–466

Chung, C. J., Fabbri, A. G., (2008). *Predicting landslides for risk analysis — Spatial models tested by a cross-validation technique* Geomorphology 94, Elsevier, Netherlands, pp. 438–452

Crozier, M. J., (2005). *Multiple-occurrence regional landslide events in New Zealand: Hazard management issues*, Landslides: journal of the International Consortium on Landslides, 2:247–256

Cruden, D. M., Varnes, D. J., (1996). *Landslide types and processes*, in Turner A. K. and Schuster R. L. (*Eds*.) *Landslides: investigation and mitigation*. Washington, D.C., National Academy Press. 247:36-75.

Dragotă, Carmen, Micu, M., Micu, Dana, (2008). *The relevance of pluvial regime for landslides genesis and evolution. Case-study: Muscel Basin (Buzău Subcarpathians), Romania*. in *Present Environment and Sustainable Development*, vol. 2, Iaşi

Glade, T., Anderson, M., Crozier, M., (2005). (Eds): *Landslide hazard and risk*. Wiley, Chichester

Gullà, G., Antronico, L, Iaquinta, P., Terranova, O., (2008). *Susceptibility and triggering scenarios at a regional scale for shallow landslides*, Geomorphology 99, Elsevier, Netherlands, pp. 39–58

Holub, M., Fuchs, S., (2009). *Mitigating mountain hazards in Austria – legislation, risk transfer, and awareness building,* Nat. Hazards Earth Syst. Sci., 9, pp. 523–537

Hungr, O., McDougall, S., Wise, M., Cullen, M., (2008). *Magnitude–frequency relationships of debris flows and debris avalanches in relation to slope relief*, Geomorphology 96, Elsevier, Netherlands, pp. 355–365.

Lee, E. M., Jones, D. K. C., (2004). *Landslide risk assessment*, Thomas Telford, London.

Melchiorre, C., Matteucci, M., Azzoni, A., Zanchi, A., (2008), *Artificial neural networks and cluster analysis in landslide susceptibility zonation*, Geomorphology 94, Elsevier, Netherlands, pp. 379–400

Micu, M., (2008). *Landslide hazard assessment in the inner Subcarpathians (Teleajen-Buzau sector)*, PhD. Thesis, manuscript (*in Romanian*), Institute of Geography, Bucharest

Micu M., Chendeş V., Sima M., Bălteanu, D., Micu, D., Dragotă, C., (2010). *A multi-hazard assessment in the Bend Carpathians of Romania*, in vol. (Edit. Glade, T., Casagli, N., Malet, J. P) *Mountain Risks: bringing science to the society*, CERG Editions, Strasbourg, pp. 11-19.

Micu, M., Bălteanu, D., (2009). *Landslide hazard assessment in the Curvature Carpathians and Subcarpathians, Romania*, Zeitschrift fur Geomorphologie, Suppl.3, 53, Stuttgart, Germany

Pasuto, A., Silvano, S., Tagliavini, S., (2004). *Evaluation of landslide hazard and risk in north-eastern Italy*, in A. Brebbia (edit) *Risk Analysis IV*, WIT Press

Remondo, J., Bonachea, J., Cendrero, A., (2008). *Quantitative landslide risk assessment and mapping on the basis of recent occurrences*, Geomorphology 94, Elsevier, Netherlands, pp. 496–507

van Westen, C. J.**,** Castellanos Abella, E. A., Sekhar, L. K., (2008). *Spatial data for landslide susceptibility, hazards and vulnerability assessment: an overview* In: Engineering geology, 102, 3-4, pp. 112-131

Weichselgartner, J., (2001). *Disaster mitigation: the concept of vulnerability revisited*, Disaster Prevention and Management Volume 10 . Number 2 . 2001 . pp. 85-94

Zêzere, J. L., Reis, E., Garcia, R., Oliveira, S., Rodrigues, M. L., Vieira, G., Ferreira, A. B., (2004). *Integration of spatial and temporal data for the definition of different landslide hazard scenarios in the area north of Lisbon (Portugal).* Natural Hazards and Earth System Sciences 4, pp. 133-146.

Zêzere, J. L., Garcia, R. A. C, Oliveira, S. C., Reis, E., (2008). *Probabilistic landslide risk analysis considering direct costs in the area north of Lisbon (Portugal)* Geomorphology 94, Elsevier, Netherlands, pp. 467–495

DOI: 10.5775/fg.2067-4635.2011.021.i