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RESEARCH ARTICLE

Quantitative evaluation of the risk induced by dominant geomorphological processes on different land uses, based on GIS spatial analysis models

Bilaşco ŞTEFAN[1,2], Roşca SANDA (✉)[1], Fodorean IOAN[1], Vescan IULIU[1], Filip SORIN[1], Petrea DĂNUŢ[1]

1 Faculty of Geography, "Babeş-Bolyai" University, 400006 Cluj-Napoca, Romania
2 Romanian Academy Cluj-Napoca Subsidiary Geography Section, 400015 Cluj-Napoca, Romania

Abstract Maramureş Land is mostly characterized by agricultural and forestry land use due to its specific configuration of topography and its specific pedoclimatic conditions. Taking into consideration the trend of the last century from the perspective of land management, a decrease in the surface of agricultural lands to the advantage of built-up and grass lands, as well as an accelerated decrease in the forest cover due to uncontrolled and irrational forest exploitation, has become obvious. The field analysis performed on the territory of Maramureş Land has highlighted a high frequency of two geomorphologic processes – landslides and soil erosion – which have a major negative impact on land use due to their rate of occurrence. The main aim of the present study is the GIS modeling of the two geomorphologic processes, determining a state of vulnerability (the USLE model for soil erosion and a quantitative model based on the morphometric characteristics of the territory, derived from the HG. 447/2003) and their integration in a complex model of cumulated vulnerability identification. The modeling of the risk exposure was performed using a quantitative approach based on models and equations of spatial analysis, which were developed with modeled raster data structures and primary vector data, through a matrix highlighting the correspondence between vulnerability and land use classes. The quantitative analysis of the risk was performed by taking into consideration the exposure classes as modeled databases and the land price as a primary alphanumeric database using spatial analysis techniques for each class by means of the attribute table. The spatial results highlight the territories with a high risk to present geomorphologic processes that have a high degree of occurrence and represent a useful tool in the process of spatial planning.

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E-mail: sanda.rosca@ubbcluj.ro

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1 Introduction

Risk represents the temporal probability of occurrence of geomorphologic processes and the extent of the events that can be seen in the field as effects upon the exposed population, material damages, and environmental changes. To identify the damages, one must consider the spatial probability of the risk processes and the vulnerability of the exposed elements (Cutter, 2001; Corominas, 2008). The cumulated risk zoning represents the process of dividing the territory into homogenous areas according to their present or potential degree of geomorphologic susceptibility, hazard, and risk (Corominas, 2008).

Quantitative risk evaluation (QRA) represents the approach requested by administration and trading companies because it allows the comparison of territories included in different risk classes and the cost-benefit analysis with the degree of tolerance and the acceptability of the risk-exposed system taken into consideration (Fell et al., 2008). In the category of geomorphologic processes affecting important territories in Romania, one must mention surface and deep erosion (Moţoc and Sevastel 1979, 2002; Ioniță, 2000; Dârja et al., 2002; Bilaşco et al., 2011) and landslides (Rădoane and Rădoane, 2006; Micu and Bălteanu, 2009; Armaş, 2011; Petrea et al., 2014; Roşca et al., 2015, 2016).

According to the EU Internal Security Strategy in Action from 2010, “Five steps to a safer Europe”, each country of the European Union must benefit at a national level from a multi-risk evaluation, the principles of these studies being also mentioned in the EUR 28615/2009 directive (Marzocchi et al., 2009).

In the analyzed territory, Maramureş Land, the main geomorphologic risk-determining processes are surface erosion and landslides, which have the inappropriate exploitation of agricultural and forest lands as a main causing factor. Because the present European[1)] and national legislations recommend the local authorities to have risk evaluations (at the level of financial damages), this study creates a complex model of GIS spatial analysis using the functions and extensions of the geoinformatic software ArcGIS 10.1 for the territory of Maramureş Land. This results in a quantitative evaluation of risk (RON/risk-exposed homogenous area) for different land use classes by considering the main geomorphologic processes occurring in the recent period of time in the study area and at the present land price.

The territory limited by the boundaries of Maramureş Land occupies an area of approximately 3376 km^2. It is spatially limited by the volcanic units of the Romanian Carpathians, namely, the Oaş and Gutâi Mountains in the west and southwest, respectively, and the Ţibleş in the south, while the eastern and southeastern boundaries are represented by the Rodnei Mountains (Ilieş, 2007). Its northern boundary coincides with the state frontier between Romania and Ukraine, spatially represented by the highest ridges of the Maramureş Mountains and the Tisa River (Fig. 1).

2 Database, methodology, and results

The databases used as the structural basis for the development of GIS spatial models represent one of the most important objectives. Choosing the most appropriate methodology for building the GIS models takes into consideration the structure, type, and accuracy of the databases. To achieve the aim of the present study, a specific GIS database was created and structured using thematic layers and different modeling levels according to the requirements of the spatial analysis models included in the more complex model (Table 1).

The risk identification model was based on the modeling of the main geomorphologic processes (soil erosion and landslides) and was developed using several database structures (primary, derived and modeled). Each element of the database is included in the complex model according to its specificity with the main purpose of determining the geomorphologic risk affecting each land use type (Roşca, 2015; Furtună, 2017).

To identify the spatial distribution of the different risk degrees, the study made use of the spatial analysis techniques based on models of territorial spacing, which are divided into three levels: the USLE model (used for identifying the surfaces vulnerable to soil erosion, which allows the prediction of annual average soil losses over the long term (Morgan et al., 1998; Singh and Phadke, 2006) for present conditions and proposed conditions), the model for determining the probability of landslide occurrence based on morphometric characteristics of the territory (used to identify vulnerable areas to mass movements), and the integration of the two models in a cumulative deterministic model used to identify spatial vulnerability.

The calculation and identification of areas with a specific risk degree was finalized, taking into consideration the qualitative value of the vulnerable areas and the land price per square meters (Fig. 2).

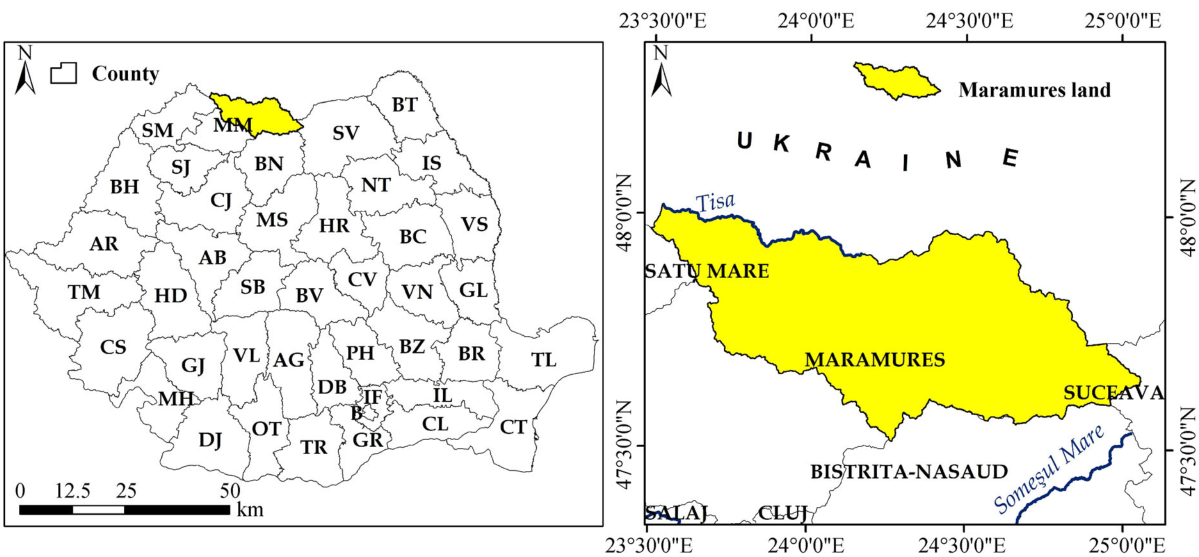

Fig. 1 Geographical position of the study area.

1) European Commission (2010). Risk Assessment and Mapping Guid elines for Disaster Management. Commission Staff Working Paper. Brussels, SEC (2010) 1626 final

Table 1 Database structure

No.	Database name	Type	Structure	Attribute	Origin	Level of modeling
1	DEM	Raster	GRID	Altitude (m)	Primary	Model level I (USLE)
2	Cover management	Vector Raster	Polygon GRID	Land use type Cover management factor	Primary Derived	
3	Slope length	Raster	GRID	Slope angle (%)	Modeled	
4	Soil	Vector Raster	Polygon GRID	Type Soil erodibility factor	Primary Derived	
5	Slope length	Raster	GRID	Length (m)	Modeled	
6	Erosion value	Raster	GRID	Soil loss (t/ha/year)	Modeled	
7	Hypsometry	Raster	GRID	Altitude (m)	Primary	Model level I (LANDSLIDES)
8	Slope	Raster	GRID	Slope angle (%)	Modeled	
9	Aspect	Raster	GRID	Aspect (8 direction)	Modeled	
10	Drainage density	Raster	GRID	Density (m/kmp)	Modeled	
11	Depth	Raster	GRID	Depth (m)	Modeled	
12	Wetness index	Raster	GRID	Value	Modeled	
13	Stream power index	Raster	GRID	Value	Modeled	
14	Profile curvature	Raster	GRID	Value	Modeled	
15	Plan curvature	Raster	GRID	Value	Modeled	
16	Landslide probability	Raster	GRID	Value (0 – 0.57)	Modeled	
17	Cumulative probability	Raster Vector	GRID Polygon	Classes (0–5)	Modeled	Model level II (cumulative probability)
18	Land use	Vector	Polygon	Land use type	Primary	Model level III (RISK EVALUATION)
19	Vulnerability	Vector	Polygon	Surface of cumulative probability/ Land use	Modeled	
20	Exposure	Vector	Polygon	Surface	Modeled	
21	Risk	Vector	Polygon	Surface Price/m^2 Reduction coefficient	Modeled	

The first approach level of the risk identification model is represented by the completion of the determinist models used to identify the vulnerability to the main geomorphologic processes.

To identify the areas susceptible to surface erosion and determine their spatial distribution, the RUSLE model (Romanian Soil Erosion Model), proposed by Moţoc et al. (1973) was implemented in a GIS environment. This model is based on the Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965). The modeling process used the GIS methodology that was employed for similar purposes in previous studies (Mitasova et al., 1998; Patriche et al., 2006; Bilaşco et al., 2009) using a raster database eventually included in the model for identifying the cumulated probability.

When analyzing the resulting database (Fig. 3), one notices the large spatial extension of areas with low values of surface erosion included in the low and medium vulnerability (values between 0 and 3 t/ha/year), which represents approximately 83% of the total territory. In Romania, the value of 2 t/ha/year represents a threshold value according to the studies made for the Romanian territory by Moţoc et al. (1979); therefore, in the present study, the territories with values larger than 3 t/ha/year need to be included in the medium high, high, and very high vulnerability, representing approximately 17% of the analyzed territory. The second category of vulnerability is spatially identified with slopes characterized by slope angles greater than 10 degrees and territories mostly used as arable lands, pastures, or deforested areas resulting from poor land management.

The cumulated probability can be modeled using the previously presented methodology by creating a database that can highlight the vulnerability degree to mass movements. The building of this database relies on a GIS spatial analysis model based on the modified methodology imposed by Romanian laws (H.G. 447/2003) and a model proposed by (Petrea et al., 2014), which takes into consideration only the morphometric elements as preparing factors for landslides in order to reduce the degree of

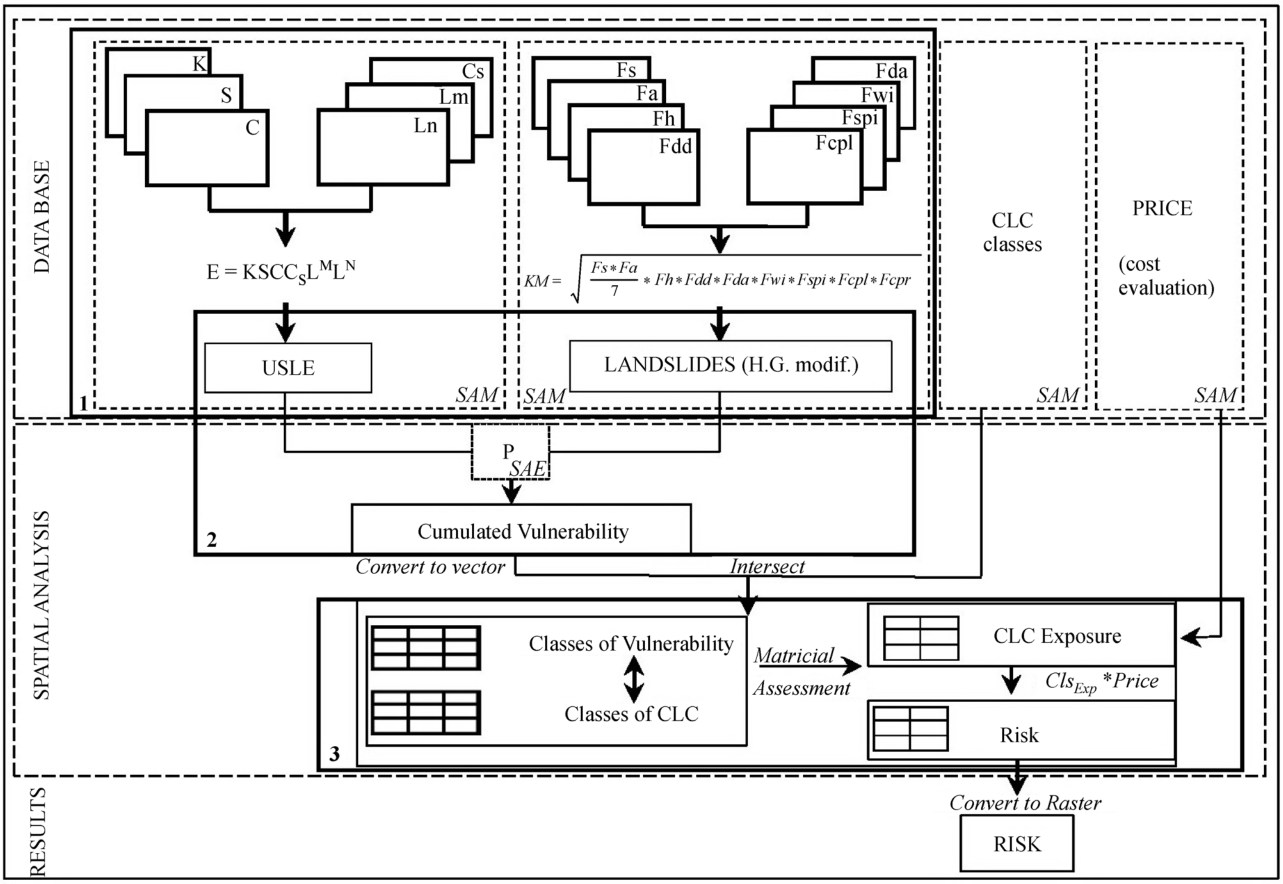

Fig. 2 Methodological flow chart of risk evaluation (where SAM – spatial analysis model, SAE – spatial analysis equation and 1,2,3–model level).

subjectivity and increase the accuracy of the database. The appropriate evaluation and classification of the factors included in the model represents an important stage in the building of heuristic landslide probability models (Carrara et al., 1992); thus, the main focus is placed on carefully selecting the variables according to their quality and relevance for the analyzed territory, the working scale and, last but not least, the practical utility of the results.

The results of the model, represented as a GRID type raster database, highlight the large territorial extent of the medium-high and high vulnerability classes, which correspond to highly deforested territories and areas with excessive animal grazing. The database that resulted from the application of the spatial analysis model was classified into 5 main landslide vulnerability classes, namely, low vulnerability 0–0.10, medium vulnerability 0.10–0.30, medium-high vulnerability 0.31–0.50, high vulnerability 0.51–0.80, and very high vulnerability 0.81–1, according to the methodological rules used in Romania (Roşca et al., 2016).

The quantitative analysis of the results for each administrative territorial unit included in the present study shows a large extent of the high landslide risk class in Poienile de sub Munte (7 km^2), Borşa (8.64 km^2), Moisei (2.66 km^2), Vişeul de Sus (10.5 km^2) and Săcel (0.59 km^2). These administrative territorial units (UATs) are located in the mountains, where deforested areas occupy large territories. These risk areas impose a risk on the human component (affecting tourist areas and access ways to inhabited areas), as well as on the components of the natural environment (the decrease in price for construction, agriculture, and forest exploitation land).

From the landslide vulnerability point of view, the analyzed territory is mostly included in the classes of medium and medium-high vulnerability, which determined a relatively high risk for environmental elements (Fig. 4).

The comparative analysis of the two types of vulnerability (Table 2) highlights major differences (low and very low soil erosion on large areas and high landslide vulnerability on large areas) in the UATs of Poienile de Sub Munte (252.83 km^2 and 221.53 km^2, respectively), Vişeul de Sus (395.05 km^2 and 331.24 km^2, respectively), and Borşa (354.13 km^2 and 285.42 km^2, respectively) due to morphologic and morphometric conditions (large fragmentation depths on large areas, low fragmentation density, steep slopes, the position of the administrative

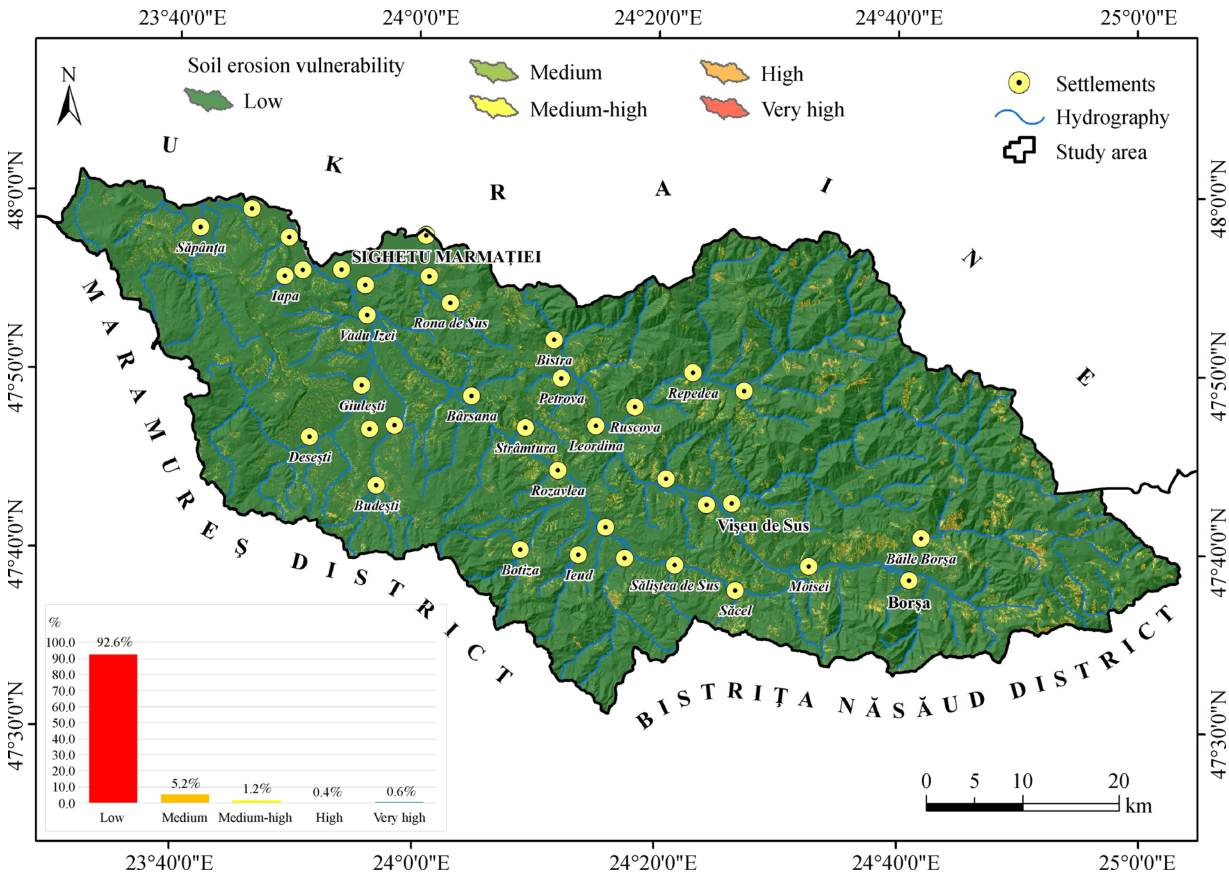

Fig. 3 Soil erosion vulnerability map.

territorial units in the secondary depressions of the Vişeu and Ruscova valleys, large extent of the main flood area, and non-fragmented terrace surfaces used for agricultural crops).

The similarity between the results of the two spatial analysis models is represented by the small territorial extent of the high and very high vulnerability classes both for soil erosion and landslides in most of the UATs from the analyzed territory. This aspect highlights the relative stability of the land. However, due to the location of these territories (in the close vicinity of inhabited areas, on pastures and grass lands, forests, etc.) and the impact they have on environmental components, they determine a high level of risk for the area.

The second level, as a stage in the development of the spatial analysis model, is represented by the identification of the cumulated vulnerability of the two risk processes.

The spatial distribution of this cumulated vulnerability was determined using the spatial analysis technique (raster-raster overlay) by means of mathematical identifiers. One of the problems encountered in the modeling process was represented by the value scale of the input databases. The raster database representing the soil erosion susceptibility includes values ranging between 1 and 48 t/ha/year, while the raster database representing the landslide susceptibility includes values ranging between 0 and 1. To equalize the databases, we used the method of classification as an intermediary stage in the development of the model. Thus, by reclassifying the raster databases through a spatial analysis technique, the quantitative values of the two raster files were reclassified into qualitative values ranging between 1 and 5 according to the vulnerability of the territory: 5 – low vulnerability, 4 – medium vulnerability, 3 – medium-high vulnerability, 2 – high vulnerability, and 1 – very high vulnerability. This reclassification using vulnerability classes must correspond to practical requirements, as their selection influences the quality of the results (Fell, 1994; AGS, 2000).

The cumulated vulnerability of the territory was determined using the raster-raster overlay spatial analysis technique through spatial analysis equations. The integration of the two raster databases in the spatial analysis model was based on the weighted average as a main study method. Using the impact analysis of the two geomorphologic processes, a value of 65% was attributed to landslides and 35% to soil erosion. The implementation of the weighted average equation in a GIS environment was performed using the Raster Calculator function in geoinformatic ArcGIS 10.1 software: (("Erosion" * 0.35) + ("Landslide" * 0.65))/2, where "Erosion" – Grid raster

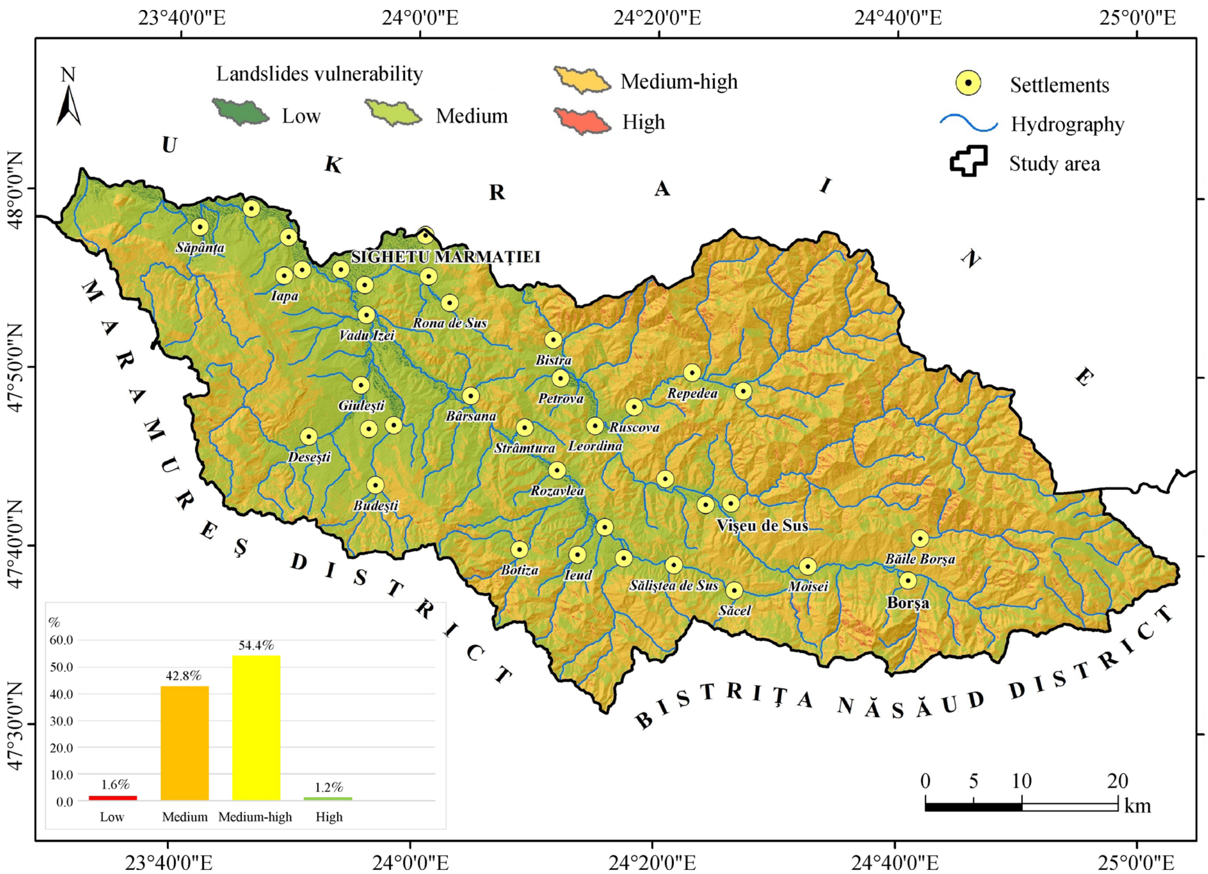

Fig. 4 Landslide vulnerability map.

database representing the soil erosion classes; "Landslide" – Grid raster database representing the probability classes for landslide occurrence; and 0.35, 0.65 – coefficients.

The result of the model using the spatial analysis equation is represented by a modeled grid type raster database with values ranging between 1 and 5 (1 – very high cumulated vulnerability → 5 – low cumulated vulnerability). The last level of the complex model of spatial analysis, the third level, highlights the management and integration methods of the databases, representing cumulated vulnerability, land use, and land price, in order to identify the spatial distribution of the risk affecting land use in Maramureş Land.

By analyzing the results of the cumulated vulnerability model, one notices that 99.05% of the whole study area is included in the medium-high and high vulnerability classes. The largest spatial extent corresponds to medium-high vulnerability, representing 55.38% of the study area, while high vulnerability corresponds to 42.14% of the territory. This highlights the large impact of these geomorphologic processes on the area and the risk they impose on the environmental components. The very high vulnerability class corresponds to approximately 1.53% of the study area. Nevertheless, this small percentage should not be neglected, as it corresponds to areas not only located in the low hills on grass lands but also on terraces and secondary depressions on lands used for agriculture and orchards.

3 Risk modeling

The risk analysis is focused on land use classes from the study area and uses the previously determined cumulated vulnerability. Its importance is stated by the small extension of the low and medium vulnerability classes, which determine a low and very low level of risk and have a very small percentage (less than 1%) of the whole study area: 0.13% for the low vulnerability class and 0.92% for the medium vulnerability class.

The evaluation of the risk using financial losses, which affect land costs in the areas with landslides and surface erosion, is based on a multi-staged methodology: identification of the sell-buy price according to its usage classes, identification of the correspondence between each territorial unit with its specific land use and the vulnerability classes, the computation of the surface of each territorial unit and their market value, the computation of the coefficient for price reduction depending on the vulnerability degree of the territorial unit and the computation of

Table 2 Comparative analysis using a quantitative basis for the extent of vulnerability classes to soil erosion (ESV) and landslides (LV) in the UAT

Territorial Administrative Units	Vulnerability classes/km^2									
	Low		Medium		Medium–High		High		Very high	
	ESV	LV	ESV	LV	ESV	LV	ESV	LV	ESV	LV
Remeți	59.7	329	1.89	46.65	0.36	13	0.12	0.04	0.29	0
Campulung la Tisa	29.69	3.67	1.65	27.42	0.22	0.92	0.08	0	0.09	0
Săpânța	128.1	5.44	4.61	73.29	0.74	55.59	0.3	0.18	0.44	0
Sarasău	16.52	2.26	1.14	15.39	0.19	0.79	0.06	0	0.1	0
Bocicoiu Mare	23.51	4.13	1.34	19.97	0.23	1.52	0.08	0.01	0.14	0
Repedea	105.44	0.02	4.12	17.3	0.94	90.87	0.27	3.16	0.36	0
Poienile de sub Munte	252.83	0	14.11	46.09	3.84	221.53	1.49	7	2.16	0
Sighetu Marmației	120.16	7.11	6.07	95.64	1	25.92	0.34	0	0.62	0
Rona de Jos	20.81	0.65	0.69	17.89	0.08	3.12	0.03	0	0.05	0
Rona de Sus	57.61	0.71	2.1	38.13	0.31	21.52	0.11	0	0.22	0
Bistra	112.22	0.73	6.82	29.28	1.39	87.49	0.48	4.2	0.64	0
Vadu Izei	15.47	1.41	0.47	11.17	0.1	3.5	0.03	0	0.02	0
Oncesti	17.61	1.63	1.43	14.54	0.21	3.23	0.07	0	0.08	0
Petrova	37.15	2.64	2.04	29.63	0.29	7.4	0.1	0.02	0.11	0
Giuleşti	68.4	3.54	5.78	55.99	0.95	16.38	0.31	0	0.47	0
Vişeu de Sus	395.05	0.47	14.64	76.72	4.41	331.24	1.55	10.5	2.31	0
Bârsana	62.99	2.4	4.71	47.16	0.72	19.3	0.22	0	0.22	0
Ruscova	37.48	0.23	1.04	17.43	0.13	20.75	0.06	0.36	0.07	0
Ocna Şugatag	79.85	0.86	4.93	58.62	0.92	27.1	0.34	0.02	0.56	0
Călineşti	58.1	2.39	3.24	50.16	0.48	9.66	0.16	0	0.22	0
Strâmtura	79.15	0.82	6.55	57.05	1.25	29.89	0.39	0.06	0.47	0
Deseşti	128.01	0.28	5.26	70.9	0.9	63.48	0.3	0.23	0.44	0
Leordina	26.48	1.01	1.53	16.27	0.3	11.26	0.09	0	0.14	0
Vişeu de Jos	47.06	0.25	3.97	18.39	0.85	33.63	0.27	0.3	0.42	0
Budeşti	73.93	0.02	5.13	42.32	0.85	38.17	0.25	0.11	0.46	0
Rozavlea	37.57	1.72	2.26	24.98	0.39	13.8	0.12	0	0.16	0
Bogdan Vodă	29.65	0.78	2.05	21.05	0.39	10.55	0.13	0	0.15	0
Şieu	18.42	0.75	1.49	15.7	0.17	3.76	0.06	0	0.06	0
Borşa	354.13	0	28.51	107.62	9.73	285.42	3.7	8.64	5.3	0
Poienile Izei	14.4	0	0.73	9.01	0.11	6.3	0.03	0	0.04	0
Ieud	68.28	0.5	2.89	41.51	0.39	29.39	0.12	0.45	0.17	0
Salistea de Sus	60.81	0.06	3.64	30.99	0.43	34.09	0.14	0.09	0.21	0
Botiza	66.76	0.01	2.89	29.75	0.44	40.01	0.13	0.63	0.18	0
Moisei	98.29	0	7.06	30.38	1.43	75.06	0.52	2.66	0.81	0
Dragomireşti	90.91	0.25	3.07	34.29	0.65	60.09	0.27	0.66	0.38	0
Săcel	70.45	0	6.27	31.7	1.18	46.84	0.4	0.35	0.59	0

the risk expressed as financial losses per territorial unit in reference to the standard acquisition price.

One of the main problems in the stages of risk identification is represented by the identification of the sell-buy value of buildings due to the large variety in their locations and typologies, which influences their costs. To perform an objective analysis, the present study has used the financial value of land depending on the land use classes determined by the evaluation of the real estate fund in Maramureş County; these values are used as tax thresholds by the Chamber of Notaries Public, and this evaluation has been in use since 2012 (Table 3).

The price value of the land, as an input database in the complex spatial analysis model, is represented by a numerical database, which is the basis for identifying the risk of financial loss per land use unit.

The management of spatial databases is based on various GIS operations, using databases that differ according to their type (vector, raster, and numerical) and integrated handling method. An important stage in the logical process of risk identification is represented by the identification of homogenous areas from the point of view of their

Table 3 Buy-sell value/land categories/TAU (Territorial Administrative Units)

Land type	Price		Territorial Administrative Units (TAU.)
	RON/m^2	EUR/m^2	
Build-up area	159	35.333	Sighetu Marmației
	100	22.222	Borşa, Vişeul de Sus
	42	9.333	Moisei, Vişeul de Jos, Ruscova, Petrova, Leordina
	36	8.000	Săliştea de Sus, Dragomireşti, Bistra, Repedea, Poienile de Sub Munte
	24	5.333	Deseşti, Giuleşti, Vadu Izei, Onceşti, Bârsana, Bocicoiu Mare, Rona de Sus, Rona de Jos, Ocna Şugatag, Budeşti, Călineşti, Câmpulung la Tisa, Sarasău, Săpânța, Remeți
Out-of-town land			
Arable	3.18	0.707	Sighetu Marmației
	3.13	0.696	Vişeul de Sus, Borşa
	1.30	0.289	Dragomireşti, Săliştea de Sus
	0.52	0.116	Moisei, Vişeul de Jos, Ruscova, Petrova, Leordina
	0.45	0.100	Bistra, Repedea, Poienile de Sub Munte, Deseşti, Giuleşti, Vadu Izei, Onceşti, Bârsana, Bocicoiu Mare, Rona de Sus, Rona de Jos, Ocna Şugatag, Budeşti, Călineşti, Câmpulung la Tisa, Sarasău, Săpânța, Remeți
Orchards and vineyards	2.78	0.618	Sighetu Marmației
	2.50	0.556	Vişeul de Sus, Borşa
	1.14	0.253	Dragomireşti, Săliştea de Sus
	0.42	0.093	Moisei, Vişeul de Jos, Ruscova, Petrova, Leordina
	0.36	0.080	Bistra, Repedea, Poienile de Sub Munte, Deseşti, Giuleşti, Vadu Izei, Onceşti, Bârsana, Bocicoiu Mare, Rona de Sus, Rona de Jos, Ocna Şugatag, Budeşti, Călineşti, Câmpulung la Tisa, Sarasău, Săpânța, Remeți
Forest	2.39	0.531	Sighetu Marmației
	1.35	0.300	Vişeul de Sus, Borşa
	1.04	0.231	Moisei, Vişeul de Jos, Ruscova, Petrova, Leordina, Bistra, Repedea, Poienile de Sub Munte
	0.98	0.218	Dragomireşti, Săliştea de Sus
	0.27	0.060	Deseşti, Giuleşti, Vadu Izei, OnceVti, Bârsana, Bocicoiu Mare, Rona de Sus, Rona de Jos, Ocna Şugatag, Budeşti, Călineşti, Câmpulung la Tisa, Sarasău, Săpânța, Remeți
Pastures	1.67	0.371	Vişeul de Sus, Borşa
	1.59	0.353	Sighetu Marmației
	0.65	0.144	Dragomireşti, Săliştea de Sus
	0.21	0.047	Moisei, Vişeul de Jos, Ruscova, Petrova, Leordina
	0.18	0.040	Bistra, Repedea, Poienile de Sub Munte, Deseşti, Giuleşti, Vadu Izei, Onceşti, Bârsana, Bocicoiu Mare, Rona de Sus, Rona de Jos, Ocna Şugatag, Budeşti, Călineşti, Câmpulung la Tisa, Sarasău, Săpânța, Remeți
Other categories / non-productive	0.88	0.196	Sighetu Marmației
	0.42	0.093	Vişeul de Sus, Borşa
	0.33	0.073	Dragomireşti, Săliştea de Sus
	0.10	0.022	Moisei, Vişeul de Jos, Ruscova, Petrova, Leordina
	0.09	0.020	Bistra, Repedea, Poienile de Sub Munte, Deseşti, Giuleşti, Vadu Izei, Onceşti, Bârsana, Bocicoiu Mare, Rona de Sus, Rona de Jos, Ocna Şugatag, Budeşti, Călineşti, Câmpulung la Tisa, Sarasău, Săpânța, Remeți

Source: evaluation of the real estate fund in Maramureş County, SC. Eval-Petrescu S.R.L., 2012, 1 EUR = 4.5 RON.

cumulated vulnerability and the land use type. As the cumulated vulnerability database (previously modeled) is in a raster format, its conversion into vector format is absolutely necessary in order to be analyzed together with the vector database of the land uses. In this respect, the convert to vector function in ArcGIS was used to create a shapefile database, whose attribute table contains the values of cumulated vulnerability.

The integrated analysis of the databases was performed using the spatial analysis technique called vector-vector overlay through the intersect function of ArcGIS. The intersection of the two vector databases, the cumulated vulnerability and land use, resulted in a vector database that represents the areas that are homogenous in what concerns their land use and their exposure to the analyzed geomorphologic processes. An important piece of information, which was obtained by performing the overlay, is represented by the attribute database that stores textual data referring to land use and numerical data represented by the cumulated vulnerability class with values between 1 and 5. These data will be used in the territorial analysis, which considers the land use/impact and has the identification of the risk of financial losses as its main purpose.

To identify the classes of exposure to geomorphologic risk, the present study has used a matrix approach based on the relationship between land use classes and cumulated vulnerability classes (Table 4). In this methodological approach, which uses matrices to describe the relationship between the probability of occurrence of a process with negative effects and its expected consequences (Long and John, 1993), one notices the problem of identifying the degree of acceptability depending on the available resources used to mitigate the damages.

Using the matrix analysis of the two elements, a theoretical risk affecting the territory was identified based on the qualitative classification of the dependency relationships between impact (vulnerability classes) and the affected territory (land use). Thus, 5 classes of risk were identified in order to preserve the scale of spatial analysis: 5 represents the low risk class and 1 the very high risk class.

The present study identifies classes of specific risk (Varnes, 1984), where expected risk is seen as a consequence of the damages that appear in the territory because of the damages to buildings and transport infrastructure and the interruption of economical and agricultural activities through a quantitative evaluation, which leads to cost-benefit analyses (Fell et al., 2008).

In the study area, the theoretical value of low risk is identified in homogenous areas where two mandatory conditions are simultaneously fulfilled: low value land uses (watercourses, swamps, and rocky fields) and any type of

Table 4 Matrix used for identifying the classes of risk exposure

Land use classes	Cumulated probability classes				
	P.VH	P.H	P.MH	P.M	P.L
Watercourses	5	5	5	5	5
Orchards	2	4	4	5	5
Swamps	5	5	5	5	5
Coniferous forests	2	2	3	3	4
Broad-leaved forests	2	3	3	3	4
Mixed forests	2	2	3	3	4
Secondary pastures	1	2	3	3	3
Urban and rural area	1	1	1	1	2
Non-irrigated arable land	1	1	1	2	2
Agricultural land and natural vegetation	1	2	2	3	4
Industrial and trading units	1	1	1	4	4
Complex cultures	1	1	2	3	3
Deforested areas	1	1	2	2	3
Scarce vegetation areas	1	2	2	4	5
Waste dumps	1	2	3	4	5
Natural pastures	1	1	2	3	3
Rocky fields	5	5	5	5	5
Subalpine vegetation	1	1	2	2	3
Recreation areas	1	1	1	4	4
Mining areas	2	3	4	4	5

P.VH – Very high probability, P.H – High probability, P.MH – Medium-High probability, P.M – Medium probability, P.L – Low probability, 1 – Very High Risk, 2 – High Risk, 3 – Medium-High Risk, 4 – Medium Risk, 5 – Low Risk.

cumulated impact. The areas included in the high risk class fulfil the following mandatory conditions: a high value of the land (urban and rural areas, cultivated arable land, recreation areas, etc.) and a medium-high, high or very high cumulated impact.

Using this method, the attribute database of the vector including homogenous territories was filled with data, and the theoretical risk map of the studied area was created.

The analysis of these results highlights a large extension of the medium-high risk (3) in Maramureş Land, corresponding to 58% of the area, and to the low hills which separate the two main watercourses that drain the analyzed hill (Vişeu and Iza), as well as the hills at the contact with the Maramureş Mountains and the glacis of the volcanic mountains, which limit the depression in the south and west. These areas are mainly used as pastures and sometimes as complex agricultural lands. The large extent (21.45%) of the high risk class (2) corresponds to the depression area of the Mara River and the terraces of the Tisa, a river that also limits the studied area in the north and the northwest. The risk identified in these depression areas is due to the main use of the lands as complex agricultural lands and urban and rural settlements. The area is highly susceptible to landslides and soil erosion due to inappropriate exploitation of the land. The very high risk class (1) is identified in only 5.28% of the area, especially in the urban and rural habitats (Fig. 5).

The identification of the risk as a financial loss first requires the computation of the market value for each homogenous territory in what concerns the land use and its vulnerability.

The market value of the land was determined per square meter, and the area computation was performed for each polygon that resulted from the intersection of the vector databases representing land use and cumulated vulnerability. The computation of the value for each homogenous area was performed by spatial analysis on attribute data through equations computed with the function Field Calculator in ArcGIS.

The spatial analysis of the attribute data included in the vector database of the cumulated vulnerability was performed using the following spatial analysis equation:

$$[\text{supraf}]^{*}[\text{eur}],$$

where: [supraf] is column from the attribute table with the calculated area for each polygon in m^2; and [eur] is financial value of a m^2 (1 EUR = 4.5 RON).

The application of the spatial analysis equation resulted in market values of the land (as unitary surfaces for cumulated vulnerability) ranging between 1 and 265,000 Euros (Fig. 6). The minimum and maximum values are determined by the great variety in size of the homogenous

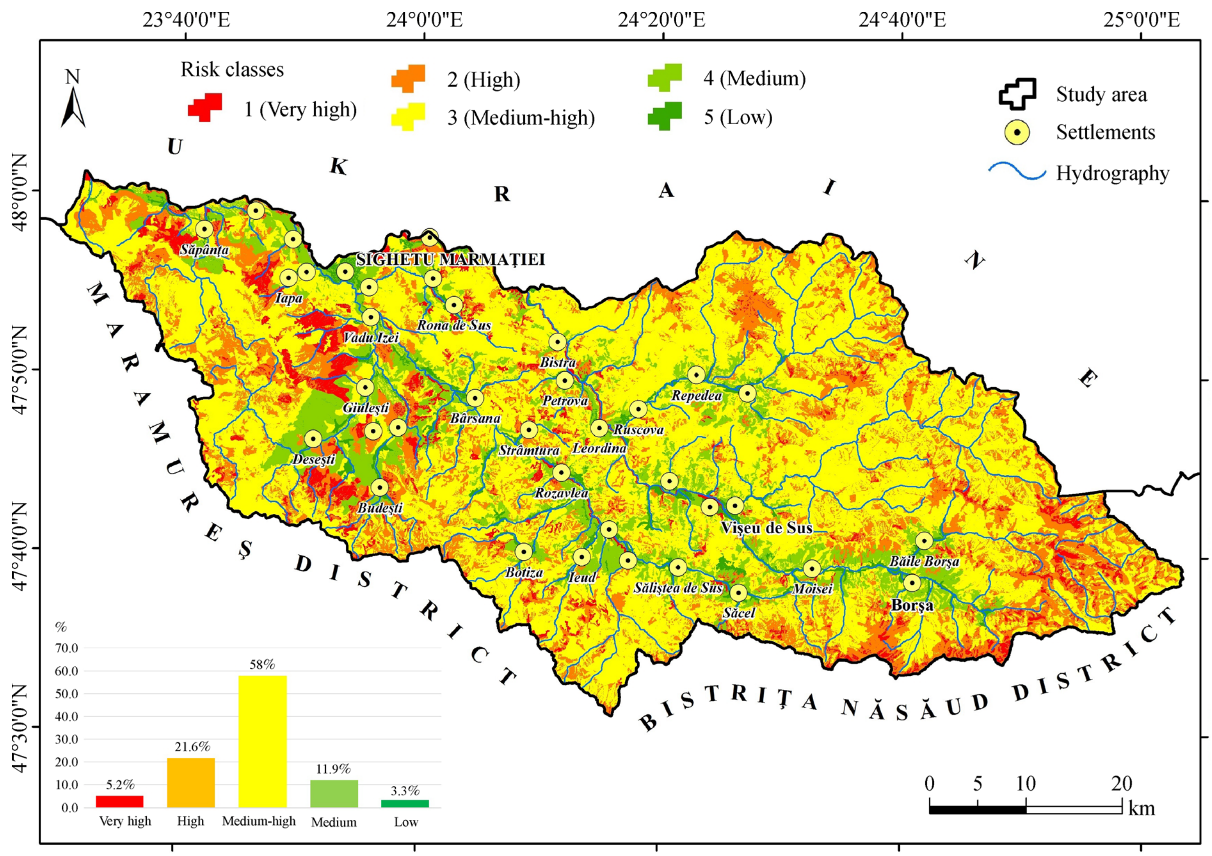

Fig. 5 Map of the cumulated risk classes.

areas with low vulnerability (usually forests with low vulnerability and high market value), which determines a large market cost per surface. In addition to these, there are agricultural lands from depressions and terraces with high vulnerability, which causes a low market value.

The computation of the market value for the vulnerability of homogenous lands only represents the first stage in identifying the areas with different risk degrees to financial losses due to the cumulated effect of mass movements and soil erosion. Another important stage is represented by the computation of the coefficient that describes the decrease of the land value depending on the theoretical risk, which has been identified in the area using the matrix analysis (Table 4).

Taking into consideration the fact that in the matrix analysis, the very high risk class had a value of 1 and the low risk class had a value of 5, in order to compute the reduction coefficient for the land value, we divided all risk exposure matrix values by 5, which represents the maximum value of the matrix. This stage is absolutely necessary to identify a subunitary coefficient that can be multiplied by the market value in order to determine a real value of the lands corresponding to the risk from the study area. The identification of the lost land value (the risk) requires the subtraction of the value obtained by applying the value reduction coefficient from the calculated total market value.

Thus, according to the matrix, the agricultural land mixed with natural vegetation, which has a low probability of occurrence for the geomorphologic processes considered in this study, was assigned a value of 4 (Table 4) (representing a medium risk); therefore, the coefficient of market value reduction was calculated as $4/5 = 0.8$.

Furthermore, if a unitary land area of 200 m^2 has a calculated market value of 900 Euros, and it is included in the category of a 0.8 reduction coefficient, the risk as financial loss will be computed as $900 - (900*0.8) = 180$ Euros.

The implementation of this equation in a GIS environment is performed through spatial analysis using the following equations:

$$[\mathrm{P\_cum}]/5,$$

$$[\mathrm{value}] - ([\mathrm{value}]^{*}[\mathrm{cf\_red}]),$$

where: [P_cum] is column of the attribute table which stores the cumulated probability value according to the matrix analysis; [value] is column of the attribute table with the calculated market values of the lands (in Euros); [cf_red] is column of the attribute table with the calculated value of the reduction coefficient.

The results of the spatial analysis are stored in a new

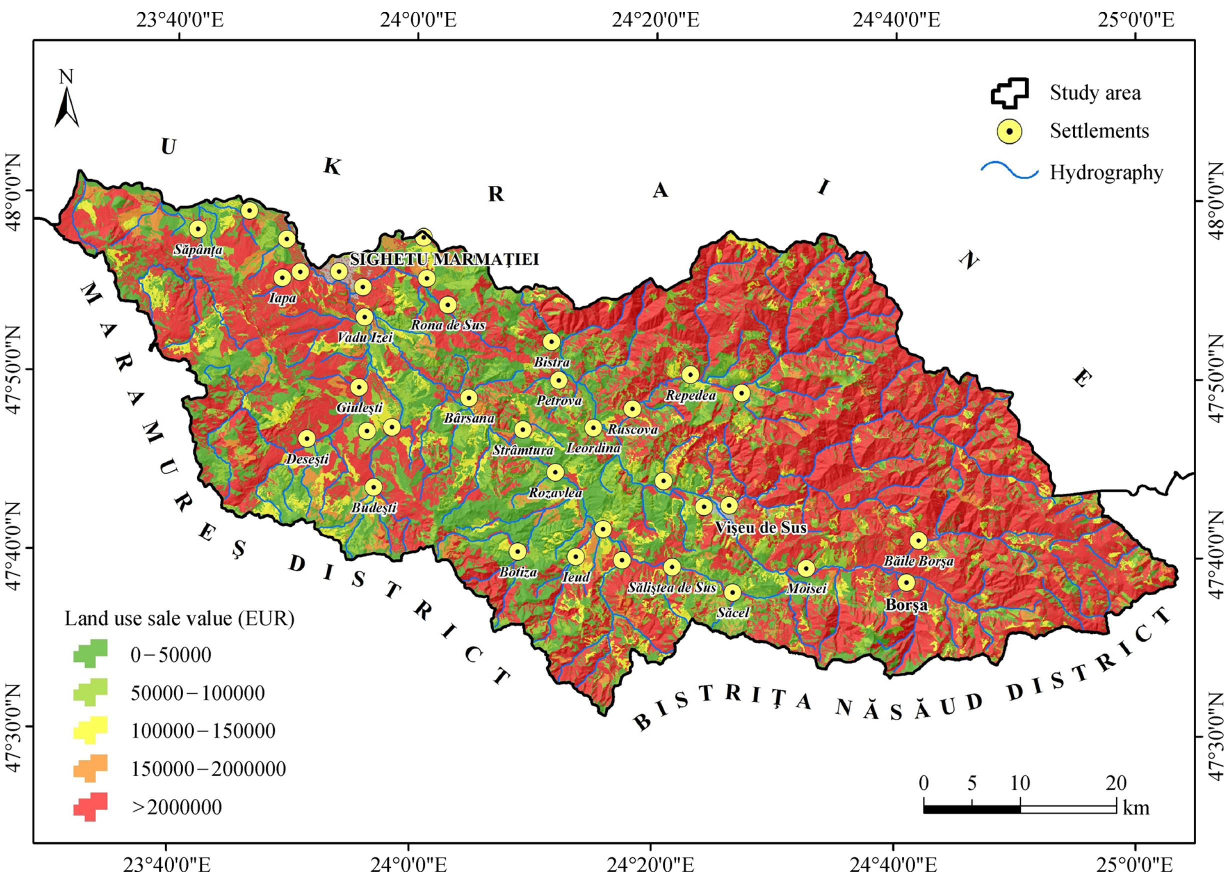

Fig. 6 Land market value in Maramureş Land.

attribute column that offers information about the real value of all the unitary areas in what concerns the risk determined by present geomorphologic processes and their specific land use (Fig. 7).

The analysis of economic losses for each administrative territorial unit highlights the fact that at a spatial level, the losses and their costs are relatively small, under 50,000 in 74% of the analyzed UATs. This fact is explained by their spatial extension in the flood plains of the four main valleys from the study area, as well as on the terraces and the low contact areas with mountains, where erosion processes and landslides appear on small surfaces and do not have a major impact on the territorial units with big land value. One exception is represented by the administrative unit of Poienile de Sub Munte, which is vastly extended in the mountain area with large unexploited forest areas that have a stabilizing role through their natural vegetation cover.

The financial loss of this UAT is given by the impact of landslides and soil erosion on the built-up area due to past deforestation, which has transformed forest land into agricultural land (large deforested lands have been replaced by potato crops and sub-mountain pastures).

Among the UATs with great losses in what concerns the financial value of the lands, one identifies the territorial areas of the three main towns from the study area (Sighetul Marmației, Borşa and Vişeul de Sus) (Fig. 8). In addition to the great value of the built-up land, one also notices the large impact of erosion processes and landslides, as these towns are mainly located at the contact of foothills and mountains or, when on their administrative surface, there are predominantly agricultural uses (arable land) on low steep hills where surface erosion is predominant.

4 Conclusions

The analysis of the identification of financial losses due to risk processes having an impact on land use needs to be performed for each administrative territorial unit in order to efficiently manage the financial resources required for mitigating these losses.

The present study has created a model for identifying the risk induced by dominant geomorphologic processes with an effect on land use in Maramureş Land (soil erosion and landslides). This endeavor was based on integrated models of GIS spatial analysis that can determine both spatially and quantitatively the risk expressed as financial loss.

The local administration has provided the numerical databases of the land acquisition costs for different categories, as well as the databases representing the land use at the level of terrain unit. These data were integrated in

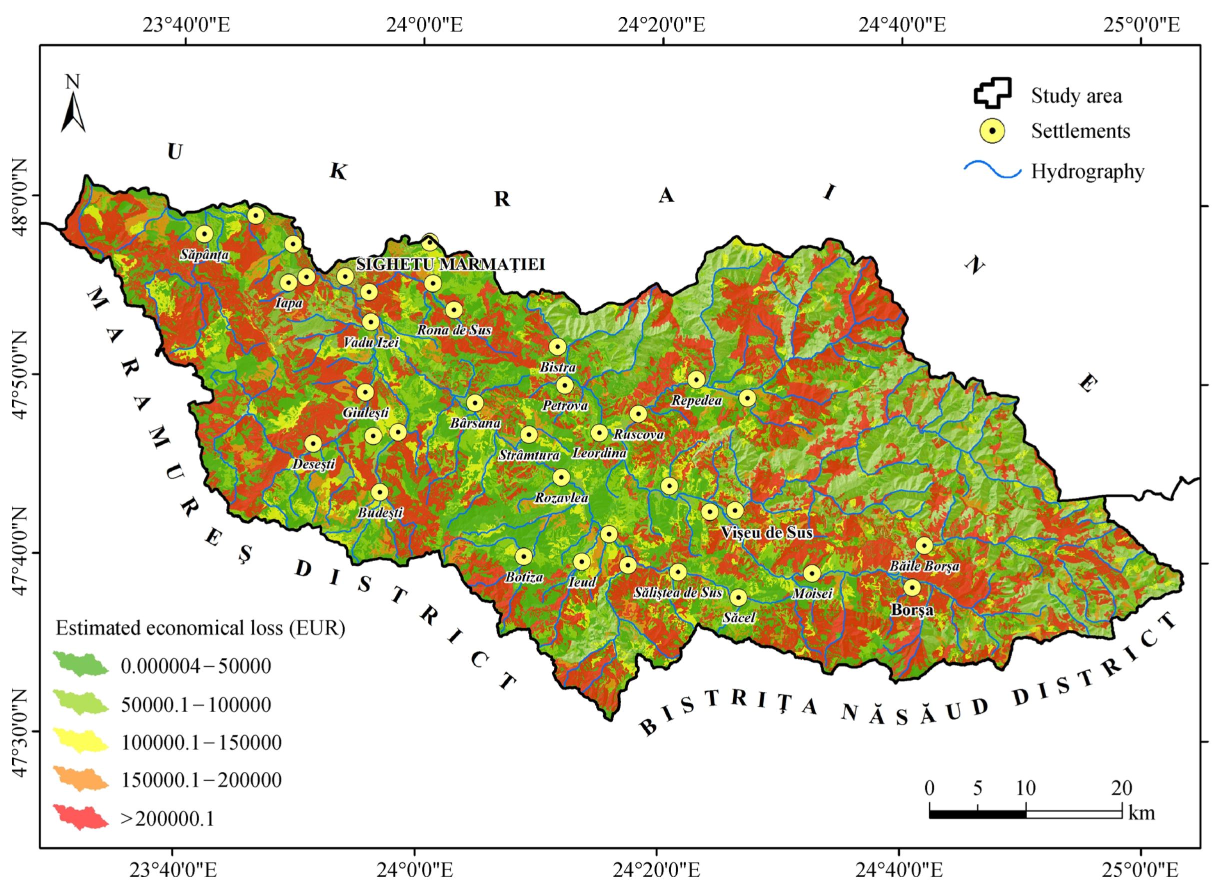

Fig. 7 Map of the risk calculated as financial loss.

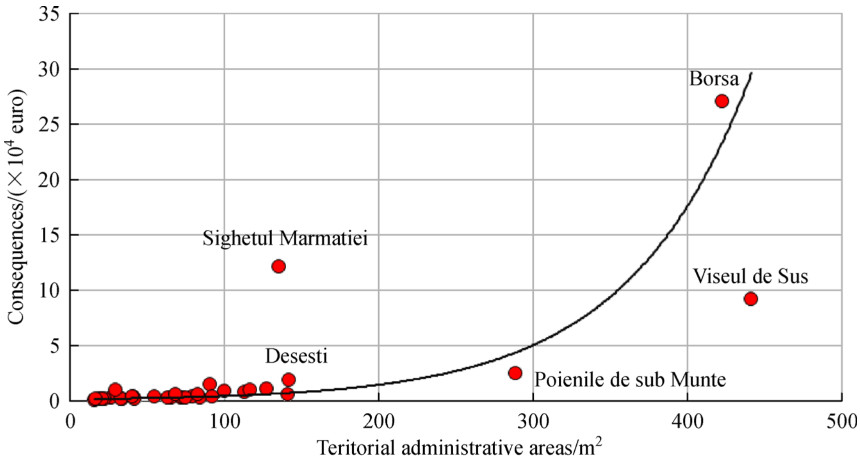

Fig. 8 Economic loss at the UAT level.

complex models of vulnerability evaluation for the analyzed geomorphologic processes and were used to identify the homogenous surfaces in what concerns the risk that these processes impose on the analyzed territory. Therefore, the data provided by the local administration have facilitated the spatial analysis of the territory in the process of identifying the financial losses that describe the risk.

The implementation of spatial analysis using raster and vector databases with high accuracy and precision by means of spatial analysis equations on spatial and non-spatial databases leads to very good field validation of the results, thus reducing the time of risk identification and mitigation in the case of financial losses.

The evaluation of the risk can be used as the basis of classification projects and for identifying the best solutions for fundraising in order to reduce the risk, both at a spatial level and as a monetary value. This can contribute to the reintroduction of these lands in their normal financial circuit the moment they can be evaluated at their true market value.

Risk reduction, as a consequence of implementing correct and practical mitigation measures, leads the process of cost-benefit evaluation at the UAT level to represent not only profit but also added environmental value, which can be eventually exploited over several years and can lead to an increase in the profit of land exploitation, changing land quality and risk affected areas to high productivity areas.

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