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SPACE PLANNING IN PRAHOVA SUBCARPATHIANS, ROMANIA. LANDSLIDES - LAND COVER RELATIONSHIP ANALYSIS

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Space planning in Prahova Subcarpathians, Romania. Landslides - land cover relationship analysis

Marina-Ramona Rujoiu-Mare, Bogdan Olariu, Bogdan-Andrei Mihai

Planificarea teritorială în Subcarpații Prahovei, România. Analiza relației dintre alunecările de teren și acoperirea terenurilor. Componenta antropică se află într-o continuă relație de interdependență cu procesele geomorfologice, rezultând limitări ale dezvoltării așezărilor, dar și modificări ale reliefului cauzate de activitățile umane. Scopul acestui articol este de a identifica un model de analiză a acestor interrelații dintre om și mediu sub aspect geomorfologic, având ca studiu de caz o zonă reprezentativă din regiunea de dealuri a României. Analiza a constat în combinarea unei metode de evaluare a susceptibilității la alunecări de teren cu cea de evaluare a componentei umane, luându-se în considerare elementele expuse riscului, dotările edilitare, tendința de expansiune a spațiului construit etc. Rezultatele indică existența unor suprafețe importante cu un nivel mare şi foarte mare de susceptibilitate la alunecări suprapuse, ocupate de vetre de așezări sau alte elemente antropice. În unele locuri problemele geomorfologice au oprit expansiunea intravilanului, în altele acestea au fost ignorate. Toate acestea conduc la concluzia că astfel de hărți complexe ar trebui utilizate în elaborarea planului de dezvoltare al unei așezări, asigurând evitarea unor catastrofe, de altfel greu predictibile.

Cuvinte cheie: susceptibilitate la alunecări de teren, acoperirea terenurilor, Subcarpați, probleme în organizarea spațiului

Space planning in Prahova Subcarpathians, Romania. Landslides - land cover relationship analysis. There is a strong relationship between the anthropogenic influence and the geomorphological processes, resulting limitations for settlements expansion, but also changes of the relief caused by human activities. The aim of this study is to identify a model for the analysis of the relationship between society and environment under a geomorphological concern, with a case study from a representative Romanian-Subcarpathian hills region. The analysis consisted in combining two methods, one for the landslide susceptibility evaluation and another for the evaluation of the human component from the study area, taking into account the elements at risk, the infrastructure, the settlement growth etc. The results show the existence of important areas with high and very high levels of the landslide susceptibility overlapped with settlements built-up areas and other anthropogenic elements. In some areas the geomorphic risk problem stopped the expansion of the built-up area, while in other cases these problems were ignored. All these lead to the conclusion that these complex maps should be used when conducting a development plan for a settlement, thus ensuring the avoidance of a catastrophic event, otherwise difficult to predict.

Keywords: landslides susceptibility, land cover, Subcarpathians, space planning issues

1. INTRODUCTION

Prahova Subcarpathians represent a complex geographical region considering its geomorphology, geology and landscape, according to many researchers (Niculescu & Dragomirescu, 1961; Velcea & Velcea, 1965; Niculescu, 1984, 2008; Armaș, 1999, Grecu, 2009). This area is characterized by a relatively high altitude (up to 800, 1000 m), a complex lithology with hard rock layers (conglomerates and sandstones) alternating with soft rock layers (marls and clays) (Murgeanu & Patrulius, 1966, Armaș et al, 2003), a dense network of faults, a high fragmentation of the relief, a high degree of human intervention and complex land cover features. All of these characteristics influenced the intensive spatial pattern of geomorphic processes. Landslides are one of the most intensive, dynamic and active processes in the Subcarpathian region and also an important issue in territorial management and space planning. The landslides process, its preparing and triggering factors and their consequences were intensely studied (Crozier, 1986; Guzzetti et al, 1999, Corominas et al, 2003; Cascini et al, 2005, Fell et al, 2008, van Westen et al, 1993). The development of GIS techniques and spatial data processing directions made possible the improvement of the methods for landslide susceptibility and landslide hazard analysis (van Westen, 1994, 2010; Glade et al, 2005; Alexander, 2008; Chițu, 2010; Mihai et al, 2014). This phenomenon was the subject of many studies in the Prahova Subcarpathians region (Chițu, 2010; Șandric et al, 2011, Armaș et al, 2003, Chițu et al, 2015), using various methods and algorithms.

Land cover represents an active and a dynamic factor for landslides. This reflect the influence of the humans over the space as a triggering factor of the mass movements by the inappropriate land use (deforestation, roads “cutting” on slopes, anthropogenic pressure by building and infrastructures) or a response, reaction to the phenomenon (the development direction of the settlement built-up areas , the water drainage, slope reforestation). The free access to Landsat 8-OLI satellite imagery and to land cover vector data (Corine Land Cover www.eea.europa.eu, Global Land Cover 30 www.globallandcover.com) made possible the modelling of land cover features together with the land cover change models.

This paper highlights the relationship between landslides, as a geomorphic process with a large spatial development, and land cover, from the perspective of space planning in Câmpinița Hills (Prahova Subcarpathians). The inventory of the active landslides and the recent land cover features obtained by data fusion between supervised classification of Landsat 8 OLI and available land cover models, were two important steps for the analysis. The main objectives of this study are the landslides susceptibility analysis using the weight of evidence method (van Westen, 2010; Armaș, 2012) and the identification of the issues that limit the space planning (Bell & Glade, 2004) in the Subcarpathian area.

2. MATERIALS AND METHODS

Study area

Câmpinița Hills represents a subdivision of Prahova Subcarpathians (Romania, South from the Romanian Carpathians), limited to the West side by the Prahova River Valley and on the East side by Doftana River Valley, Romania. The confluence between Prahova and Doftana rivers represents the southern limit, situated to the south of Câmpina town. The northern limit towards Baiu Mountains passes nearby Secăria village and Vârful Frumos Peak (1047 m) (Figure 1).

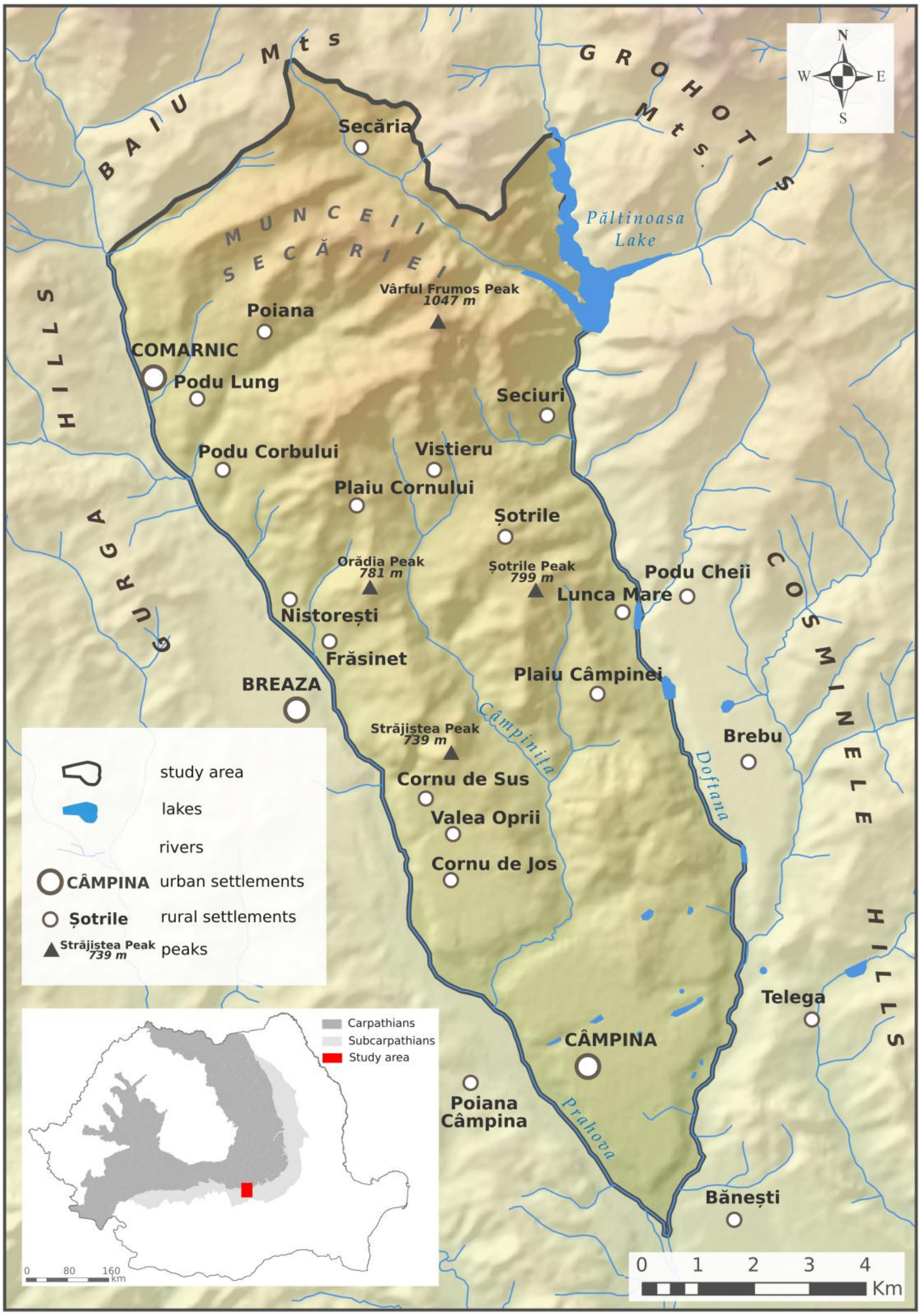


Figure 1. Câmpinița Hills. Location map

Câmpinița Hills altitude decreases from North to South from 900-1000 m (the contact zone with Baiu Mountains) to approximately 400 m, Southern from Câmpina terrace scarp. The region is longitudinally crossed by Câmpinița River, a tributary to Prahova River.

The contact area with Baiu Mountains is complex from geological and geomorphological points of view as well as from the vegetation and land use features . In this transition area, mountain landscape elements (grasslands, pastures, temporary settlements, seasonal huts, sheepfolds, plantation surfaces) interfere with Subcarpathian hills landscape elements (eroded pasture grounds, massive landslides, orchards in village built-up area, permanently inhabited scattered settlements).

Prahova River terraces are developed especially in the area of the Slănic Syncline basin, but this depends of lithology and depth of gravel layers. The 5th terrace level, the highest one, known as Străjiștea-Orădia terrace (Popp, 1939, Niculescu, 2008), is well preserved on slopes and interfluves developed on marls (Străjiștea – 739 m) and conglomerates (Orădia – 781 m), dominated by some possible outliers of an older erosion surface. Their gravel layers are 8-10 m deep and have been exploited by local communities in the past for building purposes.

The settlements are situated mainly on the terraces, but some of them are covering old landslide bodies, now stabilised. Landslide bodies often occur on large areas. These lowered the interfluve ridges that became narrower and forced the settlements to adapt to slopes micromorphology.

GIS database

For the analysis and the processing of the current vector and raster data, ArcGIS 10.1 and QGIS 2.8 software packages were used, whereas for satellite images processing and classification Envi 5.1 was preferred. For graphic operations and for map design Inkscape 0.91 software was used. Landslide susceptibility analysis and its relationship with space planning features needed the integration of specific datasets: orthophotos 1:5,000 from 2009 (A.N.C.P.I Bucharest) for the inventory of landslide bodies ; the EU-DEM elevation dataset (Digital Elevation Model for Europe) resized for the study area and processed for slope modelling; lithology derived from the Geological Map of Romania (scale 1:200,000); land cover derived from Global Land Cover 30 model (2010), Corine Land Cover (2006) and Landsat 8 OLI imagery (June, 7, 2015). For space planningfeatures , the military topographic maps from 1981 at 1:25,000 were integrated together with the orthophotos from 2009 and field data derived from observations and photos (Table 1).

Table 1 Datasets used in the analysis and their characteristics

Data sets	Year of acquisition	Scale/Spatial resolution	Source of data	Type of data
Orthophotos	2009	0.5 m	A.N.C.P.I.	Primary
Elevation (EU-DEM)	2013	30 m	GMES/Copernicus	Primary
Geological map	1966	1:200,000	Geological Institute	Primary
Lithology	1966	1:200,000	Geological map	Secondary
Slope gradient	2013	30 m	EU-DEM	Secondary
Topographic maps	1981	1:25,000	D.T.M. (Military Topographic Department)	Primary
GLC30 2010	2010	30 m	Geomatic Centre of China	Primary
CLC 2006 (Corine Land Cover)	2006	30 m	European Environmental Agency	Primary
Satellite images Landsat 8 OLI	2015	30 m	U.S.G.S.	Primary
Land cover	2012	30 m	GLC30,CLC 2012 & Landsat 8 OLI	Secondary
Territorial issues	2015	30 m	Orthophotos, topographic maps, field observations	Secondary

Landslide inventory

Landslide inventory represents an initial stage in the susceptibility evaluation (Guzzetti et al, 1999). This is the qualitative part of the methodology for the spatial representation of the phenomena, because the result represents an input dataset for the landslide susceptibility analysis. The landslides were digitised as polygon features on different cartographic materials, on satellite images, after carrying field observations in key areas. Some of these landslides were mapped on Landsat 8 OLI satellite data, pan sharpened imagery (15 m spatial resolution) from June 7, 2015 (source: U.S. Geological Survey). Others were identified on the orthophotos from 2009 with spatial resolution of 0.5 m (source National Agency for Cadastre and Land Registration – A.N.C.P.I. Bucharest). This database was completed by field mapping and observation. There were some issues concerning landslide identification based on digital imagery mostly due to the vegetal cover. Field observations were used to validate the results of the analysis.

Instability factors modelling

The instability factors have a potential role in landslide triggering. For landslide susceptibility analysis there were used several factors: slope gradient, lithology, land cover and elevation. ***Slope gradient*** and elevation were extracted from the digital elevation model of EU-DEM with a spatial resolution of 30 m. For the entire study area, slopes have a higher gradient in the northern part, in a close-relationship with elevation. Landslide bodies occur on slope gradients between 3° and 15°. Slope gradient classes of less than 3° are almost horizontal and do not influence landslides (Soeters & Westen, 1996). The areas with slope gradient values higher than 15° correspond to hard rock sectors, with only few superficial landslides (Figure 2).

Lithology was extracted from the geological map scale 1:200,000 (source: the Geological Institute of Romania) (Figure 3). The map of the study area shows many types of rocks, with narrow foldings, oriented on West-East direction. The structure continuity is complex, especially because of the strike-slip faults network. Lithological formations vary from conglomerates and sandstones (Brebu and Șotrile facieses) to marls and clays.

The northern part of the study area is formed by folded shales superposed on a Lower to Medium Cretaceous flysch, fragmented by faults and strike-slip faults which form a network similar to a chessboard. The Simila planation Surface (Popp, 1939) is similar to a flat interfluve plateau, which is preserved by harder rocks (sandstones and conglomerates).

The Prahova-Câmpinița and Câmpinița-Doftana watersheds are oriented on North to South direction, from Simila Surface (in the contact area with Baiu Mountains) towards the Câmpina terrace field (South). Those are highly degraded by the torrential erosion and old landslide bodies reactivation.

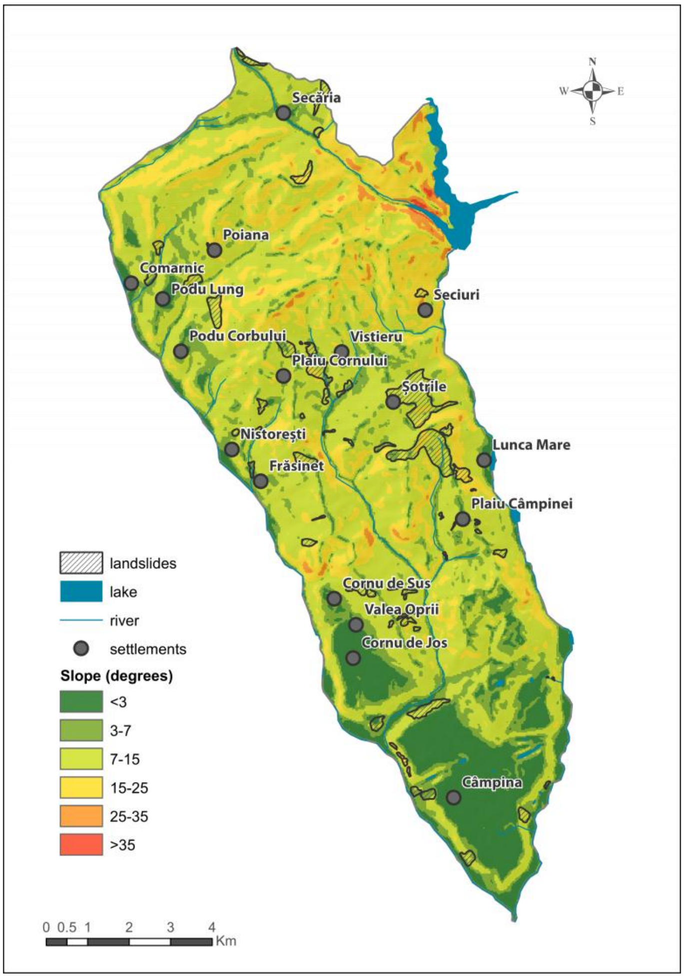
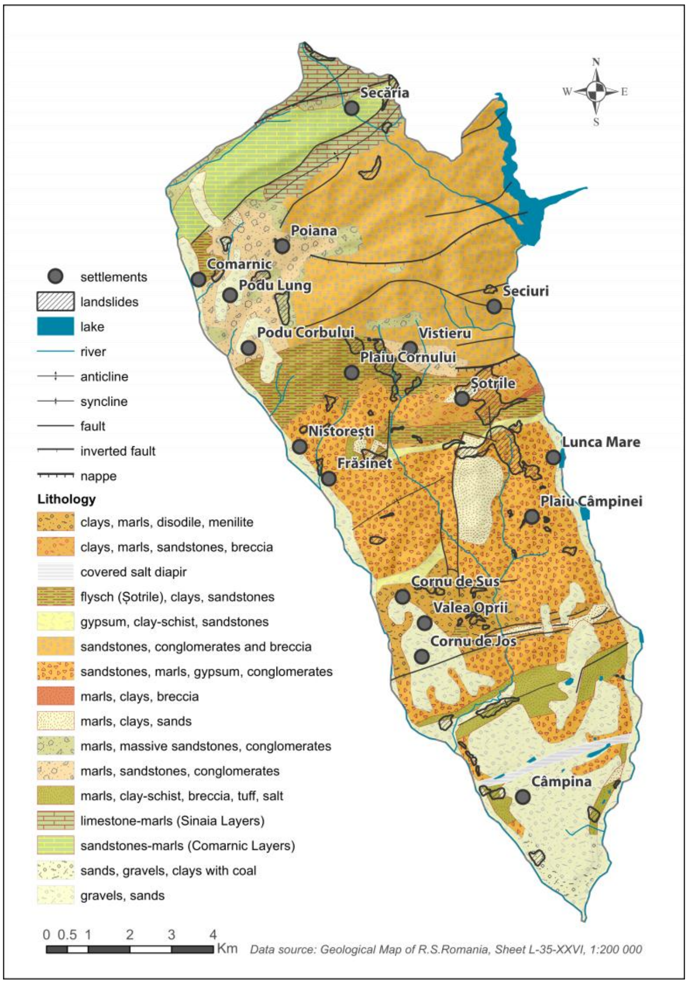


Figure 2. Câmpinița Hills. Slope Map



Data source: Geological Map of R.S.Romania, Sheet L-35-XXVI, 1:200 000

Figure 3. Câmpinița Hills. Lithological Map

The selective erosion processes revealed outliers on hard rocks and saddles on marls and clays. The Northern areas of the interfluves are more stable because of hard rock occurrences and dense forest cover. The southern sectors are more dynamic, with evolved relief and sedimentary formations from the Medium Miocene (marls and clays)(Murgeanu & Patrulius, 1966), which supports the selective erosion process. Generally, slopes are densely fragmented by landslides, especially on the marl-clay facies. This type of evolution created the low saddle topography which alternate with outliers on hard rock layers. (Niculescu, 1982, 2008; Armaș et al, 2003).

The geological structure between Prahova and Câmpinița river valleys is very complex with a dense network of faults (West-East), folds in the Palaeogene flysch zone large and asymmetric folds, strike-slip faults in the sandstones-conglomerate Miocene molasse zone. The interfluve between Câmpinița and Doftana rivers also show a geological variation with strongly folded formations, anticlines and synclines, oriented on West-East direction. The continuity of these structures is difficult to follow, especially in areas with faults and strike-slip faults. The lithology varies from conglomerates and sandstones in Brebu and Șotrile facies to Miocene marls and clay formations. The largest mass movement areas occur along the limit of Șotrile facies, where permeable rocks (sandstones and conglomerates) allowed the streams to flow over marls and clay layers.

Land use layer was created by combining several available vector data models with data extracted from supervised classification of a Landsat OLI satellite image (June 7, 2015). One of these models was Global Land Cover (GLC30, source: China Centre of Geomatics www.globallandcover.com), with a spatial resolution of 30 m which includes seven classes for the study area: arable lands, forest, grass, shrubs, built-up area and wetland (Figure 4a). Adapted to the scale of analysis, this model shows some errors along the limits between some classes, as a result of generalisation of the entire dataset (Global coverage). Another land cover model was CORINE Land Cover 2006 dataset (CLC, source: European Environmental Agency, www.eea.europa.eu). This model has about the same scale with GLC, and represents a generalised European model, adapted to regional or national scales. Another disadvantage of this dataset is the temporal resolution, with a nine year gap featured by many changes within land cover.

A third data set for land cover analysis was obtained after the supervised classification of a Landsat OLI imagery from June 7, 2015, enhanced with atmospheric correction and band rationing for illumination correction, in false-colour 543 spectral band combination (near-infrared, red, green). The result was obtained using Maximum Likelihood algorithm, which took into account the maximum probability for each pixel to belong to a previously defined class (Lillesand et al, 2015). The disadvantage of this type of classification is that it does not differentiate orchards, shrubs and forest and produces confusion between class identification in the case of built-up areas and flood-plain alluvia or rock outcrop areas (Figure 4b).

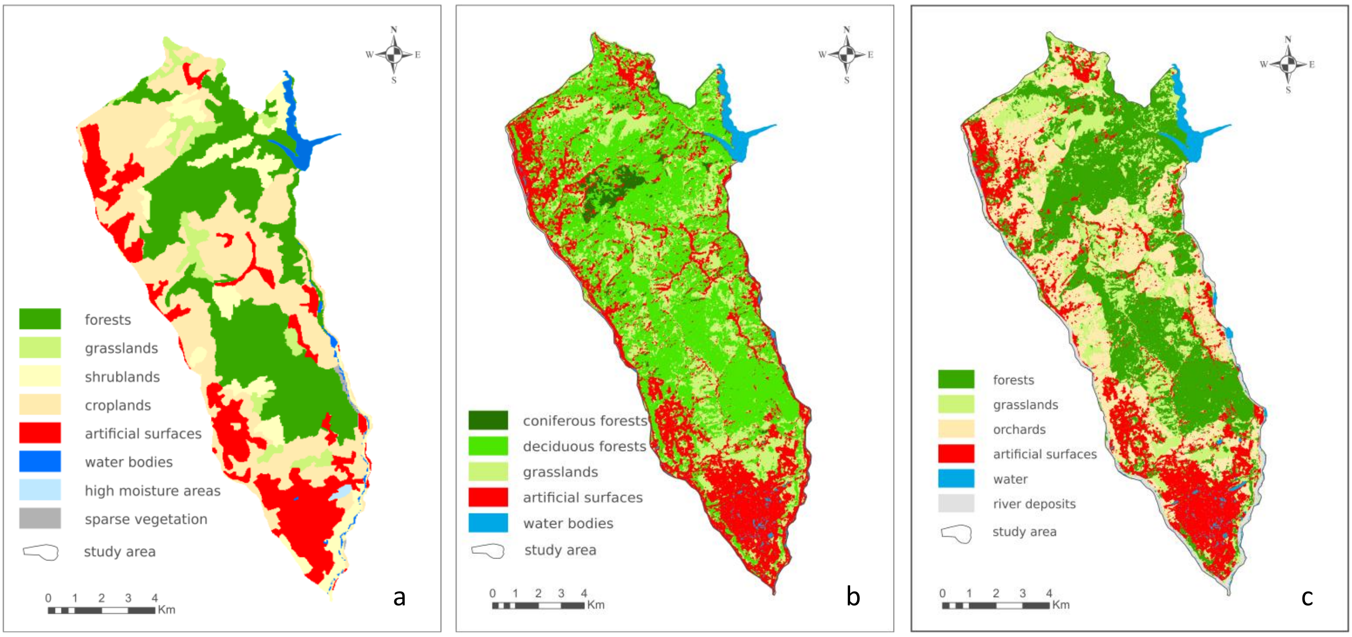


Figure 4. Land cover map of Câmpinița Hills with data processed from different sources a. Global Land Cover 30; b. Supervised classification of satellite image Landsat OLI from June 7, 2015; c. Raster obtained by combining the existing models with data obtained from the supervised classification

After the analysis, processing and combination of these three data sets (GLC 30, CLC 2006 and supervised classification) the land cover map was obtained (Figure 4c) (Rujoiu-Mare & Mihai, 2016). Finally, these three raster data sets (slope, lithology and land cover) were resampled to 30 m resolution in order to be integrated within the landslide susceptibility analysis.

Landslide susceptibility analysis

The Weight of Evidence (WOE) method (Şandric et al, 2011; Şandric, 2008; Van Westen, 1993, 2008,) consists in calculating the landslides density for each of the potential triggering factors which are included in the analysis (Table 2)(Fell et al 1999; Guzzetti et al 2008; Bathrelios et al, 2009; Mihai et al 2010). Based on these factors, the weights are derived (positive and negative) from which the contrast results. A dataset referring to each factor class contribution for triggering landslides is obtained. Another raster layer is obtained for the probabilities of the landslide occurrence in the study area. After reclassification, this corresponds to the landslide susceptibility map of the region. For the current study area the layers represented by DEM, slope gradient, lithology and land cover were used as susceptibility factors data, while for the reference dataset we used the previously mapped landslides. The WOE raster was reclassified (Van Westen et al, 2008) for a better separation of susceptible areas (Table 3).

Table 2. Variables used in the WOE analysis

Variables	Initial Data Type	Used Data Type	Spatial Resolution	Acquisition Year	Source of Data
Landslides	Vector	Raster	30 m	2015	Orthophotos 2012+field obs.
Slope gradient	Raster	Raster	30 m	2013	EU-DEM
Lithology	Vector	Raster	30 m	1966	Geological Map
DEM	Raster	Raster	30 m	2013	EU-DEM
Land use	Vector	Raster	30 m	2015	GLC30+CLC06+Landsat8 OLI

Table 3. Landslide susceptibility classes

Susceptibility Class	Range	Description	Map Colour
Absent	-73 - 0	Construction development possible	Grey
Low	0 – 2	Construction possible with suitable precautionary measures	Green
Medium	2 – 3	Construction not recommended, only if necessary with suitable precautionary measures	Yellow
High	3 - 4	Construction not recommended	Orange
Very High	4 – 5.1	Constructions of any kind should not be developed	Red

3. RESULTS

The relationship between landslides and each instability factor

In the framework the Weight of Evidence analysis each factor is assigned with a value (weight), according to its contribution in mass movement triggering (Table 4). Lithology was the main triggering factor but not all of the layers had the same contribution. For instance, the highest weights were recorded for the Macla Layers (schists, sandstones, and breccias), then for areas with marls, clays, sands with coal layers and gypsum occurrences and for clay-schist and sandstone formations. The biggest landslides bodies occur along the Șotrile Facies limit, where permeable rocks (sandstones and conglomerates) allow water to flow through clay and marls layers.

The slope gradient also has a high contribution in landslide triggering, especially the classes between 3°-7° and 7°-15°. Hypsometry between to 600 and 800 m classes show a large landslide bodies occurrence. Land cover, higher weights correspond to grasslands and orchards, which cannot provide an efficient protection of slopes to landslidings.

Table 4. Weight of Evidence scores for different landslide triggering factors

	FACTORS	WOE
LITHOLOGY	Marls, siltite, massive sandstones, conglomerates	0.65
	Schist, sandstones, breccia (Macla Layers)	**2.22**
	Marls, clays, sands, limestone	0.96
	Flysch (Șotrile), flysch with motley clays (Plopu Layers), sandstone and schist (Colți Facies)	0.40
	Marls and motley clays, flysch (Șotrile)	0.98
	Clays, marls, disodile, menilite, breccia, clay-marls schist (Pucioasa Layers), sandstone (Fusaru and Kliwa), flysch (Podu Morii layers)	0.45
	Sandstones, marls, gypsum, conglomerates	0.33
	Gypsum, clay-schist, sandstone	**1.02**
	Marls, clay-schist, breccia, tuff, salt	0.69
	Marls, clays, sands with coal layers	**1.25**
	Sands, scarce gravels, clays with coal	0.51
	Coarse sandstones, clay sandstones, conglomerates (Bucegi type), limestone breccia	-
	Clay-marls schist and calcarenites (Comarnic Layers), sandstones and marls-sandstones, schist and curbicortical sandstones (Teleajen Layers)	-
	Marls, marls-limestone, limestone-sandstones with intercalations of conglomerates and calcarenite (Sinaia Layers)	-
	Gravels, sands and loess deposits	-
LAND COVER	Forest	-
	Grass	**1.15**
	Orchards	**0.77**
	Built-up area	-
	Flood plain alluvium	
	River/Lake	-
SLOPE	0-3°	-
	3-7°	**0.11**
	7-15°	**0.79**
	15-25°	-
	> 25°	-
HYPSOMETRY	**< 400 m**	**0.28**
	400-500 m	-
	500-600 m	-
	600-700 m	**0.93**
	700-800 m	**0.71**
	800-900 m	-
	900-1 064 m	-

Landslide susceptibility map

The landslide susceptibility map for the Câmpinița Hills reveals a qualitative overview of areas with different susceptibility classes (no susceptibility, low, medium, high and very high susceptibility) (Figures 5, 6 and 7).

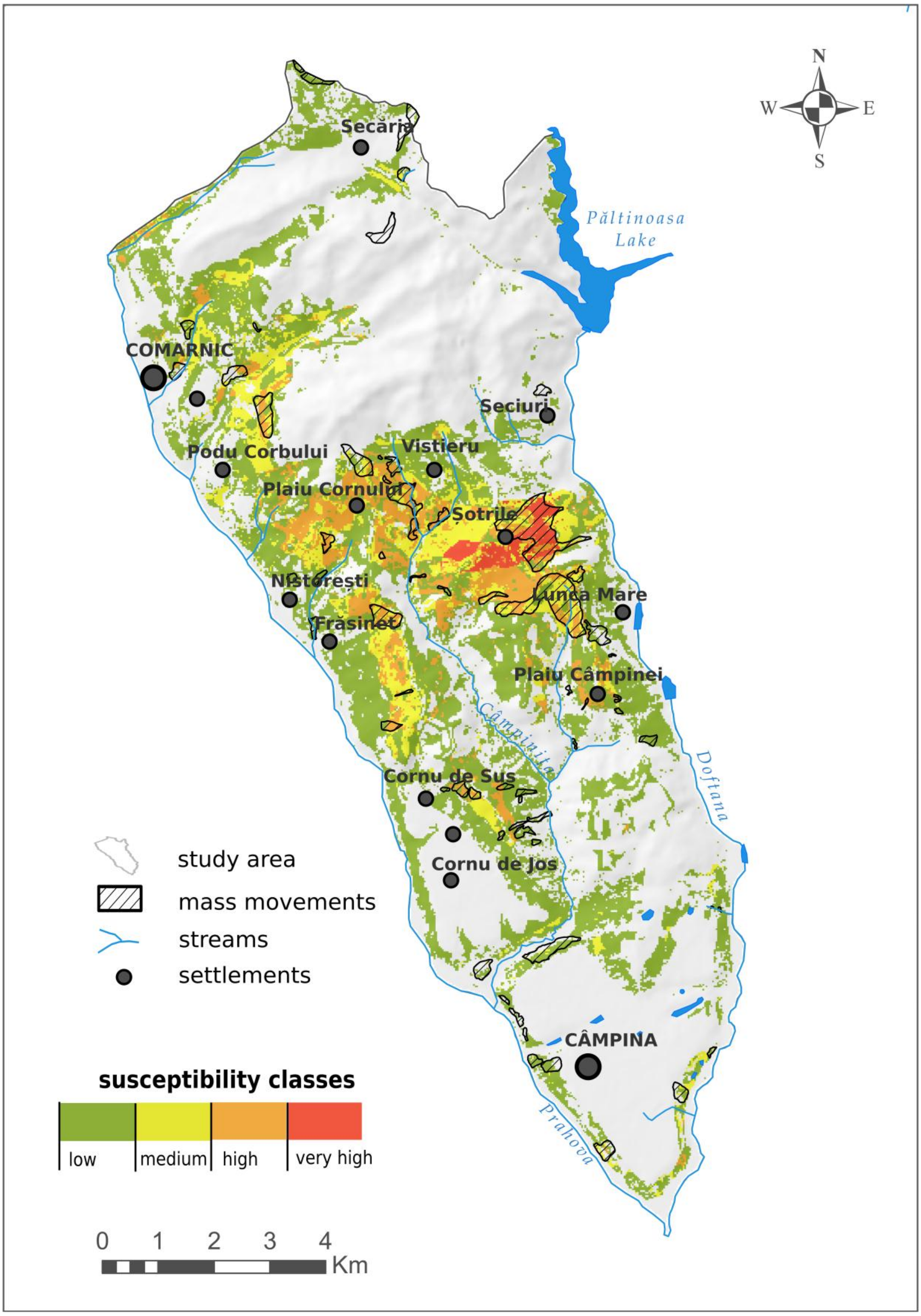


Figure 5. Câmpinița Hills. Landslide susceptibility map

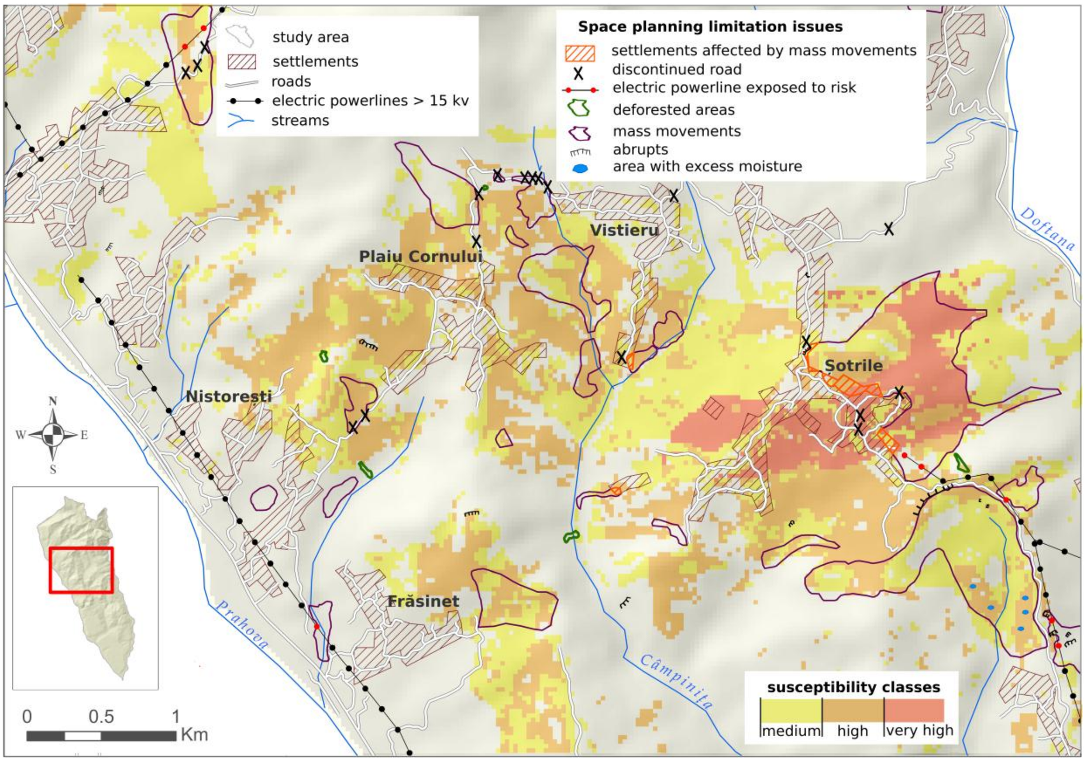


Figure 6. Câmpinița Hills. Space planning limitation map

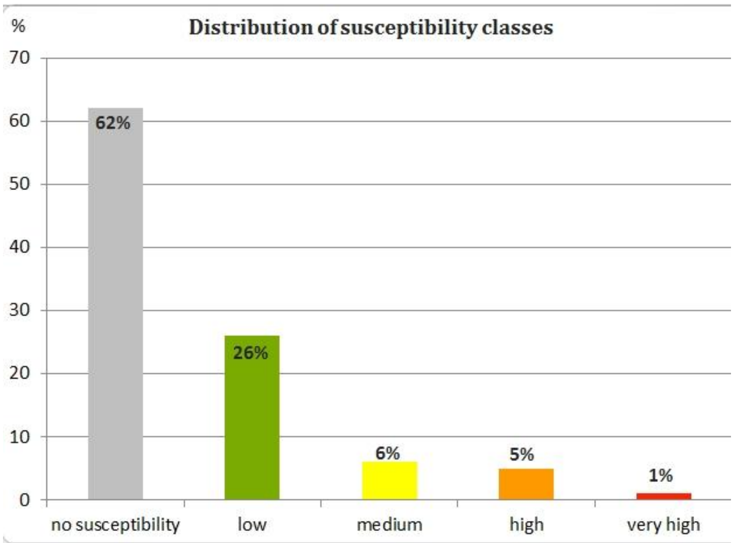


Figure 7. Percentage of susceptibility classes in the study area.

The areas without landslide susceptibility match to the stable areas represented by the Câmpina terrace field (almost flat areas where Câmpina town and Cornu de Sus-Cornu de Jos villages developed), flood plains (Prahova, Doftana, Câmpinița riverbeds) and Secăria Hills (situated in the Northern part of the study area, close to Baiu Mountains, formed of hard rocks with a plateau-like aspect). The areas with high and very high susceptibility are situated mainly within the Câmpinița River catchment, formed of marls, clays and sandstones, with grass and orchards as land cover and rock outcrops. The western slope of Prahova River Valley between Cornu and Comarnic is also featured by medium to high susceptibility for landslides because of the lithological conditions, slope declivities and land cover (grasslands and orchards).

The current landslide susceptibility map was validated by systematic field observations. Areas with high and medium susceptibility degree were identified and recorded together with the features that reveal the possibility of landslidings. This process is continuous and it can be quickly re-activated by one triggering factor (rainy periods, earthquakes, land cover changes etc.).

4. DISCUSSIONS

The model used for the evaluation of the study area is sensitive to the input data. Starting with the landslide bodies mapping and up to the input variables, the data quality is essential in order to obtain a reliable result. First it is important to accurately identify the existing landslide bodies (active and dormant landslides) in order to apply the WOE method. Landslides areas in the Subcarpathians are characterized by reactivation stages alternating with periods of stability. Several landslide bodies are known as being very old (mapped by geologists), and they are still active because of the reactivation stage (Armaș et al, 2003). On the other hand, the old landslides from the geological maps are features with a high probability of reactivation.

This type of approach can be useful for the local authorities and for the inhabitants which should reconsider the risk of landslide triggering when developing the area. They could also apply for some measures which could reduce the risk. Another issue was to identify the elements at risk in order to help the local authorities to identify possible solutions for space planning and risk reduction. For instance the built-up areas with high landslide susceptibility were identified (Șotrile, Plaiul Cornului, Vistieru, Comarnic, Nistorești, Frăsinet) together with some road sectors, power lines, social infrastructures and farms.

Space planning problem often occurs when land use related activities are not suitable to the natural potential, by ignoring the landslide risk. When a development plan is being conducted, all the potential threats (including landslides) are to be taken into account (Cascini et al, 2005). Some of the economic activities which influenced landslides bodies and the mass movements triggering process are the massive deforestations from the last years and the inadequate land use (the overgrazing, the unauthorized building development, the changing of orchards to agricultural land use etc.) (Figure 8).

Figure 8. Space planning limitation issues in Câmpinița Hills. a. Engineering works on a complex landslide body affecting Cornu Monastery, in Câmpinița Basin (January 2015); b. Deforested area on the Prahova – Câmpinița interfluve (April 2015); c. Steep-slope above the DJ 207 road in Șotrile village (May 2015); d. Humid grounds on the hill slope, generated by the moving mass of the landslides (May 2015); e. DJ 207 road affected by a landslide in Vistieru village area (May 2015).

When conducting a space planning study, local authorities should consider maps like the space planning limitation map (Figure 6). This type of map could offer a good perspective upon the general problems and the limitations of the local environment. In this particular case of the Câmpinița Hills, measures against landslidings should be taken, by designing suitable areas for settlement built-up area development and those closed for building. The controls upon overgrazing, land use and agricultural practices should be applied as special measures in order to restore the environmental balance. Last but not least, deforestation should be a highly controlled activity, with constant measures over the hill areas, together with repeated campaigns of reforestation in the attempt to stabilise the slopes. Management plans for at least a decade in advance concerning the development of the settlement area are also useful in order to avoid the repeat of management-errors of the past in the near future.

5. CONCLUSIONS

The study reveals that susceptibility to landslides in Câmpinița Hills is a problem to be considered when space planning is conducted. The use of slope gradient data, elevation data, lithology and land cover data is sufficient for a basic landslide analysis (using Weight of Evidence method) with a relative high score of reliability. It is important to correctly identify the existing landslides (active and dormant-inactive landslides) in order to correctly apply the WOE method. The landslide susceptibility map has four levels of susceptibility (low, medium, high and very high susceptibility) and is designed to be used for space planning and decision making at local scale. It is the base level of an informative map (space planning limitation map - cumulating landslide susceptibility and problems to be considered in space planning which reveals areas with need for a particular attention to be paid and detailed studies to be performed).

The methodology presented could be used for any kind of settlement built-up area where problems with landslides and space planning occurred. We consider that a good GIS database and a suitable integration of the geographical expert knowledge can help to find a solution to these planning issues.

6. ACKNOWLEDGEMENTS

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7. AUTHOR CONTRIBUTION

M.R.R.M.: conducted the study and field observations, analysed the lithology and the landslide typology, evaluated the land use and identified the spatial planning problems, wrote the paper and prepared the maps. B.O.: field observations, performed geospatial analysis of the landslide susceptibility, wrote the paper and prepared the maps. B.A.M.: field observations, data analysis and interpretation, critical revision of the manuscript.

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