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RELATIONAL ANALYSIS OF SUSCEPTIBILITY TO LANDSLIDES OF SETTLEMENTS SITUATED IN THE EASTERN AND CENTRAL PART OF ALBA IULIA HINTERLAND, USING GIS TECHNOLOGY AND MAXENT SOFTWARE

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ABSTRACT. – Relational Analysis of Susceptibility to Landslides of Settlements Situated in the Eastern and Central Part of Alba Iulia Hinterland, Using GIS Technology and MaxEnt Software. Relational analysis is an important method to analyze, generate and to predict relevant data about natural or men-made hazards. In this study, we have chosen to investigate different relations between landslides and landslide causing factors, interpolating the results and their impact on settlements. Urban and rural settlements are highly prone to landsliding because of the increased population which lives in the affected territories. Therefore, an assessment of landslide susceptibility becomes an important phase to predict the most vulnerable settlements of a certain territory in order to implement different disaster mitigation plans/works and land planning strategies. Our study area has a high tendency to landslide due to its lithological and morphological structure. Thus, our purpose is to generate a reliable and accurate analysis of the settlements using the susceptibility map generated by the MaxEnt software, based on 8 identified landslide causing factors: slope angle, slope aspect, profile and plan curvature, terrain roughness, depth of fragmentation, precipitation and temperature. The resulted map indicates a high value of accuracy, the area under the curve (AUC) showing a high performance (0.925) of our analysis.

Keywords: *vulnerability, settlements, GIS, MaxEnt, Alba Iulia, hinterland, ROC curve.*

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1. INTRODUCTION

Landslides are the most destructive men-made or natural hazards leading to increased vulnerability of affected settlements, therefore causing significant damages in property, land-use and infrastructure. According to Surdeanu (1998), in Romania, landslides, as natural disasters, have the highest occurrence frequency.

Vulnerability of urban and rural settlements represents a highly studied actual issue because of the increased world population (75%) which lives in areas prone to natural and men-made disasters (*Reducing Disaster Risk*, *A Challenge for Development*, United Nations Development Programme, 2004). High vulnerability stays in a strong relationship with a greater tendency to disasters, therefore the lack of infrastructure, hazard mitigation works and land planning strategies lead to high values of susceptibility and risk.

The aim of our study is to describe a relational analysis between settlements and down-slope movement. The most significant down-slope movement of this territory is the land sliding, which will be analyzed in our study using different methods, like the principle of maximum entropy and geospatial analyst tools. Another purpose of our study is to highlight the vulnerability to the existent landslides of the settlements from the Eastern and Central part of Alba Iulia hinterland. Landslides cause the most significant impact and have the highest dynamism from down-slope processes, thus, it becomes necessary to perform a prediction of the total vulnerable area. We decided to analyze the eastern part of the Alba Iulia hinterland due to its particular lithological and morphological structure, and through of the high frequency and dimension of the existent landslides, it transforms this area into a veritable hotspot of down-slope movement. In recent years, many methods were used and analyzed to generate valid susceptibility predictions of a certain area. The principle of maximum entropy was used successful in generating valid susceptibility analysis (Davis and Sims, 2013; Felicisimo et al., 2012; Davis and Blesius, 2015) and according to E.T. Jaynes, it represents the best approach, having high ROC values. Based on these reasons, we required to use the MaxEnt software to generate this kind of prediction, thus, we can make further analysis of the settlements included in the studied territory.

In our analysis, we used 8 parameter maps and realized an overlay with the susceptibility map and the existent situation in order to see which settlements are affected by landslides and which are prone to this disasters.

2. STUDY AREA

The hinterland of Alba Iulia was delimited using multicriterial approach, based on teorethical (GIS modeling) and empirical analysis (Nicula et al., 2015).

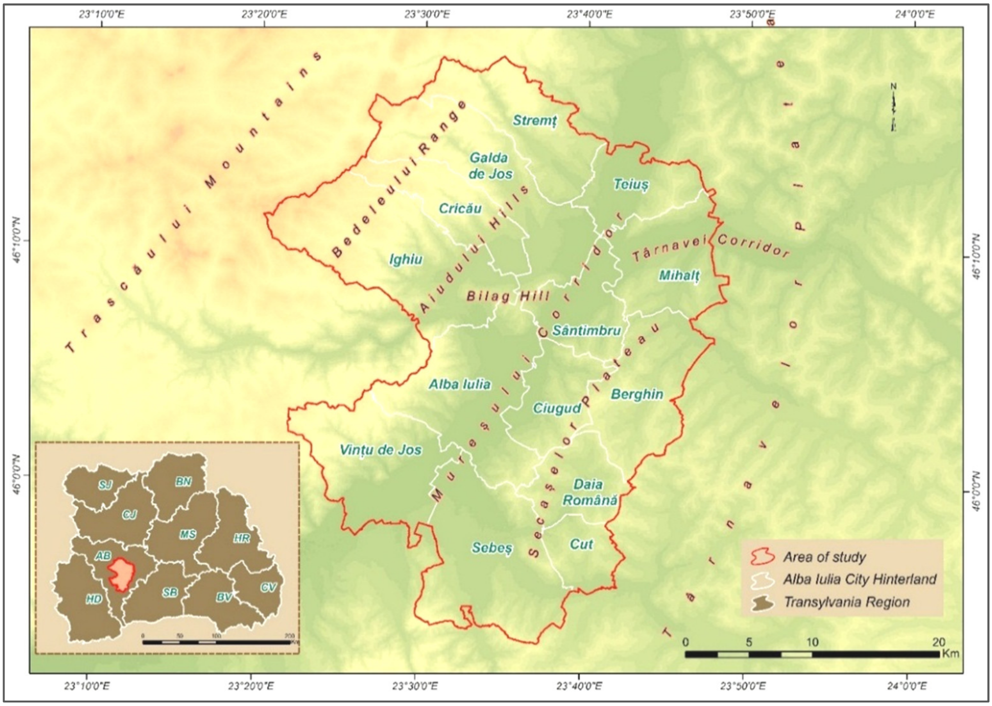

Fig. 1. Geographical position of the studied area

Our study area represents the Eastern and Central part of Alba Iulia hinterland (Fig. 1). We can observe a landslide hotspot on this territory, the majority of them being present on the Secaș (Gorganu-Gruiu) and Cergău Plateau, caused by the frequency of Pannonian depositions (depositions with high porosity). The frequency of landslides is reduced in the western part of the hinterland (which is dominated by mountains). The Alba Iulia-Aiud-Turda Corridor separates the two parts of our study area, and the connection between the Corridor and mountains is being realized by wooded slopes, characterized by the absence of land sliding. The above mentioned facts are the main reasons why we have chosen the Eastern part to investigate.

From regional point of view, our territory overlaps two mains relief units: the unit of mountains (Trascău Mountains) and hills from the western part of the Secaș Plateau and the Mureș Corridor, with the Alba Iulia-Aiud-Turda sector. The area under investigation contains 13 territorial administrative units, from which 11 is affected by land sliding.

From a morphologic point of view, we can observe a gradual transition of the relief units, from the mountain and hill/plateau units from the west (Ampoi Mountains, Bedeleu Massif, Aiud Hills) and East (Secaș Plateau) to the central part of the territory, represented by the Mureș Corridor. The Alba Iulia-Aiud-Turda (Mureș) Corridor represents a significant relief unit, with an elongated form, and a total length of 110 km (Pop, 2012). In the noth-western part, the connection between the Bedeleu Massif and the Alba Iulia-Aiud-Turda Corridor is realized gradually, with the interposition of Aiud Hills. In the case of the Ampoi Mountains, they have a discrete connection with the same Corridor.

Therefore, the territory is separated in two main areas by the Alba Iulia-Aiud-Turda Corridor: the western part, dominated by mountains, and the eastern part, dominated by plateaus.

3. METHODOLOGY AND DATA COLLECTION

In order to generate a landslide susceptibility map, which becomes useful in the prediction of the total vulnerable area of the settlements (this is our main purpose). First, we need to identify the existing landslides (landslide inventory, fig. 2) and the causative factors of this disaster (Roșian, 2009). For generating relevant parameter maps, we used ArcGIS 10.2.2 software.

The first step is represented by the vectorization of the landslides and settlements, using satellite imagery and aerial photographs (source: ANCPI, Google Earth), respectively Open Street Map. A number of 228 landslides were identified, 8 from them affecting 5 settlements: Cistei, Cut, Berghin, Hening and Obreja. This territory contains a number of 52 settlements, therefore 9.61% of them are affected by landslides.

The total surface of landslides is equal with 3489.308 ha and 0.22% of the affected surface can be found on the territory of the settlements.

The second step includes the preparation and generation of the parameter maps, representing the landslide causing factors. For the selection of the main causal factors, we need to consider the nature of the study area and the availability of the data, also we need to be assured about the fact that that the selected parameters are useful, complete, measurable, varying spatially and non-redundant (Yalcin, 2008).

Therefore, we considered the following parameters, by consulting the literature: slope, aspect, terrain roughness, depth of fragmentation, plan and profile curvature, temperature and precipitation (Bayes, 2015; Chen et al., 2016; Chung et al., 2016; Conforti et al., 2011; Pradhan and Lee, 2010).

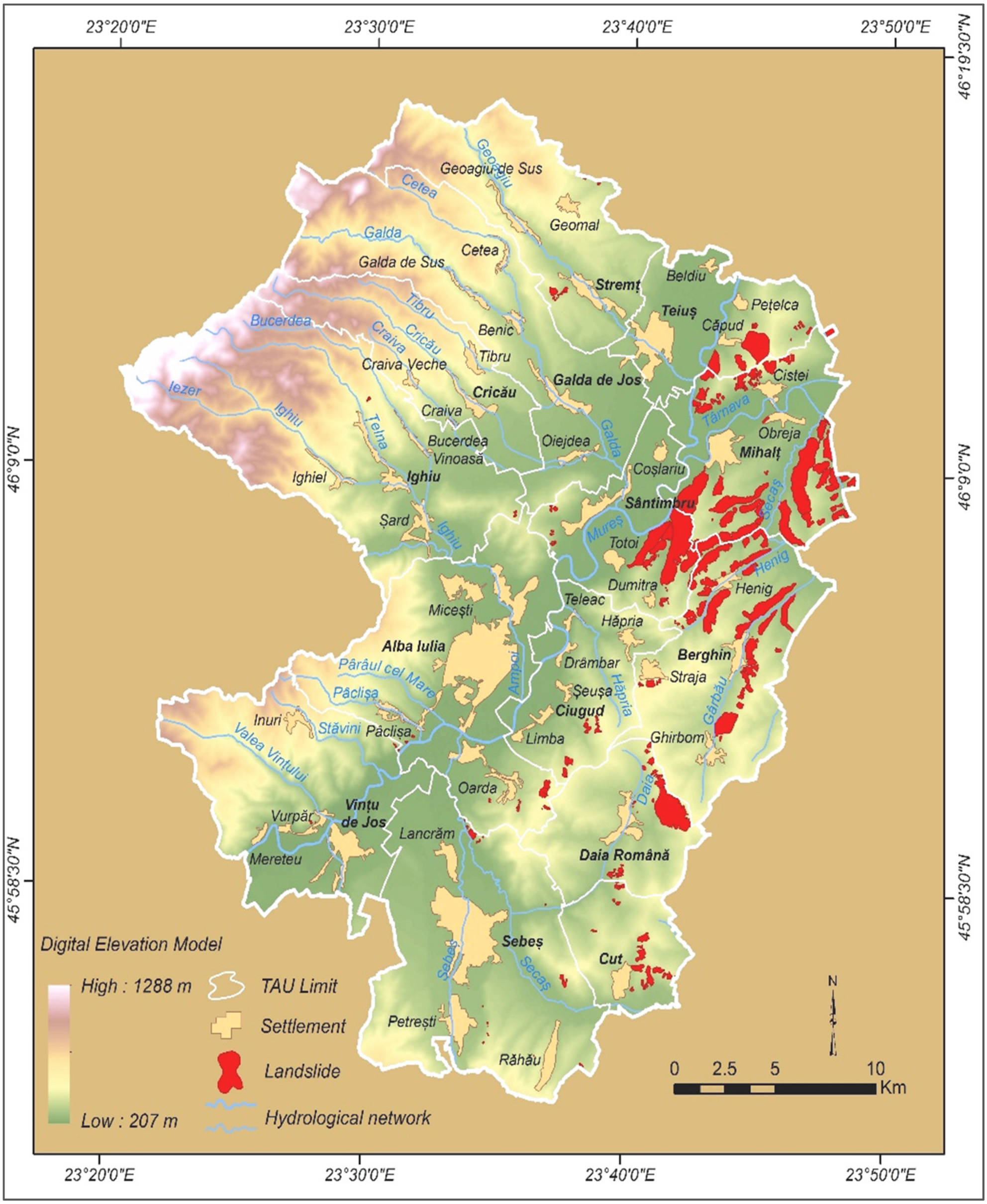

Fig. 2. Landslide and settlements inventory. The current situation

The spatial database used in our research is represented in Table 1.

Table 1. Spatial database

No.	Name	Type	Structure	Source
1	Landslide inventory	Vector	Polygon	Aerial orthophotograms and satellite imagery
2	Settlements	Vector	Polygon	OSM
3	Precipitation	Raster	Grid	National Administration of Meteorology, Romania
4	Temperature	Raster	Grid	National Administration of Meteorology, Romania
5	Slope	Raster	Grid	DEM (30x30) derived
6	Aspect	Raster	Grid	DEM (30x30) derived
7	Depth of fragmentation	Raster	Grid	DEM (30x30) derived
8	Profile and plan curvature	Raster	Grid	DEM (30x30) derived
9	Terrain roughness	Raster	Grid	DEM (30x30) derived

In our study, we identified a number of 6 landslides causing DEM (Digital Elevation Model)–derived parameters: slope angle, slope aspect, depth of fragmentation, profile and plan curvature and terrain roughness. All DEM derived parameters were generated by using the Spatial Analyst tool. Moreover, we identified 2 climatological factors, which contribute to the appearance of this disaster: temperature and precipitation, which were generated by Kriging interpolation.

Slope angle is the most influencing factor of land sliding, because all processes which are caused by the gravitational force occur under specific conditions and slope angle. Also, this parameter is frequently used in landslide susceptibility analysis (Pradhan and Lee, 2011; Chung et al., 2003). The slope parameter map was classified in 6 intervals: 0-2^0, 2-5^0, 5^0-10^0, 10-15^0, 15-25^0, >25^0. Analyzing the results, we can conclude the fact that most landslides from the area of settlements occurred between 5-10^0.

Slope aspect is an important factor by influencing the exposure to sunlight, rainfall or drying winds (Pradhan and Lee, 2010; Conforti et al., 2011) thus the degree of saturation and the quantity of solar energy are unevenly distributed on the study area: slopes with south, south-eastern and south-western orientation receive more solar energy thus becoming less saturated with moisture. This parameter describes the direction of slope (Chen et al., 2016). This thematic layer was grouped into 13 classes: flat (-1), north (337,5^0- 360^0, 0^0-22,5^0), north-east (22.5^0–67.5^0), east (67.5^0–112.5^0), south-east (112.5^0–157.5^0), south (157.5^0–202.5^0), south-west (202.5^0–247.5^0), west (247.5^0–292.5^0), and north-west

(292.5^0–337.5^0). Analyzing these groups, we can say that the most affected slopes of the settlements are the south-eastern ones.

Depth of fragmentation represents the relative altitudinal difference for a specific area. In our study, this thematic map was grouped into five classes, seen in Fig. 3. Most landslides which affect settlements occurred between values of 0-100 m.

Profile and plan curvature represent the shape of surface, negative curvature values represent concave, positive curvature values represent convex surface (Pradhan and Lee, 2010). We used the natural breaks method to classify our maps in 5 classes, as we can see in Fig. 3. In the case of profile curvature, most landslides of the settlements occurred between -0.16-10 m^{-1}, respectively -0.16-0.06 m^{-1} in the case of plan curvature.

According to Riley et al., 1999, **terrain roughness** represents a terrain ruggedness index, which quantifies topographic heterogeneity. The thematic layer was classified into five groups, using the natural jenks distribution: 0.0056-0.33m; 0.33-0.43m; 0.43-0.51m; 0.51-0.60m; 0.60-0.91m. Most landslides which affect the settlements occurred in the second group.

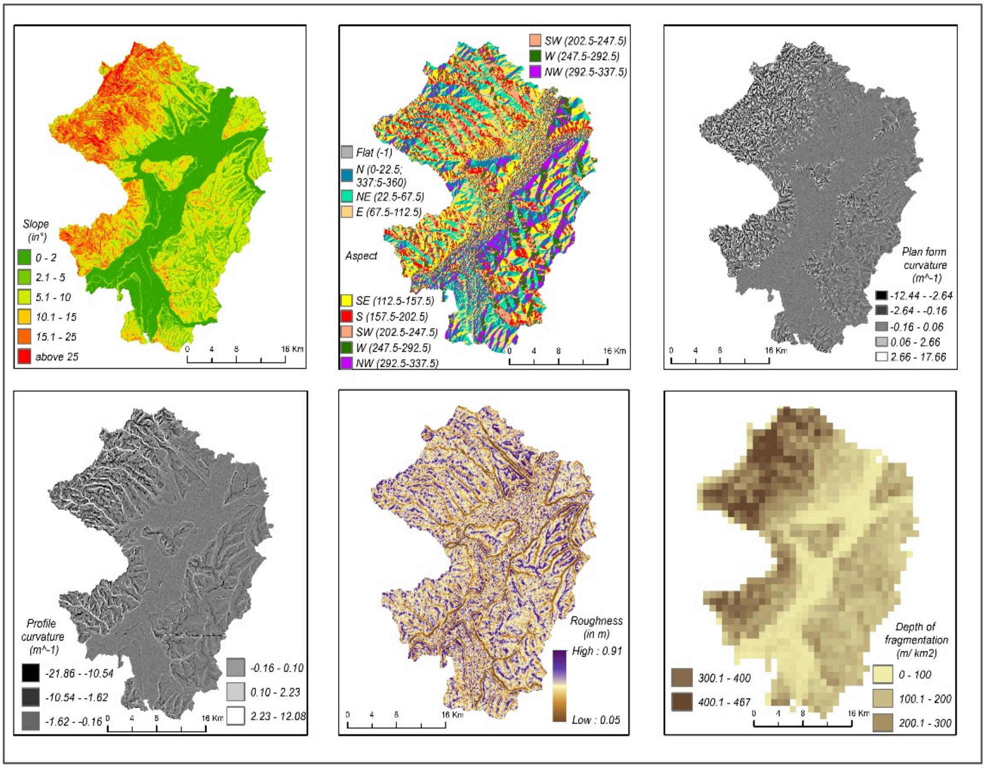

Fig. 3. Landslide causing parameters

The precipitation and temperature map (Fig. 4) was prepared by using the last 5 years rainfall data. We realized an average annual rainfall and temperature map using Kriging interpolation. Precipitation and temperature are landslide triggering factors, contributing to slope instability: freeze-thaw and wetting-drying processes, intense rains influences the down-slope movement. The most affected settlements have an average annual temperature between 9-9.5 C^0 and an average annual precipitation between 900-1000 mm.

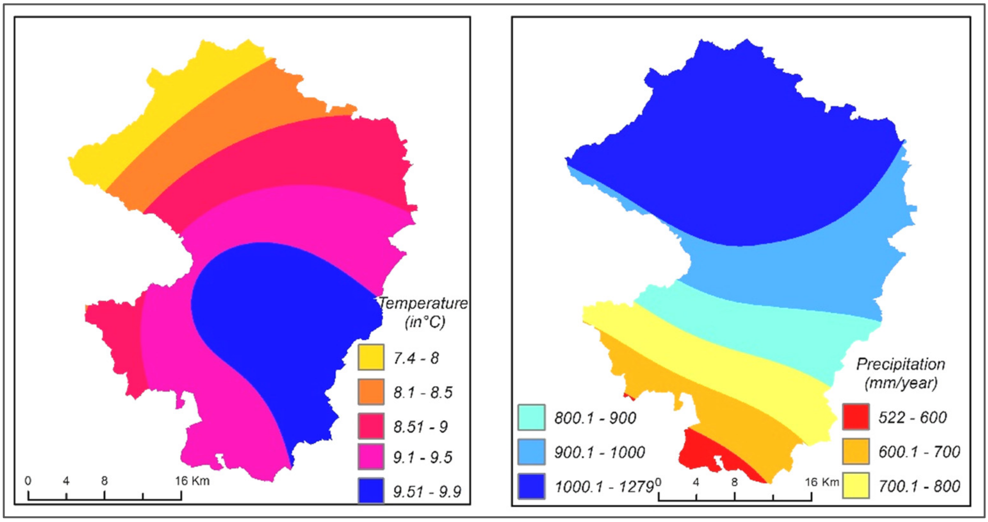

Fig. 4. Temperature and precipitation map

Using these parameters, we required to the next step, the spatial analysis, generating a valid susceptibility map, which represents the base for further research, presented in this study.

4. SPATIAL ANALYSIS

Spatial analysis is the most important phase-in receiving a valid susceptibility map. In our study we used the MaxEnt software to generate a reliable landslide susceptibility map, which is based on the Maximum Entropy Principle.

The Maximum Entropy Principle was used in several studies, mainly for species distribution, but in the last years it was successfully applied for analyzing landslide susceptibility. According to Philiphs et al. (2005), E.T. Jaynes claimed: "the best approach is to ensure that the approximation satisfies any constraints on the unknown distribution that we are aware of, and that subject to those constraints, the distribution should have maximum entropy" (Jaynes, 1957).

While running the software, all thematic layers, which were generated by the Spatial Analyst tool, were used and analyzed by the MaxEnt software. After this, we received a valid landslide susceptibility map, and the resulted values were classified into five groups (using the natural breaks distribution): very low, low, moderate, high and very high probability class of landsliding occurrence (Fig. 5).

5. RESULTS AND VALIDATION

Analyzing the resulted map, we could predict by using the overlay tool the fact that 5.49% of the existent settlements will be affected by landslides. According to the susceptibility map classification (Fig. 5), areas with very high and high tendency for landsliding are situated in the eastern, north-eastern part of the hinterland. Therefore, we realized a classification of the settlements, to predict which are the most vulnerable.

The classification was made by using the overlay tool. For every settlement we calculated the total area which is the most prone to landslides (very high and high susceptibility classes), and these values were divided with the total surface of the settlements. Therefore, we obtained values between 0 and 1. The most vulnerable areas, which have values above 0.1, are: Berghin (0.244), Căpud (0.104), Cistei (0.27), Daia Română (0.19), Drâmbar (0.27), Dumitra (0.42), Ghirbom (0.26), Hăpria (0.31), Henig (0.34), Ighiel (0.101), Mihalț (0.12), Obreja (0.14), Pâclișa (0.27), Pețelca (0.18) and Straja (0.30). Moderate values means values between 0.1 and 0.01 (in total 11 settlements), moderate-low values means values below 0.01 (in total 9 settlements) and low susceptibility class of settlements means that those settlements are not prone to further landslides.

The validation of the susceptibility map is an important step, because in the lack of this phase, we cannot decide if our analysis is valid or not and it also checks the predictive capability of the produced map (Chung and Fabbri, 2003). The MaxEnt software generated a receiver operating characteristic curve (ROC curve), which is used for testing the reliability of our research (Roșian et al., 2016). We apply the area under the curve (AUC) method. AUC values between 0.7 and 0.9 indicate reasonable discrimination ability and values higher than 0.9 represent a high accuracy of the classification (Swets, 1988). Values below 0.5 represent a poor performance of the applied. Our software generated a ROC curve, the AUC value was estimated to be 0.925 (Fig. 6), which indicates a high accuracy and reliability of our methodology.

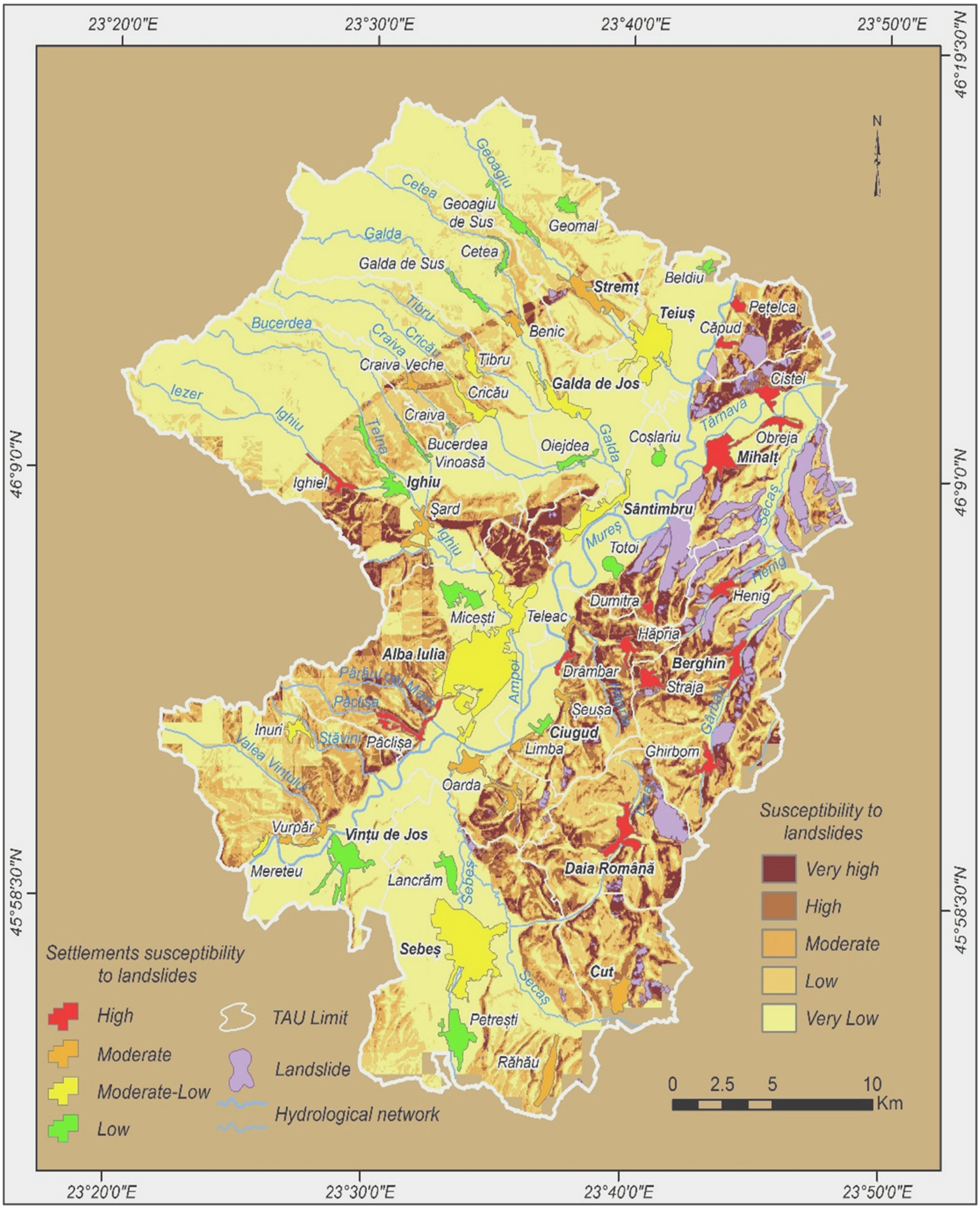

Fig. 5. Settlements susceptibility to landslides

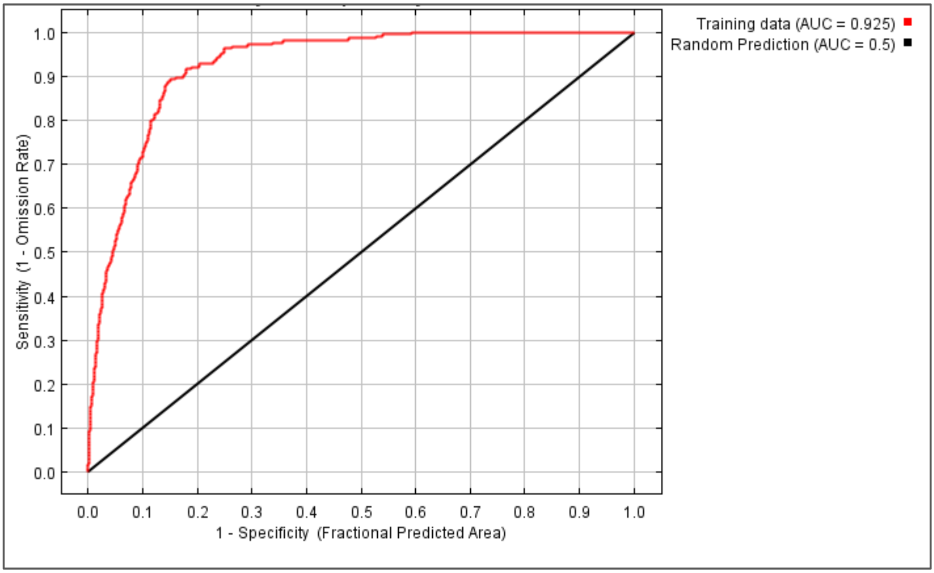

Fig. 6. ROC curve

6. CONCLUSIONS

Landslide assessment becomes important in the prediction of the areas that are most prone to landslide. Due to its devastating effects, urban and rural settlements have a higher tendency to this natural disaster, caused by the increased population.

A valid susceptibility map represents the base of the analysis of the vulnerability of the settlements. Our aim was to highlight a relational analysis between settlements situated in the Eastern and Central part of the Alba Iulia hinterland and down-slope movement.

Our purpose was realized by using GIS technology and MaxEnt software. The results were studied precisely, and validated by using the ROC method, receiving high AUC value (0,925), indicating the increased precision of our investigation. Therefore, we could generate a reliable classification about the susceptibility to landslides of the settlements.

Our model becomes useful in further analysis due to its high accuracy. Thus, based on our maps, we can conclude that the prevention of further landslides can be realized by the analysis of our results, implementing different land planning strategies, which becomes necessary because of the high percentage of susceptible areas.

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