

Landslide susceptibility assessment on the left side of the Izvorul Muntelui Lake bank, Romania

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Abstract: Landslides are mass movements that are playing a very important role when it comes to the morphological evolution of the mountainous and hilly areas. Globally, landslides represent the geomorphologic hazard that produces the greatest damages, the losses being both economic and human. In Romania, the damages caused by landslides are, in most cases, economic. This study was developed because the mountainous area of Neamț county is one of the most susceptible to landslides areas, Bistrița Valley from Borca and up to the area of Piatra-Neamț Municipality being very affected by this type of erosion. One of the reasons this study was developed is the lack of landslide susceptibility maps for the left side of the Izvorul Muntelui Lake bank, the only official maps being drawn up at county level, a too coarse approach for studying the susceptibility to landslides in a more detailed way. This study was carried out using the maximum entropy method, eleven landslide causal factors, two geomorphometric variables obtained by combining several geomorphometric derivatives and the existing landslides position data that occurred over the past 15 years. A very conclusive result of this study is the very high impact of the National Road 15 and the high slope deforested areas on the onset of the landslides and the statistical modeling of the susceptibility.

1. Introduction

1.1. Landslides. Terminology

Landslides are, by excellence, a geomorphological phenomenon, being one of the most known and studied mass movements in Romania. At a global scale, these type of mass movements produce both economic and human damages, being considered one of the most damaging geological hazard in the mountainous regions (Varnes, 1996; Parise and Jibson, 2000; Dai et al., 2002; Croizer and Glande, 2005; Kanungo et al., 2006; Pan et al., 2008; Raghuvanshi et al., 2014; Girma et al., 2015; Hamza and Raghuvanshi, 2017; Mengistu et al., 2019; Shano et al., 2020). In Romania, fortunately, most of the damages caused by landslides are mostly economical (Maftei et al., 2013). A good explanation of the “landslide” term is given by Varnes (1996), where he describes this phenomenon as a downward and outward movement of slope forming materials such as rocks, soils and artificial fills, by falling, sliding, flowing or combinations of these movements. Mărgărint and Niculiță (2016) explain that the way landslide occurs and are distributed in a certain area is linked to a large range of triggering and conditioning factors. Several causes have been explained in the international literature, the best contributions in this field being associated with Hutchinson (1968), Coates (1977), and Cruden et al. (1996). In the Romanian literature, a very great contribution, both in determining the causes of landslides, analyzing processes, elements, typology and how

to combat landslides, with special focus on the mountainous areas, had Virgil Surdeanu (1998).

1.2. Causal factors

The causal factors of landslides depend on the scale of the analyzed area. There are causal factors used in the investigation of particular sites in a local scale analysis, such as ground conditions, geomorphological processes, physical processes and man-made processes (Popescu, 2002), and causal factors used in the investigation of large, regional areas, such as geology, geomorphology, climate, hydrology, hydrogeology and land-cover (Fell et al., 2008; Guzzetti et al., 2008; Cappechi et al., 2015).

Among the natural causes of landslides, the terrain morphometry can be mentioned as relevant, from which, using the geomorphometric analysis, geomorphometric derivatives are determined, such as: terrain slope, profile and plan curvature, terrain aspect, terrain roughness, topographic wetness index or depth of fragmentation. Other important causes of landslides are the substrate lithology and the vegetation cover. These causal factors represent the preconditioning factors that increase the degree of the stability of slopes, according to Mărgărint and Niculiță (2016). Earthquakes, precipitations amount and the physico-chemical actions of the groundwater are a part of the triggering factors category representing the events with a very short duration but with great effect in causing landslides. The human induced causes are very numerous because of people's need for accessibility and space. The most important anthropogenic causes of landslides, that are included in the preparatory factors category, are the decrease of forested areas, the increase of build surfaces and road construction, over-grazing and the presence of huge lake basins

In the past decades, measures have been taken to decrease the destructive effects of landslides. One of the most used methods was to create landslide susceptibility maps by qualitative methods, but especially by quantitative methods, in order to identify areas of maximum risk, in order to act in the sense of diminishing the danger (Fernandez, 2003).

1.3. Statistical methods used to assess landslide susceptibility models

Landslide susceptibility models delineate areas, using qualitative and quantitative methods, where landslides are likely to occur based on geological, geomorphological, physical conditions and anthropogenic influences (Daniel et al., 2021). Quantitative susceptibility models are created using deterministic, heuristic or data driven approaches such as bivariate, multivariate and machine learning methods (Soeters and van Westen, 1996; Daniel et al., 2021).

Until the last decade of the past century, Romanian studies on landslides were made using classical investigation methods (Ichim, 1979; Surdeanu, 1998). In the last 15 years, statistical investigation and determination methods have been approached (Bălțeanu et al, 2010; Bălțeanu et al., 2020; Bilașco et al, 2011; Grozavu et al, 2013). At international level, landslide susceptibility determination by statistical methods had been pioneered by Mantovani (1996) and by Guzzetti (1999; 2006). Statistical landslide susceptibility models applied in the past years are varied, some of them being borrowed from other sciences. The bivariate method (Conforti, 2011), multivariate method by logistic regression (Pradhan, 2010; Patriche, 2015), fuzzy logic method (Schernthanner, 2005), analytical hierarchy process method (Grozavu et al., 2021) and the maximum entropy method developed by Davis&Sims (2013) were used. For this current research, the maximum entropy method, to evaluate the susceptibility to landslide of the left side of the Izvorul Muntelui Lake bank, was used.

The maximum entropy method is one of the most used methods in the distribution of species. This method was used in distribution studies that only refers to animal or plant species presence data in a particular area (Phillips et al, 2006). Because the species distribution methods are based on the relationship between the positioning of the

inventoried species and the factors that can influence the distribution in a given area and the studies on landslide susceptibility are closely related to the position data of the landslides in accordance with the causal factors of these mass displacements, this method of maximum entropy can also be successfully applied in the studies of landslide susceptibility (Elith et al., 2011; Liu et al., 2012; Vorpahl et al., 2012; Convertino et al., 2013; Felicisimo et al., 2013; Davis and Blesius, 2015; Kim et al., 2015; Park, 2015; Moosavi and Niazi, 2016; Pradham et al., 2016; Kerekes, 2016).

1.4. Study area

The left side of the Izvorul Muntelui Lake bank is located in the north-eastern part of Romania, more precisely in the western part of Neamţ county, or in the south-western part of the Stânişoara Mountains. The delimitation of this area was made according to the drainage basins boundaries of the left side of the Izvorul Muntelui Lake bank (Figure 1).

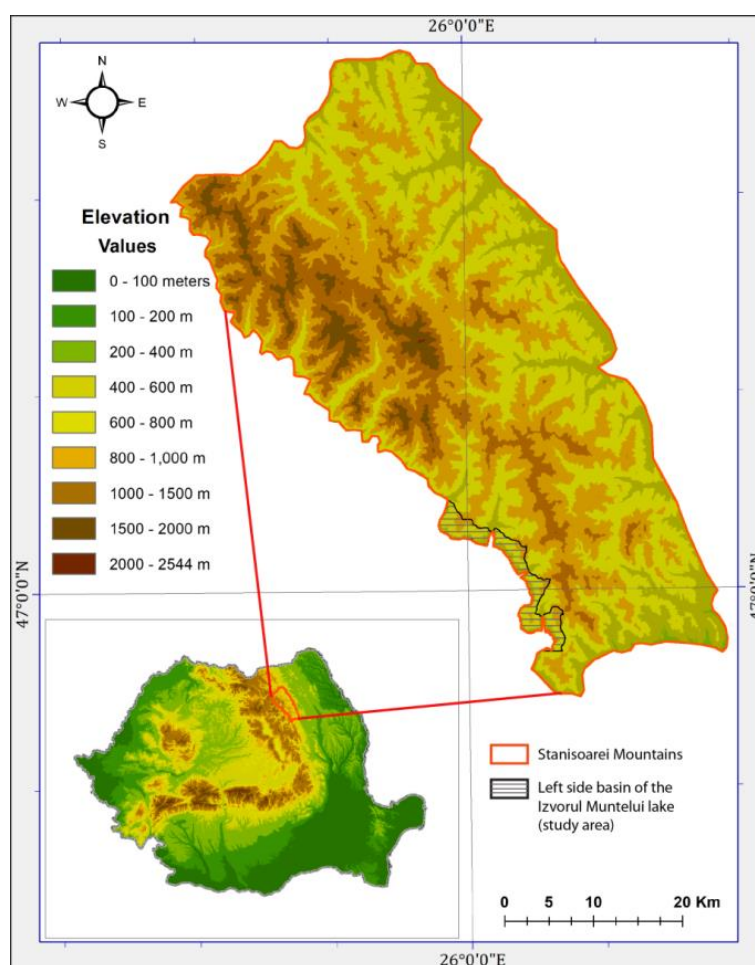


Figure 1. Geographical location of the left side of the Izvorul Muntelui Lake bank

The study area (Figure 1) is fully positioned in the Carpathian Flysch Belt and it is composed basically from sedimentary rocks deposited since Cretaceous up to Paleogene time. Within this territory, three nappes outcrop on a north-west – southeast direction. These nappes are the Teleajen nappe, the Audia nappe and the Tarcau nappe. In the left side of the Izvorul Muntelui Lake bank the most predominant sedimentary rocks are sandstones, claystones with a series of Cretaceous conglomerate intercalations in the Teleajen nappe (Romanian Geology Institute, 1968).

Within the morphostructure of the relief forms or elements, the greatest influence is held by the endogenous factor which refers to tectonics, structure and lithology. Within the left side of the lake bank, three lithological complexes can be identified and ranked

by their resistance to the erosion caused by weathering. For this area, there are low resistant lithological complexes, medium resistant lithological complexes and high resistant lithological complexes (Ichim, 1979).

The depth of fragmentation, density of fragmentation and the slopes of this area have medium and high values, the longitudinal profile is large and concave and the climatic conditions are favorable for the production of freeze-thaw phenomenon that accelerates the disintegration and alteration of soil and rock. The vegetation of this area was affected very much by humans, especially in the time and after the construction of Bicaz Dam when villages that were near the banks of the Bistrita river were relocated uphill, on the slopes of the Stanisoara Mountains (Gaman, 2015). The national road 15, which crosses the left part of the Izvorul Muntelui Lake bank at an altitude of 500-600 meters, is a very important communication route for the economy of the area, but also an anthropic factor that led to the destabilization of the slopes.

The most important mass movements that still have a very big importance in the geomorphological modeling of the left side of the lake bank surface, and also of the Stanisoara Mountains, are landslides and pseudo-solifluctions.

In the last 14 years, landslides that have affected the National Road 15 have occurred mostly because of the increase of heavy traffic coming/going from/to Transylvania due to the European Union integration of Romania. This road is intensely used because is the easiest and cheapest way to connect the northern part of Transylvania with the central and southern part of Moldova. The overall limit for trucks is 15 tons for this road, but this was not taken into account because trucks over 50 tons pass frequently on this particular road. From on-field observations, the road has become almost unusable in several sectors since 2007, due to landslides. Also, the number of tourists in this area has increased after the EU integration of Romania, also increasing the traffic on the National Road 15.

This study aims to bring to the fore the problem of landslides on the left side of the Izvorul Muntelui Lake bank, to be helpful for people living in this area or for those who want to build houses, pensions, motels, etc., and for the local administrations of Bicaz town, Hangu commune and Poiana Teiului commune. Tourism has developed a lot in recent years and it is very opportune for those who want to develop business in this area to have knowledge in this regard.

2. Materials and Methods

2.1. Materials

In order to determine the susceptibility to landslides in the left side of the Izvorul Muntelui Lake bank, several factors that contribute to the production to landslides have been used. These causal factors have been chosen after analyzing the terrain reality and the causal factors that were specified and studied in the national and international literature. (Fernandez, 2003; Grozavu et al, 2013; Tseng, 2015; Yuan, 2017, Mărgărint and Niculiță, 2017; Grozavu et al., 2021), but also from the use of the accumulated knowledge regarding the slope processes and land degradation.

To obtain de DTM, topographic maps from the second edition of 1984 were used, from which contour levels with equidistance of 2.5 meters and 5 meters had been digitized. The digitization was made using the semi-automatic digitization plugin Raster Tracer in QGIS. Georeferencing has been made with the GIS software TNTMips and the corrections of errors coming from combining the shapefiles obtained from 50 topographic maps, were made with the QGIS 3.4. After generating the shapefile with existing and added contour lines, several interpolations were made using several GIS softwares. After interpolating with the Multilevel B-spline method (SagaGIS), Minimum Curvature (TNT Mips), TIN method (TNTMips) and with the Topo to Grid method (ArcMap), several ridge and valley profiles were compared. The results showed that Multilevel B-spline method is the best method in representing the terrain surface for landslide susceptibility studies.

Thus, to evaluate the susceptibility to landslides of the left side of the Izvorul Muntelui Lake bank, there were used a number of grids, representing the preconditioning factors, obtained by using a 2.5 meters resolution Digital Elevation Model, from which primary and secondary derivatives were obtained. Two variables were obtained using primary and secondary derivatives, and were used in this study as preconditioning factors. Also, two grids representing preconditioning factors, such as Normalized Difference Vegetation Index and the Lithology, were obtained using Sentinel 2 satellite images, respectively the Geological Map of Romania. Distance from the road is the only preparatory factor that was used in this study.

The preparation of the landslide inventory map was made using two methods: landslide field mapping using GPS and landslide mapping using high resolution satellite images, offered by Esri Satellite Imagery and Google Satellite Hybrid. To analyze how many landslides occurred between 2005 and 2019, orthoimages made in 2005, 2010, 2015-2017 and 2018 were analyzed using the National Agency for Cadaster and Real-Estate Advertising Geoportal (<https://geoportal.ancpi.ro/geoportal/imobile/Harta.html>). After analyzing the satellite images and the orthoimages between 2005 and 2018, 29 landslides that occurred between 2005 and 2019 were found (Figure 2).

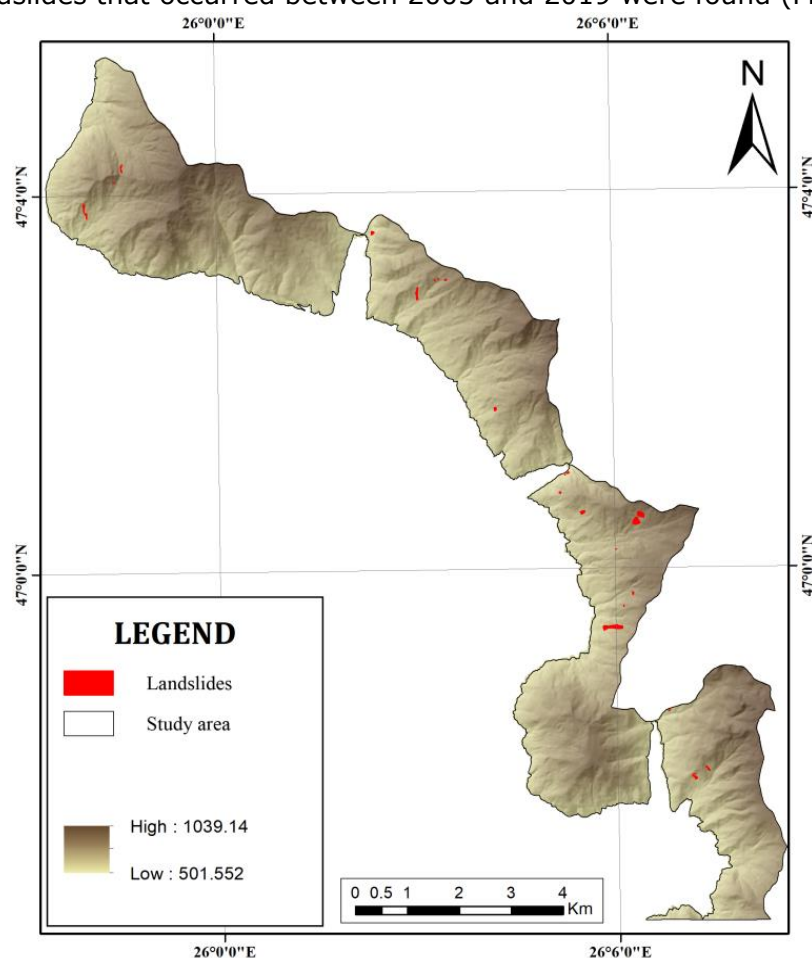


Figure 2. Distribution of landslides within the left side of the Izvorul Muntelui Lake bank

2.2. Used data

Lithology (Figure 3) has an important role in assessing the areas with high and very high landslide risk. Usually, landslides occur in areas where there are alternations of permeable and impermeable rocks (Surdeanu, 1998). In the study area, the rocks with the least resistance to modeling are related to Tarcau Nappe, the resistance increasing in the more northern areas.

Terrain slope (Figure 4) represents one of the most important causal factors of slope processes, having an increasing importance in the high-altitude areas (Surdeanu, 1998). Slope values between 10° and 25° are dominating the landscape of the left side of Izvorul Muntelui Lake bank, the slope class with the highest percentage is the one with values between 15° and 20° . The average slope of the study area is about $17,5^\circ$.

Plan and profile curvature (Figure 4) are two geomorphometric derivatives with an important impact when it comes to their influence on landslide occurrence. Plan curvature is perpendicular to the direction of maximum slope, thus influencing the convergence or divergence of downhill flowing water. Values lower than 0 are equivalent to the concave areas of the slope. Values bigger than 0 are equivalent to convex areas as shoulders or spurs (Schmidt&Hewitt, 2004; Ohlmacher, 2007). Profile curvature is parallel to the direction of the maximum slope and it measures the rate of change of the slope. Positive values are equivalent to concave areas where water flow has a decelerated rhythm and negative values are equivalent to areas where water flow has an accelerated rhythm (Wilson, 2000).

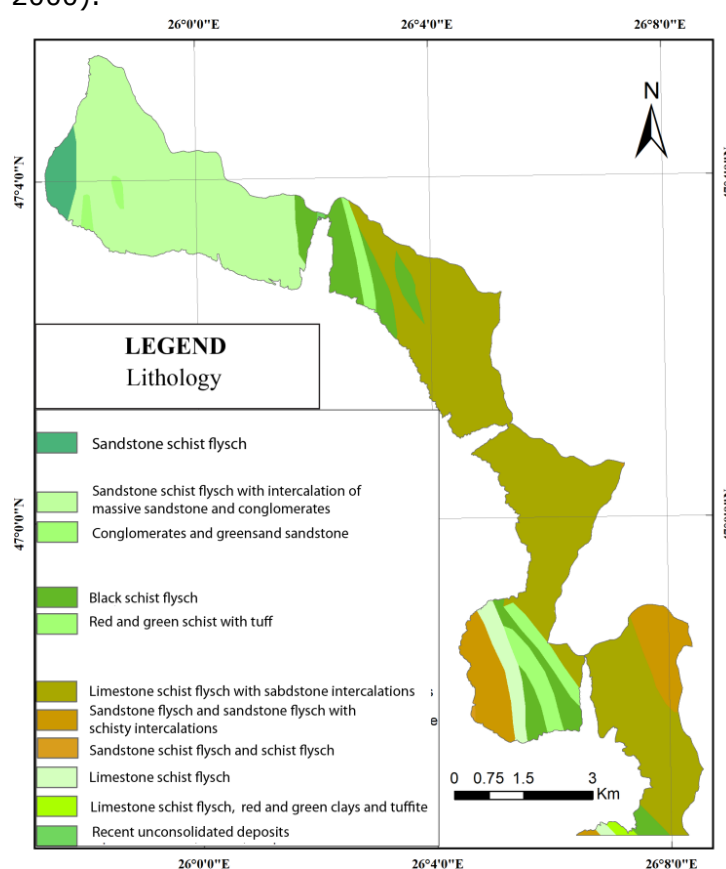


Figure 3. Lithological map of the left side of the Izvorul Muntelui Lake bank

Depth of fragmentation (Figure 4) is a geomorphological index that has a very important influence in the instability of slopes, its values representing the amplitude of altitudes in a given perimeter.

Terrain aspect (Figure 4) is one of the factors that affect other important indices in assessing the susceptibility to landslide of the study area, such as soil moisture, vegetation cover or soil layer thickness. These indices are affected because certain areas could have lower or greater exposure to sunlight, wind and precipitation (Clerici et al, 2006).

Terrain roughness (Figure 4) is very useful to identify landscape patterns. By applying this index, the altitudinal difference between a central point and the surrounding pixels can be determined. It is used to determine the terrain heterogeneity (Riley, 1999; Schlogl, 2018).

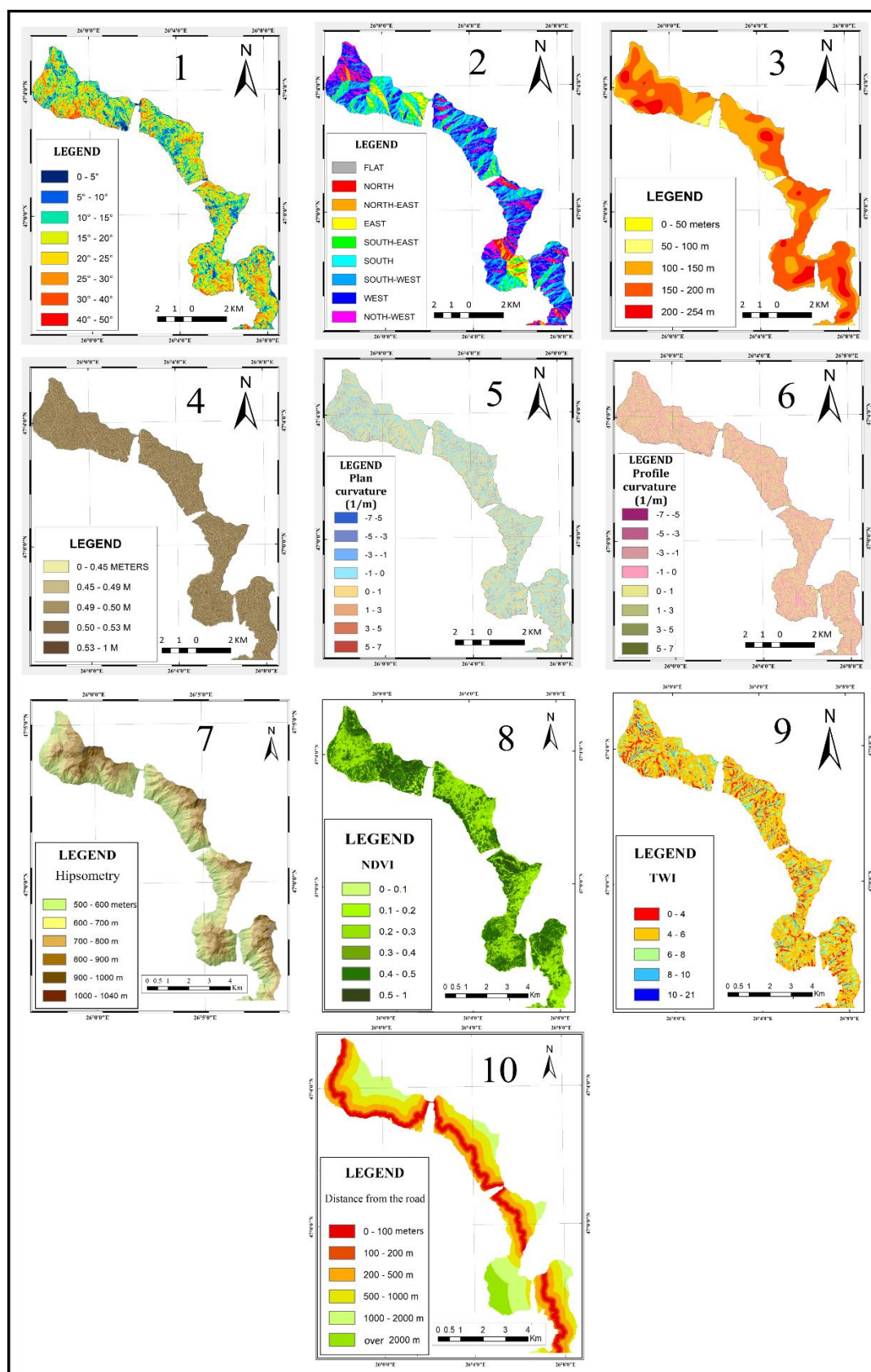


Figure 4. Landslide predictors: (1) terrain slope; (2) terrain aspect; (3) depth of fragmentation; (4) terrain roughness; (5) plan curvature; (6) profile curvature; (7) Hypsometry; (8) NDVI; (9) Topographic Wetness Index; (10) Distance from the road

Normalized Difference Vegetation Index (Figure 4) was calculated using spectral images 3(Red) and 4(Infrared). Values less than or equal to 0 are associated with areas without vegetation, values bigger than 0, up to 0.3 are associated with meadows and grasslands, values up to 0.5 are associated with deciduous forests and values bigger than 0.5 are associated with coniferous forests.

Topographic Wetness Index (Figure 4) was proposed to measure the degree of soil moisture that occurred after water flows on slopes. This index uses the proximity to drainage areas and slope values (Malgorzata, 2018). This index represents a very important indicator in the study of landslide susceptibility because water plays a very important role from this point of view in the left side of the Izvorul Muntelui Lake bank.

Distance from the National Road 15 (Figure 4) was chosen as an index for landslide susceptibility evaluation because the studied area is confronted with landslides caused by heavy traffic. Large vehicle traffic is quite dense on this road because it is the fastest and cheapest route for such vehicles to transport lumber to Piatra Neamt or to Bacau. This raster was created using the Open Street Map Road lines and the Buffer tool in QGIS.

To evaluate the susceptibility to landslides, two grids representing two land surface classifications were used. These classifications were proposed by Jo Wood, 1996 and Pike & Iwahashi, 2007 (Figure 5). The Jo Wood classification of the morphometric elements was achieved by deriving the terrain slopes, terrain aspect and the curvatures, so as to identify the six specific elements of this type of classification, namely: peaks, ridges, channels, saddle, depressions and flat areas. Automatic classification by overlapping algorithms and three geomorphometric derivate layers of Iwahashi and Pike were created using slope values and surface convexity.

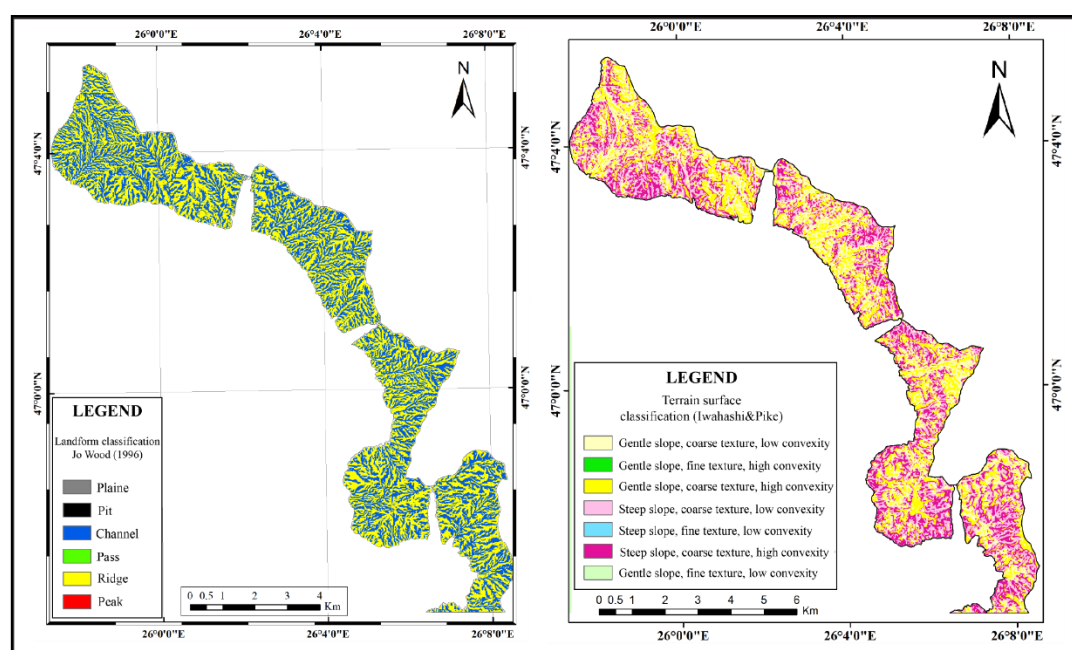


Figure 5. Terrain surface classification by Jo Wood method (left) and by Pike & Iwahashi method (right)

2.3. Methodology

Firstly, the rasters, that were used in this analysis, were created using the Terrain Analysis Tool from Saga GIS and QGIS. For the Normalized Difference Vegetation Index (NDVI), Sentinel 2 Satellite Images were downloaded using Google Earth Engine, and were processed using the Semi-Automatic Classification Plugin in QGIS. After these steps, the rasters were clipped, so that they can have the same number of pixels, and were converted into ASCII file format so that they can be used in the MaxEnt software.

The polygons representing the inventoried landslides from the studied area were converted into point shapefile. The point shapefile was converted into csv format, so it can be used in MaxEnt software. In MaxEnt samples and environmental layers were inserted. The sample represent the csv file that shows us the distribution of landslides, species of other phenomena, The Environmental layer section is the place were ASCII files representing the causal factors are inserted. The output format of the resulted was set as logistic and the output file type was set as *.asc.

To evaluate the effectiveness of the results of the susceptibility model, landslide point data was divided in two data sets for model training and testing purposes. For model training, 70% of the points were taken randomly and the rest of the landslide points were used for validation of the results (Figure 6).

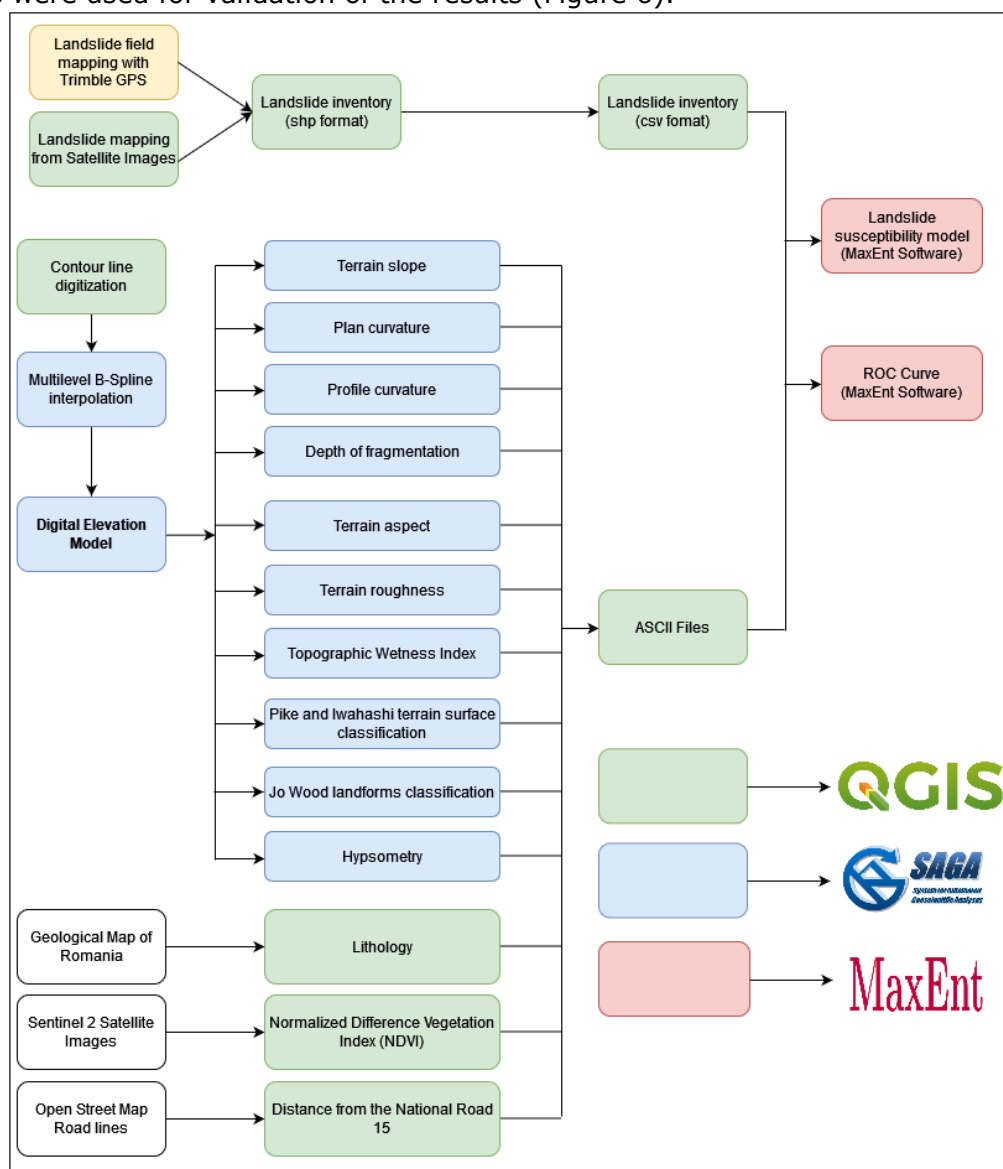


Figure 6. Methodological flow-chart

3. Results

The landslide susceptibility map (Figure 7), the one in which the National Road 15 is taken as a landslide preparatory factor, reveals very high values of the susceptibility in the immediate proximity of the road. The rest of the areas have medium, small or very small values of the susceptibility. The traffic with large vehicles carrying wood and weighing over 15 tones (the allowed limit) is very dense, representing one of the most important causes of slope destabilization near the road. Of course, the road itself, from

the moment it was designed, was an important factor in destabilizing the slopes by the discontinuities that appeared. In this case, the factors with the greatest contribution in identifying the areas with high susceptibility to landslides are the NDVI vegetation index, the distance from the road, the lithology and the terrain slope, the other factors taken into account in this modeling having a contribution of less than 3.8%. 67% of this area has very low values of susceptibility to landslides, 17% of the area has low values of susceptibility to landslides, 11% has medium susceptibility to landslides and 5% of the area has high susceptibility to landslides.

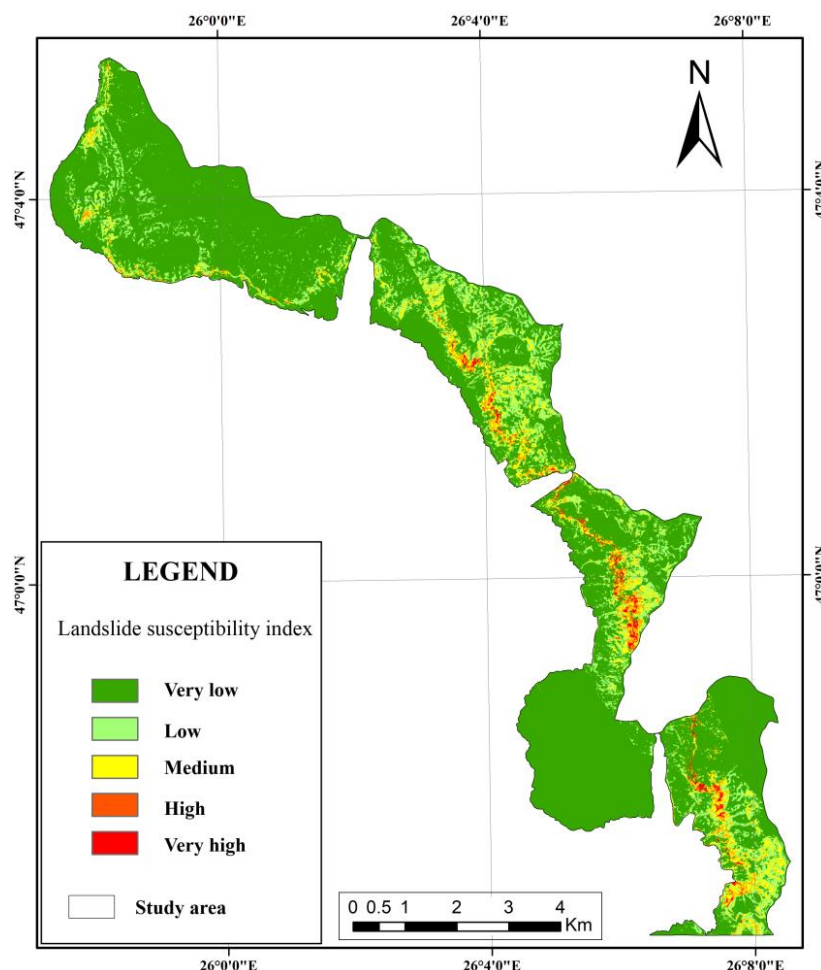


Figure 7. Landslide susceptibility map obtained considering all 13 landslides predictors

High and medium susceptibility values can be found in the center and south-eastern part of the area. This is mostly explained by the presence of low resistant rocks from the Tarcau Nappe, the density of the population that is a main reason for the existence of preparatory factors for landslides, such as large deforested areas, presence of the roads, a big number of buildings that increase the pressure on the terrain. High susceptibility values can be found mostly near the National Road because of the heavy traffic vehicles that are crossing this area and destabilize the slopes and sometimes become a triggering factor.

In order to validate the results of the landslide susceptibility model, the accuracy of the generated values must be verified. To test the reliability of the landslide susceptibility map, the Receiver Operating Curve (ROC Curve) was generated using MaxEnt software. Depending on the resulted value, the generated model can have high or low accuracy. If the values are higher than 0.9, then the generated model has very high accuracy, if the values are between 0.7 and 0.9, then the model has reasonable results, values between 0.6 and 0.7 are showing that the model has good accuracy, but with quite a

few errors, and the values below 0.5 are showing that the results of the generated model have poor accuracy, the degree of reliability of the susceptibility map being very low (Swets, 1988). The resulted susceptibility model has high accuracy according to the ROC curves of the training and validation data that have values higher than 0.9. (Figure 8)

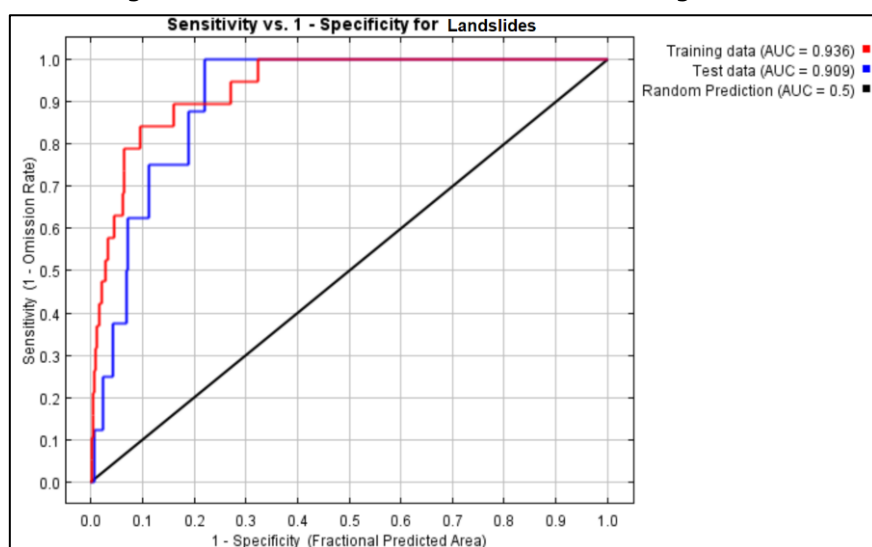


Figure 8. ROC curve for the model in which all 13 predictors are considered

4. Discussion

This study is a novelty in modeling the susceptibility to landslides with the method of maximum entropy. Most of the published studies on this topic were conducted for large areas and less for small areas. This detailed study on the susceptibility to landslides within the left bank of the Izvorul Muntelui Lake is a novelty because susceptibility studies have been made only at county scale, a too coarse approach to analyze the susceptibility in this area. Also, the Digital Elevation Model used in this study has high resolution, compared to other studies where 30 meters SRTM Digital Elevation Model was used.

The Digital Elevation Model (DEM) was created by digitizing the contour lines from the second edition of topographic maps published in 1984. On large scale, there were no major morphometric changes in the last 40 years, so the final result coincided approximately with the terrain reality. The primary and secondary derivatives and the variables were created using the DEM, so the results are qualitative, especially because of the high resolution. The Normalized Difference Vegetation Index was created using Google Earth Engine, where satellite images were cloud filtered so that the result would represent as well as possible the terrain reality. After using 30% of the inventoried landslides to validate the results of the susceptibility model, where 70% of the inventoried landslides were used, a ROC curve was created, whose values over 0.7 showed that the model has a high accuracy.

Because most of the high values of susceptibility to landslides were concentrated mostly near to the National Road 15, another susceptibility model was created without the distance from the road preparatory factor. In the second susceptibility map (Figure 9) a significant change was observed. Following the exclusion of the distance from the road factor, the model no longer had high values only near the road, but also in other areas, taking into account the other predisposing factors. As can be seen, the NDVI index has a great contribution in modeling the susceptibility to landslides. Both in the field and in the raster representing the NDVI, most of the landslides appeared in the areas with low values of NDVI, equivalent in the areas occupied by pasture, grasslands, or areas without vegetation. Beside the NDVI, which had a contribution of over 49%, the slope contributed with 12.3%, lithology with 10.3%, hypsometry with 8.1%, the combination

of slope and convexity from Iwahashi and Pike's classification with 5.6% and the depth of fragmentation with 5.1%. Analyzing the ROC curve, that was realized in the same way as the first one, a high accuracy, as that of the first susceptibility model, was observed (Figure 10).

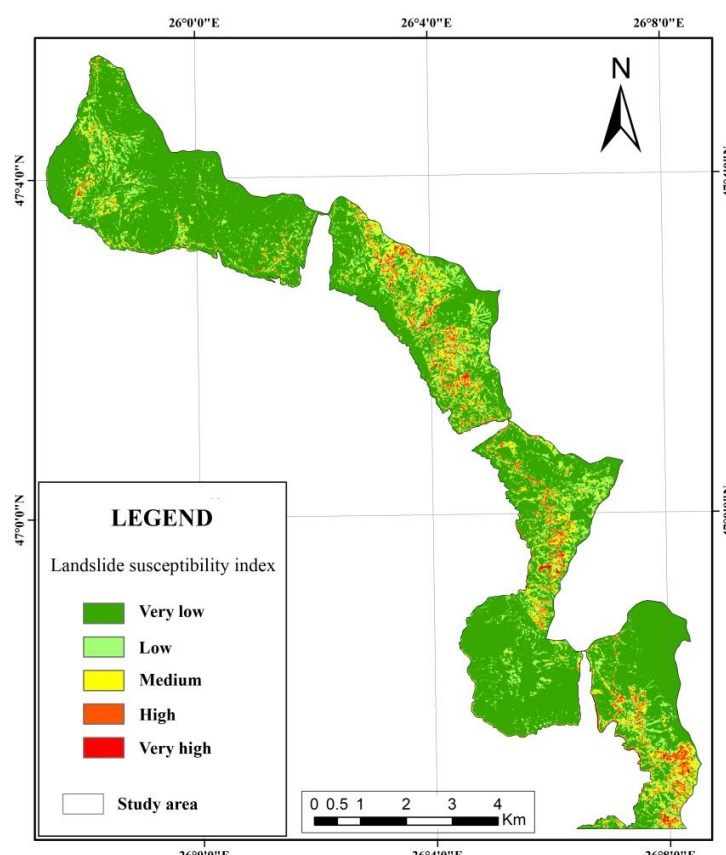


Figure 9. Landslide susceptibility map obtained without considering the predictor Distance from the road

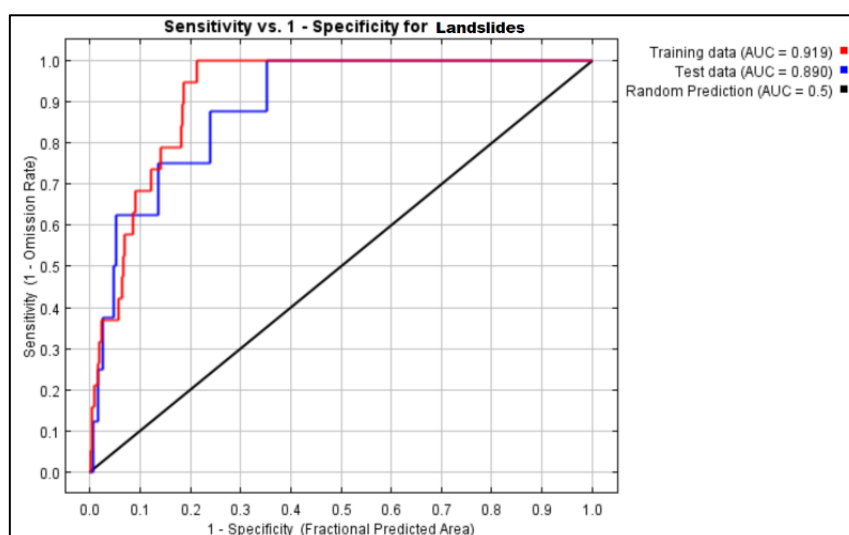


Figure 10. ROC curve for the model in which the predictor Distance from the road is not considered

As it has been pointed out, although the road buffer zone has not been taken into consideration in the second susceptibility map, it still has quite large portions with high

susceptibility values. A probable explanation would be that most of the mapped landslides are in the proximity of the road, the NDVI index has very low values in the proximity of the roads and most of the slope discontinuities, which automatically affect the slope of the land, are caused by the national road.

Of course, the landslides from the proximity of the road are also caused by the fact that drains and wells used for capturing the groundwater are in a very bad condition.

Analyzing the areas where there are landslides and the values of susceptibility offered by the two landslide susceptibility models, the best option would be the model where the buffer zone of the road is not taken into account. The first model omits many areas where there have been several important landslides, and the respective areas are indexed in the first model as having low or very low susceptibility.

5. Conclusions

In Neamț county there are very few landslide susceptibility maps, the only public maps being generated on a county scale that do not have a very high accuracy.

The statistical method of maximum entropy (using MAXENT software) was chosen for determining the susceptibility to landslides because it is one of the few methods successfully applied when the only data available for conducting the study are those regarding the distribution of landslides, presence data, and the causal factors of the landslides. Following the modeling, good results were obtained, reliable and with high accuracy as it resulted from the specificity-sensitivity curves (ROC Curves).

Following an analysis of the in-field situation, the model that didn't used the grid representing the distance from the road is the closest to the truth. First of all, the rest of the causal factors have a very important role in determining the susceptibility, most of the landslides inventoried in the area of Ruginești, Grozăvești and Potoci villages are in areas where the susceptibility is high or very high, this aspect was ignored in the first model where the area around the road had high and very high values of susceptibility and the rest of the study area had low and very low susceptibility values.

The Normalized Difference Vegetation Index, slope of the terrain and lithology play an important role, if distance from the road is taken or not into consideration, in determining the susceptibility to landslides in the left part of the Izvorul Muntelui Lake bank. Areas with low vegetation, steep slopes and low resistant to erosion rocks are very susceptible to landslides.

The area near the road has high and very high susceptibility to landslides because, in the past, after the relocations made when the Bicăz dam was build, no feasibility studies were carried out in a detailed way to determine if a national road in this area is feasible. The national road designed on the left side of the Izvorul Muntelui Lake bank followed the old roads used in the past by the inhabitants of Hangu commune. Also, the design of the road led to the appearance of slope discontinuities.

Also, the statistical methods for modeling the susceptibility to landslide occurrence for a certain area, independent of their high degree of accuracy, cannot be infallible, requiring the in-field validation, while also using measurements, and in-situ statistical validation means, which would give such a study added-value, and would also confirm and quantify the methodological approach used.

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