Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XI, 2022
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

LANDSLIDE ANALYSIS USING GIS TOOLS - CASE STUDY ANALYZED IN THE CROSS-BORDER GeoSES PROJECT

Tiberiu Mihai KALMAR[1], Marcel DÎRJA[1], Adrian Traian Gh.M. RĂDULESCU[2], Petru Daniel MĂRAN[2], Virgil Mihai Gh.M. RĂDULESCU[2], Corina M. RĂDULESCU[2], Gheorghe M.T. RĂDULESCU[2], Mihai HERBEI[3]

[1]University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca, 3-5 Calea Manastur, Cluj-Napoca, Romania
[2]Technical University of Cluj-Napoca, 15 Constantin Daicoviciu Street, Cluj-Napoca, Romania
[3]Banat University of Agricultural Sciences and Veterinary Medicine "King Mihai I of Romania" from Timisoara, 119 Calea Aradului, Timisoara, Romania

Corresponding author email: mdirja@usamvcluj.ro

Abstract

The international cross-border project GeoSES-Extension of the operational "Space Emergency System" towards monitoring of dangerous natural and man-made geo-processes in the HU-SK-RO-UA cross-border region HUSKROUA 1702 /8.1. / 0065 was included in Thematic objective 8. TO - Common challenges in the field of safety and security, Program priority 8.1 Support to joint activities for the prevention of natural and man-made disasters as well as joint action during emergency situations of the HUSKROUA ENI CBC Program 2014-2020. Technical University of Cluj Napoca was one of the participants in the project together with the Project Leader Uzhhorod National University, Ukraine and Pavol Jozef Šafárik University in Košice, Budapest University of Technology and Ecomomics, Self-government of Szabolcs-Szatmár-Bereg County. The overall objective of the project is geo-monitoring of natural and man-made processes in the cross-border territory with the aim of preventing emergency situations. The project specific objectives are the following: 1. Reduction of the risks of natural disasters by means of geomonitoring of dangerous landslide and mudflow processes in the valley of the Tisza River; 2. Forecasting the occurrence of heavy rainstorms in cross-boundary areas with the aim of preventing unexpected river floods, 3. Development of a joint innovation strategy for preventing ecological disasters and adopting to change climate in the Carpathian Region. Located at the foot of Solovan Hill, Sighetu Marmației was subjected to numerous landslides. In these conditions, the role of the Romanian partner in the project was to monitor this situation, operations carried out both globally, for the entire municipal territory and neighborhoods and privately through six locations chosen both due to the gravity of events over time and the fact that these landslides had different causes. The paper presents the GIS mechanisms used to generate the landslide risk analysis.

Key words: *Landslide, GIS, Maxent, 3D model.*

INTRODUCTION

In 2021 we celebrated ten years of collaboration between the Department of Land Measurements and Cadastre of the Faculty of Civil Engineering at the Technical University of Cluj-Napoca and the team of specialists in Disaster Management at the National University of Uzhhorod, Ukraine. Then, after winning the position of eligible project, through the application "SPACE EMERGENCY SYSTEM", cross-border system for predicting natural disasters based on the exploitation of satellite technologies in Hungary, Slovakia, Romania and Ukraine (Program: ENPI CBC 2007-2013 Hungary - Slovakia - Romania - Ukraine, Cross-Border Cooperation Program), together with teams from the University of Miskolc, Hungary, the Vihorlat Observatory (Humenne, Slovakia), the International Association for Regional Development Institution "IARDI" (Uzhhorod, Ukraine), the project leader being the same as in this project, we carried out an intense activity of scientific research in 2014 and 2015. We wanted that the project analysed in this paper GeoSES-Extension of the operational "Space Emergency System" towards monitoring of dangerous natural and man-made geo-processes in the HU-SK-RO-UA cross-border region, Indicative

Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XI, 2022
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

HUSKROUA 1702/8.1./0065 to continue this activity, this time in relation to the Romanian bank of the Tisza River, the area of the Municipality of Sighetu Marmației and neighborhoods, in terms of land stability (aspects presented in the paper) and the dangers of exposure to floods (Figures 1 and 2).

Figure 1. Location of the study area within the HUSKROUA program region
(Source: https://huskroua-cbc.eu/news/)

Figure 2. Area monitored (Sighetu Marmației) for landslides in the GeoSES Project
(Source: GeoSES Project)

Landslides pose a major natural hazard. Reported landslides are usually reduced for a variety of reasons (Kirschbaum et al., 2015) and thus total rates are likely to be underreported. Even so, Froude and Petley reported 32,322 deaths over seven years, a high rate that disproportionately affects the world's poorest regions (Froude and Petley, 2018). Infrastructure is also frequently affected, with damage in excess of $ 1 billion annually in the United States alone (Dale et al., 2001). Climate change is expected to lead to an increase in landslides due to more frequent storms at higher intensities (Dale et al., 2001), which historically correlates with higher landslide activity (Kirschbaum et al., 2010).

However, the long-term implications of landslides, mass removal and relocation of soil, the initiation of succession in the first place (Walker and Shiels, 2012) and the implications of potential future increases due to increased storm intensity (Jakob and Lambert, 2009) requires a strong understanding of how these ecosystems respond to and recover from landslides.

Due to climate change, the border area between Romania-Hungary-Slovakia and Ukraine could be vulnerable to landslides. In the centre of the Maramureş Depression, drained by the river Tisza, is located the town of Sighetu Marmației. The municipality of Sighetu Marmatiei is part of the North-West Region, Maramureş County, being the second city in size and importance, after the county seat, the municipality of Baia Mare. Sighetu Marmației is located at the foot of Solovan Hill, on the lower terraces of the Tisza, Iza and Ronişoara rivers, the city center being located at an average altitude of 274 m. It is very important, in this new context, in which the impact of human society on the environment is globalized, that local and even cross-border landslide risk mapping is developed. These will have to be done according to a scientific methodology and at a level of detail high enough to be useful in emergency management.

MATERIALS AND METHODS

The purpose of this study is to perform and present an analysis of the risk of landslides in the municipality of Sighetu Marmației. This analysis can contribute to the sustainable development of the Romanian-Ukrainian-Hungarian-Slovak cross-border region of the upper Tisza Basin and its tributaries.

The objective of the research is to achieve through the case study on the Municipality of Sighetu Marmației a working methodology that would be useful from the perspective of drafting risk maps for landslides in the project region.

The methodology is based on the use of geographic information systems as a tool for spatial modeling of landslides in the project region. This report refers to interim research

Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XI, 2022
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

resulting from the GEOSES project. Following the preparation of the statistical model, it was found that some variables need to be updated and the sample needs to be enlarged so that the whole model can be improved.

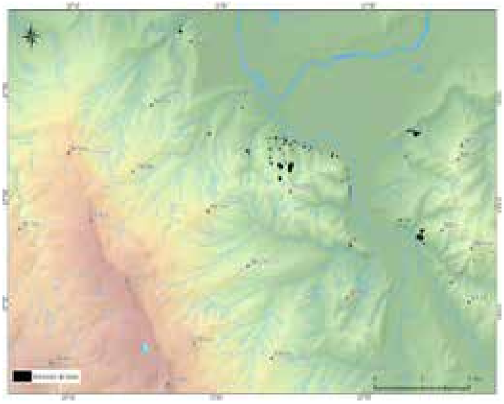

Figure 3. Spatial distribution of landslides in the area of Sighetu Marmației Municipality and surroundings (Source: GeoSES Project)

Following consultations with local authorities and project partners, the TUCN project team decided to monitor six locations (Figure 4) of which five in the Sighetu Marmației Municipality area and one in the neighboring commune of Sarasău.

Figure 4. The 6 locations monitored within the GeoSES Project (Source: GeoSES Project)

The municipality of Sighetu Marmației is located in the Maramureș Depression. Extended in the form of a large, elongated bay (over 90 km) in a northwest-southeast direction, between the eruptive chain and the central crystalline-Mesozoic area, the Maramureş Depression is one of the most characteristic natural units of this kind in the Eastern Carpathians. The boundary is the synthetic result of the combination of all geographical elements, but depending on the case, there is a dominant element: geological structure, relief energy, vegetation, soil, the organization, and exploitation of the relief. Sarasău is a township in Maramureş County, Transylvania, Romania, consisting only of the village of residence with the same name. Sarasău village, which is also a township, is

Location 1. Ulița Pădurii Street (Veterinary Dispensary), Sarasău, landslide open in several points on a length of approx. 200 m and a width-depth of approx. 100 m. The cause was the lack of vegetation, heavy rains causing landslides. About 50 years ago, the entire upstream area was reforested, and conditions were created to stabilize the area.

Location 2. Valea Hotarului Street (Bortoșoi Hill), Sighetu Marmației, landslide taking place since 2016, natural causes, steep hill without trees and without forest vegetation. The consequences are the partial destruction of the foundation of a property at the base of the hill. The measurements show that it is an active landslide.

Location 3. Câmpul Negru Street (Peșec), Sighetu Marmației, landslide taking place over the past 10 years, the cause being the construction of an access road without ensuring conditions for consolidating the destabilized slope. The upstream hill is without trees; the landslide is active.

Location 4. Valea Cufundoasă Street (N. Boar), Sighetu Marmației, very steep area, landslide taking place over the past 20 years, several areas with open landslide, the upstream area is forested, a property at the base of the hill is in danger of being affected.

Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XI, 2022
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

Location 5. Valea Cufundoasă Street (Cheresteşi), Sighetu Marmaţiei, very steep area, landslide taking place over the past 10 years, upstream area is forested, a property at the base of the hill was destroyed and was rebuilt downstream; the area seems to be stabilized.

Location 6. Câmpul Negru Street (Malec), Sighetu Marmaţiei, the massive deforestation carried out in the last 10 years has led to large landslides, just below the deforested area; the landslide is active; there are no properties in the vicinity.

All variables have been integrated into a geo-database developed with ArcGIS Pro. Only the landslide locations on the Romanian territory were registered. The landslides have been incorporated into the model in the form of a set of points representing the centroids of polygons with mapped landslides.

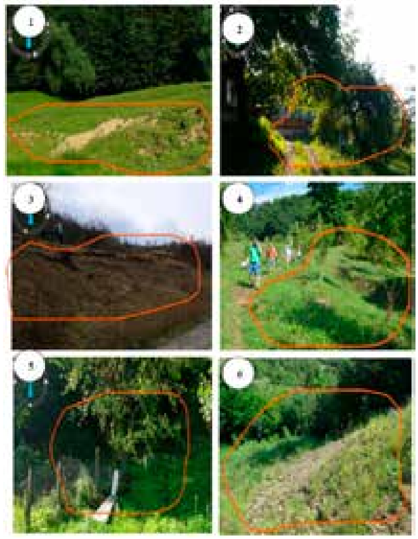

Figure 5. Images of landslides in the monitored areas (Source: GeoSES Project)

Table 1. The six monitored locations (landslides) and the coordinates of Ground Control Points (GCP) for each area monitored and the central points (Source: GeoSES Project)

	Name of area monitored for landslides	Contour point code	Latitud	Longitud	North (m)	East (m)	Altitude (Black Sea)
1	Uliţa Pădurii (Dispensarul Veterinar	GPS003	47° 57' 10.11744573" N	023° 48' 29.99169320" E	717769.688	411109.275	275.956
		GPS003	47° 57' 09.71848066" N	023° 48' 31.03718003" E	717757.036	411130.779	282.836
		GPS0002	47° 57' 10.84869839" N	023° 48' 31.64564560" E	717791.751	411143.934	280.784
		GPS0001	47° 57' 11.58079161" N	023° 48' 30.09525019" E	717814.851	411112.111	272.449
		L1 Central	47° 57' 12.51223200" N	023° 48' 28.81465200" E	717844.023	411085.984	275.000
2	Valea Hotarului (Dealul Bortoşoi)	marisca4	47° 55' 43.48970093" N	023° 50' 42.94054164" E	715052.874	413828.224	335.742
		marisca3	47° 55' 44.51178717" N	023° 50' 41.52217428" E	715084.875	413799.248	336.690
		marisca2	47° 55' 44.24931185" N	023° 50' 42.14468362" E	715076.578	413812.050	334.782
		marisca1	47° 55' 43.68046693" N	023° 50' 41.74024272" E	715059.133	413803.396	338.378
		L2 Central	47° 55' 43.87418400" N	023° 50' 41.63031600" E	715065.150	413801.206	342.504
3	Câmpul Negru (Peşec)	drum4	47° 55' 10.68592094" N	023° 51' 47.82943794" E	714020.038	415160.441	323.643
		drum3	47° 55' 11.64528720" N	023° 51' 48.05824568" E	714049.599	415165.621	320.789
		drum2	47° 55' 12.67682901" N	023° 51' 50.89211653" E	714080.605	415224.916	307.115
		drum1	47° 55' 12.35489532" N	023° 51' 53.14961365" E	714069.983	415271.639	301.651
		L3 Central	47° 55' 12.48884400" N	023° 51' 52.88691600" E	714074.199	415266.249	300.979
4	Valea Cufundoasă (N. Boar)	boar6	47° 53' 59.92063976" N	023° 54' 15.62629608" E	711790.759	418198.279	324.313
		boar5	47° 54' 00.53776914" N	023° 54' 16.59384155" E	711809.538	418218.640	320.493
		boar4	47° 53' 59.32517501" N	023° 54' 18.20440637" E	711771.620	418251.566	302.607
		boar3	47° 53' 58.90698521" N	023° 54' 17.33706738" E	711758.956	418233.372	303.341
		boar2	47° 53' 57.87423999" N	023° 54' 18.11234595" E	711726.835	418249.028	291.256
		boar1	47° 53' 58.97702599" N	023° 54' 19.40236887" E	711760.52	418276.296	294.707
		L4 Central	47° 54' 00.32014800" N	023° 54' 16.47932400" E	711802.850	418216.172	311.674
5	Valea Cufundoasa (Cheresteşi)	cherestes3	47° 54' 55.51048180" N	023° 53' 45.28074741" E	713516.484	417592.229	267.443
		cherestes2	47° 54' 55.40180531" N	023° 53' 44.57497211" E	713513.334	417577.528	270.628
		cherestes1	47° 54' 55.75782699" N	023° 53' 43.66482619" E	713524.596	417558.786	267.591
		L5 Central	47° 54' 55.08100800" N	023° 53' 44.41790400" E	713503.473	417574.131	274.516
6	Câmpul Negru (Malec)	drum5uunrht5	47° 55' 05.18660995" N	023° 51' 34.93088654" E	713854.083	414890.185	417.411
		drum5uunrht4	47° 55' 05.44525572" N	023° 51' 34.58740132" E	713862.175	414883.170	412.403
		drum5uunrht3	47° 55' 07.08759322" N	023° 51' 36.78028209" E	713912.236	414929.435	384.153
		drum5uunrht2	47° 55' 07.56882007" N	023° 51' 36.03392889" E	713927.324	414914.156	384.822
		L6 Central	47° 55' 05.51161200" N	023° 51' 35.96878800" E	713863.808	414911.883	402.181

RESULTS AND DISCUSSIONS

The elaboration of a statistical model for the study of landslides and the creation of geo-morphological risk maps is an activity that involves the incorporation of several explanatory variables and the establishment of correlations with the explained (dependent) variable. In order to choose the independent variables, 119 landslides were inventoried in the study area.

The free and open source Maxent software was used for the modeling. A diagnostic test was performed to verify the model that used 25% of the data from the initial sample, with the remaining 75% of the data being used to generate the model. The main result of this statistical modeling process is the map of the susceptibility to landslides in the municipality of Sighetu Marmației and its surroundings. The chance of landslides was estimated in three classes: low, medium, and high probability.

In this study, a model of the risk of landslides was used based on the probability of new landslides starting from a sample of older (stabilized) landslides and active landslides.

The first stage of work involved identifying landslides in the sample. GPS coordinates were recorded, and photos were taken.

For mapping landslides, GPS data was imported into Google Earth, where the landslides were digitized.

The Google Earth program was chosen because it is possible to visualize each digitized polygon by overlapping and analysing it visually based on a set of satellite images recorded at different dates, so the risk of including erroneous data in the sample decreased considerably. During the summer, the development of vegetation does not allow the easy identification of areas with landslides, instead the images taken in autumn or spring are much more suitable for mapping.

All variables have been integrated into a geo-database developed with ArcGIS Pro.

Figure 6. Carrying out the monitoring cycles of the six areas (Source: GeoSES Project)

Figure 7. Spatial distribution of landslides in the area of Sighetu Marmației Municipality and surroundings
(Source: GeoSES Project)

Landslides have been incorporated into the model as a set of points representing the centroid of polygons with mapped landslides. They are observed by simply mapping a certain spatial grouping of points, and the first alternative hypotheses are formulated, which provide a relationship between landslides, slope, slope exposure and geological structure. After mapping the sample representing the dependent variable, the data necessary for the geo-processing of the explanatory variables were acquired. By digitizing, the level curves with the equidistance of 10 meters and the elevations of the altitude were taken from the topographic map 1:25.000, constructing a model of the elevation of the land with the resolution of 15 meters. From the 1:200,000 scale geological map, the geological structure was generated in vector format, then a raster with a resolution of 15 meters was generated by geo-processing. Also, through geoprocessing, starting from the land elevation model, several variables were generated: slope map, slope exposure, slope curvature, distance from the hydrographic network and relief energy. An independent variable named "Vegetation Index Normalized Difference" NDVI, was included in the model. It was generated by geo-processing based on a Landsat 8 satellite images, captured in autumn 2020, considering that the degree of coverage with clouds should be as low as possible. The eight variables are presented below in the form of thematic maps (Figures 8 to 15).

Figure 8. Variable 1. Digital Elevation Model, Sighetu Marmației Area
(Source: Proiect GeoSES, Măran and Herbei, 2021)

Figure 9. Variable 2. Slope, Sighetu Marmației Area
(Source: Proiect GeoSES, Măran and Herbei, 2021)

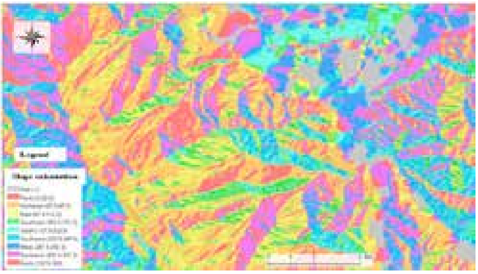

Figure 10. Variable 3. The exposure of the Slope, Sighetu Marmației Area
(Source: Proiect GeoSES, Măran and Herbei, 2021)

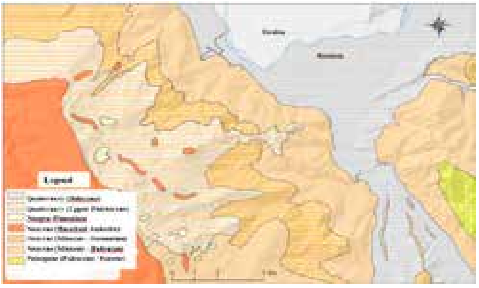

Figure 11. Variable 4. Geological Structure, Sighetu Marmației Area
(Source: Proiect GeoSES, Măran and Herbei, 2021)

Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

Figure 12. Variable 5. Relief Energy, Sighetu Marmației Area
(Source: Proiect GeoSES, Măran and Herbei, 2021)

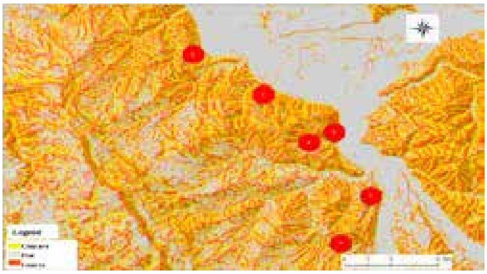

Figure 13. Variable 6. Curvature of the Slope, Sighetu Marmației area and the position of the six monitored locations
(Source: Proiect GeoSES, Măran and Herbei, 2021)

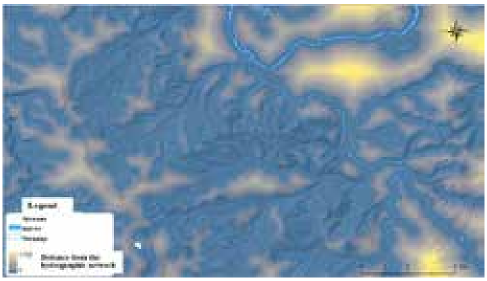

Figure 14. Variable 7. Distance from the hydrographic network
(Source: Proiect GeoSES, Măran and Herbei, 2021)

Figure 15. Variable 8. NDVI, Sighetu Marmației Area
(Source: Proiect GeoSES, Măran and Herbei, 2021)

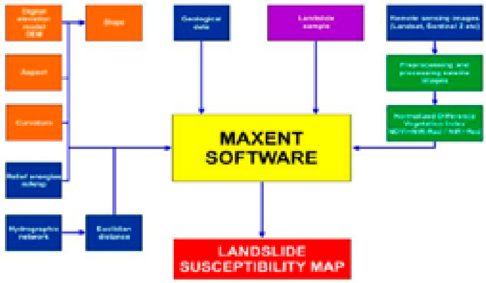

Figure 16. Workflow for Software MAXENT
(Source: Proiect GeoSES, Măran and Herbei, 2021)

The result of this workflow is the landslide risk map (Figures 17 and 18), which indicates the susceptibility to landslides through the three classes (low, medium, and high risk), (Table 2).

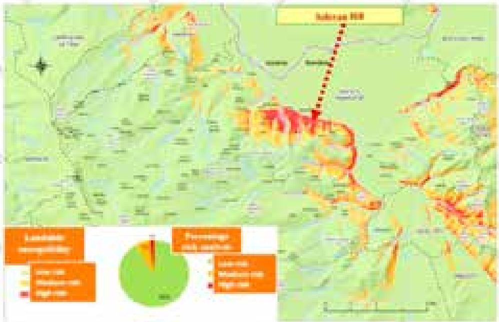

Figure 17. Sighetu Marmației Municipality - map of risk and susceptibility to landslides
(Source: Proiect GeoSES, Măran and Herbei, 2021)

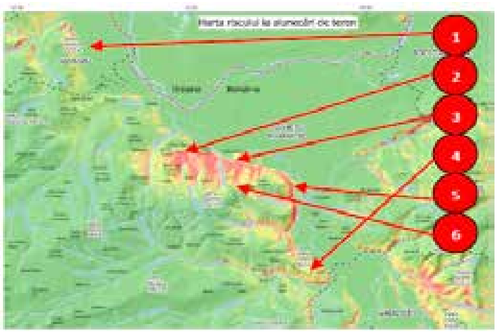

Figure 18. Position of the monitored locations on the landslide susceptibility map
(Source: Proiect GeoSES, Măran and Herbei, 2021)

It can be seen that the risk of landslides is high in the case of steep slopes and for areas occupied by rocks from the Cenozoic era, the Neogene geological period and the Miocene period.

Table 2. Landslide susceptibility - Sighetu Marmatiei
(Source: Proiect GeoSES)

The level of risk	Areas, ha	%
Low risk	25243	91.61
Medium risk	1877	6.81
High risk	434	1.58
Total	27554	100.00

This period began 23 million years ago and ended 5.3 million years ago. These rocks are deposits of clays, marls and sandstones that are very prone to landslides. It can also be seen that northern and eastern exposures are more prone to landslides compared to southern or western exposures.
The classification of the contribution of the variables considered to the statistical model on landslides in the Sighetu Marmației area is presented in Table 3.

Table 3. Classification of the contribution of variables
(Source: Proiect GeoSES, Măran and Herbei, 2021)

Variable code	Variable name	Contribution to model	Position
V1	Altitude (DEM)	16.2947	3
V2	Slope	35.7730	1
V3	Slope exhibition	6.1782	5
V4	Geological structure	22.7949	2
V5	Relief energy m per km	15.6407	4
V6	The curvature of the slopes	0.1910	8
V7	Distance from the hydrographic network	2.8135	6
V8	Normalized difference vegetation index (NDVI)	0.3140	7

The (MAXENT) model based on the statistical-physical principle of entropy maximization (Banavar et al., 2010) derived from information theory (Ruddell et al., 2013) provides a model of medium level complexity and high accuracy, useful in predicting spatial-temporal models of the occurrence and magnitude of variable landslides, which lead to the determination of the causes in which a particular pattern occurs (Figure 16). This paper combines landslide data from heuristic models (Catani et al., 2005) and uses a similar correlative approach to statistical methods for landslides. The model can be easily used for landslide predictions. An approach to statistical physics that focuses on similarities rather than differences in landslides is considered (Banavar et al., 2010; Ruddell et al., 2013). The principle of maximum entropy is, in fact, an interference technique for constructing an estimate (Brunetti et al. 2009, Dudik et al. 2007, Wang et al. 2011).
The Table 3 gives estimates of relative contributions of the environmental variables to the Maxent model. To determine the first estimate, in each iteration of the training algorithm, the increase in regularized gain is added to the contribution of the corresponding variable or subtracted from it if the change to the absolute value of lambda is negative.
The AUC test is a diagnostic test that can be interpreted scientifically as follows: 0.90 - 1 = excellent; 0.80 - 0.90 = good; 0.70 - 0.80 = fair; 0.60 - 0.70 = weak; 0.50 - 0.60 = failure. The AUC test in the case of the selected model has values above the threshold of 0.90 which indicates excellent results of the predictive capacity regarding the risk of landslides in the municipality of Sighetu Marmației (Figures 19 and 20).

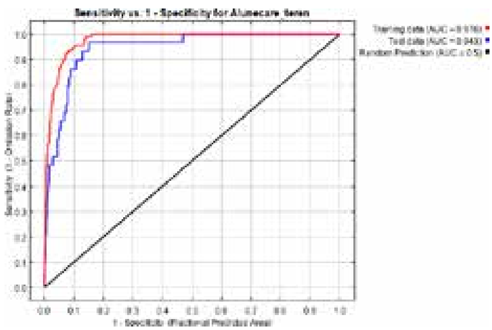

Figure 19. Model performance for Landslides Predictions in Sighetu Marmației Area
(Source: Proiect GeoSES)

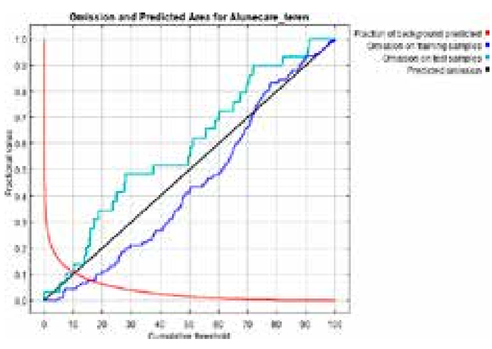

Figure 20. Omission and Predicted Area for Landslides in Sighetu Marmației Area
(Source: Proiect GeoSES)

Some common thresholds and corresponding omission rates are as follows. If test data are available, binomial probabilities are calculated exactly if the number of test samples is at most 25, otherwise using a normal approximation to the binomial. These are 1-sided p-values for the null hypothesis that test points are predicted no better than by a random prediction with the same fractional predicted area. The "Balance" threshold minimizes 6* training omission rate + .04* cumulative threshold + 1.6* fractional predicted area.

Table 4. Data processing results regarding landslides in the Sighetu Marmației area with the Maxent software (Source: Proiect GeoSES)

Cumulative threshold	Cloglog threshold	Description	Fractional predicted area	Training omission rate	Test omission rate	P-value
1.000	0.011	Fixed cumulative value 1	0.230	0.000	0.034	1.084E-16
5.000	0.051	Fixed cumulative value 5	0.157	0.011	0.034	5.404E-33
10.000	0.110	Fixed cumulative value 10	0.109	0.014	0.103	1.288E-42
4.895	0.057	Minimum training presence	0.159	0.000	0.034	7.642E-33
19.993	0.247	10 percentile training presence	0.064	0.100	0.345	2.694E-39
15.804	0.192	Equal training sensitivity and specificity	0.078	0.078	0.276	6.58E-39
11.274	0.131	Maximum training sensitivity plus specificity	0.101	0.014	0.138	1.274E-42
10.265	0.122	Equal test sensitivity and specificity	0.107	0.044	0.103	2.018E-43
5.433	0.064	Maximum test sensitivity plus specificity	0.152	0.011	0.034	1.147E-34
5.050	0.054	Balance training omission, predicted area and threshold value	0.154	0.000	0.034	4.091E-26
15.905	0.187	Equate entropy of thresholded and original distributions	0.087	0.047	0.172	4.898E-44

This is a representation of the Maxent model for landslides. Warmer colours show areas with better predicted conditions. White dots show the presence locations used for training, while violet dots show test locations (Figure 21).

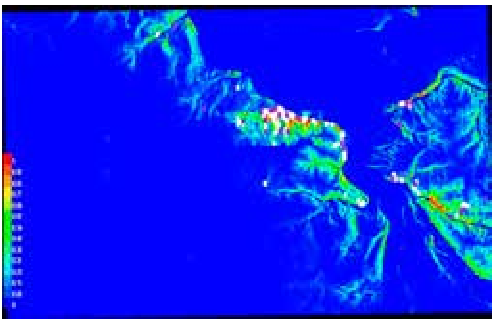

Figure 21. Plot for landslides predictions in the Sighetu Marmației area
(Source: Proiect GeoSES)

CONCLUSIONS

GIS programs can be used successfully for predictive analysis of natural hazards, but also to record and present the consequences of a disaster. The results of the GEOSES project can be useful for urban and cross-border development planning. A working methodology was developed that allowed the elaboration of the map of geo-morphological risks in the municipality of Sighetu Marmației. The sample should be analysed using spatial statistics tools to calculate global and local spatial autocorrelation indicators. Certain points can be removed from the sample if statistically significant spatial groups are identified. The null hypothesis was rejected, being accepted the alternative hypothesis that indicates a close statistical relationship between the dependent variable (landslides) and the explanatory variables. The results obtained will be useful in the project and for urban and cross-border development planning. It would be advisable to develop an alternative model by using another statistical method to better verify the results of this research.

ACKNOWLEDGMENTS

The entire activity presented in this paper was carried out within the project GeoSES - Extension of the operational "Space Emergency System" towards monitoring of dangerous natural and man-made geo-processes in the HU-SK-RO-UA cross-border region, HUSKROUA 1702/8.1./0065. The team of authors of this paper, which is also the project team, would like to thank their colleagues from Uzhhorod National University for inviting the Technical University of Cluj-Napoca as a partner in the project.

REFERENCES

Banavar, J., A. Maritan, and I. Volkov (2010). Applications of the princi-ple of maximum entropy: From physics to ecology, J. Phys. Condens. Matter,22, doi:10.1088/0953-8984/22/6/063101
Brunetti, M. T., F. Guzzetti, and M. Rossi (2009). Probability distributions of landslide volumes, Nonlinear Processes Geophys., 16, 179–188.
Catani, F., N. Casagli, L. Ermini, G. Righini, and G. Menduni (2005). Land-slide hazard and risk mapping at catchment scale in the Arno River basin, Landslides, 2, 329–342, doi:10.1007/s10346-005-0021-0.
Dale, V. H., et al. (2001). Climate change and forest disturbances: Climate change can affect forests by altering the frequency, intensity, duration, and timing

of fire, drought, introduced species, insect and pathogen outbreaks, hurricanes, windstorms, ice storms, or landslides. Bio Science 51: 723–734.

Dudik, M., S. J. Phillips, and R. E. Schapire (2007). Maximum entropy density estimation with generalized regularization and an application tospecies distribution modeling, J. Mach. Learn. Res.,8, 1217–1260.

Froude, M. J., and D. N. Petley (2018). Global fatal landslide occurrence from 2004 to 2016. Natural Hazards and Earth System Sciences 18: 2161– 2181.

https://earth.google.com/web/

https://huskroua-cbc.eu/news/programme-news/public-consultations-regarding-the-interreg

Jakob, M., and S. Lambert (2009). Climate change effects on landslides along the southwest coast of British Columbia. Geomorphology 107: 275–284.

Kalmar, T.T., Rădulescu, A.T.G.M., Rădulescu, V.M.G.M., Rădulescu, G.M.T., Dirja, M. (2021). The effect of deforestation on landslides, Case study analyzed within the GeoSES cross-border project, The Publication of the North University Centre of Baia Mare, Series D, Mining, Mineral Processing, Non-Ferrous Metallurgy, Geology and Environmental Engineering, Vol. XXXV Nr. 2 – 2021.

Kirschbaum, D. B., R. Adler, Y. Hong, S. Hill, and A. Lerner-Lam (2010). A global landslide catalog for hazard applications: method, results, and limitations. Natural Hazards 52: 561–575.

Kirschbaum, D. B., T. Stanley, and Y. Zhou (2015). Spatial and temporal analysis of a global landslide catalog. Geomorphology 249: 4–15.

Măran, P.D. and Herbei, M.V. (2021). Using GIS technologies for spatial analysis of landslides Case Study Sighetu Marmatiei Municipality, Scientific Bulletin Series D: Mining, Mineral Processing, Non-Ferrous Metallurgy, Geology and Environmental Engineering; Baia Mare Vol. 35, Iss. 2 (2021): 69-76.

Project GeoSES-Extension of the operational "Space Emergency System" towards monitoring of dangerous natural and man-made geo-processes in the HU-SK-RO-UA cross-border region, HUSKROUA 1702 /8.1./ 0065

Rădulescu, A.T.G.M., Kalmar, T.T. Rădulescu, G.M.T., Naș, S.M., Rădulescu, V.M.G.M., Măran, P.D., Rădulescu, C.M., Bondrea, M. (2021). The role of cross-border projects in Disaster Management, The Publication of the North University Centre of Baia Mare, Series D, Mining, Mineral Processing, Non-Ferrous Metallurgy, Geology and Environmental Engineering, Vol. XXXV Nr. 1 – 2021.

Rădulescu, A.T.G.M., Rădulescu, C.M., Rădulescu, G.M.T., Kalmar, T.T., Naș, S.M., Herbei, M., Rădulescu, V.M.G.M., Bondrea, M., Măran, P.D., Bondrea, M. (2021). Management of HUSKROUA Cross-border Projects, GeoSES Project Case Study, 38th IBIMA International Conference, Seville, Spain, conference proceedings (ISBN: 978-0-9998551-7-1) and (ISSN: 2767-9640)

Rădulescu, G.M.T., Naș, S.M., Rădulescu, A.T.G.M., Măran, P.D., Rădulescu, V.M.G.M., Bondrea, M., Herbei, M., Kalmar, T.T. (2021). Geomatic Technologies in Landslide Monitoring, Sarasău Case Study, Maramureș County, Romania, X International Scientific and Technical Conference «New Technologies in Geodesy, Land Planning and Management of Nature», October, 28-30 2021, Uzhhorod, Ukraine, ISBN 978-617-7825-60-8, pg. 69-75

Ruddell, B. L., N. A. Brunsell, and P. Stoy (2013). Applying information theory in the geosciences to quantify process uncertainty, feedback, scale, Eos, T. Am. Geophys. Union,94(5), 56–56, doi:10.1002/2013EO050007

Walker, L. R., and A. B. Shiels (2012). Landslide ecology. Cambridge University Press, Cambridge, UK.

Wang, J., and R. L. Bras (2011). A model of evapotranspiration based on the theory of maximum entropy production, Water Resour. Res.,3, 47, doi:10.1029/2010WR009392.