UNIVERSITATEA DE ŞTIINTE AGRICOLE ŞI MEDICINĂ VETERINARĂ CLUJ-NAPOCA
ŞCOALA DOCTORALĂ DE ŞTIINȚE AGRICOLE INGINEREŞTI

Phd THESIS

Research on the Effect of Landslides in the Area of Sighetu-Marmației Municipality Subsequent to Deforestation and the Potential for their Mitigation

Summary

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INTRODUCTION

Deforestation and degradation of forests continue to take place at alarming rates, so between 1990 and 2020, it is estimated that 420 million hectares of forest were lost by conversion to other land uses. Between 2015 and 2020, the deforestation rate was estimated at 10 million hectares per year, down from 16 million hectare per year in the 1990s. (FAO and UNEP, 2020).

Regardless of the causes of deforestation, the main effects are climate change and the cumulative effect of landslides.

Maramureş County faces an important number of natural and anthropological risks: floods, there being a significant risk on several water courses in the county, including, according to the risk maps in particular Tisa with its affluents from the study area Rona, Vişeu, Sarasău, Iza, etc., landslides and crashes (32 UATs, many of which are at the foot of Solovan Hill, Sighetu Marmaţiei area), forest fires and dry vegetation, avalanches, earthquakes, etc.

We have chosen as a study area on the effect of deforestation on landslides, the Municipality of Sighetu Marmaţiei and a neighboring village of Sarasău, for the following reasons:

1. Over time, deforestation occurred in the study area, considered to be among the most massive in the whole country, 2.The area of study is hilly, especially through Solovan Hill, at the foot of which the town of Sighetu Marmaţiei developed, being naturally subjected to instability processes of the terrestrial surfaces, 3.Given the diversity of the causes of landslides studied and monitored within a interregional cross-border project, I decided to participate in all the project's activities from collecting the field data to processing them and creating GIS database, and then, implementing a WebGIS portal along with mobile applications. Thus, my belief was to better investigate to what extent and which is the impact of deforestation on landslides.

4. Following a careful analysis of the situation on the ground on landslides, three locations were selected for monitoring, all of which had different causes. Among these we find a situation which has as its cause deforestation, another, by which landslides have been stopped by reforestation and the third, at which the aforementioned phenomena continue to occur, because, although the talus of the slope at the foot of which this location is very steep, it has not been reinforced by any known method.

Both for the implementation of the project and for the acquisition of the entire material for documentation and elaboration of doctoral thesis it was very important to establish the approach strategy, during the more than two years of conducting the research (March 2020-May 2022), namely the choice of technologies, methods and tools for taking field data, data processing and interpretation software, publication and communication technologies.

PURPOSE AND OBJECTIVES OF THE RESEARCH

The purpose of the research is to analyse the effect of deforestation on land slides, in an area strongly exposed to these phenomena of instability, the base of Solovan hill, Sighetu Marmației Municipality. The overall objective of the entire work is to establish the causal relationship between deforestation actions and determinant factors of landslides and to identify the possibilities of diminishing and stopping the consequent phenomena.

Although landslides do not occur immediately after the vegetation of a forested slope is empty, at an interval of five to ten years, after the roots of deforested trees are rotten, instability phenomena occur and develop rapidly, causing the most serious damage.

We started the investigations by initially identifying over 100 cases of landslides in the vicinity of Sighetu Marmației Municipality, at the foot of Solovan Hill, from which we selected for study three cases, all related to the forest. The first case was an area where, after the land slide was detected, the area was re-forested, the second where for about ten years tree cuts were made upwards, with effects of instability of the ground and the third where, although the forested slope slid downwards, causing the destruction of a household as a whole.

Thus, after the documentation phase and the establishment of a database, on the sites in danger of instability in the operating area, we went to the analysis of the methods for tracking the evolution of landslides established as case studies, the conduct of the four cycles of monitoring, establishing the development over time of the phenomena studied and not least to finding solutions to mitigate the effects.

STRUCTURE OF THE DOCTORAL THESIS

The thesis contains two parts , comprising 8 chapters , 143 pages , two Annexes and 178 references .

PART ONE: The current state of knowledge

Chapter 1. The current state of knowledge regarding the phenomenon of deforestation of forests, influences and effects

In the first chapter we analyze both the causes and effects of forest deforests on the environment in general and life in particular, highlighting the relationship between these human actions and landslides. It is also stressed that the effects of global warming and associated climate change on landslides remain difficult to quantify and predict. At the same time, deforestation is considered to have an immediate effect and one of the main and visible consequences is landslides.

Chapter 2. Geomatic Landslide Monitoring Technologies

The choice of a geomatic landslide monitoring technique often depends on the specific requirements of the monitoring project. In order to guarantee the acquisition of accurate and relevant information, it is necessary to integrate analytical monitoring techniques with other methods and technologies. These additional resources not only provide the necessary information, but also facilitate the processing of data collected on the ground.

PART TWO: Personal contribution

This part consists of five chapters on the basis and results of research, conclusions and recommendations aimed at achieving the proposed objectives, even within the first chapter of this part.

Chapter 3. Objectives pursued and assumptions of work, in the two sub-chapters, presents the proposed objectives of research, emphasizing the importance of the topic addressed.

Chapter 4. Particularities of the environment, in which the experiment took place, contains two sub-chapters that analyze the peculiarity of the natural framework of the area where the research was carried out, stressing at its end that the entire monitored area falls, from an urban point of view, into the category L3 – Area of rural type housing. The chapter also covers the first objective of the documentation phase research.

Chapter 5. Materials and Methods, consists of three sub-chapters, the first presenting **Research Methodology** describing and graphically presenting the strategy considered regarding the approach of the entire research activity. The second sub-chapter presents the steps taken in identifying all locations subject to instability (119 locations identified, of which 13 were severely affected) highlighting the reasons for choosing the three locations as case studies. The last sub-chapter of this part of the paper presents the technologies/instruments used in monitoring the study area. The following objectives of the research proposed in the Chapter are thus covered, namely Identification and selection of landslides in the study area and Creation of a database of hazardous sites, in terms of land sliding in the area of the Municipality of Sighetu Marmației.

Locația 1, Strada Ulița Pădurii, Comuna Sarasău

Locația 2, Strada Câmpul Negru (Malec), Sighetu Marmației

Locația 3, Strada Valea Cufundoasă, Sighetu Marmației

Fig. 5.9. (Excerpt) Images of the six landslide monitored locations, Images indicate the area affected by landslides for each location (Source: Author)

Chapter 6. Results and discussions, in the three sub-chapters that make it up, based on and respecting the methodology of research mentioned in the previous chapter, solve all the established components, general and specific objectives of research. Thus, the other proposed objectives of research are covered within this chapter as follows:

- Conducting field studies, Monitoring of landslides in the valley of the Tisa River, the monitored area, by conducting 4 geodesic measurement cycles using different Geomatic methods,
- Monitoring of landslides in the study area was carried out through four cycles as follows, Cycle "0", 29-30.07.2020; Cycle "1", 13-14.04.2021; Cycle "2", 22-23.06.2021; Cycle "3", 25-26.10.2021. The measurements were carried out using the aforementioned technologies, the basic being the medium geometric level, high precision, performed with both the classical level and the digital level and UAV technology.
- Verify the stability of each of the three locations monitored for the four measurement cycles using the high-precision geometric leveling method.

For all three locations monitored there were observed displacements in time of the terrain, but significant values of up to 140 mm were recorded for Location 2, Câmpul Negru, an area affected by constant deforestation actions.

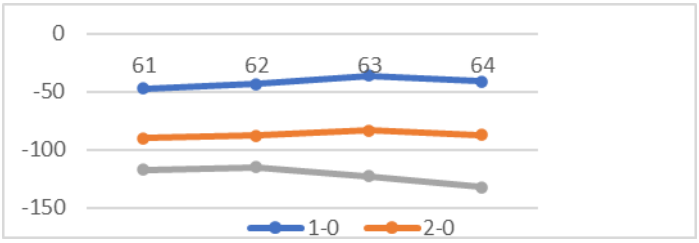

Fig. 6.2. The evolution of the position in space of the rappers installed in Location 2, Câmpul Negru Street, SM (Source: Author)

- The establishment of an operation flow in the use of UAV technology is the theme of the third stage of the previously mentioned monitoring strategy, Phase C. Primary processing of terrain data The operation flow in the use of UAV technology, for the purpose of monitoring landslides, through the four previously mentioned cycles, through which the following, field operations were identified:
    1. C 1. Delimitation of the operating area, respectively of the monitored area;
    2. C 2. Selection of GCP control points (Ground Control Points);
    3. C 3. Establishing the flight plan;
    4. C 4. Carrying out the flight;
    5. C 5. Image processing with the software Agisoft Photoscan Professional;

Photogrammetries processing stage

The stages used that had the purpose were specified in the paper making the DEM, the Orthomosaic and the Orthophotoplan for all three locations monitored through four cycles.

The second sub-chapter deals with the generation of land slide maps in the operating area using GIS technology begins with preliminary documentation studies, on the causality of the instability phenomenon and then proceeds to the definition of the model of the monitored phenomena. The research phase begins with the collection of field data using GIS technology, import of data pairs, Orthofotoplans and DEM .

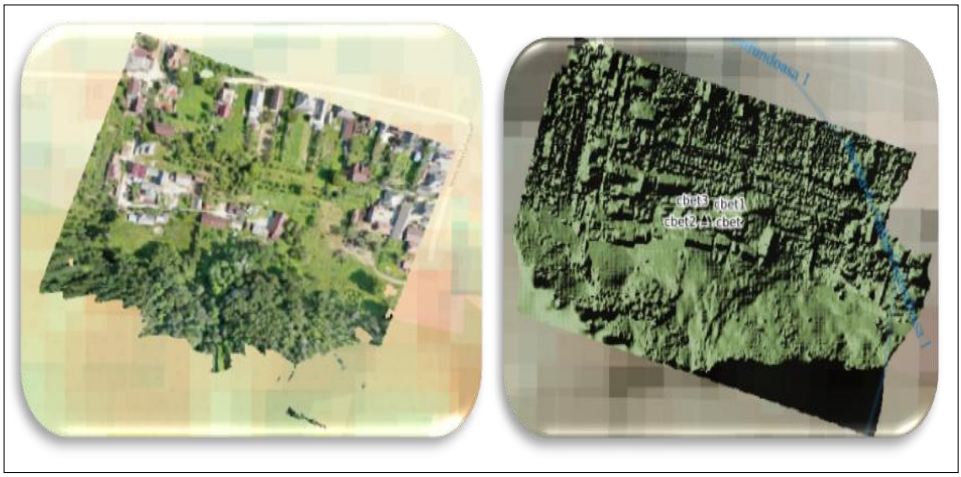

Fig. 6.15.(Selection) Import of data pairs , Orthophotoplanes (left) and DEM (right) (Source: Author based on data from the GeoSES Project)

Subsequently, the *development of the spatial database was performed with the help of the ArcGIS Pro program* and then, *a spatial analysis was carried on,by defining the model variables in the monitored area* using indicators as :

- Hot Spot Analysis, in follow which resulted in the statistical indicator Getis - Ord Gi*)

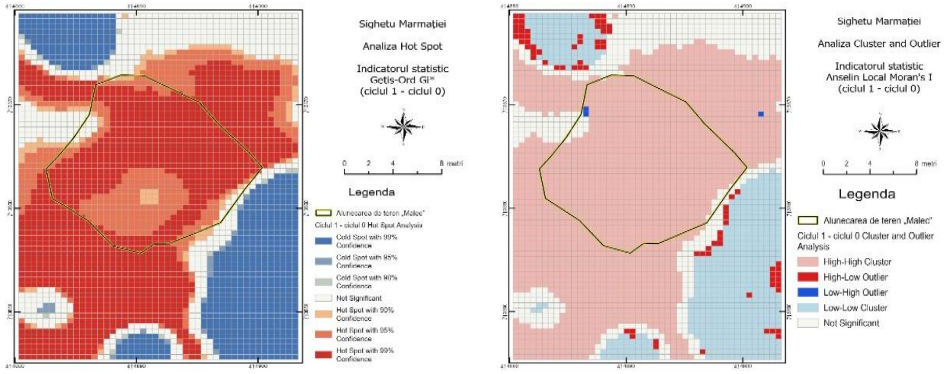

Fig. 6.17. Hot Spot analysis (Getis -Ord Gi* statistical indicator), Fig. 6.19. Cluster and Outlier analysis (Anselin statistical indicator Moran, s I) (Source: Author)

- Outlier Analysis (Anselin Local Moran I) resulting the Anselin statistical indicator Moran, s I.

The definition of the eight variables generated by geoprocessing , in the form of a thematic map presented for the Municipality of Sighetu Marmației, the study area was carried out within the framework of the topic: *Using the MaxeEnt model for the prediction of landslide susceptibility and the development of the landslide risk map.*

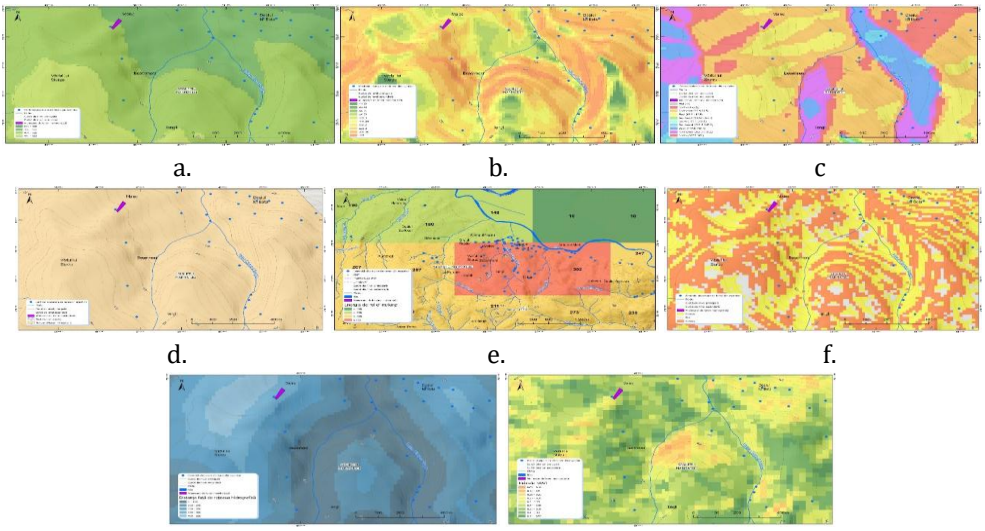

Fig. 6.25. a. Map in relief, digital elevation model (Var. 1 - DEM), b. Map slopes (Var. 2 – Slope)) , c. Var. 3 - Exposure slopes , d. Map lithography (Var. 4 - Map geological), e. Var. 5 – Relief energy , f. Var. 6 – Curvature slopes , g. Var. 7 – Distance against the network hydrographic , h. Var. 8 – NDVI, Maps in the coordinates Cartesian with highlighting SITE monitor (Source: KALMAR, 2024)

The eight variables/thematic maps were incorporated into the software MaxEnt generating landslide risk maps in ArcGIS Pro (Figures 6.35.-6.38.). The classification of the contribution of the variables considered to the statistical model regarding landslides in the Sighetu Marmației area is presented in the following table which provides estimates of the relative contributions of the environmental variables to the Maxent model .

Table 6.16. Analysis of the contribution of explanatory variables to the model (Source: Author)

Variable code	Contribution to the model	The position
V1	16.2947	3
V2	35.7730	1
V3	6.1782	5
V4	22.7949	2
V5	15.6407	4
V6	0.1910	8
V7	2.8135	6
V8	0.3140	7

The definition of the Performance Model for landslide predictions in the Sighetu Marmatiei area is presented in Figure 6.33.

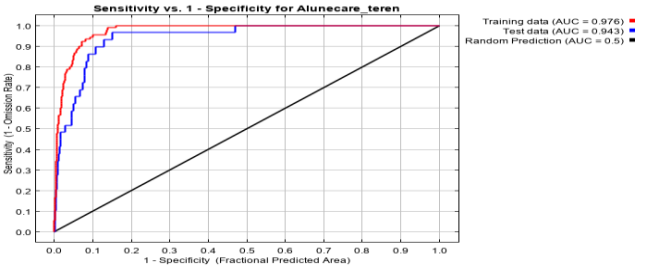

Fig. 6.33. Performance model for the predictions landslides in the area of Sighetu Marmatiei (Source: Author)

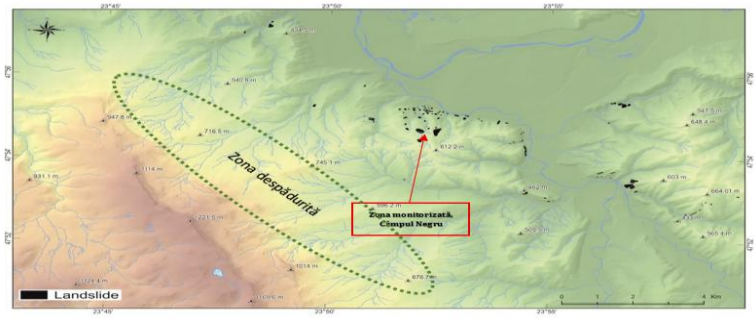

Fig. 6.35. Map landslides for the study area (Location 2, Strada Câmpul Negru, Sighetu Marmații) and surroundings (Source: KALMAR, 2024)

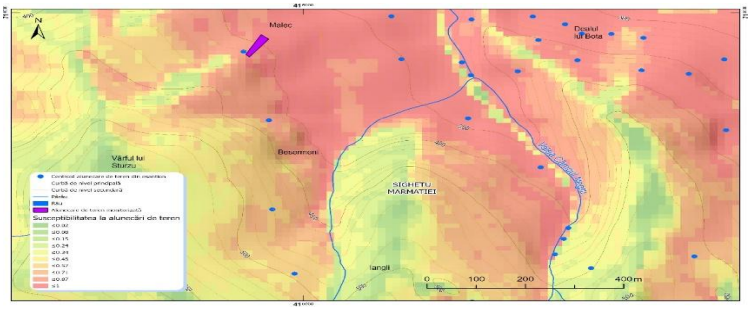

Fig. 6.36. Susceptibility to landslides (Source: KALMAR, 2024)

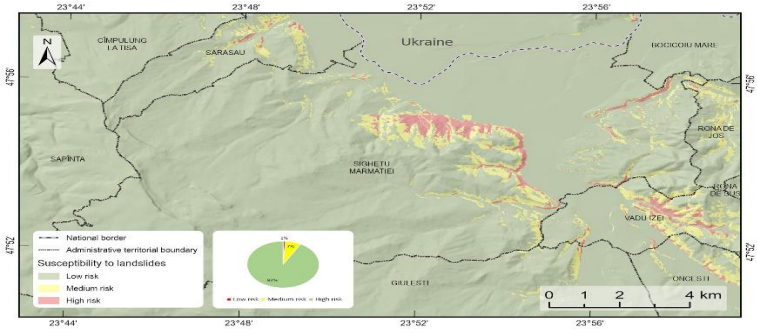

Fig. 6.37. Map the risk of landslides (Source: KALMAR, 2024)

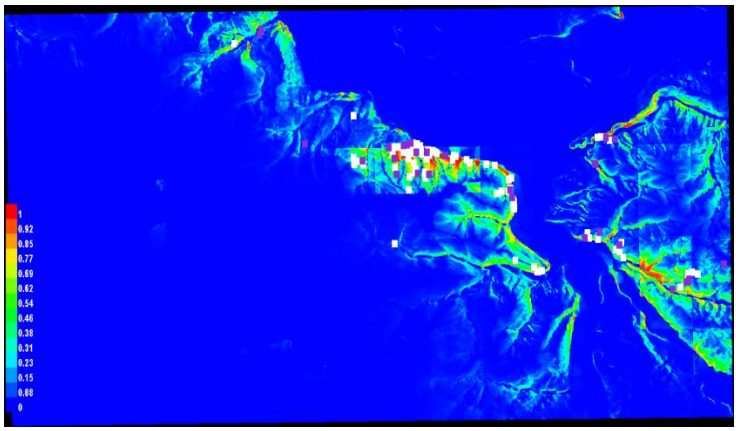

Fig. 6.38. Plot for Preach them Landslides in the Sighetu area Marma tia This one is a representation of the Maxent model for Landslide . colors May warm show areas with conditions better predicted . points whites to miss locations of presence use for testing , in time what the points purple to miss locations monitored (Source: KALMAR, 2024)

Chapter 7. Conclusions and recommendations

7.1. Conclusions and recommendations on the effect of deforestation on landslides

Determining measures to reduce the effects of deforestation and solutions to prevent and reduce the effects of landslides caused by deforestation should be analyzed from the following perspective:

1. Solutions for the prevention of landslides
2. Solutions for reducing the effects of landslides

a. In the initial phase

b. In the evolution phase

c. In the final phase

Factors affecting slope stability can be grouped into those that tend to increase shear stress and those that tend to reduce shear strength. It provides a basis for examining the likely influence of vegetation on landslide stability, as follows:

1. Root reinforcement: Roots mechanically strengthen the soil by transferring shear stress into the soil's tensile strength due to root anchorage.

2. Changing soil moisture: Vegetation affects the rate of snowmelt, which in turn affects the soil moisture regime.

3. Strengthening and arching: Anchored and embedded stems can act as a reinforced buttress or arch in the slope, counteracting the shear stress.

4. Supplementation: The weight of vegetation on a slope exerts both a downward (destabilizing) stress and a stress component perpendicular to the slope that tends to increase sliding resistance.

5. Root extension: The presumed tendency of roots to invade cracks and channels in the soil or rock mass.

Stability increases when the ground water, located below the areas affected by landslides, is prevented from rising into the mass of the slope, and for this the following measures can be taken:

• Directing surface water away from the landslide,

• Drainage of groundwater away from the landslide to reduce the potential to raise the groundwater level,

• Covering the slide with an impermeable membrane, in order not to allow precipitation to infiltrate into the water table and (or)

• Minimizing surface irrigation.

7.2. Conclusions and recommendations regarding the ways to approach the solutions for managing the effect of deforestation on landslides, with particularity for the analyzed area, Sighetu Marmației Municipality

Overall, the entire monitoring activity must be integrated into a managerial program for managing the territorial situation from the point of view of stability over time, taking into account the establishment of the following characteristic factors:

1. Identification of the presence of the event – landslides in a certain area;

2. Evaluation of the severity and destructive potential of the event(s) identified;

3. Studying the history of the event;

4. Establishing the causes that led and favored the initiation and development of landslides;

5. Identification of which category of landslides the analyzed case(s) fall into;

6. Establishing the monitoring program, precision indicators, the density of monitoring stages, the density of monitoring points;

7. The stage of testing the technologies, methods and tools that can be used in the monitoring process to identify those instrumental and technological patterns that can meet the requirements of the previous point;

8. Performing the origin cycle, Cycle "0" of recording the initial situation, creating the 3D Model of the land at the reference moment, the elevations of the mobile witnesses planted in the ground/reference longitudinal and transverse profiles, etc. ;

9. Performing the following monitoring cycles, "1", "2", "3", "4", etc. depending on the evolution of the analyzed phenomenon, until ensuring the stability of the area or establishing a created natural stability/total extinction of spatial displacements.

These stages were also completed in the case of the research that was the subject of this doctoral thesis.

• In the first phase, the phenomenon is studied and the calculation values for sizing the remedial measures are determined. The following must be identified: the geometry of the unstable mass, the existence of multiple sliding surfaces, shear resistance parameters (through laboratory determinations confirmed by reverse calculation), permeability coefficients, etc.

• The second phase is the design of the remedial works with viable technological phases that take into account labor protection norms.

• The last phase represents the actual consolidation execution.

It is very important to mention that the measures presented in the paper are not applied either individually or according to fixed schemes. The engineering solution is a set of measures that are prescribed both quantitatively and qualitatively following numerical modeling.

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7.3. Conclusions and recommendations on stopping, limiting, managing and ameliorating the effect of landslides following deforestation for the monitored locations

By summarizing the case studies analyzed in this doctoral thesis, it can be found that for the first case, the one located in the village of Sarasău, MM, the stage of the landslide is - stabilized, the replanting carried out previously producing the expected effects in a few years. The case in Strada Valea Cufundoasă is unpredictable due to the very high slope of the hill upstream of the previously affected property, the situation can be repeated at any time, especially due to infiltrations, heavy rains, etc. As can be seen in Figure 6.41. the area monitored for landslides, Location 2, Strada Câmpul Negru, Sighetu Marmaţiei Municipality has a very high slope, being susceptible to landslides. These occurred mainly after the deforestation process carried out over several years, starting 20 years ago. Landslides are of high amplitude, but there are no inhabited properties in the immediate vicinity.

• In this PhD thesis, a landslide risk modeling was used based on the probability of the occurrence of new landslides starting from a sample in which older, (stabilized) landslides and active landslides are recorded.

• Through the use of modeling with the Maxent program, the landslide risk map was created, thus achieving the research objective. The alternative hypothesis of the research was that the occurrence of landslides has a specific spatial distribution, correlated with a series of variables such as: geological structure, relief energy, slope, curvature and exposure of slopes, altitude, distance from the hydrographic network, land use. The null hypothesis assumed that the distribution of landslides has a random spatial structure.

• As can be seen from the landslide risk map generated, following data processing with the help of the Maxent software, for Sighetu Marmaţiei Municipality and the surrounding areas, the entire area at the foot of Solovan Hill, including the one studied in the work, Câmpul Negru, are heavily exposed.

• Following these determinations, it resulted that location 1 (Strada Uliţa Pădurii, Sarasău Commune) is the most stable, resulting in displacements, within the limits of precision and vegetation cover, respectively of the order of 1-7 mm, in location 3, s - they produced low-amplitude slips and subsidences of the order of 10-70 mm and for location 2 (Strada Câmpul Negru-, Sighetu Marmaţiei) important displacements in space were found, reaching up to 140 mm.

• The use of GIS in the field of natural disaster prevention and mitigation has proven to be the most effective way of risk management, in the field of environmental

monitoring, but it is still hindered by factors such as the difficulty of obtaining adequate raw data, the intrinsic complexity of model prediction, the lack of effective graphical user interfaces, the high cost of digitization and the persistence of bottlenecks in hardware capabilities.

• There are several types of statistical models that can be used to make these landslide risk maps, the most important ones are those that calculate the frequency ratio, logistic regression or the calculation of the probability of occurrence according to the weights of the old landslides that were manifested in the study area.

• As part of the thesis, a working methodology was developed that allowed the development of the map of geomorphological risks in the municipality of Sighetu Marmației. The obtained model can be adjusted by using more accurate data sources (geological map at 1:100000 scale instead of 1:200000) and by increasing the number of landslides recorded in the sample. The sample should be analyzed using spatial statistical tools to calculate global and local spatial autocorrelation indicators. Certain points may be removed from the sample if statistically significant spatial clusters are identified. The null hypothesis was rejected, the alternative hypothesis being accepted indicating a close statistical relationship between the dependent variable (landslides) and the explanatory variables.

The scientific approach undertaken within the doctoral thesis leads to the following recommendations:

- The results obtained in the thesis will also be useful 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 obtained through this research.
- Landslide measurements are recommended to be performed by combining UAV aerial photogrammetry with GNSS technologies, precision planimetric surveys made with total stations and precision geometric leveling.
- For the processing of UAV frames, I recommend the Agisoft Photoscan Professional Metashape software.
- To generate landslide susceptibility and risk maps, it would be recommended to use the Maxent software combined with different GIS software and technologies.
- The main recommended measures to prevent landslides are:
- Increasing the binding capacity of the soil (consolidation by tree roots or by artificial means) and
- Decreasing surface runoff either by adding barriers or by increasing the infiltration capacity of the soil.
- I recommend the application of landslide stabilization measures, and in response to other locations with land destabilization situations, proposed in the thesis.

- I recommend updating and completing the map with the landslides identified on the territory of the Municipality of Sighetu Marmaţiei and in the neighboring areas, developed in the framework of the thesis, with other locations, so that a complete database on this aspect is made available to the authorities in order to obtain a optimized management of territorial information regarding the analyzed phenomena,
- In this context, having available several areas with landslides, covering the entire mentioned territory, I recommend redoing the Maxent-ArcGIS analysis, I recommend drawing up the map with susceptibility and risk to landslides, with reference to the entire mentioned area, complete and current, to be updated annually.
- I recommend a complete analysis of the authorities that grant building permits and those that approve the territorial investment plans of locations identified with landslide problems, also specified by the previously mentioned documents, limiting the approvals only to those sites considered free of problems of the nature those mentioned.
- The application of the measures recommended in this paper will allow the authorities to reconsider the entire risk management activity of territorial destructive phenomena such as landslides, but not only, with specific adaptations these measures may also be applicable in the management of floods, disasters generated of earthquakes, etc.

Chapter 8. Originality and innovative contributions of the thesis

I believe that the main note of originality of the thesis is the complete and integrated way of approaching the problem of landslides produced in a certain area, with different causes, of which the main cause addressed in the thesis compared to the other factors favoring the production of these phenomena is that of deforestation. Thus, the thesis presents all the stages necessary to manage the situations created by these phenomena, from the identification of the affected locations, the choice of those areas that require inclusion in the monitoring program, the testing of the vast majority of monitoring methods, technologies and tools, the design and management of the activities of monitoring, the realization of the four cycles of tracking the behavior of the land over time, the processing of frames and the editing of orthophoto planes and 3D DEM models, the generation of maps of susceptibility and risk to landslides, of behavioral mathematical models, including at the end of the work a chapter on the dissemination of the results research through a portal and mobile applications.

In this context, the personal contribution and originality in the elaboration of this doctoral thesis was realized through the following six research directions:

A. Creation of a database of dangerous sites (landslides), from the region adjacent to the Tisa River, in Romania, with particularization for the study area Sighetu Marmaţiei Municipality and neighboring localities;

B. Carrying out geomonitoring of dangerous landslide processes in the Tisa river valley on the territory of Romania, the mentioned area, by performing 4 cycles of geodetic measurements using the methods: UAV aerial photogrammetry, GNSS observation, high-precision trigonometric and geometric leveling;
C. Creation of maps of risk zones in the area of the mentioned territory;
D. Building mathematical models of dangerous landslide processes in the mentioned area;
E. Construction of the three-dimensional model of the movement of the Earth's surface on areas of dangerous landslide processes using geodetic measurements in the Tisa river valley and risk maps on the territory of Romania, for the mentioned area;
A replicable managerial model for monitoring landslides was thus created, within the framework of this doctoral thesis.
As a note of originality, the manner of choosing the technologies and tools that were used to carry out the four monitoring cycles and with which, annually/biannually, on a case-by-case basis, the activity will be continued, should also be included. Thus, there was a session to test the capabilities of solving existing problems on the ground, more specifically the need to monitor, with a certain precision, some landslides. We carried out short monitoring operations and compared the results, finally choosing a mixed solution, GNSS-UAV-Total Station, through which we considered that the problems can be solved operationally and with the necessary precision and detail.
I also undertook a performance analysis of UAV aerial photogram processing software, for example DroneDeploy 3D mapping mobile app, Pix4D Mapper photogrammetry, DroneDeploy Enterprise 3D Map, AutoDesk ReCap photogrammetry, after which I chose Agisoft PhotoScan photogrammetry.
Also as an element of originality of the thesis to point out the development for the first time for the area of the Municipality of Sighetu Marmației of landslide risk maps and mathematical models of the studied phenomena, using recognized software such as ArcGIS Pro 2.7.0 - ESRI; QGIS 3.4.5; ArcGIS Online – ESRI; Google Earth – Google; Maxent.
An element of novelty introduced in the paper was also the comparison of the results regarding the effect of different provocative and favoring causes of landslides on the behavioral models, resulting in a combination of deforestation-water infiltration, corroborated with the effects of climate change, that of location 2 analyzed within the thesis is the most likely cause, which can have large and immediate effects.

SELECTIVE REFERENCES

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