The landslides in the contact zone between the mountainous and the hilly space. Case study: Bucovina mountain range – Suceava plateau (North-East Romania)

TODICA S.[1], ANGHEL T.[1], SURDEANU V.[1]

ABSTRACT

The objective of our study consists in creating a thematic map having in view the susceptibility of the terrains to the landslide release. In order to delimit the areas with different degrees of susceptibility to landslide release, three models of quantitative analysis will be used and compared: *Landslide Index Method*, *Certainty Factor* and *Frequency Ratio*. These models require the use of mathematical and statistical operations in order to emphasize the relations between variables. The information on the susceptibility map could be useful for explaining the known existing landslides, making emergency decisions and relieving the efforts on the avoidance and mitigation of future landslide hazards.

Keywords: landslides, quantitative model, susceptibility, GIS.

1. INTRODUCTION

The contact zone between the Bukovina Mountain Range and the Suceava Plateau is given by a continuous strip situated at the border of the Oriental Carpathians, between the Moldova Valley (in the south) and the Suceava Valley (in the north).

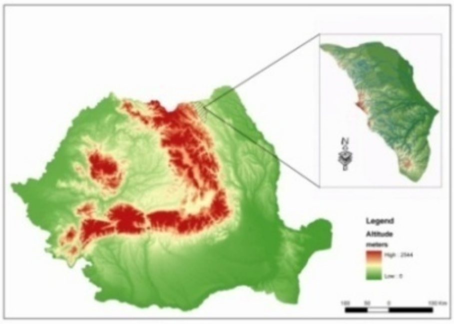

Figure 1: Location of study area

The geomorphological features of this territory are reflected mainly in the geology of the area (i.e. lithology, tectonics). Most of the landforms are carved in Sarmatian deposits (clays, sandy clays, sands and gravels, in which there are several sandstones and oolitic limestones levels). The relief is represented by a series of piedmont hills, with elevations of 400-600m and low sedimentary plains with piedmont character.

2. METHODOLOGY

The concepts that define the terrains susceptibility to landslides include the spatial distribution of the factors that are responsible for triggering instability processes, which help with determining the susceptible areas, without implications in time. A map of susceptibility divides the slope stability into categories which vary from stable to unstable. It illustrates the sites where the landslides might occur or be reactivated. Most of these maps use bright colours (red, orange, yellow) for unstable areas and dark colours (blue and green) for more stable ones.

The strategies used in the landslides analysis must be done in order to predict the occurrence of new landslides with the aim of reducing the damage produced by them. For mapping the areas with different degrees of susceptibility to landslides, we have used and compared three quantitative models: Certainty Factor (Chang-Jo F. Chung, 1994), Frequency Ratio (*Saro Lee*, 2006, Aykut Akgun et al., 2007) and Landslide Index Method (*Van Westen*, 2004).

These three models require, apart from measurements and mappings, the use of mathematical and statistical operations in order

[1] *University ―Babes-Bolyai Cluj-Napoca, Faculty of Geography*

to point out the relations between variables. The models presume that the future landslides will occur under the same circumstances and due to the same factors as the ones triggered in the past.

Certainty Factor (CF) is a model that has long been studied from the experimental point of view by different researchers, such as *Chung* (1994, 2002), *Binaghi et al*. (1998), *H.X. Lan et al*. (2004), *Dai F.C.* (2006) etc. The formula used to calculate it is the following:

$$CF = \begin{cases} \frac{ppa - pps}{ppa \cdot (1 - pps)} & if \quad ppa \geq pps \\ \frac{ppa - pps}{pps \cdot (1 - ppa)} & if \quad ppa < pps \end{cases},$$

where ppa is the conditional probability of having a number of landslide event occuring in class a and pps is the prior probability of having the total number of landslide events in the study area A.

With the help of the Certainty Factor, each class or area is assigned a value that varies within the interval [-1, 1]. A positive value means a growth in the certainty of the landslide occurrence, whereas a negative value coincides with a decrease in the certainty of landslide occurrence. A value close to 0 means that there is not enough information about the variable and thus, it is difficult to give information about the certainty of landslide occurrence.

Frequency Ratio (FR) is a simpler model, which relies on noticing the relationship between the landslide distribution and each factor (parameter) which triggers them in a certain area. In this model, the frequency ratio is the ratio between the area of the existing landslides and the area of the parameter class that triggers them. For example, the parameter can be the slope. The slopes of 2-6° represent a class of the parameter. Thus, a value ≥1 indicates the fact that the percentage of the landslides is higher in that class and there is a strong correlation, while a value below 1 shows a slight correlation.

Landslide Index Method (LIM) is a model suggested by *Van Westen*. In this case, for each class of an analyzed parameter, one should calculate an index through natural logarithmation of the ratio between the landslide density from that class and the landslide density from the study area. If the values are negative, it means that the landslide density in that class is lower than usual, and if the values are positive, then their density is higher than usual and thus, one can speak about a correlation. The method can be expressed through the following formula:

$$\ln Wi = \ln\left(\frac{Dclass}{Darea}\right) = \left(\frac{\frac{A(Si)}{A(Ni)}}{\frac{\sum A(Si)}{\sum A(Ni)}} \right),$$ where

Wi= index given to the class of A parameter (e.g. a type of land use or a slope class); Dclass= landslide density in the class of A parameter; Darea= area of the landslides from the class of A parameter; A(Ni)= area of the A parameter class.

The first step is to create a spatial database for landslides, which in this case is made up of two parts: a part that contains the inventory of the landslides, and another one that contains the inventory of the triggering factors.The inventory of the landslides has been made with the help of a GPS and the data we obtained have been converted into digital format by using the GIS applications. Thus, 42 new active landslides of different types (shallow, stepped landslides, translational, complex) and 29 partially stabilized or stabilized landslides have been identified. In this paper, seven factors which might trigger landslides have been used, such as: slope, slope aspect, fragmentation depth, drainage density, curvature, land use and precipitation distribution. An important factor like lithology has not been used as it has a homogeneous distribution in the study area. Each factor in turn was classified.

The slope may be considered a major parameter in the evolution of the mass movement processes.

The paleogeomorphological evolution of this area is responsible for the appearance of slopes of different gradients and with different profiles. In general, the slopes of less than 2°(flat or gently sloping) are regarded as thresholds, that characterize the landforms resulted through fluvial processes or the interfluves. These gently slopes represent 43.1% of the studied area characterizing mainly the Radauti and Marginea depressions, as well as the valleys of the main rivers (the Suceava, the Sucevita and the Solca). On these surfaces, the most frequent geomorphologic processes are splash erosion, surface runoff and fluvial processes.

Beginning with the 2-6° slope class, characteristic to the contact zones between valley and slope or the slope and the interfluves, there occur slight erosional processes or colluvio-proluvio-deluvial deposition. This class of values represents 36.2% of the territory.

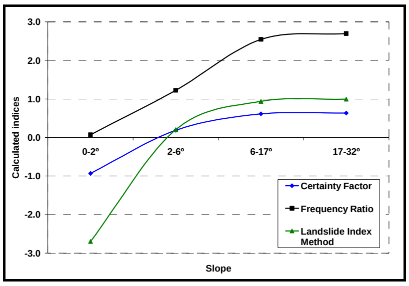

Figure 2: Calculated indices for slope

On slopes of 6-17° (20.37% of the territory) we notice the predominance of mass movement processes such as landslides, as well as gully erosion. The lower consistency of the vegetation cover is, the more intense they are. The values of the slopes higher than 17° are less frequent (0.25% of the territory), especially at the contact with the mountain, on the escarpments of the cuestas and where the slopes have been carved by the hydrological network.

The indices calculated through all the three methods have higher values for the slopes with gradients higher than 6° and lower values for those with gradients below 2°. Thus, the certainty of landslides occurrence grows once the threshold of 6° is crossed (Fig. 2).

The *fragmentation depth* expresses a tight connection with the valley generations, the intensity of neotectonic, the lithology and hydro-climatic conditions differentiated on landforms units. In general, we can say that the values decrease from west to east, according to the strata inclination. The values vary between 0.1 - 228.7m/km², almost half of the territory having values between 0.1 - 50m/km². Values between 50 - 100m/km² characterize the interfluves between the Solonet, the Solca and the Sucevita rivers, and values higher than 100m/km² are at the contact with the mountainous region.

For this factor, the highest values have been obtained for the areas where the fragmentation depth has values that vary between 100-150m/km² (Fig.3). 44.2% of the surface affected by landslides is included in this class. We can say that the landslides frequency is higher where the fragmentation depth has higher values. The last class is an exception because it represents only 1.9% of the territory.

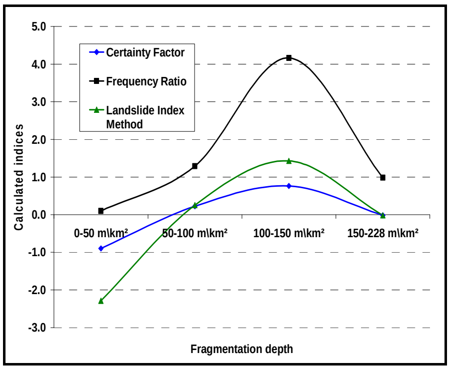

Figure 3: Calculated indices for fragmentation depth

The *drainage density* has a strong influence in growing the morphodynamic potential, being influenced by the drainage network organization and the geomorphological evolution of the region.

The drainage density presents rather high values, which vary between 0.1-7.2km/km². Values of 0-3km/km² characterize 89% of the territory (the Radauti Depression, the back slopes of cuestas), and the highest values are in the Ciungi Massive or near the contact with the mountainous area. Where the high values of the drainage density are corroborated with the high values of the fragmentation depth, there is a frequent presence of the deluvial deposits on the slopes. The highest values of the indices for the drainage density are of 5-6km/km² (Fig.4).

In conclusion, the landslides are frequent in the areas with high drainage density and high fragmentation depth.

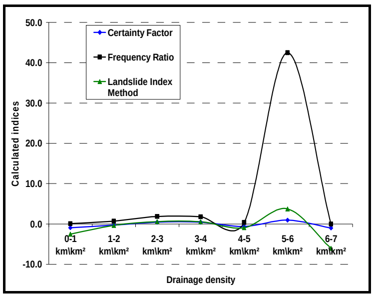

Figure 4: Calculated indices for drainage density

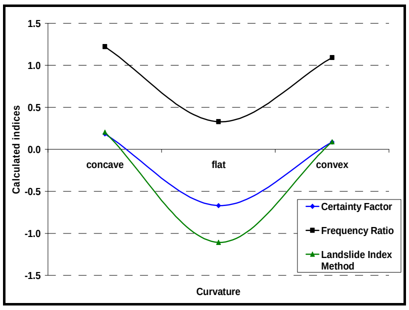

Figure 5: Calculated indices for curvature

As far as the *curvature* is concerned, we notice that both the concave and the convex slopes have high values for the indices calculated through the three methods. The concave slopes have higher values (Fig. 5). After rains, the concave slopes keep more water and for a longer period of time, and this leads to breaking the equilibrium. In the study area, 48.7% of the surfaces affected by landslides characterize the concave slopes.

The *slope aspect* also plays an important part in the landslide distribution. The shaded slopes have lower temperatures and higher humidity, characteristics which are favorable for landslide occurrence. 38.8% of the territory presents slopes with northern, north-eastern or north-western aspect. However, the slopes with southern, south-eastern or south-western aspect have higher values for the calculated indices (Fig. 6).

The sun-facing slopes lose faster the humidity, leading to the appearance of rills, which favor, in the rainy periods, a fast and deep infiltration of the water in soil and the breaking of the equilibrium.

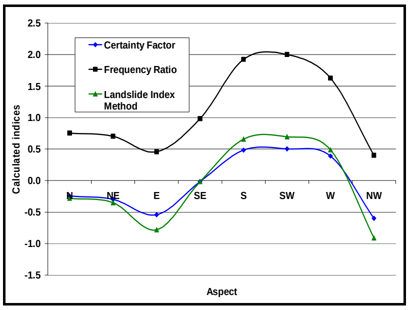

Figure 6: Calculated indices for slope aspect

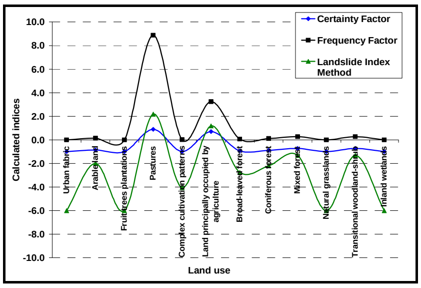

Figure 7: Calculated indices for land use

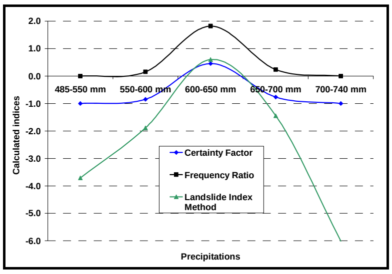

Figure 8: Calculated indices for precipitation

Most of the studies have pointed out that the vegetation covering, especially with forests, of the slopes is good for their stability. The highest values of the indices have been calculated for the slopes where the natural grasslands predominate, but also on the surfaces which are cultivated, but have considerable areas of natural vegetation (Fig. 7).

In the case of the precipitation, we noticed a growth of the indices with the growth of the annual average amount of precipitation. So, for precipitation of 600-650mm we obtained the highest value (Fig. 8).

Over the threshold of 650mm, there is a decrease in the values of these three indices due to the fact that these quantities are recorded on small surfaces from the contact with the mountain. These surfaces are in generalforested, and this enhances a higher stability to slopes.

The existent landforms favor the morphodynamic processes through their morphometric features (slope, drainage density, fragmentation depth, aspect, curvature etc.), imposing the intensity and the efficiency of the present day geomorphologic processes.

At the same time, they are evidence in the geomorphological landscape of the evolution in time under the influence of these processes.

The last step of this study was to combine the three models in ArcGis, according to integration rules (Fig. 9). Thus, were obtained three susceptibility maps, one for each model.

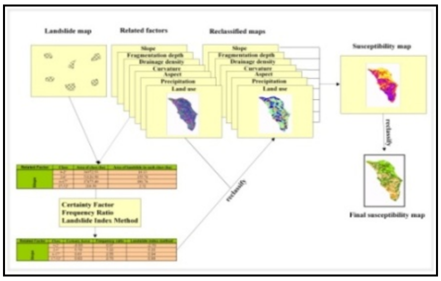

Figure 9: Landslide susceptibility modeling in ArcGis

The integrated values were reclassified into six classes of susceptibility to make the results easier to understand.

These maps were compared two by two by overlapping in ArcGis, to choose the best model for the study area. The comparison was made with the help of matrices tables (Remondo, 2003).

By comparing the maps with the help of Certainty Factor (Fig. 10) and Frequency Ratio (Fig. 11), we have drown the conclusion that there is a similarity of 43.5% in mapping the areas with different degrees of susceptibility.

The differences are higher (56.5%) and occur, mostly, in the southern half of the territory.

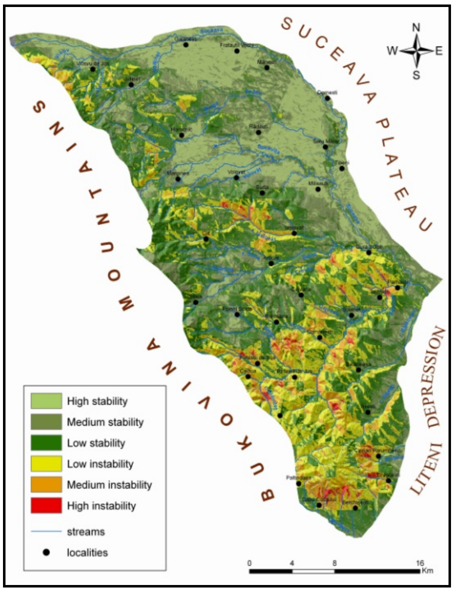

Figure 10: Landslide susceptibility map using Certainty Factor model

For example, 24.5% of the areas with low stability through Certainty factor have included in high stability with the Frequency Ratio, 11.3% of the areas with low instability through Certainty Factor have been mapped as areas with low stability through Frequency Ratio.

Generally speaking, if in the case of the Certainty Factor, 27% of the whole territory has a low, moderate and high instability, in the case of the Frequency Ratio only 11.5% of the territory has the same instability.

The same percent of similarity (43.3%) can also be noticed by comparing the Certainty Factor and the Landslide Index Model (Fig. 12). This time, the differences occur mostly in the southern half of the territory, where certain areas with high and moderate stability through the Certainty Factor are characterized by moderate and respectively, low stability through the Landslide Index Model.

Through the Landslide Index Model, 52% of the territory presents low, moderate and high instability, as compared to 27% obtained with the help of Certainty Factor.

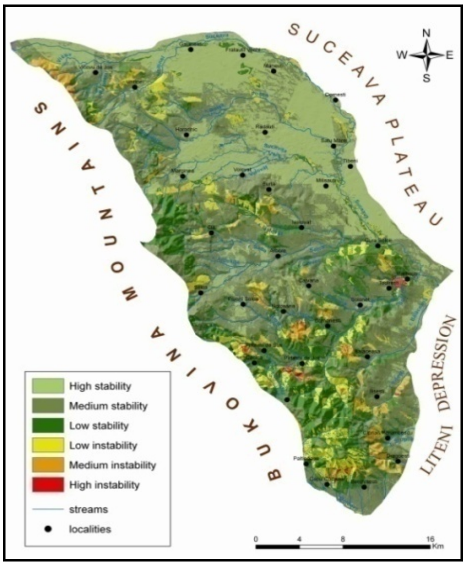

Figure 11: Landslide susceptibility map using Frequency Ratio model

Most of the differences occur on the maps resulted through the Frequency Ratio and the Landslide Index Model. Between these two maps there is a similitude of only 17%. The differences occur on the whole surface and inside each class of susceptibility.

A comparison between these three models is not enough to take a decision in what is concerning the choice of the best model in analyzing the susceptibility of the territory from this region, consequently their validation was accomplished.

The validation has been made by comparing the sites with existent landslides and which have been measured in the field with the three susceptibility maps, resulted after applying the three models (Fig. 13, 14).

There are three situations:

Through the Certainty Factor, the surfaces which present instability represent 27% of the whole surface of the study area and explain 94% of the landslides.

Through the Landslide Index Model, the surfaces which represent instability characterize 42% of the study area and explain 95% of the landslides.

3. CONCLUSIONS

The Landslide Index Model and the Certainty Factor have been regarded as valid models as in both cases the classes of instability have explained 94%, respectively 95% of the landslides. The Frequency Ratio cannot be considered a valid model as 40% of the existent landslides overlap the surfaces characterized by high stability to landslides. Nevertheless, a second validation, when the number of the subjects grows, will make it possible to choose the best model.

The mapped areas through all the three models as being susceptible to landslides release are: the Iaslovat drainage basin, Ciungi-Socu Massive, the escarpments of the cuesta of the Solonet and Solca rivers, the areas around some villages, such as Partestii de Sus and Vicovu de Jos. The rest of the territory, especially the Marginea and Radauti depressions are

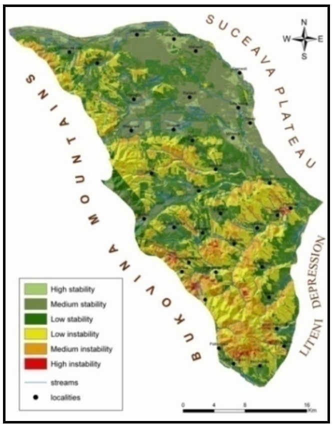

Figure 12: Landslide susceptibility map using Landslide Index Method

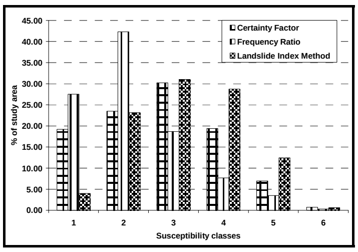

Figure 13: Percentage of the susceptibility classes in the study area

characterized by stability. This apparent stability may sometimes be disturbed by certain anthropic factors (e.g. the area from Poieni Solca, where the deforestation led to slope instability).

The damage resulted from the landslides may be reduced in two ways: either by modifying the hazard in itself or by reducing the human susceptibility to it. Both ways require a mapping of the terrain susceptibility. Such maps normally aim at providing a document that depicts the likelihood or possibbility of new movements occuring in the area, and therefore helping to reduce future damages. In this case, the susceptibility maps represent a forecast of future terrain behaviour.

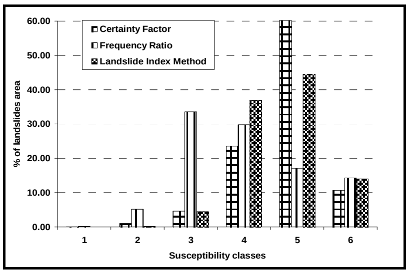

Figure 14: Percentage of the surface of landslides for each class of susceptibility

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