MAPPING SNOW AVALANCHE RISK USING GIS TECHNIQUE AND 3D MODELING. CASE STUDY- CEAHLAU NATIONAL PARK*

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This study consisted in a precise mapping project (GPS field campaign, on-screen digitization of the topographic maps at 1:5.000 scale and updated with ASTER mission) of the Ceahlău mountain area in Romanian Carpathians in order to address the snow avalanche risk management, surveying and monitoring. Thus we considered the slope, aspect, altitude, landforms and roughness resulted from a high resolute numerical terrain model (31 square km at 1: 5.000 scale resulted in a spatial resolution of 3 m by the help of Topo to Raster tool). These parameters were calibrated after a model applied into Tatra Mountains and used over Ceahlău Massive. The results were adapted and interpreted considering to the European Avalanche Hazard Scale. This work was made in the context of the elaboration of Risk Map and is directly concerning both in the security of tourism activities but also in the management of Natural Park Ceahlău. The extension of this method to similar mountain areas is ongoing and finally the work has also an educational purpose.

Key words: GIS, ASTER sensor, avalanche risk, natural park management, 3d modeling.

1. INTRODUCTION

The human activity is increasing and thus affecting the natural environment. Due to this dynamic natural processes can be activated and accelerated. Snow avalanches are natural processes. Favorable sites commonly present values of slope angles between 25°–55° (McClung and Shaerer, 2006), due to the fact that below 25° slopes are too shallow for the snow to become unstable and above 60° slopes are too steep. Even so, slush avalanches were reported on slopes as low as 2° (Nobles, 1966 quoted by Keylock, 1997).

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In Europe the Alps are "affected" by the intense tourism activity. A black statistics of a period of 35 years in Alps gives a medium value of 75 persons per year covered by avalanches, from which approximately 35 per year are reported dead. In French Alps a 28 years statistic presents a medium value of 100 persons per year involved in avalanche, with a "black statistic" of 30 recorded dead per year. "Black" years were 1969/1970, 1980/1981 and 2005/2006 with over 55 victims. Although the Carpathians are shorter and less affected by the snow avalanches, Romania has a history of tragically events. The year 1977 was a black one, when in 17th of April 23 skiers died, most of them young ones due a major snow avalanche. Also in Gutâi Mountain a small avalanche in 22nd of February 2004 caused the lost of 3 lives and the 2003-2004 winter was calamitous causing 8 skiers and mountaineers to die in February 24th.

This tragically events prompted the scientists to study the phenomenon. In Romania the scientifically community started researching in a complex matter recently (2004/2005) when Maria Motoiu elaborated and published snow avalanches reports with the team from National Meteorological Administration. Also*,* Făgăraş and Bucegi Mountains were researched by Voiculescu, M. (2004, 2008). General aspects (classification, mechanism, survival techniques) were studied by Dinu Mititeanu (2006, 2008) and the digital mapping of the avalanche risk was elaborated by Bogdan Mihai and Ionuț Şandric (2003, 2005 and 2007).

2. STUDY AREA

The study focused on Ceahlău Mountain. This massive is located in Carpathians Eastern Carpathians subgroup within Romania (Fig. 1).

Ceahlău Mountain is located in the eastern part of Romania being situated in the flysch area (conglomerates, calcareous rocks centrally disposed in a highly elevated synclinal structure).

In this area the table lands are mostly wavy with high peaks which opposes as aspect with structural surfaces and anticlines. The versants are cut by degrees, having vertical walls (shelfs, "brâne", fences, karling, and chutes).

The currently research area is located in the National Park Ceahlău (Fig. 2). The protected area has a total area of 84.74 km^2, from which the potential area spreads over 31.05 km^2.

The purpose of the experiment was to combine in a GIS technique the use of the existing topographical maps and GPS records with the ASTER *(Advanced Spaceborne Thermal Emission and Reflection Radiometer)* mission aiming at mapping the Potential Release Areas of snow avalanches within Ceahlău Mountain. ASTER mission due to the reflection radiometer "returned" the precise altitude of the terrain in the current area of research and helped the digital surface model in the matter of accuracy and novelty.

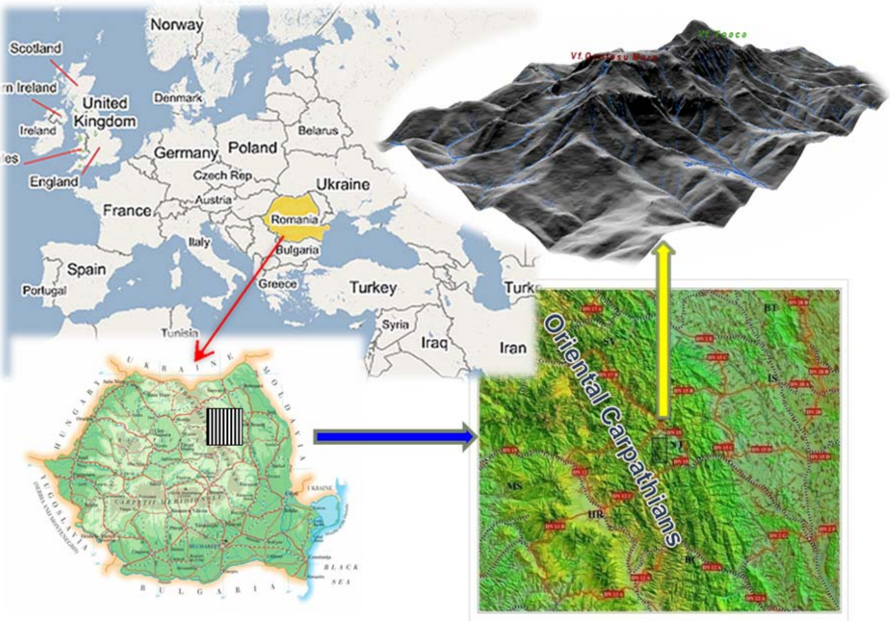

Fig. 1 – Location of the mountain area in Europe.

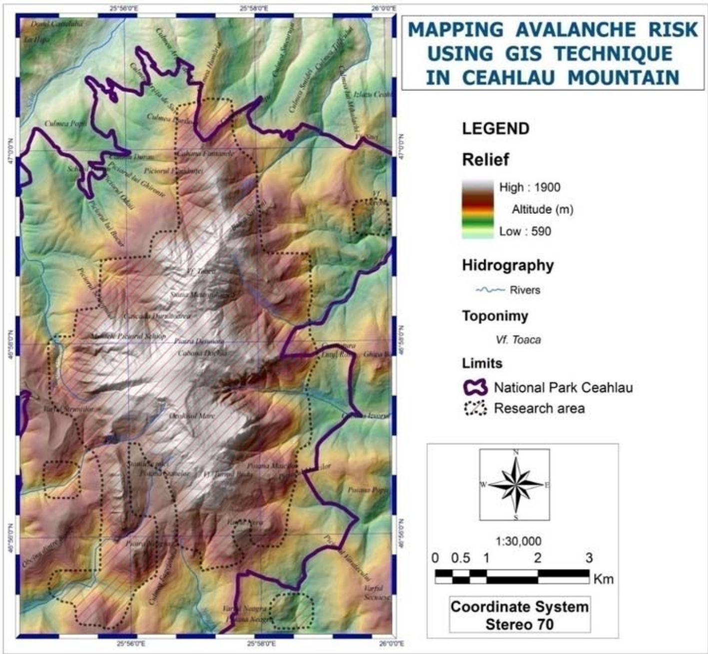

Fig. 2 – Research area within National Park Ceahlău.

3. METHODOLOGY

This experiment is an adaptation by the model applied by J. *Hersko şi G. Bugar* in 2000 over Belianske Tatry Mountains. Over Ceahlău the model was modified and updated according to the specifics of the massive.

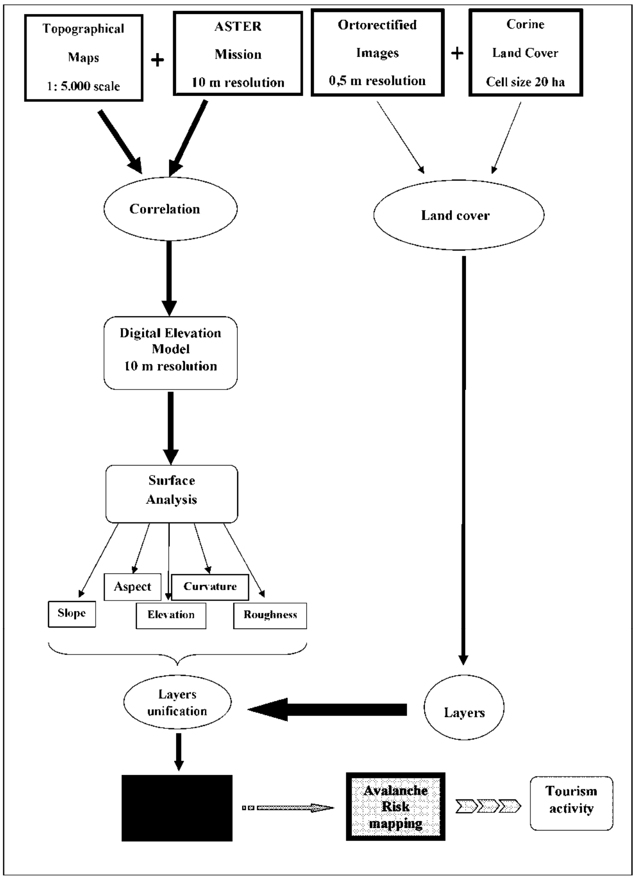

Fig. 3 – Methodology of the experiment.

Input data were composed of derived digitization and simplification methods specific to GIS technique. All the vector data (elevation values from on screen digitization and filtering ASTER data) were combined with raster (ortorectified imagery) and correlated, finally analyzing the derived geomorphologic parameters (Fig. 3). The geomorphologic parameters (slope, aspect, elevation, curvature of terrain and roughness) were analyzed individually and put together in a formula, returning the risk of snow avalanche.

$$R\ av = (S + Ex + Al + Fx) * Rg$$

3.1. TERRAIN PARAMETERS

Slope is between one of the most important geomorphometric parameters of terrain surface, representing an important role in determining the geomorphologic processes that affect a certain area. It represents the quantitative measure of maximal change of elevation values (Shary *et al.*, 2002), ranging from 0° to 90°. Geometrically, slope describes the angle between the horizontal plane and the tangential to the surface and is expressed as it follows:

$$S = \arctan(p^2 + q^2)^{1/2}, \text{ where } p = \frac{\partial z}{\partial x}, \; q = \frac{\partial z}{\partial y} \tag{1}$$

Slope gradient can be expressed in either degrees or radians, but more commonly percentages are used to refer to slope values (tan (S) *100).

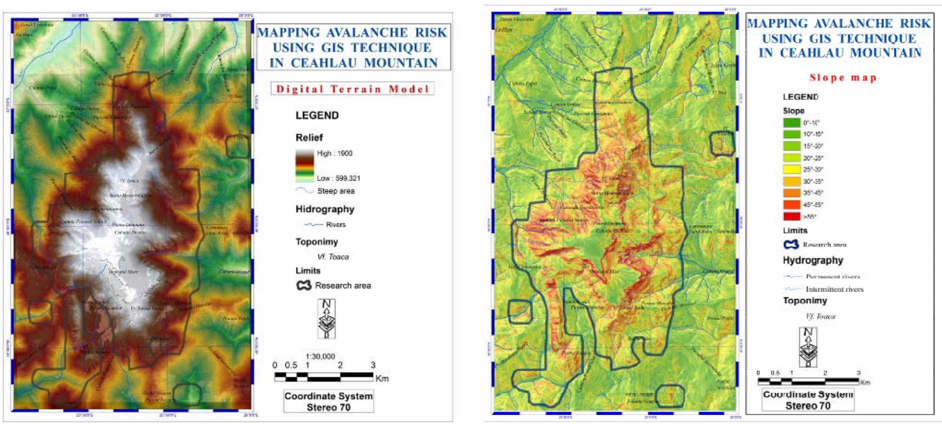

Fig. 4 – Digital terrain model (left) and Slope Map (right).

Fig. 4 shows the digital terrain model (left) which was obtained from digitization of topographic maps at 1:5.000 scale and updated with the newer elevation vectors from ASTER mission. The result was a digital terrain model with a 10 meters cell resolution. In the end, the product was filtered and corrected by the help of Topo to raster tool from 3D Analyst extension within ESRI ArcView. Next, the slope map was elaborated (right). The most representative slopes values "suitable" for snow avalanche risk are over 35 degrees. The lowest values of less than 15 degrees slope are in the table land area.

Another parameter is represented by *aspect* which represents a crucial role in a number of morphological, hydrological and ecological processes. It is defined as the compass direction to which a slope faces, measured in degrees from North in a clockwise direction and ranging from 0° to 360°.

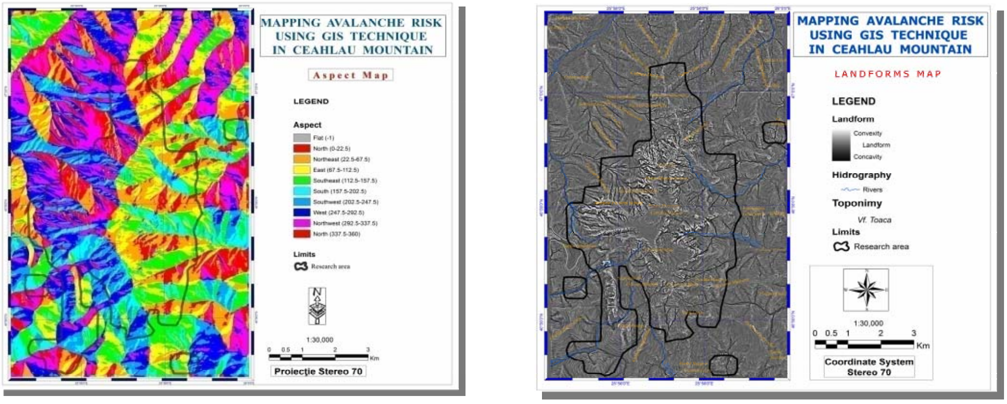

Fig. 5 – Aspect map (left) and Curvature Map (right).

Aspect can be defined as (Shary *et al.*, 2002):

$$A=-90[1-\text{sign}(q)](1-|\text{sign}(p)|)+180[1+\text{sign}(p)]-180/\pi\, sign(p) \arccos \frac{-q}{(p2+q2)^{1/2}} \quad (2)$$

where sign(x) = 1 for $x > 0$; 0 for $x = 0$; –1 for $x < 0$, arccos() is measured in radians and $p=\frac{\partial z}{\partial x}$, $q=\frac{\partial z}{\partial y}$.

As seen in Fig. 5, the South, South-West and South-East versants are the most representative due to the fact that the avalanche risk is higher in those areas.

Profile curvature is the curvature of a line formed by the intersection of a fictional vertical plane with the ground surface. While a zero value of profile curvature indicates a flat surface, negative values indicate that the surface is upwardly concave and positive values indicate that the surface is upwardly convex. Profile curvature can be determined using the following calculation formula (Evans 1972, quoted by Shary *et al.*, 2002):

$$\text{ProfileC}=-\frac{p^2 r-2pqs+p^2 t}{(p^2+q^2)(1+p^2+q^2)^{3/2}},$$

where

$$p=\frac{\partial z}{\partial x},\ q=\frac{\partial z}{\partial y}, r=\frac{\partial^2 z}{\partial x^2}, s=\frac{\partial^2 z}{\partial x \partial y}, t=\frac{\partial^2 z}{\partial y^2} \quad (3)$$

Nonetheless landform is very useful for snow avalanche risk because it determines the possible snow accumulation areal or the possible areas of propagation. The concave areas are mostly represented by the bed's rivers. The convex one's, in general, are represented by the highest slope values.

4. RESULTS

Finally, all the geomorphologic parameters were analyzed together. The study area (31 square km) was divided in 448 cells with a resolution of 125*125 meters. Every cell risk coefficient was independently obtained by entering the specific parameters of that area in the final formula. A class of values of Risk of avalanche was established. Finally, for each cell we obtained values varying from 0 to 16.5.

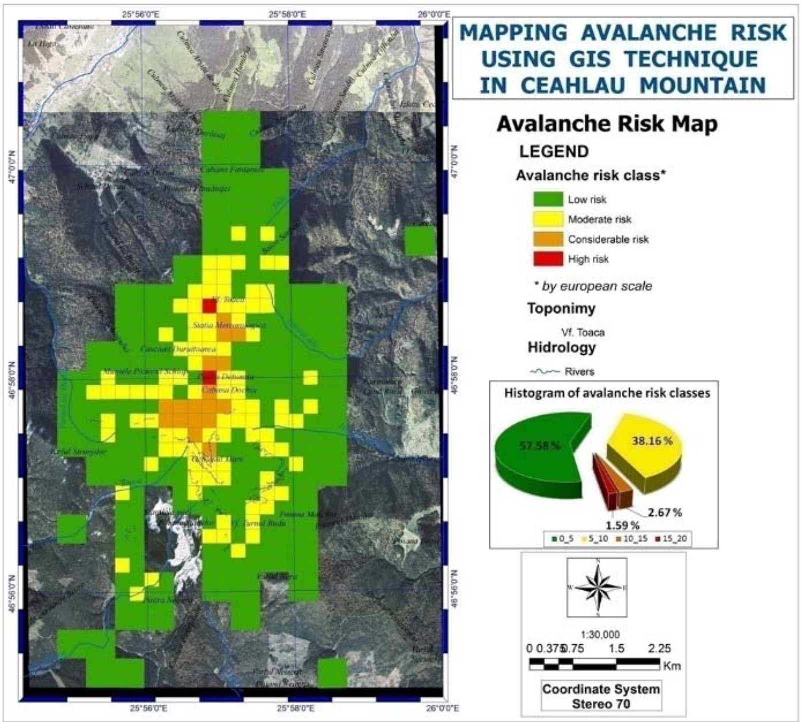

Fig. 6 – Avalanche risk map.

The avalanche risk classes where elaborated conform to the European Scale. According to Fig. 6, the highest risk of snow avalanche is near Toaca Peak and close to Dochia chalet. The lowest class corresponds with the fact that tourism activity is not forbidden in winter season and the highest class restricts the access under certain conditions.

The experiment was completed with the overlap of the current tourists tracks elevated from GPS points of interests. All of the tourists paths are affected by the risk of snow avalanche (Fig. 7).

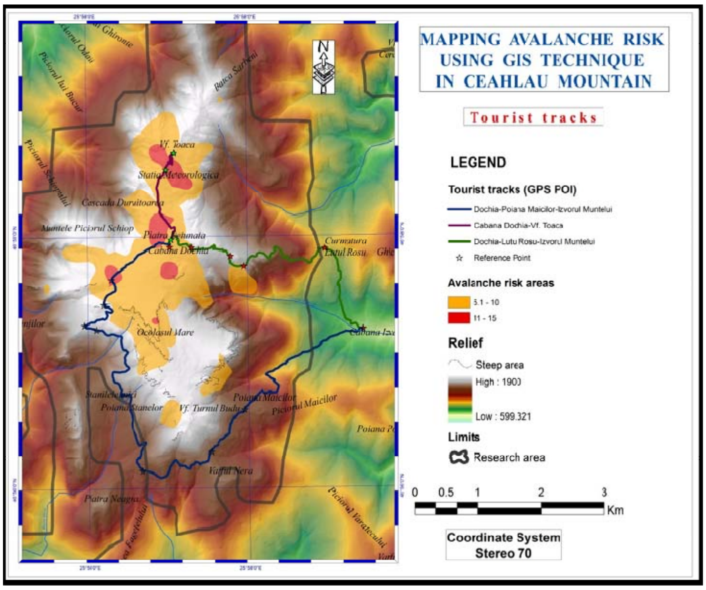

Fig. 7 – Tourists tracks affects by the risk of snow avalanche.

5. CONCLUSIONS

In conclusion, the experiment was tested and the results confirmed the risk of snow avalanche to be present in Ceahlău National Park. The final results were compared with the background from the "terrain", the mountaineers and salvamont services confirmed the potential areas which were in a 90 % accurate. The current mapping project could represent a base for the tourism activity (represent a more accurate perception for tourists, a method for prevention, maybe a future interactive webmapping), a useful tool for the Management of Natural Park Ceahlău and can be applied in similar mountain areas and has an educational goal.

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