Abstract

Many of the mountains in Bulgaria are affected by avalanches each year. Avalanches are typical of any mountain range that accumulates a large enough snow cover. In the mountainous terrain, avalanches are among the most serious hazards to the life of tourists and mountaineers. They have destructive capacity, due to their potential to carry a huge mass of snow over long distances.

This paper is focused on cartographic visualization of avalanche areas in Pirin National Park. There are more than 50 marble and granite peaks within the park with a height of more than 2500 m. Some of the slopes in the park are at avalanche danger. The paper presents 2D and 3D cartographic visualization of avalanche slopes based on analysis of the main factors of avalanche formation mainly attaching importance to terrain factors: slope steepness, slope aspect, height.

Keywords: Snow Avalanches, Cartographic Modeling, Visualization, Thematic Mapping

INTRODUCTION

Snow avalanche is the major natural hazard in Europe's mountain during the winter (Javier, 2003). Bulgaria is a country with a lot of mountains and many of them are affected by avalanches each year. The statistics of Mountain Rescue Service of Bulgaria shows numerous avalanches with human and material losses in Rila, Pirin, Stara planina, Belasitsa and other mountains in the last 50 years. Statistic information could be very useful for prevention. Snow avalanches that occurred in the past give an idea of the size and type of avalanches that may occur in the future (Maggioni et al, 2002). The last fatal snow avalanche accident in Pirin mountain is from February 2018 when a young woman lost her life near Momin vrah Peak during mountain trekking (Mountain Rescue Service, 2018). Just three days earlier a snowboarder was buried by an avalanche at Echnishtite, Pirin, which is reported by Bulgarian Extreme and FreeSkiing Association - BEFSA (Panayotov, 2004a) for one of the most avalanche-prone slopes of freeriding in the Bulgarian mountains. Fortunately the snowboarded was found and saved due to the rapid reaction of the Mountain Rescue Service (Mountain Rescue Service, 2018). Activities such as mountain hiking, trekking, skiing and climbing that are negatively impacted by snow avalanches (Munteanu et al., 2013).

Type of snow is of utmost importance for the formation of avalanches. Fierz et al. (2009) give a detail International classification for seasonal snow on the ground. Ancey Christophe considers two cases of avalanches depending on the form of motion: flowing (with a high-density core at the bottom) and airborne avalanches (most of the snow particles...
are suspended in the ambient air by turbulence) (Ancey Ch, 2018). Panayotov (2004b) defines the types of avalanches in the Bulgarian mountains: dry avalanches of soft snow, wet avalanches of soft snow, soft slab avalanches, hard slab avalanches, powder avalanches. The are also cornice fall avalanches in Bulgaria. Formation of all these types of avalanches depends on the snowpack, terrain surface, weather, etc. Avalanches can have extreme violence and can cause human loss and significant damages. It is necessary the avalanche prone slopes to be presented on maps that may be used for route planning and disaster management.

INFORMATION MATERIALS OF AVALANCHE DANGER

Information about avalanche danger can be provided by avalanche bulletin which combines meteorological and topographical factors (Eckerstorfer, 2008). European Avalanche Warning Services (2018) defines five levels of avalanche danger: 1 - low, 2 - moderate, 3 - considerable, 4 - high and 5 - very high. Bulletins should describe the level of avalanche danger and give information about the prone areas, avalanche problems (incl. new snow, wind-drifted snow, persistent weak layers, wet snow, gliding snow), danger description, information concerning the snowpack and the weather (European Avalanche Warning Services, 2018).

The Mountain Rescue Service of Bulgaria is a specialized organization that deals with the mountain rescue activity, which is regulated by the legislation of the Republic of Bulgaria. The Mountain Rescue Service provides avalanche bulletins for four of the highest mountains in Bulgaria - Rila, Pirin, Stara planina and Vitosha. The bulletins describe the avalanche danger, direction of avalanche danger, snowpack conditions, weather conditions, recommendations and predictions. Bulgarian Extreme and FreeSkiing Association - BEFSA is a nonprofit organization established by a group of Bulgarian freeskiers. The mission of BEFSA is to develop and popularize the freeskiing sport in Bulgaria and within the Balkan region, as well as to represent the needs and interests of the Bulgarian freeskiing community. BEFSA provides information on conditions of avalanche formation, also a snow profile of avalanche areas. All the information described in the bulletins can be more easily understood if it is supported by maps. Bulgarian avalanche bulletins are still not supported by maps of avalanche danger. The maps of avalanche prone areas should be in close relation to the bulletins. Kriz (2001) describes the main objectives of avalanche hazard mapping: cartographic design, layout and presentation using multimedia technology; Digital Terrain Model assessment for high quality feature derivation; combination of avalanche science, risk research, design, psychology of perception. Eckerstorfer (2008) made detailed analysis of cartographic products presenting avalanche hazard and gave requirements for a high quality hazard map.

DETERMINATION AND CARTOGRAPHIC VISUALIZATION OF AVALANCHE PRONE SLOPES

Main factors of formation of snow avalanches

To present enough accurate and helpful cartographic representation of avalanches to our users, we need to find information about topography, snow pack and weather condition, which are defined by Lied K (2004) as important factors for avalanche formation. We can add here vegetation and human factor. More detailed description of these factors is following.

Determination of avalanche prone slopes is based on analysis of the main factors of avalanche formation. One of the main factors is terrain (including slope steepness, slope aspect, relief and landforms).

Slope steepness is one of the most important terrain factors (Covasianu et al., 2011). Most common avalanches occur at a slope of 30° to 45°. From 25° to 30° there is frequently occurrence of avalanches, from 45° to 50° there is a rare fall of avalanches and at a slope below 25° and over 50° very rarely fall avalanches. In slopes above 50° small amounts of snow falls are observed. Fig. 1 shows the results of statistics for the most likely fall of avalanches depending on the slope (Bulgarian Red Cross, 2009).
Figure 1. The most likely fall of avalanches depending on the slope

Slope aspects represents a significant role in morphological, hydrological and ecological processes (Covasniu et al., 2011). Northern slopes receive much less heat than the sun compared to the southern slopes. For this reason, the snow compression is much less, and the stabilization process is very slow. That is why in the winter the northern slopes are much more avalanche dangerous than the southern ones. In the spring, however, the snow cover on the southern slopes can be overloaded with moisture from the melting of the snow and they become more avalanche dangerous (Bulgarian Red Cross, 2009).

Some landforms are at higher danger than others. The steep, smooth and open leeward slopes where a large amount of snow can accumulate are very dangerous. It is difficult to predict exactly where the avalanche start area would be. The leeward slopes collect a lot of snow under the influence of the wind. In these locations cornices are formed. If there is a thin layer in the cornices and if it is overloaded, it is possible a cornice fall avalanche to occur. Frequently, a large amount of snow is collected in deep, concave, elongated relief forms. Therefore, such kind of landforms are a common track of avalanches (Bulgarian Red Cross, 2009). It is most safe to hike along edges and ridges in the winter.

Other main factors of avalanches are vegetation, snowpack, weather and human factors. Mountain vegetation is of utmost importance of avalanche formation. Slopes of alpine grass create conditions for snow slipping and avalanches falling. Much less is the avalanche danger in forest areas. Forests have a protective role - they cannot stop avalanches that pass through them, but they can prevent the formation of avalanches as they prevent the snow from falling. Avalanche formation is affected by the conditions of the snowpack: thickness and structure of the snow cover; presence of weak layers; presence of cornices; humidity of the snow; compression of the snow; presence of a new amount of snow (Bulgarian Red Cr, 2009).

Weather factors that affect snow avalanche formation are temperature, wind direction and wind speed, solar radiation, snowfall, snow intensity (Bulgarian Red Cross, 2009; Eckerstorfer, 2008).

Human factor has a great impact on avalanche fall. The most common cause of avalanches is the passage of people through avalanche prone areas.

Cartographic visualization

Determination of the avalanche slopes is based on analysis of the main factors of avalanche formation mainly attaching importance to terrain factors: slope steepness, slope aspect, height, taking into account solar radiation and wind direction. Based on GIS analysis a series of thematic maps of slope steepness and aspects of Pirin National Park were compiled according to the slope steepness and aspects at different time of the day and different months, taking into account, solar radiation and wind direction.

A 2D map of the slope of the terrain of “Pirin National Park” was created (Fig.2). The map shows the steepness of the slope and the dangerous zones displayed in red, which provide the formation of avalanche.
Figure 2. 2D map of the slope of the terrain of “Pirin National Park”

A 2D map of the aspect of the terrain of “Pirin National Park” was created (Fig. 3). The map shows the aspect of the terrain, which represents the quantity of sun, which comes to the slopes during a winter day.

Figure 3. 2D map of the aspect of the terrain of “Pirin National Park”
Using such kind of information cartographers can provide mountaineers useful information for avalanche danger. There are cartographic products that represent safe winter routes and avalanche prone slopes through symbols – arrows, showing the start area and possible directions.

The maps can be used to support: assessment of safe winter tourist paths; defining locations of avalanche warning sign in the mountains; production of information boards for avalanche danger; compiling avalanche bulletins; planning a trekking route in the winter. These maps support pre-disaster activities including preparedness and assessment. In emergency the maps can be processed into reference maps through adding special symbols presenting the type and location of the accident and symbols for affected people and infrastructure (Marinova, 2017). By adding information about operational sites and activities the teams of the Mountain Rescue Service can get maps for evacuation and rescue planning (Marinova, 2017).

### 3D Modeling of Snow Avalanche Areas

In the last decades 3D maps became a very powerful tool of cartography. They give cartographers more possibilities to represent thematic and special information in a way that is understandable to map users (Bandrova & Bonchev, 2010). 3D modeling can be defined as creation of a spatial model using special computer programs. The built-in 3D model can be viewed from all sides and also be located in one or another environment. There are several steps in processing the information to reach the original 3D model: collecting primary data, preparation in points, polylines, or polygons, and finally creating a 3D model, typically consisting of triangulated network. A data source is any source of information that can be used on the map.

For the creation of the 3D map of avalanche prone zones in the area of Todorka peak the Directorate of “Pirin National Park” provided the following data: contours in vector form (vectorized in 50 m, with sufficient precision for the next steps of working); peaks with altitude; rivers and lakes; tourist paths and hiking trails. Integration of various data is essential to build a good base for environmental analysis and planning (Cioli et al., 1998) Data processing is a complex process. It requires reconciliation of different types of information presented in its formats. As there are many zones of potential avalanche risk in every valley in Pirin National Park, there is an automatic generalization of the rivers and the tourist trails, which fall in the region of Todorka Peak, as a limiting parameter is the maximum length of the polyline - 3 km.

The western slope of Mount Todorka is an “ideal” combination of conditions for the formation and falling of avalanches. The traces of vegetation and historical evidence show that this is indeed the case, and during certain periods it has a very active avalanche activity. A 3D map of the avalanche zones in the area of Todorka peak was created. The basic map represents: terrain relief; hydrography; tourist routes; chalets; avalanche danger zones. The additional content of the map depicts: annotation for the north and scale.

First step of producing morphologic map is creating slope map. After creating the slope map, it is needed to differentiate between the hazardous slopes and non-hazardous ones. In avalanche hazard assessments, different intervals have been determined as hazardous slopes. In this case, slopes between 28° and 55° are considered as the hazardous slopes. Based on the slope of the terrain and descriptions provided by Panayotov (2004a) at the web-site of Bulgarian Extreme and FreeSkiing Association, the avalanche zones in the western slope of Todorka peak are presented. They are characterized by polygons depicted in red. In this case, red color symbolizes danger.

The chalets Vihren and Bunderitsa are located in the research area. Vihren chalet is located in the Pirin Mountain, on a cliff-side threshold on the left bank of Banderitsa river at 1950 m above sea level. It was built in 1939-1941 by the tourist company in Bansko and it is called Eltepe. The chalet consists of 2 massive buildings, which can be reached by a road from Bansko (16 km). Banderitsa chalet is in the North Pirin, situated on the left bank of Banderitsa river at 1810 m above sea level. It was built in 1915. It is located 14 km away from Bansko, leading to an asphalt road. In imminent proximity - 300 meters southwest along the asphalt road - there is a suitable place for a palace camp. Designing a chalet as a virtual object, it is intended to be close to the real object. It was made with measurements, using electronic roulette.

Volume scaling is used, which is a simultaneous increase or decrease of object dimensions on the three axes of a local rectangular coordinate system. One scale section corresponds to 25 m. A north-arrow sign is placed on the west side of the map, near a location where there are not many situated objects.

The purpose of the map is to help users practicing winter sports and mountaineering with the introduction of areas of potential avalanche risk in the area (Fig. 4). The 3D dimension of the map makes orientation easily in the research area.
CONCLUSIONS

Based on developed models reflecting the avalanche field factors (including slope steepness, slope aspect, relief forms) a series of thematic maps of the territory of Pirin National Park are presented according to the slope steepness and aspects at different time of the day and different months, taking into account, solar radiation and wind direction. To summarize, information provided by responsible organizations, a 3D map of the avalanche prone zones in the area of the west slope of Todorka peak (2746 m) was created. The area of Todorka peak is one of the most popular tourist destinations in Pirin Mountain. All these thematic maps of avalanche prone areas aim to provide mountaineers, skiers, alpinists with additional information about the avalanche danger near ski areas and tourist routes. The cartographic information that comes from the 3D map will help the users for better understanding of the area and will be a caution of the danger zones in the mountain.

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BIOGRAPHY

Silvia Marinova is Secretary General of Bulgarian Cartographic Association and Chief Assist. Prof. at the University of Architecture, Civil Engineering and Geodesy, Sofia. She is also a member of Bulgarian Chamber of Graduated Surveyors, Commission on Cartography in Early Warning and Crisis Management and Commission on Mountain Cartography - International Cartographic Association. She serves as a cartographer at KartGeo Ltd. where her main activities are map design and editing. Her science interests are focused on thematic mapping for early warning and disaster management, cross-border mapping, mountain cartography.

Dobrin Veselinov Petkov is graduated student at University of Architecture, Civil Engineering and Geodesy, Sofia with major Geodesy, specialization Cartography. In January, 2018, he presented his master thesis with topic “Cartographic modelling of avalanches”, which is one of his science interests. Currently, he works as a geodesist in company “GeoMobile” and have previous experience at company “Geo Engineering” and “Agency of Geodesy, Cartography and Cadastre”. During his student years, he joined an internships in “Here Maps”, with contribution of updating data base.

Prof. Temenoujka Bandrova is President of Bulgarian Cartographic Association and head of Laboratory on Cartography, University of Architecture, Civil Engineering and Geodesy, Sofia. Cochair of the ICA Commission of Cartography and Children (2007-2011), a member of the Council board and chair of Young Scientific Commission of International Society of Digital Earth, a member of: Commissions on Map Projections, Cartography in Early Warning and Crisis Management – International Cartographic Association (ICA); Editor’s group of the International Journal of Digital Earth, and Cartographia and Geoinformatika Journal, Croatia. She is Project manager in DataMap Ltd where her school atlases and maps are published. She is an author of 30 school atlases and more than 90 wall maps in geography and history, approved by Ministry of Education for Bulgarian schools. She is the organizer of series International Conferences on Cartography and GIS.