



THEMATIC MAPPING OF AVALANCHE-THREATENED AREAS

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Summary

Providing avalanche-threatened areas with modern thematic data mapping is an urgent task. It will allow us to predict and prevent catastrophic consequences of snow avalanches. The purpose of this paper is to create a set of thematic raster maps of Polonyna Borzhava mountain ridge, including a physical map, a map of relative avalanche hazards, and a map of avalanche paths, on the basis of analysing certain morphometric and environmental factors. Modelling and analysing morphometric parameters of the ridge surface were implemented, and they were represented as factors of avalanche occurrence. The areas with consistent snow avalanche occurrence in the Polonyna Borzhava mountain ridge were allocated by combining cartographic material, remote sensing data, statistical meteorological data and some geomorphometric data about the surface in one unified geographic information system. Thematic mapping of snow avalanches of Polonyna Borzhava ridge has been implemented in the scale of 1:50000. The resulting thematic maps can be used when developing winter tourist routes.

Keywords

thematic mapping • avalanche hazard • surface geomorphometric parameters • digital elevation model • ArcGIS

1. Introduction

Avalanche is a spontaneous natural phenomenon that shifts large masses of snow on mountain slopes and causes their movement downwards at high speed, which can lead to loss of life and considerable damage [Kolotukha 2008]. The formation and shift of avalanches is affected by many factors, among which we distinguish two main groups: one being the weather (intensity of snowfall and its daily increase, rain, wind, temperature, etc.), and the other, the landscape (steepness and exposure of slopes, relative altitude of terrain, forms of relief, presence of vegetation etc.). Since avalanches occur on the surface of the mountain slopes that have a broad spatial range, the best visual representation of the threats caused by this phenomenon is the thematic map.

From the perspective of mapping, it is difficult to represent all the factors of avalanche occurrence and formation on the map. The slope, exposure and curvature

of surface are the main geomorphometric parameters that are often used for modelling and mapping of avalanche areas. They can be obtained from digital terrain model (DTM) and can improve visual recognition of various forms of relief, which in turn is a fundamental concept in any geomorphological analysis [Huabin et al. 2005].

Meteorological factors are more difficult for cartographic representation because of their inherent variability in time, dynamism and lack of unique spatial reference. They can be used for short-term forecasting and mapping of current weather and avalanche threat level for several days following their occurrence, but they are not suitable for creating general thematic maps [Kriz 2001].

Swiss researchers [Maggioni and Gruber 2003] identify three stages to define avalanche-threatened areas. Such research projects provided the foundation for creating thematic maps of avalanche risk for mountains of North America [Lasky 2015], Central Asia [Yistyikul and Baygurin 2015] and Europe, including: The High Tatras (Republic of Slovenia) [https://mapy.hiking.sk/blog/#legenda-lavinova_mapa], mountain ranges in the Czech Republic [Tumasjeva 2009], Catalan Pyrenees [Oller et al. 2013], Dolomites of the Eastern Alps [Izadifar and Babae 2014], Northwestern Caucasus [Kanonnikova 2012], Khibiny of the Kola Peninsula [Vikulina 2009].

Mapping of snow avalanche phenomena, using geomorphometric parameters of the surface of the Carpathians territories, was carried out by Romanian researchers [Covăsnianu et al. 2009; Simea 2012]. As a result, raster maps of avalanche risk in the mountain ranges of Ceahlau and Rodna in the Eastern Carpathians in Romania were created. However, for many areas, including the Ukrainian Carpathians, amount of information about past cases of avalanches is scarce, and sometimes such data is altogether absent or not properly referenced. In such cases, the mapping of avalanche areas involves determining the spatial distribution of surface parameters that are favourable to the instability of snow cover and avalanche occurrence [Simea 2012].

The analysis of literature sources leads to a conclusion that creating modern thematic mapping material for avalanche-threatened areas is an urgent task, and it can have a bearing on predicting and preventing catastrophic consequences of avalanches. Therefore, the aim of the present research is to create set of thematic raster maps of the Polonyna Borzhava mountain ridge, including a physical map, a map of relative avalanche hazards, and a map of avalanche paths, based on the analysis of certain morphometric and environmental factors of avalanche occurrence.

2. Material and methods

For conducting our experimental study, we have selected the Polonyna Borzhava ridge in the Ukrainian Carpathians, which in recent years has become very attractive and popular with tourists.

Polonyna Borzhava ridge is the longest mountain ridge of Transcarpathia. Its length is about 50 km, the average width, 3.4 km (sometimes up to 10 km or more), and its height is up to 1681 m (m. Stiy). The ridge has specific asymmetry of transverse profile and deep transverse valleys. The depth of dismemberment is 500-1000m.

[Mjagkov and Kanaev 1992]. Avalanches occur on almost all treeless steep slopes, as evidenced by the avalanche paths: the sites of mountain slopes and valley bottom, on which avalanches are formed, move and stop. Sometimes the avalanches are wedged in forests. At altitudes of over 1,000 meters above sea level, snow cover reaches a capacity of 1.0–1.5 m, and in some sections of avalanche paths, snow accumulation is more than 3.0 m. Snow is blown out by wind (mostly south-western rhumbs constituting more than 50% of all winds) from near-crest and forestless areas of mountains onto slopes, and it is accumulated as large mass in different lowlands (denudation basins, erosion furrows, thalweg), and in the upper forest areas. [Mjagkov and Kanaev 1992; Kolotukha 2008].

Within the area of the ridge, systematic stationary and semi-stationary studies of avalanche activity have been carried out, using the snow avalanche station (SASt) Plai (Figure 1a). Stationary studies include the examination of meteorological conditions on the basis of data obtained on the meteorological site. For research of snow cover, four areas were identified on slopes with different exposures, where snow pits were established. Additionally, studies into increasing height of snow cover were implemented using 46 remote rails (Figure 1b). Semi-stationary studies involve the monitoring of avalanche activity on three routes: m. Temnatyk – m. Plai – m. Velykyy Verh; m. Ryapetska – m. Velykyy Verh – m. Hymba; m. Velykyy Verh – m. Stiy [Bilanyuk and Tyhanovych 2015, Zvity ... 2014].



Source: a) <http://emkoval.blogspot.com/2011/03/2011.html>; b) photo by L. Laykun

Fig. 1. a) meteorological snow avalanche station Plai; b) remote rails for snow measurement

The data resulting from several years' observations [Bilanyuk and Tykhanovych 2013, 2015, Zvity ... 2014] formed the basis for the establishment of avalanche path schemes (Figure 2a), and became a thematic supplement to the tourist maps in the scale of 1 : 50000 (Figure 2b). Schemes of avalanche paths do not have georeferencing, therefore they can only be used for the determination of visual schematic relative positions of dangerous areas without quantitative characteristics. On the tourist map, the location of avalanche paths can be shown, but it is not possible to determine the

boundaries of avalanche areas as the paths are designated in conventional symbols, in the form of arrows. Representation on the map of the boundaries of avalanche areas could greatly simplify the planning of safe tourist routes. Taking this into account, we conclude that the complete thematic mapping, with the ability to obtain and analyse quantitative and qualitative parameters of avalanche areas location, is important and necessary.



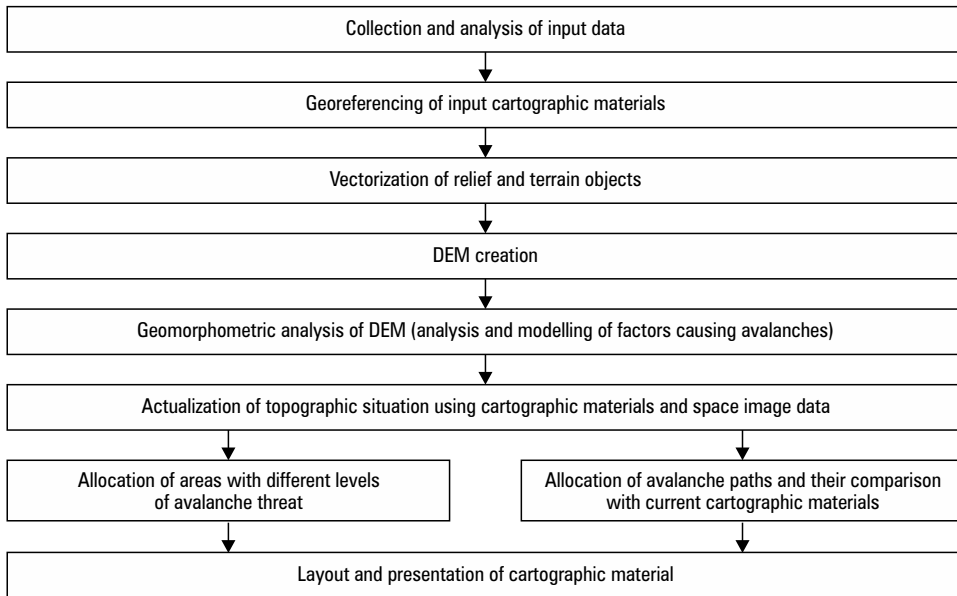
Source: authors' study

Fig. 2. Fragments of thematic materials: a) scheme of avalanches paths; b) tourist map

The method used for the creation of a physical map was an automated creation of DEM on the basis of relief components represented in vector form, using interpolation tools. For the creation of thematic maps of avalanche threat, geomorphometric analysis of DEM was applied. Modelling and analyses of morphometric parameters of the ridge surface were implemented. Studies were carried out according to the technological workflow shown in Figure 3.

The following input materials were used in the studies:

1. Topographic map of Svaliava district in the scale of 1 : 50000 with contour interval of 20 meters, published by SSPE "Kartographia" in 2010. The map was used as a base for the creation of vector layers.
2. Statistic meteorological observations of prevailing wind directions in the Carpathians. [Lavnyy 2009]. The data were used for the reclassification of the hill exposure raster according to the prevailing wind directions, and for the allocation of snow motion and accumulation areas [Hrytskiv et al. 2016].
3. Plan of avalanche paths and reports about snow avalanches in the Trans Carpathian region provided by Trans Carpathian Regional Center for Hydrometeorology. This plan and another amended plan [Bilanyuk and Tyhanovych 2015] were used to compare the detected avalanche paths with created and existing maps.
4. Tourist map of Plonyna Borzhava ridge in the scale of 1 : 50000 (2014), and WorldView-1 satellite images (2015) were used for updating topographic situation, and comparing avalanche paths location with the data from SAST and from the modelling.



Source: author's study

Fig. 3. General workflow of study

All subsequent phases of work were done using the ArcGIS for Desktop software. This fully functional Geographic Information System is a software product for geodata analysis, enabling to solve applied problems, including thematic mapping.

Referencing the input topographic map of Svaliava district in the scale of 1 : 50 000 was done using the Georeferencing tool. The coordinate system WGS_1984_UTM_Zone_34N was assigned to the map.

The geodatabase was created for data storage. For vectorization of relief and terrain objects, the features shape files were created in the geodatabase. They were used for the creation of DEM, and for the layout of thematic cartographic material during vectorization:

- marks of altitude above sea level – point features for drawing points with known absolute heights (mountain peaks);
- contour lines – line features for drawing contours that are the basis of DEM;
- ledges, cliffs – line features for drawing ledges, cliffs, steeps, tracts, large excavation edges and steep river valleys that are shown on input maps;
- rivers, streams – line features for drawing hydrographic network, which clearly reflects the dissection of the studied area;
- marks of the water line – point objects that give additional information about relief;
- line of forest upper boundary – polygonal object reflecting avalanche lower edge;

- weather Station “Plai” – a point object, showing the location of the primary source of weather information collected on the ridge;
- forest and field roads – line features that reflect the road network;
- footpaths – line features that reflect the network of footpaths and dirt roads;
- forest – polygonal object for drawing forest areas below its upper boundary;
- glade – polygonal object for visual display of cleared forest space;
- avalanche paths - polygonal objects reflecting avalanche paths which were detected in the process of modelling and using data of weather centre.

Geomorphometric analysis of DEM was implemented using set of tools for the analysis of the surface (Spatial Analyst Tools). Detailed description of this technology is presented in [Hrytskiv et al. 2016].

With a purpose of updating and refining the thematic objects’ locations on the map, the raster tourist map of Polonyna Borzhava ridge in the scale of 1 : 50 000 (Figure 2b), issued in 2014 was added to the project development, along with space image data. Using the new cartographic materials, the road network was updated. Additionally, the upper boundaries of the forest were shown in a more updated and clearer version. This map contains the designation of avalanche paths that match the avalanche paths determined on SAsT “Plai” and shown on the corresponding scheme (Figure 2). Satellite images of the territory of the studied area were obtained using the SASPlanet resource. The images were produced in 2015, using the WorldView-1 equipment for remote satellite sensing. Image analysis showed that the line of the upper boundary of the forests on satellite images coincides with the corresponding line on the map of 2014.

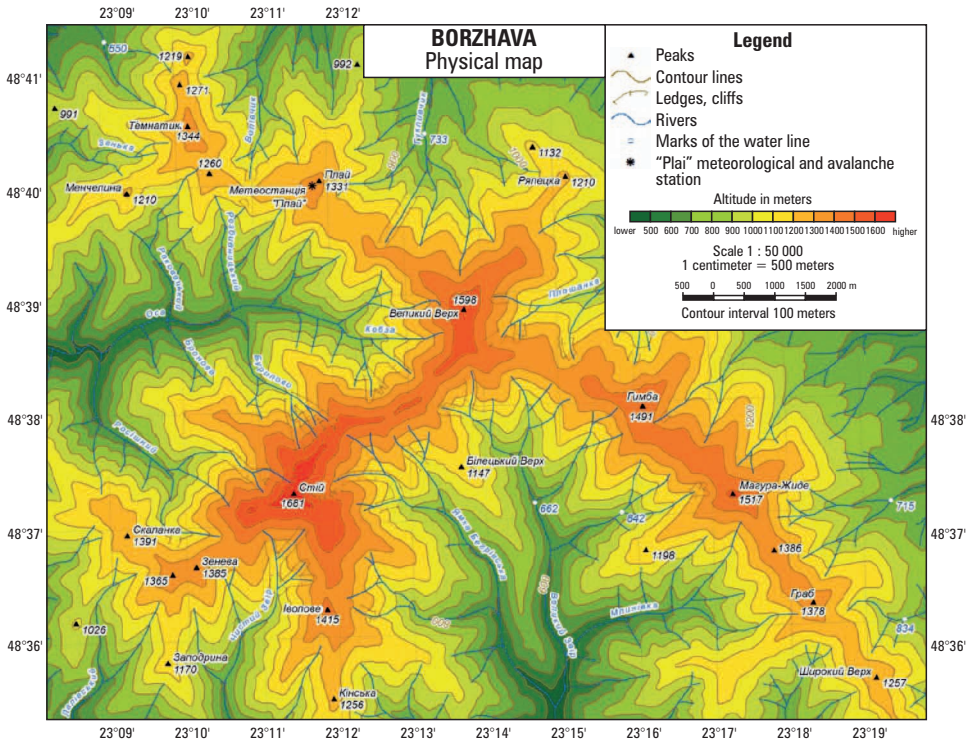
Based on the created DEM, one of the thematic maps was designed. It is a physical map of the Polonyna Borzhava ridge in the scale of 1 : 50000 (Figure 4).

On the basis of the reclassified raster maps of surface morphometric parameters, zones of relative avalanche threat in the Polonyna Borzhava ridge were allocated using expressions of map algebra. For the creation of the resulting raster map, we have used the Raster Calculator tool. As a result of summing the hill slopes’ raster, hills’ curvature raster and hill exposure raster, followed by the generalization of number of received classes, we allocated four classes of areas depending on the combination of the values of slope and exposure:

- high degree of avalanche threat is assigned to the hills with the most active and the largest snow accumulation as well as the largest slope;
- average degree of avalanche threat is assigned to hills with intermediate exposures in relation to the prevailing wind direction as well as the average slope value;
- low degree of avalanche threat corresponds to the hills, on which there is the most active snow movement, and the hills with little slopes value;
- zero degree corresponds to areas that are not prone to avalanches.

The resulting raster was cut along the upper boundary of the forest, which is considered the lower boundary of avalanche phenomena. At the created thematic maps of

relative avalanche threat (Figure 5), areas with the highest potential level of avalanche threat are shown in red; areas with medium potential level of avalanche threat are shown in yellow; areas with low level of avalanche threat are green; while areas with no avalanche threat are represented in light green.



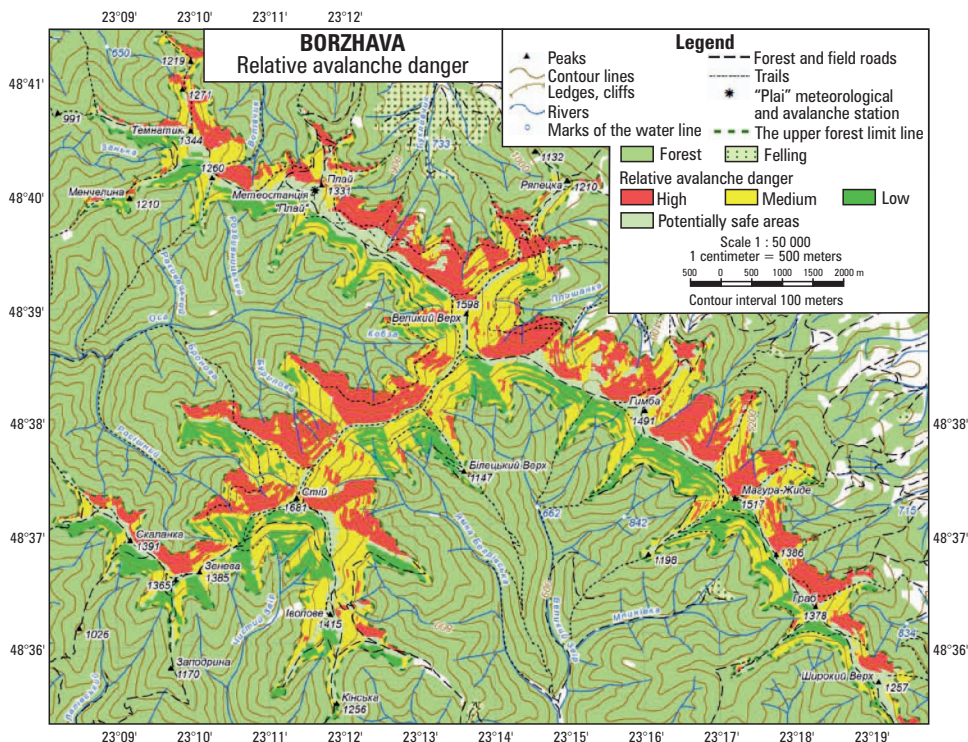
Source: authors' study

Fig. 4. Physical map of the Polonyna Borzhava ridge

So created digital thematic maps allow performing quantitative analysis of the distribution of areas under threat (i.e. dangerous territory). Thus the total land area of the spine territory above the upper boundary of the forest is 39.4 km². Area of areas with threat of avalanche is 33.4 km² (84.8%). This includes, according to the implemented classification: 10.6 km² (31.7%) of areas with high avalanche threat; 15.6 km² (46.7%) of areas with a medium level avalanche threat; and 7.2 km² (21.6%) of areas with low avalanche threat. The area of potentially safe territories is 6.0 km², representing 15.2% of the total area of the ridge above the upper boundary of the forest.

As a next step in the research, 38 avalanche paths on the Polonyna Borzhava ridge were allocated according to the preliminary stationary and semi-stationary observations of avalanche activity, which had been conducted on the SAsT "Plai", and shown

schematically. After modelling, using the raster maps of hills slope and surface curvature, the thematic map of avalanche paths of the ridge in the scale of 1 : 50000 (Fig. 6) was created.

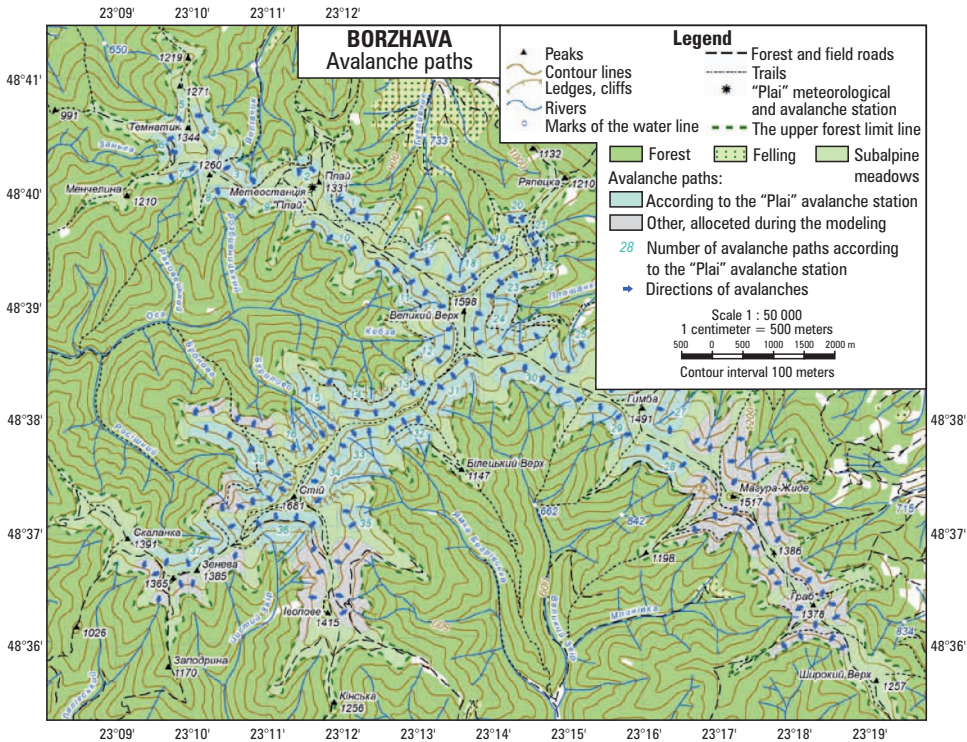


Source: authors' study

Fig. 5. Map of relative avalanche danger of Polonyna Borzhava ridge

We show on the map the numbered avalanche paths determined by observations on SAST "Plai" (in blue) and the areas, which – according to parameters of relief – are favourable for avalanches and can be allocated as avalanche paths. Avalanche paths on the Polonyna Borzhava ridge are usually located on the concave slopes and river valleys, which are their continuation. After modelling the avalanche paths for whole ridge area, it can be observed that the avalanche paths specified on the scheme of SAST "Plai" correspond to avalanche paths shown on the tourist map of 2014. Location of avalanche slopes' map does not match with the modelled plan only in two instances: the areas of paths No 2 and No 4 (Figure 7). The comparison shows that only those avalanche slopes are drawn on the tourist map of 2014 that correspond to avalanche paths determined by SAST "Plai". The territories of the ridge, which are outside the area of observations as implemented by SAST "Plai", are not classified according to avalanche

activity. Therefore, on our map we have drawn 19 avalanche paths determined after the modelling process, but not specified on the SAST “Plai” plan. They are located in parts of the ridge that are remote from the station: near the mountains of Stiy, Magura-Zhyde and Hrab, and are shown in light purple.



Source: authors' study

Fig. 6. Map of avalanche paths of Polonyna Borzhava ridge

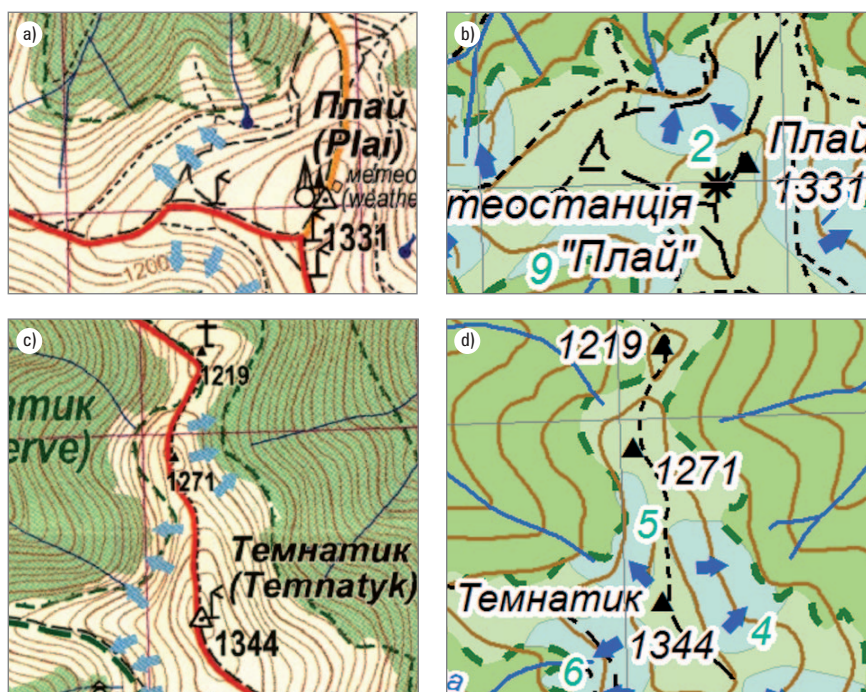
All three thematic maps are created in the scale of 1 : 50000. They contain the grid and the corresponding explications (legends) of conventional symbols.

3. Results and discussion

A set of thematic maps of Polonyna Borzhava ridge was created, including a physical map, a map of relative avalanche danger, and a map of avalanche paths.

The areas with consistent snow avalanche phenomena on Polonyna Borzhava ridge were allocated – by the integration of cartographic material, remote sensing data, statistical meteorological data and some geomorphometric data about the surface – in a unified geographic information system. The mapping of snow

avalanche phenomena on Polonyna Borzhava ridge was implemented, in the scale of 1 : 50 000. Thus created thematic maps have overviewing and informative nature about such natural hazards as avalanches. As the network of field roads and trails on the Polonyna Borzhava ridge is very developed, many rounds and traverses of mountain peaks pass through avalanche paths. The developed maps can be used for the planning of winter tourist routes, but they are not interactive. Instead, they represent the overall avalanche situation, without considering the variables of meteorological factors used for short-term forecasting.



Source: authors' study

Fig. 7. Discrepancy of avalanche paths on the tourist map 2014 (a, c) with corresponding areas on the modeled thematic map (b, d)

4. Conclusions

1. The main factors that cause avalanches or affect them; and therefore can be used for mapping are: orographic (absolute altitude of terrain), geomorphometric (slope, exposure and surface curvature), and weather-related (rain, wind, solar radiation). Additionally, the presence of woody vegetation on the slopes should be considered as a factor.

2. The area of avalanche threat within in Polonyna Borzhava ridge covers 84.8% of the total area of grassland, which confirms the high level of avalanche threat on the ridge.
3. According to the implemented modelling method, the total number of the determined avalanche paths on the ridge was higher than the number recorded at the SAsT “Plai”. This can be the basis for expanding the network of semi observations of avalanche activity from m. Hymba to m. Hrab.
4. Further studies into the regularity of snow avalanche distribution and their mapping are possible, provided that statistical materials can be accumulated in the form of reports about snow avalanches that are annually produced by Trans Carpathian Regional Center for Hydrometeorology, based on the cases of avalanche appearance recorded on SAsT “Plai”. Detailed statistics about the cases of avalanches over a long period of time (several decades) will enable to follow the regularity of avalanche activity in a particular area, and to create more detailed maps.

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