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Mapping and geoinformation analysis of snow avalanche processes in geocomplexes of the subalpine and alpine highlands of the Chornohora (Ukrainian Carpathians)

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SUMMARY

The principles of using GIS for the study and mapping of avalanche geocomplexes, as well as the geospatial analysis of the distribution of centers of process development are described. The factors and features of the development of snow avalanche processes, the nature of their distribution in the geocomplexes of the highlands of Chornohora, etc. are characterized. On the example of the key area of the headwaters of the Mreye Stream basin, the peculiarities of the placement of avalanche geocomplexes in the highland of massif are presented, which affect the dynamics and are an important element of the morphological structure of large glacial-exaration landscape complexes – corries, cirques, glacial troughs.

Keywords: snow avalanches, avalanche period, avalanche geocomplex, geoinformation technologies, highlands, Chornohora Landscape

Introduction

One of the most dangerous modern physical and geographical processes in the Ukrainian Carpathians is snow avalanches, which belong to the group of hydro-meteorological processes and are an integral property of geocomplexes of the mountain system. Their formation is influenced by the hypsometric position of the territory and the morphometry of the relief, the amount of precipitation and air temperature fluctuations in the winter period, the thickness and density of the snow cover, the exposure of the slopes and the circulation of surface air flows, the general climatic features of the territory and changes in weather conditions, the nature and structure of the vegetation cover and a number of other factors (Tretyak, 1980; Tikhanovich, 2016; Tikhanovich & Bilanyuk, 2017; Karabiniuk, 2020). Therefore, snow avalanche processes have clear landscape determinism and are confined to the highlands landscapes of the Ukrainian Carpathians. Their most intensive development is observed in the subalpine and alpine highlands, i.e., high-mountain landscape tier of Chornohora. It is located at altitudes above 1450–1600 m above sea level and formed by a set of denudations, ancient -glacial-exaration and nival-erosion highlands geocomplexes (Melnyk & Karabiniuk, 2018; Karabiniuk, 2020).

In the geocomplexes of the sub-alpine and alpine highlands of Chornohora, avalanches are one of the most dynamic and large-scale modern physical-geographical processes that can change the morphology of the territory relief, destroy the soil and vegetation on the way to their ascent, etc. (Karabiniuk, 2020). Today, there are more than 500 active avalanche centers in the Ukrainian Carpathians, a significant part of which are concentrated in the high-mountain landscape tier of Chornohora (Tikhanovich, 2016; Karabiniuk, 2019, 2020). Therefore, a full-fledged study of snow avalanche processes and features of their development with the aim of establishing landscape differentiation and mapping of centers with increased snow avalanche activity is possible only with the help of modern GIS technologies in combination with field methods of territory survey.

Theory and Method

The activation of avalanche processes occurs under the influence of various factors, and therefore there are several types of avalanches. Excessive growth of snow cover is the main prerequisite for the formation of *syngenetic avalanches*. It can occur as a result of intense snowfall (*freshly fallen snow avalanches*) or blizzards (*blizzard avalanches*), as well as due to the sudden melting of the upper layers of snow (*epigenetic avalanches*), which are caused by the general warming of weather conditions (*advective avalanches*) or intense solar radiation (*insolation avalanches*). The last two subtypes of avalanches are combined into one type – *snowmelt avalanches* (Dzyuba & Laptev, 1984; Tykhanovych, 2016; Tykhanovych & Bilanyuk, 2017). Despite the long history of geographic study of Chornohora and the subalpine and alpine highlands in particular, the peculiarities of the development of snow avalanche processes remain insufficiently studied. Significant progress in the identification and study of the functional and dynamic features of a number of avalanches centers in the landscape has taken place since the beginning of the 80s of the 20th century (Tretyak, 1980; Tretyak & Bazilekich, 1980) and is actively continuing now (Tikhanovich, 2016; Tikhanovich & Bilanyuk, 2016, 2017; Karabiniuk, 2019, 2020; etc.).

Considering the significant diversity and high intensity of snow avalanche processes in the geocomplexes of the subalpine and alpine highlands of Chornohora, theoretical foundations and methods of study are of great importance for the study of avalanches and centers of their development. They determine the parameters of avalanche mapping of active areas and the criteria for identifying avalanche cells by means of GIS. In our study, it is necessary to distinguish between two key concepts: "*avalanche geocomplex*" and "*avalanche center*". Avalanche geocomplex is a collection of several landscape facies of the same or different genesis, which are morphodynamically united by processes of systematic avalanche descent, zone of origin and form a general avalanche collection (Tikhanovich, 2016; Karabiniuk, 2019, 2020). Instead, the term avalanche center has a much broader meaning both conceptually and territorially. Under this term, in our opinion, this term means a set of territorially close avalanche geocomplexes or their parts, which are located within one landscape subtract or a simple tract and are characterized by a similar mode of accumulation of snow cover and avalanche activity, which

is due to the peculiarity of the relief morphology, exposure and surface slope, insolation features of the territory, etc. Therefore, the study of the location and functioning of avalanche centers in the subalpine and alpine highlands of Chornohora is directly related to the study of the morphological structure of the territory and the properties of landscape complexes.

Mapping and geoinformation analysis of the spread of snow avalanche processes in the high mountain geocomplexes of Chornohora is based on a detailed comprehensive study of the territory natural conditions the determination of real areas of avalanche development using methods of modelling, decoding and field survey of the territory. In the process of our research, geoinformation data processing was carried out in the ArcGIS software environment. The morphological and morphometric features of the relief are of particular importance for the development of avalanches (Fig. 1). The digital topographic model of the Chornohora highlands was developed on the basis of a digital topographic base with a cross section of 5 m (Karabiniuk et al., 2020). On its basis, a detailed morphometric analysis of the surface was carried out and the exposure structure and steepness of the slopes were determined, which significantly affect the activation and spread of avalanches in the high-mountain landscape tier of the massif. Deciphering satellite images and aerial photography tablets, identification of avalanche geocomplex and nival niches by analyzing the dissection of the relief and the vegetation cover structure using GIS methods, as well as conducting our own field research during 2015–2022, etc. allowed us to record and map 288 centers of avalanche development in the highlands of Chornohora. The monitoring data of the snow avalanche station "Pozhezhevska", which is located in the upper reaches of the Prut River basin within the leeward sector of the north-eastern macroslope of Chornohora, is also important for studying the dynamics and spatial distribution of avalanches in the highlands of the massif (Technical reports..., 2022). Statistical processing of the data of these hydro-meteorological observations on the power of the snow cover and conditions of avalanches makes it possible to predict the avalanche danger in the highlands of Chornohora under different weather conditions.

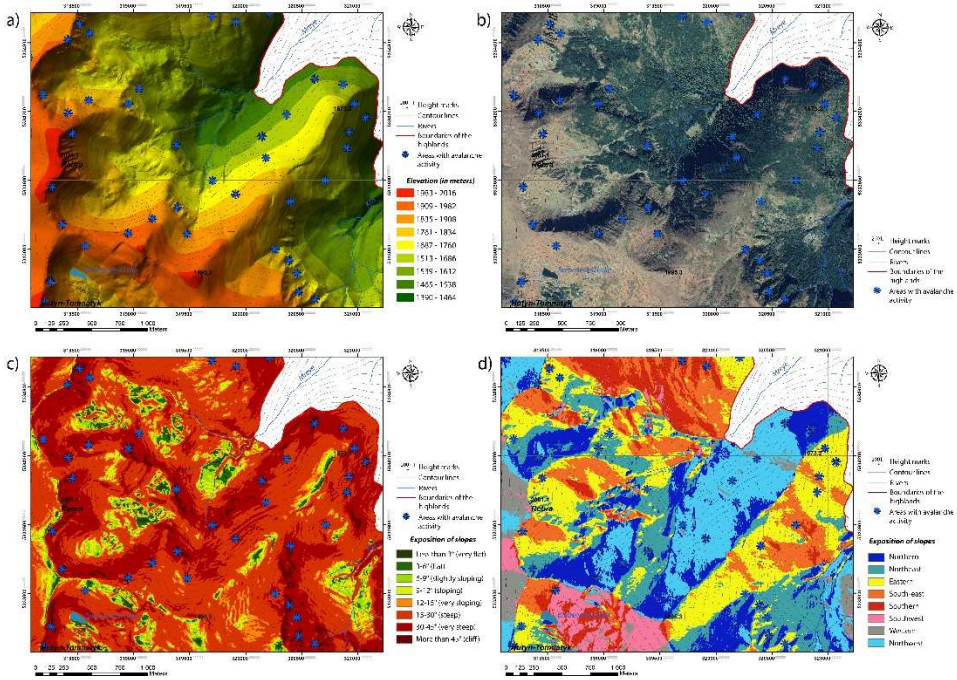

Figure 1 *Analysis of the natural conditions for the development of avalanche in the geocomplexes in the highlands of Chornohora (the upper basin of the Mreye Stream): a – TIN-model of the relief; b – estimation of satellite imagery; c – map of steepness of slopes; d - map of the exposure of slopes.*

Examples

The study of the features of the distribution of avalanche centers in the highlands of Chornohora indicates a significant development of these processes in the north-eastern macroslope of the main ridge, which is characterized by the dominance of leeward slopes with a steepness of more than 30–45° and

significant dismemberment of the surface. This is the result of the placement here of peculiar geocomplexes of glacial-exaration origin (corries, cirques, glacial troughs, etc.) and massive spurs of ridges with steep slopes of northern and north-eastern exposures (Miller, 1963; Karabiniuk, 2020). They are characterized by the most favourable conditions for the development of avalanches. The intensive processes of snow transfer from the crested surface of the main ridge of the massif and the windswept slopes of the opposite southwestern sector of the landscape also play an important role in avalanche activity in the high-mountainous part of the north-eastern sector of Chornohora (Melnyk et al., 2019). Thus, according to the stationary research data of the snow avalanche station "Pozhezhevska" during ten winter periods (2011–2021), 90 avalanches were recorded at the monitoring avalanche centers in the upper reaches of the Prut River basin, the volume of 4 of which exceeded 10 000 m^3. The largest avalanche in the upper basin of the Prut River in the last decade occurred in March 2017 in the weakly incised lower corries east of the town of Breskul with a total volume of 61 500 m^3 (Technical reports..., 2022).

The use of GIS to study avalanche processes and identify centers of their development made it possible to determine the features and relationships of avalanche geocomplexes in the general landscape structure of the highlands of the massif. The geospatial analysis of avalanche centers based on geoinformation data and field research shows that most avalanches in the corries tracts and slopes of the highlands of Chornohora are trough-like in the nature of snow movement (Fig. 2). They have limited snow collection (zone of origin), and therefore the volume of avalanches mainly depends on the depth of cut and the accumulative capacity of the geocomplex. In the highlands of Chornohora, their volumes range mainly from 200–700 m^3, but can exceed 2–3 thousand m^3 or more. The mapping of the avalanche geocomplexes of the headwaters of the Mreye Stream basin also confirms their attachment to the glacial-exaration landforms and their special elevation position. In particular, more than 70 % of avalanche geocomplexes are located in the height range of 1500–1700 m above sea level. Therefore, the most intense snow avalanche processes are observed here. The largest avalanche geocomplexes with a length of more than 400–500 m are confined to the steep walls of corries and reach their moraine-talus bottoms. Avalanches here are accompanied by the destruction of thickets of *Pinus mugo* (Turra), etc.

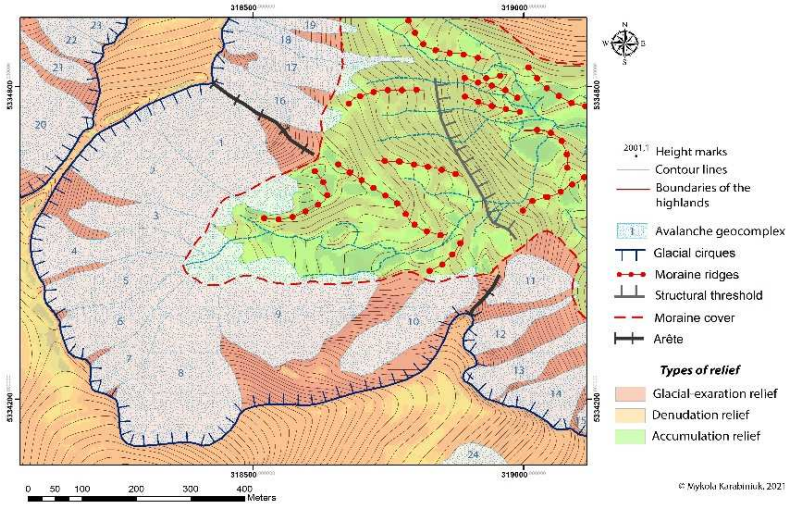

Figure 2 *Avalanche geocomplexes on the walls of glacial cirques in the upper basin of the Mreye Stream (leeward north-eastern sector of Chornohora Landscape)*

Conclusions

Mapping and geo-informational analysis of avalanche processes in the highlands of Chornohora shows the significant intensity of their development, the study of the factors and peculiarities of their formation is possible only with the help of a combination of expeditionary, monitoring (stationary) and modern geo-informational methods. The subalpine and alpine highlands of Chornohora are characterized by intensive development of avalanches in winter, about 50% of which belong to the insolation type. The use of GIS technologies to study avalanche processes makes it possible to conduct geospatial analysis

and determine the landscape differentiation of avalanche centers in the highlands of the massif. As a result of the study, it was established that 185 centers (64,7 %) of avalanche development are confined to geocomplexes of glacial-exaration genesis.

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