Introduction

The natural territorial complexes (NTC) of the subalpine and alpine highlands in the Ukrainian Carpathians occupy the highest hypsometric level at altitudes above 1 450–1 600 m a.s.l. They form a high-altitude landscape layer, which is represented by three genetic types of high altitude terrain – denudational alpine and subalpine high-mountain, ancient-glacial-exarational subalpine high-mountain and nival-erosion subalpine high-mountain (Melnyk & Karabiniuk, 2018b). In the Ukrainian Carpathians, the high-altitude landscape layer is best expressed in the highest mountain landscape of Chornohora, which is represented here by two plots with a total area of 80,5 km^2 (Melnyk & Karabiniuk, 2018a).

The high-mountain NTCs of Chornohora are in a very close functional and dynamic relationship. Their functioning, dynamics and development are related to the transfer of energy, matter and information, mainly from geocomplexes of higher hypsometric levels to lower ones. Of particular note are the negative and deleterious physical and geographical processes that cause destabilization of the NTC structure and have a negative impact on human life. Among these processes a special place is occupied by geological and geomorphological processes, which are most common in the high-mountain landscape tier of Chornohora and require detailed mapping and study using a methodical combination of classical methods of field survey and modern methods of GIS-analysis and modeling.

Method

The study of modern geological and geomorphological processes in the natural territorial complexes of the subalpine and alpine highlands of Chornohora was conducted in three stages, which methodologically differed significantly:

- Analysis of literary and cartographic sources of information, modeling of the research area and identification of potential sites for the development of processes based on GIS-analysis.
- Field expedition research and mapping of process development centers.
- Geoinformation analysis of features of distribution and landscape differentiation of geological and geomorphological processes, calculation of intensity of their manifestation in landscape complexes of different hierarchical level.

Information about the distribution and development of geological and geomorphological processes in the highlands of Chornohora are partially presented in the works of B. Swiderski (1937), J. Kravchuk (2008), G. Miller (1963), V. Shushnyak (2007) and others. Important information was obtained as a result of processing the funds materials of DP NAK “Zakhidukrgeologiya” (Vashchenko et al., 1985) and reports of the geomorphological party of the research sector of the University of Lviv (Kravchuk et al., 1966; Boljuh & Kravchuk, 1967).

In the process of studying modern geological and geomorphological processes, modern GIS-technologies play an important role, which are used to identify and map the centers of their development, as well as monitoring. To study these processes in the highlands of Chornohora, a comprehensive geoinformation analysis of the territory was conducted and a database on the properties of natural components and the landscape structure of the highlands was formed. In particular, with the help of ArcGIS software the morphometric analysis of the territory on the basis of digital topographic basis of SOE “Zakarpatgeodeskcenter” of scale 1: 25 000 with cross section of 5 m was carried out, which allowed to build high quality DEM and TIN-relief model *(Fig. 1)*. For their development, other elements of the topographic basis were also vectorized, namely: vertex points and their altitudes, water edge points and their altitudes, thalweg lines of streams etc. Since the development of negative geological and geomorphological processes is closely related to the slope of the surface, we have compiled a map of the steepness of the slopes. Based on it, potential places of manifestation of these processes were determined. A map of slope exposure was also developed, which allowed to analyze the exposition timing of the centers of development of modern geological

and geomorphological processes and to determine potential places of their development with similar morphometric parameters. To build these maps, the functions of the Spatial Analyst module of the ArcTolbox toolbar were used, namely: steepness of slopes – "Slope"; exposure of slopes – "Aspect". After that, in order to identify the centers of development of negative geological and geomorphological processes, space images and aerial photographs of high resolution 0,4 x 0,4 were analyzed and deciphered in detail (Planshety…, 2017). The Pulkovo 1942 (GK Zone 5N) projection coordinate system was used to process the geoinformation data. Thus, with the help of modern methods of GIS-analysis of the territory, numerous screes and rockfalls, as well as landslides.

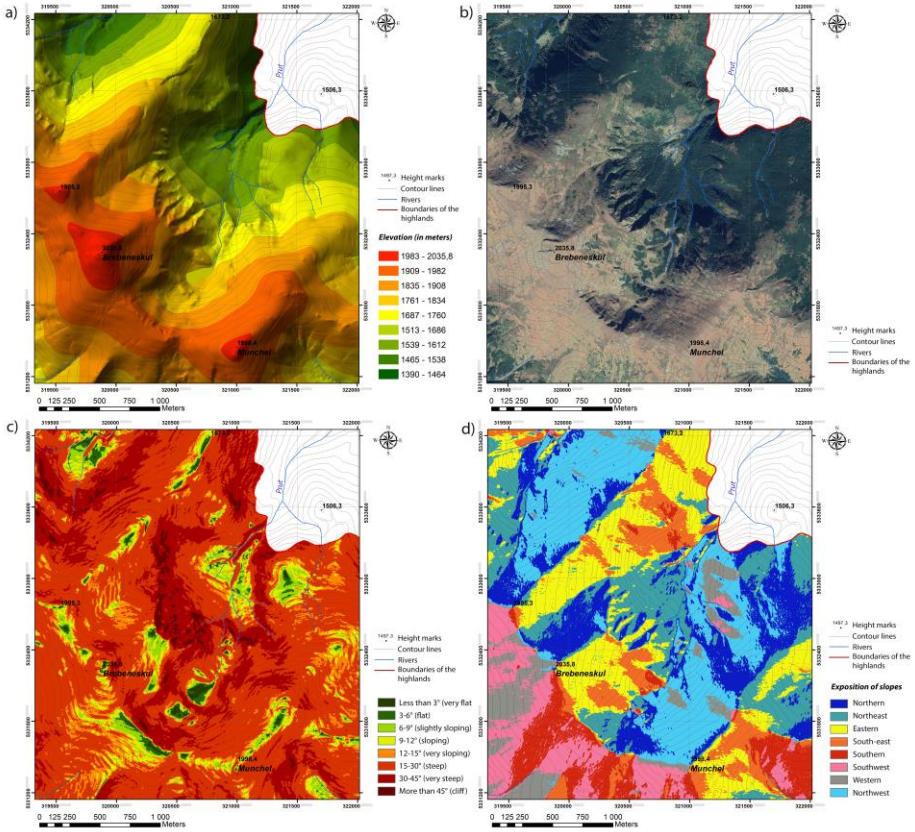

Figure 1 *An analysis of natural features and changes in the development of geological and geomorphological processes in the highlands of Chornohora (upper Kizi Stream): a – TIN-model of the relief; b – estimation of cosmological space; c – map of steepness of slopes; d - map of the exposure of slopes.*

The next stage in the study of modern geological and geomorphological processes in the high-mountain landscape complexes of Chornohora was field research in expeditionary form. As a result, 1 258 centers of development of negative physical and geographical processes were recorded within the high-mountain landscape tier, including 789 centers of geological and geomorphological processes, in particular: 190 – rockfalls, 338 – screes, 24 – landslides, 237 – linear erosion. During the field survey of the territory, direct mapping of the centers of development of processes and their boundaries was carried out, their main parameters were recorded, etc. Garmin eTrex10 GPS receivers were used in our study.

Examples

The main result of the study is the developed high-quality map of the distribution of modern geological and geomorphological processes in the highlands of Chornohora *(Fig. 2)*. Based on the quantitative ratio of recorded centers of geological and geomorphological processes in the highlands of the landscape, at the final stage of our study, calculated the percentage distribution of each species of these processes in high altitude terrains and landscape striyas, which expresses the dependence of

their manifestation on the landscape structure. Due to the ratio of the total number of centers of geological and geomorphological processes to the area of NTC, within which they occur, the intensity (centers/km^2) of the manifestation of negative processes was calculated. The analysis of landscape differentiation and intensity of manifestation of geological and geomorphological processes in high-mountain NTCs of Chornohora was integrally carried out on the basis of GIS-analysis methods.

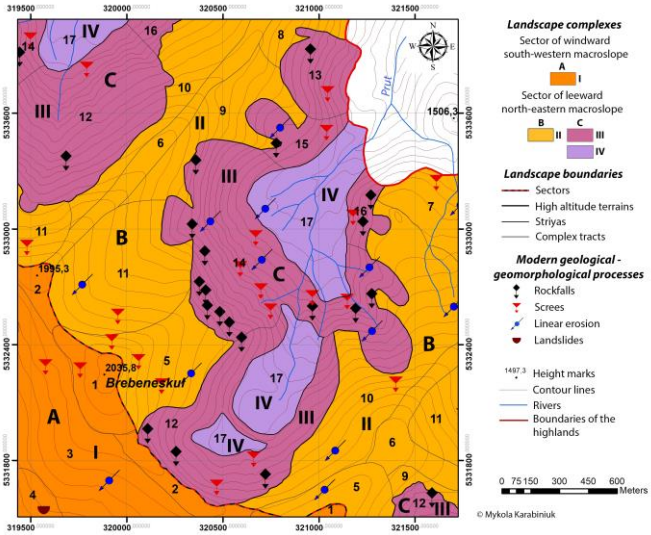

Figure 2 *Modern negative geological-geomorphological processes in the landscape complexes of the highlands of the Chornohora (upper Kizi Stream).*

In addition to the centers of development of modern geological and geomorphological processes, *Figure 2* simulates the landscape structure of the upper reaches of the Kizi Stream basin, which is formed by a number of landscape complexes, in particular: SECTOR of the south-western windward highly humidified macro-slope drained by a parallel system of rivers with dominance of beech and spruce-fir-beech forests. High altitude terrain A – Slightly convex denudated surfaces of supalpine-alpnie high-mountain meadows formed mainly in the conditions of consistent occurrence of rock stratum of very cold and wet climate (average temperature of the coldest month -12 °C; and of the warmest months + 9 °C; annual precipitation up to 2 000 mm) on mountainous brown meadow soils. Striya I – steeply convex domed tops, wavy surfaces of the ridge and steep ridge slopes are consistent with the direction of the fall of stratum of non-calcareous mica coarse-layered and massive multi-grained gray sandstones, conglomerates and gravelites with *Nardus stricta*, *Juniperus sibirica* and *Vaccinium myrtillus* on mountainous brown meadow soils and mountainous brown peat bog soils. SECTOR of the north-eastern leeward macroslope with a colder (approximately 2 °C) than in the south-western sector, vegetation period, lower (200–300 mm) annual precipitation with spruce and beech-fir-spruce forests. High altitude terrain B – Slightly convex denudated surfaces of supalpine-alpnie high-mountain meadows of very cold and wet climate (average temperature of the coldest month -12 °C; and of the warmest months +7 °C; annual precipitation up to 2 000 mm) on mountainous brown meadow soils and mountainous brown peat bog soils. Striya II – Convex domed tops and steep ridge slopes are formed in the heads of stratum of non-calcareous mica coarse-layered and massive multi-grained sandstones, conglomerates and gravelites with *Vaccinium myrtillus*, *Nardus stricta* and *Deschampsia caespitosa* meadows on mountainous brown meadow soils and mountainous brown peat bog soils. High altitude terrain C – Concave old-glacial subalpine high-mountain surfaces of very cold and wet climate (January – 12 °C; July +8 °C, precipitation over 1500 mm) with deciduous and coniferous shrubs on mountainous brown peat bog soils and stony talus. Striya III – Territorially separated system of corries with very steep and steep slopes, laid in the heads of stratum of non-calcareous mica coarse-grained and massive sandstones, conglomerates and gravelites with a predominance of *Juniperus sibirica*, *Alnus viridis* and *Pinus mugo* on mountainous brown meadow soils and mountainous brown peat bog soils. Striya IV – Very sloping wavy surfaces of loamy-boulder moraine-talus bottoms of corries with *Alnus viridis* and *Pinus mugo* on mountainous brown peat bog soils.

Conclusions

As a result of the research, it was found that in the subalpine in the alpine highlands of Chornohora geological and geomorphological processes are the most common and account for about 63 % of the number of centers of process development. The highest intensity of manifestation in the high-mountain landscape tier of Chornohora is characteristic of screes (4,2 centers/km^2), linear erosion (2,9 centers/km^2) and rockfalls (2,4 centers/km^2). Landslides have the lowest intensity (0,3 centers/km^2). The greatest intensity of geological and geomorphological processes is observed in the north-eastern sector of Chornohora, which is due to the peculiarities of the lithogenic base, in particular – monoclinic occurrence of bedrock stratum and the dominance of slopes steeper than 15–30°. Rockfalls and screes are most characteristic of complex tracts of corrie and slopes of glacial troughs, amphitheaters of ancient firn fields, as well as the ridge slopes of the north-eastern exposition. Landslides are confined to mainly complex tracts of landslide slopes and the upper parts of the amphitheaters of firn fields of the south-western macroslope of Chornohora.

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