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Influence of natural hazards on the infrastructure facilities of Pokut Carpathians

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SUMMARY

This article presents the results of own field research, which determined the impact of natural hazards on the infrastructure facilities of Pokut Carpathians. Based on the decoding of space images, three types of land were determined: forests, meadows and built-up areas, which occupy about a fifth of 19.3%. A more detailed deciphering of the territory was carried out in the key part of Bukovets-Ritskyi landscape, where a few more types of land were distinguished: forests, meadows, cuttings, plough lands, buildings, dirt roads and asphalt roads. The studied landscape is representative for Pokut Carpathians, buildings are placed evenly throughout the territory, and not concentrated in river valleys, as in other regions of the Ukrainian Carpathians. In addition to a peculiar settlement in this landscape, frequent dangerous physical and geographical processes of a geological and hydrological nature, which are characteristic of Pokut Carpathians, are recorded in this landscape – these are landslides, mudslides, erosion and floods. Eight landslides were recorded on the Bukovets-Ritsky ridge and two on the slopes of Ternoshora Mount. Lateral and bottom erosion and floods develop intensively in the bottoms of rivers, which provoke the occurrence of erosion, and linear erosion is often manifested in steep banks. All these processes, taking into account the settlement of the territory, lead to the destruction and neutralization of infrastructure facilities. Commercial buildings, roads, bridges, power lines and agricultural lands are most often destroyed. Analyzing the influence of natural hazards on the infrastructure facilities of Pokut Carpathians, it was found that the studied territory is characterized by a moderate category of influence of dangerous physical and geographical processes on the infrastructure of the region. The key area has been assigned a strong category of damage from the effects of natural hazards.

Introduction. The territory of Pokut Carpathians is located in the southwest of the Outer Zone of Ukrainian Carpathians. The region is represented by a system of parallel ridges that stretch from the northwest to the southeast from River Volovyi in the middle highlands and Lyuchka River in the lowlands to Cheremosh River. Pokut Carpathians are a combination of low and medium mountains. The lowlands are represented by symmetrical ridges with wide ridges, steep and gentle slopes, which stretch from the northwest to the southeast and are dissected by relatively wide river valleys. Middle Highlands are characterized by the asymmetry of mountain ranges (steep north-eastern and steeper south-western slopes), a significant vertical and horizontal dissection of the relief, the predominance of narrow and deep river valleys, and the presence of large-sized drainage basins in the headwaters of rivers. The combination of certain geological, geomorphological and hydro-climatic features in the studied territory contribute to the formation and development of dangerous physical and geographical processes, which are also called natural hazards. The most common processes that form on the territory of Pokut Carpathians are landslides, mudslides, floods, and various types of erosion. The consequence of these processes is not only changes in landscape complexes, but also significant damage to infrastructure (destruction and damage to residential buildings, roads, bridges, coastal fortifications, power lines, tourist infrastructure), agriculture (destruction and damage to agricultural plantations, hayfields, perennial plantations, etc.). In addition to destruction and damage to infrastructure, they are dangerous for society as they threaten human life and health. Therefore, scientific research on the causes of natural hazards, their prediction, occurrence, minimization measures and assessment of their impact on infrastructure objects are becoming more and more relevant.

Theory and methods. Since ancient times, a man lived in harmony with nature and observed the phenomena and processes that occur around him. Even in century-old literature, one can come across descriptions of floods, landslides, or other dangerous processes that caused damage to the then infrastructure (Pelypeiko, 2004). More detailed studies of dangerous processes were conducted in the second half of the 20th century in the context of studies of the geological structure of the territory, surface waters, climate and forest cover (Herenchuk, 1968 1973; Main Department of Geodesy…, 1947-1960; Rudko et al., 2002; "Zakhidukrgeologiya"…, 1968-1985). The active period of scientific research of dangerous physical and geographical processes on the territory of Pokut Carpathians began after the creation of the National Nature Park "Hutsulshchyna" in 2002 (Prorochuk et al., 2013).

The first stage of our research was the collection of information about natural hazards. Cartographic materials, space photographs, published works, data from hydrostations and weather stations have been analyzed. With the help of geoinformation technologies, a digital database was created, which contains information about the geological structure, geomorphology of the territory, surface water, landscape structure, land structure. Decryption of space photographs with a resolution of 20x20 m using *SASPlanet*, *GoogleEarth*, cadastral maps of settlements and topographic maps (The main administration of the state geocadaster in Ivano-Frankivsk region…, 2006; Main Department of Geodesy…, 1947-1960; "Zakhidukrgeologiya"…, 1968-1985) was carried out, with the help of which the spatial distribution was established and the area of land plots was determined. Three types of land are distinguished: forests, meadows and buildings. Spatial placement of infrastructure facilities on the territory of Pokut Carpathians has been determined. Probable places of occurrence of natural hazards that may affect the infrastructure have been identified.

The next stage of the research was direct field experiments, during which landslides and mudslides were detected, floods were recorded, and damage caused to infrastructure facilities in the study area was analyzed. Cartographic materials were used during field research: 1) topographic maps on a scale of 1:50,000 and 1:25,000 (Main Department of Geodesy…, 1947-1960; "Zakhidukrgeologiya"…, 1968-1985); 2) geological maps of Pre-Quaternary and Quaternary deposits and a geomorphological map on a scale of 1:50,000 ("Zakhidukrgeologiya"…, 1968-1985); 3) SRTM Digital Terrain Model, 4) satellite images, 5) land map. During the fieldwork, the method of Miller H.P. (Miller, 1996) was used, which involves the study of external signs of the dynamics of natural territorial complexes. The new research method that we used is the application of SMART software during field and camera works.

At the final stage, all the information collected during the two previous stages of research has been systematized and analyzed. All field data received were processed in ArcGIS 10.0 and SMART

software. The digital database has been improved, based on reliable information obtained during own research. Locations of dangerous processes and their impact on infrastructure objects are determined. In addition, infrastructure objects that may be affected by dangerous natural processes in the future have been identified.

Results. After analyzing the natural features, the materials, as well as results collected during our own field research, it was found that landslides, mudslides and erosion are the most common dangerous processes in the territory of Pokut Carpathians. For the occurrence of these processes, in addition to the presence of certain geological and geomorphological features, torrential and prolonged rains, which are characteristic of the territory of Pokut Carpathians, are necessary. All these processes are extremely dangerous for the infrastructure of the region. Analyzing the spatial distribution of the structure of land plots, it was found that the studied territory is characterized by a dispersed type of development (Hostiuk, 2021), settlements are located not only in river valleys, as in most other mountain regions of Ukrainian Carpathians, but also on gentle and steep slopes, ridges that in turn, it creates a greater danger for infrastructural objects during the occurrence of physical and geographical processes. According to the results of the decoding of the satellite images, it was determined that buildings in Pokut Carpathians occupy 19.3%, almost a fifth of the territory, forests occupy more than half – 57.9%, meadows occupy almost a quarter of the territory, 22.7% (Fig. 1).

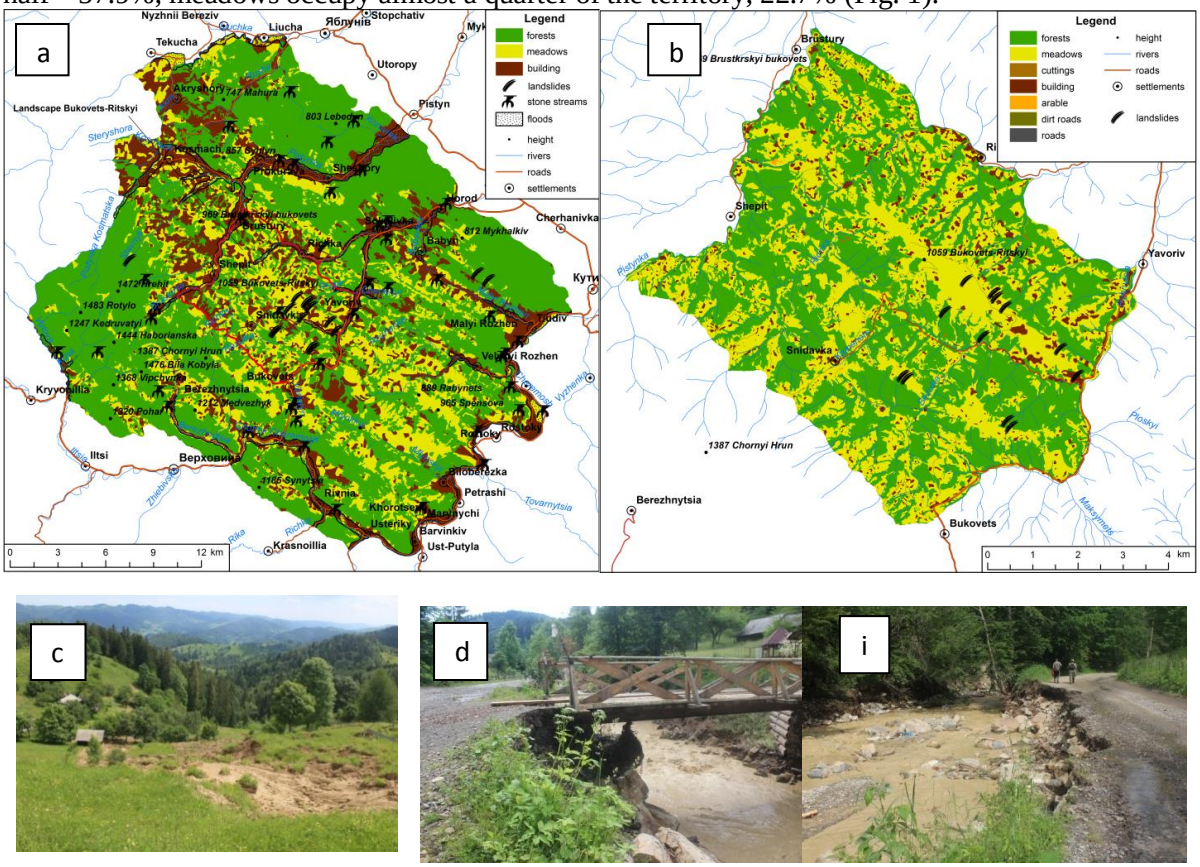

Figure 1 *a) distribution of land in Pokut Carpathians, b) distribution of land in the landscape of Bukovets-Rytskyi, as well as the spatial distribution of natural dangerous physical and geographical processes, c) a landslide on Bukovets-Ritskyi ridge, d) damage to the road as a result of lateral erosion, i) destruction of the bridge as a result of the flood in June 2020*

During 2020-2022, field expedition research was carried out within Pokut Carpathians and more than 15 landslides were recorded (see Fig. 1). Most of the landslides were recorded in the low-mountain part of Pokut Carpathians, somewhat less in the mid-mountain. During the research, it was found that landslides are widespread throughout the studied territory, often confined to contact structural-tectonic zones (Rudko et al., 2002; 2017), the border of Pokut Carpathians and Precarpathians, and the borders of natural territorial complexes of different taxonomic ranks (localities, strata, tracts). Landslide-hazardous areas are mostly steep areas with the distribution of clayey deposits of Carpathian flysch,

mainly steep and very steep ridge slopes, steep river valley slopes and water catchments. The most common are landslides, where significant volumes of rocks, soil, and plants slide down the slope (Sirenko, 2003).

A more detailed decryption of the space images was performed on the key area of the Bukovetsk-Ritskyi landscape, where a few more land types were highlighted, including forests, clearings, meadows, plough lands, buildings, dirt roads, and paved roads. On its territory, almost the same area is occupied by forests and meadows – 51% and 40%, respectively (see Fig. 1) (Hostiuk, 2021). A significant area within the landscape is occupied by 6.5% of buildings, which are not confined to any part of the landscape, but are distributed almost evenly throughout the territory. About 1% of the landscape area is occupied by dirt roads and runs, and the smallest area is occupied by paved roads, 0.1% (Hostiuk, 2021). This landscape best represents the territory of Pokut Carpathians, in terms of population placement within its borders. Bukovets-Ritskyi landscape is a low-mountain part of Pokut Carpathians with the highest peak of the same name at 1059 m above sea level, represented by synclinal ridges and deep river valleys (see Fig. 1).

The territory of the key part of Bukovetsk-Rytskyi landscape was not chosen by chance, because natural hazards of both geological and hydrological nature have been recorded here. Landslides were recorded on slopes with meadow vegetation, less often with forest vegetation. Huge destructive floods, in addition to the destructive effect of water, provoke landslides, earth falls, erosion both deep and lateral.

The researched landscape is an area where housing estates are almost uniformly located and, accordingly, infrastructure objects are located throughout the territory: power lines, Internet communication lines, residential and commercial buildings, dirt and asphalt roads, bridges, crossings, agricultural lands, tourist estates, etc. As a result of the occurrence of various natural hazards, all these objects are subject to significant destruction and damage. According to the results of our own field research, it was found that when floods occur, the road infrastructure and buildings are most damaged, especially in the floodplains of rivers, and residential and commercial buildings on the slopes. Floodwaters often destroy plough lands and crops. Landslides destroy buildings, roads, grasslands intended for cattle grazing and haymaking, disrupt the ground cover. Erosion most often occurs on steep plowed slopes, resulting in the destruction of crops.

Taking into account the formation, development and consequences of natural hazards for infrastructure facilities in Pokut Carpathians, we have developed a scale of categories of the impact of natural hazards on infrastructure facilities (Table 1). With the help of the scale, it is possible to determine the category of damage to the infrastructure object and subsequently determine the financial costs required for its restoration.

Table 1 Categories of impact of natural hazards on infrastructure

No.	***Categories of damage***	***Categories***
1	Insignificant	The facility suffered minor damage, which can be repaired without financial support and in a short period of time using a minimum of human resources.
2	Delicate	The facility has minor damage that can be repaired with little financial support and human resources in a short period of time.
3	Moderate	The facilities are damaged but can be restored with the help of significant financial support and human resources.
4	Bad	Infrastructural facilities are heavily damaged, in some places destroyed, significant financial costs and human resources are required to restore them.
5	Very significant	In a certain area, the facilities have suffered significant damage and destruction, which is almost impossible to restore, and which may require large financial costs, a significant period of time and significant human resources.
6	Catastrophic	Infrastructural facilities in a certain area have been completely destroyed and are not subject to reconstruction.

In addition to determining the category of damage, it is necessary to carry out measures that can minimize the impact of dangerous processes on the infrastructure. First of all, do not create infrastructure objects in those territories where dangerous processes are likely to occur, before the construction of any object, it is necessary to conduct a geological and ecological examination. In order to prevent the destruction of the banks of rivers, which are most often paved with roads, it is necessary to strengthen the banks. To reduce the impact of landslides, it is necessary to plant trees and build retaining walls on landslide-prone slopes. To reduce the destructive effect of villages, it is necessary to change their direction of movement, since it is impossible to stop them.

Conclusions. The presence of certain geological, geomorphological, climatic and other natural factors in the territory of Pokut Carpathians contributes to the formation and development of dangerous physical and geographical processes. The most common of which are landslides, mudslides, erosion and floods. As a result of our own field research during 2020-2022, more than 15 landslides, several villages and a large number and variety of erosion processes were recorded in Pokut Carpathians. Taking into account the specifics of settlement of the studied territory, the occurrence of these processes leads to damage and destruction of infrastructure facilities. Economic and residential buildings, roads, bridges and agricultural lands are most affected by physical and geographical processes. Determining the impact of natural hazards on the infrastructure, it was found that the territory of Pokut Carpathians has a moderate category of impact from natural hazards. The impact of natural hazards on a key area in a certain period of time, in our case the second half of June 2020, when the development of natural hazards reached the highest level, is separately determined. For the landscape of Bukovets-Rytskyi, the category of damage from natural processes is defined as very significant, since some bridges and parts of the road have been completely destroyed here, and residential and commercial buildings and agricultural lands have been severely damaged. In order to prevent the destruction and damage of infrastructure facilities, it is necessary to carry out a geological and ecological examination before construction. In addition, measures should be taken to minimize the impact of dangerous physical and geographical processes on the region's infrastructure.

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