

## NATURAL HAZARDS WITHIN THE REACH OF IMPORTANT HIKING TRAILS IN THE TATRA MOUNTAINS (SLOVAKIA)

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### Abstract

Over the past 40 years, we have observed increased dynamics of processes in all vegetation levels of the Tatras, both in summer and winter. As a result, the risk of endangering hiking trails and ski slopes has increased, which is confirmed by several sudden events with fatal consequences for the lives of tourists. A greater number of sudden events are related to avalanches during the early spring period, while in the summer period there are storms and intense supercell rains. In both cases, there were fatal consequences for people's lives.

The aim of the paper is to point out processes that have a sudden course with an impact on hiking trails, infrastructure and pose a high threat to tourists themselves. On the other hand, knowledge of the dynamics and course of morphodynamic processes is the starting point for strengthening the infrastructure and management of tourism in high mountains.

**Key words:** Morphodynamic processes, hiking trails, climatic changes, natural hazards

### Introduction

The Tatras represent the highest mountain range of the Carpathians, which has provided opportunities for the development of tourism and travel since the 19th century, which was highlighted by the construction of the Czech-Bohumín railway in 1864. The High Tatras region (Poprad and Kežmarok districts) recorded a total of 912 000 accommodated visitors in 2025.

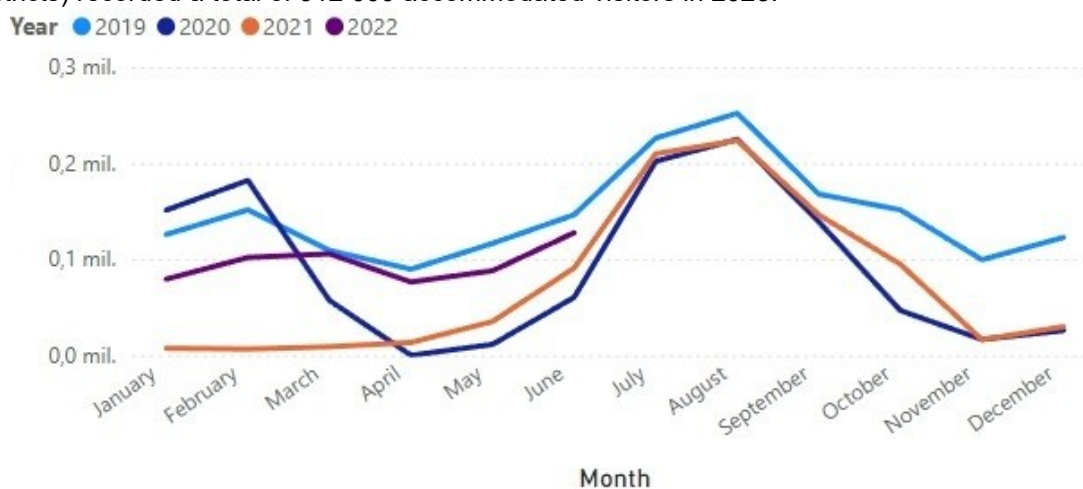


Fig. 1: Overnight stays on a monthly basis (Source: Slovak statistical office and Regional Tourism Organization Region Vysoké Tatry)

As we can see from the data in Figure 1, the number of visitors peaks in two periods of the year, namely in February and August. This indirectly implies the possibility of natural hazards in the summer and winter season to which the occurrence is linked such as flash floods, hydro-gravitational geomorphic processes and snow avalanches.

At the beginning, it should be said that under the term "significant hiking trails" includes trails open year-round, ski touring areas, and trails that lead to tourist huts (cottages). All of these areas represent locations with a certain degree of threat from flash floods, snow avalanches, debris flows and landslides to rock falls and collapses. In this paper, we focused on identifying and classifying the threat of selected tourist areas represented by hiking trails sections, with subsequent proposals for protection against possible risks for tourists and the hiking trails themselves.

## Material and methods

The starting point for this kind of focused research is long-term field research and observation of geomorphic processes, including their connection with climatic variables such as local storms or sudden warming of the air. However, these interactions have been the subject of our other studies and articles. A good basis for identifying threats in the vicinity of trails are primarily ground photographs that we conducted during research or that were provided to us by employees of the Tatra National Park Administration and employees of the Mountain Rescue Service. We determined the threat assessment by expert estimation based on the number and frequency of events and their effects on the environment and tourist infrastructure.

Based on these estimations, a set of 9 study areas have been selected (Table 1). These areas are represented by hiking routes sections derived from OpenStreetMap data and processed in ArcGIS Pro 3.6.

Tab. 1: A list of study areas and their characteristics

<i>Site code</i>	<i>Site name</i>	<i>Location</i>	<i>Main activity</i>
RV	Roháčska dolina	Western Tatra Mts. (north)	ski touring, hiking
ZV	Žiarska dolina	Western Tatra Mts. (south)	ski touring, hiking
PPL	Popradské pleso	Mengusovská dolina, High Tatra Mts.	hiking
CPR	Chata pod Rysmi (cottage)	Mengusovská dolina, High Tatra Mts.	hiking
HZC	Hrebienok - Zamkovského chata (cottage)	Studené doliny, High Tatra Mts.	hiking
ZC	Zbojnická chata (cottage)	Veľká Studená dolina, High Tatra Mts.	hiking, ski touring
TC	Téryho chata (cottage)	Malá Studená dolina, High Tatra Mts.	hiking, ski touring
KP	Kopské sedlo	Zadné Meďodoly, Belianske Tatry Mts.	hiking
PC	Chata Plesnivec (cottage)	Dolina siedmich prameňov, Belianske tatry Mts.	hiking

## Results

Based on previous knowledge and published works, we present the basic characteristics of natural threats that have actually affected hiking trails or the infrastructure in their vicinity and in some cases could also endanger tourists.

### *Avalanche events (AV)*

The most significant avalanches, which endangered hiking trails, infrastructure, and even hikers and ski tourists themselves, have occurred since year 2000 in several locations in the Tatras. The first important location of the avalanches we consider the Žiarska valley in the Western Tatras. In the Eastern Tatras (Belianske Tatry Mts.), the most endangered areas Zadné Meďodoly valley and Dolina Siedmich prameňov valley. In the High Tatras, this is primarily the Mengusovská valley and Malá Studená valley.

### *Debris flows (Df)*

Currently, very active debris flows have been observed for a long time in the areas of Mlynická valley, Mengusovská valley, Javorová valley, Zadné Meďodoly valley, Veľká studená and Malá Studená valleys. In the area of Malá Studená valley, we confirmed the current manifestations of a massive debris flow under the walls of Lomnický peak, whose source area begins at an altitude of approximately 2200 m above sea level. Its length in 2014 was approximately 1250 m, which is 50 m more than in images from 2004. Its width in the accumulation zone has also increased from the original 5-12 m to 96 m (Tomko-Králo, 2015).

### *Rock falls (Rf)*

The activity of gravitational processes of rock slopes and walls is predominantly situated in valleys with a large relative elevation of ridges and peaks. A significant factor is the presence of discontinuities of rock massifs in the form of primary separation surfaces, mylonite zones and a secondary network of fractures. The occurrence of rock collapse or falling fragments occurs most often in the spring due to the heating of rock slopes by increased solar radiation and the effects of ice in fracture systems. From the observed events in the last 20 years, we have identified an increased frequency of free falling fragments, but also concentrated collapse in rocky troughs. The falling is also accompanied by forms of rock collapse in the form of massive blocks of 2-5 m in size with identified fresh abrasions on the surface of boulders and grooves with crushed blocks on the surface of often stabilized debris cones. The most recent cases of rockfall occurred on the trail in the area of the mouth of the Studená valley, at the entrance to the Mengusovská valley, and permanent falling of debris is observed above the trail in the Zadné Meďodoly valley to the Kopské sedlo (pass).

### Landslides (Ls)

In the Tatras region, we have confirmed an increased incidence of landslides, which are closely related to intense precipitation events in 2010 and 2013, similarly to the case of debris flows. The slopes of moraines, glacial cones and slopes formed by mesozoic rocks are often affected, as is the case in the Belianske Tatry Mts. and Javorová Valley. In many locations, the formation of landslides is initiated after the windstorm events and as a result of the alluvial effect of snowfields. The areas are exposed to erosion processes with the subsequent formation of erosion grooves and potholes. Some of the landslides directly threaten or destroy hiking trails, which causes not only a difficult passability or changes in route alignment, but also total closures of the affected route sections.

### Flash floods (FI)

Flash floods represent an extreme case of surface water runoff, when not only the river floodplain is flooded, but in mountainous areas also the bifurcation of the riverbed and the displacement of large amounts of sediment. We have observed the occurrence of floods in the mountain streams of the Tatras since 2008 – Javorová valley, 2018 – Javorová valley, 2023 – Hlboký potok (creek) – Tatranská Lomnica, 2024 – Monkova valley, Studená valley. In addition, destructions of hiking trails and roads, damaged bridges, underground electrical lines, water sources and water supply infrastructure, and landslides due to bank slopes undercuts have been recorded.

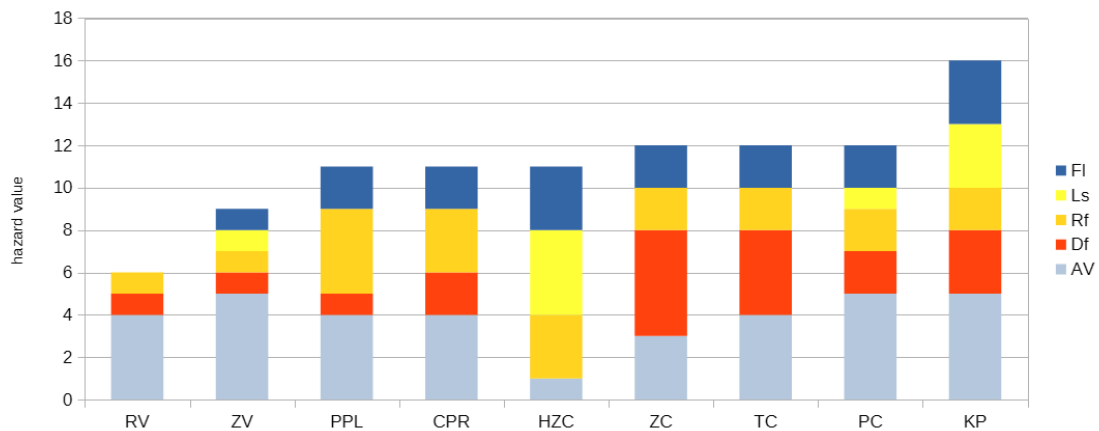


Fig. 2: Evaluation of natural hazards in the last 25 years in selected valleys in the Tatras.

The graph (Figure 2) shows the ranking of sites based on evaluation of each hazard type as well as the cumulative values. Practically all locations show significant threat values, where 12 points and above indicate the extreme threat to hiking trails. The assessment exhibit also regional differences between individual locations, with lower cumulative and individual hazards in the Western Tatras (RV, ZV), except for snow avalanches (Figure 3). The High Tatra and Eastern Tatra regions reflect more diverse abiotic conditions and land cover in higher values and more even proportionality of natural hazards. However, one of the study areas, the hiking trail from Tatranská Javorina to Kopské sedlo in Zadné Medodoly valley (KP), stands out significantly, with high values of all evaluated hazard types.

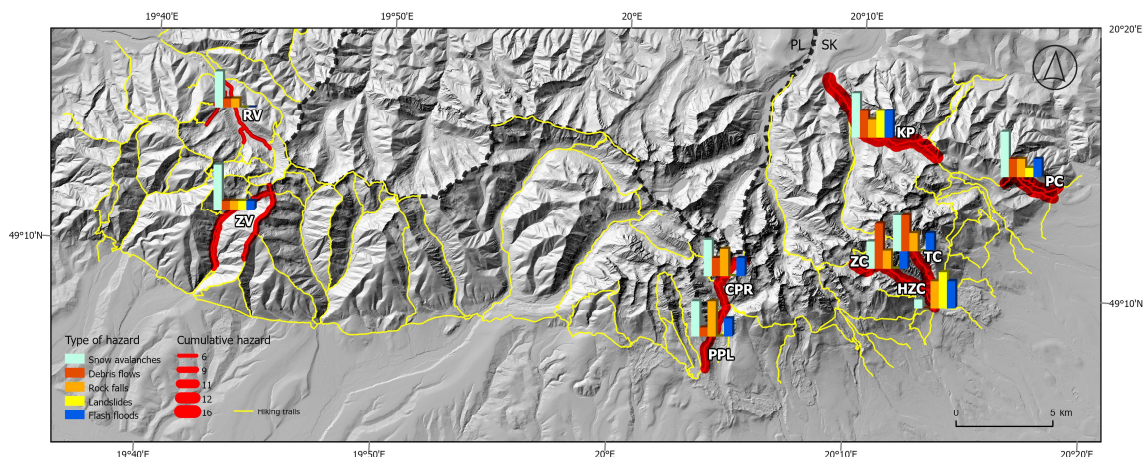


Fig. 3: Location and natural hazard values of the study areas in the Tatras (Basemap: merged hillshaded LiDAR DEMs from Slovak and Polish open data sources – ÚGKK SR; GUGIK)

## Discussion

The presented results point to a high degree of morphodynamic potential of the Tatras as the highest mountain range of the Western Carpathians. Natural threats are such an important category of environmental assessment of the territory as pointed out by Drdoš, (1992), Minár et al. (2006), Hreško et al. (2011, 2022), and Krajčí et al. (2019). Climatic factors, especially intense precipitation totals and the aforementioned sudden changes in air temperature, have contributed to the intensity of the processes over the last 20 years. The intensity of extreme precipitation has increased compared to older measurements carried out by Niedźwiedz (2003). As stated by Kotarba (2005), since 1995 we have been observing a transition to a humid climate in the Tatras with the development of fluviation processes, i.e. manifestations of area and concentrated surface runoff in the form of erosional streams and grooves. In accordance with what we stated in the article Bugár, Hreško, Piscová (2025) the mentioned processes create limit conditions for the implementation of tourist activities in the supramontane and alpine stages of high mountains. At the same time, as Pelfini, Brandolini (2010) emphasized that information about natural hazards should be clearly expressed as part of tourist maps, which are such a preventive tool for risk mitigation in the extreme environment of high mountains.

## Conclusion

The results show that a significant part of the selected routes, according to the above conditions, have a high probability of being endangered both in summer and in winter. According to the impacts of processes on tourists, tourist trails and the environment, avalanches, water-gravitational processes and floods are most common, and to a lesser extent rockfalls and landslides. Also in this case we point out the cumulative effect of processes, which brings the degree of threat of individual parts of the trails into higher categories.

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## Souhrn

V příspěvku jsme navázali na problematiku přírodních hrozeb v okolí turistických stezek Tater s důrazem na významné trasy, které zpravidla směřují k turistickým chatám, mají význam při rychlém nástupu na túry a zároveň plní podmínku celoroční otevřenosti – dostupnosti. Z dosavadních výsledků vyplývá, že podstatná část vybraných tras podle uvedených podmínek má vysoký předpoklad ohrožení jak v letním, tak v zimním období. Podle dopadů procesů na turisty, turistické trasy a prostředí se nejvíce uplatňují laviny, vodně-gravitační procesy a povodně, v menším rozsahu skalní řízení a sesuvy. I v tomto případě však poukazujeme na kumulativní efekt procesů, čímž se stupeň ohrožení jednotlivých částí chodníků dostává do vyšších kategorií. Podobně jako v předchozím příspěvku Bugár, Hreško, Piscová (2025), význam tohoto výzkumu vidíme především v oblasti managementu turismu vysokohorských oblastí a při návrhu návštěvního řádu TANAP-u.

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