MORPHO DYNAMIC PROCESSES IN THE TATRA MTS. (SLOVAKIA) AS LIMITS OF ALPINE TOURISM

Gabriel Bugár[1], Juraj Hreško[1], Veronika Piscová[2]
[1] Department of Ecology and Environmental Science, Faculty of Natural Sciences and Informatics, Constantine the Philosopher University in Nitra, Slovakia
[2] Institute of Landscape Ecology of SAS, Bratislava, the Nitra Branch, Slovakia

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Abstract
The Tatras, with their location on the northern edge of the Carpathian arc, have their own specific position both in the field of nature protection and in the socio-economic development of Slovakia. Practically since 1949, the principles of nature protection have been applied within the Tatra National Park, which was associated with significant restrictions on socio-economic activities mainly limited to the area of tourism development. A large part of the capacity of the territory was gradually designated for concentrated forms of tourism, while forms of hiking were limited not only by the availability of the relief, but also by the defined routes of tourist trails. The most frequently used trails are from the mouth of the valleys, through their bottoms to the saddles, through the ridges to the more accessible peaks. In the article we focus mainly on valley or valley-saddle routes, as in the case of the Belianske Tatras. Since 1993, the bilateral Tatra Biosphere Reserve has been approved, which has emphasized the attribute of sustainable forms of tourism. In the article we want to point out the importance and impact of morphodynamic processes as limiting factors of alpine tourism. The frequency of occurrence of sudden and difficult to predict events is increasing, and thus the risk of endangering humans. Gradient structures of valley systems in some parts of the valleys increases the risk of endangerment of hiking trails, as well as tourists themselves.

Key words: Tatra Mts., morphodynamic processes, alpine tourism

Introduction

The high-mountain type of the Slovak landscape represents the highest part of the Carpathians, which was formed after the retreat of valley glaciers of the last Würmian glaciation (Lukniš, 1973). In the conditions of the deglacial high-mountain landscape of the Tatras, vertically differentiated climatic and vegetation stages have developed, of which the highest, alpine, represents a type of nival and periglacial environment with the occurrence of a whole range of geomorphological processes, closely related to climatic conditions (Midriak, 1983, Kotarba, Kaszowski, Krzemien, 1987, Hreško J., Bugár G., Boltižiar M., Kohút F., 2008). The alpine environment of the Tatras represents a group of very sensitive and vulnerable ecosystems, forming from the post-glacial to the present. The Tatras, with their location on the northern edge of the Carpathian arc, have their own specific position both in the field of nature protection and in the socio-economic development of Slovakia. In the period from 2008 to 2025, several events related to the recent development of the relief of the high-mountain landscape were recorded in the Tatra Mts, which can be considered natural threats and subsequently also as risks for human activities. We consider most morphodynamic processes to be natural threats determined by extreme climatic conditions. Valley systems as basic spatial units of the mountain range are modelled by water-gravity, slope-gravity, snow-gravity and fluvial processes. In this context, the aim of the paper is to bring arguments for tourism development regulations in order to eliminate potential threats to the alpine environment.

Materials and methods

The process of assessing the impact of morphodynamic processes on hiking trails is based on the theoretical basis of understanding morphodynamic systems. In the conditions of the Tatras, morphodynamic systems are considered to be the basic spatial units of relief formation and their dynamic manifestations at valley scales, or at the scales of valley slopes (Hreško, 1997; Hreško, Kohút & Bugár, 2015). The first step is the identification and classification of processes in space based on the analysis of aerial images and orthophotomosaics at one or more time levels. The result of the analysis is the preliminary delineation of the areas of individual elements of morphodynamic systems. The second step is the assessment of the manifestations of the processes, including synergistic effects and their impact on the soil-weather cover. The basis for assessing the activity of the processes is detailed field research, mapping and photo documentation. The third step is the interpretation of the real and potential threat to hiking trails in the context of the identified

morphodynamic processes and forms associated with their effects. We assess the potential threat and effects of morphodynamic processes within the reach of the hiking trail in terms of their intensity, frequency, soil and vegetation vulnerability, environmental impact and threats. We base our assessment on the findings of research conducted in the West Tatras, High Tatras, Belianske Tatras and Low Tatras (Hreško, Bugár & Petrovič, 2009).

Results

A significant part of the threats on tourist trails is related to the course of climatic variables such as precipitation totals, precipitation intensity, the course of air temperatures and subsequently with the flow rates of streams. Most of the threats accumulate in the summer period, when the frequency of high precipitation totals increases in high-altitude areas. The occurrence of floods on fast-flowing streams of the high-mountain landscape of the Tatras is closely related mainly to intensive precipitation in the summer period. According to records, precipitation activity at the meteorological station in Tatranská Javorina in 2008 reached a precipitation total of 1487 mm in the summer period. The maximum daily total reached in Tatranská Javorina on 23.7.2008 147.1 mm of precipitation recorded in July. The response to these precipitations was the culmination of the flow on the Javorinka creek in Podspády with a value of Qmax = 71.33 m³ on 23 July 2008 at 6 PM. The next extreme event of the total precipitation in July 2018 is documented by data from Tatranská Javorina village, where the maximum daily precipitation was 126.8 mm. Such rainfalls were followed by a flash floods with destructive consequences of road and touristic infrastructure. The flood activity of Javorinka creek is associated with the embankment of flowing water from the riverbed, wilding – the branching of the watercourse and the crossing of the riverbed. In 2024, during a summer storm (July 11, 2024), about 100 mm of precipitation fell per hour in the Monk Valley area on the north-eastern edge of the Belianske Tatras, which caused a debris-mud avalanches. The event had fatal consequences for tourists hiding under a shelter located directly at the mouth of a juvenile valley, which transported a large mud-debris mass with fragments of trees and woody skeletons.

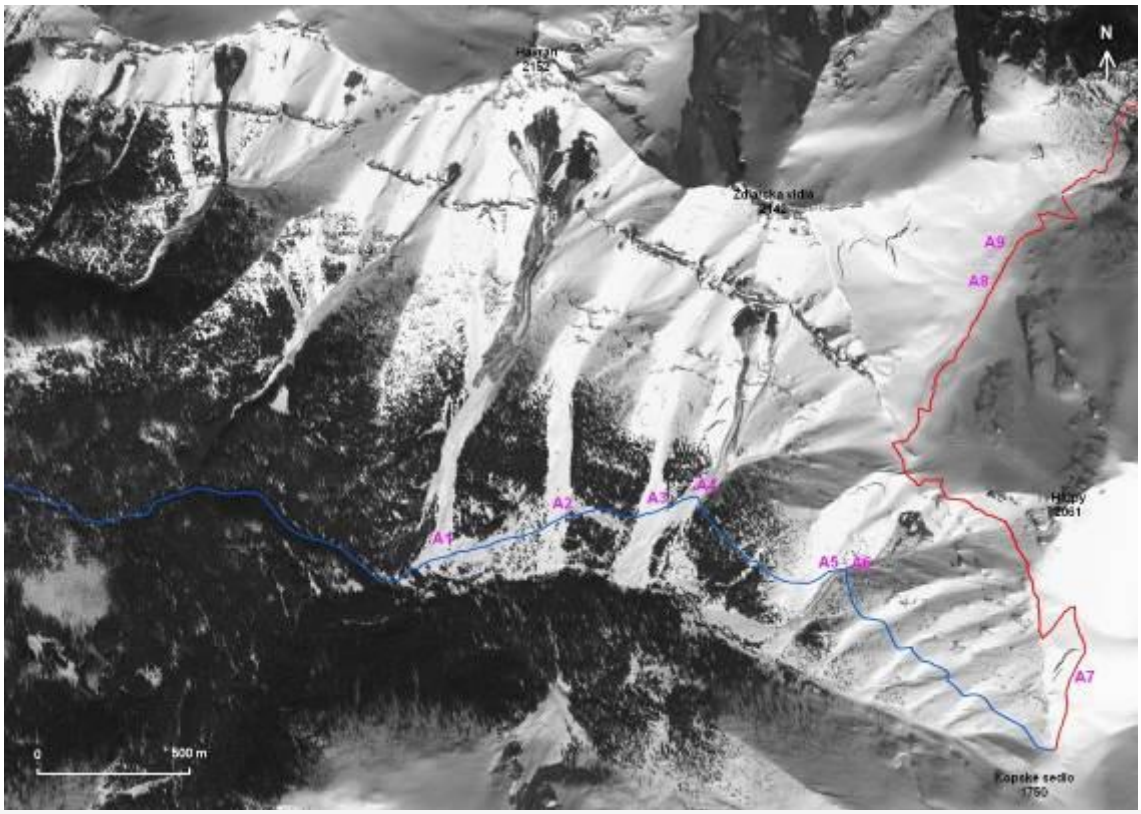

Fig. 1: Avalanche hazard on hiking trails in the Belianske Tatry Mts with avalanche tracks signed A1 to A9. (Basemap: Historical Imagery – 2 April 2009; Google Earth/Maxar technologies;)

Avalanches, as a landscape-forming phenomenon of the alpine environment, disrupt, destroy and limit the basic components and elements of the landscape structure. Often, hiking trails, tourist huts and often tourists themselves are also affected. Avalanches represent a process associated with the current changing climate, which is mainly reflected in the difficult predictability of the formation of

avalanches and their effects. In the Belianske Tatras region a huge avalanches started in spring 2000. Further avalanche events occurred in early spring 2009 (Fig. 1 - beginning of the avalanche season in 2009) and then repeated until 2023. In 2019 we documented an unusually large base avalanche after significant warming on the slope of Ždiarska Vidla (2142 m alt.) with SE exposure. Its transport-accumulation zone also extends to Monkova Valley (Fig. 1, A8, A9). Air temperatures near Biele Pleso lake reached +3.9°C on 15 April 2019, which was the triggering factor for several snow mass breaks.

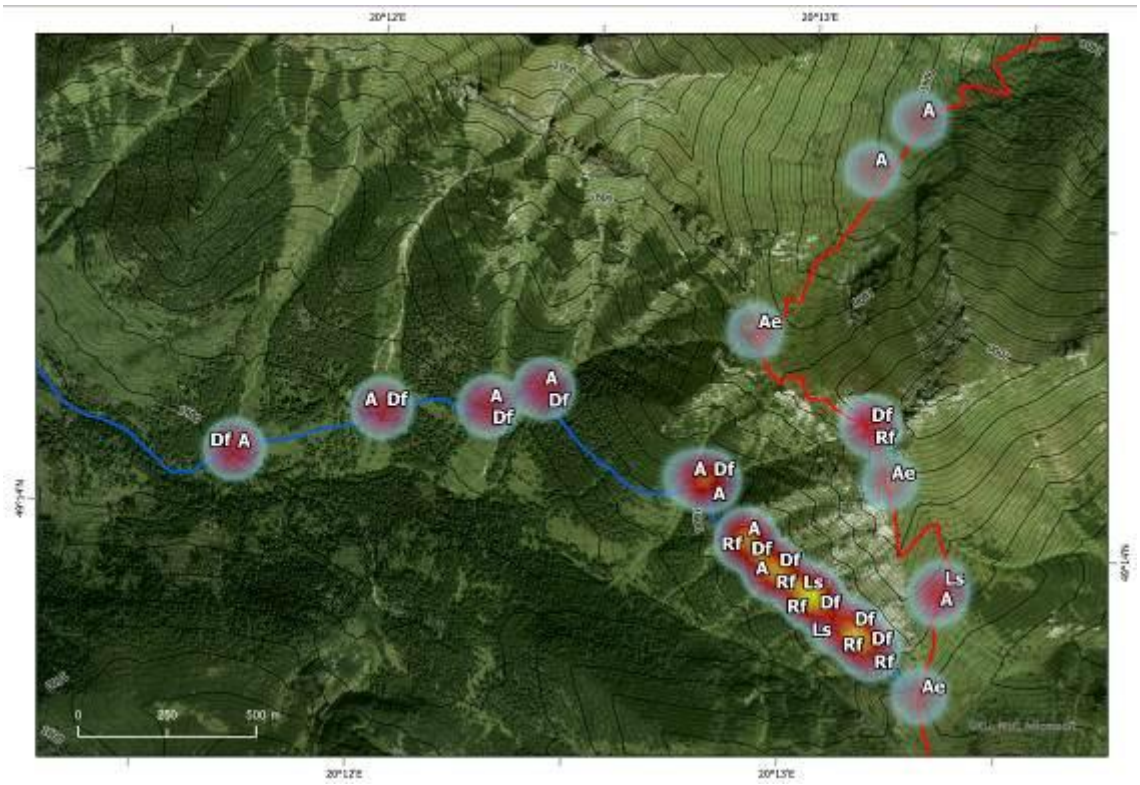

Fig. 2: Cumulative hazards of Avalanches (A), debris flows (Df), rock falls (Rf), aeolian deflation (Ae) and shallow landslides (Ls) along hiking trails in Belianske Tatry Mts. (Basemap: Orthophotomosaic 2022, GKÚ Bratislava)

Discussion

The knowledge about natural threats in the conditions of the Tatras corresponds to several works in the conditions of other European mountain ranges, especially the Alps, where the impacts of human activities through changes in land-cover and land-use on agro-ecosystems and their ecosystem services are emphasized (Vigl, Schripke, Tasser, Tappeiner, 2016). Natural processes have a great influence on changes in the landscape cover and, with their disturbing effects, significantly change the conditions of the current development of ecosystems. Such processes are primarily slope gravity processes such as landslides, debris flows, avalanches, but also floods with significant modelling of the stream bed (Midriak,1983, Kotarba, A. 2007, Hreško, Bugár, Petrovič, 2009, Šilhán, Tichavský, 2017). Many of the above processes limit and in some cases threaten human activities, as pointed out by Pelfini, Brandolini (2010) and at the same time they emphasized that information about natural threats 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. On the other hand, activities can contribute to accelerating or triggering processes, as pointed out by Piatek, D. and Krzemien K. (2023) on the ski slopes of the Polish Carpathians. In the conditions of the Slovak Carpathians, Stankoviansky and Barka (2007) emphasized the research of processes, which point to the historical human influences in the cryonival stage of the high mountains of Slovakia since the Wallachian colonization.

Conclusion

Research focused in this way is also supported by strategic documents and programs of the State Nature Conservancy and the UNESCO MAB bilateral Tatra Biosphere Reserve with an emphasis on the sustainability of the use of ecologically important ecosystems of the high mountain landscape. Our results will also significantly contribute to the creation of implementation proposals and management plans for the basins of the Tatra valleys with an emphasis on lakes (Čajková, Hrivnáková, Hreško,

2024). We also want to contribute to knowledge about the impacts of processes associated with extreme manifestations of meteorological phenomena such as intense and torrential rains, snow accumulation, wind storms, sudden changes in air temperature. In accordance with this, the impact of tourism in some localities is above the sensitivity threshold of ecosystems and creates frequent conflict situations that have a negative impact on the tourists and visitors of the Tatras themselves. An important category of using the alpine environment above the forest line is hiking as the most widespread form of relaxation in practically the entire territory of the Tatras. In the article, we pay attention to the impact of current geomorphological processes on the stability of hiking trails, as well as on the direct or indirect threat to tourists themselves. In the conditions of a changing climate, especially in the last 25 years, the frequency of occurrence of such threats has been increasing. Practically since 2000, we have recorded an increase in avalanche events, debris flows, rockfalls, landslides and processes associated with flood situations in the immediate vicinity of the trails.
We can agree with Chiroiu et al (2022) that the minimum return period of major avalanche events is 3.3 years, but most probably, weak to moderate avalanches can occur every year. Other geomorphic hazards related to debris flows, landslides and rockfall, can be identified primarily in the context of stormy summer rains and sudden changes in air temperature in spring and autumn. Particularly problematic are those parts of the slopes where there is a cumulative effect of at least two processes, even if in different time periods of the year. In some cases, the original hiking
trails are completely destroyed, or their passability is made difficult, but in many cases they threaten the safety of the tourists themselves, or climbers. From the observations and research so far, it is evident that it is necessary to anchor the issue of natural threats into basic information and regulations both within the TANAP visitor regulations and in the form of warning signs at the beginning of hiking trails and, in critical cases, on endangered sections of trails.

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Souhrn
Výše uvedené výsledky výzkumu v Tatrách korespondují se záměry strategických dokumentů a programů Státní ochrany přírody a MAB UNESCO bilaterální biosférické rezervace Tatry s důrazem na udržitelné využívání ekologicky významných ekosystémů vysokohorské krajiny. Chceme přispět k poznání dopadů procesů spojených s extrémními projevy počasí na intenzivní cestovní ruch ve vysokohorské krajině. V souladu s tím je vliv cestovního ruchu v některých lokalitách nad hranicí citlivosti ekosystémů a vytváří časté konfliktní situace, které negativně ovlivňují turisty i samotné návštěvníky Tater. Významnou kategorií využívání vysokohorského prostředí nad hranicí lesa je pěší turistika jako nejrozšířenější forma relaxace prakticky na celém území Tater. V podmínkách měnících se klimatických podmínek, zejména v posledních 25 letech, se četnost těchto ohrožení zvyšuje. Prakticky od roku 2000 pozorujeme v bezprostřední blízkosti stezek nárůst lavinových událostí, suťových proudů, sesuvů kamení, půdy a procesů spojených s povodňovými situacemi. Lze souhlasit s Chiroiuem et al (2022), že minimální doba návratu velkých lavinových událostí je 3,3 roku, ale že s největší pravděpodobností se každoročně vyskytují slabé až středně silné laviny. Další nebezpečí, jako jsou suťové proudy, sesuvy půdy a skalní řícení, lze identifikovat především v souvislosti s letními bouřkovými dešti a náhlými změnami teploty vzduchu na jaře a na podzim. Problematické jsou zejména ty oblasti, kde dochází ke kumulativnímu působení alespoň dvou procesů, i když v různých ročních obdobích. V některých případech jsou původní turistické trasy zcela zničeny nebo je ztížena jejich průchodnost, v mnoha případech však ohrožují bezpečnost samotných turistů nebo horolezců. Z dosavadních pozorování a průzkumů je zřejmé, že problematiku přírodních rizik je třeba zahrnout do základních informací a předpisů, a to jak do Návštěvního řádu TANAPu, tak do mapových podkladů, a to formou výstražných cedulí a v kritických případech i vyznačením varování na ohrožených úsecích stezek.

Contact:
Prof. RNDr. Juraj Hreško, PhD.
E-mail: jhresko@ukf.sk