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QUANTITATIVE ANALYSIS OF NATURAL HAZARDS IN THE EASTERN PART OF THE SLOVAK TATRA MOUNTAINS AND THEIR FORELAND

Abstract. In this contribution we quantified some natural hazards in the eastern part of Slovak Tatra Mountains (i.e. the High Tatra Mountains, the Belianske Tatra Mountains and the eastern part of the Western Tatra Mountains) as well as the Popradská kotlina and the Podtatranská brázda basins. The paper focuses on the processes of water erosion, snow avalanches and debris flows and other mass-movements processes.

Keywords: water erosion, snow avalanches, debris flows paths, mass-movements, eastern part of Slovak Tatra Mountains

INTRODUCTION

Geomorphological hazards are widespread across the Tatra Mountains. Recent geomorphic hazards in the Tatra Mountains are defined by Z. Rączkowska (2006) as rapid destructive processes. Despite the occurrence of many destructive factors that trigger geomorphic processes (e.g. strong wind storms, – wind erosion, soil ice – cryogenic destruction – A.L. Washburn (1979), M. Boltižiar (2009), etc.) in the eastern part of the Tatra Mountains and their foreland, we only briefly interpret some selected processes classified as geomorphic hazards. In the specific high-mountain relief of the Tatra Mountains and their relatively flat foreland, we considered hazards posed by potential water erosion due to surface runoff, by the occurrence of mass-movements (e.g. slope failures), occurrence of permanent or potential snow avalanche paths (or avalanche slopes respectively), and debris flows. In this paper we attempted to quantify the above mentioned environmental hazards in study area of the eastern part of the Slovak Tatra Mts and their foreland.

Spatial distribution of these processes in the Tatra Mountains (as a part of wider area) according to the author (Midriak 2002a,b) is also presented in Landscape Atlas of the Slovak Republic (Atlas krajiny Slovenskej republiky), chapter IX, as maps No. 76 (*Threatening of the mountain and high-mountain* *areas by water erosion, snow avalanches, and debris flows*) and No. 77 (*Gravitational and mixed landforms as slope failures in the mountain and high-mountain areas*).

The purpose of this paper is to provide a brief quantitative assessment and outline of the pattern of potential surface destruction and other hazards to the natural environment in the eastern part of the Slovak Tatra and their foreland. This work has a dual character, being partly an original scientific contribution and partly a literature review.

STUDY AREA

The study area (approx. 610 km^2) encompasses the eastern part of the Tatra Mountains and their foreland (Fig. 1), that is the Slovak part of the High Tatras, the Belianske Tatra Mountains, the eastern part of the Western Tatras (the Liptovské kopy and the Červené vrchy); and their foreland i.e. Tatranské Podhorie foothill, the basin of Popradská kotlina and the eastern part of Podtatranská brázda basin. As such, the study area does not correspond precisely with geomorphological units of the Tatra Mountains, and instead uses mostly social-administrative division. The study area discussed here was also a part of the study by M. H u b a et al. (2005) on sustainable development of the Tatra Mountains.

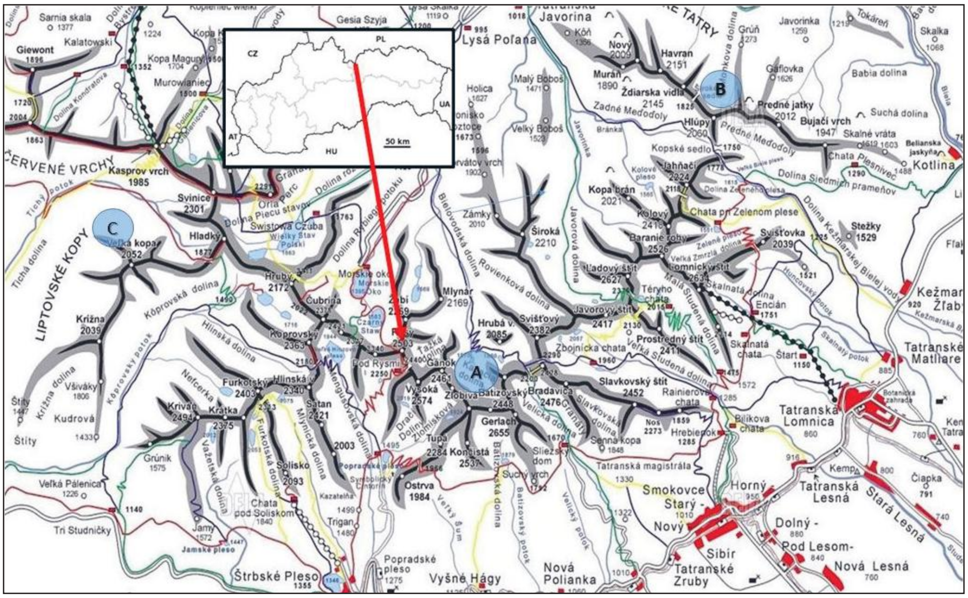

Fig. 1. Study area – the eastern part of the Slovak Tatra Mountains (High Tatra Mountains – A, Belianske Tatra Mountains- B, and the eastern part of the Western Tatra Mountains – C) and their foreland.

METHODS

Some of the methods used in this study are partially described in the cited works.

In order to assess the hazards resulting from potential surface *water erosion*, we have chosen methods to calculate the intensity (rate) of potential soil erosion that depends on a range of natural factors and conditions (coefficients of slope inclination, geological/substrate conditions, humus content in the soil, and frequency of rainfall of a given intensity) and occurs in the absence of forest and effective plant cover. The methods of hazard assessment we use were described by O. Stehlík (1970) and adapted to the natural conditions of Slovakia by the author (Midriak 1977). The hazard is assessed on the basis of the potential erosion intensity according to the classification scale by D. Zachar (1982), specified for Slovakia conditions by R. Šály and R. Midriak (1995) and by R. Midriak (2002c). See also Table 1 in this paper.

With regard to *snow avalanche* danger, the methods include recognition of relief and interpretation from aerial photographs using the universal photogrammetry method. Data on the number of permanent tracks are derived from the *Atlas of avalanche paths* with 1: 50,000 maps by L. Kňazovický (1979), where the slopes are classified into three categories depending on the frequency of avalanche occurrence: with rare, frequent and very common avalanches. Further assessments of snow avalanches in the Tatras can be obtained on the basis of the map by Z. Rączkowska et al. (2015) or the maps (1: 100,000) by M. Žiak and M. Długosz (2015). The methods are described by the authors of the cited works.

Natural hazard posed by *debris flows* is inferred from the number and location of debris flows paths shown in the geomorphic map of the High Tatras and their foreland by M. Lukniš (1973) as well as in the map of gravitational failures in crystalline part of the Western Tatras by T. Mahr (1973), both at the scale of 1: 50,000. Similarly as in the case of snow avalanches, also the map of the debris flows tracks in the Tatra Mountains (1: 100,000) was published by M. Długosz (2015).

The occurrence of *mass-movement* processes and forms was inferred from the 1: 1,000,000 map of landslides in the Slovak Carpathians after A. Nemčok (1982) as: – gravitational, water-gravitational, nivation-gravitational and cryo-gravitational processes in core high mountains, foothill highlands and highlands; – gravitational, water-gravitational, nivation and cryo-gravitational processes in flysch foothill of highlands and higher uplands – gravitational and water-gravitational processes in intramountain depressions and intermontane basins. The methods used to elaborate the map are described in the respective publication (Nemčok 1982). In the map by A. Nemčok (1982) I added boundaries of slopes endangered and impacted by both snow avalanches and cryogenic processes in mid-mountain and high mountain areas of highlands and higher uplands.

Table 1

Potential water erosion hazard in the eastern part of the Slovak Tatra Mountains and their foreland by R. Midriak and L. Zaušková (2007)

Degree of erosion hazard – Rate of possible soil loss (mm/year):	Area of the endangered surface	
	(ha)	(%)
1st insignificant – < 0.10	16 217.86	26.60
2nd slight – 0.11 – 0.50	4 802.39	7.87
3rd medium – 0.51 – 1.50	8 196.86	13.45
4th strong – 1.51 – 5.00	8 205.33	13.46
5th very strong – 5.01 – 15.00	23 388.56	38.37
6th catastrophic – >15.00	150.90	0.25
Total	**60 961.90**	**100.00**
Average rate of potential erosion on the total surface of the study area	**4.49 mm/year**	

RESULTS AND DISCUSSION

HAZARD POSED BY POTENTIAL WATER EROSION RESULTING FROM SURFACE RUNOFF

In contrast to some authors who define natural hazards as rapid, high energy processes, the author (Midriak 1997 and other works) considers water erosion as the major process associated with geomorphic *hazard* because it acts permanently throughout the year and removes soil/land from the slope surface. Water erosion processes are widespread also in the Tatra Mountains among other exogenic relief-forming processes. Quantification of potential water erosion in the study area is shown in Table 1.

Figure 2 indicates vertical distribution of the areas with particular degrees of erosion hazard. Although the average intensity of potential erosion falls to the degree of strong threat, on the largest part (38.4 %) of the study area erosion hazard falls within the *very strong* category, while on more than 25% of the area the erosion hazard is insignificant.

In particular, the area above the upper limit of the forest (on average, at 1412 m a.s.l. on the southern slopes of the High Tatras and at 1385 m a.s.l. in the Belianske Tatras (Midriak 1994), is highly prone to potential erosion (very strong hazard – 5th degree), and locally areas with 6th degree hazard also occur (valleys under Mt. Končistá, Mt. Ostrva and the Monkova Valley). However, surfaces with 4th (locally with 3rd) degree of erosion hazard are found here, especially in the valleys and their heads (the Tichá, the Kôprová, the Hlinská, the Mengusovská, the Bielovodská, the Javorová, the Zadné Meďodoly, the Predné

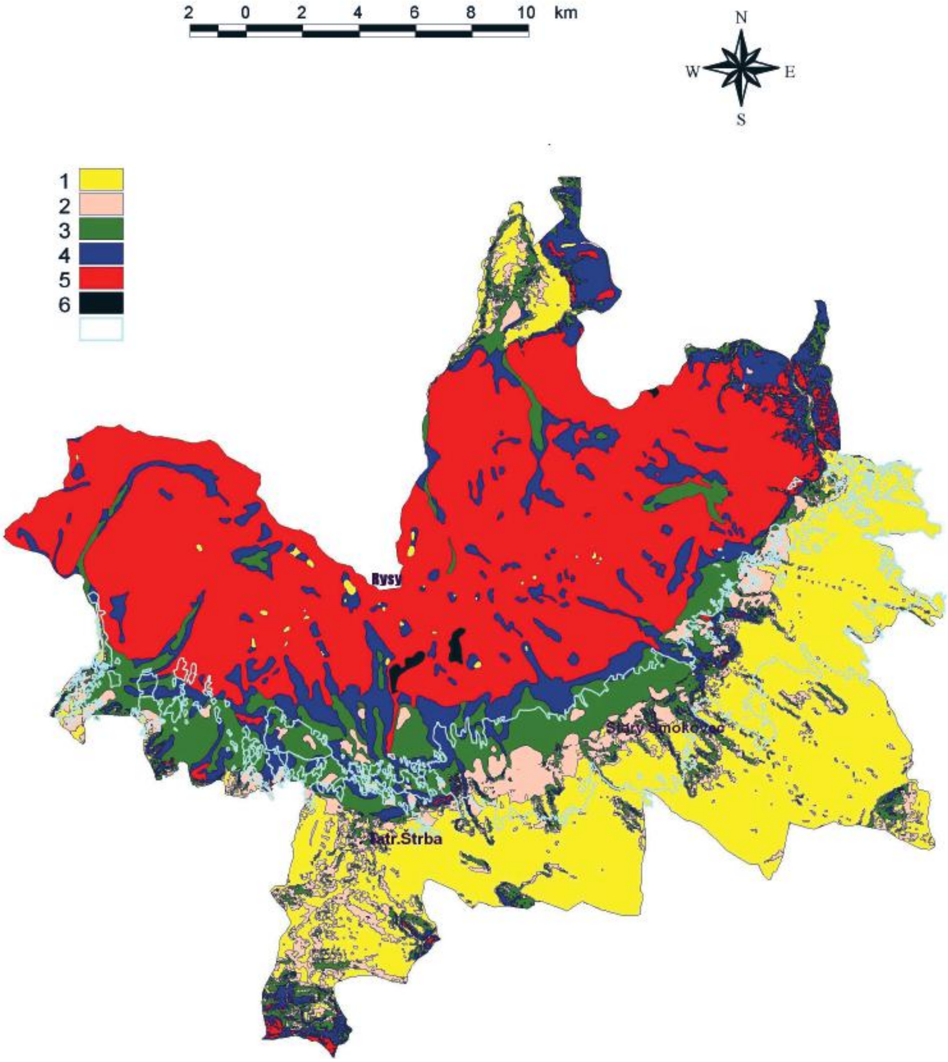

Fig. 2. Spatial distribution of water erosion hazard zones in the eastern part of the Slovak Tatra Mountains. Rate of possible soil loss (mm/year): 1 – insignificant (< 0.10); 2 – slight (0.11 – 0.50); 3– medium (0.51 – 1.50); 4 – strong (1.51 – 5.00); 5 – very strong (5.01 – 15.00); 6 – catastrophic (>15.00); blue line – boundary of 2004 windstorm.

Meďodoly, the Kežmarská Biela voda), but also on the bottom of several glacial cirques in others valleys heads.

Less compact zone affected by erosion of strong intensity is located in the High Tatras approximately at altitudes between 1000 m a.s.l. (in the east) – 1100 m a.s.l. (in the central and western parts) and 1300–1400–1500 m a.s.l.; in the foreland of the Belianske Tatra Mountains it occurs on the slopes descending to Biela and Ždiarsky streams, as well as to the large area north of the Podspády setllement. In the western half of the study area, however, the zone of 4th degree erosion hazard are interspaced with large patches with lower (3rd degree) erosion hazard. This significant zone with medium erosion hazard surrounds the Tatra Mountains from west to east, extending vertically to their lower boundary. Although the erosion intensity drops to 0.51–1.50 mm/year, the area of the Tatranské Podhorie foothill (with the area of 7725 ha) is prone to increased erosion because here the substrate consists of moraines of the last glaciation with rare glacio-fluvial deposits (L u k n i š 1973; M i d r i a k 1993). They are, for example, at the mouth of Kôprová Valley, but especially in the valleys of Važecká, Furkotská, Mlynická, Mengusovská, Batizovská, Velická and Veľká Studená, and partly in the Kežmarská Biela voda Valley. In this area moraines form prominent morainic amphitheaters with multi-lobed geometry (Z a s a d n i and K ł a p y t a 2014).

The erosion hazard in the northwest parts of the Popradská kotlina basin and the Podtatranská brázda basin is insignificant (slight on Fig. 2), but within this zone there is a mosaic of tiny patches of surface prone to medium- to strong intensity erosion.

The area with 1st degree hazard forms the second widest, continuous zone in the eastern part of the study area. However, over large areas the hazard increases from 2nd to 4th degree. Such situation occurs e.g. in the area surrounding villages of Štrba and Tatranská Štrba, Mengusovce and Štôla, Gerlachov, Tatranská Polianka, Tatranské Zruby, Starý Smokovec city to Tatranská Lesná and Nová Lesná, Tatranská Lomnica city, Veľká Lomnica, Tatranská Kotlina, etc. Thus, the intensity of potential erosion ranges from 0.1 to 1.5–5.0 mm/year on the bottom of these basins.

In comparison with the potential soil losses, we report that actual soil losses due to water erosion in the study area above the upper timberline (measured with the deluometric method) range from 0.12 mm/year in the High Tatras to 0.72 mm/year on average in the Belianske Tatra Mountains (M i d r i a k 1983a). This demonstrates the important function of vegetation cover. On the other hand, on barren surfaces denuded due to surface water erosion soil losses reach 5.01 mm/year and as much as 8.8–26.6 mm/year in the erosion gullies (M i d r i a k 2011).

NATURAL HAZARDS DUE TO SNOW AVALANCHES

Snow avalanches, especially the full-depth (or slush) ones, are among the serious hazards to the relief in the eastern Tatras. They transform relief, destroy or damage upper timberline, forest and dwarf pine stands, and pose a threat to people, animals and infrastructure (M i d r i a k 1979; M i l a n 2006). Through a delivery of increased volumes of fine sediment they affect streams and mountain lakes. Their starting zones are next transformed by other geomorphic processes. The total avalanche area reaches 3 707 ha in the Slovak part of the High Tatras (K ň a z o v i c k ý 1967) and about 360 hectares in the Belianske Tatras (M i d r i a k

Table 2

Snow avalanche slopes and avalanche paths in the eastern part of the Slovak Tatra Mountains

Category of snow avalanche slopes	Area of avalanche slopes (ha)	Avalanche paths * (number of pieces)
With rare occurrence of avalanches	1 211.42	242
With frequent occurrence of avalanches	904.31	226
With very frequent occurrence of avalanches	447.20	253
Total	**2 562.93**	**721****

* Source: L. Kňazovický (1979); ** Difference in comparison to the previously reported 649 paths in the eastern Tatra Mountains results from the fact that the most western part of the assessed surface in the Tichá Valley catchment belongs to the Western Tatra Mountains and the 5 avalanche paths on the right slopes of the Hlinská Valley (outside eastern part of Tatra Mountains) were taken into account (Fig. 3) because they threatened the bottom of the valley.

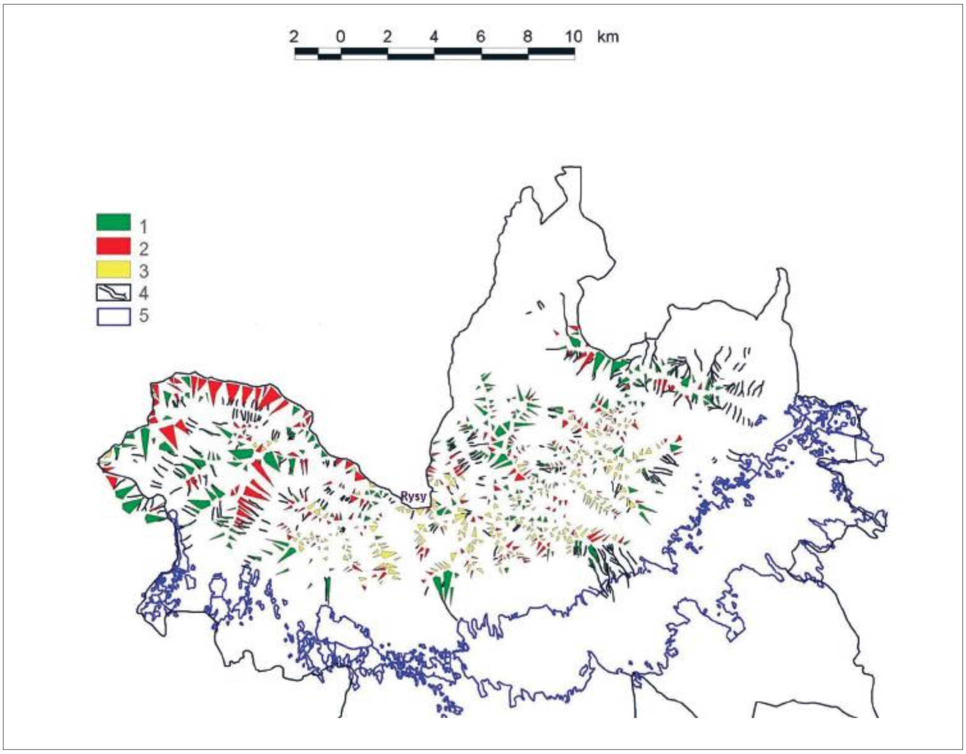

Fig. 3. Potential snow avalanches and debris flows hazards in the eastern part of the Tatra Mountains. 1 – avalanche slope with rare occurrence of avalanches; 2 – avalanche slope with frequent occurrence of avalanches; 3 – avalanche slope with very frequent occurrence of avalanches; 4 – paths of debris flows; 5 – boundary of the 2004 windstorm (R. Midriak, Ľ. Zaušková 2007), black line – boundary of study area

1983a). According to L. Kňazovický (1979) there are in total 649 permanent avalanche tracks (586 in High Tatras and 63 in Belianske Tatras). 30.2% and 71.4% of the avalanches descend into the forest area in the High Tatras and in the Belianske Tatra Mountains, respectively (Midriak 1979). However, the number of all (also potential) avalanche paths is considerably larger (Milan 1981, 2006). According to L. Milan (2006) there are 1 749 avalanche fields with an area of 3 124.4 ha in the whole High Tatras and 160 avalanche paths with area 605.2 ha in the Belianske Tatry. The overview of avalanches in the eastern part of Slovak Tatra Mountains is given in Table 2 and in Figure 3.

Figure 3 schematically shows the position of snow avalanche paths (along with tracks of debris flows) – more precisely, perhaps, avalanche slopes – from which avalanches are breaking-away and falling down mostly by rapid to very rapid motion to a distance greater than 50 m. The size and form of signs in Figure 3 is equivalent to the actual size and configuration of the avalanche slopes. Depending on the frequency of avalanche occurrence each avalanche slope is classified into one of three categories – with a rare-, frequent- or very frequent occurrence of avalanches.

Most paths (avalanche slopes) belong to the category of slopes with very frequent occurrence of avalanches. They are located in the central part of the High Tatra Mountains – from Mt. Kriváň to Mt. Jahňací, and are typified by small area and relatively short avalanche tracks. Many of these avalanche paths do not reach the upper timberline. Snow cover does not accumulate here in thicker layers, because of sharp glacial relief, and usually slips after every major snowfall, forming smaller or medium-sized slides of snow. Larger accumulations of snow mass that would allow a release of a greater snow avalanche are formed only during exceptional meteorological situations.

Avalanche slopes with the frequent occurrence of avalanches are less common but they have larger total area. This type of avalanche slope alternates with the previous category also within sharp relief between Mt. Kriváň to Mt. Jahňací but here avalanche paths extend further downslope. In the peripheral parts of the high-mountain landscape with cliff relief, in the northwest part of the study area, especially on smooth relief of the Červené vrchy, Mt. Kasprov vrch and Liptovská Tomanová, Javorová valleys, Mt. Veľká Kopa, Krížna, Malé Krížne and Všiváky as well as on the smooth relief of the Belianske Tatry, slopes of this category also have considerable size.

Slopes with rare occurrence of avalanches are typified by largest dimensions (area). They occur mainly around zone with very frequent occurrence of avalanche/around the most sharp glacial relief – in the catchments of Tichá, Kôprovnica, Kôprová and Kobylia valleys, Mt. Kôprovský and Mt. Mengusovský, in Bielovodská, Široká and Javorová valleys, both ridge sides of the Belianske Tatry Mountains and on the southern and southeastern side of the High Tatras, especially on smooth-facetted surfaces of slopes where avalanches have very long paths and can also threaten some of the Tatra settlements.

Fig. 4. Map of snow avalanche tracks and avalanche starting zones in the High Tatra Mountains. (by Z. R ą c z k o w s k a et al. 2015).

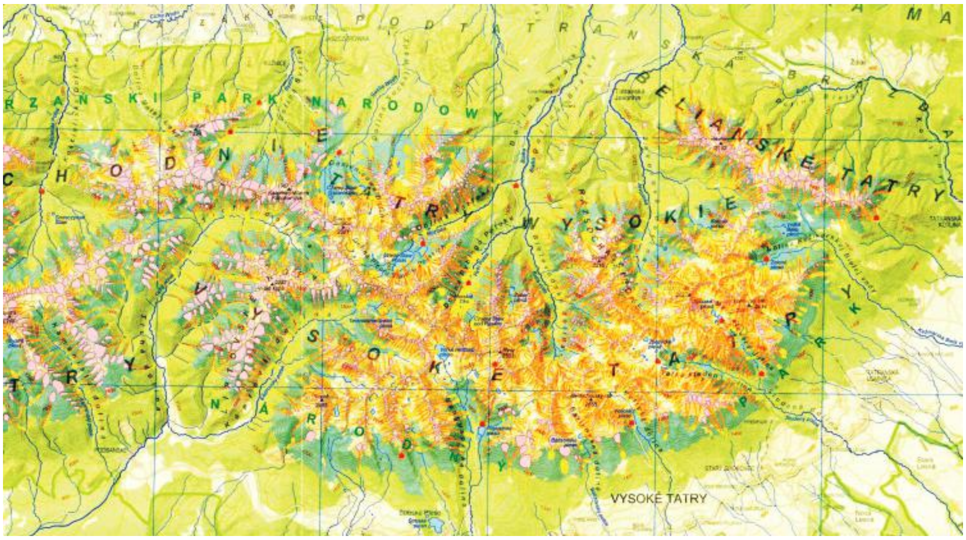

Fig. 5. Map of potential snow avalanche paths in the eastern part of the Tatra Mountains and a section of the Western Tatra Mountains (Ž i a k, D ł u g o s z 2015).

Above mentioned quantitative analysis of avalanche hazard (Fig. 3; Table 2) was based on the data from earlier mapping (mainly by K ň a z o v i c k ý 1979). Maps of avalanche paths in the Tatra Mountains by Z. R ą c z k o w s k a et al. (2015; Fig. 4) as well as by M. Ž i a k and M. D ł u g o s z (2015; Fig. 5) are not an object of quantitative evaluation of the hazard in our work.

The above maps show potential avalanche paths. Because of detailed interpretation of relief model (Digital Terrain Model), the number of such avalanches paths is greater than in our quantification. According to the map (Fig. 4) by Z. Rączkowska et al. (2015) 166 potential avalanche paths occur in the Belianske Tatra Mountains, in contrast to 63 actual (permanent) paths considered in our evaluation. According to the map (Fig. 5) by M. Žiak and M. Długosz (2015) there are 3 000 potential avalanche paths in the Slovak part of the Tatra Mountains, in contrast to 1 042 paths mapped by Kňazovický (1979). Based on the mean length of potential avalanche paths, the total length of avalanche paths amounts to 1 860 km (Žiak and Długosz 2015; Rączkowska et al. 2016). The presented data thus accurately designates a massive snow avalanche hazard in the Tatra Mountains (including our study area) – see also data of R. Midriak (1979) and L. Milan (2006).

NATURAL HAZARD DUE TO DEBRIS FLOWS

Debris flows in the Tatras have been described by R. Midriak (1984), A. Kotarba (2007 and other works), A. Kotarba and M. Długosz (2010), A. Kotarba et al. (2013) and partly by other Polish authors. Debris flows are plastic, water-saturated muddy masses (as a product of weathering and others destruction processes), which move downslope within chutes and gullies at slow to moderate velocity (Laatsch and Grottenthaler 1972).

Although these debris flows originate predominantly above the upper timberline, they often transport alongside the rock debris and boulders also entire trees or ripped out stands of dwarf pine. Downslope they may reach sides of mountain stream valleys delivering excessive amounts of sediment to their channels. In all cases, devastating force of these water-gravitational processes is significant (e.g. in 1913 a large debris flow deposited boulders in close vicinity of Starý Smokovec).

By analyzing the geomorphological map of the High Tatras (Lukniš 1973) and partially the map of gravitational deformations in the crystalline Western Tatra Mountains (Mah r 1973) we found that there are 362 paths of debris flows in the eastern part of the Tatra Mountains. We show them in Figure 3 together with the avalanche slopes/paths. We emphasize the double threat to the same slope surface on which avalanche paths overlap with the paths of debris flows. Up to 113 avalanche slopes are also transformed by debris flows. Such overlapping may occur especially on the wider avalanche slopes. The majority of avalanche slopes with such paths (57%) are slopes with rare occurrence of avalanches, 33% with frequent occurrence of avalanches while on only 10% of avalanche slopes both snow avalanches and debris flows occur very frequently on the same paths. While in winter there is a considerable avalanche hazard, in the late spring, but especially in summer and partly in autumn (Midriak 1983a) both processes may occur, in particular on the open slopes above the boundary of the continuous dwarf pine stands and in the rocky chutes (Midriak 1994; Kotarba 2004).

Out of 362 debris flows paths in the eastern part of the Tatra Mountains 235 are single (simple) and 43 multi-branches (bifurcated) paths. Bifurcated paths are composed of 127 branches which may, depending on the intensity of filling with free debris, pose means isolated (local) hazard as a separate unbranched path of the debris flow.

In the eastern part of the Tatra Mountains there are 5 categories of the occurrence of the debris flows paths (Midriak 1984): paths in the subalpine belt up to 1900 m a.s.l. and in the forest belt (below 1400 m a.s.l.) – but often reaching valley floors (over 23%); paths extending from the alpine belt (over 1 900 m a.s.l.) to the upper timberline only (ca. 1400 m a.s.l.) (the same share); paths occurring between 1400 and 1900 m (22%); paths entirely above 1900 m a.s.l. (almost 17%) and paths starting below the upper timberline (1400 m a.s.l.) (14%).

As for the length of the debris flow paths, the category 250–500 m (over 51%) prevails, 36.5% are 500–1000 m long. Only 9% of the paths are longer than 1000 m and paths shorter than 250 m constitute 3%.

Activation of debris flows is rather rare (Kotarba 1992, 2004). The author (Midriak 1983a) associates their frequency with the rainfall intensity exceeding 100 mm/24 hours (according to the observations of Kłapa (1980) in the Polish Tatra Mountains), that is one rainfall event every 3.2 years on average.

Similarly as in the case of snow avalanche paths also a map of debris flows paths in the Tatra Mountains was developed in the recent years by M. Długosz (2015). We show it in Figure 6. According to this author, in the entire Tatra Mountains there are about 3 500 recent, old and very old debris flow paths. This contrasts with 362 paths shown on our map of the study area – Figure 3, or about

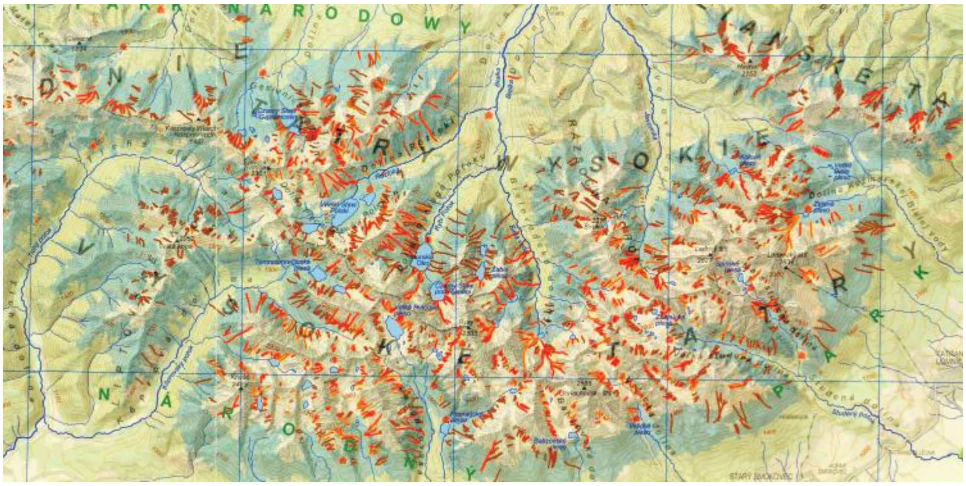

Fig. 6. Map of old and recent debris flows paths in the eastern part of the Tatra Mountains (by Długosz 2015, Atlas of the Tatra Mountains)

Table 3
Mass-movement processes in the landscape of the eastern part of the Slovak Tatra Mountains and their foreland

Types and forms of mass-movement processes according to landscape types	Number of locations	Area (ha)
Gravitational, water-gravitational, nivation and cryo-gravitational processes in flysh foothill of highlands and higher uplands	3	154
Gravitational, water-gravitational, nivation-gravitational and cryo-gravitational processes in core high mountains, foothill highlands and highlands	29	3 177
Gravitational and water-gravitational processes in intramountain depressions and intermontane basins	8	527
Endangered and destroyed slopes by both snow avalanches and cryogenic processes in middle mountain and high mountain areas of highlands and higher uplands		11 800
Total	**40**	**15 658**

450 on maps by A. Nemčok (1972) from Slovak Tatra Mts. This great number of debris flow paths, mapped in detail, gives evidence of the actual debris flow hazard and its potential geomorphological effect (Kotarba et al. 2013) in the high-mountain landscape of Tatra Mountains.

HAZARDS FROM OTHER MASS–MOVEMENT PROCESSES

For the sake of completeness we quantify also the hazards associated with other mass-movements processes. In the eastern part of the Tatra Mountains and their foreland, we focused on the areas with multiple slope disturbances (due to mass-wasting processes) according to the map by A. Nemčok (1982). Their quantification is given in Tab. 3 and in Figure 7.

Most of the mass-movement processes occur in the crystalline part of the High Tatras, and in their Mesozoic part (Javorová Valley and Mt. Javorinská Široká). They are concentrated mainly in the west. Such slope disturbances are typified by scree slopes, rugged ridges, debris cones, fewer landslides, debris flows, slush avalanches, stone streams, and other.

Three local clusters of mass movement occur where flysch outcrops are present on the surface (in the area of Podspády settlement, Mt. Tokáreň and Bachledova Valley – along the boundary of Spišská Magura). The most typical forms include block disruptions and block fields, but in particular landslides and sometimes earthflows.

In the higher part of the Poprad basin there are eight slope disturbances, mainly landslides. Within their reach ski jumps are situated, along with other sports facilities.

Figure 7 shows areas prone to and affected by snow avalanches and various diffused cryogenic processes (frost shattering of rock walls, solifluction, activity of needle-ice and other forms of soil ice causing surface material sorting, freeze-heaving and other regelation processes) in the eastern part of the Tatra Mountains. Such areas extend over more than 11 800 ha from the western border of the study area to the entire range of the Belianske Tatry Mountains in the northeast of the study area (total about 26 % of the evaluated study area).

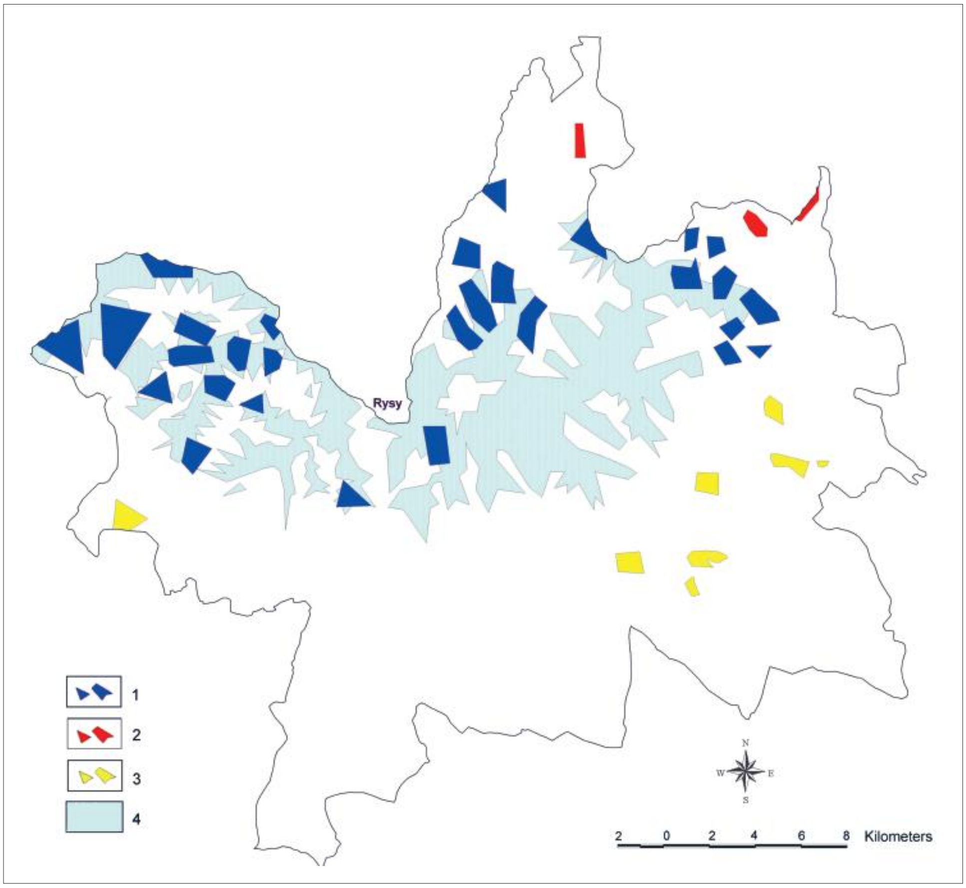

Fig. 7. Hazards related to mass-movement processes in the eastern part of the Slovak Tatra Mountains and their foreland 1 – gravitational, water-gravitational, nivation-gravitational and cryo-gravitational processes in core high mountains, foothill highlands and highlands; 2 – gravitational, water-gravitational, nivation and cryo-gravitational processes in flysh foothill of highlands and higher upland; 3 – gravitational and water-gravitational processes in intramountain depressions and intermontane basins; 4 – slopes endangered and destructed by both snow avalanches and cryogenic processes in mid-mountain and high mountain areas of highlands and higher uplands

CONCLUSIONS

Geomorphic hazards in the eastern part of the Slovak Tatra Mts and the easternmost part of the Western Tatras and their foreland, analysed and assessed in this paper are relatively serious. They mostly depend on relief and precipitation. Very high slope inclinations in the Tatra Mountians (L u k n i š 1973; M i d r i a k 1983a – according to our investigation 56% of slopes above upper tree line in the High Tatras and 76 % in the Belianske Tatry Mts have inclinations over 30 degrees) support not only avalanche and debris flow hazards, but also water erosion processes and almost all gravitational mass-movement processes.

Climate conditions are also very important (M i d r i a k 1983b). According to the Landscape A t l a s of the Slovak Republic (2002) mean annual precipitation in the Tatra Mountains ranges from 1 000 mm to ≥ 2 000 mm, the number of days with snow cover ranges from 140 to ≥ 250 and mean annual thickness of snow cover reaches 55.7 cm (in Štrbské Pleso at 1 330 m a.s.l.). Extreme rainfalls fluctuate from 106 mm to 300 mm/day in Hala Gąsienicowa at 1 520 m a.s.l. (K ł a p a 1980).

Each of the analysed processes and the above mentioned climate conditions expressly affect the progressing destruction of relief in the Tatra Mountains and their foreland (see also B o l t i ž i a r 2009).

DEDICATION

This paper I devote to my fellow Prof. dr. habil. Adam Kotarba on the occasion of his 80th birthday.

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