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L A N D F O R M E V O L U T I O N I N M O U N T A I N A R E A S
Recent geomorphological hazards in Carpatho-Balcan-Dinaric region

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GEOMORPHOLOGICAL HAZARDS IN SLOVAKIA

Abstract. The article is focused on an assessment of spatial distribution and mutual relations of the most marked geomorphological hazards in Slovakia. There are defined areas threatened by partial hazards, namely by earthquakes, landslides and related phenomena, karst and mining subsidence and collapsing, snow avalanches, water and wind erosion as well as both regional and local floods. Consequently, the spatial structure of combinations of extreme values of various hazard types from the viewpoint of their possible synergetic operation and multiplication effect is analysed. Finally the authors present synthetic characteristics of hazards and delimit basic hazardous regions. Typifying the Slovak area from the viewpoint of various types of geomorphological hazards represents the result, which is utilisable in the process of landscape planning at a regional level.

Key words: geomorphological hazards, total hazard value, cumulative effect of hazards, hazardous regions, Slovakia

INTRODUCTION

Problems of geomorphological hazard evaluation start to appear in the literature more frequently from the 1990s (e.g. Cooke and Doornkamp 1990; Panizza 1996; Kalvoda and Rosenfeld 1998). As for Slovakia, though a lot of partial hazard assessments have been published so far (cf. the representative maps of some hazards in the "Landscape Atlas of the Slovak Republic" (*Atlas krajiny Slovenskej republiky*, 2002)), a comprehensive, synthetic evaluation of the most important geomorphological hazards has not been done yet. This paper presents the first attempt to fill this gap.

The Slovak territory includes the majority of the West Carpathians, a small part of the East Carpathians and adjacent parts of the Pannonian Basin. Morphostructural effect of young tectonic movements, miscellaneous natural conditions and human interventions into the landscape result in a relatively high degree of numerous partial geomorphological hazards. These are namely earthquakes, landslides and related phenomena, karst and mining subsidence and collapsing, snow avalanches, water and wind erosion as well as floods, with many of them showing mutual relations. The spatial distribution of geomorphological hazards is largely in accordance with the geomorphological division of the country, however some specific exclusions exist, as explained in detail below.

Although the territory of Slovakia is not ranked among the most hazardous regions of the world, geomorphological hazards represent a serious issue for the economy and development of the country. The average annual loss of some tens of human lives and financial damage of tens of millions of € results from geomorphological processes. Regional analysis of the problem is therefore essential for the public administration, insurance business but also for decision-making of investors and private individuals.

MATERIAL AND METHODS

Geomorphological hazards are understood here as a probability of occurrence of the geomorphological processes endangering human interests in the affected area. The probability of frequency and magnitude of these processes defines a value of a partial hazards. The geomorphic effect of a partial process (per time unit) also depends on its magnitude and frequency and than it can be considered as an estimate of a hazard value.

The maps evaluating either geomorphic effect or magnitude and frequency of the main hazardous geomorphological processes in Slovakia represented the basis for our analysis. We have unified these various source materials into a homogeneous database based on elementary geomorphological units (in the original scale of 1 : 500,000) that were delimited by an overlay of the map of the individual geomorphological regions (Mazúr and Lukniš 1980) and the map of the morphometrical-morphological types (Tremboš and Minár 2002). It enabled us to achieve the necessary degree of generalisation of unequal sources while the relative homogeneity of hazard-forming natural conditions in the units is ensured by the high correlation of georelief characteristics with properties of rocks, soils, climate and hydrological conditions as well as with a basic character of land cover.

The majority of maps of partial hazards (namely seismic, landslide, wind and water erosion hazards) were made by an overlay of source maps and a map of elementary geomorphological units, computation of the average value of hazard in these units (using map algebra) and then its subsequent visualisation. Naturally, the use of geomorphological units for the expression of partial hazards in these maps leads to loss of some spatial details. Only one value of hazard was estimated for the whole unit regardless of land cover differentiation. However, this differentiation is reflected in partial hazard values. The remaining three maps, namely of karst/mining subsidence and collapsing, snow avalanche and flood hazards were constructed using geomorphological units as a basis for a unified database from the beginning of their elaboration. A consistent 3-degree scale (i.e. low, medium, high) was used for the estimation of all partial hazard´s values.

ArcView 3.3 was used as the main tool for the geoinformatic processing. The DVD-version of the above mentioned "Landscape Atlas of the Slovak Republic" was used as the source of borrowed analytical information. The resultant synthetic map representing synthetic characteristics of hazards and basic hazardous regions was created using just this database. Genetic types of hazardous geosystems, total value of hazards and probability to create cumulative effect were taken into account as the three classification criteria. The first of these criteria, i.e. genetic types of hazardous geosystems, was defined according to dominance of hazards determined either litho-structurally (earthquakes, landslides, karst/mining subsidence and collapsing) or climatically (snow avalanches, wind and water erosion, floods). The algorithm for estimation of the last two of these criteria was based on system analysis of geomorphological hazards (Fig. 1). The weighted sum of values of partial hazards was used for the estimation of total hazard (Table 1) and the estimation of the probability to create a cumulative effect (Table 2).

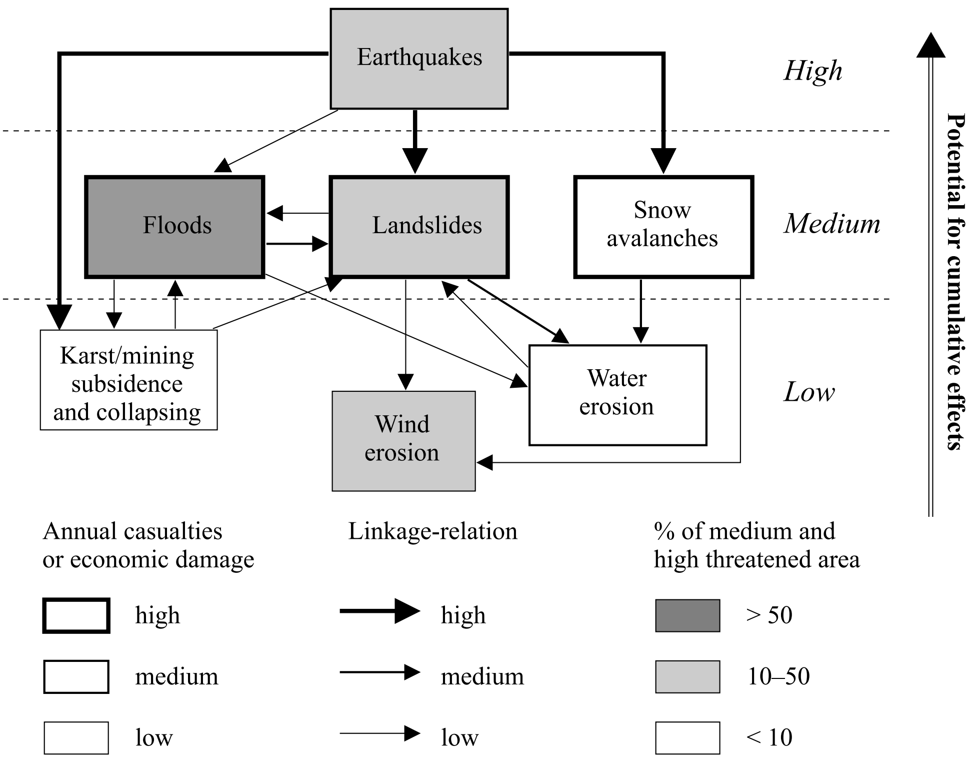

Fig. 1. System scheme of main geomorphological hazards in Slovakia

Table 1

Weight of partial hazard's values in the estimation of the total hazard value

Hazard value / Name	Earth-quakes	Land-slides	Karst/mining subsidence	Snow avalanches	Water erosion	Wind erosion	Floods
Low	0	1	1	0	1	0	1
Medium	1	3	2	3	2	1	3
High	2	5	3	5	3	2	5

Table 2

Weight of partial hazard's values in the estimation of probability to create a cumulative effect

Hazard value / Name	Earth-quakes	Land-slides	Karst/mining subsidence	Snow avalanches	Water erosion	Wind erosion	Floods
Low	0	0	0	0	0	0	1
Medium	3	2	1	1	0	0	2
High	6	4	2	3	0	1	3

PARTIAL HAZARD ASSESSMENT

HAZARDS DETERMINATED LITHO-STRUCTURALLY

The seismic hazard has a specific position among geomorphological hazards in Slovakia. In fact, it represents the only threat connected with endogenous processes. The country is characterised by weak to medium seismic hazard in comparison to worldwide conditions (2–3 weak earthquakes per year, once every 5–10 years earthquake accompanied by little damage and once every 50–100 years an earthquake causing bigger damage). However, some strong earthquakes (to 9° MSK-64) were recorded in the past (e.g. in Komárno 1763: seven churches and 297 houses were destroyed completely and 63 people were killed). The supposed frequency of such events is some hundreds of years.

Seismic hazard have been studied from the detailed level (e.g. Viskup and Janotka 1996; Labák et al. 1998; Hrašna 2002) to regional generalization (e.g. Brouček 1980; Šefara et al. 1998; Schenk et al. 2002; Kováč et al. 2003). Until 2004, the studies were based on the network of six fixed seismic stations and four specific stations that were rather outmoded and not fully spatially representative. Estimation of differentiation of actual seismicity was facilitated with the help of macroseismic observations. The historical records are also not sufficiently homogeneous and thus represent the weakest link of seismic hazard assessments relating to the occurrence of long-frequency disastrous earthquakes. In 2004 the new National Network of Seismic Stations was established. It consists of 12 modern stations and makes the more accurate location of future active epicentral zones possible.

The map of seismic hazard (Fig. 2) was elaborated by adaptation of a layer of maximum expected seismic intensity from the map "Selected geodynamic phenomena" (Klukanová et al. 2002). Such an expression of seismic hazard seems to be suitable as the seismic intensity correlates with the frequency of earthquakes. The less distinguishable level of the source map is reflected in a smaller territorial differentiation of this hazard than it is probable in reality. Seismic activity is concentrated along main active fault structures mainly on the boundary between the Carpathians and Pannonian Basin and between the Outer and Inner West Carpathians. Epicentres of earthquakes are as a rule situated on the fault junctions (surroundings of the Malé Karpaty Mts., towns Komárno, Žilina, Zvolen, Humenné etc.). Although Slovakia was not affected by serious earthquake within the last hundred years, a probability of its occurrence is rising every year. As the earthquake also acts as a trigger of some other geomorphological processes, the approaching seismic event does not only increase the hazard of the earthquake as such but also of accompanying phenomena, or in other words it raises the probability to create the cumulative effect.

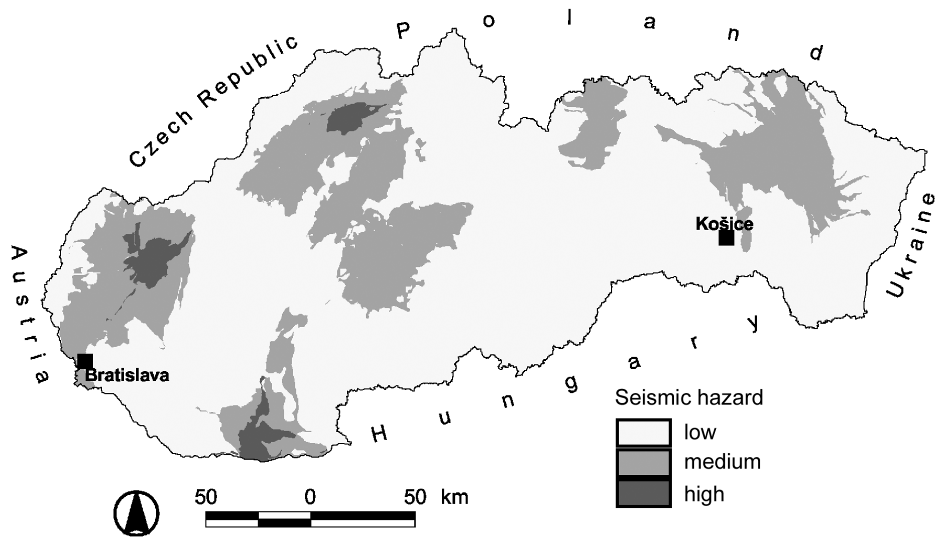

Fig. 2. Seismic hazard (the modification of one layer of the map by Klukanová et al. 2002)

The hazard of landslides and related phenomena (creeping, flowing, falling) is relatively high in connection with the predominantly mountainous character of Slovakia. Landsliding is represented by rotational, planar and combined landslides, flowing is represented by earth flows (as well as by debris flows in the highest positions of high mountains), falling is represented by rock topples and planar rock falls (cf. M a l g o t and B a l i a k 1994). Also a deep-seated creep can be transformed into a dangerous phenomenon under special circumstances. The regional extent of the above slope failures depends on the geologic structure and rock type, geomorphic, hydrogeologic and climatic conditions. The most affected areas are flysch uplands, the intra-mountain basins and marginal parts of young volcanic mountains. Partial types of slope failures were formed in the so-called core mountains.

Naturally, up to now special attention was devoted mostly to present slope failures, especially to landslides. The total number of these failures in Slovakia is approximately 20,000, while the total area of their occurrence covers more than 1,900 km^2, i.e. almost 4% of Slovak territory (L i š č á k 2002); their spatial distribution was introduced in the latest map by A. K l u k a n o v á et al. (2002). About 90% of new landslides are influenced by human activity (M a l g o t and B a l i a k 2002).

Besides the maps assessing the spatial distribution of existing slope failures the maps dealing with landslide hazard were also created, some of them for the whole of Slovakia. J. U r b á n e k (1980) elaborated the map of potential landslide areas and recently R. L i š č á k (2002) elaborated the map of susceptibility to landslides. The latter author delimited areas with three different degrees of susceptibility, namely high, moderate and low. His map was used as a source material for our map of landslide hazard (Fig. 3). In fact, the areas with a high degree of susceptibility to landslides correspond well with areas of the highest concentration of existing landslides.

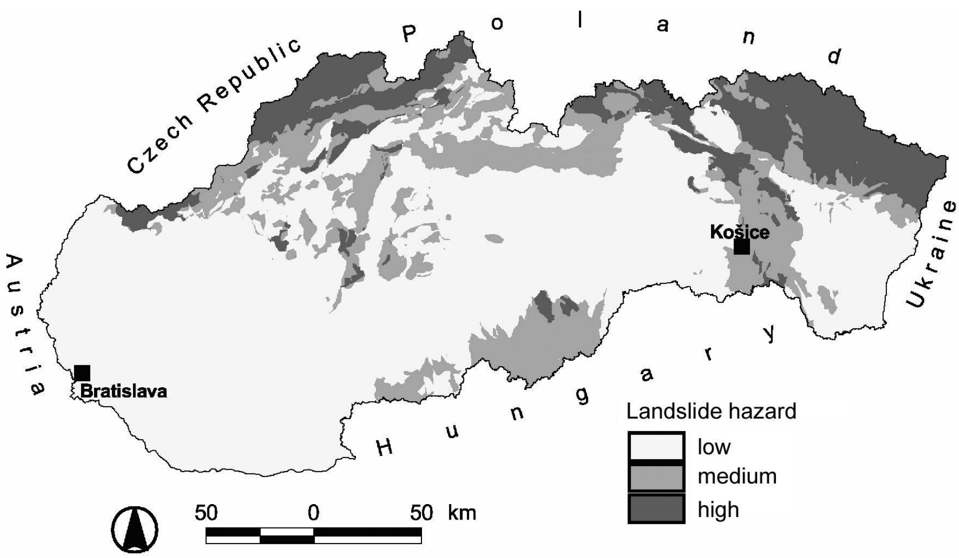

Fig. 3. Landslide hazard (the modification of the map by L i š č á k 2002)

The 3rd partial geomorphological hazard of this type represents the hazard of both **karst and mining subsidence and collapsing** (Fig. 4). According to J. Jakál (2000), a significant predisposition to this hazard in the karst landscape is a high degree of subterranean karstification at a near-surface part of karst massifs. This is characterized by an occurrence of extensive subterranean cave systems in a senile stage of evolution with an existence of domed spaces threatened by sudden collapses of cave ceilings. The hazard of collapsing increases in areas where carbonate massifs are strongly affected by tectonics and also where the genetically oldest cave levels lie close to a terrain surface. Block sinking or cave ceiling collapsing are caused by corrosive broadening of fissures, by congelifraction acting along these fissures and by the consequent free circulation of precipitation water in the vadose zone. The most frequent occurrence of these phenomena is in the Silicicum tectonic unit, mostly in the central parts of the Silická and Plešivecká planina Plateaus, where their surface is deformed more markedly by sinking of big blocks often accompanied by collapsed chasms of the "light hole" or "aven" types. Gravitational sinking of karstified blocks and the origin of fissure caves and chasms is linked to the high-mountain karst in the Červené vrchy Mts. and Belianske Tatra Mts.

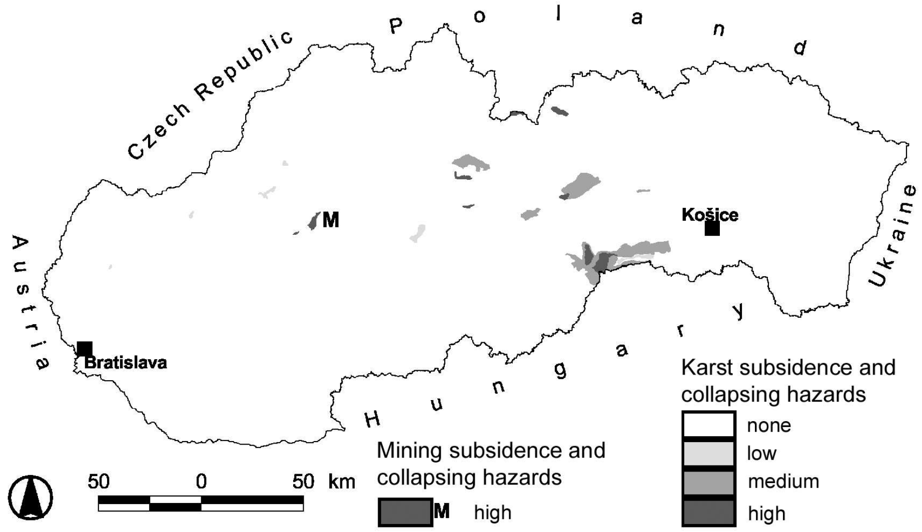

Fig. 4. Karst/mining subsidence and collapsing hazards

The active collapsing of the karst surface, disturbing the stability of buildings and roads, occurred within the basin karst type in the area of the Bystriansko-valaský kras Karst in the 1960s (cf. Kubíny 1974). The Rissian terrace of the Hron River is penetrated by a system of subterranean cavities (up to 30 m long), culminating in narrowed openings into overlying terrace gravels. Collapses were triggered by erosion due to underground water during a sudden rise of the water resulting from heavy rains.

Subsidence and collapsing are phenomena also typical for mining areas. Of course, the process is similar but its cause is different. The most marked manifestations of these processes due to mining occur in the contact zone of the Hornonitrianska kotlina Basin and the Vtáčnik Mts. Underground and also partially surface mining of brown coal and lignite has distinctly changed the relief configuration due to sinking ground. The occurrence of large, shallow, closed sinking depressions and deep depressions of a shaft-like form disturb the original appearance of the landscape. Surface consequences of underground mining resulted in a necessity of the gradual partial evacuation of some villages in the area (Jakál 1998).

HAZARDS DETERMINED CLIMATICALLY

Snow avalanches represent serious geomorphological hazard in the high mountains of the West Carpathians. Avalanches cause several deaths annually in Slovakia. 24 people were killed and 33 injured by avalanches from 2000 to 2005. Skiers, mountain climbers and hikers are the most endangered groups. Up to 300 avalanches are registered each winter season in the Slovak Carpathians.

Snow avalanches occur in the Tatras, Low Tatras, Malá and Veľká Fatra Mts., and Chočské vrchy Mts. Their occurrence in other mountains is very rare and is linked only with periods with very thick snow cover (e.g. Súľovské vrchy Mts., Oravská Magura Mts.). The most avalanche-prone areas are mountain slopes with inclination of 30–45° and a smooth surface (grass, fine gravel etc.), especially above the upper timberline. However, avalanches were also reported in broadleaf forests, especially during the last winters, some of them temporarily blocking highway transport (in Strečnianska úžina Valley, Malý Šturec Saddle etc.).

The main avalanche season is from January till March, but the first avalanches start to fall at the end of November, and the last occur in May. In the Tatras smaller avalanches can also fall exceptionally in summer, namely during unexpected drops of temperature with snowfall, as it happened for example in August 2005.

The map of snow avalanche hazard (Fig. 5) was elaborated on the basis of maps from "Atlas of avalanche paths in Slovakia" (Kňazovický 1979) and "Avalanche register" that is kept by the Mountain Rescue Service — Avalanche Prevention Center.

Contrary to snow avalanches, the spatial distribution of **the wind erosion hazard** is associated mostly with the lowland landscape. Though it does not belong to the most marked hazards, this process can cause, under favourable circumstances, not only negligible environmental issues.

Some works were devoted to an assessment of the spatial distribution of wind erosion so far, namely from the viewpoint of its present occurrence or of its prospective hazard. K. Jůva and J. Cablík (1954) distinguished the areas threatened by dry or cold winds and especially delimited areas prone to deflation. Š. Bučko and V. Mazúrová (1958), Š. Bučko et al. (1966) and J. Jakál (1980) delimited

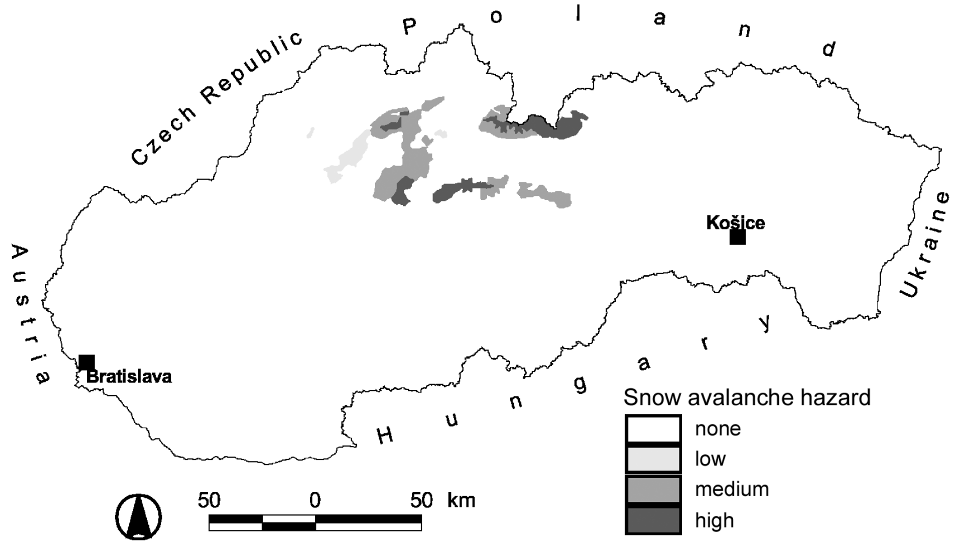

Fig. 5. Snow avalanche hazard

only the affected or threatened areas but did not categorise them. V. Pasák (1978) was the first who categorised the hazard of wind erosion; he distinguished five categories, namely slight, moderate, moderate to severe, severe and very severe. A. Klukanová et al. (2002) distinguished three categories (namely moderate, high and extreme) in the up to now most detailed map of wind erosion hazard (1 : 500,000).

Wind erosion occurs mostly in all three Slovak lowlands, namely the Záhorská nížina Lowland (together with the adjacent part of the Dolnomoravský úval Valley), the Danube Lowland and the Východoslovenská nížina Lowland. Less threatened areas are represented by parts of the Juhoslovenská kotlina Basin, the Cerová vrchovina Upland, the Košická kotlina Basin and the lower Váh Valley. In these areas, wind erosion threatens both flat and sloping positions, but in fact during only a small part of the year. From the temporal viewpoint it is concentrated into the period of winter and early spring months when the most favourable conditions for deflation (frozen, dusty and vegetation-free surface of soil) occur. After the winter transition the dry soil is easily detachable and under a strong, gusty wind large quantities of the most fertile surface layer are often blown out which could result in sandy or dusty storms (according to texture of affected soils). Particularly vulnerable are larger parcels with texturally lighter sandy soils, but deflation is not rare on loamy soils either (Jambor 2002). Unfortunately, the map of the wind erosion hazard (Fig. 6), elaborated on the basis of the above mentioned map by A. Klukanová et al. (2002), introduces almost exclusively endangered areas with sandy soils.

Water erosion means a marked geomorphological hazard and is a hot environmental issue. A broad palette of studies devoted to its assessment at various

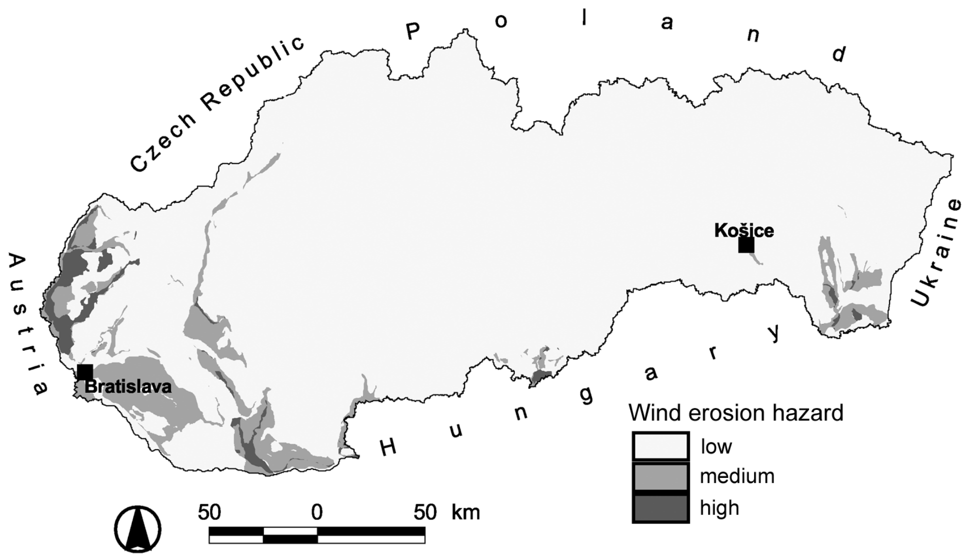

Fig. 6. Wind erosion hazard (the modification of the one layer of map by Klukanová et al. 2002)

spatial scales corresponds well with the importance of this phenomenon. It is possible to distinguish three groups of works assessing the spatial distribution of water erosion within the whole of Slovakia. The first includes the maps illustrating the areas affected by gully erosion (Bučko and Mazúrová 1958; 1 : 400,000), or by both areal and gully erosion (Bučko 1980; 1 : 1,500,000). The second group consists of the maps of potential water erosion hazard that do not take into account vegetation cover, e.g. the maps by R. Midriak (2002) and especially M. Šúri et al. (2002a), both at the scale of 1 : 1,000,000. The third group represents the maps of actual water erosion hazard taking into consideration the protective function of a forest. The first work in this group was the map by Š. Bučko et al. (1966; 1 : 1,000,000). The most realistic attempt to assess the actual hazard of water erosion is the map by M. Šúri et al. (2002b), taking into account a contemporary land cover. The map shows that in total about 55% of Slovak territory is actually endangered by water erosion, while about 17% of the area is threatened by erosion at moderate to very high rates (Šúri et al. 2002c). This map served as the source material for our map of water erosion hazard (Fig. 7).

The highest actual hazard of water erosion occur mostly in the agricultural areas lying in wide contact zones between lowlands or intra-mountain basins with mountains, as well as in the intra-mountain erosion depressions. These are remarkable for a relatively high share of medium to low resistant rocks (especially flysch and volcanic ones) with a thick cover of easily erodible regolith. The most harmful manifestations of water erosion are linked with extreme events such as heavy rains or sudden snowmelts. Beside the so-called on-site effects of

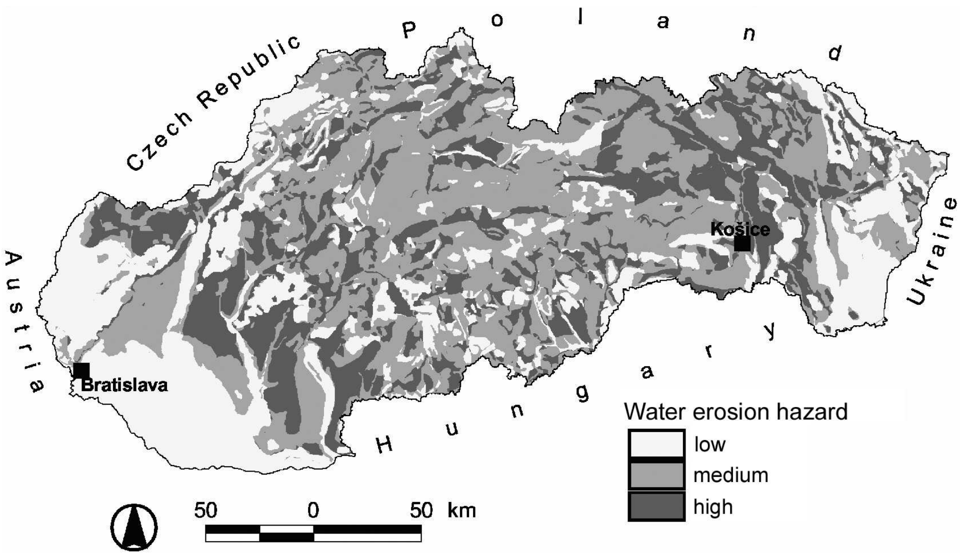

Fig. 7. Water erosion hazard (the modification of the map by Šúri et al. 2002b)

water erosion, the significant environmental issue is also represented by its off-site impacts, especially by muddy floods (Stankoviansky et al. 2006).

The flood hazard belongs to the most dangerous partial hazards in Slovakia. The regional, area-wide flooding has occurred here in the last 10–15 years on a smaller scale in comparison with neighbouring or other European countries. Slovak territory has not been affected by precipitation that would cover a major part of it and would exceed its extreme rate values (as it was in Moravian part of Czech Republic in 1997 or in Czech Republic, Poland, Germany, and in other countries in 2002). However, in Slovakia the local floods (so-called flash floods) occur regularly. Flooding of this type on the Malá Svinka Brook killed 44 people in 1998 in the village of Jarovnice in the Eastern Slovakia. We can state an increase in the number of extreme runoff events associated with an increase in intensity of extreme rainfall events of local character.

Flood hazard problems are discussed in works devoted to the evaluation of existing flood situations, which are both of regional (Hambek 1995; Škoda et al. 1997) and local (Pacl 1959; Svoboda and Pekárová 1998) character. Studies dealing with flood hazard and flood risk management problems (e.g. Gilard 1996) appeared only few years ago (Minár and Tremboš 1994; Trizna and Minár 1996; Trizna 1998). The work by J. Minár et al. (2006) deals with the landscape potential for flooding in Slovakia (taking into account the system of current flood protection). The generalised results of this work are introduced in Figure 8.

Territorial differences of the flood hazard in Slovakia can be defined on two levels. On the first level, it is the flood hazard caused by regional floods from cyclonal precipitation or from the snowmelt. Principally the Východoslovenská

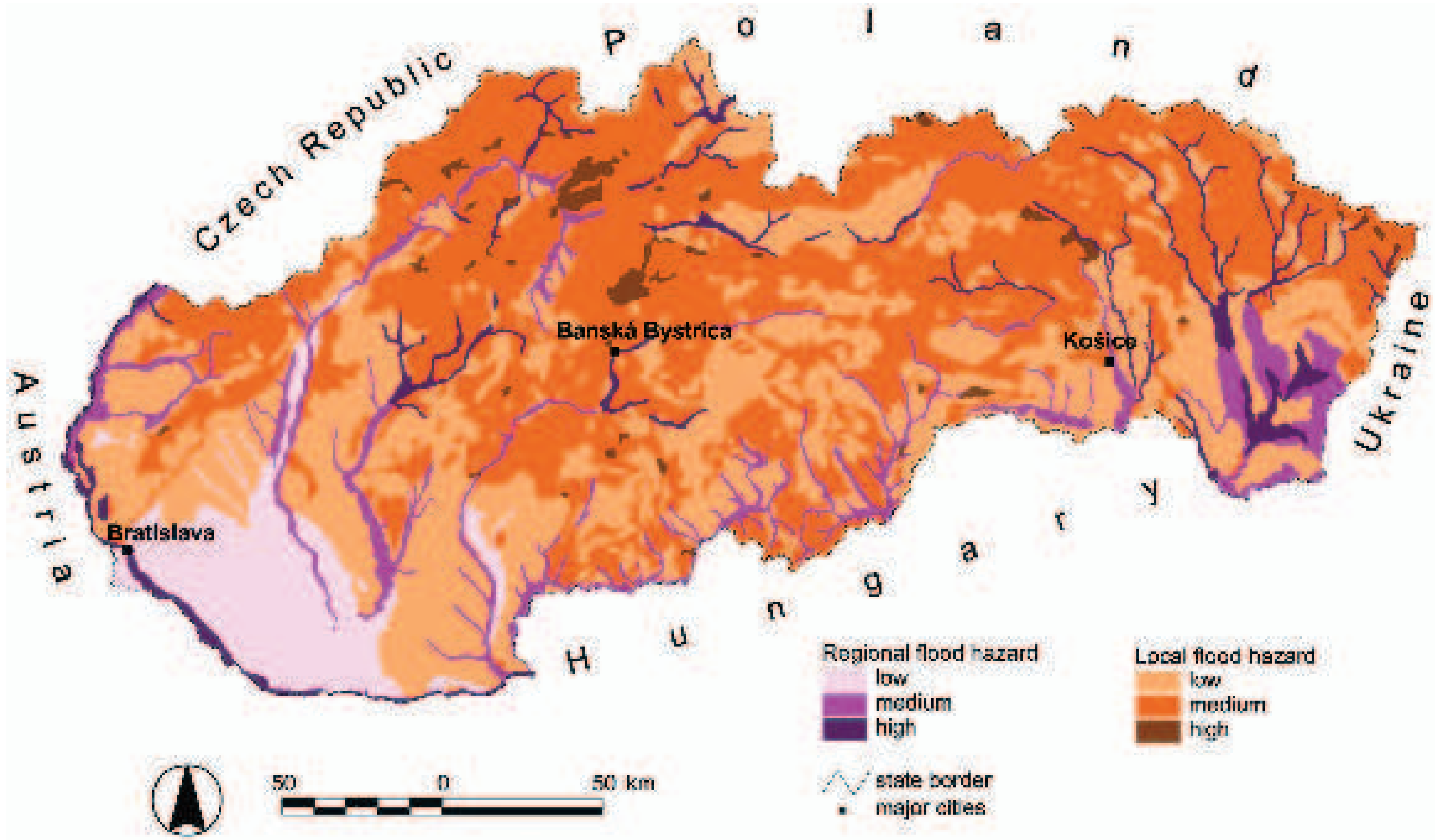

Fig. 8. Flood hazard (the generalisation of the map by Minár et al. 2006)

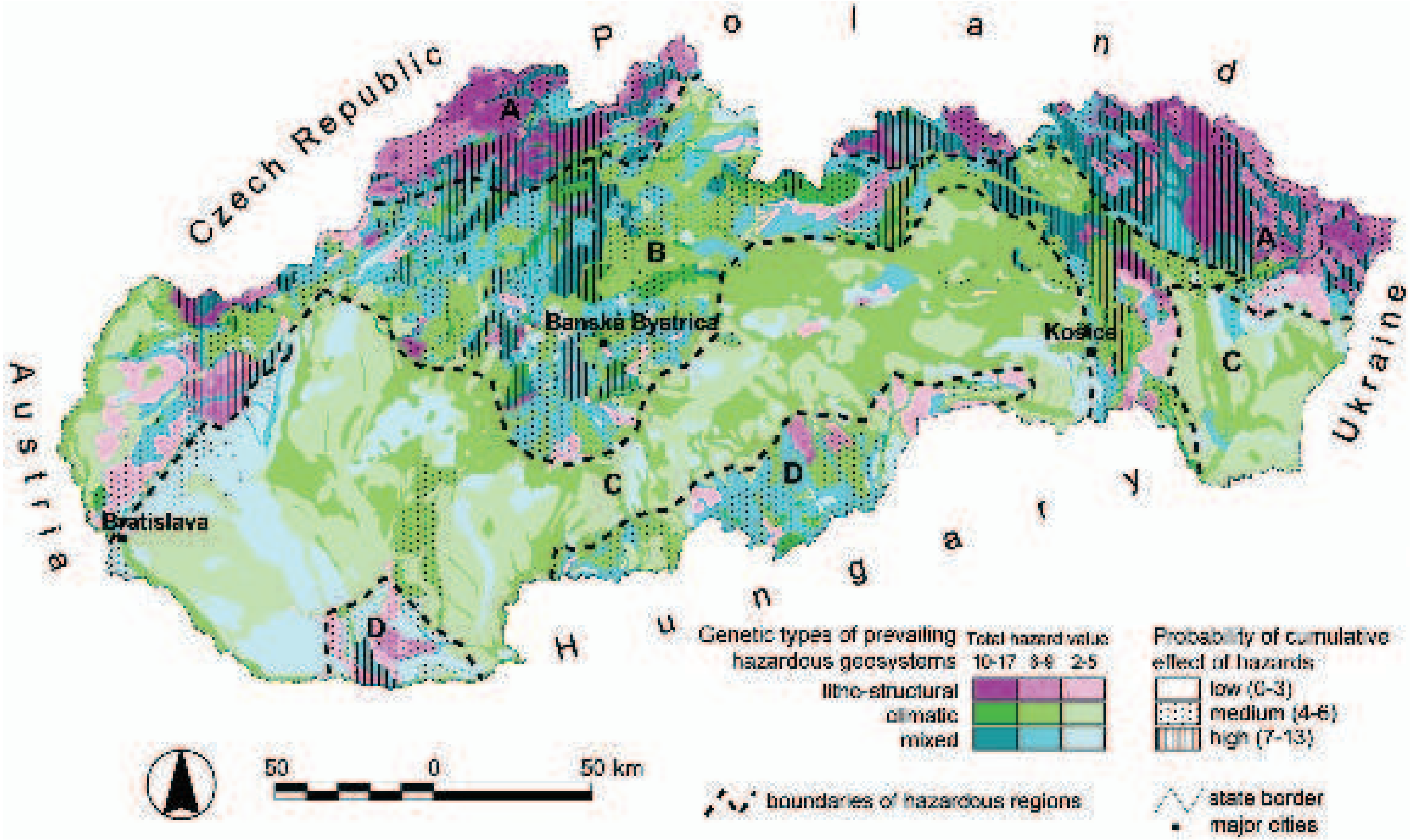

Fig. 9. Synthetic characteristics of hazards and basic hazardous regions. A — extremely hazardous flysch region, B — north contrast hazardous region, C — central low hazardous region, D — south contrast hazardous region

nížina Lowland belongs to one of the most endangered regions besides the floodplains of larger rivers (the Danube, Hron, and Ipeľ Rivers). It is induced by the georelief morphology that determines the occurrence of internal waters (i.e. waters that are accumulating in closed depressions under increased water levels in rivers or during sudden snowmelts). On the second level, it is the measure of the local flash flood hazard. From the point of view of conditions for the formation of extreme runoff, the territory of the flysch belt is the most endangered area besides the highest mountains (the High Tatras, Low Tatras, Malá Fatra Mts.).

The present systematic observation of flood events in Slovakia together with geoecological research of flood hazard of the landscape gives a good basis for the perspective development of research in this sphere.

SYNTHETIC CHARACTERISTICS OF HAZARDS AND BASIC HAZARDOUS REGIONS

The structure of the created database on partial hazards gives us various synthetic views on geomorphological hazards in Slovakia, both of lower and higher order. The authors introduce three selected syntheses of lower order, namely territorial differentiation of three basic genetic types of hazardous geosystems (determined litho-structurally, climatically or mixed), total hazard value as a weighted sum of a partial hazard's value (Table 1) and probability of the cumulative effect of the hazards (Table 2) that are presented in the synthetic map (Fig. 9). Even though undoubted linkage exists between total hazard value and cumulative effect, their interpretation value is variable. This is why three different, independent synthetic informations are included in this map: 1) main controlling factor (litho-structural or climatic conditions), 2) probability of occurrence of any hazardous process and 3) probability of a chain reaction of hazardous process. Their combinations in situ and the spatial structure of these combinations represents the synthesis of higher order. A typical feature of synthetic hazardous characteristics in Slovak territory is heterogeneity (see Fig. 9). However, a similar pattern (similarity in heterogeneity) represented a basis for the identification of four basic hazardous regions that are characterised below.

The extremely hazardous flysch region is characterised by a high total hazard value as well as by a cumulative effect (more than 50% of its area is in the highest degree and almost all area in the medium degree in both cases, but their territorial distribution is different) and by the dominance of litho-structural and the near absence of purely climatically hazardous geosystems. The region represents the majority of the Outer Carpathians and the landslide-prone flysch lithology is a determining factor in its formation. However, a high total hazard value is also determined by intensive agricultural land use (water erosion and flooding) and by increased tectonic activity. A mosaic of three depicted synthetic characteristics in Figure 9 is formed by their values that differ from each other only slightly.

This is why the region is in fact more homogenous than it looks on the map mosaic. An area-wide representation of a high degree of synthetic hazard indicators suggests a necessity to pay the maximum attention to hazard management.

The north contrast hazardous region is characterised by high variation in all synthetic characteristics, but the most frequent are medium values. Contrary to the previous region, the north region is markedly heterogeneous also from a morphostructural point of view and includes all the main geomorphological units of Slovakia. The mosaic of hazards that it unifies is determined by various local factors, which makes the delimitation of more distinct subregions possible. The southern spurs of this region at the border with neighbouring lowlands near Bratislava and Košice represent two of the most notable subregions. The seismic activity (delimiting the whole region from the neighbouring central low hazardous region and connecting with young differential tectonic activity) may be the integrating factor of the region's formation. Due to the character of the region, it is necessary to study hazard issues carefully and in more detail for hazard management purposes.

The central low hazardous region represents the most stable part of Slovakia from the point of view of geomorphological hazards. The general absence of litho-structural hazards (except small areas of karst/mining subsidence and collapsing) and lower values of other hazards (except water erosion) are a precondition for this stability. Mostly, a low total hazard value is thus connected with minimal possible cumulative effect and absolute dominance of climatic hazardous geosystems. In spite of the maximum hazardous homogeneity of the region, some differences between lowlands (west and east parts) and mountains (central part) exist. A medium value of flood and water erosion hazard is characteristic for the very homogeneous mountainous area consisting mainly of the oldest and most stable parts of the West Carpathians. The lowlands are more differentiated in detail, with areas of extreme flooding, wind and water erosion, but without their overlapping. The research of differential hazard of these areas should be sufficient for effective hazard management.

The south contrast hazardous region, despite of its resemblance with the north region, has several differences. The main difference is the lower degree of total heterogeneity. However, a generally lower total hazard value as well as a lower cumulative effect and a higher abundance of mixed and litho-structural geosystems are close to the character of the Košice and Bratislava spurs (subregions) of the north contrast hazardous region. Their spatial configuration also indicates an alternative to accept both south and north contrast hazardous regions as parts of a joint belt encircling the stable central part of the West Carpathians and adjacent parts of the Pannonian Basin. The south region shows two distinctive parts. The smaller west subregion is linked to the seismically "hotest spot" in Slovakia in the surroundings of Komárno. A larger, more easterly situated subregion is characterized by minimal seismicity which also differentiates it from the majority of the north contrast region. As for the study of hazards, a similar level is necessary as in the case of the north contrast hazardous region.

CONCLUSIONS

The possibility of synthetic study of geomorphological hazards of Slovakia was outlined in the paper. The method used is based on the creation of a geomorphologically unified database in GIS that enables transparency of analysis, operative actualisation, modification and input of data as well as modification and improvement of evaluation algorithms. In the future, other geomorphological hazards can be added in analysis (e.g. the hazard associated with a tree uprootal is clearly important but so far without adequate research in Slovakia) and analysis can be expanded into non-geomorphological hazards too. Characterizing interactions of partial hazards in more detail and looking for mechanisms of the creation of their territorial structure are other possibilities.

The limitation of the presented analysis by the state boundary seems to be principally unsuitable. Territorial spreading of the database could enable more comprehensive and more valuable interpretation of reasons and characteristics of regional differences. Necessary international cooperation on the given topic is the challenge for geomorphologists of the Carpatho–Balcan–Dinaric region.

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STRESZCZENIE

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ZAGROŻENIA GEOMORFOLOGICZNE W SŁOWACJI

Praca przedstawia ocenę przestrzennego występowania oraz wzajemne relacje najważniejszych zagrożeń geomorfologicznych w Słowacji. Wyróżniono obszary, na których występują trzęsienia Ziemi, ruchy masowe, ze szczególnym uwzględnieniem osuwisk, krasowe i górnicze obszary podlegające osiadaniu, obszary zagrożone przez lawiny śnieżne, erozję wodną i eoliczną oraz obszary charakteryzujące się występowaniem powodzi. Syntetyczna, geomorfologiczna typologia terytorium Słowacji, opracowana na podstawie wyróżnionych zagrożeń i przedstawiona w postaci map, jest podstawą do opracowywania planów racjonalnego użytkowania obszaru Słowacji na poziomie regionalnym.