Contributions to Geophysics and Geodesy Vol. 53/4, 2023 (413–424)

Geological and geomorphological preconditions for flash floods in Slovakia

Vladimír BEZÁK[1,*], Ján SOTÁK[1], Dušan BILČÍK[1], Martin BEDNARIK[2], Ján MADARÁS[3], Veronika SOLDÁNOVÁ[4]

[1] Earth Science Institute, Slovak Academy of Sciences, Ďumbierska 1, 974 11 Banská Bystrica, Slovak Republic

[2] Faculty of Natural Sciences, Comenius University, Ilkovičova 6, 842 15 Bratislava, Slovak Republic

[3] Earth Science Institute, Slovak Academy of Sciences, Dúbravská cesta 9, 840 05 Bratislava, Slovak Republic

[4] ESPRIT, s.r.o., Pletiarska 2, 969 01 Banská Štiavnica, Slovak Republic

Abstract: In Slovakia, we singled out thirty areas in which flash floods occurred repeatedly. The aim of our analysis was to assess the influence of geological and geomorphological factors on the occurrence of such floods. Two areas were selected as an example of the influence of these factors. It is the area of the upper reaches of Rimavica River and the area of Levočské vrchy Hills. In the first case, the relief appears to be the main factor in the occurrence of sudden floods, in the second one it is mainly the geological composition of the area formed mainly by flysch formations, which make it difficult for intense precipitation to soak in and also encourage the susceptibility of the area to landslides.

Key words: Slovakia, flash floods, geology, geomorphology

1. Introduction

Flash floods are a phenomenon that has long been considered a threat especially in the mountainous areas of Slovakia. Sudden or flash floods are sudden surges of water after a short (several hours to several days long) intense to extremely intense rainfall on small streams. They usually occur in the upper reaches of the streams and cause significant damage in the lower populated areas. These floods are not the large-scale floods on large streams, especially in the lowlands, which occur gradually and last for several days. The absolute majority of flash floods occur as a result of intense rainfall. The floods are caused by the accumulation of ice floes, trees and branches from an uncleaned forest or other objects, mudflows, landslides,

*corresponding author, e-mail: geofbezv@savba.sk

doi: 10.31577/congeo.2023.53.4.6

dam breaks etc., only occur rarely.

Flash floods are difficult to predict and are capable of causing great damage – and sometimes human casualties. According to the Slovak Hydrometeorological Institute (SHMI) data published online (`https://www.shmu.sk/en/`, Flood report) more than 110 such floods have been recorded in Slovakia over the past 30 years. So far, if they have been studied, then mainly from a meteorological and hydrological point of view and mainly by researchers from SHMI and the Hydrological Institute of the SAS (e.g. *Blaškovičová, 2010; Grešková, 2005; Majerčáková and Škoda, 1998; Šťastný, 1998*). In this paper, we will try to approach this issue based on the relevant geological and geomorphological contexts.

We charted all the floods from the above period on the map (Fig. 1), which made it possible to distinguish between the areas with frequent flash floods and areas without them, which automatically raised the question why some areas are affected more than others in the neighbourhood given the same intensity of precipitation. We will mainly focus on the geological composition of the subsoil and the relief of the territory, although other factors can also play a role, such as engineering geological properties, forest cover, technical conditions of the existing barriers, etc.

We delineated the areas with the occurrence of flash floods in the geological map (Fig. 2). This involves up to 30 areas, which can be classified

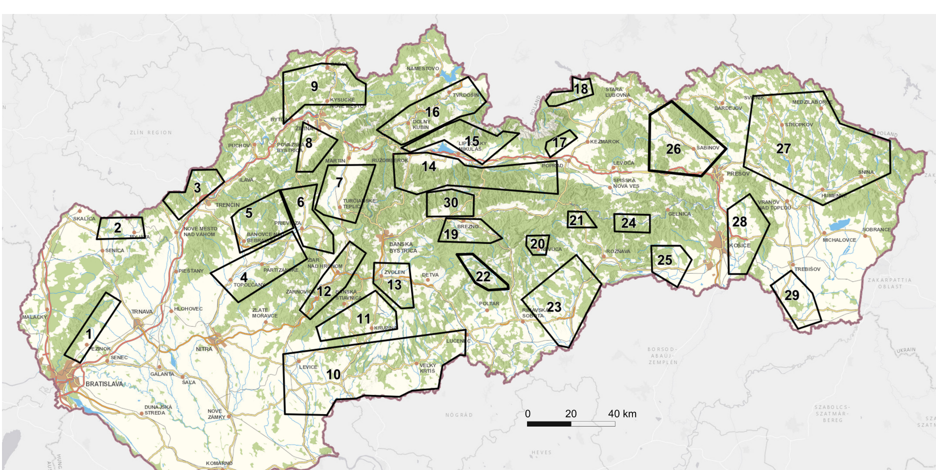

Fig. 1. Main areas of occurrence of flash floods in Slovakia (based on SHMI online data).

into four types from a geomorphological and geological point of view:

a) border regions of mountain ranges where mountain valleys open into basins and lowlands;
b) upper reaches of some rivers (e.g. the Nitra River, Rimavica River, Revúca River);
c) areas formed by flysch rocks mainly in the north and north-east of Slovakia;
d) areas at the foot of some volcanic mountains (e.g. the Slánske vrchy Hills, Vtáčnik Mts., Javorie Mts.).

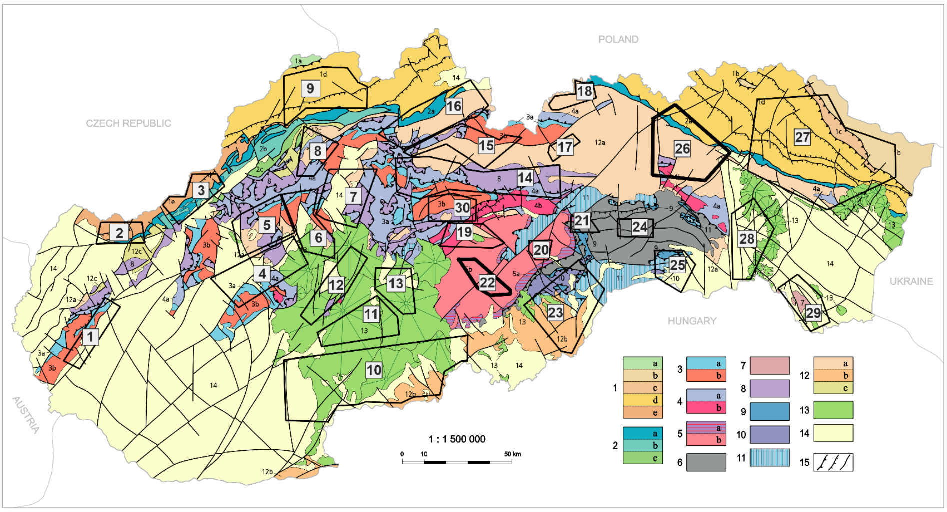

Fig. 2. Areas of flash floods in geological map after *Bezák et al. (2011)*. Neoalpine tectonic units of the Outer Western Carpathians: 1 – Flysch Belt: a – Silesian Nappe, b – Dukla Unit and Smilno tectonic inlier, c – Miková–Snina Zone, d – Magura group of nappes , e – group of Biele Karpaty nappes; 2 – Klippen Belt s.l.: a – Klippen Belt s.s. undivided, b – Klape tectonic unit, c – Manín and Haligovce tectonic units; Paleoalpine tectonic units of the Inner Western Carpathians: 3 – Tatricum: a – mostly Mesozoic and Late Paleozoic formations, b – crystalline complexes; 4 – Fatricum and northern Veporicum: a – Mesozoic and Late Paleozoic formations, b – crystalline complexes; 5 – southern Veporicum: a – Mesozoic and Late Paleozoic formations, b – crystalline complexes; 6 – Gemericum; 7 – Zemplinicum; 8 – Hronicum; 9 – Meliaticum; 10 – Turnaicum; 11 – Silicicum; formation superimposed over the nappe structure: 12 – sedimentary basins with Paleogene and Late Cretaceous fill: a – Inner Carpathian Palaeogene basin, b – Buda Basin, c – Late Cretaceous and Paleogene deposits; 13 – Neogene and Quaternary volcanics; 14 – Neogene and Quaternary deposits; tectonic boundaries: 15: a – main Alpine thrusts, b – other overthrust lines, c – unspecified faults.

In this paper, we present two of the above areas as an example of how the geological and geomorphological properties of the area interact during a flash flood. We selected an area from the upper reach of a stream, which flows through a crystalline massif, and a typical flysch area in NE Slovakia. Other areas are to be documented in the final report of the BLEPOSK project.

2. Geological and geomorphological preconditions for flash floods in the selected areas

2.1. Upper reaches of the Rimavica River

This area is labeled as area No. 22 in the map in Figs. 1 and 2 and is also shown in the section of the geological map in Fig. 3. The spring of the Rimavica River has a wide catchment area. It is located on the slopes of the Sihlianska planina Plateau in the vicinity of villages Sihla, Drábsko and Lom nad Rimavicou. These are the highest situated settlements in Slovakia with relatively abundant rains and long-lasting snow cover. The spring streams converge from all sides into a narrow valley (area A in Fig. 4b). The Rimavica River flows through this valley and several smaller settlements such as Havrilovo, Salajka, then continues through the industrial village Utekáč all the way to Kokava nad Rimavicou where the valley widens. This area has been struck by floods several times, with the most extreme one in June 2013. At that time, for example, the village Utekáč was cut off from the rest of the world for several days and there was great damage to homes, roads and railway lines.

The geological structure of this area is shown in the geological maps in a scale of 1:25000, deposited in the Geofond. Based on these, a geological map of the entire region was compiled in a scale of 1:50,000, and published (*Bezák et al., 1999*). We can see in the geological map (Fig. 3) that the entire area affected by floods is made up of crystalline rocks – mainly granitoids and migmatites. The absorbency after rains is relatively low despite the fissures. Although the Quaternary cover, mainly the weathering, is relatively thick in the upland parts, it does not affect absorbency (it mostly involves granite eluvia/residues, which are eroded on the slopes and carried away by the streams). Only few landslides have been recorded in the area.

From the point of view of geomorphology (Fig. 4a), it can be noted that the Rimavica River has a wide catchment area on the Sihlianska planina Plateau. Additionally, practically the entire area of the Sihlianska planina Plateau is deforested for agricultural use (area A in Fig. 4b). In case of heavy rainfall, which cannot be absorbed in the ground in these areas, all the water from the small tributaries is concentrated in the narrow and long valley of the Rimavica River (area B in Fig. 4b). This creates a "funnel effect" in which the water can rise suddenly. The valley only widens in Kokava nad Rimavicou where the harder granitoid rocks are replaced by softer metamorphites behind a significant fault.

We can therefore conclude that the main cause of floods in this area is most likely the interplay of heavy rainfall with the nature of the relief. A similar phenomenon was noted in June 2023 in the nearby Liešnica Valley south of Kokava nad Rimavicou (area C in Fig. 4b), which also drains water from the plateau through a narrow valley in a crystalline environment.

When we compare this area with the neighboring ones, e.g. the Ipeľ Val-

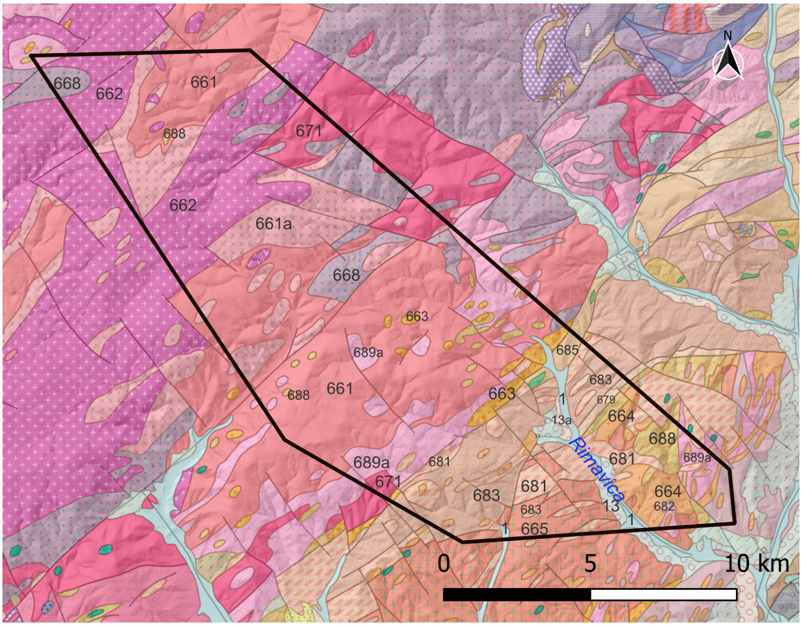

Fig. 3. Geological map of territory No. 22 (after *Bezák et al., 2008*). 1 and 13-Quaternary fluvial deposits (floodplains and terraces), 661 to 671-various types of granitoids, 681 to 689-metamorphic complexes.

a)

b)

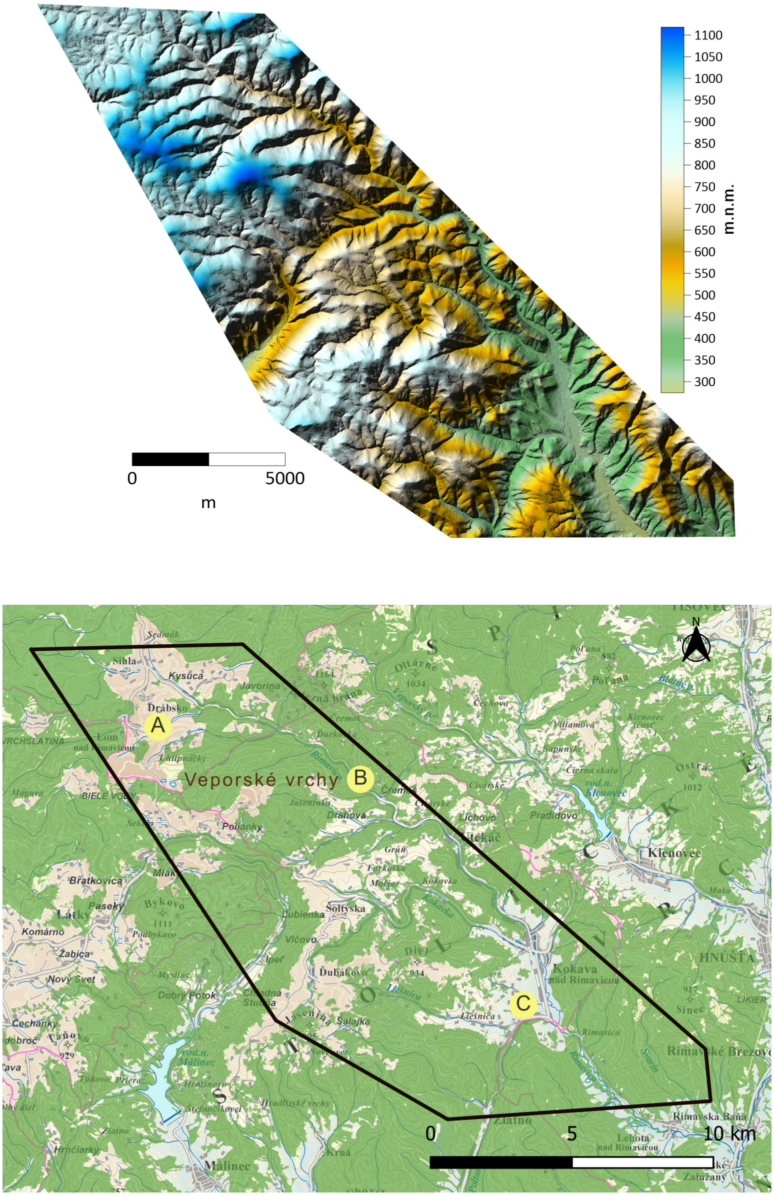

Fig. 4. Terrain relief (a), watercourses and forest cover (b) of the territory No. 22.

ley, Klenovecká Rimava Valley, the upper reaches of the Slatina River etc., these are relatively wide and sufficiently wooded. The comparison is also partially invalid because these areas also contain dams for drinking water. However, the situation is similar in the area of Muránska Zdychava in the east of Veporské rudohorie Mts. or in the area of Čierny Hron and Pohronská Polhora in the north, where the valleys are also narrow, have many tributaries from higher altitudes and the destructive floods are frequent.

2.2. NE part of the Levočské vrchy Hills and SW part of the Šarišská vrchovina Highland

Another investigated area includes the NE part of the Levočské vrchy Hills and the SW part of the Šarišská vrchovina Highland (No. 26 on the map in Fig. 1 and 2). This area is one of the most vulnerable areas in Slovakia in terms of floods and landslides (*Bednarik and Liščák, 2010*). Extensive floods occurred in these areas in 1998 on the Svinka River, Torysa River, Žehrica River and others, and affected the villages of Jarovnica, Renčišov, Dubovica, Uzovské Pekľany and 80 other villages. In July 1998 when the Jarovnice tragedy occurred with 50 recorded casualties, the floods affected another 10,000 people in 86 villages in the Prešov and Košice self-governing regions. The floods hit 2,500 houses, of which 357 were destroyed or significantly damaged, 20,000 hectares of agricultural land were flooded, and approximately 1,000 farm animals died in addition to poultry. Other flood events affected the villages of Ľubica (2010), Jakubovany (1973), Tichý potok (1997), Žehra (2010), Levočské Lúky (2010), Holumnica and Jurské (2008). In July 2008, there were two casualties in Čirč. The floods in this area were also recorded in Ľutina on Ľutinka Creek, in Bertotovce on Svinka Creek, in Brežany on Brežianka Creek and in Žipov.

Area is geologically formed mainly by flysch sediments, which belong to Outer and Inner Carpathian flysch divided by Klippen belt (Fig. 5). Except of extreme rainfall, floods in these areas are also caused by the flysch subsoil, which prevents the infiltration of rainwater and greatly increases the surface runoff of the area. A similar effect is also caused by the gravitational instability of slopes in this territory with a high frequency of landslides (Fig. 6).

The geological structure was presented on geological map by *Nemčok (1990)* and the geomorphology, hydrogeological conditions and landslide risks in the Levočské vrchy Hills and Šarišská vrchovina Highland were studied in the published research reports by *Novodomec (1982), Nemčok (1982), Zakovič et al. (1995), Jetel (1995), Cibuľka (1993)* and other sources.

The predispositions for the occurrence of floods and landslides are largely caused by the flysch subsoil with alternating massive sandstones and clays, subhorizontal deposition of layers and permeability of fissures. The geomorphology of the Levočské vrchy Hills is characterized by a regionally extended flat relief (pediplen) at a height of 800–1200 m, which is divided by deep erosion of valleys (in Fig. 6a). Therefore, the flysch mountainous areas and plains in this area, such as Bachureň, Javorina, Škapová, Zámčisko, Repisko, Kuligura, Siminy, Oľšavica and others, form extensive areas with

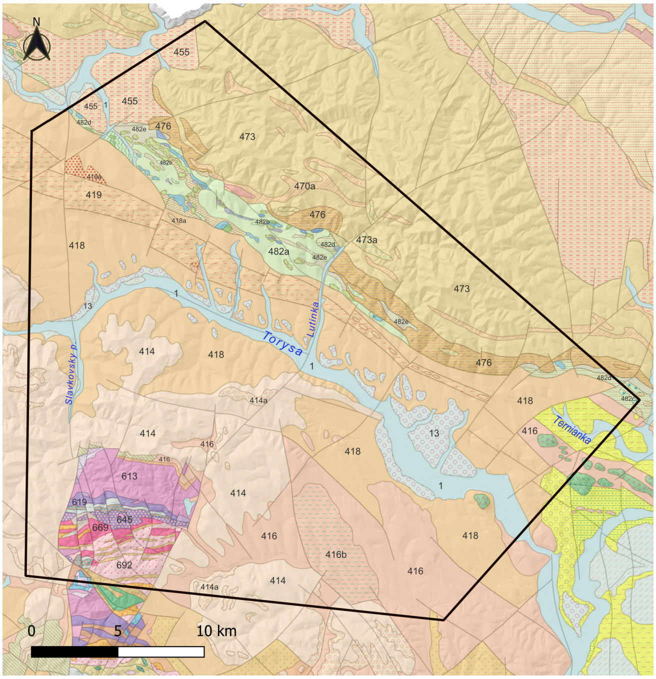

Fig. 5. Geological map of territory No. 26 (after *Bezák et al., 2008*). Main formations: Quaternary: 1 –fluvial sediments, 13 – sediments of fluvial terraces. Sediments of the Inner Carpathian Palaeogene: 414 – mainly sandstones, 416 – claystones and sandstones (flysch), 418 – mainly claystones, 419 – alternation of sandstones and claystones, 482 – mostly Cretaceous sediments of Klippen Belt, 455, 476, 473, 470 – sediments of Outer Carpathian flysch belt, 613, 619, 645 – Mesozoic complexes of Branisko Mts., 669, 692 – crystalline complexes.

a)

b)

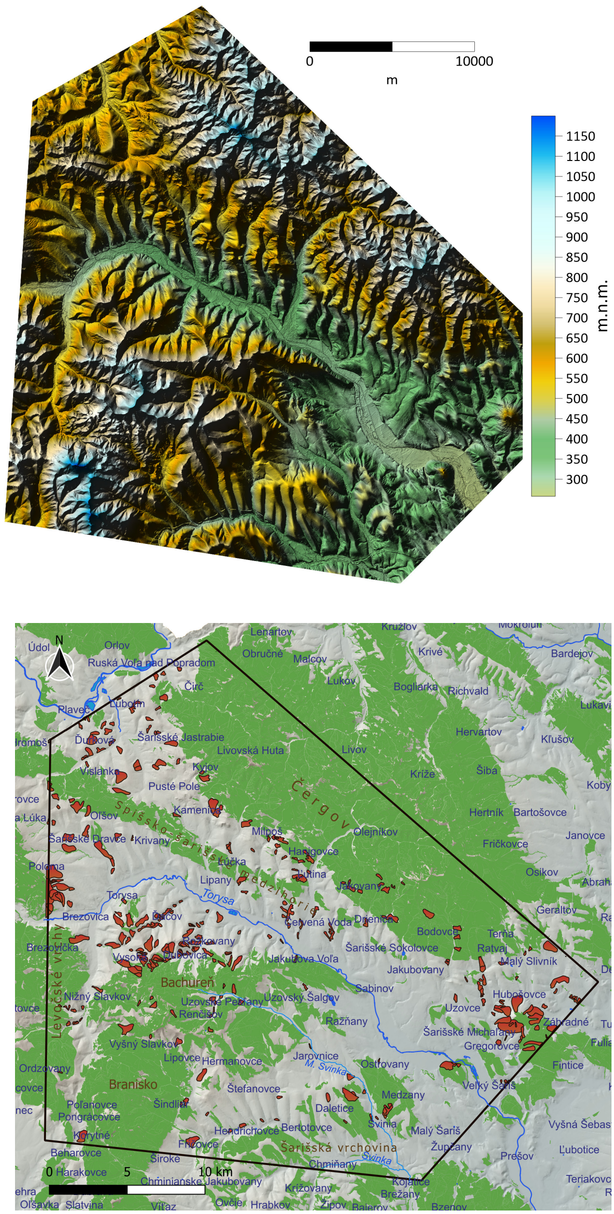

Fig. 6. Terrain relief (a), forest cover and landslides (the red areas) (b) of the territory No. 26.

surface runoff, which often cause flash floods during heavy rainfall (up to 120 mm on Bachureň Hill during the flood in 1998) and low permeability of the subsoil.

This territory is part of the main European drainage divide, with the western and northern parts drained by the Poprad River to Baltic Sea and the southern one by the Hornád River to Black Sea. The radially arranged network of valleys and streams of the Levočské vrchy Hills is mainly based on tectonic faults. The Torysa River valley, which is the main dividing valley of the Levočské vrchy Hills is a threat of devastating floods with its extensive catchment area of 1349 km^2 especially in Tichý potok Creek (1997, 2008). Important streams in the area include Doľanský potok Creek, Holumnický potok Creek, Lomnický potok Creek, Poľanovský potok Creek, Kolačkovský potok Creek, Lúčanský potok Creek, Slavkovský potok Creek, the Torysa River, Svinka River, Ľubica River, Jakubianka River and others.

Intense rainfall and the erosion-denudation shapes of the Levočské vrchy Hills relief also cause gravitational instability of slopes in this territory with a high frequency of landslides in the area of Tichý potok Creek and villages Repaše, Bajerovce, Krivany, Pečovská Nová Ves and many other locations (Fig. 6b). The most extensive landslide area in the Levočské vrchy Hills is located between Tichý potok Creek and Brezovica, and is gravitationally disturbed by landslides, creeping deformations, block fissures, etc. (*Nemčok, 1973*). The gravitational instability is caused by the monoclinally inclined flysch layers with a slope of $8°-20°$, which create slab landslides (e.g. Čierny vrch Hill above Tichý potok Creek) and numerous fissure caves (*Orvošová et al., 2020*). At some places, the landslides also disrupt the drainage network of valleys, as in the case of the damming of the Voškové pod Repiskami Valley, which formed Baňúr Lake with an area of 1700–1800 m^2 (*Lukniš, 1946; Novodomec, 1982*). During the floods of 2010, the Kolačkovský potok Creek was dammed by a landslide and put the village of Kolačkov in danger.

3. Conclusions

It can be noted that the geological and geomorphological characteristics of the territory have a great impact on the occurrence of flash floods, as was shown using the example of the two territories in this paper. When examining the remaining territories in which such floods occurred – especially the repeated ones – it will be necessary to focus on these factors, but it seems that especially the relief and also the forest cover are among the key factors. As for the measures, these should be solved in the relevant administrative units, which will adopt appropriate and effective measures in the specific locations based on expert projects. It is certainly important to have enough dams in the respective valleys and also increase forestation and implement early warnings in the event of sudden intense rainfall in these areas.

Acknowledgements. This work was supported by the project "Development of a system for assessing the threat of flash floods and to support the creation of blue-green infrastructure proposals, ITMS 2014+ code 313011BWT8 (BLEPOSK)".

References

Bednarik M., Liščák P., 2010: Landslide susceptibility assessment in Slovakia. Miner. Slovaca, **42**, 2, 193–204.

Bezák V. (Ed.), Dublan L., Hraško Ľ., Konečný V., Kováčik M., Madarás J., Plašienka D., Pristaš J., 1999: Geologická mapa Slovenského rudohoria – západná časť 1:50,000 (Geological map of the Slovenské rudohorie Mts. – west part 1:50,000). MŽP SR – GSSR, Bratislava.

Bezák V. (Ed.), Elečko M., Fordinál K., Ivanička J., Kaličiak M., Konečný V., Kováčik M., Maglay J., Mello J., Nagy A., Polák M., Potfaj M., Biely A., Bóna J., Broska I., Buček S., Filo I., Gazdačko Ľ., Grecula P., Gross P., Havrila M., Hók J., Hraško Ľ., Jacko S. ml., Jacko S. st., Janočko J., Kobulský J., Kohút M., Kováčik M., Lexa J., Madarás J., Németh Z., Olšavský M., Plašienka D., Pristaš J., Rakús M., Salaj J., Siman P., Šimon L., Teťák F., Vass D., Vozár J., Vozárová A., Žec B., 2008: Prehľadná geologická mapa Slovenskej republiky 1:200 000 (Geological map of Slovakia 1:200,000). ŠGÚDŠ, Bratislava.

Bezák V., Biely A., Elečko M., Konečný V., Mello J., Polák M., Potfaj M., 2011: A new synthesis of the geological structure of Slovakia – the general geological map at 1:200 000 scale. Geol. Quart., **55**, 1, 1–8, Warszawa.

Blaškovičová L., 2010: Metódy hodnotenia prívalových povodní (Methods of flash floods evaluation). PhD. thesis, Bratislava, 222 p. (in Slovak).

Cibuľka Ľ., 1993: Paleogén povodia Svinky – hydrogeologický prieskum (Paleogene of the Svinka River basin – hydrological survey). Geofond, Bratislava, 44 p. (in Slovak).

Grešková A., 2005: Analýza vybraných parametrov povodia z hľadiska výskytu prívalových povodní (Analysis of selected basin parameters from the point of view of flash flood occurrence). Geografický časopis (Geogr. J.), **57**, 2, 131–144 (in Slovak with English abstract).

Jetel J., 1995: Nové pohľady na hydrogeológiu karpatského flyšu a centrálnokarpatského Paleogénu (A new views on the hydrology of the Carpathian Flysch and the Central-

Carpathian Paleogene). In: Kaličiak M. (Ed.): Zbor. III. geologické dni Jána Slávika. GÚDŠ, Bratislava, 137–139 (in Slovak).

Lukniš M., 1946: Jakubiany. Zborník prác PRIF SU Bratislava 14, Práce Geografického ústavu, 2, Bratislava, 5–66 (in Slovak).

Majerčáková O., Škoda P., 1998: Prívalové povodne na severovýchodnom Slovensku (Flash floods on the Northeastern Slovakia). Vodohospodársky spravodajca (Water Manag. J.), **41**, 10, 18–19 (in Slovak).

Nemčok A., 1973: Význam gravitačných deformácií Čiernej hory pre výstavbu vodárenskej nádrže Tichý Potok (Importance of the Čierna hora Hill gravity deformations for the building-up of the Tichý Potok water-supply reservoir). Final report, Geofond, Bratislava, 65 p. (in Slovak).

Nemčok A., 1982: Zosuvy v slovenských Karpatoch (Landslides in the Slovak Carpathians). VEDA publ. house, SAS, Bratislava, 318 p. (in Slovak).

Nemčok J., 1990: Geologická mapa Pienin, Čergova, Ľubovnianskej a Ondavskej vrchoviny 1:50,000 (Geological map of Pieniny, Čergov Mts., Ľubovnianska and Ondavská vrchovina Highlands 1:50,000). GÚDŠ, Bratislava.

Novodomec R., 1982: Geomorfológia Levočských vrchov (Geomorphology of Levočské vrchy Hills). Zborník Pedagogickej fakulty v Prešove Univerzity P. J. Šafárika v Košiciach. Prírodné vedy, **XXI**, 1, 75–138 (in Slovak).

Orvošová M., Hajduk M., Pavlarčík S., Krempaská Z., 2020: Geomorfologická charakteristika Levočských vrchov – povrchové a podzemné javy (Geomorphological characteristics of the Levočské vrchy Hills – surface and subsurface phenomena). Vlastivedný zborník Spiš, 10, 181–198 (in Slovak).

Šťastný P., 1998: Rekonštrukcia priebehu zrážok, ktoré vyvolali povodne na severovýchodnom Slovensku dňa 20.7.1998 (Reconstruction of the rainfalls which caused floods in the Northeastern Slovakia on July 20, 1998). Práce a štúdie 60, SHMÚ, Bratislava (in Slovak).

Zakovič M., Bajo I., Cibuľka Ľ., 1995: Hydrológia Šarišskej vrchoviny (Hydrology of Šarišská vrchovina Highlands). Podzemná voda (Groundwater), **I**, 1, 38–57 (in Slovak with English abstract).