Acta Montanistica Slovaca
ISSN 1335-1788
actamont.tuke.sk

Morphometric parameterization of flash flood risk assessment

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Funding information:
Funding Agency: Slovak Research and Development Agency
Grant Number: APVV-20-0281

Acknowledgement:
This work was supported by the Slovak Research and Development Agency under contract no. APVV-20-0281.

How to cite this article:
Zelenakova, M., Junakova, N., Ondrejka Harbulakova, V., Iannaccone, B., Hlinkova, M., Fijko, R. and Abd-Elhamid, H.F. (2024). Morphometric parameterization of flash flood risk assessment. *Acta Montanistica Slovaca*, Volume 29 (3), 712-723

DOI:
https://doi.org/10.46544/AMS.v29i3.17

Abstract
Individual morphometric characteristics of river basins significantly impact their activity; they affect the flow rate of water, water accumulation in the river basin, water runoff time and other attributes that affect their intensity during flash floods and hydrological droughts. The aim of the paper is to express the risk and impact of flash floods in the Topla River basin (Slovakia) and its sub-basins with regard to the morphometric characteristics of the area. The studied locality, especially the spring of the Topla river, belongs to the area with an existing, potentially significant flood risk threatening not only important localities but also the population. The objective is to support the territories with flood mitigation measures by assessing the basin morphometric factors and classifying such areas into high, medium and low-risk categories of flash floods. The model situation is developed in the ArcGIS program, where the selected important morphological characteristics are assigned to all sub-basins for the Topla river together with its assessment. For each characteristic, the level of risk affecting the flash flood is determined. An important part of this study is developing a river basin susceptibility scale to flood activity in terms of morphometric characteristics obtained from available literature, empirical relationships and human experiences. The result of the sensitivity risk map of the upper part of the Topla river basin is to show where adverse impacts on people and the surrounding environment are expected after flash floods hit (or in the event of hydrological droughts).

Keywords
Floods; Hydromorphometric characteristics; Sensitivity map of the catchment area; The Topla River

Introduction

River basins represent basic geomorphological units for hydrological management and permanently sustainable development of natural water resources. Geological and morphological environment, topography and climate are the main physical factors that govern the geological structure of the fluvial system. Changes in these physical conditions of the river basin lead to changes in its hydro-morphometric characteristics and river systems. In order to recognize the catchments' hydrological system and their properties, the study of hydro-morphometric characteristics is very necessary. The physical properties of the river basin, such as area, slope, forest cover, and shape, are the main representatives of the hydro-morphometric characteristics. These properties are also used in environmental management. Without knowledge of the given characteristics and properties, it would not be possible to analyze the sensitivity state of the selected area.

The significance of the hydro-morphometric characteristics is recognized by many authors. The study by Ptak et al. (2018), carried out based on 14 lakes located in northern Poland, evaluated the effect of environmental conditions and morphometric parameters on lake water temperature changes. The assessment was based on the daily water and air temperature for the reference period. It took into account the location of lakes (latitude, longitude, altitude), morphometric parameters (surface area, maximum and mean depth, volume), hydrological processes (rate of water exchange, course of ice phenomena), and trophic status (water transparency) as factors that can modify lake water temperature changes. The study provided by Abdel–Fattah et al. (2017) investigated the relationship between variations in geomorphometric and rainfall characteristics of flash floods in the Wadi Qena catchment in Egypt, which is a typical arid basin. The catchment was divided into 14 sub-basins, and 38 geomorphometric parameters representing the topographic, scale, shape and drainage characteristics of the basins were considered. The geographic information system (GIS) techniques and DEM (digital elevation model) were used to evaluate the morphometric parameters of two drainage networks derived from different sources by Ozdemir and Bird (2009). The study examined the morphometric parameters, where the data for the study was obtained from a topographic map, which was done by authors Eze and Efiong (2010). Other studies using the GIS approach for morphometric analysis and morphometric characteristics include those of Farhan et al. (2016), Mirzavand and Ghasemieh (2013), Biswas et al. (1999) and Ghosh et al. (2015). One of the approaches to analyze the hydro-morphometric parameters was described in the study by Elewa et al. (2016). The study presents a detailed hydro-morphometric analysis of the El-Arish watershed in Sinai, Egypt, using ASTER DEM and SPOT-4 satellite images. All the mentioned approaches are ways to assess the watershed's vulnerability by morphometric parameters using GIS modelling. Kannan et al. (2018) utilized GIS and remote sensing to extract the watershed and its drainage network. The most important morphometric parameters of the Wadi Mezal basin, Iraq, are described in the study by author Al-Assadi (2020), which were obtained through GIS. As mentioned above, the definition of the river network within a river basin or sub-basin is traditionally presented based on maps, often using geospatial analytical techniques such as GIS systems that represent powerful tools for calculation, quantitative and qualitative description as well as evaluation of hydro-morphometric parameters. There are also many other interesting similar research studies regarding flood risk assessment, etc. (Zeleňáková, 2009; Xiong et al., 2020; Abd-Elaziz et al., 2020; Youssef et al., 2011; Abu El-Magd et al., 2021; Carvalho et al., 2020; Lechman, 2019).

In this paper, ArcGIS software was also chosen to draw the maps of selected parameters in order to find out the influence of hydromorphometric characteristics of the partial basin on the territory of the upper part of the Topla River, Slovakia. Hydro-morphometric analysis of sub-basins provides basic information that helps to understand the hydrological development of the river basin in the event of a flash flood at the interaction of slopes, the shape of the basin, and forest cover and to identify areas susceptible to erosion. This information is necessary to determine the sensitivity of the river basin to protect people as well as other components of the environment (Junakova and Balintova, 2014). Finally, the maps are used to express the hydrological and environmental hazards of individual basins' characteristics.

Material and methods

Study area description

The studied area, the Topla River basin, is located in eastern Slovakia in the district of Bardejov, and it falls within the main catchment area of the Bodrog River. Its most important and, therefore, the main stream, is the Topla River, which is a right-bank tributary of the Ondava River. This important basin drains a large area of approximately 1,595 km^2. Due to its type, it is classified as a highland-lowland river with a length of 129.8 km. The upper part of the Topla River springs in the Cergov Mountains. Its river path (Fig. 1) points to the east, and below the territory of Bardejov, it turns and heads to its lower part to the south. At this point, it flows as a right-bank tributary to the Ondava River at a river km 34.2, below the village Sacurov in the district of Vranov. The flow of the upper part is navigable from Bardejov in a length of about 103 km, and in this part, it flows turbulently through a wide valley.

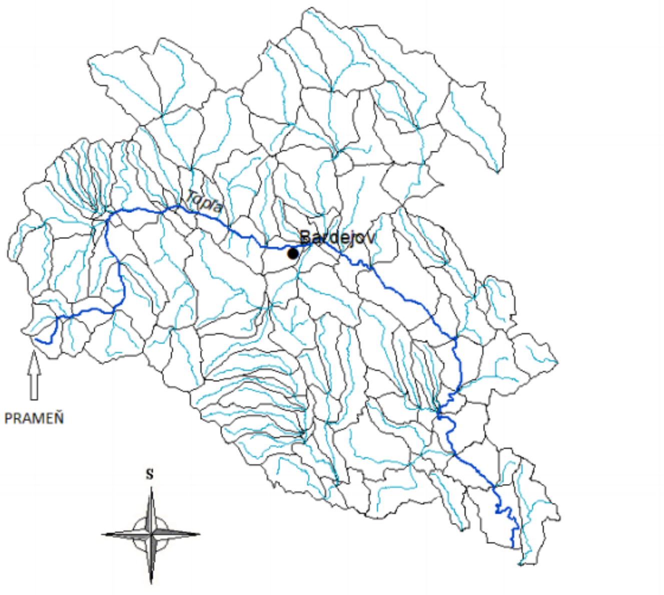

Fig. 1. River path of the Topla River

Under the village of Marhan in the Bardejov district, the Topla River calms down, the slope and velocity are lost, and the flow is laminar. A calm stream, in places with silences and tones, flows smoothly to its mouth at the bottom of the Topla River (Lechman, 2019).

Methodology to determine morphological parameters of the river basin

The following hydro-morphometric characteristics were studied to determine the influence of the hydro-morphometric characteristics of the partial basin on the territory of the upper part of the Topla River. The first group of factors included the catchment area, the flow length, the longitudinal slope and the forest cover. The second group contained parameters that combine several environmental factors, such as an indicator of the shape and density of the river network (Dobija et al., 1975; Allairea et al., 2015; Vogel, 2011; Kimaszewskli, 1978; Thorne, 1998).

The essence is to determine the parameters of the river basin using numerical characteristics, which can then serve to study the relationship between the river basin and type, intensity, and fluvial processes or by comparison between different systems.

The catchment area is an area from the plan view of the basin. In small river basins, the response to excessively heavy rainfall will depend, to a large extent, on climatic conditions, environmental factors, geological structure, land use, etc. Large river basins have a much greater potential to sustain extreme rainfall, but the dynamics of water runoff from the area are much more complicated.

Flow length - is expressed as the length of the axis of the riverbed from its mouth to the source. Therefore, the beginning is the intersection of the centres of the main river and the tributary. The path of length is the line connecting points lying at the same distance from the shores. The length of the flow is most accurately determined by direct measurements, and this is combined with height measurements. Then, we most often display them graphically, namely using longitudinal profiles or the river scheme system. The length of the stream is one of the most important characteristics of the river basin, and according to the significance of the rivers, it also has a sufficiently high value.

Longitudinal slope - the slope, height, and exposure of the slopes of river systems significantly affect the regime of rivers, water content, climatic conditions, rainfall distribution, and air temperature of the river basin and its surroundings. It expresses the height of the difference of the start and end points of the investigated river basin flow to the length of the riverbed and is expressed by equation (1).

$$i = (Hmax - Hmin)/L * 100 = \Delta H/L * 100 \quad (1)$$

where i is the slope (%); Hmax is the highest point (m); *Hmin* is the lowest point (m); L - line connecting *Hmax* and *Hmin* (m).

By its nature, the longitudinal slope influences the erosive activity of the river. The greater the slope, the more intense the detachment and removal of the topsoil will be.

The density of the river network and its arrangement - The river structure is directly connected to the relief and geological structure of the basin. Individual parts of the river system differ from each other by the so-called density of the river network, which is expressed as the length of the flows per square kilometre of the concerned areas.

The mathematical formulation is given by equation (2):

$$\rho = (L + L1 + \dots Lx)/A \tag{2}$$

where: ρ - river network density (-); L - flow length (m); $L1$ - flow length (m); Lx - flow length (m); A - catchment area (m^2).

It follows from equation (2) that the representativeness of the result is determined by the type of maps used and the evaluation method. An example is the division of the map of interest by a square grid, and the density is determined for each of these squares. Areas of equal value are defined and marked graphically.

The impact of the arrangement of the river network on the river basin is manifested only significantly after the flood. It is unfavourable when the duration of the flood wave on the main stream and on tributaries is approximately the same. After the confluence, both flood waves meet, and a significantly higher resulting flood wave is created. The encounter of flood waves occurs first on fan-shaped river networks.

Basin shape coefficient - is based on the arrangement of the river system and is of considerable importance in the creation of flows. The mathematical formulation of this coefficient is expressed by the equation (3):

$$\alpha = A/L^2 \tag{3}$$

where: α - coefficient of shape (-); L - flow length (m); A - catchment area (m^2).

Forest cover - In addition to the hydro-morphometric parameters described above, other climatic characteristics of the natural environment, which greatly influence the type, course and extent of morphogenetic processes, are often analyzed in studies of river systems. Among the characteristics influencing the structure and dynamics of the river basin, it is necessary to mention, in particular, the geological structure and land use, which are most often expressed by the forestry factor. It characterizes the extent of the river basin's cover of forests, wooded areas, grasslands, arable land, and non-cultivated land. The value of the afforestation index can be calculated by equation (4):

$$\lambda = A_L/A \tag{4}$$

where: λ - forest coefficient (%); A_L - total forested area (m^2); A - catchment area (m^2).

The methodological procedures for obtaining hydro-morphometric data in this study were divided into three parts. In the first part of the survey, preparations and analyses of the collected source data were performed in a GIS environment, which was key to the output. The second part identified and completed all necessary hydromorphometric characteristics of the Upper Topla River. The Characteristics not found in the literature or the GIS file were calculated by equations (1) - (4).

Results and Discussions

Determination of hydromorphometric characteristics

To develop a river basin susceptibility scales to flood activity in the terms of morphometric characteristic, important morphological characteristics assigned to all sub-basins for the Upper Topla River basin were determined.

Catchment area of the Upper Topla River

The Upper Topla River and its sub-basins belong to the area of the Čergov mountain range, which significantly impacted the development of river basin shapes, including the area. In the Upper Topla River territory, a survey and data collection were carried out, which resulted in the acquisition of river basin districts, which were then thoroughly recorded in the ArcGIS software environment and were used to obtain the results of this study. Rating scales were automatically generated by the mathematical environment of ArcGIS, with a pre-selected number of classification classes (five classes). The values are based on the measured areas of the micro-basins located in the selected area.

Categories of River catchment areas in the Upper Topla River area are: 0,0 – 3,0 km^2; 3,1 – 6,0 km^2; 6,1 – 9,0 km^2; 9,1 – 15,0 km^2; 15,1 – 27,0 km^2.

The map (Fig. 2) shows risk sites with different river basin sizes can be assessed and identified. As these areas will influence the effects and consequences of floods or droughts, the shades of map colour (Fig. 2) have been chosen to illustrate the extent of this impact. The red and orange colours indicate the river basins, whose areas and water content will significantly affect their surroundings. Shades of yellow and green have a milder effect.

Fig. 2 shows that the most attention is required by the river basins in the north of the selected area where there are abundant streams (Kamenec, Sverzovka, Rusucka voda) and their associated river basins, which reach 15.1 - 27.0 km^2: Olchovec river basin (4-30- 09-033), Sverzovka upon Kamenec catchment area (4-30-09-035), Rusucka voda catchment area above Stebnicky creek (4-30-09-059). It is known that flood polders are currently being built on the Kamenec and Sverzovka rivers, as they have had problems with floods in the past. The results show that larger river basins are most often at risk of floods.

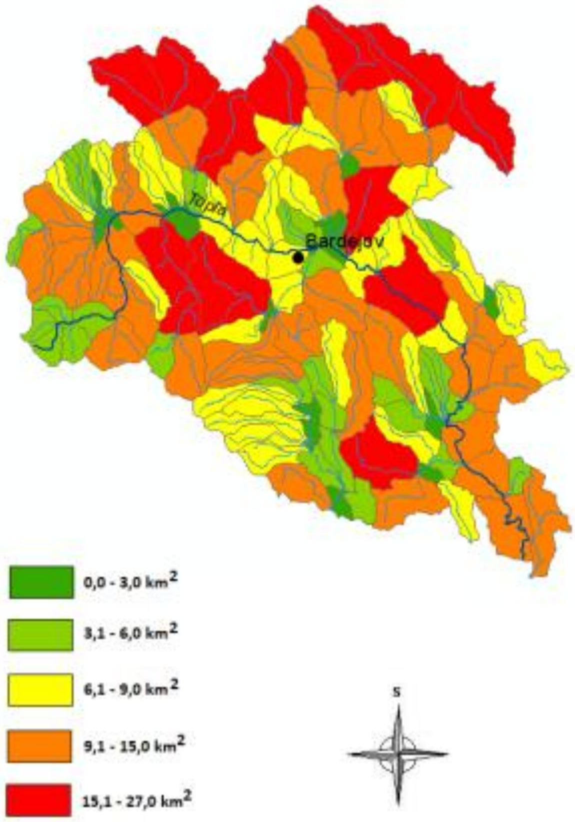

Fig. 2. The micro-basins in studied area

Length of streams in the Upper Topla River sub-basins

To assess the significance of streams in the Upper Topla River region in individual sub-basins (Fig. 3), the assessment threshold was determined on the basis of the levels generated by the ArcGIS program. The values are based on the lengths of the streams that are located in the selected area. The evaluation scale is intended only for a given area of research and is divided into five categories, namely: 0,80 – 3,6 km; 3,61 – 6,0 km; 6,1 – 11,0 km; 11,1 – 21,0 km; 21,0 – 74,0 km.

As mentioned above, the dominant flow in the area is the Topla River, which, in its upper part from the source to the border of the Upper Topla River area, has 74 km. It forms the upper limit categories of flows from 21.1 - 74.0 km. The river passes through 24 sub-basins. The streams marked in orange in Fig. 3 are mainly formed by the tributaries of the Topla River. Their length range is a category of streams from 11.1 km to 21.0 km. These watercourses have the greatest effect on the water content of the main watercourse, the Topla River. An increase in water level at a given tributary causes a fold increase in the flow of the Topla River below the tributary, thus endangering this area with an increased risk of water flooding. This category's flows include the River Sekcov, Slatvinec, Sibska voda, Cernosina, Hrabovec, Sverzovka and others. The middle range is formed by watercourses whose lengths range from 6.1 to 11.0 km and are shown in yellow (Fig. 3).

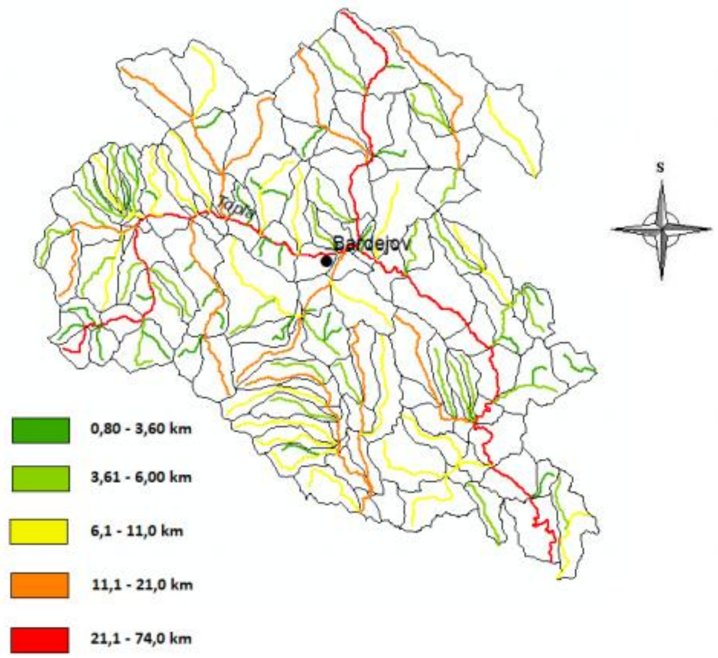

Fig. 3. Map of the division of streams

From this interval is the most important representative of the Koprivnicka River, Richvaldsky creek, Mirosovec, Hazlinka, Frickovsky creek, Olchovec, Magdanec and others. Intervals shown in shades of green represent the least risk among others. They are in the category from 3.61 - 6.0 kilometres (Podlazsky creek, Bardejovsky creek, Hlboky creek) and the category from 0.80 - 3.60 kilometres (Kosiarsky creek, Stebnicky creek, Krizovsky creek). As with any evaluation, it should be recalled that no category is defined for areas where there will never be a flood or its effects. It points to the most exposed areas with streams characterized by high water content, where the phenomenon of floods can occur especially.

Longitudinal slope of the Upper Topla River basin

At the selected locality, a survey and data collection were prepared with regard to the slopes of the individual slope sub-basins, which were subsequently incorporated into the data input in ArcGIS. Fig. 4 shows the morphological fragmentation of the terrain, which indicates the occurrence of mountains (coloured brown), raised places (dark green) and also the lowlands (marked light green colour).

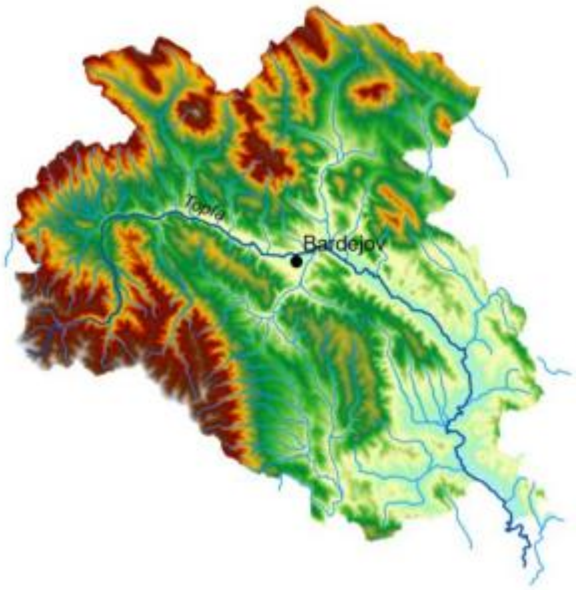

Fig. 4. Morphological division of Bardejov district

Subsequently, the evaluation threshold for this study was divided into five categories/intervals: 15 – 20 % - steep slope; 12 – 14 % - slightly steep slope; 10 – 11 % - slight slope; 7 – 9 % - slightly gradual slope; 2 – 6 % - gradual slope.

In the Topla River basin, the greatest slopes are reached by the area in the northwest due to the location of this area in the part of the Cergov mountain. The slopes' values of the river basin here reach 15 - 20%, which are steep slopes. This area has been affected by floods in the past, which have had a destructive effect. Currently, the construction of polders is being carried out in the area, protecting the surroundings from water accumulation during floods. Other risk areas are located in the north and in the northwest of the area. The slopes of the basin there reach 12 - 14% (slightly steep slope) and 10-11% (slight slope). In this area, polders called Fricka and Kamenec have already been realized. As shown on the map (Fig. 5), it can be stated that the whole area to the west and north of the town of Bardejov is extremely prone to floods with devastating effects in the event of lightning and heavy rainfall.

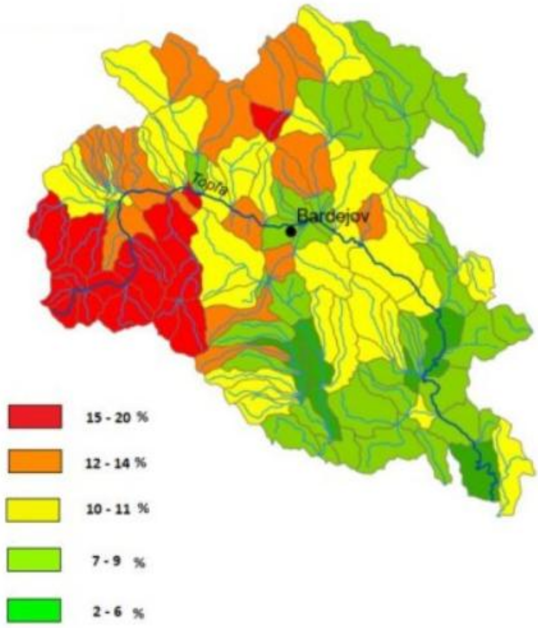

Fig. 5. Map of the division of the selected area according to slopes

Partial findings on the issue of slopes confirmed the occurrence of floods from the past and also the suitability of the location of polders, which currently serve to protect the environment from flooding. The River basins, mainly in the south and east of Bardejov, show reduced risk rates due to the gradients of 7-9% (slightly gradual) and 2-6% (gradual gradient). Based on the graphical representation, floods in these places are not excluded. The created map of the division of the territory points to the localities that need the most attention and where there is a greater risk of vulnerability to deteriorate the country.

Density of the river network of the Upper Topla River and its arrangement

The assessment of the river network density is best carried out from a more global point of view, i.e. a minimum assessment at a regional level. The density of the river network was determined as the ratio of the total length of flows of the surveyed area expressed in kilometres and the area of this area in square kilometres. The sum of the lengths of streams in the whole territory from all micro-basins is almost 630 km. Based on the sum of all micro-catchment areas, the total area of the Upper Topla river basin is 998.9 km^2. According to equation (2), the density of the river network of the Upper Topla river basin is 0.63 km^{-1}. As for the arrangement of the river network, part of the Upper Topla river basin has a tree-like shape. It is a river system of approximately equal streams flowing to the Topla River from both sides (Fig. 6) but with predominant tributaries in the northern part of the Topla river.

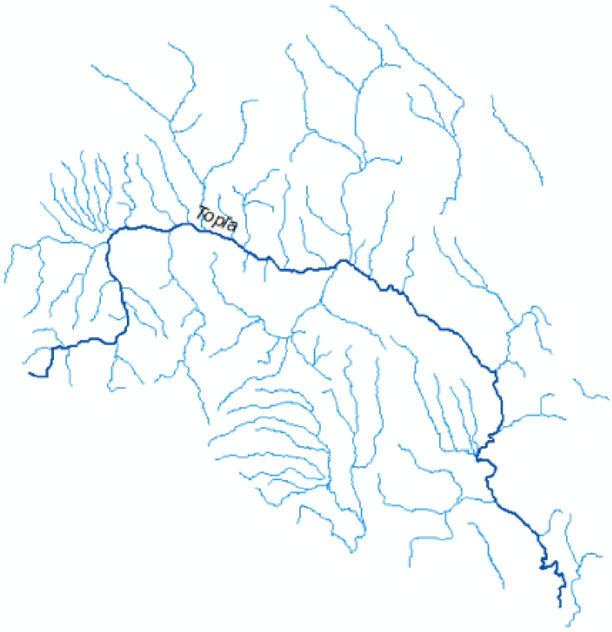

Fig. 6 Tree-like shape of the Upper Topla River network

Within the studied part of the Upper Topla River, the ground plan asymmetry of the basin is obvious. The selected area has a double number of tributaries on the right side. This fact is supported by the location of the Topla River in the given area from its source to the end of the studied part, i.e. from west to east with a slight turn to the south. Locations of the main orographic watershed divide lining the highest points around the Topla River, where almost all right-hand sub-basins belong, are also considered. Parts of the left-hand basins are tributaries of other river basins, but they contribute to the water levels of the Upper Topla River.

The Upper Topla River basin shape coefficient

The shape of the basin is one of the basic geomorphological features and, therefore, needs to be addressed in each hydrological study. The categories of river basin shape coefficients for the Upper Topla River are 0.24 – elongated shape, 0.24 – 0.26 transitional shape, and 0.26 fan shape (Fig. 7).

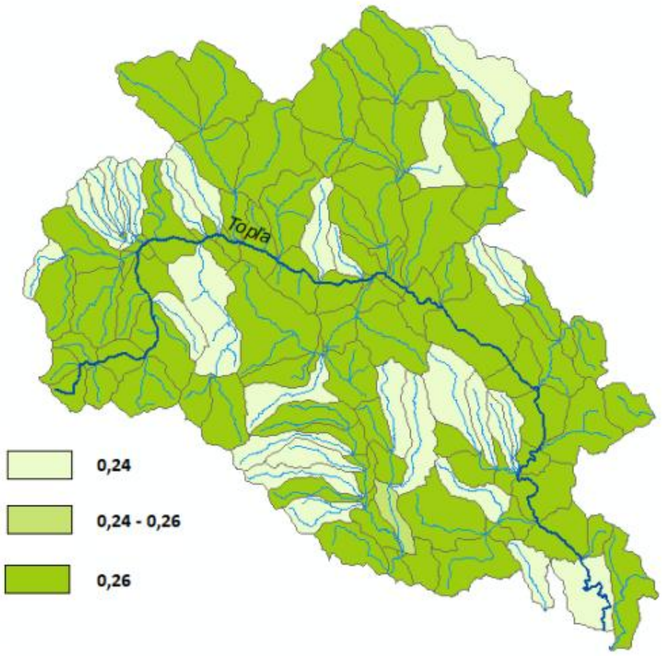

Fig. 7. Map of micro-basin shapes in the Upper Topla River

According to Fig. 7, we can express the state of sub-basins in terms of shape characteristics. River basins with a coefficient of shape up to 0.24 are determined as elongated river basins (white colour in Fig. 7). This basin has an orographic watershed divide, most often close to its mainstream. It can be assumed that in the event of flash floods, there will be a rapid outflow of water from the slopes (depending on their inclination). In this way, the riverbed fills faster (the flow rate is also important), even under the assumption of adverse effects from other characteristics. If the shape coefficient is in the range of 0.24 - 0.26, it is a transitional shape of the basin. It is a shape with changing properties, similar to an elongated or fan-shaped shape. Only one river basin from the Upper Topla area can be classified here. The last group are fan-shaped river basins with a coefficient above 0.26. This type stretches especially around the main stream of Topla River. The type of fan-shaped basin is, in this case, more ideal when the runoff is spread by flowing down the slopes during heavy rains into the riverbed.

Afforestation of the Upper Topla River basins

Accurate determination of the percentage of forest cover is a complex process due to the fact that even in the case of 100% forest cover of the river basin, it is not possible to speak with 100% certainty that floods will not occur and will not have devastating effects. The boundaries of the afforestation assessment were divided into five categories: 100 – 70 % - very densely forested; 50 – 70 % - densely forested; 30 – 50 % - little forested; 10 – 30 % - very little forested; 0 – 10% - unforested.

According to the generated map of the Upper Topla River basin in the ArcGIS program (Fig. 8), the given area around the Bardejov district can be evaluated in terms of forestry as follows. A very densely forested area is around the Cergov Mountains, which is located northwest and west of the town of Bardejov. It is interesting that even though this part is very densely forested, severe floods have occurred here in the past. It confirms the claim that even up to 100% forest cover will not protect the area from floods if other parameters are not met.

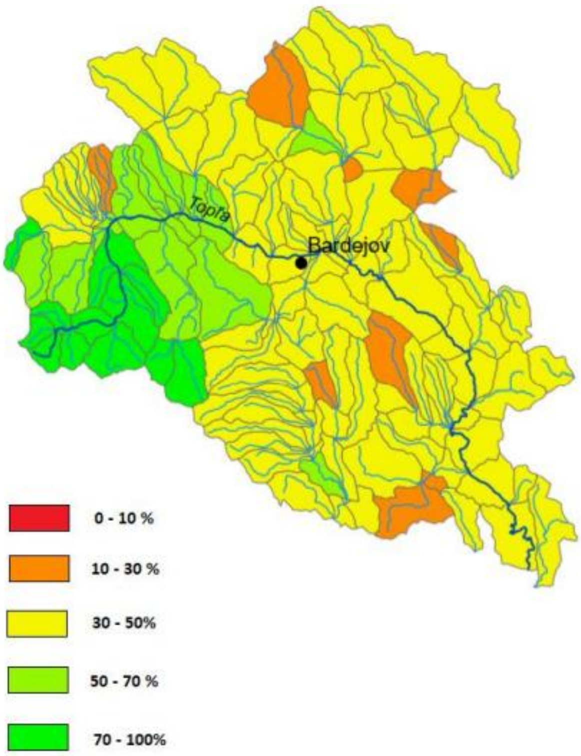

Fig. 8. Map of the forested area of the Upper Topla River

The predominant part of the territory consists of areas with little afforestation, at the level of forest cover from 30-50%. This includes the areas near Bardejov and the areas in the south, east and north of the town of Bardejov. These sites are densely built-up and deforested areas. A small group consists of very little forested river basins (10-30%).

Determining the sensitivity of the selected area

The created database of hydromorphometric data of micro-basins was used to determine the sensitivity of the Upper Topla River basin to lightning precipitation, including melting snow (flash floods) and hydrological drought during periods of water shortage. A sensitivity map with the following sensitivity scale was prepared for the selected area; highly sensitive river basin; moderately sensitive river basin; and slightly sensitive river basin.

Based on the evaluation of individual hydromorphometric characteristics, electronic maps were modelled. These maps were the basis for determining the sensitivity of the river basin to lightning precipitation.

In the ArcGIS program, the possibility of overlapping map data of hydromorphometric characteristics of micro-basins was established. In this mode, all maps became a single map, which at first glance seemed chaotic. The reason was that in a certain territory, there was a conflict of interest in different evaluations, either positive, medium, or negative results of the effect of the given hydromorphometric characteristic. However, based on this map, it was possible to create a model map representing the areas of different sensitivities of the Upper Topla River basin. River basins where at least one unsatisfactory characteristic was located (most often marked in red) have been included in the category of highly sensitive areas. The river basins, where the characteristics marked in orange and yellow had an expected less negative impact on the occurrence of floods than before, formed a category of moderately sensitive river basins. Subsequently, there were river basins whose characteristics did not show adverse effects and their marking on the maps was in shades of green. Based on this procedure, a river basin sensitivity map was generated (Fig. 9).

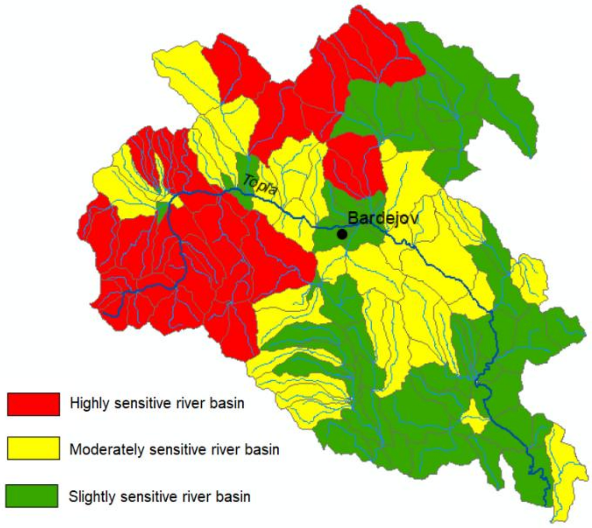

Fig. 9. A river basin sensitivity map of the Upper Topla River basin

Slightly sensitive catchment area

The name of a slightly sensitive river basin characterizes areas that cannot be described as fully resistant to floods, but the area is dominated by morphometric parameters that do not support the effects and occurrence of floods.

The southern part of the Upper Topla River basin in the district of Bardejov can be considered a representative area. This part of the area was presented by the forest cover of sub-basins in the range of 30 - 50% (slightly forested), alternating fan-shaped and elongated river basin types and showed the smallest slopes (2 - 6%). The main course, the Topla River, also flows through this part of the territory. In addition, the area can be assessed positively due to the fact that the given river basins do not border with an area of high sensitivity.

The group of slightly sensitive River basins also includes the catchment area of the town of Bardejov and the northeastern territory of this district. The forest cover and the slopes are identical. Another important stream flows through the given area, namely Kamenec, which has a length of 21.7 km. Partial river basins occurring here are most often fan-shaped, with the large river basins occurring at 9 km^2. However, these river basins are adjacent to highly sensitive areas. These findings show that the greatest effect on the sensitivity in terms of hydromorphometric parameters is the slope of the basin and forest cover. Other parameters help to influence the properties of river basins, and their impact depends on the surrounding conditions, especially the slope and forest cover.

Moderately sensitive catchment area

The second group of sensitivity consists of river basins whose characteristics have overlapped between compliant ones and less satisfactory. They thus form a kind of middle path, which, from a theoretical point of view, tends to the side of greater sensitivity, which, however, depends on the interaction of hydrological properties in the river basin. However, these characteristics are not the subject of this study, so we can speak about a group of moderately sensitive River basins with the interaction of hydromorphometric properties of the sub-basin. Sections assessed as moderately sensitive should not be abruptly subject to the effects of floods. Long-term adverse weather events, such as torrential rains with high intensity and excessive duration, become dangerous in some places. On the territory of the Upper Topla River basin, these are the most numerous areas southeast of the town of Bardejov and further a strip of moderately sensitive places northwest and southwest of Bardejov.

These River basins represent a mixture of characteristics, where forest cover predominates in the range of 30-50% (few forested), the slopes are mostly above 10% and a maximum of 12% (slightly steep basin). It prevails in a fan-shaped river basin up to the southwestern part of moderately sensitive river basins where the shape of the watershed is elongated. The lengths of streams and their tributaries do not exceed 11 kilometres, and the river basins mainly range up to 15 km^2. By analogy, as in slightly sensitive river basins, we can say that the most important characteristic for the assessment was the slope and the forest cover of the river basin, considering the important cooperation of all investigated characteristics. Confirmation that this is a moderately sensitive area and where the negative effects of the flood are not excluded is the fact that in the territory of the Kamenec basin to Olchovec and on the Kamenec stream, the polder called Fricka is built. It was built based on frequent floods in the area.

Highly sensitive catchment area

These areas pose the greatest risk of floods. Characteristics of these sections represented increased or unfavourable values worsening the effect of sudden floods. These are mainly mountain areas (Cergov and Busov Mountains), where steep slopes prevail. In the event of a flood, it is assumed that the characteristics of the river basin will contribute to the worsened effect of water flow in these places. As mentioned, the evaluated area is mainly the Cergov Mountain west of Bardejov in the locality of the Topla River spring and the Busov Mountain north of Bardejov and the border with Poland.

The area of the Cergov Mountains belongs to this group due to the fact that it is the steepest part of the Upper Topla River basin with a slope of 15 - 20% (steep). The forest cover of this area is at a very good level of afforestation. The River basins are fan-shaped with a river length of 6 - 21 km and river basins between 9 - 27 km^2. The area of the Busov Mountains has slightly steep slopes of 12-14% and forest cover from 10-30% (very little forested) to 30 - 50% (slightly forested). As in the part of the Cergov Mountain, the fan-shaped type of partial ones predominates here, as well as river basins with a length of 6 - 21 km and basin area up to 27 km^2.

Conclusions

The vulnerability of a territory is measured by environmental factors, which, in incorrect combinations, make places vulnerable. This is reflected in the danger of a flood event, which is reflected in the increase in unexpected costs for individual regions related to the destruction of infrastructure, property and, in the worst case, human life. Flash floods pose a significant threat to socio-economic development not only in the territory of the Slovak Republic but also on a global scale. As these floods cause mainly torrential rains, it is necessary to know their cycle and characteristics. Lightning floods are usually characterized by turbulent currents after heavy rains that flow through meadows, city streets or mountain canyons and sweep everything that stands in their way. They can occur in just a few minutes or even a few hours of excessive rain. They can also show up when there has been no rain, but there has been dam failure or after a sudden water leak by rapidly thawing snow or ice.

Analyzes of the period of hydrological drought have shown in several cases that the decrease of spring runoff compared to other hydrological years, where the water content is usually higher, showed a deficit of the water source in the summer months, and thus, a period of drought occurred.

This paper helps to express the risk of sudden local floods due to heavy rain in the sub-basins of the Upper Topla River. The aim is to support the territory with measures for their mitigation and to classify areas with high, medium and low risk of flash floods by assessing topographic, hydrological and geological factors. These morphological parameters were used to evaluate the most sensitive sub-basins to floods and to create maps of the area's sensitivity to flash floods. The model situation is created in ArcGIS, where individual morphological characteristics are assigned to all sub-basins together with its assessment, and the degree of risk affecting the flash flood is determined for each characteristic. After processing maps of individual characteristics, a sensitivity map of the area was created, pointing out the places and localities where catastrophic impacts on the surrounding environment in the given sub-basin are expected. After creating such maps also for other hydrological phenomena as well as for other river basins, it is easier to decide in which locality, in what way, in what order and to what extent is the need to build flood protection measures to prevent or mitigate consequences of hydrological extremes.

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