

# Flood Risk Assessment from Flash Floods in Bodva River Basin, Slovakia

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**Abstract** The main objective of flood management as well as the entire management cycle is regulated by Directive of the European Parliament and of the Council 2007/60/EC on the assessment and management of flood risks. The paper deals with an application of preliminary flood risk assessment, particularly flood risk assessment from flash floods in the Bodva river basin, which is situated in the south of the Slovak Republic. The aim of the preliminary assessment of flood risk from flash floods is determining the hazard and the vulnerability of assessed area. The result of identification of a hazard is the determination of critical points in the basin and their contributing surfaces on the basis of the geometric and physiogeographic characteristics of the contributing surfaces. Vulnerability in the study area is determined on the basis of the type and density of the built-up area. The resulting flood risk is stated as a moderate risk. The scope and extremity of flood episodes point to the need to build a comprehensive system of flood protection measures in potential flood areas.

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## 1 Introduction

The increase in damage due to natural disasters is directly related to the number of people who live and work in hazardous areas and who continuously accumulate assets [1, 2]. Land-use planning authorities therefore have to manage effectively the establishment and development of settlements in flood-prone areas in order to prevent further increase in vulnerable assets [3, 4]. Flood risk analysis provides a rational basis for prioritizing resources and management actions. Risk analysis can take many forms, from informal methods of risk ranking and risk matrices to fully quantified analysis [5, 6]. It is important to keep in mind that a flood nowadays is expected to bring about a whole gamut of consequences. The costs of damages caused by extreme weather events (among which floods are a major category) have exhibited a rapid upward trend world-wide. The scope and extremity of flood episodes point to the need to build a comprehensive system of flood protection measures in potential flood areas.

Geographical information systems and multicriteria analysis (MCA) methods have been applied in several studies in flood risk assessment [7–12].

The paper is focused on preliminary flood risk assessment of flash floods in Bodva river basin, south of Slovakia. The task is to obtain knowledge on the spatial variability of flood risk from flash floods and in doing so supplement a preliminary flood risk assessment already conducted in 2011 for the purpose of proposing suitable flood mitigation measures for reducing the risk found. Thus a process for managing risk in locations endangered by flooding is secured. The added value of this work versus the preliminary flood risk assessment already conducted consists in the supplemental assessment of flood risk from flash floods and the fact that flood risk is not perceived only as a function of flood hazard but is also understood as a combination of flood hazard and vulnerability. The result of identification of a hazard is the determination and selection of critical points and their contributing surfaces, determined by the authors on the basis of selected basic geometrical and physiogeographical characteristics of the contributing surfaces.

Among the factors influencing flow and crucial in regard to the origin and size of flash floods, very intensive torrential rains play a key, primary role. The origin of flash floods is secondarily influenced by local or regional physiogeographical and hydrological conditions, and the hydrological conditions which can through torrential rains further accelerate or moderate the initiated process [13]. According to Acreman and Sinclair [14] the type and speed of hydrological processes occurring in the interior of a basin are determined by its natural environment and its characteristics. The mentioned authors assume that the dominant conditioning factors can also be represented by a small number of variables. This may be the surface and shape of the basin, the incline of its slopes, the length of the flow, the incline of the flow, the density of the river network, a dissection of the relief, precipitation, the

soil cover, the retention capacity of the basin, the landscape vegetation cover, its fragmentation and others. At the same time we could further specify each one, e.g. precipitation—by duration, intensity and frequency; soils—by character, type, depth, initial dampness (the actual amount of water in the soil), infiltration capacity, retention capacity, etc.

In the majority of scientific works [11, 12] etc., variables (parameters) are accepted for practical reasons which can be easily read (or measured) from existing maps and databases.

The aim of the paper is to apply a generally usable methodology, based on flood causal factors, realized in the GIS environment, the result of which will be the determination of areas with the occurrence of flood risk from flash floods.

## **2 Materials and Methods**

In the following sub-chapters the need for assessment of flood risk from flash floods, a description of the methodology as well as an assessment of this flood risk are substantiated.

A foundation was the existing “Methodological instructions for identification of critical points”, which was prepared in 2009 within the project “Assessment of floods in June and July 2009 on the territory of the Czech Republic” by the T.G. Masaryk Water Research Institute in Brno.

### ***2.1 Identification of Risk***

Knowledge on the material and spatial occurrence of flood situations and knowledge of the reasons that condition the increased frequency or regional differences in the occurrence of floods are an essential foundation for accepting effective and sustainable preventive flood mitigation measures.

#### **2.1.1 Determining of Critical Points and Their Contributing Surfaces**

A critical point is stipulated as a point of intersection of the borders of built-up territory of an urban area with the linear path of concentrated surface flow. For each critical point a contributing surface, so-called component basins, is generated the closing profile of which is formed by the relevant critical point. In practice this means that a surface flow of precipitation which falls on the territory of the contributing surface, flows to the profile of the critical point and continues further to the urban area, where it represents a danger for people and their property [15].

### 2.1.2 Selection and Characterization of Causal Factors

For this methodology causal factors are selected on the basis of those geophysical characteristics of basins which determine the character and course of the flash floods [16]: the surface of a basin, the slope of the basin, pedological relations, climatic relations—total precipitation (maximum daily total of precipitation in mm with probability of repeating once in 100 years; in Slovakia this is from 70 to 180 mm (70–180 l per m<sup>2</sup>)), land use.

### 2.1.3 Defining of Contributing Surfaces

This step deals with the process of defining the contributing surfaces or the segments of a basin which are crucial from the viewpoint of the creation of a concentrated surface flow from flash floods and have adverse effects on built-up urban areas. On the basis of the previous literature as well as expert research, the following criteria have been selected as being crucial in relation to flash floods:

- relative value of the size (area) contributing surface (0.2–40 km<sup>2</sup>),
- average slope of the contributing surface ( $\geq 5$  %),
- share of arable land on the contributing surface ( $\geq 40$  %),
- share of heavy soils on the contributing surface,
- relative value of the sum of 1-day precipitation with a period of repeating of 100 years on the contributing surface.

The criterion  $H$  which represents a combination of geometric and physiogeographical factors (hazard) was calculated according to the following Eq. (1):

$$H = (w_1 \times P) + (w_2 \times A_{CS}) + (w_3 \times S) + (w_4 \times AL) + (w_5 \times HS) \quad (1)$$

where:

$P$	relative value of the sum of one-day precipitation with a period of repeating of 100 years in mm with regard to maximum sum in the given area (–);
$A_{CS}$	relative value of the size of the contributing surface with regard to maximum considered size of the surface 40 km <sup>2</sup> (km <sup>2</sup> );
$S$	average slope of the contributing surface (%);
$AL$	share of arable land on the contributing surface (%);
$HS$	share of heavy soils on the contributing surface (%);
$w_1, w_2, w_3, w_4, w_5$	weights (0.39; 0.20; 0.27; 0.09; 0.06)—importance of the causal factors was calculated by analytical hierarchy process (AHP) in Microsoft Excel [16]

Defining of contributing surfaces was done in Arc GIS 9—version ArcView 9.3. For all identified critical points are generated the relevant contributing surfaces and the parameters calculated which enter into the analysis of the resulting assessment:

- Size of the contributing surface—calculation using ArcGIS—*Calculate Geometry*.
- Average slope of the contributing surface—calculation of the slope using arc-toolbox: Spatial Analyst Tools—Surface—Slope and subsequently calculation of the average slope—*Spatial Analyst Tools—Zonal—Zonal statistic*.
- Share of arable land on the contributing surface—calculate using Field Calculator.
- Share of the area of heavy soils on the contributing surface—calculate using *Field Calculator*.
- Relative value of the sum of 1-day precipitation with a period of repeating of 100 years in mm with respect to the maximum sum in the given area (max. 95 mm)—using *Field Calculator*.

A component of Spatial Analyst is a set of Hydrology instruments which contain a function enabling hydrological analyses of a basin to be carried out.

## 2.2 Risk Analysis

The riskiness of a locality is determined on the basis of a combination of the hazard of the contributing surfaces and the vulnerability of the territory beneath the critical point according to the rules of a  $3 \times 3$  matrix (Table 1).

The primary aim of risk assessment of contributing surfaces is determining the riskiness of the locality using an ordinal scale (i.e. low, moderate, and high) and providing a foundation for the next stage, called risk management.

## 2.3 Results

For a practical illustration of the assessment of flood risk from flash floods the entire basin of the Bodva River, situated in the south of Slovakia, is selected. For practical application of the methodological process of selecting measures for flood protection with a focus on lowering the potential for adverse consequences of floods on human health, property and the environment the small town of Medzev in a partial basin of the Bodva was selected. The town of Medzev was in the scope of preliminary assessment of flood risk in Slovakia assessed as an area with an existing potential for significant flood risk.

**Table 1** Matrix for calculation of the resulting flood risk from flash floods

V/H	A ( $\geq 17.7$ )	B (8.1–17.6)	C ( $\leq 8$ )
A ( $> 2.3$ )	AA (high risk)	AB (high risk)	AC (moderate risk)
B (1.5–2.3)	BA (high risk)	AC (moderate risk)	BC (low risk)
C ( $< 1.5$ )	CA (moderate risk)	CB (low risk)	CC (low risk)

## 2.4 Study Area

The river basin of the Bodva is demarcated by a contour dividing line which is to the north and east a dividing line toward the component Hornád basin. This dividing line leads along the ridge of the Volovský Mountains and from there turns to the southeast to Košice basin, where it runs along the highest places of the hilly parts of the Košice basin on the border with the Hungarian Republic. From the south the Slovak part of the Bodva basin is bordered by the state border with the Republic of Hungary. The western border of the basin is formed by a dividing line with the Slaná basin. This dividing line leads along the peaks of the Slovak karst region again in the direction of the Republic of Hungary [17].

The Bodva River arises in the Volovský Mountains at an elevation of 900 m a.s. l. The length of its flow along the state border is 48.4 km [18]. Within the territory of Hungary it flows into the Slaná River. A larger right-hand side inflowing tributary of the Bodva is the Turňa and on the left-hand side the Ida. The land use is as follows: artificial surfaces—4.7 %; agricultural areas—48.1 %; forested and semi-natural areas—46.6 %; wetland areas—0.1 %; waters—0.5 %.

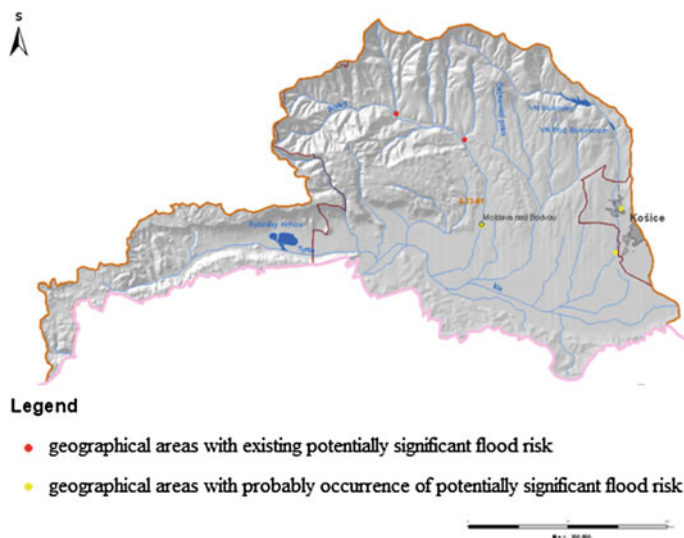
## 2.5 Description of Floods in the Basin

The year 2010 was from the viewpoint of rainfall exceptionally above average in the Bodva basin. The first flood of 2010 in the component basin of the Bodva occurred in the first half of January. In April a second flood occurred which resulted from long-lasting and substantial rainfall which fell over the course of 3 days. These rains caused a rapid and significant rise in water levels. The floods in May and June 2010 were exceptional from the viewpoint of time and spatial distribution in the Bodva basin. In nearly all water measuring stations water stages designated as third degree flood activities were surpassed. Further above-average rainfall occurred in November. Basins reacted to the rainfall with increased flows and in the Bodva the flow of water was at a level which can be achieved or surpassed only one time every 1 to 2 years. Precipitation activities continued even into the early part of December and the larger part of the precipitation was repeatedly in the form of rainfall [19].

In the scope of a flood risk assessment in the Bodva river basin 5 areas (17.2 km) were identified with the occurrence of significant flood risk [19], from this:

- 2 areas with the existing potential for significant flood risk (6.7 km),
- 3 areas with probable potential for significant flood risk (10.5 km).

The list of the areas in which the occurrence of significant flood risk was determined is graphically presented in Fig. 1.



**Fig. 1** Geographical area with potentially significant flood risk in the component basin of the Bodva [19]

## 2.6 Data

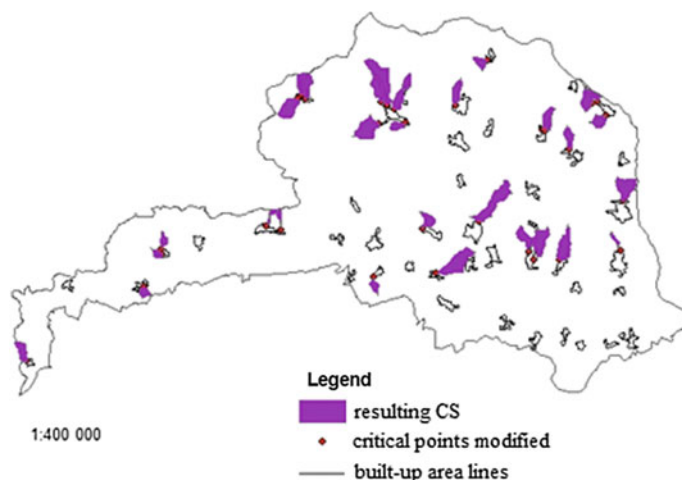
With the assessment of flood risk from flash floods the following data foundations are utilized:

- an analysis of flash floods on the territory of the Slovak Republic,
- a digital model of terrain of the assessed territory,
- the edges of built-up municipalities,
- CORINE Land Cover 2006,
- a map of values of the sum of one-day precipitation with a period repeating of 100 years (Slovak Hydrometrological Institute—SHMÚ),
- a map of soil types (Research Institute of Soil Sciences and Soil Protection—VÚPOP).

The documents, analysis and conversion of data are prepared in the GIS environment, specifically ArcGIS 9—version ArcView 9.3 with Spatial Analyst and ArcHydro.

## 2.7 Results

The aim of the preliminary assessment of flood risk from flash floods is determining the critical points in the basin and their contributing surfaces on the basis of the



**Fig. 2** Resultant contributing surfaces (CS) of the identified critical points in the component of the Bodva basin

physiogeographic and geometric characteristics of the contributing surfaces. Individual characteristics enable the determining of the flood hazard; therefore, before the flood risk assessment itself it is important to know the natural relationships of the resolved territory.

The sequence of individual steps of the preliminary assessment of flood risks from flash floods in the partial basin of the Bodva emerges from the proposed methodological procedure described in previous chapter.

Overall, 32 critical points are identified in the basin. For all critical points identified the relevant contributing surfaces are generated (Fig. 2) and the parameters calculated which enter into the analysis of the resulting assessment.

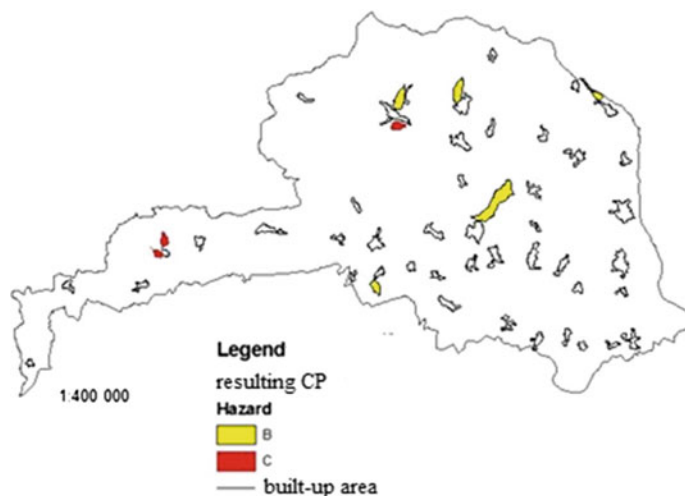
The preliminary parameters are used for calculation of the H criteria, i.e. indicator of critical conditions, according to the relationship (1). All critical points whose relevant contributing surfaces satisfy the given criteria are assigned to another assessment—calculation of risk. From the total number of 32 critical points, 8 critical points, or 8 contributing surfaces, satisfy the entered criteria ( $H \geq 5.3$ ).

For the needs of calculation of flood risk from flash floods of the assessed contributing surfaces, it is necessary to determine the hazard of the selected contributing surfaces and the vulnerability of the territory below the critical points. The class of hazard (A, B and C) depends on the value according to Table 1.

A graphic presentation of the determined hazard classes of the selected contributing surfaces (8 in total) is shown in Fig. 3.

Overall, 5 contributing surfaces in the component basin of the Bodva were determined to be class B hazard (moderate hazard) and 3 contributing surfaces were assigned to class A (high hazard) (Fig. 3).





**Fig. 3** Resulting hazard of selected contributing surfaces and critical points (CP) in the Bodva basin

Vulnerability below the critical point is determined according to the relation (2). The determined values of the individual criteria and resulting vulnerability require reconnaissance of the terrain. Given this fact, vulnerability is determined illustratively for only one critical point, which is located in the northeast part of the town of Medzev. The resolved segment for assessing vulnerability is determined only by a professional estimate, and territories adjacent to the flow, i.e. a built-up area directly adjacent to the bank of the flow, are taken into consideration.

In the resolved segment built-up areas make up only 16.6 % of the total endangered territory, i.e. less than 30 % of the territory is built-up. On the basis of this fact, it is assigned a value of 1 of criteria D (density of built-up areas). Greater emphasis is placed on the type of built-up area below the critical point—criterion T. In the case of this critical point, almost only residential areas are involved, where damage in the case of torrential floods could possibly also lead to loss of human lives. One building is non-residential (for industry). The value of this criteria is calculated as the weighted average of the values of the class of vulnerability, on the basis of the share of built-up areas of individual types of buildings in the endangered (adjacent) territories (a building with vulnerability 1 represents 2.7 % share of built-up areas and the buildings with a vulnerability of class 3 represent a 13.9 % share of the built-up area). Criterion T (type of built-up area) acquires a value of 2.7.

The resultant vulnerability is calculated according to relation 2 and in the case of this solution of the critical point is numbered by the value 2.01. This involves moderate vulnerability, which is in the range from 1.5 to 2.3.

The risk according to the proposed method and the determined matrix (Table 1) is calculated as a combination of hazard and vulnerability. In the case of this critical point the contributing surface is assigned to the risk category BB, which means that the locality is at moderate risk in terms of flash flooding of the basin.

### 3 Conclusion

The contribution, dealing with solving the problem of assessment and management of flood risk with the goal of effective control aiming at reducing flood risk and thus increasing the measure of flood protection, is developed in the sense of currently valid legislation in the area of flood protection, primarily in the sense of the already mentioned directive 2007/60/EC on the assessment and management of flood risk. The aim of the work was expanding the set of scientific knowledge in the field of assessment and management of flood risk in Slovakia and in the world, and a proposal for directing the management of flood risks with the goal of reducing the adverse effects on human health, the environment and economic activities connected with floods. A goal so conceived had a primary task, namely “Proposal of a methodology for the process of preliminary assessment of flood risk—a methodological procedure for preliminary flood risk assessment from flash floods with respect to the need for its updating following from directive 2007/60/EC and its application in the conditions of a modelled territory”.

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