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ORIGINAL PAPER

Methodology of flood risk assessment from flash floods based on hazard and vulnerability of the river basin

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Abstract Flood protection is a society-wide task. The basic rules of prevention in flood protection are stipulated by the regulation of a secondary right of the European Union—Directive of the European Parliament and Council 2007/60/EC on assessment and management of flood risks. The paper is focused on preliminary flood risk assessment of flash floods. The task was 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. Flood risk in this study is understood as a combination of flood hazard and vulnerability. The main part of the work is devoted to the proposal of a methodological approach for preliminary flood risk assessment of flash floods. Application of the proposed approach in Bodva river basin, southern Slovakia, is described in the results section.

Keywords Flood risk · Hazard · Vulnerability · Flash floods

1 Introduction

When resolving questions about floods, establishing the concept of risk is an important task. It is essential to note that the problem of risk was developed and formulated in a broad spectrum of different disciplines (crisis management, economics, environmentalism, geography, sociology), and each of them understands it and perceives it a little differently. Despite the fact that the concept of risk belongs at present to frequented concepts, it is marked by lack of clarity, complexity and ambiguity. In regard to research of flood risk, this has a multidisciplinary character and is a subject of interest for hydrologists, sociologists, economists, environmentalists and geographers. Each of these disciplines approaches the

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assessment of flood risk from its own point of view, which brings with it a certain diversity in the matter of expressions of flood risk, in terminology and in methodological approaches of its assessment and management (Solín et al. 2011; Solín 2012). For the need of analysis, assessment and control of flood risk, an unambiguous definition of flood risk is essential. Thanks to this, an entire order of methodological processes which enable risk to be defined, evaluated and controlled has been developed (Langhammer and Vilímek 2008). The greater the hazard, the longer the exposure, and the greater the vulnerability of an object is, the greater the risk is (Lavell et al. 2012; IPCC 2012). 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 (Hanák and Korytárová 2014).

In flood risk assessment, the most often are applied combination of multicriteria analysis (MCA) methods and geographical information systems (GIS). These methods have been used recently in several studies. Yalcin and Akyurek (2004) applied a GIS-based multicriteria evaluation in order to analyse the flood vulnerable areas in south-west coast of the Black Sea. Chandran and Joisy (2009) introduced an efficient methodology to accurately delineate the flood hazard areas in Vamanapuram river basin in a GIS environment. Yahaya et al. (2010) identified flood vulnerable areas in Hadejia-Jama'are river basin, Nigeria, by using a spatial multicriteria evaluation technique. Tanavud et al. (2004) assess the risk of flooding and identified efficient measures to reduce flood risk in Hat Yai Municipality, southern Thailand, using GIS and satellite imagery. Scheuer et al. (2011) present an approach to modelling multicriteria flood vulnerability which integrates the economic, social and ecological dimension of risk and coping capacity. Kandilioti and Makropoulos (2012) applied a GIS-based multicriteria flood risk assessment methodology for the mapping of flood risk in the Greater Athens area and validated for its central and the most urban part.

The aim of this paper is to propose a generally usable methodology realized in the GIS environment, the result of which will be the determination of areas with the occurrence of flood risk from flash floods. When determining flood risk, an ordinal scale is used, i.e. the risk will be (unlike the preceding preliminary flood risk assessment) divided into three triads. Likewise, it is necessary to take into consideration the simplicity of the application of the selected methodology. The new proposal of the preliminary flood risk assessment follows from the fact that preliminary assessment of flood risk, which was according to the requirements of directive 2007/60/EC prepared as of 21 December 2011, needs to be updated every 6 years. The aim of a preliminary flood risk assessment in the individual component basins of the administrative territories of a basin is to determine, in compliance with directive 2007/60/EC, those geographical areas where a potentially significant flood risk exists, or where it is possible to anticipate that its occurrence is likely.

2 Materials and methods

The use of mathematical models and geographical information systems has become a completely common instrument for the assessment and interpretation of data in flood management. The goal of deploying these resources is in particular to speed up the processing of risk analysis of flood territories and subsequently creation of a map of flood hazard and risks. Equally, the goal is to use data sources that would be easily accessible and sustainable over time and that have a unified form for the entire territory. Multicriterial analysis has likewise become a common instrument used in flood management or a tool in decision-making processes.

2.1 Data

A preliminary flood risk assessment from flash floods requires a quantity of data foundations of a corresponding range. With the assessment of flood risk from flash floods, the following data foundations are utilized:

- an analysis of flash floods on the territory,
- 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 (source: Slovak Hydrometeorological Institute—SHMI—in Slovakia),
- a map of soil types (source: Research Institute of Soil Sciences and Soil Protection—VUPOP—in Slovakia).

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 superstructures.

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

2.2 Identification of risk

In Slovakia, rains of exceptionally great intensity are the most frequent reason for local flash floods, which occur especially during the warmer parts of the year and are almost always connected with the formation of storm clouds and the origin of storms. Flash floods occur especially in small basins, and therefore their description in historical materials is relatively rare. Despite this, it is possible in professional hydrological collections and reports or in municipal chronicles to find reports on summer storms and floods in a whole line of municipalities (Pekárová et al. 2009).

2.3 Determination of critical points and their contributing surfaces

The first point is the determination of critical points (CP) and their contributing surfaces (CS). The basis 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 (TGM WRI 2009). Critical points with contributing surfaces from the viewpoint of creation of a concentrated surface flow from flash floods are stated on the basis of basic geometrical and physiogeographical characteristics of the area.

A CP is a point of intersection of the borders of built-up territory of an urban area with the path of concentrated surface flow which may have adverse effects on the built-up parts of a municipality (TGM WRI 2009).

2.4 Selection and characterization of causal factors

The process of selection of causal factors enables the recognition of risk factors, or identification of risk areas for the potential origin of flash floods in a given component basin. In the process of identification not only are time and spatial analysis of precipitation and the culmination of flows decisive, but likewise other characteristics on the territory on which the entire precipitation-flow process takes place. A flash flood as an extreme hydrological response of a basin (the basic spatial hydrological unit) has an autochthonic character, that is, it is the product of the primary impulse of extreme floods transforming the basin through physiogeographical parameters (Grešková 2001).

In scientific works (Yahaya et al. 2010; Yalcin and Akyurek 2004), variables (parameters) are accepted for practical reasons which can be easily read (or measured) from existing maps and databases.

For this methodology, causal factors are selected by the authors on the basis of those geophysical characteristics of basins which determine the character and course of the flash floods.

- The surface of a basin
- The slope of the basin
- Pedological conditions
- Climatic conditions—total precipitation (with probability of repeating once in 100 years; in Slovakia, it is from 70 to 180 mm)
- Land use

2.5 Definition of contributing surfaces

In regard to the selection of critical contributing surfaces, combined criteria are chosen, i.e. those contributing surfaces are selected which satisfy the criteria given in Table 1. On the basis of a survey of modelled basins which were afflicted by flash floods, the boundaries of the individual criteria are set as follows and are presented in Table 1.

From detailed analyses, it follows that in the majority of cases, basins affected by flash floods are those with contributing surfaces of sizes from 0.2 to 40 km^2, with an average slope equal or higher than 5.0 %, with a share of arable land of more than 40 %, and with a larger indicator of critical conditions, less than or equal to a value of 5.279. The C4 value is set on the basis of a professional judgment such that it expresses approximately one-third of the interval of values, calculated using the general relationship supplemented by the weights of the relevant constants, which express the importance of the individual factors in the process of origin, or the course of flooding. The C4 criterion represents a combination of geometrical and physiogeographical factors and is calculated according to the following Eq. (1):

$$\mathrm{C4} = (a_1 \times P) + (a_2 \times A) + (a_3 \times I) + (a_4 \times L) + (a_5 \times S) \quad (1)$$

where P is relative value of the sum of one-day precipitation with a period of repeating of 100 years in millimetre with regard to maximum sum in the given area (–), A relative value

Table 1 Description of selected criteria with the determined boundary

Criteria code	Description of criteria	Boundary set
C1	Relative value of size of the contributing surface	0.2–40 km^2
C2	Average slope of the contributing surface	≥5 %
C3	Share of arable soil on the contributing surface	≥40 %
C4	Indicator of critical conditions	≥5.279

of the size of the contributing surface with regard to maximum considered size of the surface 40 km^2 (km^2), I average slope of the contributing surface (%), L share of arable land on the contributing surface (%), S share of heavy soils on the contributing surface (%), and a_1, a_2, a_3, a_4 and a_5 weights (0.386414; 0.19526; 0.265579; 0.091627; 0.061)

In the following sub-chapter, the process of calculating the weights of individual factors (a_1, a_2, a_3, a_4 and a_5) entering into the calculation of the C4 indicator of critical conditions is described.

2.6 Determining the importance of causal factors

Several methods exist which have as a rule the same principles—the assessment of several variants for resolving a problem according to the selected criteria and determining the order of the variants. The individual methods are differentiated according to how the so-called weights of individual criteria are determined and how the degree to which the selected criteria meet individual variant solutions is assessed numerically. For determining the importance of the causal factors, an analytical hierarchy process (AHP) is used in this work.

The AHP method was developed in 1970 by Thomas L. Saaty, and since then, its use in the world has significantly expanded. It is based on a paired comparison of the degree of significance of the individual criteria and measures of how the assessed variants fulfil the resolution of these criteria. The assessment is in both cases based on expert estimates, during which experts in the given field compare the mutual influences of two, possibly several factors. The mutual influences are evaluated on the basis of the selected scale (Saaty 1980).

The aim of the calculation is to obtain the relative importance of the selected criteria. This can be achieved by normalization of the actual vector which gives the relative weight of the criteria. The normalized actual vector is calculated on the basis of an iterative process and the matrix of the paired comparison, where the matrix $\bar{A}$ of type $p \times p$ (i.e. it has p rows and p columns) is calculated by the normalization of the columns A (Boroushaki and Malczewski 2008) according to the relation (2):

$$\bar{A} = \left[a^*_{qt}\right]_{p \times p} \tag{2}$$

and for calculation of the element of the matrix a^*_{qt} the relation applies (2):

$$a^*_{qt} = \frac{a_{qt}}{\sum_{q}^{p} a_{qt}} \tag{3}$$

The matrix $\bar{A}$ x $\bar{A}$ is calculated and normalized in $\bar{A}_2$, and then $\bar{A}_3$,…, $\bar{A}_z$ are calculated until all columns of the obtained matrix are identical. The column further gives the vector ω defined by the relation (4):

$$\omega_q = \bar{a}^*_{qt(z)} \quad \text{for all } q = 1, 2, \ldots, p \tag{4}$$

The results of the calculation of relative importance of the selected criteria: a_1—precipitation, a_2—soil type, a_3—land use, a_4—slope of the contributing service, a_5—the size of the contributing surface, and verification of the consistency are carried out in the program Microsoft Excel and are presented in Table 2.

Table 2 Calculation of normalized weight criteria

	a_1	a_2	a_3	a_4	a_5	Weight
a_1	0.413793	0.306122	0.6	0.285714	0.266667	0.386414
a_2	0.206897	0.153061	0.066667	0.285714	0.333333	0.19526
a_3	0.137931	0.459184	0.2	0.285714	0.2	0.265579
a_4	0.137931	0.051020	0.066667	0.095238	0.133333	0.091627
a_5	0.103448	0.030612	0.066667	0.047619	0.066667	0.061119
Sum	1	1	1	1	1	1

It can be expected that each human judgement is to a certain measure imperfect (or inconsistent). For this reason, it is necessary to know a certain measure of discrepancy which arises with paired comparisons of the matrix $\bar{A}$. In order to be able to gauge the measure of consistency, it is necessary to calculate the so-called consistency index (CI). This index (Boroushaki and Malczewski 2008) is calculated according to the following relation:

$$\mathrm{CI} = \frac{\lambda - p}{p - 1} = \frac{5.416144 - 5}{5 - 1} = 0.10411 \tag{5}$$

where λ is the larger actual number, which can be obtained as soon as we have its affiliated actual vector, and p is the number of criteria (columns) of matrix $\bar{A}$.

Subsequently we calculate the consistency ratio (CR) (Boroushaki and Malczewski 2008), which is calculated according to the relation:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} = \frac{0.0411}{1.12} = 0.092956 \tag{6}$$

where RI is the random index of consistency according to the number of evaluated criteria p of matrix $\bar{A}$ on the basis of Table 3.

Comparison of level of consistency:

$$\mathrm{CR} < 0.1$$
$$0.092956 < 0.1$$

If the resulting consistency ratio CR is <0.1, then the ratio indicates an appropriate level of consistency of the paired comparison, and conversely, if CR is >0.1, this means that the paired comparison is a fully inconsistent determination (Boroushaki and Malczewski 2008). This process can be calculated automatically in Microsoft Excel, the same as in the Expert Choice (Expert Choice Quick Start Guide 2000–2004) software called multi-criteria decision analysis (MCDA).

The consistency factor is smaller than 0.1, and from this, it follows that the level of consistency is appropriate, i.e. the importance of the individual criteria was determined correctly. The calculated weights enter into the calculation of the critical factor C4.

Table 3 Random index of consistency (Saaty 1980)

Number of criteria	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

2.7 Risk analysis

The main goal of risk analysis is determining the hazard of contributing surfaces and the vulnerability of the land beneath the critical point. A description of a determination of hazard and vulnerability is described below.

2.8 Determining the hazard of a contributing surface

The hazard of a surface means the size of the threat of flash floods, and it is determined on the basis of an indicator of critical conditions: the C4 criteria. The individual contributing surfaces are divided on the basis of C4 assessment into three hazard classes (A, B and C). The limit C4 value is selected such that it always expresses approximately one-third of the interval of the values which the measure of hazard of a territory can acquire (Table 4).

2.9 Determination of the vulnerability of a territory

Vulnerability is determined by expert estimate and reconnaissance of the terrain, since during flash floods the range of the floods is not known in the adjacent territory. The adjacent territory is understood to be the immediate surroundings of the flow; this means the built-up areas directly along the banks of the flow. Therefore, the estimate of vulnerability is only orientational, and in future it would be necessary to work up a detailed hydrological and hydraulic model and to determine flooded territories with a variety of periods of repeated floods.

Vulnerability is determined on the basis of two criteria, namely: the type of built-up area and the density of the built-up area beneath the critical point. The type of built-up area is considered to be the more important criterion; therefore, it is assessed with a higher weight, with a value of 0.6. The density of built-up areas was assigned a weight value of 0.4. The density of built-up areas represents the number of endangered buildings below the critical point. A graphical presentation of the criteria together with a description and value class of vulnerability is given in Table 5.

The type of built-up area determines whether built-up areas are involved where flash floods would lead to serious material damage or could possibly lead to the loss of human lives, or built-up areas where material damages would not occur at all. Buildings are classified according to the annexes of national legislation. In Table 6, the classification of the individual types of buildings is presented with the assigned vulnerability value.

The resulting vulnerability of the given territory beneath a critical point is calculated according to the following formula (7):

$$\mathrm{LV} = (c\mathrm{I} \times v_1) + (c\mathrm{II} \times v_2) \tag{7}$$

where LV is vulnerability of land below a critical point, cI value criteria I—type of built-up

Table 4 Description of hazard

Hazard class	Description of hazard class (H)	Hazard value (C4)
A	High hazard	≥17.66
B	Moderate hazard	8.1–17.65
C	Low hazard	≤8

Table 5 Criterion *c*II—density of built-up areas

Description of the vulnerability class	Vulnerability class	Value of vulnerability class	Image expression
High density of built-up area (more than 70 % of the territory is built-up)	High	3	
Moderate density of built-up area (more than 30 % and less than 70 % of the territory is built-up)	Moderate	2	
Low density of built-up area (less than 30 % of the territory is built-up)	Low	1	

Table 6 Criterion *c*I—type of building (built-up area)

Type of building (built-up area)		Vulnerability class	Value of vulnerability class
Residential buildings	Single-residence buildings, two or more resident buildings, other residential buildings	High	3
Non-residential buildings	Hotels, education, health care and administrative buildings	High	3
	Buildings for culture, public amusement, trade and services	Moderate	2
	Buildings for transport and electronic communications, industrial buildings and warehouses, others	Low	1

Table 7 Description of vulnerability

Vulnerability class	Description of the vulnerability class (LV)	Value of vulnerability
A	High vulnerability	>2.3
B	Moderate vulnerability	1.5–2.3
C	Low vulnerability	<1.5

areas, *c*II value criteria II—density of built-up areas, and v_1 and v_2 weights of criteria (0.6 and 0.4).

Vulnerability is subsequently divided into classes according to the acquired value. The limit values of the resulting vulnerability of a territory were determined such that they always express approximately one-third of the interval of values which the measure of vulnerability of a territory can acquire (1–3) (Table 7).

2.10 Risk assessment

The aim of risk assessment is determining the risk of the area using an ordinal scale (i.e. low, moderate, high). The riskiness of the area 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 × 3 matrix (Table 8).

The categories of flood risk are described in Table 9. The highest flood risks threaten in contributing surfaces where the hazard from flash floods and vulnerability of the territory beneath the critical point are assigned to category A—high—AA, AB and BA. These surfaces should be resolved as a priority. The areas AC, BB and CA all belong to the category of moderate risk. Areas categorized as CB, CC and BC belong to the category of low risk. Built-up areas in these localities are under minimal threat.

2.11 Use of GIS with applications of the proposed process

With application of the above-proposed process of assessment of flood risk from flash floods, the software ArcGIS 9—version ArcView 9.3, was used, specifically its two superstructures:

- Spatial Analyst and
- ArcHydro.

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—e.g. identification of flow-free areas, determination of the direction of the flow from a cell, the delineation of a basin, and also contains a set of instruments for interpolation—e.g. Inverse Distance Weighting (IDW) and Kriging.

Table 8 Matrix for calculation of the resulting flood risk from flash floods

LV	*H*		
	A	B	C
A	AA	AB	AC
B	BA	BB	BC
C	CA	CB	CC

Table 9 Categories of flood risks

Hazard (*H*)	Vulnerability (LV)	Resultant risks (*R*)	Description of the risk
A	A	AA	High risk
A	B	AB	High risk
B	A	BA	High risk
B	B	BB	Moderate risk
C	A	AC	Moderate risk
A	C	CA	Moderate risk
B	C	BC	Low risk
C	B	CB	Low risk
C	C	CC	Low risk

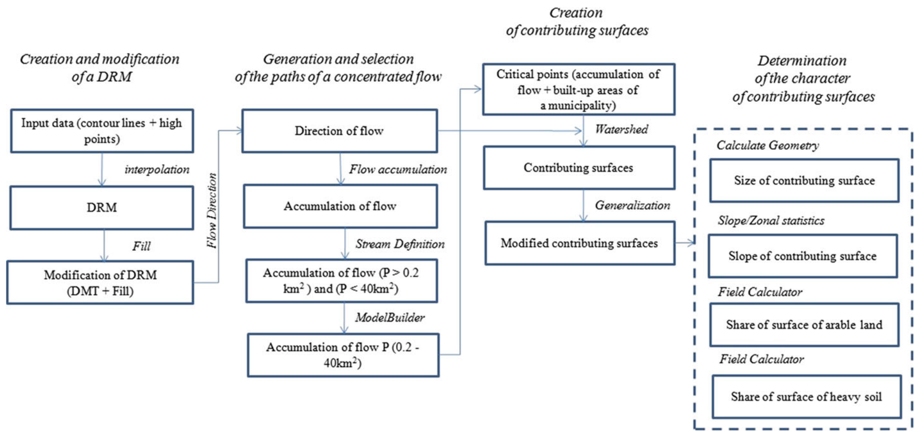

Fig. 1 Sequence of steps for performing ArcGIS analysis

ArcHydro is a model of spatial and time data for hydrological analyses. It is composed of two main components—ArcHydro Data Model and ArcHydro Tools—which offer a basic database structure and a set of instruments for common hydrological analyses.

In the following part, the use of the ArcGIS 9 software during the individual steps of preliminary flood risk assessment from flash floods is described. The process is graphically portrayed in Fig. 1.

The hazard of the skeletal contributing surfaces is calculated according to the entered formula (1) for calculating criteria C4 using the function *Field Calculator*, which is subsequently, on the basis of the value of the attribute, classified into three categories (high, moderate and low hazard) based on Table 4.

For determining vulnerability, a reconnaissance of the terrain is necessary, and it can possibly be done using the tool Google Earth. The values of vulnerability are entered manually into the ArcGIS environment.

For calculation of the relevant values of the resulting risk, also the function *Field Calculator* is used. This function enables advanced calculations using the scripting languages VBSscirpt or Python. In this case, the scripting language Python, which works with logical operations like IF and THEN, is used.

3 Study area

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

In the following section, the natural conditions of the assessed Bodva basin and the procedure and results of preliminary assessment of flood risk from flash floods in this basin are described.

3.1 Description of the natural conditions of basins

The territory of the component basin of the Bodva is situated in two orographic areas: the Slovenské Rudohorie Mountains and the Lučenec–Košice lowlands. From the morphological side, the component basin of the Bodva is a markedly diverse territory with a distinctive relief. The central and eastern part of the basin is formed by the moderately hilly Košice basin, which is enclosed to the north by the notable Volovské Mountains. From the west, the basin is bordered by the Slovak Karst region and from the south the Bodvianska Hills.

In terms of soil types, bottom land soils to bottom land clayey soils predominate. These consist of the wide alluvium of the Ida River, including its right-hand side feeder streams, the alluvium of the Bodva River in the lower part and a narrow-band alluvium of the Turnianský stream. The hydrogeological characteristics of the rock in the basins are presented in Table 10 (WRI 2009).

Forests cover 417 km^2 of the territory of the component basin of the Bodva, which represents 46.8 % forestation. The forestation of the territory in the individual geomorphological units of the component basin is significantly distinct. More continuous forested complexes are located only in the Volovské Mountains, in the source regions of the Bodva and Ida Rivers. In the past, however, in the vicinity of mining settlements here and the surroundings of the water hammers, relatively large areas were deforested. Forest vegetation was also removed in the western part of the basin on the territory of the Slovak Karst, where deforested areas were collectively transformed into pasturage. From the total amount of forests in the basins (417 km^2), 59.2 % represent agricultural forests with mainly productive functions. Protected forests (soil protection for exceptionally unfavourable locations) take up 24.3 % and special use forests (in zones of hygienic protection of water sources, forest parks, spa forests) 16.5 % of forested areas (MoE 2011).

The geological construction of the territory predetermines the hydrogeological relationship of the component basin of the Bodva. Older Palaeozoic rocks, the original character of which was pellet-psammitic from metamorphosis or volcanic with interkernel permeability, are characteristically cracked permeable (MoE 2011).

The component basin of the Bodva thanks to the complex orographic relationships includes several climatic areas. The long-term average annual air temperature in the component basin is from 5 to 8 °C. The average annual sum of precipitation moves from 600 to 1000 mm (MoE 2011).

The general geographical characteristics of the component basin of the Bodva relating especially to the use of the land are presented graphically in Fig. 2.

Table 10 Hydrogeological characteristics of rock in the basin of the Bodva (WRI 2009)

Basin	Occurrence of permeability of rock in % from the total area of the basin				
	Impermeable to very weakly permeable Coefficient of permeability (m^2s^{-1})	Weakly permeable	Weakly to well permeable	Well to very permeable	Karst area
	$<1.10^{-4}$	1.10^{-3}–1.10^{-4}	1.10^{-2}–1.10^{-3}	$>1.10^{-2}$	
Bodva					
4-33-01	17.0	33.0	2.0	28.0	20.0

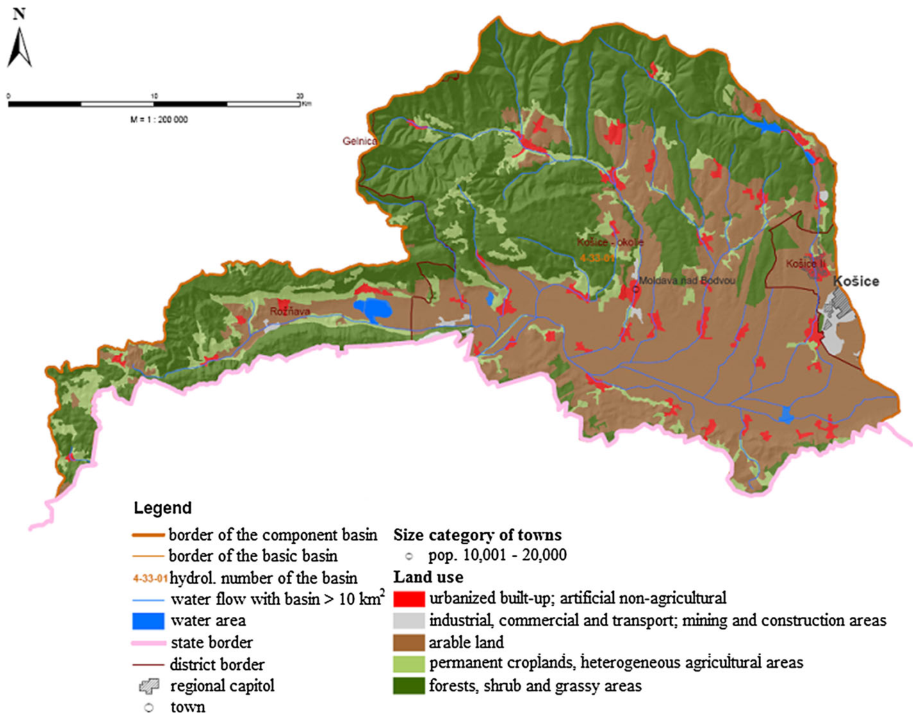

Fig. 2 General geographical characteristics of the component basin of the Bodva (MoE 2011)

The map was worked up in the scope of preliminary flood risk assessment in Slovakia.

4 Results

The sequence of individual steps of the preliminary assessment of flood risks from flash floods in the component basin of the Bodva emerges from the proposed methodological procedure described in Fig. 1.

The first identification of critical points (CP) is carried out on the basis of analysis of the intersections of the generated paths of concentrated surface flow with a contributing surface (CS) from 0.2 to 40 km^2 and the borders of built-up areas of municipalities. Overall, 32 critical points are identified in the basin. For all critical points identified, the relevant contributing surfaces (CS) are generated and the parameters calculated which enter into the analysis of the resulting assessment.

The preliminary parameters are used for calculation of the C4 criteria, i.e. indicator of critical conditions, according to the relationship (1), which represents a combination of geometrical and physiogeographical factors. The higher the value of this criterion is, the higher the potential hazard (of origin) by flash flooding is.

Identification of the final critical points consists in selection of the critical points on the basis of criteria determined in the proposed methodology. Those critical points are selected which fulfil the criteria in Table 1, i.e. with an average slope of the contributing surface $\geq$5 %, with the share of arable land on the contributing surface $\geq$40 % and an indicator of the critical conditions $\geq$5.279. Criterion C1 was already considered with the selection of the critical points. This means that the critical points are generated only for the surface flow with a large contributing surface from 0.2 to 40 km^2.

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 CP, eight critical points, or eight contributing surfaces, satisfy the entered criteria (C2–C4).

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 of the criteria C4 according to Table 4, where a contributing surface with a value of C4 >17.66 represents a high hazard, a contributing surface with a value of C4 from 8.1 to 17.65 a moderate hazard, and a contributing surface with a value of criteria C4 <8 a low hazard.

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

Vulnerability below the critical point is determined on the basis of two criteria, namely: type of built-up area and density of the built-up area below a critical point according to the relation (7). 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 north-east part of the town of Medzev (Fig. 3).

Given the fact that the range of floods near the basin is not known, it is not possible to determine the vulnerability exactly. 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 (Fig. 3).

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 according to Table 5 of criteria *c*II (density of built-up areas).

Greater emphasis is placed on the type of built-up area below the critical point—criterion *c*I. 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 and according to Table 6 is assigned to the category of industrial buildings and warehouses—industrial buildings. The value of this criteria is calculated as the weighted average of the values of the class of vulnerability from Table 7, 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 2.68 % share of built-up areas, and the buildings with a vulnerability of class 3 represent a 13.94 % share of the built-up area). Criterion *c*I (type of built-up area) acquires a value of 2.68 according to the following calculation:

$$cI = \frac{(2.66\,\% \times 1) + (13.94\,\% \times 3)}{16.6\,\%} = 2.68$$

The resultant vulnerability is calculated according to relation 23 and in the case of this solution of the critical point is numbered by the value 2.01 according to the following calculation:

$$LV = (2.68 \times 0.6) + (1 \times 0.4)$$

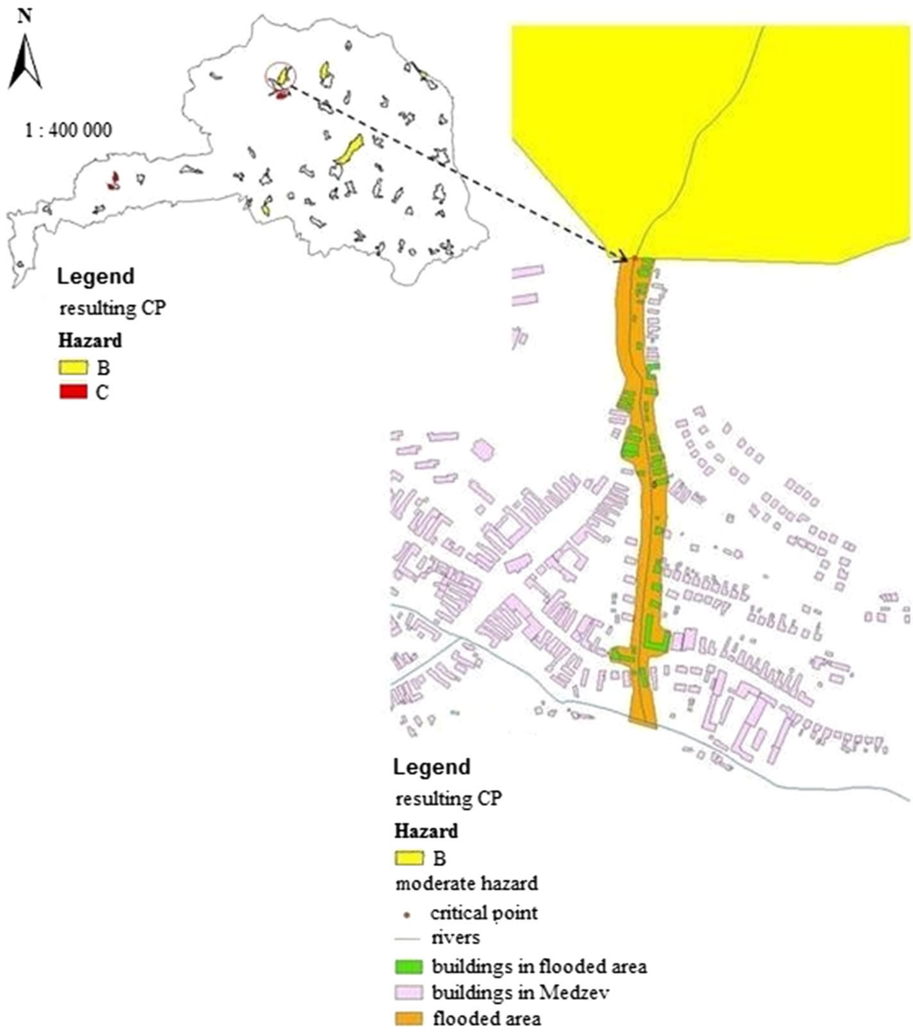

Fig. 3 Detail of the resolved critical point and hazard of the territory beneath the critical point in the town of Medzev

According to Table 7, 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 9) 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 (Table 11).

On the basis of the knowledge of the current state of existing modifications, we propose in the resolved area of the town of Medzev these possible preventive anti-flooding measures:

- removing sediments from the riverbed and vegetation on the bank of the water flow, thus securing the flow-rate capacity of the channel of the watercourse,

Table 11 Categories of flood risk

Hazard (*H*)	Vulnerability (LV)	Resultant risks (*R*)	Description of the risk
A	A	AA	High risk
A	B	AB	High risk
B	A	BA	High risk
B	B	BB	Moderate risk
C	A	AC	Moderate risk
A	C	CA	Moderate risk
B	C	BC	Low risk
C	B	CB	Low risk
C	C	CC	Low risk

- on unmodified segments of the watercourse, carrying out modification, e.g. reinforce the slopes of the watercourse banks,
- possible construction of a reservoir above the town which lowers the maximum flow rate during increased water stages.

5 Conclusion

Flood events, the frequency of which has shown an increasing tendency over the past decades and consequences of which have made up 31 % of economic losses, have a very special place in the area of natural catastrophes. And for these reasons solutions to the question of flood protection are acquiring a wider international dimension and are increasing pressure on the realization of the system-wide working of complex measures. The transition from protection from flooding to complex flood management is reflected most of all in directive 2007/60/EC on the assessment and management of flood risk. The guideline strengthened the converging of national approaches to flood management and control and likewise brought parallel development in the area of the assessment of flood risks and management of flood risk of member states of the European Union.

Before the proposal of the methodology itself, a search of the literature for available documents relating to flood risk, risk analysis, legal arrangement of flood risk management and likewise of existing and developing approaches for assessing flood risk in Slovakia and around the world was developed. The contribution of the work is the proposal of a methodology for preliminary assessment of flood risk from flash floods, which can be used when accomplishing the goals of directive 2007/60/EC, i.e. reducing the probability of floods and reducing their potentially adverse consequences.

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 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".

The proposed methodological approach is applied in a modelled territory. For preliminary flood risk assessment, the Bodva basin was chosen, where through the selected methodology eight critical points (CP) were identified. Five of the critical points were assigned to the moderate hazard class, and three critical points were placed in the high-hazard class. Given the complexity of determining the vulnerability of the territory below the critical point, where reconnaissance of the terrain is essential, vulnerability was determined for only one critical point with moderate hazard: in the north-eastern part of the town of Medzev. Vulnerability in the resolved territory was determined on the basis of type and density of the built-up area as moderate. The resulting risk was assigned to the risk category BB, which means that the locality is from the standpoint of flash flooding at moderate risk.

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