Assessment of flood vulnerability in Bodva river basin, Slovakia

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Abstract: *The aim of the paper is to present the results of the assessment of flood vulnerability using multicriteria analyses (MCA) and geographical information systems (GIS) tools. The analyses were made in case study area of the Bodva river basin located in the eastern part of Slovakia. In the study, attention was focused on the causative natural factors for flooding in the river basin, such as soil type, precipitation, land use, the size and slope of the basin. The identification of flood vulnerability is comprised of two basic phases. Firstly, the effective factors causing floods are identified. Secondly, several approaches to MCA in a GIS environment are applied, and these approaches are evaluated in order to prepare flood vulnerability map. The flood vulnerability was evaluated in four classes – acceptable, moderate, undesirable and unacceptable. The results of analyses are a vulnerability map of the study area and a calculation of percentage area of each vulnerability class.*

More than 40% of the area represents an area with a higher scale of vulnerability. The results show areas to which should be given greater attention in the implementation of preventive or rescue work.

Keywords: *flood, vulnerability, geographical information system, multicriteria analysis.*

Introduction

Flood risk and vulnerability are increasing due to changes in rainfall pattern, increased frequency of extreme events, changes in land use and development in flood prone areas as a result of socio-economic demand. Human lives, property, environment, and socioeconomics are at increasing risk due to flooding (Begum et al., 2007). There are different methods to quantify flood hazard, vulnerability, and risk. This study is focused on vulnerability assessment. The vulnerability is best defined as an aggregate measure of human welfare that integrates environmental, social, economic and political exposure to a range of potential harmful perturbations. The vulnerability is a multi-layered and multidimensional social space defined by the determinate, political, economic and institutional capabilities of people in specific places at specific times (Proske, 2008).

Multicriteria analysis (MCA) methods have been applied in several studies in flood risk assessment. Yalcin and Akyurek (2004); Ouma and Tateishi (2014) applied a GIS-based multicriteria evaluation in order to analyse the flood vulnerable areas in Turkey and Kenya. Yahaya et al. (2010) identified flood vulnerable areas in Hadejia-Jama'are river basin in Nigeria. Tanavud et al. (2004) assessed the risk of flooding in Hat Yai Municipality, southern Thailand using GIS and satellite imagery. Kandilioti and Makropoulos (2012) and Kazakis et al. (2015) applied GIS-based multicriteria flood risk assessment in the Greater Athens area and the Rhodope–Evros region, Greece.

The aim of the presented study is to generate a composite flood vulnerability map of the Bodva river basin in Slovakia for decision makers by mapping the potential natural sources of flooding.

Material and methods

The Bodva river basin belongs to an international Danube river basin. Slovak part of the Bodva river basin (figure 1) is defined by the border with Hornád river basin on the northern and eastern side. The Bodva river basin encompasses a total area of 11 727 km^2, including 890.4 km^2 within the territory of Slovakia. It has 113 km of the total length, with 48.4 km in Slovakia. The total volume of water draining from the territory of Slovakia is 88 million m^3 per year. The Bodva's river drainage basin contains 25 villages in total with a population of 41 500 inhabitants. The river directly threatens 5 villages, such as Medzev, Jasov, Hosťovce, Peder, Drienovec and one city, namely Moldava nad Bodvou. To sum up, based on the data from the year 2010, 19 750 inhabitants are potentially threatened by the Bodva river (Kelemen, Blišťanová, 2014).

From the south, the Slovak part of the Bodva river basin is bounded by the border with Hungary and by Slaná river basin on the west.

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From the morphological point of view, the Bodva sub-basin is a considerably diverse area with a different relief. Central and eastern part of the basin consists of slightly wavy Kosice basin, which is concluded in the north by mountains –Volovske hills. There is a predominance of heavy loamy soils that occupy a contiguous area of Kosice basin. Lighter soils – sandy-loam occupy forests in the mountains Volovske hills and partially Slovak Karst.

Bodva sub-basin, regarding the complex orographic ratio, ranges into several climatic zones. South and east part – the largest part of basin belongs to the district of the climate, which is warm and slightly damp with cold winters. Long-term average annual air temperature is 5° C to 8° C. Long-term average rainfall in the basin ranges from 600 to 1,000 mm.y^{-1}. Height and slope conditions affect climatic conditions, especially the size and distribution of rainfall, the air temperature and thus on the overall water balance and runoff regime (ME SR, 2009).

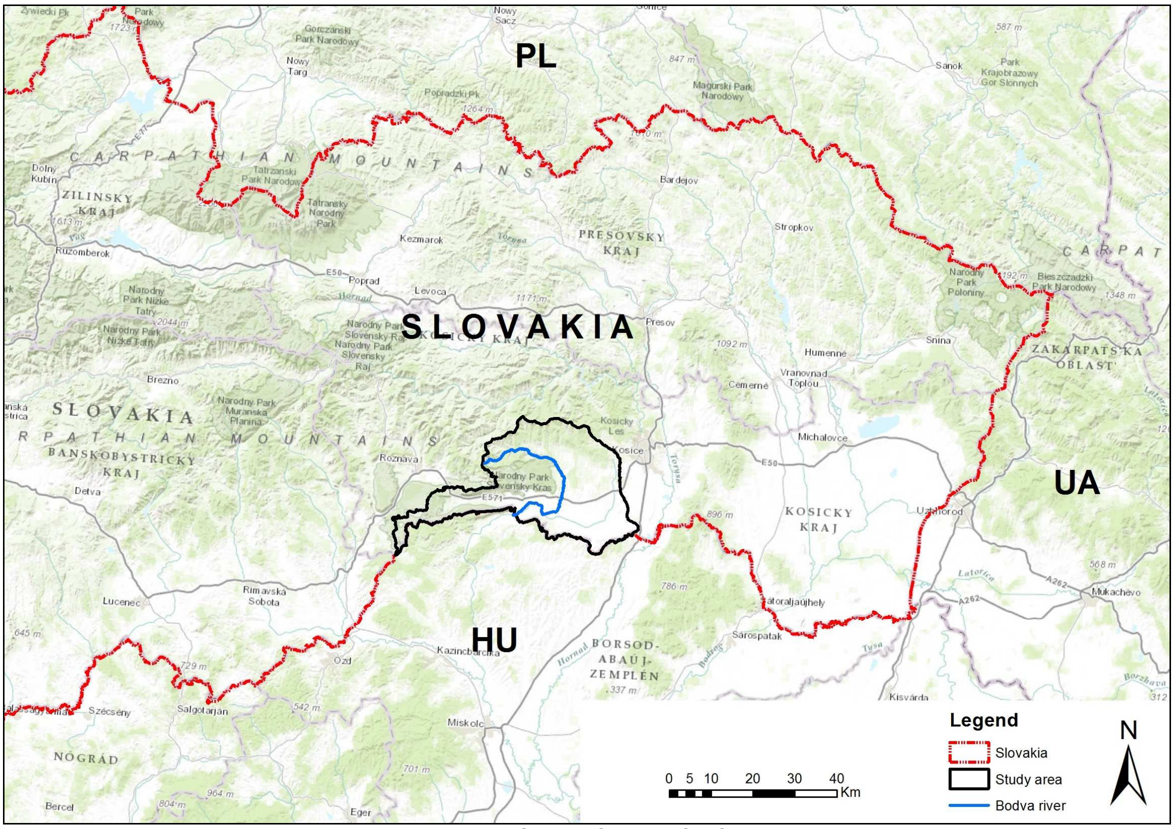


Fig. 1. Bodva river basin in Slovakia.

The last floods in the Bodva river basin occurred in 2010. Heavy 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 (ME SR, 2011).

In this study, basically two phases are applied to analyze flood vulnerability in Bodva river basin in eastern Slovakia: firstly, to identify the effective factors causing floods – the potential natural sources of flooding, and secondly, to apply the method of MCA in GIS environment to evaluate the flood vulnerability of the area. A GIS application was used for managing, producing, analyzing and combining spatial data (Blišťanová and Blišťan, 2014; Blišťan et al., 2016).

The initial data required for this study were acquired from the Atlas of the Slovakian Landscape, and further data were provided by Slovak Water Management Enterprise, s.c. Košice, Soil Science and Conservation Research Institute, Slovak Hydrometeorological Institute.

We use the set of causative factors concerning mostly hydrological, geological and physio-geographical characteristic of the study area that can be measured and evaluated (Zeleňáková and Gaňová, 2011):

1) Precipitation
2) Basin slope
3) Land use
4) Soil type
5) Catchment area.

Precipitation

The spatial distribution of the rainfall intensity has been performed considering the allocation of stations in the studied area. Taking into account their relatively sparse set-up, the authors used the spline interpolation method (Hurčíková and Molčíková, 2014). (Figure 3a). Precipitation data divided into classes (Table 1) are presented in Figure 3b.

Basin slope

The slope of the land in the watershed is a major factor in determining the water velocity. The slope map (Figure 2d) was prepared in percent grade using the DEM of the study area (Figure 3c). The district's values were subdivided into five classes (Figure 3e) as shown in Table 1.

Land use

Land use data present data from CORINE Land Cover (Figure 3f). The data were divided into five classes (Figure 3g) based on Table 1.

Soil type

Soil type was obtained from Soil Science and Conservation Research Institute, Slovakia. Data (Figure 3h) were divided on the basis of the content of clay particles into five classes. (Figure 3i).

Catchment area

The river basin area is divided into sub-catchments (Figure 3j) and their size was subsequently identified in ArcGIS. Sub-basins were divided into five classes (Figure 3k).

The conceptual framework for data processing using multicriteria analyses in geographic information system (GIS) is presented in Figure 2.

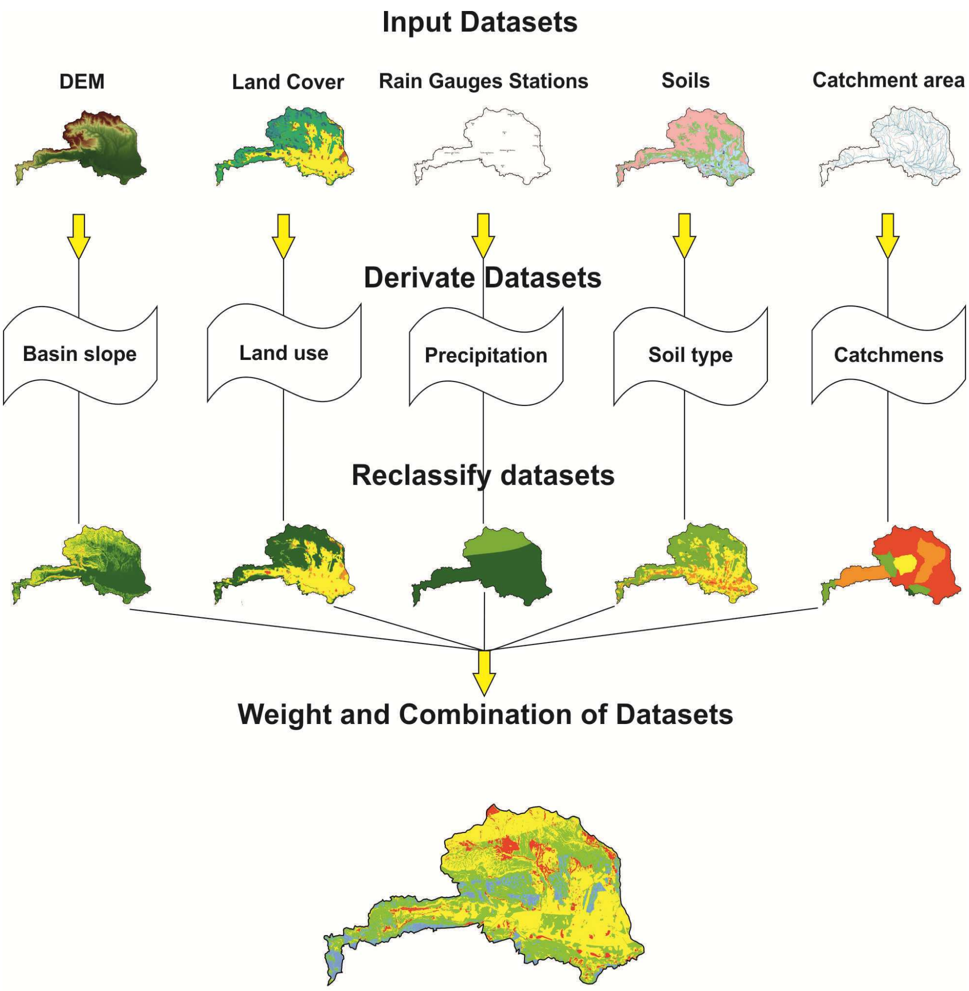
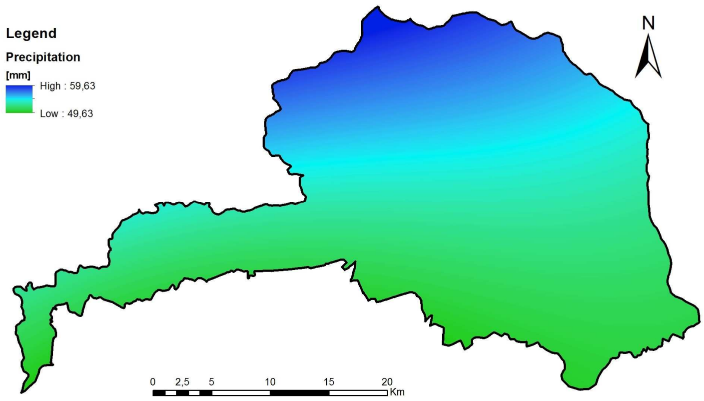


Fig. 2. Framework for data processing using multicriteria analyses in Geographic Information System.

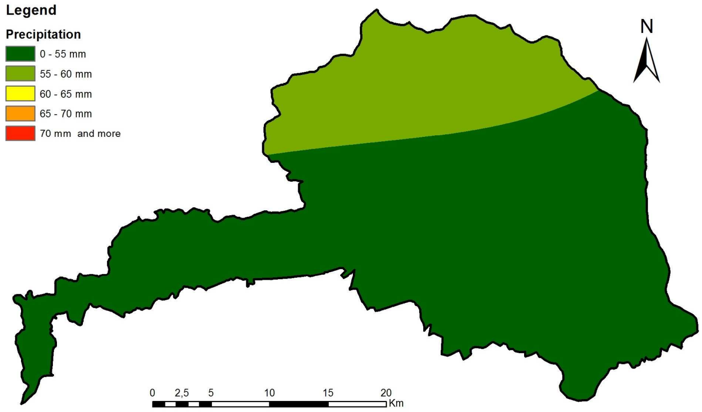
Tab. 1. Dividing factors into the factor's classes.

Factors	Factor's classes	Importance of factor's classes
Precipitation	0 - 55 mm	1
	55 - 60 mm	2
	60 - 65 mm	3
	65 - 70 mm	4
	70 mm and more	5
Slope of watershed	0 - 5 %	1
	5 - 15 %	2
	15 - 30 %	3
	30 - 55 %	4
	55 - 80 %	5
Land use	forest	1
	pastures and meadows	2
	agricultural land	3
	urbanized area	4
	Water area	5
Soil type (content of clay particles)	0 - 20 %	1
	20 - 30 %	2
	30 - 45 %	3
	45 - 60 %	4
	60 % and more	5
Catchment area	0 - 10 km^2	1
	10 - 50 km^2	2
	50 - 100 km^2	3
	100 - 200 km^2	4
	200 km^2 and more	5

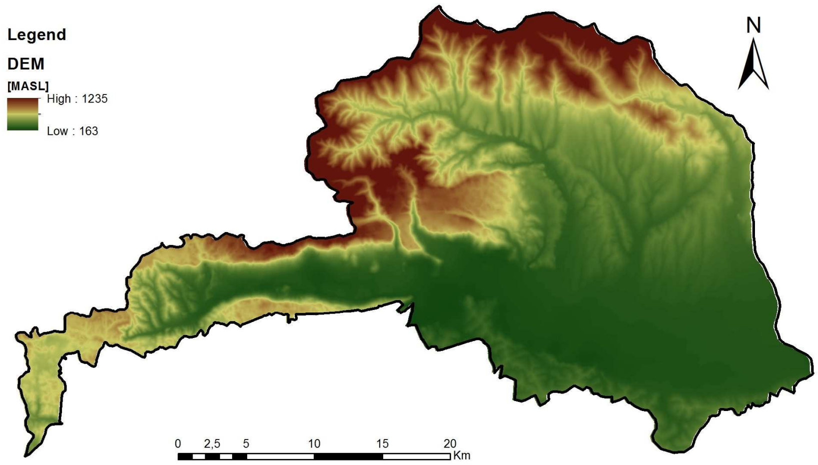
Each factor was divided into classes (Table 1) (Zeleňáková et al., 2015a, Zeleňáková et al., 2015b). The inverse ranking was applied to these factor's classes, with the least risk for flood occurrence = 1, next risk = 2, etc. ArcGIS 10 was used for transferring data to appropriate GIS layers. The factor's classes are presented in the individual factor maps in Figure 3 a-k.



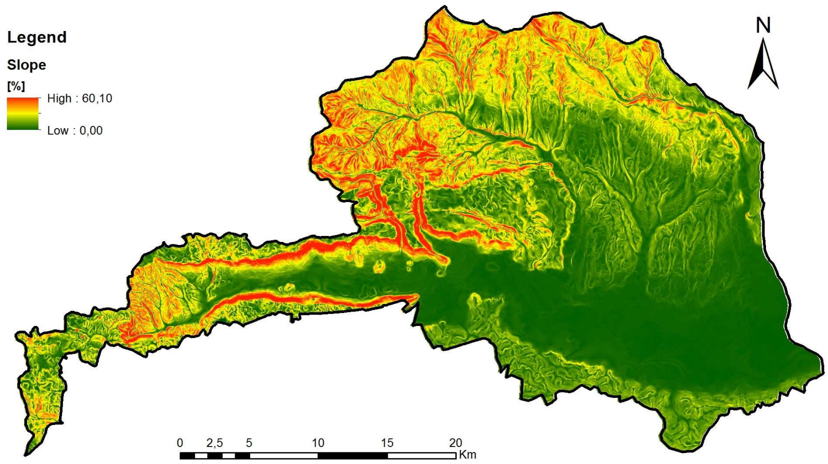
a) Precipitation.



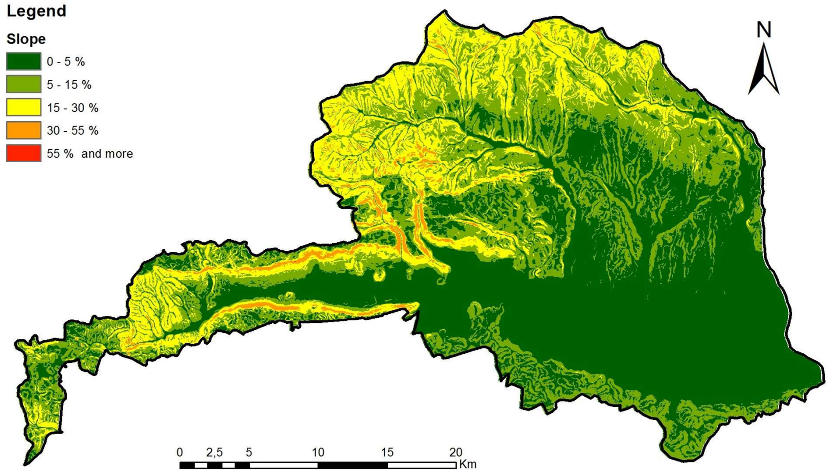
b) Precipitation data divided into five classes.



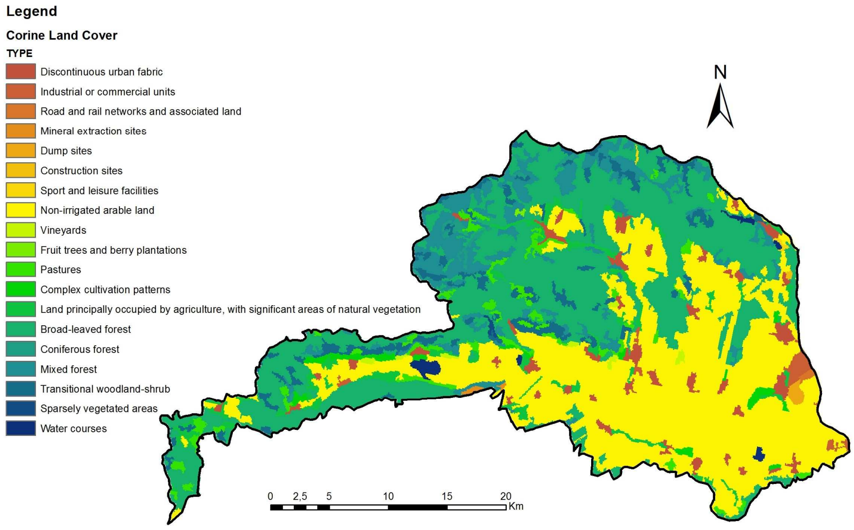
c) Digital elevation model.



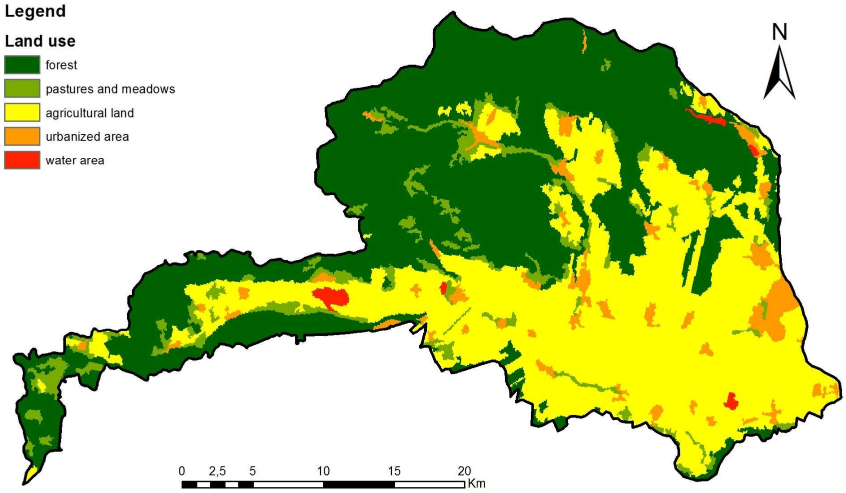
d) Slope.



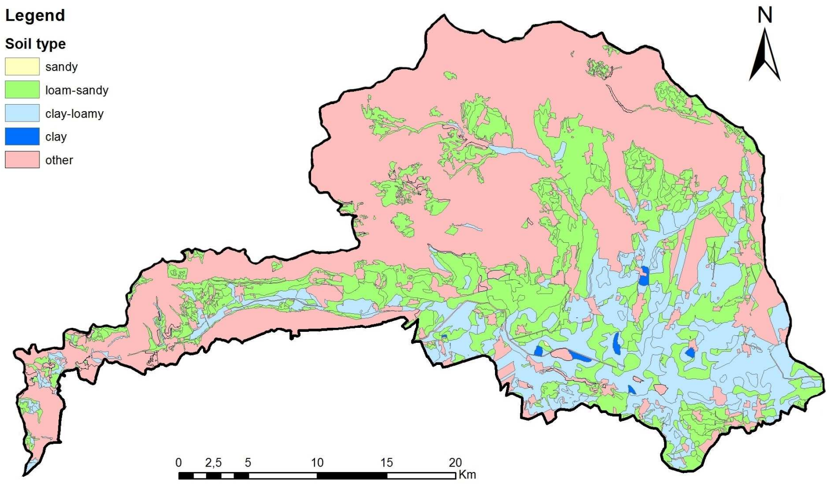
e) Slope data divided into five classes.



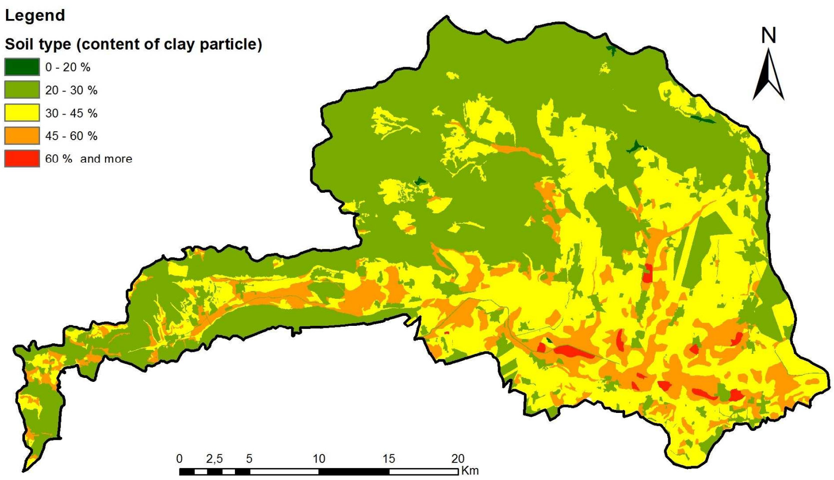
f) Land use.



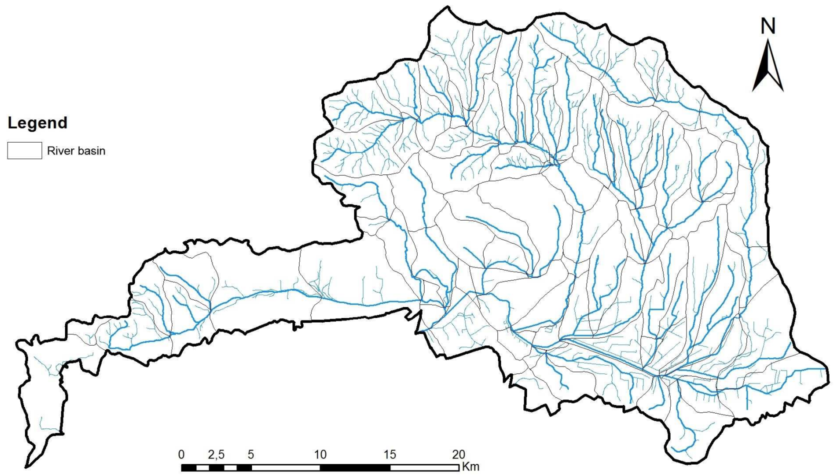
g) Land use data divided into five classes.



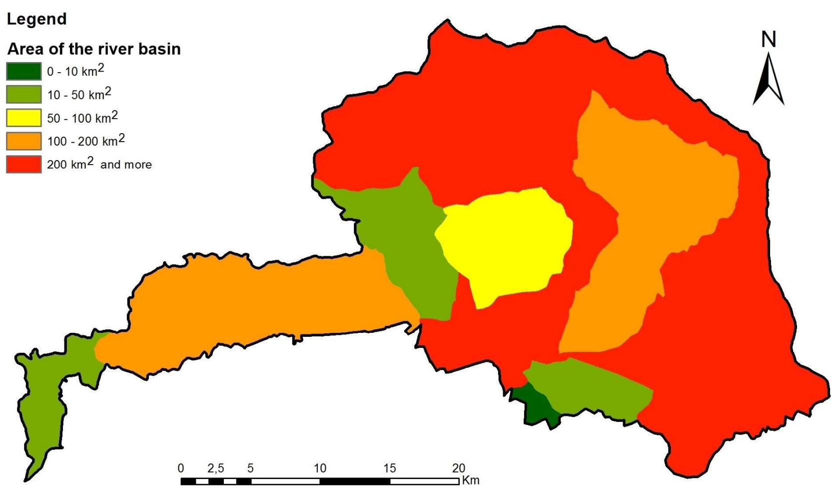
h) Soil type.



i) Soil type data divided into five classes.



j) River basin.



k) River basin data divided into five classes.

Fig. 3. Maps of selected causative factors with factor’s classes.

The ranking method (RM) is used if ordinal information about the decision makers' preferences on the importance of criteria is available. In the first step, criteria are ranked in the order of their importance. In the second step, ranking method is used to obtain numerical weights from this rank order (Meyer, 2007).

Using the rank sum method, normalized weights of the criterion were calculated according to (Eq. 1) (Yahaya et al. 2010):

$$W_j = n - r_j + 1 \Big/ \sum (n - r_k + 1) \tag{1}$$

where:

W_j is the normalized weight of the each factor;
n is the number of factors under consideration ($k = 1, 2\dots n$);
r_j is the rank position of the factor.
Each criterion is weighted (Eq. 2)

$$W_j = n - r_j + 1 \tag{2}$$

and then normalized by the sum of weights, that is (Eq. 3)

$$\sum (n - r_k + 1) \tag{3}$$

Weight assessment by the ranking method is as follows:

1) Precipitation (W=0.333)
2) Basin slope (W=0.267)
3) Land use (W=0.200)
4) Soil type (W=0.134)
5) Catchment area (W=0.066)

Resulting hazard was calculated using the following formula (Eq. 4):

$$H = \sum \left(F_1.W_{j1} + F_2.W_{j2} + F_3.W_{j3} + F_4.W_{j4} + F_5.W_{j5} \right) \tag{4}$$

where:

F_1, F_2, F_3, F_4, F_5 are the respective factors,
W_{j1}, W_{j2}, W_{j3}, W_{j4}, W_{j5} are the normalized weights for each factor.

Results

Regarding our task of flood vulnerability assessment, the result will be a ranking or categorization of areas with regard to their flood vulnerability level, and hence a recommendation as to where flood mitigation action is mostly required. The flood vulnerability was evaluated in four classes – acceptable, moderate, undesirable and unacceptable, according to the Table 2.

Tab. 2. Flood vulnerability acceptability and its significance.

Vulnerability rate	Vulnerability acceptability	Scale of vulnerability
1	acceptable	1 - 1,73
2	moderate	1,73 - 2,13
3	undesirable	2,13 – 2,46
4	unacceptable	2,46 and more

A composite map is showing the flood vulnerability created using the ranking method - Figure 4. The map was created by map algebra in GIS environment.

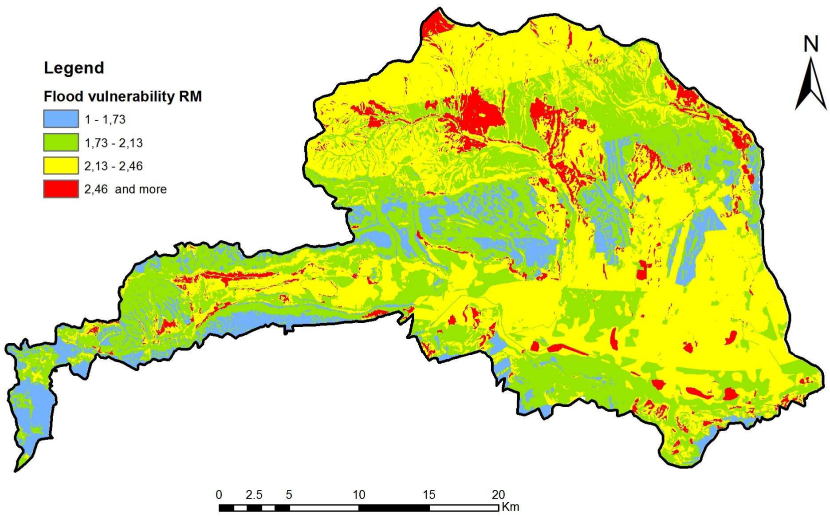


Fig. 4. The map of flood vulnerability in the study area based on the ranking method.

In this application, the flood vulnerability level ranges as acceptable, moderate, undesirable and unacceptable on the output map depicting the flood vulnerability in the study area. The percentage area of each vulnerability level was calculated as 18.43 % (acceptable), 40.25 % (moderate), 28.99 % (undesirable) and 12.33 % (unacceptable) respectively.

Conclusions

Floods endanger the lives and health of the inhabitants, cultural heritage, the environment, causes damage to property and limits economic activities. It is not possible to prevent them, but flood simulation and risk assessments are strategic planning tools for effective reduction of flood risk and damage.

This paper presents work carried out in the Bodva river basin using GIS tools and multicriteria analysis method – ranking method to generate maps of flood-vulnerable areas. The composite map (Figures 4) shows the resulting map of flood vulnerability in the study area. The area is divided into four classes (acceptable, moderate, undesirable, and unacceptable). Red and yellow colors on the map indicate a higher degree of vulnerability, which raises the issue of increased flood risk. Information from theoretical studies may be helpful in the management of flood risks.

The aim of flood risk management is the proposal of flood protection measures. The main objective of management, as well as the entire management cycle, is regulated by the Directive of the European Parliament and the Council 2007/60/EC on the assessment and management of flood risks. The aim of this directive is to reduce and control the adverse consequences for human health, the environment, cultural heritage and economic activity associated with floods.

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