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Multicriteria Analysis for Flood Vulnerable Areas in Southeastern Slovakia

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ABSTRACT

Floods are natural phenomena which cannot be prevented. The causes of flooding are extremely heavy rains or rapid melting of snow combined with a significantly reduced ability to detain stormwater in areas. However the negative human-based factors cause changes in runoff ratio and increase the risk of flooding. Human activities change flood behavior in many circumstances. Activities in flood plains and catchment areas such as land clearing for urbanization or agriculture, or construction of infrastructure such as highways, roads and bridges across the flood plain may increase the magnitude of flooding, which in turn increases the damage to property and lives. Determining the flood vulnerable areas is important for decision makers for planning and management activities. Multicriteria analysis methods (MCA) are used to analyze the flood vulnerable areas. Geographical information system (GIS) applications are used for managing, producing, analyzing and combining spatial data. The aim in integrating MCA with GIS is to provide more flexible and more accurate decisions to the decision makers in order to evaluate the effective factors. Some of the causative factors for flooding in watershed are taken into account as daily rainfall, size of watershed, land use, slope and the type of soil. The selection of criteria that has spatial reference is an important step in MCA. The objective of this article is to analyze the flood vulnerability in Bodva river basin, eastern Slovakia. We determined the flood-effective factors, estimate their significance and applied two different approaches of MCA inside the GIS environment.

Keywords: Analytical hierarchy process, causative factors, flood risk, geographical information system, ranking method.

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. 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 (Petrow *et al.*, 2006) 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 (Hall, 2010).

Multicriteria analysis (MCA) methods have been applied in several studies in flood risk assessment. Yalcin and Akyurek applied a GIS-based multicriteria evaluation in order to analyse the flood vulnerable areas in south-west coast of the Black Sea (Yalcin & Akyurek, 2004). The ranking method and pairwise comparison method were introduced and applied in this study. Yahaya identified flood vulnerable areas in Hadejia-Jama'are river basin Nigeria by using pairwise comparison method, analytical hierarchy process and ranking method (Yahaya *et al.,* 2010). Kandilioti and Makropoulos applied analytic hierarchy process, weighted linear combination and ordered weighting averaging to precede the overall flood risk map of the area of Athens (Kandilioti & Makropoulos, 2012).

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

MATERIAL AND METHODS

Study area

The river basin Bodva belongs to an international Danube river basin. Slovak part of the river basin Bodva (Figure 1) is defined on the north and east by border with Hornád river basin. From the south the Slovak part of the catchment Bodva is bounded by the border with Hungary and on the west by Slaná river basin.

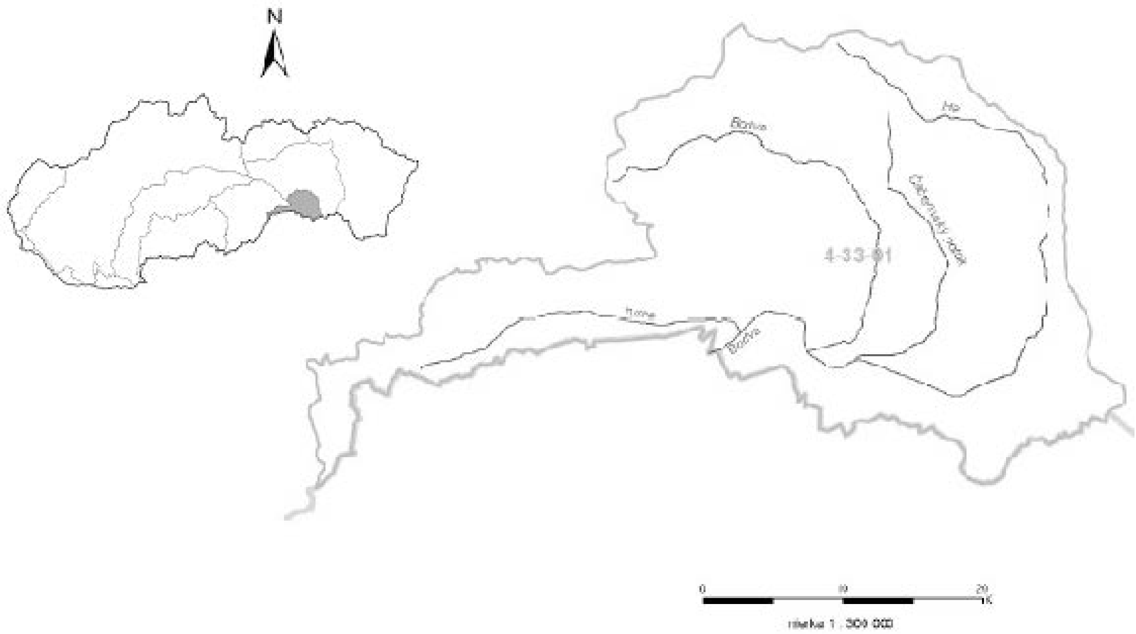

Figure 1. Slovak part of Bodva river basin

Bodva river Basin is situated in the southwestern part of the Kosice region. The river Bodva rises in the mountains Volovske hills, on the northeastern slope of the hill Osadník (1 186 m asl.). Geological structure of the area forms the hydrogeological conditions of the sub-basin Bodva. Basic characteristics of the river basin Bodva contains Table 1.

Table 1. Basic characteristics of the river basin Bodva (2007/60/ES, 2007).

Area of the Danube river basin	807 827 km^2	
Area of the Bodva river basin (in the Slovak republic)	858 km^2	
Bordered places of the Bodva basin in Slovakia:		
– the westenest point	Kamenec	48° 33′ N 20° 27′ E
– the easternest point	Milhosť	48° 33′ N 21° 15′ E
– the northest point	Kloptaň	48° 47′ N 20° 52′ E
– the southest point	Kečovo	48° 27′ N 20° 28′ E
– the highest point	Osadník	1186 m asl.
– the lowest point	Hosťovce	168 m asl.
The total length of the river Bodva in the Slovak republic	48 km	
Long-term average flow of Bodva in Hosťovce	4.48 m^3.s^{-1}	
The catchment area of Bodva extends into states	Hungary	
Region	Košice	
District	Košice II, Košice – okolie, Rožňava	
Number of villages in the basin area	45	
Population	56 245 (year 2009)	
Land use:		
Urban areas	1.6 %	
Agricultural areas	47.1 %	
Forest areas	46.8 %	
Water areas	1.6 %	
Other (industry etc.)	3.4 %	

South and east part of Bodva river 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 range 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. There is a predominance of heavy loamy soils and sandy-loam.

Data

The first step in assessing the flood vulnerability in the study area is to determine the factors affecting the flood on the basis of an analysis of existing studies and knowledge. The criteria used in this study are following: monthly precipitation, basin slope; soil type; land use; and catchment area. The initial data required for this study were acquired from Slovak Hydrometeorological Institute, Digital Terrain Model of the Slovak Republic, Soil Science and Conservation Research Institute, Corine Land Cover, Slovak Water Management Enterprise (Figures 2 – 6).

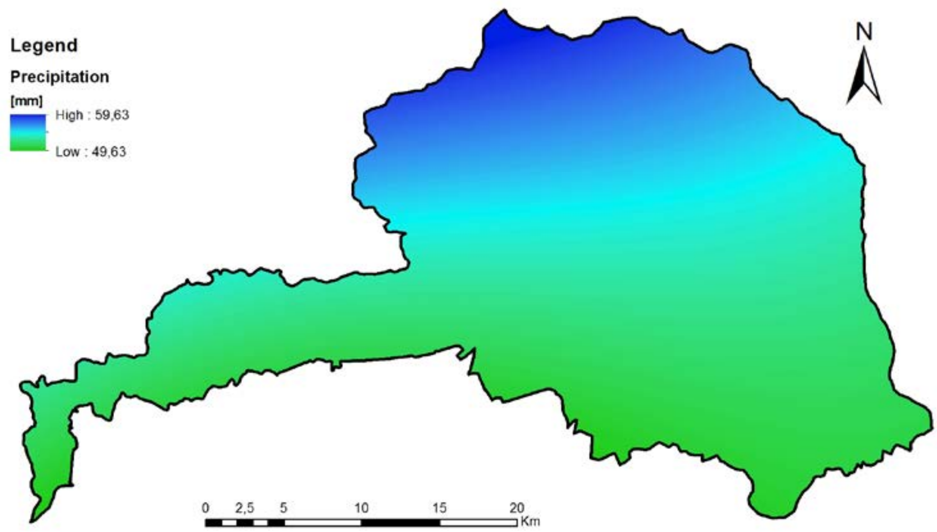

Figure 2. The monthly precipitation.

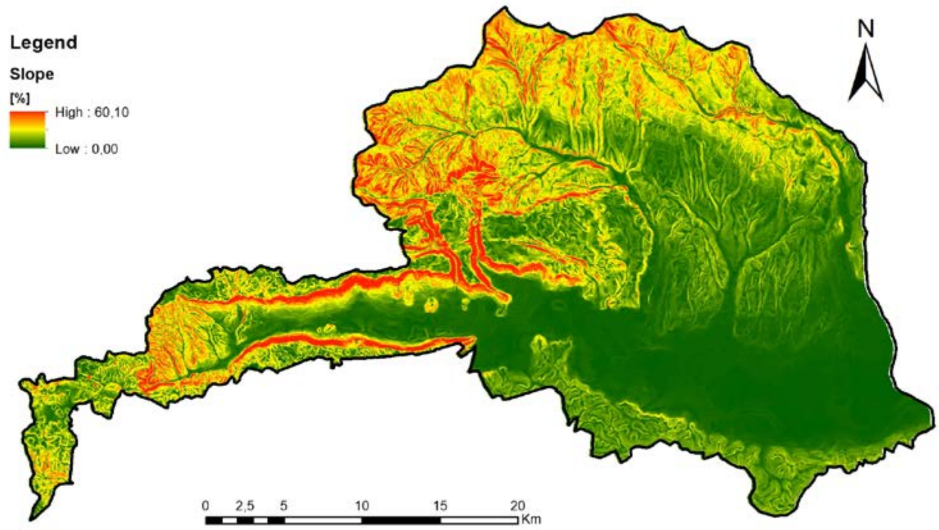

Figure 3. Basin slope.

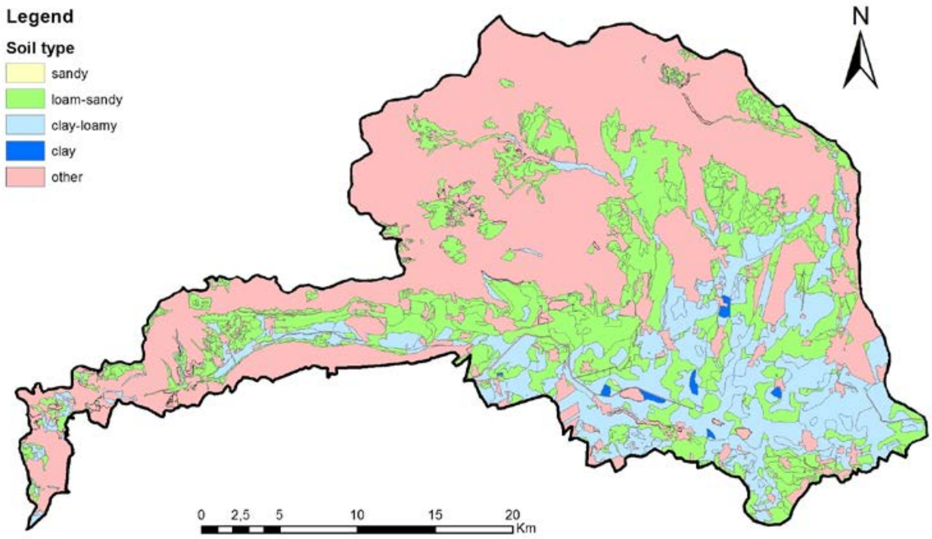

Figure 4. Soil types.

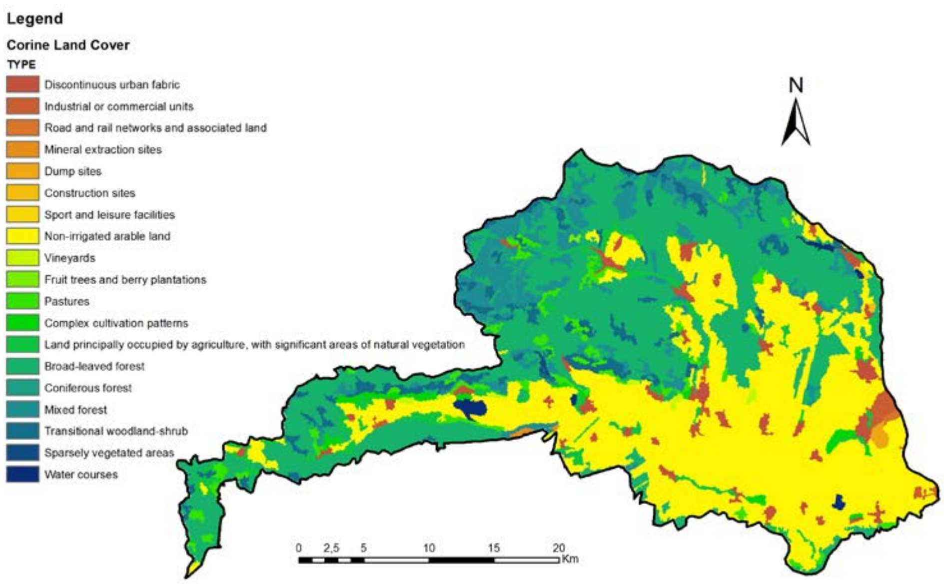

Figure 5. Land use.

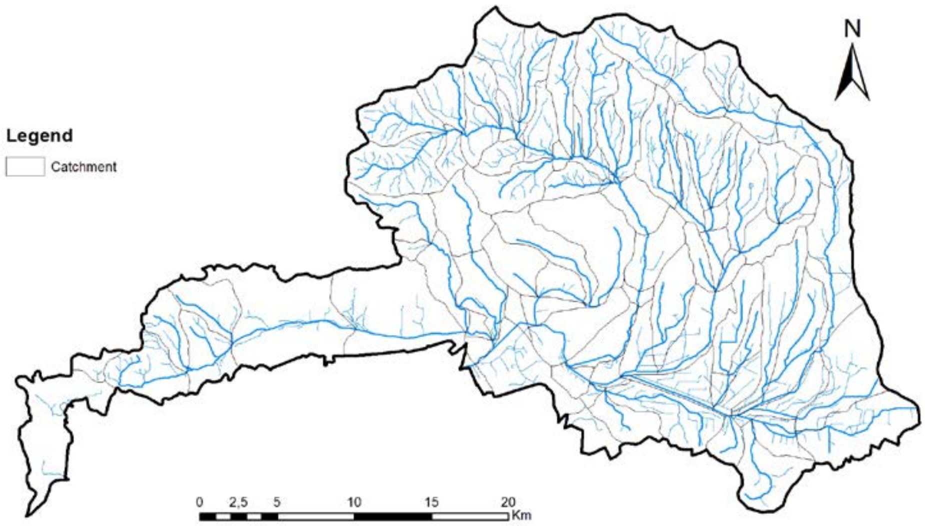

Figure 6. Catchment area.

The Maps of causative factors (Figures 2 – 6) were created in software ArcGIS 10.2 based on background data provided from mentioned institutions.

The criterion values for each factor were divided into five classes according the Table 2 while the inverse ranking (the least important =1, next least important=2 etc.) was applied to these factors.

The next maps, using the division of factors criteria to classes according the Table 2, were also created in ArcGIS 10.2.

Table 2. The significance of the impact of flooding causative factors.

Classes	Causative factors				
	Monthly precipitation (mm)	Basin slope (%)	Soil type (content of clay particles) (%)	Land use (-)	Catchment area (km^2)
1	0 - 55	0 - 15	0 - 10	forest	0 -10
2	55 - 60	15 - 30	10 - 30	pastures and meadows	10 - 50
3	60 - 65	30 - 45	30 - 45	agricultural land	50 - 100
4	65 - 70	45 - 80	45 - 60	urbanized area	100 - 200
5	70 and more	80 and more	60 and more	water area	200 and more

In this study to analyze flood vulnerability two phases are applied: firstly to identify the effective factors causing floods – the potential natural causes of flooding, and secondly to apply two methods of MCA in GIS environment to evaluate the flood vulnerability of the area.

Multicriteria analysis methods

We used two methods in determining flood vulnerability – the ranking method and the analytic hierarchy process.

Ranking method (RM). 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 a second step, ranking method is used to obtain numerical weights from this rank order (Meyer, 2007). Straight ranking was applied to these factors, which means that 1 is the most important factor and 5 is the least important factor: monthly precipitation = 1; basin slope = 2; soil type = 3; land use = 4; catchment area = 5. The purpose of the criterion weighting is to express the importance of each factor relative to other factors.

Using the ranking method normalized weights of the criterion were calculated as (Eq. 1) (Yahaya *et al.*, 2010):

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

where:

W_j is the normalized weight for the each factor;
n is the number of factors under consideration (k = 1, 2… n);
r_j is the rank position of the factor.

Each criterion is weighted (Eq. 2)

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

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

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

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

$$IV = \sum (IF_{1j}W_1 + IF_{2j}W_2 + IF_{3j}W_3 + IF_{4j}W_4 + IF_{5j}W_5) \tag{4}$$

where:

IV is index of vulnerability;
IF_{1j}, IF_{2j}, IF_{3j}, IF_{4j}, IF_{5j} are importance of factor's class;
W_1, W_2, W_3, W_4, W_5 are the normalized weights for each criterion.

More important factors have greater weighting in the overall evaluation.

Analytical Hierarchy Process (AHP). AHP is a flexible and yet structured methodology for analyzing and solving complex decision problems by structuring them into a hierarchical framework (Saaty, 1980). The AHP procedure is employed for rating/ranking a set of alternatives or for the selection of the best in a set of alternatives. The ranking is done with respect to an overall goal, which is broken down into a set of criteria (objectives, attributes) (Boroushaki & Malczewski, 2008). Twelve river stations in Bodva river basin were assessed.

For each river station a matrix 5 x 5 – factors x class (1 – 5) was established. This matrix was completed with values from 1 to 5, depending on the class of each factor for the relevant river station in the following way: e.g. when a river station is located in an area where precipitation is class one, the number 1 is written in column "1" for the line "precipitation", and other values on this line are zero. In this way the whole matrix was completed for all factors.

The AHP method programmed in Microsoft Excel was used to determine the weighting of each river station. Matrices were developed for all twelve river stations in Bodva river basins. From the results calculated for separated stations was done interpolation by kriging method (using extension Geostatical analyst) (Blišťan, 2012; Stein, 1999) in ArcGIS 10.2 for the whole area of Bodva river basin.

RESULTS AND DISCUSSION

The multicriteria analysis ends with a more or less stable ranking of the given alternatives and hence a recommendation as to which alternative(s) should be preferred. The spatial variability of flood vulnerability is an important part of flood risk assessment on the national level, as well as for application of spatially differentiated approaches to flood defence strategy (Solín & Skubinčan, 2013).

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 most required. Weight assessment for causative factors by the ranking method (Table 3) is as follows:

Table 3. Weights of causative factors.

	Causative factors				
	Monthly precipitation	Basin slope	Soil type	Land use	Catchment area
Weight	0.333	0.267	0.200	0.134	0.066

A composite map showing the flood vulnerability created using the ranking method with ArcGIS 10.2 is presented in Figure 7.

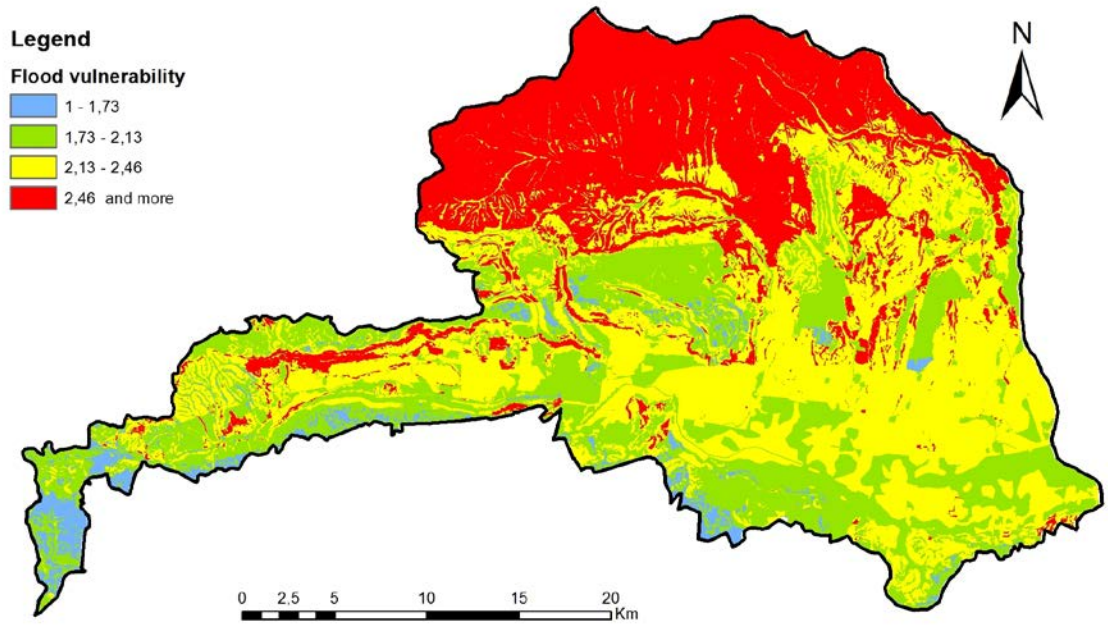

Figure 7. Flood vulnerability of Bodva river basin using the ranking method.

The flood vulnerability in the study area was evaluated in four classes according Table 4. In this application, the flood vulnerability level range as acceptable, moderate, undesirable and unacceptable (Zeleňáková & Gaňová, 2011) on the output map depicting the flood vulnerability in the study area.

Table 4. Vulnerability acceptability.

	Vulnerability acceptability	Scale of vulnerability	
		RM	AHP
1	acceptable	1.00 - 1.73	0.000 - 0.025
2	moderate	1.73 - 2.13	0.025 - 0.050
3	undesirable	2.13 - 2.46	0.050 - 0.075
4	unacceptable	2.46 and more	0.075 and more

The resultant weightings with analytic hierarchy process for all river stations are shown in Table 5.

Table 5. Weights of river stations.

River station	Weight
Štos	0.051097
Zlata Idka	0.051097
Perín	0.051097
Jablonov nad Turňou	0.071072
Malá Ida	0.080109
Košice - Šaca	0.090646
Kečovo	0.087918
Moldava nad Bodvou	0.090646
Jasov	0.103193
Janík	0.103598
Turňa nad Bodvou	0.108868
Silica	0.110658

River stations are ranked by the value of weightings from largest to smallest.

The obtained results from software ArcGIS 10.2 are presented in Figure 8.

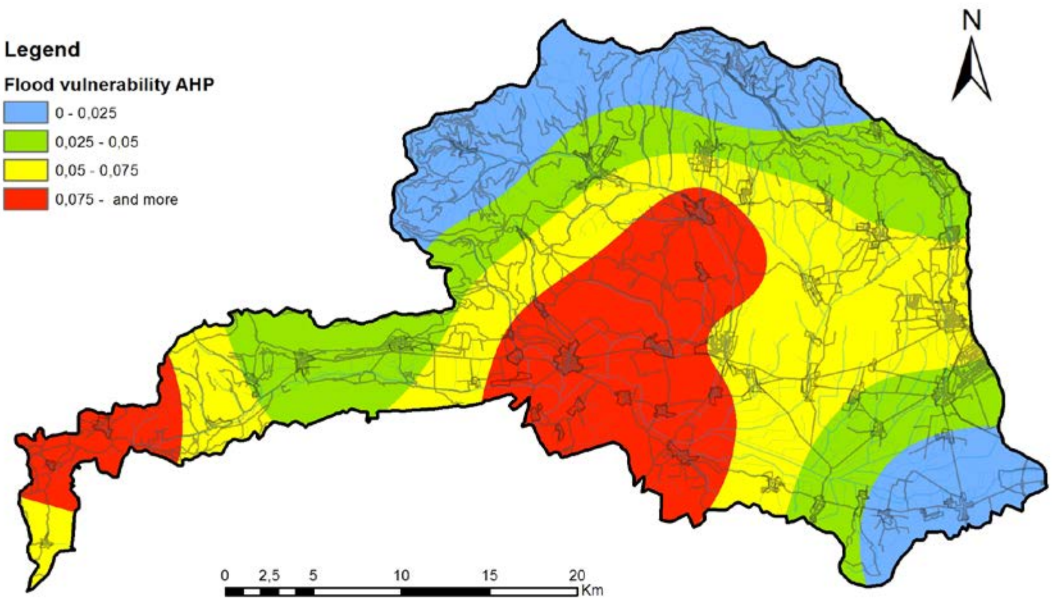

Figure 8. Flood vulnerability of Bodva river basin using analytic hierarchy process.

The flood vulnerability assessment based on the analytic hierarchy process shows that the Bodva river basin is mainly in areas with moderate and undesirable flood vulnerability. Zones with unacceptable and acceptable level of flood vulnerability were also identified, in smaller areas. The similar results – presence mainly of moderate and undesirable flood vulnerability are shown also by ranking method in the study area – although space assessment of acceptable and unacceptable flood vulnerable areas by both methods are prove completely different results. Preliminary flood risk assessment which has been done in the Slovak Republic based on requirements of European Union – 2007/60/EC (Flood directive) in 2011 prove that results obtained by ranking method are more precisions than that obtained by analytic hierarchy process.

CONCLUSION

Flood vulnerability is a common effect of two independent mechanisms natural conditions and the human activities in the basin. The primary impulses of floods are usually extremely intense precipitation. The total catchment's hydrological response to intense rainfall is determined by its natural environment, a whole complex of characteristics of the basin (Zeleňáková, 2009). Some of them may be a process initiated by the intense rain accelerate, respectively amplified.

The aim of the present study was to generate a composite map for decision makers using selected factors causing floods. In the analyses, some of the causative factors for flooding in a basin area are taken into account, such as soil type, precipitation, land use, size of the catchment and basin slope. A case study of flood vulnerability identification in the Bodva catchments' areas in eastern Slovakia is employed to illustrate the different approaches. A geographical information system (GIS) is integrated with multicriteria analysis (MCA) in the paper. We created two multicriteria vulnerability maps for Bodva river basin. Our pilot study showed significant differences between both methods shown in Figure 7 and 8. The different results obtained from these two methods indicate the importance of the decision maker in determining the weights and the proper method, and making the decision. The weighting of the criteria significantly affects the results of the overall evaluation.

We can say, that the results obtained by the ranking method are more representative. The same results were proved by other studies (Yalcin & Akyurek, 2004; Yahaya *et al.*, 2010) regarding the same topic. In the case of flood vulnerability assessment for Bodva river basin AHP method is not suitable. It should be noted that RM method shows the best results comparing the existing flood in the recent years. The development of RM method for whole catchment has the advantage that there is a method which is easy to apply.

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