Flood vulnerability assessment of Bodva cross-border river basin

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The disasters of the past few years have shown the importance of prevention and preparedness, not only in Hungary and in the Slovak Republic, but all over the world. In 2010, the floods of the rivers Hernád/Hornád, Sajó/Slaná and Bódva/Bodva caused serious problems for these nations, affecting several settlements with thousands of inhabitants. The inhabitants and enterprises of the targeted area come in for the results from the flood risk assessment, by having a more secure environment. The methodology is applicable in other water courses in Hungary and in the Slovak Republic as well in the other countries. The aim of the presented study was to assess the distribution of flood-risk potential at the regional scale. A progressive approach integrating geographical information system (GIS) with method of multicriteria analysis (MCA) – analytic hierarchy process (AHP). In the analyses, the most causative factors for flooding were taken into account such as monthly precipitation, soil type, land use, basin slope. A case study of flood vulnerability identification in the Bodva catchment area has been employed. Spatial estimation of flood-risk potential should be one of the basic steps for complex geo-ecological evaluation and delimitation of landscape considering water resources management, groundwater pollution, prediction of soil erosion and sediment transport and some other important landscape-ecological factors. The obtained results indicate that AHP method shows good results as related to the existing floods in the recent years in Bodva catchment.

Key words: *flood vulnerability, geographical information system, multicriteria analysis*.

Introduction

The disasters in Hungary and Slovakia are linked mostly to extreme weather. The number and effects of natural disasters increased significantly and caused more loss than ever before. The floods of May and June 2010 in the valley of Bodva and other rivers flowing from Slovakia to Hungary demonstrated the importance of time during an emergency and the necessity of new systems and methodologies to reduce the damages, protect human lives and material goods (Blišťanová et al., 2016; Zeleňáková et al., 2018).

The increase in damage due to natural disasters is directly related to the number of people who live and work in hazardous areas and where their property is accumulated (Petrow et al., 2006; Van Alphen et al., 2009, Kiss et al., 2014). Flood risk analysis provides a rational basis for prioritizing flood protection and flood management activities. Risk analysis can take many forms, from informal methods of risk ranking and risk matrices to fully quantified analysis joined with modelling (Merz et al., 2010). The multi-criteria analysis method (MCA) is widely used scientific approach, which may be implemented in the GIS environment for risk-mapping of populations or regions and for identification of risk zones (Blistanova, Blistan, 2014). An analytical hierarchy process (AHP) is one of the most widely used multicriteria method based on the pair-wise comparisons in order to create a ratio matrix and estimate a ranking or weighting of each of the evaluated criteria (Saaty, 1980). Multicriteria analysis (MCA) methods have been applied in several studies in flood risk assessment. Chandran and Joisy (2009) introduced an efficient methodology to accurately specify the flood hazard areas in Vamanapuram river basin using GIS. Yalcin and Akyurek (2004) applied a GIS and multicriteria analyses to evaluate the flood-vulnerable areas in south-west coast of the Black Sea by the ranking method and pairwise comparison method. Tanavud et al. (2004) assessed the risk of flooding and identified efficient measures to reduce flood risk in Hat Yai Municipality, southern Thailand using GIS and satellite imagery. Yahaya et al. (2010) identified flood vulnerable areas in Hadejia-Jama'are river basin Nigeria by using a spatial multicriteria evaluation technique – pairwise comparison method, analytical hierarchy process and ranking method. Scheuer et al. (2011) present an approach to modeling multicriteria flood vulnerability in the city of Leipzig in Germany, which integrates the economic, social and ecological dimension of risk and coping capacity. Meyer et al. (2009) developed a GIS-based multicriteria flood risk assessment and mapping approach and applied it for the River Mulde in Saxony, Germany. Kandilioti and Makropoulos (2012) applied three MCA methods: analytic hierarchy process, weighted linear combination and ordered weighting averaging in GIS environment to produce the flood risk map of the Greater Athens area and validated it for its central and the most urban part. Ramlal and Baban

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(2003) used GIS to map the extent of the flooding area, estimate soil loss due to erosion and estimate sediment loading in the rivers in the Caparo River Basin in Trinidad and Tobago. Scolobig et al. (2008) applied social multicriteria evaluation to analyze a recent case of controversy in flood mitigation in Malborghetto-Valbruna (Northern Italy) and to improve flood-mitigation decision processes. Two different multicriteria decision rules, a disjunctive and an additive weighting approach, were utilized for an overall flood risk assessment in the area (Şerban et al., 2016). Kenyon (2007) introduced study builds on existing deliberative processes to develop a new participant-led multicriteria method to evaluate flood risk management options in Scotland. The results show that participants preferred regeneration or planting of native woodland to other flood management options, and least preferred building flood walls and embankments (Simonovic, 2002). Wang et al. (2011) used a semi-quantitative model and fuzzy analytic hierarchy process weighting approach for assessment of flood risk in the Dongting Lake region, Hunan Province, Central China, an area where flood hazards frequently occur. The obtained results can provide useful information for decision makers and insurance companies. Papaioannou et al. (2015) presented a framework for mapping potential flooding areas incorporating geographic information systems, fuzzy logic and clustering techniques, and multi-criteria evaluation methods. Results show that multiple MCA techniques should be taken into account in initial low-cost detection surveys of flood-prone areas and/or in preliminary analysis of flood hazard mapping. Rahmati et al. (2015) assessed the efficiency of analytical hierarchical process to identify potential flood hazard zones by comparing with the results of a hydraulic model. Four parameters via distance to river, land use, elevation and land slope were used in some part of the Yasooj River, Iran. The results showed that the AHP technique is promising of making accurate and reliable prediction for flood extent. Therefore, the AHP and geographic information system techniques are suggested for assessment of the flood hazard potential, specifically in no-data regions. Romanescu et al. (2016) examined the vulnerability of the population and buildings of a village situated in the eastern part of the Eastern Carpathians by applying the multicriteria method, areas with high flood vulnerability were pointed out in the Sucevita catchment.

The flood vulnerability model to be developed gives the possibility to forecast the flooding risks which means highly valuable information for both Slovakian and Hungarian Disaster Management Directorates and Water Management Companies as well as for inhabitants of the area. The results of this paper will help to flood risk management in the study area and support the decisions of the actions of inhabitant flood protection and present a valuable knowledge for research in the field of flood risk mitigation.

Study area

Bodva River rises in Slovakia, on the southern part of Slovenské Rudohorie (the Slovak Ore Mountains) at the foot of the 1187 m high peak Osadník. The total catchment area is 1733 km^2, of which 867 km^2 in Hungary. 97 towns and villages are located in the catchment area, including 42 in Slovakia. Bodva Valley can be divided into the following sections:

- Upper Bodva Valley: narrow and deep valley of ore mountain above Medzev; expanding swampy valley in the atrium of ore mountain;
- Košice basin;
- Bottom Bodva Valley: valley of uniform width above Perkupa (Hungarian "upper valley"); Gorge Szalonna; Basin Szendrő; Gorge Szendrőlád; Entrance to the Slaná valley, near Edelény.

The river flows 111 km and after the village Boldva mouths into Slaná River, in its river kilometre 69.3. Several millennia of human presence in the basin Bodva and conversion of land as a result of his actions reflect current coverage of the country. As a result of human activity occurs in excessive downstream communities including grassland. Such territories include the once cultivated arable land and orchards extending the border villages. Marshy meadows and continuous alder stands can also be found along waterways. These were previously much more widespread, but because of the machining of fertile valleys along streams, most of them narrowed only a narrow area along the flow. Mining activity (coal, iron ore), which was previously characterised for the basin and its adjacent areas, no longer exists, except in mining gypsum. There is no major industrial plant near the river. Water quality in Bodva River influences Hungarian sources of pollution and also pollution originating from the territory of Slovakia. To protect water quality, it can be considered fortunate that in the river basin there is practically no industrial production, therefore polluting industrial process is not significant. There are no specific data on the pollution that gets into Bodva. A role of runoff and precipitation are important regarding the pollution characteristics; due to changes in the flow the pollutants are mixed with water in different/changed ratio. From an agricultural area, pollution gets into the groundwater and then to the river by a splash of fertilisers and plant protection products/nutrients.

The studied region – Bodva watershed (Fig. 1.) – covers a rural area with inhabitants living mostly from agriculture. Tourism potential is also evident and prioritised.

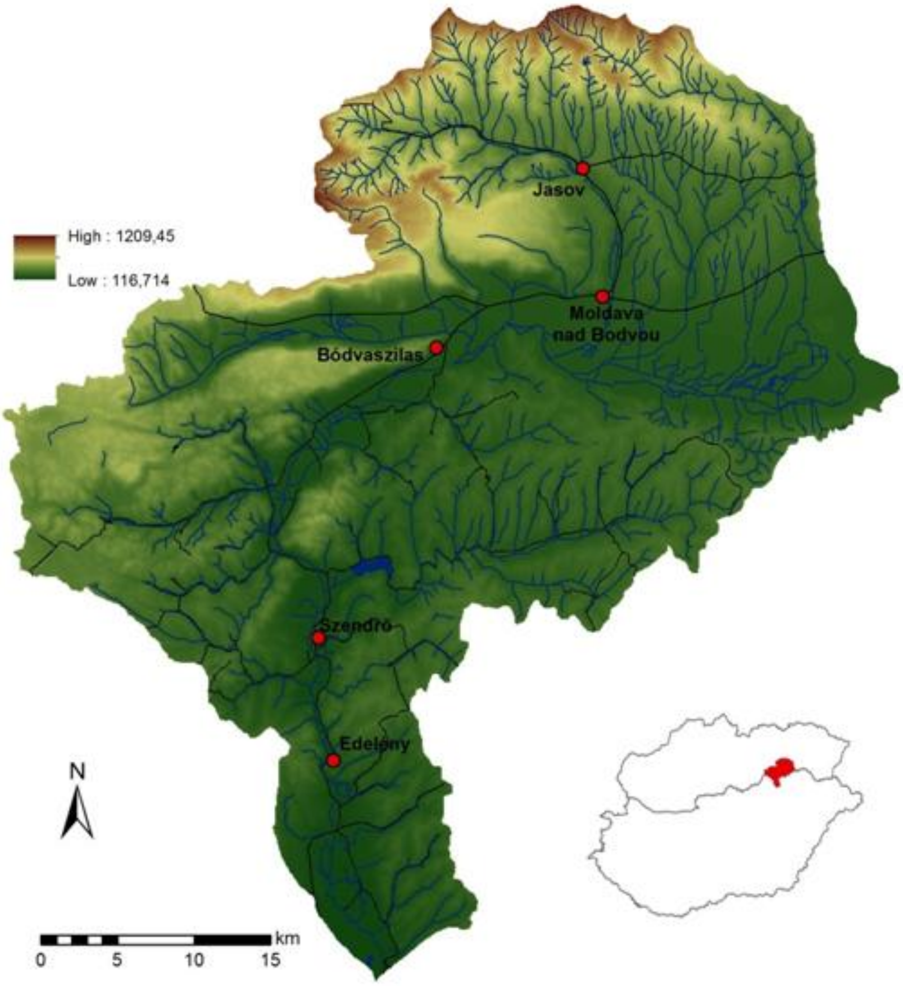

Fig. 1. Bodva watershed.

In general, the area is classified as an underdeveloped region, with inhabitants of low income and living standards. The educational level is generally low; the proportion of the population living on a very low level of living standard is very high compared to the national averages. The regional development plans focus mainly on the agricultural and tourism potential and aim to increase the level of education and life quality through the support of the small and medium enterprises. These SMEs are mainly involved in the agricultural sector and the processing of the local products. This agricultural potential and also the area of the settlements and the human infrastructures are endangered by the flooding and ponding waters. The safety of the agricultural production, the clean environment and the building infrastructure is highly important in a region like this, where the majority of the properties have no insurance. Due to the lack of financial means and savings, any damage occurring in these properties is critical and requires major efforts from the governmental organisations to revitalise the area without any relevant self-contribution to decrease the negative impacts of the natural, flood damages.

Materials and methods

Water resources management is one of the fields in which multicriteria methods have been used extensively. Multicriteria analysis (MCA) has been applied in many flood risk assessment management studies (Scolobig et al., 2008; Boroushaki and Malczewski, 2008; Meyer, 2009; etc.); some of them are already mentioned in the introduction. GIS has been developed and often applied to examine spatial and temporal patterns of flood occurrence with the main aim to find associations among geographical factors causing flood evens (Ramlal and Baban, 2003; Romanescu and Stoleriu, 2014; Diaconu et al., 2017).

We used the multicriteria method – the analytic hierarchy process (AHP) (Saaty, 1980) for determining flood vulnerability. The methodology of flood vulnerability map development is presented in the flowchart in Figure 2.

The analytical hierarchy process is employed for rating a set of alternatives or for the selection of the best of alternatives.

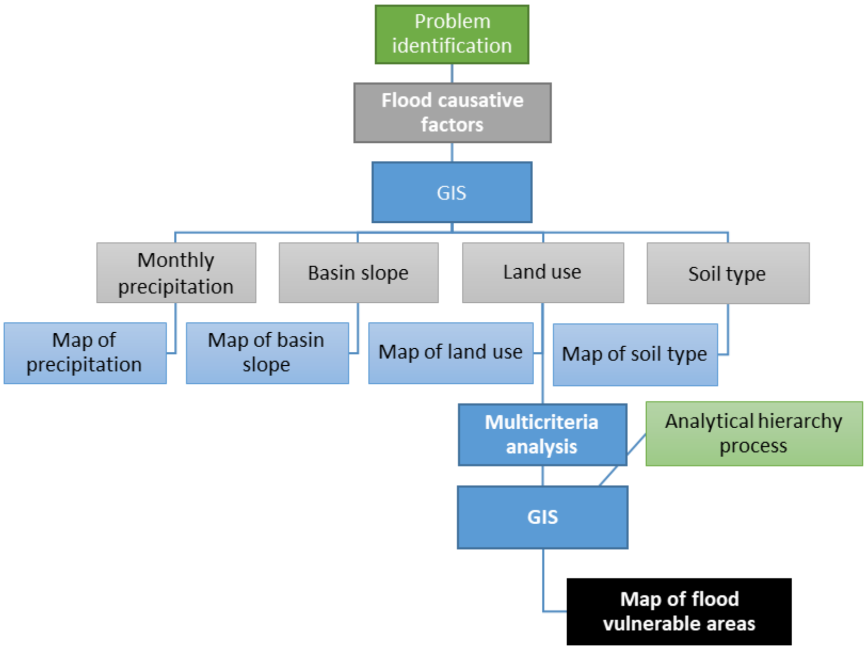

Fig. 2. The methodology of flood vulnerability map development.

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. Kosice, Soil Science and Conservation Research Institute, Slovak Hydrometeorological Institute.

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

Choosing the risk factors

The first step in assessing the flood vulnerability in the Bodva catchment was the selection of hydrological and geographical factors which can influence the flood occurrence. We have selected: monthly precipitation, soil type, basin slope, land use. The data were obtained from Hydrometeorological Institute (precipitation); Soil Science and Conservation Research Institute (soil type); Digital Terrain Model (basin slope) and Corine Land Cover (land use). The next step was a determination of classes of each factor and importance of factor's class, as shown in Table 1.

Tab. 1. Risk factor's class and his importance.

Risk factors	Risk factor's classes	Importance of factor's class ($RF_{q,t}$)
Monthly precipitation	0 – 54.9 mm	1
	55 – 59.9 mm	2
	60 – 64.9 mm	3
	65 – 69.9 mm	4
	70 mm and more	5
Soil type (content of clay particles)	0 - 10 %	1
	10 -30 %	2
	30 - 45 %	3
	45 - 60 %	4
	60 % and more	5
Basin slope	0 - 15%	1
	15 - 30 %	2
	30 - 45 %	3
	45 - 80 %	4
	80 % and more	5
Land use	forest	1
	pastures and meadows	2
	agricultural land	3
	urbanised area	4
	water area	5

The risk factor´s classes according to Table 1 are presented in the separate factors maps in Fig. 3-6. ArcGIS 9.3 was used for transferring data to the appropriate GIS layers. Maps in Figures 3-6 present the real values of the risk factor in the river basin as well as reclassification according to Table 1.

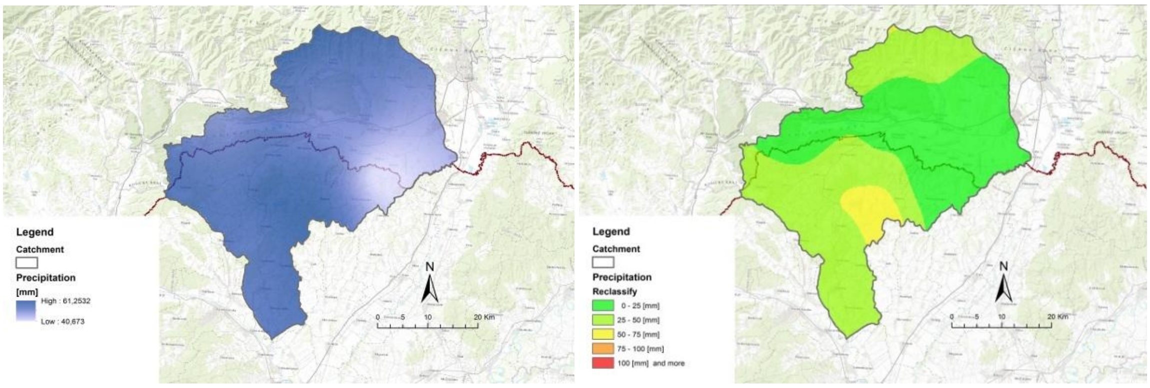

Fig. 3. Map of daily rainfall.

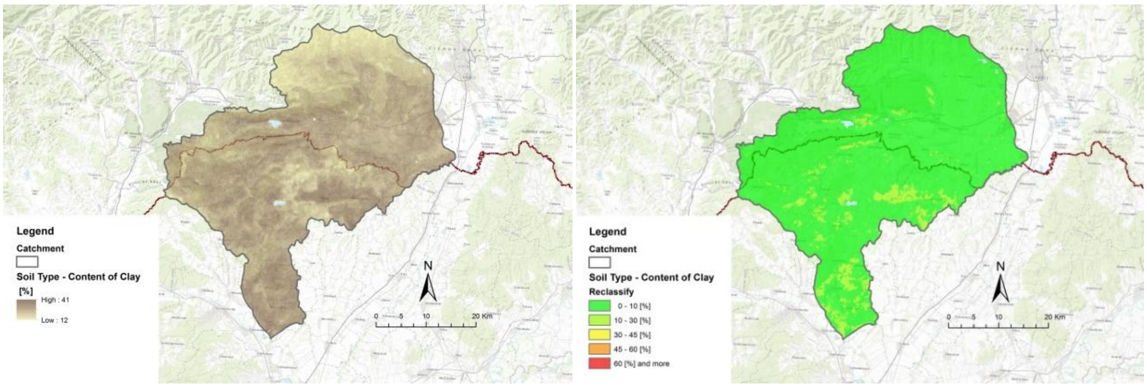

Fig. 4. Map of soil types. Weight-percentage of the particles with diameter <0.01mm.

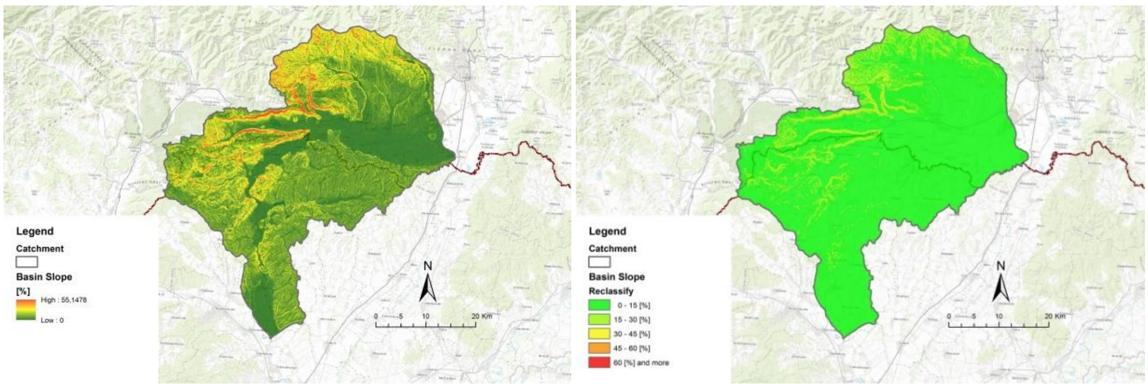

Fig. 5. Map of basin slope.

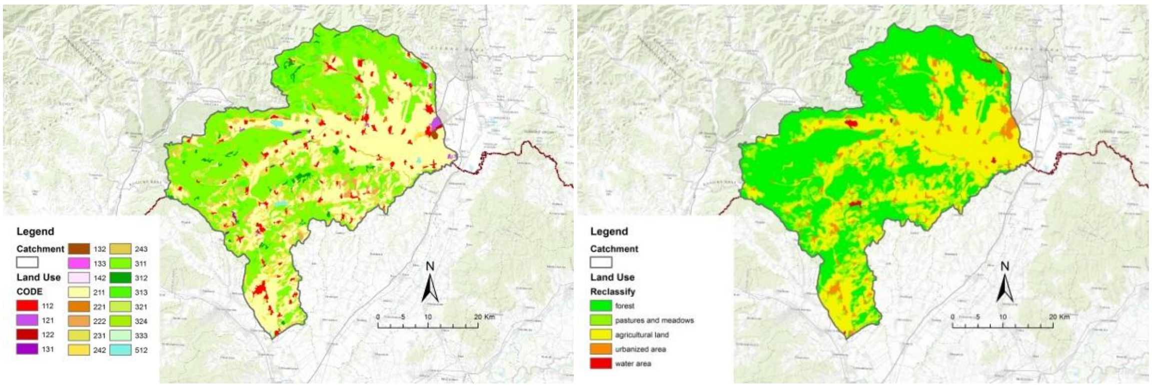

Fig. 6. Map of land use.

MCA method: analytical hierarchy process was used for defining the flood vulnerability in Bodva river basin. 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 and Skubinčan, 2013). The multi-criteria 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.

Defining flood vulnerability areas using MCA – AHP

The analytical hierarchy process (AHP) developed by Saaty (1980) was applied for the determination of the importance of selected causal factors. The matrix of pairwise comparison of causative criteria (Table 2) was used to assess the degree of significance of the individual criteria and measures, and to determine how the evaluated variants fulfil the resolution of these criteria. AHP method is a structured mathematical technique for organising and analysing complex decisions. Assessments are based on expert estimates by comparing the mutual influences of two or several causative factors based on the selected scale (Saaty, 1980) in order to obtain the relative importance of selected factors. The relative weight of selected criteria was based on an iterative process and the matrix of pairwise comparison, where the matrix Ā of type p x p (i.e. it has p rows and p columns) was calculated by the normalisation of the columns A (Boroushaki & Malczewski, 2008) according to the relation:

$$\overline{A} = \left[RF_{qt}^{*}\right]_{p\times p} \quad (1)$$

For calculation of the element of the matrix a_{qt}^{*}, the relation applies (2):

$$RF_{qt}^{*} = \frac{RF_{qt}}{\sum_{q}^{p} RF_{qt}} \quad (2)$$

The matrix Ā x Ā was calculated and normalised in $\bar{A}_2$, subsequently $\bar{A}_3$, ..., $\bar{A}_z$ were calculated until all columns of the obtained matrix are identical. The column then gives the vector ω defined by the relation (3):

$$\omega_q = \overline{RF}^{*}_{qt(z)} \quad (3)$$

for all $q = 1, 2, ..., p$

Tab. 2. The matrix of pairwise comparison of causative criteria and calculation of the normalised weight of criteria.

	RF_{MP}	**RF_{ST}**	**RF_{BS}**	**RF_{LU}**	**Weight**
RF_{MP}	1.00	5.00	5.00	7.00	0.49
RF_{ST}	0.20	1.00	3.00	5.00	0.09
RF_{BS}	0.20	0.33	1.00	5.00	0.17
RF_{LU}	0.14	0.20	–	1.00	0.25
Sum	1.54	6.53	9.20	18.00	1.00

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

$$V = \sum (RF_{1j} W_1 + RF_{2j} W_2 + RF_{3j} W_3 + RF_{4j} W_4) \tag{4}$$

where: V is a vulnerability, RF_{1j}, RF_{2j}, RF_{3j}, RF_{4j} are the importance of factor's class, and W_1, W_2, W_3, W_4 are the normalised weights for each criterion.

Results and Discussion

The result of our assessment is the categorisation of the flood vulnerability of the Bodva catchment into four flood risk classes. The flood vulnerability was evaluated in four classes – acceptable, moderate, undesirable and unacceptable (Table 3) – arranged according to MILSTD 882D Standard practice for system safety. The results are inevitable for the flood risk management and proposing flood mitigation measures for the most vulnerable territories. Vulnerability´s classes were divided using Box plot method (Tukey, 1977). The obtained results from software ArcGIS 9.3 are presented in Fig. 7.

Tab. 3. Vulnerability acceptability and its significance.

Vulnerability rate / acceptability	The significance of flood vulnerability in the watershed	Scale of vulnerability
1 / acceptable	Vulnerability in watersheds are acceptable – current practice	1 – 1.73
2 / moderate	Vulnerability in watersheds are moderate – the condition of continual monitoring	1.73 – 2.13
3 / undesirable	Vulnerability in watersheds are undesirable – flood protection	2.13 – 2.46
4 / unacceptable	Vulnerability in watersheds are unacceptable – immediate flood protection	2.46 and more

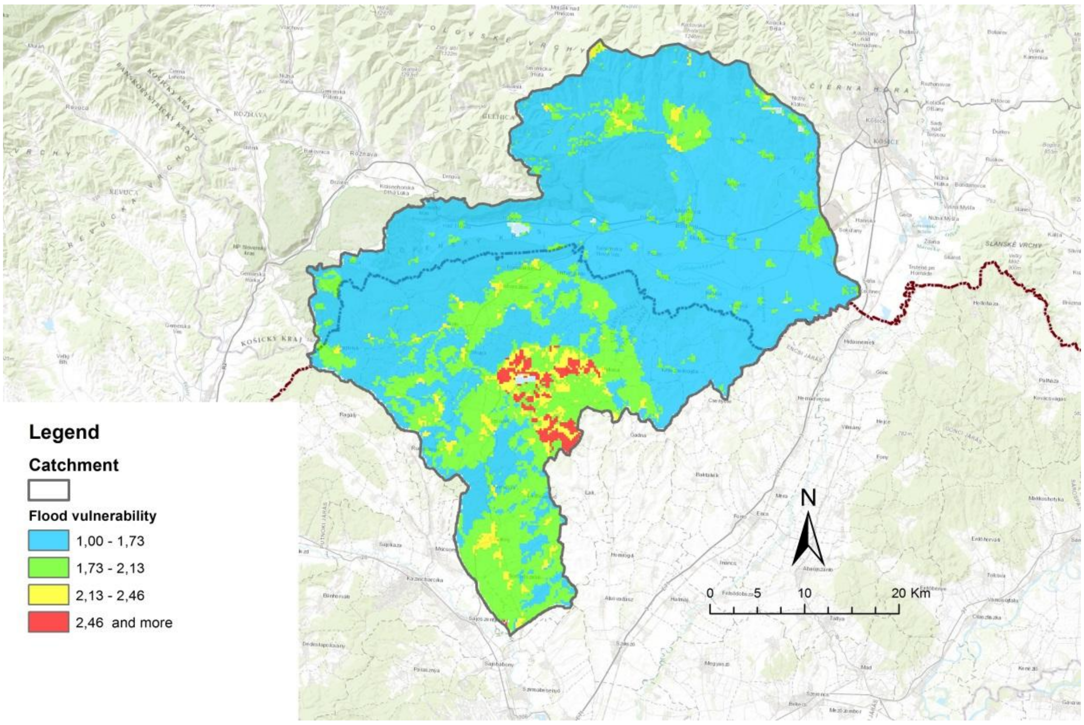

Fig. 7. Map of flood vulnerability in the study area based on the analytic hierarchy process.

The flood vulnerability assessment based on the analytic hierarchy process shows that the Bodva river basin is formed mainly by areas with acceptable and moderate undesirable flood vulnerability. Zones with the undesirable and unacceptable level of flood vulnerability were also identified, but with only relatively small areas. The undesirable and unacceptable zone covers only some part of the hilly Cserehát Region in Hungary and represents 3 % respectively 1 % of the study area. Moderate vulnerability zones in 24 % of the study are also mostly in the Hungarian part of the watershed. Acceptable flood vulnerability is covering 72 % of the assessed area mostly in Slovakia.

Flood vulnerability is a joint 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 watershed.

The results are mostly coincident with the results from preliminary flood risk assessment which has to be done in the Slovak Republic in 2011 (Zeleňáková and Gaňová, 2011).

It should be noted that AHP method shows suitable results of flood vulnerability assessment as related to the existing floods in the recent years. It is a suitable method for analysing the flood-vulnerable area. The development of this assessment for whole Bodva catchment has the advantage that there is a method which is easy to apply.

As described above, we created multicriteria vulnerability map for Bodva river basin. The results obtained from this assessment indicate the importance of the determination of flood-vulnerable areas for decision makers in water management, especially in the flood risk management.

Conclusion

Rivers act as natural connectors between Slovakia and Hungary due to the geographical and hydrogeological features of these countries. Slovakia and Hungary are concerned mutually in conservation and protection of the rich ecosystem of the related areas and shielding the settlements along the riversides.

This paper presents a work carried out in the Bodva river basin involving the use of GIS tools and multicriteria analysis methods to generate maps of flood vulnerable areas. Basically, two phases are applied in this study to analyse flood vulnerability: firstly, to identify the effective factors causing floods – the potential natural causes of flooding, and secondly to apply methods of MCA in GIS environment to evaluate the flood vulnerability of the area. The level of flood vulnerability was evaluated in four classes (acceptable, moderate, undesirable, and unacceptable). The composite map (Fig. 7) showing the flood vulnerability provides the results based on the use of the multicriteria method in ArcGIS software. A flood vulnerability risk map can be a quick decision support system tool to study the impact of planned human activities on the catchment area.

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References

Blišťanová, M., Zeleňáková, M., Blišťan, P., Ferencz, V. (2016). Assessment of flood vulnerability in Bodva river basin, Slovakia, *Acta Montanistica Slovaca, 21(1), 19-28.*

Blišťanová, M., Blišťan, P. (2014): The GIS tooin the Process of Flood threat evalution. In: SGEM 2014: 14th International Multidisciplinary Scientific GeoConference: Conference Proceedings :Volume III: 17-26 June, 2014, Bulgaria. - Sofia : STEF92 Technology, 2014 P. 957-965.

Boroushaki, S., & Malczewski, J. (2008). Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS. *Computers & Geosciences, 34(4), 399-410.*

Chandran, R., Joisy. M.B. (2009). Flood Hazard Mapping of Vamanapuram River Basin-A Case Study. In *Proceedings of 10th National Conference on Technological Trends (NCTT09) (pp. 6-7).*

Diaconu, D.C., Andronache, I., Ahammer, H., Ciobotaru, A.M, Zelenakova, M., Dinescu, R., Pozdnyakov, A.V, Chupikova, S.A. (2017). Fractal drainage model – a new approach to determinate the complexity of watershed. *Acta Montanistica Slovaca. 22(12-21).*

Kandilioti, G., Makropoulos, C. (2012). Preliminary flood risk assessment: the case of Athens. *Natural hazards, 61(2), 441-468.*

Kenyon, W. (2007). Evaluating flood risk management options in Scotland: A participant-led multi-criteria approach. *Ecological Economics, 64(1), 70-81.*

Kiss, I., Wesely, E., Blistanova, M., (2014).Contribution to Logistics of Catastrophes in Consequence of Floods In: Procedia Engineering, no. 69, 2014, p. 1475-1480

Merz, B., Hall, J., Disse, M., & Schumann, A. (2010). Fluvial flood risk management in a changing world. *Natural Hazards and Earth System Sciences, 10(3), 509.*

Meyer, V., Scheuer, S., Haase, D. (2009). A multicriteria approach for flood risk mapping exemplified at the Mulde river, Germany. *Natural hazards*, *48(1), 17-39*.

Papaioannou, G., Vasiliades, L., Loukas, A. (2015). Multi-Criteria Analysis Framework for Potential Flood Prone Areas Mapping. *Water Resour Manage 29*(399) https://doi.org/10.1007/s11269-014-0817-6

Petrow, T., Thieken, A. H., Kreibich, H., Merz, B., & Bahlburg, C. H. (2006). Improvements on flood alleviation in Germany: Lessons learned from the Elbe flood in August 2002. *Environmental management*, *38(5), 717-732*.

Rahmati, O., Zeinivand, H., Besharat, M. (2015). Flood hazard zoning in Yasooj region, Iran, using GIS and multi-criteria decision analysis, *Geomatics, Natural Hazards and Risk, 7(3), 1000-1017, DOI: 10.1080/19475705.2015.1045043*

Ramlal, B., Baban, S. M. (2008). Developing a GIS based integrated approach to flood management in Trinidad, West Indies. *Journal of environmental management*, *88(4), 1131-1140.*

Romanescu, G., Hapciuc, O.E., Minea, I., Iosub, M. (2016). Flood vulnerability assessment in the mountain–plateau transition zone: a case study of Marginea village (Romania). *J Flood Risk Management*, *11(502–513). doi:10.1111/jfr3.12249*

Romanescu, G., Stoleriu, C. (2014). An inter-basin backwater overflow (the Buhai Brook and the Ezer reservoir on the Jijia River, Romania). *Hydrol. Process., 28(3118–3131). doi:10.1002/hyp.9851*

Saaty, T. L. (1980). The analytic hierarchy process: planning. *Priority Setting. Resource Allocation, MacGraw-Hill, New York International Book Company*, *287*.

Scheuer, S., Haase, D., Meyer, V. (2011). Exploring multicriteria flood vulnerability by integrating economic, social and ecological dimensions of flood risk and coping capacity: from a starting point view towards an end point view of vulnerability. *Natural Hazards*, *58(2), 731-751*.

Scolobig, A., Broto, V. C., Zabala, A. (2008). Integrating multiple perspectives in social multicriteria evaluation of flood-mitigation alternatives: the case of Malborghetto-Valbruna. *Environment and Planning C: Government and Policy*, *26(6), 1143-1161*.

Şerban, G., Rus, I., Vele, D., Breţcan, P., Alexe, M., & Petrea, D. (2016). Flood-prone area delimitation using UAV technology, in the areas hard-to-reach for classic aircrafts: case study in the north-east of Apuseni Mountains, Transylvania. *Natural Hazards*, *82(3), 1817-1832*.

Simonovic, S. P. (2009). Managing flood risk, reliability and vulnerability. *Journal of Flood Risk Management*, *2(4), 230-231*.

Solin, L., Skubincan, P. (2013). Flood risk assessment and management: review of concepts, definitions and methods. *Geographical Journal, 65(1), 23-44*.

Tanavud, C., Yongchalermchai, C., Bennui, A., Densreeserekul, O. (2004). Assessment of flood risk in Hat Yai municipality, Southern Thailand, using GIS. *Journal of Natural Disaster Science*, *26(1), 1-14*.

Tukey, J. W. (1977). Some thoughts on clinical trials, especially problems of multiplicity. *Science, 198(4318), 679-6*

Van Alphen, J., Martini, F., Loat, R., Slomp, R., Passchier, R. (2009). Flood risk mapping in Europe, experiences and best practices. *J Flood Risk Management*, *2(4), 285-292.*

Wang, Y., Li, Z., Tang, Z. et al. (2011). A GIS-Based Spatial Multi-Criteria Approach for Flood Risk Assessment in the Dongting Lake Region, Hunan, Central China. *Water Resour Manage 25*(3465) https://doi.org/10.1007/s11269-011-9866-2

Yahaya, S., Ahmad, N., Abdalla, R. F. (2010). Multicriteria analysis for flood vulnerable areas in Hadejia-Jama'are River basin, Nigeria. *European Journal of Scientific Research*, *42(1), 71-83*.

Yalcin, G., Akyurek, Z. (2004, July). Analysing flood vulnerable areas with multicriteria evaluation. In *20th ISPRS Congress (pp. 359-364).*

Zeleňáková, M., Gaňová, L. (2011). Integrating multicriteria analysis with geographical information systems for the evaluation the flood vulnerable areas. *11th International Multidisciplinary Scientific GeoConference SGEM2011*, *2, 433-440*.

Zeleňáková, M., Gaňová, L., Purcz, P., Horský, M., Satrapa, L. (2018), Determination of the potential economic flood damages in Medzev, Slovakia. *J Flood Risk Management, 11(1090–1099). doi:10.1111/jfr3.12298*