IDENTIFICATION OF URBAN FLOOD VULNERABILITY IN EASTERN SLOVAKIA BY MAPPING THE POTENTIAL NATURAL SOURCES OF FLOODING - IMPLICATIONS FOR TERRITORIAL PLANNING

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Abstract. The aim of the presented study was to assess the distribution of flood-risk potential (FRP) at the regional scale. A progressive approach integrating geographical information system (GIS) with two different methods of multicriteria analysis (MCA) – analytic hierarchy process (AHP) and ranking method (RM) was applied in the process. In the analyses, the most causative factors for flooding were taken into account, urban spatial planning, such as soil type, daily precipitation, land use, size of the catchment and average basin slope. A case study of flood vulnerability identification in the Hornád and Bodrog catchments' areas in eastern Slovakia has been employed to illustrate two different approaches. Spatial estimation of FRP should be one of the basic steps for complex geoecological 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 RM method shows better results as related to the existing floods in the recent years in Bodrog and Hornád catchment than AHP method.

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

1. Introduction

The increase in damage due to natural disasters is directly related to the number of people who live and work in hazardous areas and who continuously accumulate assets. 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; Korytárová *et al.*, 2007). 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; Hassan *et al.*, 2006).

Multicriteria analysis (MCA) methods have been applied in several studies in flood risk assessment. Chandran and Joisy (2009) introduced an efficient methodology to accurately delineate the flood hazard areas in Vamanapuram river basin in a GIS environment. 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. The ranking method and pairwise comparison method were introduced and applied in this study. 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. 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 were applied in the study. Scheuer *et al.*, (2011) present an approach to modeling multicriteria flood vulnerability which integrates the economic, social and ecological dimension of risk and coping capacity (Pintilii *et al.*, 2016). The approach is tested in an urban case study, the city of Leipzing, Germany. Kandilioti and Makropoulos (2012) applied three different multicriteria decision rules (analytic hierarchy process, weighted linear combination and ordered weighting averaging) to produce the overall flood risk map of the area. A GIS-based multicriteria flood risk assessment methodology was developed and applied for the mapping of flood risk in the Greater Athens area and validated for its central and the most urban part. Meyer *et al.*, (2009) developed a GIS-based multicriteria flood risk assessment and mapping approach (Shamsi 2002; Ramlal and Baban, 2003; Scolobig *et al.*, 2008). The approach is applied to a pilot study for the River Mulde in Saxony, Germany. 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).

Flood risk assessment remains a main direction in scientific research to assist decision indispensable in specific territorial management decision making.

In numerous studies it starts from a systemic approach to planning, presenting variable components on which one can act to reduce imbalances (Petrisor *et al.*, 2015a; 2015b; 2015c; Peptenatu *et al.*, 2012a; 2012b; 2014; Ladzianska and Finka, 2014; Ran and Nedovic-Budic, 2016; Tira *et al.*, 2006; Gourbesville and Laborde, 2006; Van Alphen *et al.*, 2009; Saelze and Urbina, 2015).

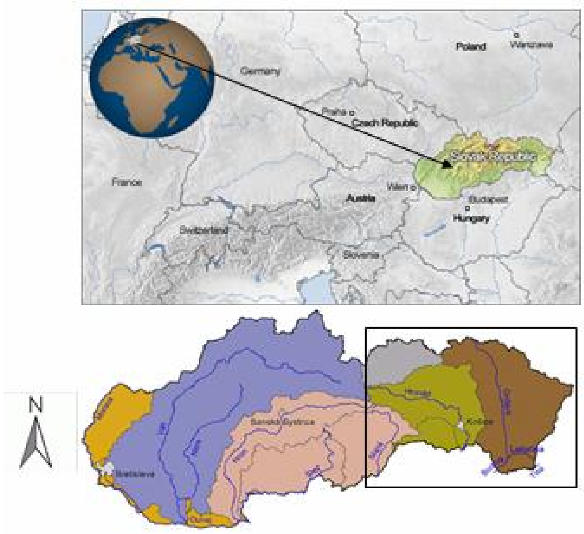

Fig. 1. Location of the study area with the Hornád and (Slovakian part of) Bodrog river basins

The aim of the presented study is to evaluate the applicability of two MCM for the flood-risk assessment under the specific conditions of eastern Slovakia and to generate a composite flood vulnerability map of this region for decision makers.

1.1. Study area

The areas most endangered by floods in Slovakia lie in the eastern part of the country, particularly in the Bodrog and Hornád river basins (Fig.1.). The morphological type of terrain in the Hornád valley is dominated by rolling hills, higher and lower uplands. The southern sub-basin is part of the lowland and the Slovakian Karst and is formed by moderately higher uplands. The morphological type of the relief is predominantly flat in the southern part but hilly in the northern part. The mountainous parts of the Bodrog basin are built mostly by flysh susceptible to quick runoff generation and subsequent soil erosion, hillslope failures and sediment transport.

The Bodrog river basin has varied climatic conditions. Precipitations are highly differentiated. The highest annual totals are mainly in the eastern border mountains and Vihorlat where the rainfall totals are about 1000 mm. Decrease in total precipitation is evident in direction to south, where the annual totals fall to below 800 mm (Zeleňáková and Gaňová, 2011). As the climate has become more extreme during the last three decades, the region was more times affected by heavy rains, which together with the destabilized flysh have caused several destructive floods with loses on both, property and lives in the northern part of the basin.

The floods have a variegated course in the territory of eastern Slovakia, which is caused by their differing physical and geographical conditions. It is with no doubt, that in a distant past the territory of eastern Slovakia was frequently the place of flood disasters, as well. Cities as Kosice, Presov, Trebisov, Humenne, Michalovce, Bardejov, Roznava, are directly exposed to flood risks.

From preserved records as such the century water in the drainage area of Bodrog river the one in 1888 can be supposed. From the biggest floods there can be mentioned the hundred year water in drainage area of Bodrog in 1924. The extended floods occurred also in 1967, 1974, 1979 or 1980 (Bajtoš *et al.*, 2006). The whole drainage area of the Hornád and Bodrog rivers was affected by the last disastrous flood in May and June 2010.

Figure 2 presents the number of flood days during the period 1990–2015 in Slovakia and in eastern Slovakia, respectively.

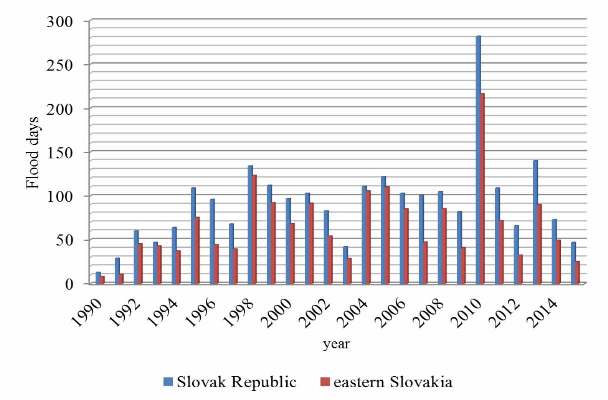

Fig. 2. Number of flood days during period 1990–2015

Costs of flood damages at property of Slovak Water Management Enterprise, s.c. Košice in eastern Slovakia during the period 1990–2015 are decreasing (except the extreme flood year 2010). It is caused by the construction of flood protection measures in the catchments. Figure 3 present some of flood protection measures that were built in the last period in eastern Slovakia.

2. Materials and methods

2.1. Structure and layout

Water resources management and territorial planning is one of the fields in which multicriteria methods have been used extensively. On their pioneering work in the Netherlands, Nijkamp and Vos (1977) used MCA for the planning of water resources development. Thereafter MCA has been applied in various flood management cases (Scolobig *et al.*, 2008). GIS analysis has been developed to examine spatial and temporal patterns and to find associations between various geographical factors (Ramlal and Baban, 2003).

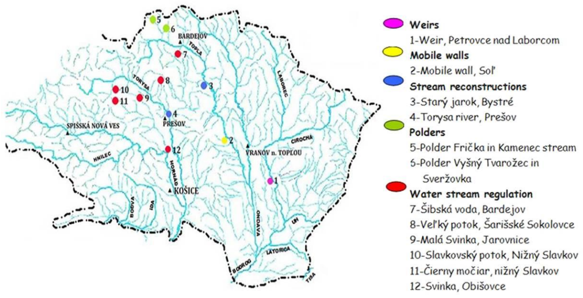

Fig. 3. Flood protection measures in eastern Slovakia

We used two methods in determining flood vulnerability – the ranking method and the analytic hierarchy process. The evaluation procedure consists of the steps presented at the flowchart in Figure 4.

The analytical hierarchy process (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 should be broken down into a set of criteria (objectives, attributes) (Boroushaki and Malczewski, 2008).

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 a second step, ranking method is used to obtain numerical weights from this rank order (Meyer, 2009).

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.

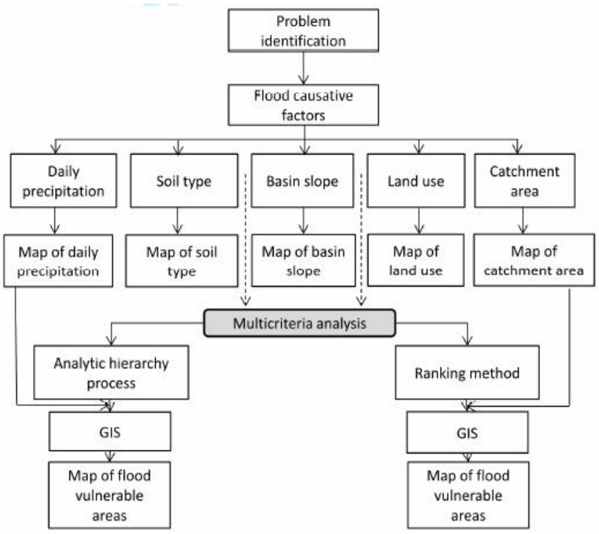

Fig. 4. Methodology of flood vulnerability maps based on the natural sources of flooding

Basically two phases are applied in this study to analyze flood vulnerability: 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.

2.2. Choosing the determinant factors

The first step in assessing the vulnerability structure is to identify the factors affecting flooding on the basis of an analysis of existing studies and knowledge. We use set of causative factors concerning mostly hydrological and geographical characteristics of the target area that can be measured and evaluated. The factors used in this study were selected due to their relevance in the study area, and these are listed below: soil type, daily rainfall, land use, catchment area, basin slope and spatial planning of the cities.

GIS has been applied for managing, producing, analyzing and combining spatial data. The data needed in this study were produced from collected or existing data using different kinds of spatial functions and analysis. ArcGIS 3.2 and ArcGIS 9.3 were used for transferring data to the appropriate GIS layers.

Each factor was divided into classes. Inverse ranking was applied to these factor's classes, with the least important = 1, next least important = 2. This classification shall enter into a narrative or numeric character, as shown in Table 1.

Table 1. Factor's class and his importance

Factors	Factor's classes	Importance of factor's class ($IF_{i,j}$)
Daily rainfall	0 – 1,8 mm 1,8 – 2,0 mm 2,0 – 2,2 mm 2,2 mm and more	1 2 3 4
Soil type (content of clay particles)	0 - 10 % 10 -30 % 30 - 45 % 45 - 60 % 60 % and more	1 2 3 4 5
Slope	0 - 15% 15 - 30 % 30 - 45 % 45 - 80 % 80 % and more	1 2 3 4 5
Land use	forest agricultural land urbanized area	1 2 3
Catchment area	0 - 100 km² 100 – 500 km² 500 – 1000 km² 1000 and more km²	1 2 3 4

The factor´s classes according Table 1 are presented in the separate factors maps in Fig. 5-8.

Two MCA methods were used for defining the flood vulnerability in eastern Slovakia.

2.3. Defining flood vulnerability areas using MCA approaches

Ranking method

In the ranking method (RM), every factor/criterion under consideration is ranked in the order of the decision-maker's preference. To generate factor values for each evaluation unit, each factor was weighted according to the estimated significance for flooding.

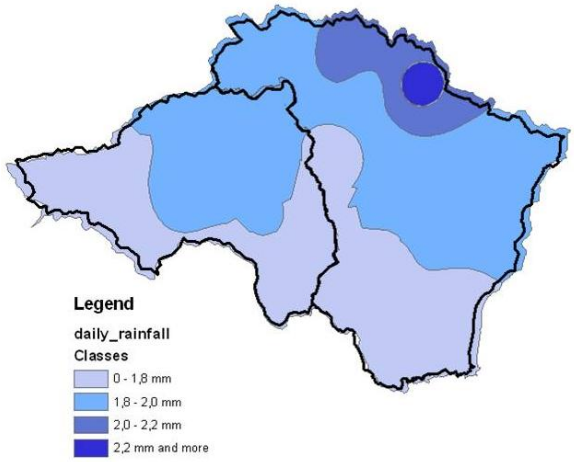

Fig.5 . Map of daily rainfall

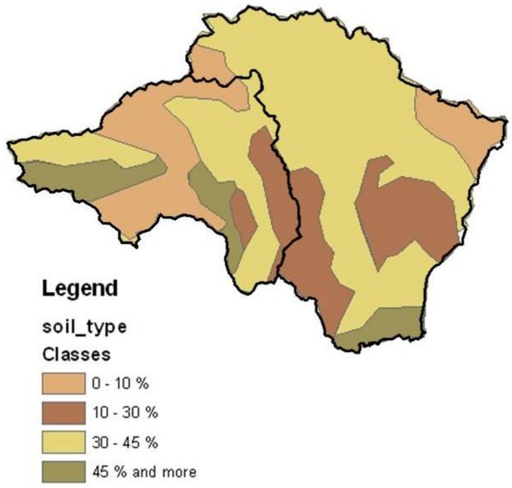

Fig. 6. Map of soil type. Weigh-percentage of the particles with diameter <0.01mm

Straight ranking was applied to these factors, which means that 1 is the most important factor and 4 is the least important factor:

- Daily rainfall (F1) = 1
- Basin slope (F2) = 2
- Soil type (F3) = 3
- Land use (F4) = 4
- Catchment area (F5) = 5

The purpose of the criterion weighting is to express the importance of each factor relative to other factors. More important factors have greater weighting in the overall evaluation.

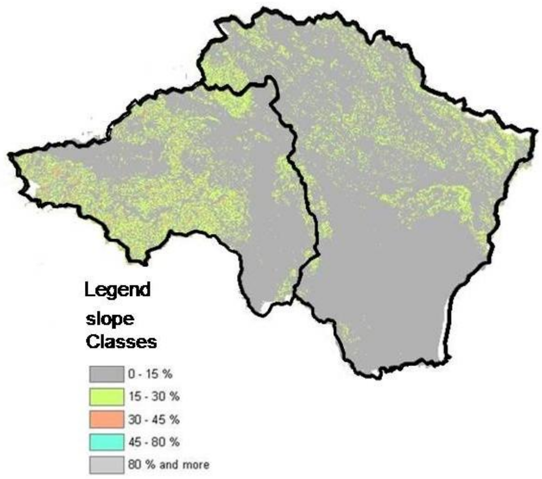

Fig. 7. Map of basin slope

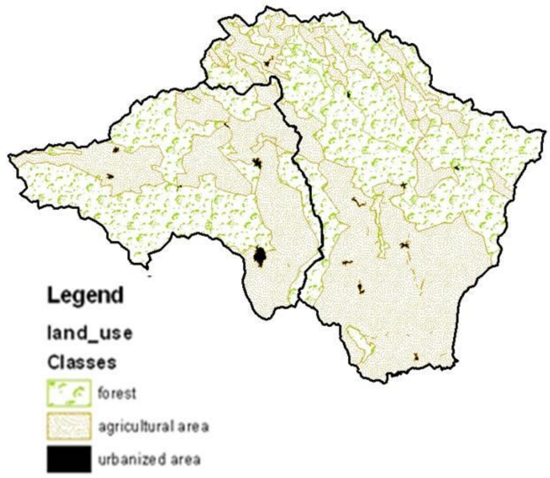

Fig. 8. Map of land use

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

$$W_j = \frac{n - r_j + 1}{\sum (n - r_k + 1)} \quad (1)$$

where:

W_j is the normalized weight for the each criterion,

n is the number of criteria under consideration ($k = 1, 2, \ldots, n$),

and r_j is the rank position of the criterion.

$$W = n - r_j + 1 \quad (2)$$

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

$$\sum (n - r_k + 1) \quad (3)$$

Table 2 shows weight assessment by the ranking method.

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

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

where:

IV is index of vulnerability,

IF_{1j}, IF_{2j}, IF_{3j}, IF_{4j}, IF_{5j} are importance of factor's class,

and W_1, W_2, W_3, W_4, W_5 are the normalized weights for each criterion.

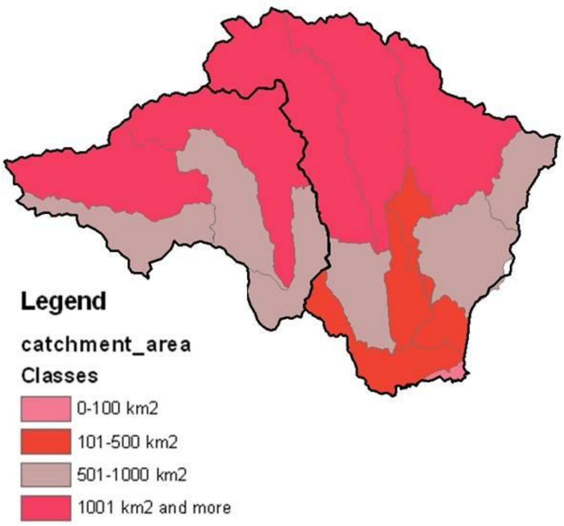

Fig. 9. Map of catchment area

Analytic hierarchy process

The second method for determining flood vulnerability is the analytic hierarchy process (AHP). This is a structured technique for organizing and analyzing complex decisions. Nineteen river stations in the Latorica, Laborec, Cirocha, Topľa, Ondava, Bodrog, Hornád and Torysa streams 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 rainfall is class one, the number 1 is written in column "1" for the line "rainfall", and other values on this line are zero. In this way the whole matrix was completed for all factors. An example of a completed matrix for river station Michalovce is shown in Table 3.

Table 2. Weight assessment by the rank sum method

Criterion	Straight Rank	Weight (W)	Normalized Weight (W_j)	Weight (%)
Daily rainfall	1	5	0.333	33.3
Slope of watershed	2	4	0.267	26.7
Soil type	3	3	0.20	20.0
Land use	4	2	0.134	13.4
Size of watershed	5	1	0.066	6.6
Sum		15	1	100

Factor's classes are usually proposed based on expert knowledge, which however is still the subjective method, which cannot be applied elsewhere. We solved this problem of weighting the factors' classes using the calculation of entropy, as follows:

A = (a_{ij}) decision matrix,

$i = 1, \ldots, m$ (m – number of factors),

$j = 1, \ldots, n$ (n – number of attribute),

p_{ij} normalized values of j^{th} attribute

Ej entropy of the set of normalized j^{th} attribute,

dj information diversification level given by j^{th} attribute,

vj weigh of the j^{th} attribute.

Table 3. Matrix for AHP assessment

Station	Factor	Class				
		1	2	3	4	5
Michalovce	Daily rainfall	0	2	0	0	0
	Soil type	0	0	3	0	0
	Land use	0	2	0	0	0
	Basin slope	1	0	0	0	0
	Size of watershed	0	0	3	0	0

Calculation follows the next algorithm:
We normalize the values of attributes from the decision matrix:

$$p_{ij} = \frac{a_{ij}}{\sum_{i=1}^{m} a_{ij}} \quad (5)$$

For each *i, j*
In the next step we calculate the entropy of the j^{th} attribute:

$$E_j = -\frac{1}{\ln m} \times \sum_{i=1}^{m} (p_{ij} \ln p_{ij}) \quad (6)$$

For each *j*
We calculate the diversification level given by j^{th} attribute:

$$d_j = 1 - E_j \quad (7)$$

For each *j*
The result is normalized and the weights are obtained:

$$v_j = \frac{d_j}{\sum_{i=1}^{n} d_i} \quad (8)$$

For each *j*
i.e. for each evaluation category.

3. 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 defense strategy (Solín and 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. The flood vulnerability was evaluated in four classes – acceptable, moderate, undesirable and unacceptable (Table 4) – arranged according to MILSTD 882D Standard practice for system safety.

Table 4. Vulnerability acceptability and its significance

Vulnerability rate / acceptability	Significance of flood vulnerability in watershed	Scale of vulnerability	
		AHP	RM
1 / acceptable	Vulnerability in watersheds are acceptable – current practice	0 - 0,025	1 - 1,73
2 / moderate	Vulnerability in watersheds are moderate – condition of continual monitoring	0,0256 - 0,050	1,73 - 2,13
3 / undesirable	Vulnerability in watersheds are undesirable – flood protection	0,051 - 0,075	2,13 – 2,46
4 / unacceptable	Vulnerability in watersheds are unacceptable – immediate flood protection	0,076 and more	2,46 and more

Vulnerability´s classes were divided using Box plot method (Tukey, 1977).

A composite map showing the flood vulnerability created using the ranking method with ArcGIS 9.3 is presented in Figure 10. The calculated area percentages of particular vulnerability classes were 18.43 % (acceptable), 40.25 % (moderate), 28.99 % (undesirable) and 12.33 % (unacceptable) respectively.

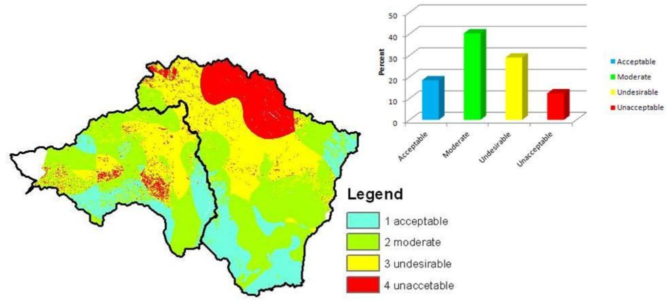

Fig. 10. Map of flood vulnerability in the study area based on the ranking method

The resultant weightings with analytic hierarchy process for all river stations are shown in Table 4. River stations are ranked by the value of weightings from largest to smallest.

Table 4. Resultant weightings for river stations

River station	Weight	River station	Weight
Krásny Brod	0.102286	Spišské Vlachy	0.049978
Stropkov	0.080597	Horovce	0.049406
Michalovce	0.072222	Košické Olšany	0.049406
Spišská Nová Ves	0.065754	Ždaňa	0.049406
Snina	0.055459	Bardejov	0.047895
Hanušovce	0.055459	Ižkovce	0.029255
Prešov	0.055459	Veľké Kapušany	0.029255
Sabinov	0.055459	Kysak	0.027339
Svidník	0.055459	Streda nad Bodrogom	0.018550
Humenné	0.051357		

The flood vulnerability in the study area was evaluated in four classes according Table 4. The obtained results from software ArcGIS 9.3 are presented in Fig. 11.

The flood vulnerability assessment based on the analytic hierarchy process shows that the Bodrog and Hornád watersheds are formed mainly by areas with moderate and undesirable flood vulnerability. Zones with unacceptable and acceptable level of flood vulnerability were also identified, but with only relatively small areas. The undesirable zone covers most of the northern part of eastern Slovakia and represents 65.51 % of the study area.

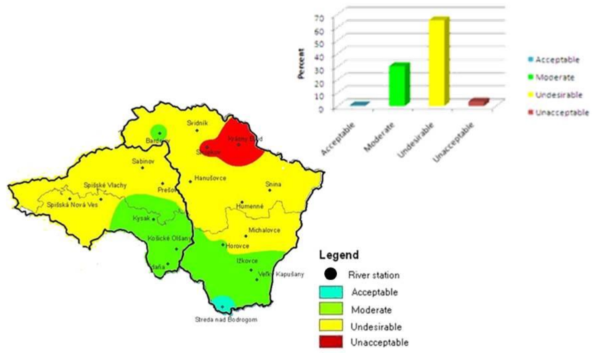

Fig. 11. Map of flood vulnerability in the study area based on the analytic hierarchy process

Unacceptable level of flood vulnerability was found in the surroundings of Krásny Brod and Stropkov and represents 3.43 % of the study area. The south-eastern part of Slovakia falls in the moderate vulnerability zone, and the percentage area of this zone is 30.42 %. Acceptable flood vulnerability is found in a very small part of the territory covering 0.64 % of the assessed area. The area of acceptable level of flood vulnerability was detected around Streda nad Bodrogom in the southern part of Slovakia.

As described above, we created two multicriteria vulnerability maps for Bodrog and Hornád watershed. Our pilot study showed significant differences between both methods shown in Figure 12. 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.

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 river basin. Some of them may the process initiated by the intense rain even accelerate, respectively amplified.

Although floods are natural phenomena, human activities and human interventions into the processes of nature, such as alterations in the drainage patterns from urbanization, agricultural practices and deforestation, have considerably changed the situation in whole river basins (Watts, 2013). On the other hand, human activities such as construction of flood measures can reduce negative impacts of floods. For example if area with high vulnerability index has a flood protection, index vulnerability can become lower.

If we compare different method regarding percentage area of flood vulnerability zone (Fig. 12) we can see, that the results obtained with the ranking method are more representative.

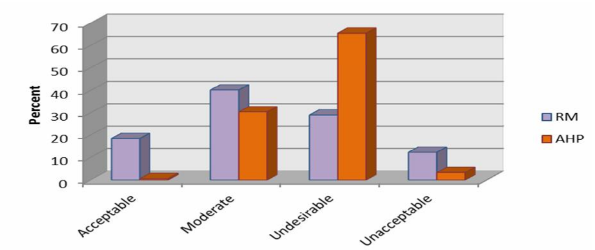

Fig. 12. Percentage area of each flood vulnerability zone

The results are mostly coincident with the results from preliminary flood risk assessment which has to be done in the Slovak Republic in 2011. The results of mentioned assessment are presented in Fig. 13. The geographical areas with existing potentially significant flood risk are marked in red color. The geographical areas with probable potentially significant flood risk are marked in yellow color (MŽP SR, 2011).

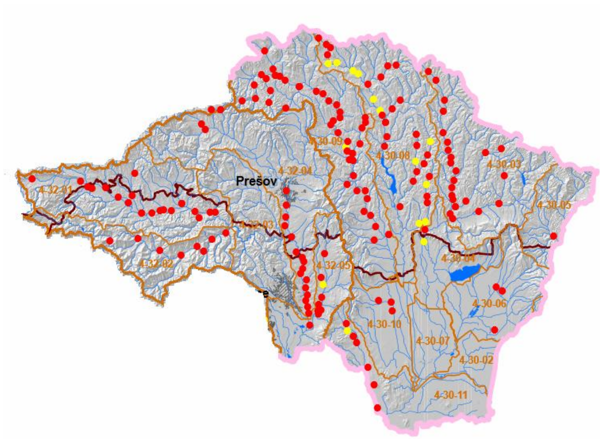

Fig. 13. Geographical areas with potentially significant flood risk (MŽP SR, 2011)

It should be noted that RM method shows better results as related to the existing floods in the recent years. In this case AHP method is not suitable for analyzing the flood vulnerable area. The development of RM method for whole Bodrog and Hornád catchment has the advantage that there is a method which is easy to apply.

4. Conclusion

Flood disaster has a special place among the natural hazards and is considered as a major environmental risk due to its devastating effects on the impacted area. Generating flood extent models and mapping flood vulnerable areas is one of the ways how to study the integral impact of regional environmental changes on flooding at regional scale.

This paper presents work carried out in the Hornád and Bodrog basins in eastern Slovakia involving the use of GIS tools and multicriteria analysis methods to generate maps of flood vulnerable areas.

The level of flood vulnerability was evaluated in four classes (acceptable, moderate, undesirable, and unacceptable). The composite maps (Fig. 10, 11) showing the flood vulnerability provide a comparison of results based on use of the ranking method with those obtained through the analytic hierarchy process in ArcGIS 9.3. The ranking method manifested higher ability to follow the real recent flood history in particular subregions than does the AHP.

A flood-risk map can be a quick decision support system tool to study the impact of either planned or unplanned human activities on the catchment area of the river system. The future upgrading of these regional maps assumes the incorporation of the drainage density, evaporation, percolation as well as factors like frequency of flood, inundation depth, duration of flood, etc.

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