FLOOD VULNERABILITY IN BODVA RIVER BASIN IN SLOVAKIA

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ABSTRACT. – Flood vulnerability in Bodva river basin in Slovakia. The aim of the paper is to generate a composite map for decision makers using selected factors, mainly of natural character, causing floods. In the analyses, some of the causative factors for flooding in a catchment area are taken into account, such as soil type, precipitation, land use, size of catchment and basin slope. A case study of flood vulnerability identification in the Bodva river basin in eastern Slovakia is employed to illustrate the different approaches. A geographical information system (GIS) is integrated with multicriteria analysis (MCA) in the paper. The identification of flood vulnerability consists 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 prepared flood vulnerability map.

Keywords: causative factors, floods, geographical information system, multicriteria analysis.

1. INTRODUCTION

When extreme and non-extreme physical events, such as floods can affect elements of human systems in an adverse manner, they assume the characteristic of a hazard (Lavell et al., 2012). Generally speaking, *hazard* is understood as the potential damage or damage created by an event, a natural disaster, an occurrence, phenomenon or human activity which can cause a loss of lives, injury, damage to property, an interruption of social or economic networks and activities, or environmental degradation (IPPC, 2012). Hazard is a threat or potential for adverse effects, not the physical event itself (Lavell et al., 2012). *Vulnerability* can be defined as a proneness to the origin of damage. In systems of natural risks it represents the element which decides on the course of a natural hazard, the character of consequences and the resulting range of damages (Langhammer et al., 2008; Solín, 2012). *Exposure* is the period during which nature and a landscape are exposed to an adverse phenomenon e.g. floods.

The greater the hazard, the longer the exposure and the greater the vulnerability of an object, the greater is the risk. If we want to reduce the risk

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associated with floods in flooded territories, we have to reduce at least one side of this triangle that defines the field of risk (Langhammer et al., 2008).

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

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

2. MATERIAL AND METHODS

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 is bounded by the border with Hungary and on the west by Slaná river basin.

Fig. 1. ***Bodva river basin in Slovakia within Danube river basin***

From the morphological point of view is a sub-basin Bodva 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 contiguous area of Kosice basin. Lighter soils – sandy-loam occupy forests in the mountains Volovske hills and partially in Slovak Karst.

Sub-basin Bodva 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 from 5°C to 8°C. Long-term average precipitation 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 (ME SR, 2009).

The last floods in the Bodva river basin occurred in 2010. Heavy rains caused a rapid and significant rise of water levels. The floods in May and June 2010 were exceptional from the viewpoint of time and spatial distribution in the Bodva river basin. In nearly all river stations measuring water stages the third (the worst) flood degree was surpassed (ME SR, 2011).

Basically two phases are applied in this study 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 two methods 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.

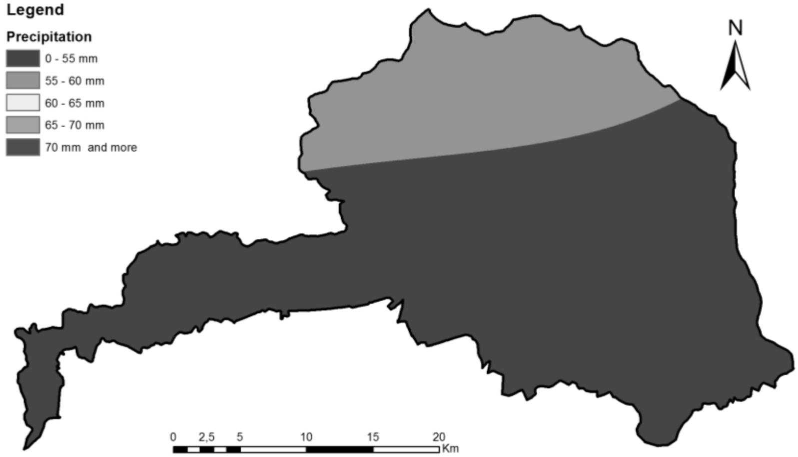
The initial data required for this study were acquired from the Atlas of the Slovakian Landscape and further data were provided by Slovak Water Management Enterprise, s.c. Košice, Soil Science and Conservation Research Institute, Slovak Hydrometeorological Institute.

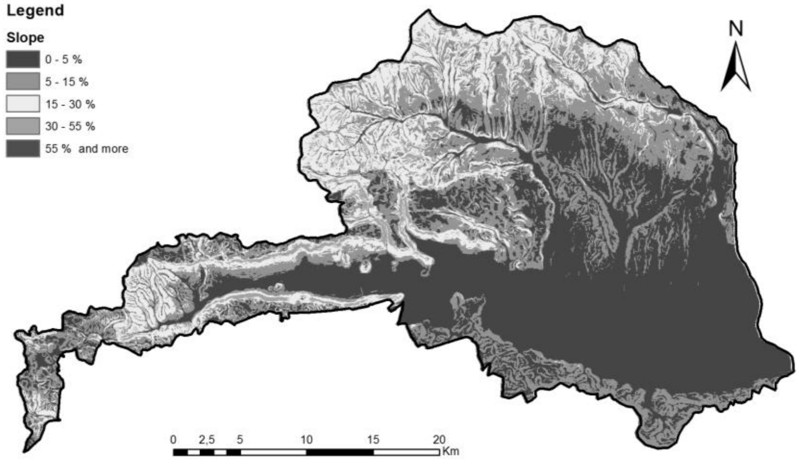
We use set of causative factors concerning mostly hydrological and physio-geographical characteristic of the study area that can be measured and evaluated (Zeleňáková, Gaňová, 2011): *1) Precipitation;2) Basin slope;3) Land use;4) Soil type;5) Catchment area*

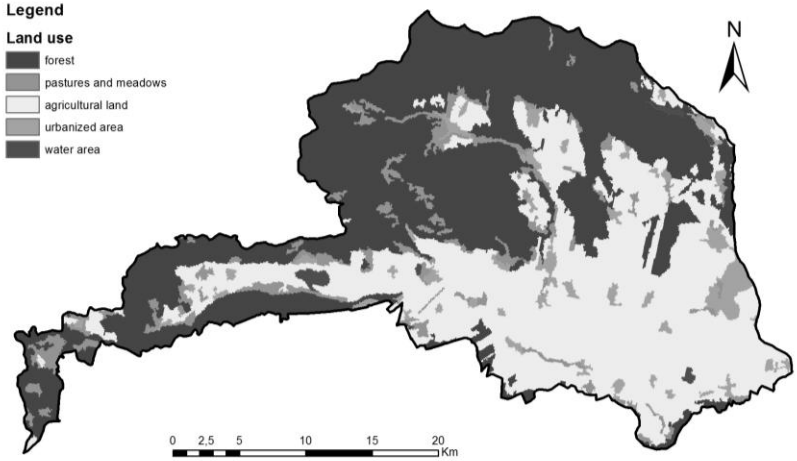
Each factor was divided into classes. Inverse ranking was applied to these factor's classes, with the least risky for flood occurence = 1, next least risky = 2, etc. ArcGIS 10.2 was used for transferring data to appropriate GIS layers.

The factor's classes are presented in the individual factor maps in Figure 2.

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, 2007).


Legend
Precipitation
0 - 55 mm
55 - 60 mm
60 - 65 mm
65 - 70 mm
70 mm and more
N
0 2,5 5 10 15 20 Km


Legend
Slope
0 - 5 %
5 - 15 %
15 - 30 %
30 - 55 %
55 % and more
N
0 2,5 5 10 15 20 Km


Legend
Land use
forest
pastures and meadows
agricultural land
urbanized area
water area
N
0 2,5 5 10 15 20 Km

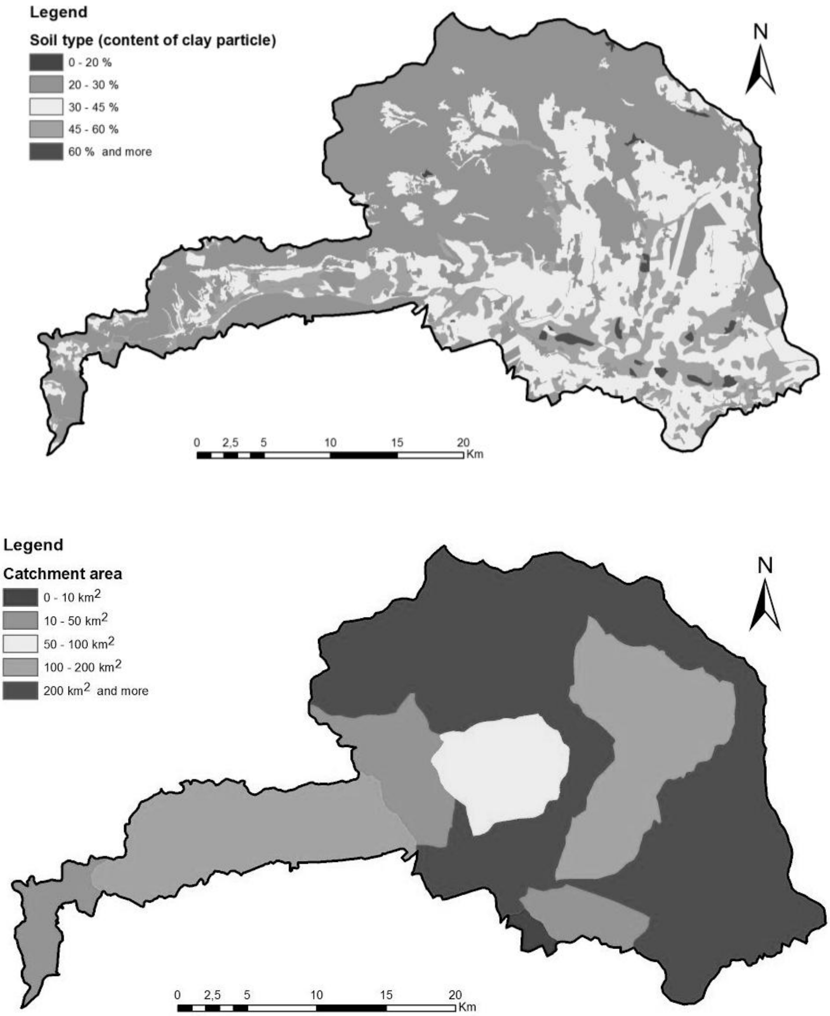


Fig. 2. ***Maps of selected causative factors with factor's classes***

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

$$W_j = n - r_j + 1 / \sum (n - r_k + 1) \qquad (1)$$

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)

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

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):

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

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.

3. 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 most required. The flood vulnerability was evaluated in four classes – acceptable, moderate, undesirable and unacceptable according to Table 1.

Table 1. ***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 of flood vulnerability is presented in Figure 3. It was created using the ranking method with ArcGIS 10.2. For data analysis was used ArcGIS tool – Raster calculator. According to equation (4) was calculated the resulted vulnerability (Fig. 3) from reclassified data in Figure 2 and the resulting data were again reclassified into four classes (Fig. 3) according to Table 1.

In this application, the flood vulnerability level range 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 3.37 % (acceptable), 28.43 % (moderate), 39.35 % (undesirable) and 28.85 % (unacceptable) respectively.

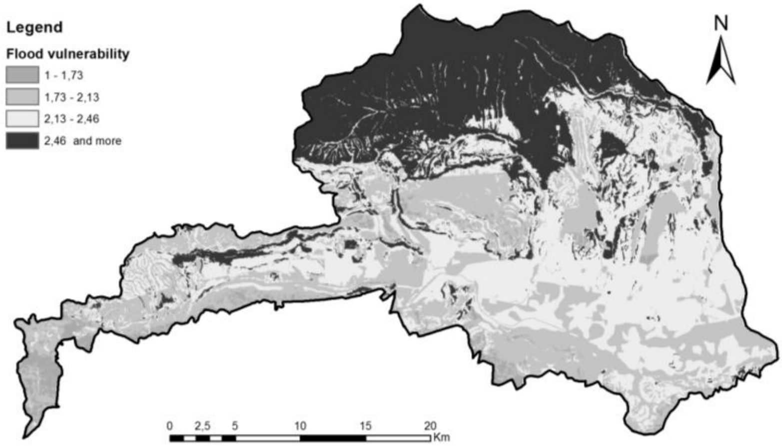


Fig. 3. ***Map of flood vulnerability in the study area based on the ranking method***

5. CONCLUSIONS

Floods endanger the lives and health of inhabitants, cultural heritage, the environment, causes damage to property and limits economic activities. It is not possible to prevent them, but we can estimate the measure of flood risks and take effective measures for mitigating their adverse consequences.

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 of 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 on human health, the environment, cultural heritage and economic activity associated with floods.

This paper presents work carried out in the Bodva river basin in Slovakia involving the use of GIS tools and multicriteria analysis method – ranking method to generate maps of flood vulnerable areas. The composite map (Figure 3) shows the flood vulnerability in the study area developed in ArcGIS 10.2. The level of flood vulnerability was evaluated in four classes (acceptable, moderate, undesirable, and unacceptable). A flood 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 a river system.

The purpose was to prepare maps of flood vulnerability by mapping the potential natural sources of flooding for local governments and other stakeholders and to make recommendations based on local knowledge and needs regarding flood risk reduction activities.

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