

A RAINFALL DISTRIBUTION AND THEIR INFLUENCE ON FLOOD GENERATION IN THE EASTERN SLOVAKIA

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Abstract

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This paper aims to geographically assess the flood occurrence in eastern Slovakia by using one of the methods of multi-criteria analysis – rank sum method. Flood risk assessment is conducted in three specific cases: the long term period 1989–2009, the extremely wet 2010 year, and the extremely dry 2011 year. In the analyses, some of the causative factors for flooding in a basin area are taken into account. We use set of causative factors concerning mostly hydrological and physio-geographical characteristic of the target area that can be measured and evaluated such as soil type, daily precipitation (for the years 1989–2009, 2010, 2011), land use, catchment area and basin slope. For recommendation which causative factors should be preferred we use method of multicriteria analysis – ranking method. In the ranking method (RM), every factor/criterion under consideration is ranked in the order of the decision-maker's preference. Geographic approach to flood risk assessment provides a descriptive presentation of the results obtained. Geographic information systems as a visualization tool is presented in a manner that aids understanding in a user friendly way.

Regarding our task of flood risk assessment, the partial results are three composite maps, which present comparison of flood risk zones in percentage of the area in years 1989–2009, 2010, and 2011. The composite maps are background for risk assessment of the impact of rainfall on flood generation. This study of hydrological data and physio-geographical characteristic was carried out with the purpose of the identification of flood risk occurrence in eastern Slovakia. Results from our study shows, that rainfall distribution has high influence on flood risk of the area. Area percentage with very high flood risk index was calculated for “wet” year 2010 as 11.73 %, for “dry” year 2011 as 0.01 % and for period 1989–2009 as 0.28 %.

geographical information systems, flood risk, rainfall distribution

Floods are natural phenomena causing adverse conditions in the flood-prone areas by extensive inundation. The consequences of floods can be direct or indirect, and can cause loss of lives, economic damages, damages on the environment and the cultural heritage (Korytářová *et al.*, 2007). They can also influence the life and activities of large populations within and adjacent the flooded zone (Messner and Meyer, 2006; Tsakiris, 2010).

River floods in Slovakia have proven devastating for communities and individuals for centuries.

Their risk is spatially variable, however floods have generally been well documented where and when they take place. The most complex situation has been in Bodrog and Hornad river basins in the eastern part of Slovakia in the recent years, mainly in 2010.

The present study develops a hybrid approach to identify flood risk zones and assess the impact of rainfall by integrating multicriteria method and GIS technologies. Multicriteria analysis (MCA) methods and GIS technologies 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 south-west coast of the Black Sea. The ranking method and pairwise comparison method were introduced and applied in this study. Chandran and Joisy (2009) introduced an efficient methodology to accurately delineate the flood hazard areas in Vamanapuram river basin in a GIS environment. 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. 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. 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. The approach is tested in an urban case study, the city of Leipzig, Germany. Kandiloti and Makropoulos (2012) applied three different multicriteria decision rules (analytic hierarchy process, weighted linear combination and ordered weighting averaging), to procedure the overall flood risk map of the area. A GISbased 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.

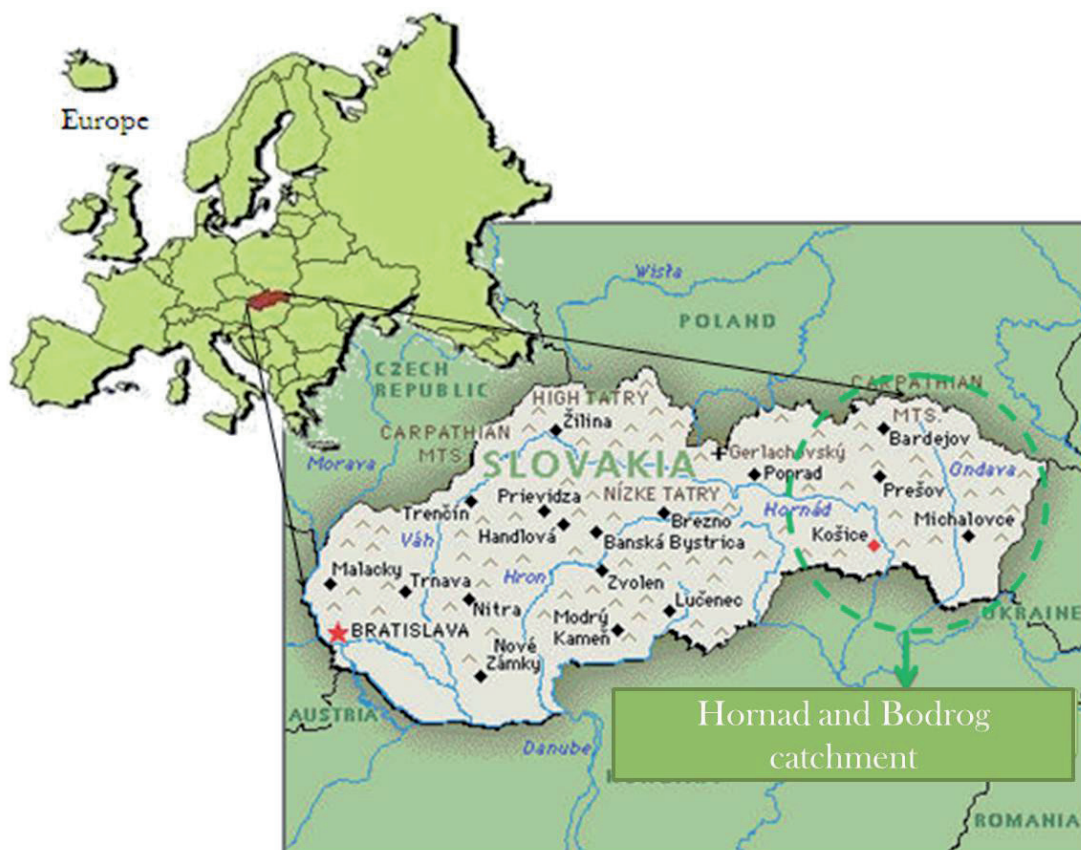
Many studies have shown that flood properties are influenced by a combination of precipitation characteristics including volume, intensity, duration and spatial distribution (see among others Bracken *et al.*, 2007).

The aim of this study is to prepare flood risk maps and assess the impact of rainfall on flood generation.

DESCRIPTION OF STUDY AREA

We are interested in the eastern part of Slovakia, particularly in the Bodrog and Hornád river basins (see Fig. 1), which have faced severe floods. 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 Slovakian Karst plain and is formed by moderately higher uplands. The geological structure of the territory determines the hydro-geological conditions of the basin. The sub-basin of the Hornád valley has strong predominance of impervious (or at least poorly permeable) rock. Well-drained rock with high permeability exists only in Spiš and Gemer areas and in the Slovakian Karst near Košice.

The Bodrog watershed area, consisting of the Cirocha, Laborec, Latorica, Ondava, Topľa and Uh river basins, is located in two orographic



1: The study area

subassemblies, which are the Carpathian Mountains and the Pannonian Basin. The morphological type of the relief is predominantly flat in the southern part and hilly in the northern part. The Bodrog river valley has variable climatic conditions. The annual precipitation is higher in the eastern border mountains and Vihorlat (1000 mm), and reduces at the south (800 mm) (Zeleňáková and Gaňová, 2011).

METHODOLOGY

Modeling the complex interaction of river flow hydraulics with topographical and land use features of the floodplains is usually required to map flood risk zones.

We use data from the Atlas of the Slovakian Landscape, provided by Slovak Water Management Enterprise, s.c. Košice, Soil Science and Conservation Research Institute, Slovak Hydrometeorological Institute, to compute index of flood risk based on multicriteria analysis. We use set of causative factors concerning hydrological and physio-geographical characteristic of the target area that can be measured and evaluated.

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 causing flooding. Straight ranking was applied to these factors, which means that 1 is the most

important factor and 5 is the least important factor. 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 (Yalcin *et al.*, 2004).

Hydrological analysis

Daily rainfall records from 19 rain gauges stations concerning Bodrog and Hornad catchment during the period 1989–2011 (Tab. I) were used. The lowest and highest average daily rainfall is 0.7 and 3.2 mm in year 2011 and 2010, respectively. The period 1989–2011 was divided as: extremely wet year 2010, extremely dry year 2011 and the long time period 1989–2009 (see Tab. I).

Fig. 2 presents the spatial distribution of rainfall for all three periods. The inverse distance weighting method was used to spatially interpolate the raingauge-based records.

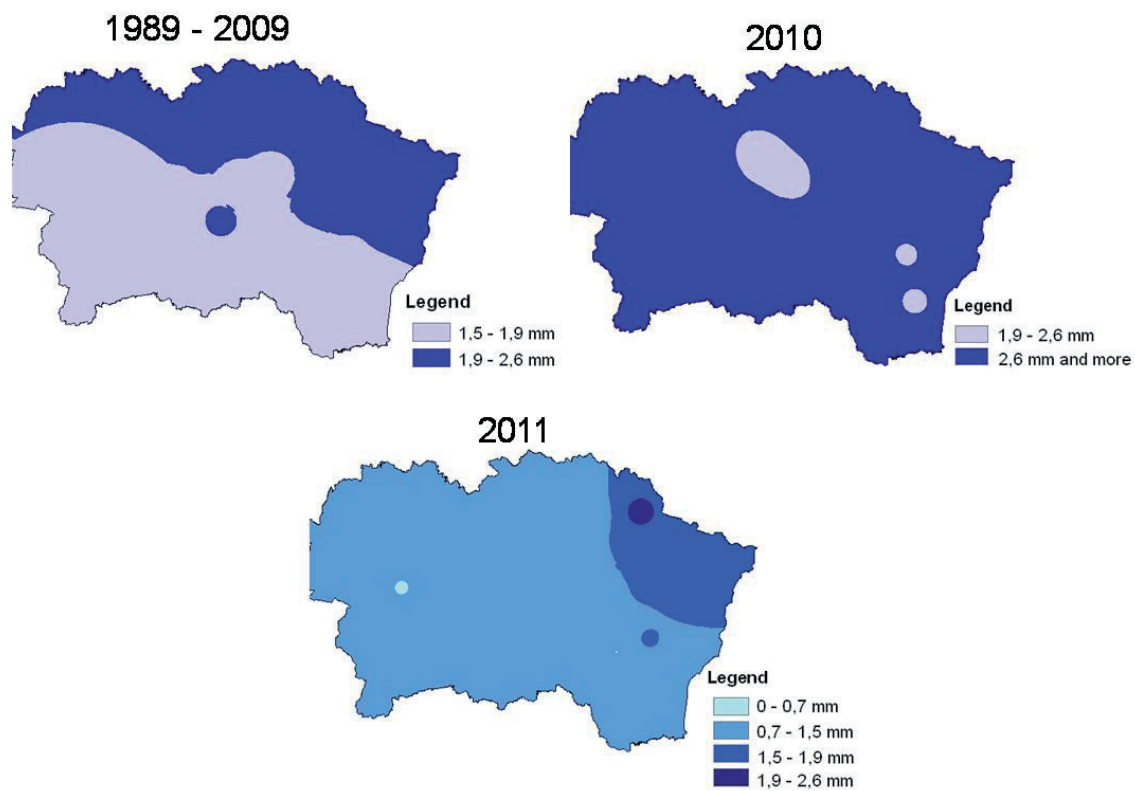
Analyses of physio-geographical characteristic

Physio-geographical characteristic for this study were selected due to their relevance for flood occurrence in the study area. Selected causative factors of floods are listed below:

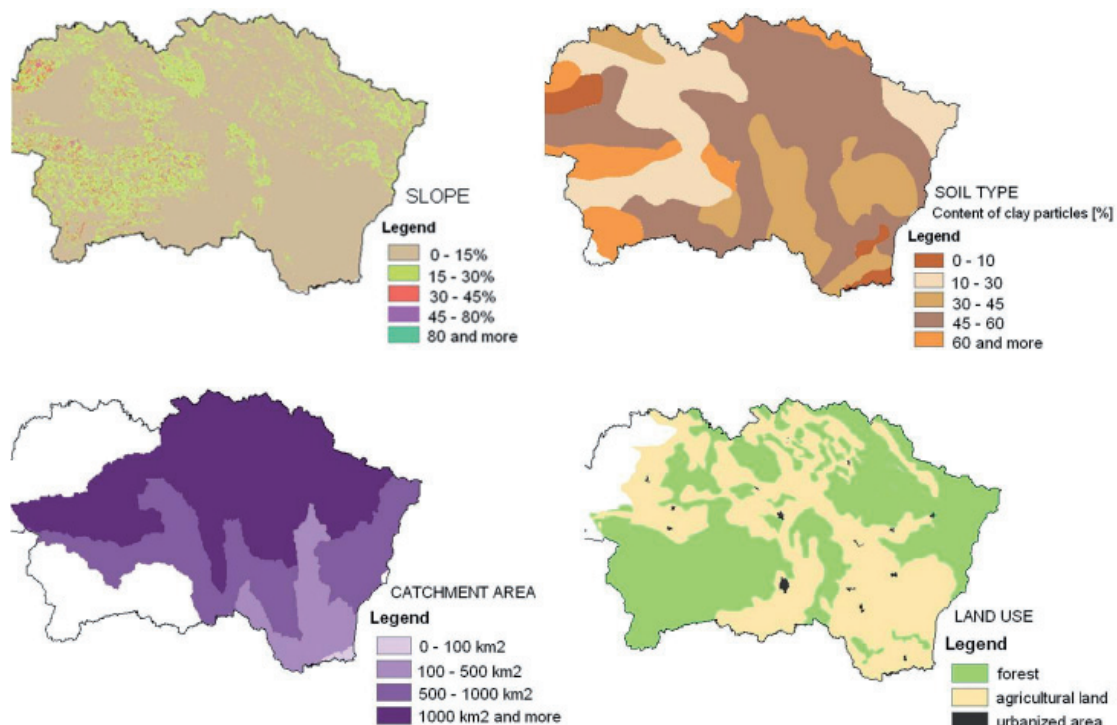
- Soil type
- Slope
- Land use
- Catchment area.

I: Rain gauge stations and their average daily rainfall for the 3 periods

ID	Station	Period		
		1989–2009	2010	2011
		average daily rainfall (mm)		
ST1	Streda nad Bodrogom	1.6	3.0	1.3
ST2	Horovce	1.8	2.7	0.7
ST3	Hanusovce	1.8	2.6	1.4
ST4	Bardejov	2.0	2.6	1.4
ST5	Stropkov	2.0	2.7	1.3
ST6	Svidnik	2.2	2.9	1.4
ST7	Izkovce	1.8	2.6	1.3
ST8	Velke Kapusany	1.8	2.6	1.3
ST9	Michalovce	1.9	2.5	1.5
ST10	Humenne	2.1	3.1	1.5
ST11	Snina	2.1	2.9	1.9
ST12	Krasny Brod	2.4	3.2	2.0
ST13	Kosicke Olsany	1.7	2.7	1.4
ST14	Presov	1.9	2.4	1.3
ST15	Jakubovany	1.9	2.5	1.2
ST16	Cana	1.8	2.7	1.3
ST17	Kysak	1.9	3	1.5
ST18	Spisske Vlasy	1.9	3	1
ST19	Spisska Nova Ves	1.8	2.8	0.7
average		1.9	2.8	1.3



2: Maps of daily rainfall distribution for the periods 1989–2009, 2010, and 2011



3: Maps of the selected causative factors

The corresponding maps are shown in Fig. 3. The soil data for the catchments were collected from the Soil Science and Conservation Research

Institute. Soil types in the catchments were detected and soil map was digitized. Slope has a dominant effect on the contribution of rainfall to stream flow.

It controls the duration of overland flow, infiltration and subsurface flow. The slope map was prepared from the Triangular Irregular Network (TIN) of the region. Slope in percentage was calculated using contour map. Land use was prepared using thematic map of the Slovak Republic (1:200 000). The map was digitized and the % area of each category was calculated. The catchment area map was also digitized and the size of each watershed was computed.

RESULTS

After digitizing and plotting the maps, the rank of each factor was given on the basis of its significance in causing floods. The rank of each factor is as follows:

- Daily rainfall (D) = 1
- Slope (S) = 2
- Soil type (ST) = 3
- Land use (L) = 4
- Catchment area (C) = 5.

The straight ranking was applied to these factors: “1” is the most important factor and “5” is the least important factor (Yahaya *et al.*, 2010; Meyer, 2007).

Each factor was divided into a number of classes and each class was weighted according to the estimated significance for causing flooding. The inverse ranking (the least important = 1, next least important = 2, etc.) was applied on sub factors division (see Tab. II).

The rank sum method was used to identify the flood risk index (RI) after assigning weights to each factor; this weight is an index of sensitivity.

Normalized weight to each main factors was assigned and normalization using the rank sum method and were calculated as (1) (Zeleňáková *et al.*, 2011):

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

where:

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

r_j is the rank position of the criterion.

Each criterion is weighted $n - r_j + 1$ and then normalized by the sum of weights, that is $\Sigma(n - r_k + 1)$. The normalized weight W_j of criterion j is calculated by (2) (Zeleňáková *et al.*, 2011):

$$W_j = n - r_j + 1 / \Sigma(n - r_k + 1). \quad (2)$$

Resulting weights are listed in Tab. III.

The total weight (score) for estimating the flood risk in particular zone is equal to the sum of each causative factor calculates as (3):

$$R = \Sigma(C_1 W_{1,i} + C_2 W_{2,i} + C_3 W_{3,i} + C_4 W_{4,i} + C_5 W_{5,i}) \quad (3)$$

where:

C_1, C_2, C_3, C_4, C_5 criterion,

$W_{1,i}, W_{2,i}, W_{3,i}, W_{4,i}, W_{5,i}$... normalized weight for each criterion.

Finally composite flood risk maps were created using weighted overlay analysis and raster calculator in ArcGIS 9.3 software.

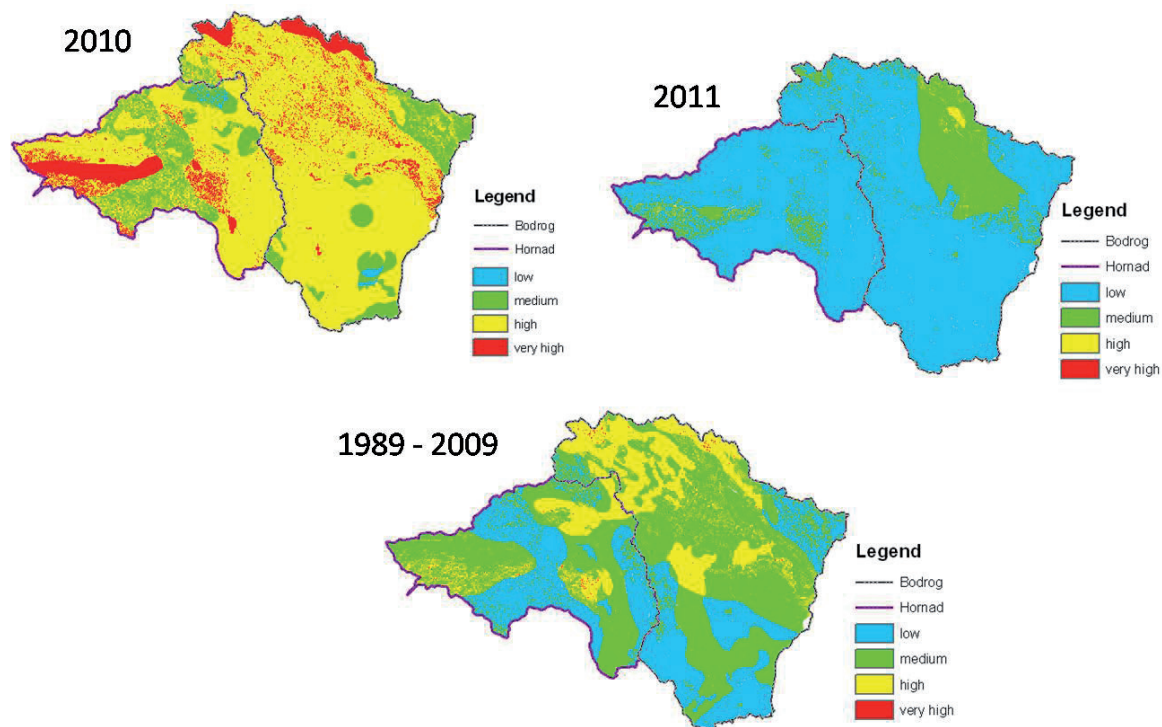
The values of risk index (RI) vary across the study area ranging for years 1989–2009: 1.732–3.866, for the extremely wet 2010: 2.199–4.265 and for the extremely dry 2011: 1.399–3.456. These values were

II: The significance of flooding causative sub factors

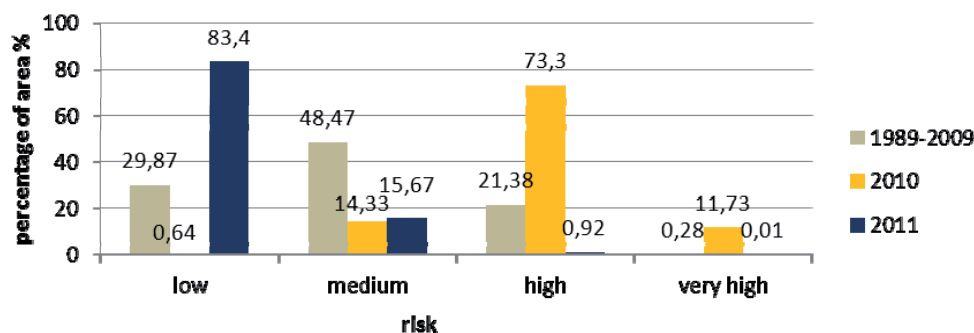
Class of sub factors	Factors				
	Daily rainfall (mm)	Slope (%)	Content of clay particles (%) (Soil type)	Land use (-)	Catchment area (km ²)
Sub factors					
1	0–0.7	0–15	0–10	forest	0–100
2	0.7–1.5	15–30	10–30	agricultural land	100–500
3	1.5–1.9	30–45	30–45	urbanized area	500–1000
4	1.9–2.6	45–80	45–60	-	1000 and more
5	2.6 and more	80 and more	60 and more	-	-

III: Resulting weights from calculation by the rank sum method

Criterion	Straight Rank	Weight (W)	Normalized Weight (W _j)	Weight (in %)
Rainfall	1	5	0.333	33.3
Slope	2	4	0.267	26.7
Soil type	3	3	0.200	20.0
Land use	4	2	0.134	13.4
Catchment area	5	1	0.066	6.60
SUM		15	1.00	100



4: Maps of flood risk for the periods 2010, 2011 and 1989-2009



5: Percentage of the area with flood risk in year 2010, 2011 and 1989-2009

divided into four classes: very high (3.3–4.3), high (2.8–3.3), medium (2.4–2.8) and low (1.6–2.8). The flood risk maps of Bodrog and Hornad catchment for three time period are shown in Fig. 4.

In order to observe the impact of rainfall on flood risk the percentage area of flood prone areas was computed (Fig. 5). Results show that for the year 2010 the percentage of flood prone area was 0.64% (low), 14.33% (medium), 73.30% (high) and 11.73% (very high); for the year 2011 it was 83.40% (low),

15.67% (medium), 0.92% (high) and 0.01% (very high); and for the period 1989–2009 it was 29.87% (low), 48.47% (medium), 21.38% (high) and 0.28% (very high).

Results show that rainfall distribution has a very high impact on flood occurrence. The comparisons showed that there was a significant change in the extent of daily rainfall in years 2010 and 2011 and so significant differences in percentage area of flood risk between 2010 and 2011.

SUMMARY

This paper presents work carried out in the Hornad and Bodrog catchment involving the use of GIS tools and runk sum methods to generate maps of flood vulnerable areas. Analysis of the flood risk in the area was based on the ranking method. The level of flood risk was divided in four classes (low, medium, high and very high).

This GIS-based approach allows spatial visualization and quantification of the results. In this study the rank sum method was used to calculate the weights of the factors that contribute to flood risk. The study is limited to environmental factors such as soil type, daily precipitation (for the years 1989–2009, 2010, and 2011), land use, catchment area and slope. The results of our study are three composite maps which compare the area percentage of flood risk zones in the periods 1989–2009, 2010, and 2011, and further assessing the impact of rainfall on flood generation. Rainfall intensities are of prime importance for flood generation in all catchment sizes and it has been shown that high discharges are produced as a result of basin morphometry and storm intensity (Pitlick, 1994).

The Hornad and Bodrog catchment shows extreme variability in terms of flood risk due to the effect of rainfall distribution. During the extremely wet year (2010) the area has a risk index about 100% greater compared to the extremely dry year (2011) and the period 1989–2009.

Created maps can offer a cost-effective solution for planning flood mitigation measures and preparedness in flood risk areas.

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