ГЛАСНИК Српског географског друштва 99(2) 1-16
BULLETIN OF THE SERBIAN GEOGRAPHICAL SOCIETY 2019

Original scientific paper

UDC: 556.166 (497.6 reka Ukrina)
https://doi.org/10.2298/GSGD1902001L

Received: August 28, 2019
Corrected: September 23, 2019
Accepted: October 3, 2019

Novica Lovrić*, Radislav Tošić*, Slavoljub Dragićević[1], Ivan Novković****

** University of Banja Luka, Faculty of Natural Sciences and Mathematics, Banja Luka, Bosnia and Herzegovina*
*** University of Belgrade, Faculty of Geography, Serbia*

ASSESSMENT OF TORRENTIAL FLOOD SUSCEPTIBILITY: CASE STUDY - UKRINA RIVER BASIN (B&H)

Abstract: Torrential floods are the most frequent natural catastrophic events in the Republic of Srpska (B&H). The main objective of this study is susceptibility assessment to torrential floods in Ukrina River Basin using Index Based Method (IBM) and Flash Flood Potential Method (FFPI), which operates entirely in a GIS environment. The definition and identification of influencing factors for torrential floods was the first step in the process of developing the Torrential Flood Susceptibility Model (TFSM). According to the results of these models, 54.00% and 40.86% of the Ukrina Basin area is in the categories of strong and very strong susceptibility to torrential floods. The second task was to identify the torrential basins and create the Register and the Cadastre of Torrential Basins in the Ukrina River Basin. After detailed field survey and analyses, 154 torrential basins have been identified, occupying 551.37 km^2 of the Ukrina Basin. According to the validation indicators of the Torrential Flood Susceptibility Model, 138 torrential basins are in the category of strong and very strong susceptibility according to Index Based Method, while 112 torrential basins are in the same category of susceptibility according to Flash Flood Potential Index Method, which are very good results of the validation. This paper presents the significant step towards better understanding of the phenomenon of torrential floods in the Republic of Srpska (B&H). The data presented in this paper are also significant to practical issues such as integral water management projects, spatial planning, sustainable land planning and protection of soil, forest ecosystems and environmental protection, sediment management, agriculture and other human activities.

Key words: torrential flood, flash flood potential index, index based method, Ukrina River Basin

---

[1] sasa@gef.bg.ac.rs (corresponding author)

Introduction

Torrential (flash) floods are one of the most devastating natural hazards that affect the lives of many human beings. Quantifying the extent and coverage of damage due to flooding is extremely difficult (Alcantara, 2002; Schmidt et al., 2006; Toya & Skidmore, 2007; Spalevic et al., 2017; Blöschl et al., 2019). If we consider the analyzed climate scenarios, by the end of the century we can expect higher air temperatures and more days with precipitation greater than 20 mm (IPCC, 2019). This can produce extreme flow rates and greater floods in the Ukrina River Basin than those recorded in the reference period of the 20th century. The data on the increase in the number of days with precipitation greater than 20 mm, which are often in practice classified in the group of torrential rains, indicate a need to analyze and observe all characteristics of torrential floods in the Ukrina River Basin. Bosnia and Herzegovina's institutions responsible for water do not have an official torrential river basin register. The river basins that have the characteristics of a torrential hydrological regime have been identified based on the field data, and various project documentation. Some torrential floods have been registered but unfortunately with incomplete information. It is possible to use the data of registered torrential floods where detailed information on the maximum flow rates, the intensity, and duration of rainfall, water level or an explanation for the torrential flood trigger is recorded. However, it should be borne in mind that the torrential floods in small torrential basins which are not inhabited and where there were no adverse human consequences are not registered. The lack of the above-mentioned information greatly complicates the understanding of the cause of torrential floods, development of a quantitative description of torrential floods in space and time, or the defining of the threshold of their occurrence. In this sense, most of the torrent basins in the Republic of Srpska (B&H) are not hydrologically studied and are poorly researched.

The most commonly used both globally and in our region, is the Flash Flood Potential Index (FFPI). This method was developed at the Colorado Basin River Forecast Centre (USA). Its main purpose is to supplement the conventional tools, such as Flash Flood Monitoring & Prediction System (FFMP). The Flash Flood Potential Index (FFPI) is determined by using GIS software tools through a statistical approach based on the principle of established correlations between the factors and the spatial distribution of drainage basins of the flash flood basin, or heuristic approach, indexing weighting factors, i.e. assigning a weight to individual factors which cause flash floods on the basis of empirical experience (Smith, 2003; Ristić et al., 2009; Prăvălie & Costache, 2014; Minea et al., 2016; Kostadinov et al., 2017; Novković et al., 2018).

The main objective of this study is assessment of the susceptibility to torrential floods in Ukrina River Basin using Index based Method and FFPI, which operates entirely in a GIS environment. This paper presents the significant step towards better understanding of the phenomenon of torrential floods as the most common natural hazard in the Republic of Srpska (B&H). The data presented in this paper are also significant to practical issues such as integral water management projects, spatial planning, sustainable land planning, protection of soil, forest ecosystems and environmental protection, sediment management, agriculture and other human activities.

Study area

The study area selected for the investigation is located in the north of the Republic of Srpska. The study area is 1,498.81 km^2, Ukrina River is 134.9 km long and flows from south to north (Fig. 1). The geographical location of study area indicates 44°35'09" N to 45°05'12" N, and 17°23'53" E to 18°07'53" E. The Ukrina River Basin spreads within boundaries of five municipalities: Brod, Derventa, Prnjavor, Teslić and Čelinac. According to the B&H population and household census of 2013, approximately 62,000 residents live in the Ukrina River Basin. The Ukrina River Basin belongs to the southern part of the Pannonian basin, located at the contact of two macro-regional units of the Pannonian and mountain ranges.

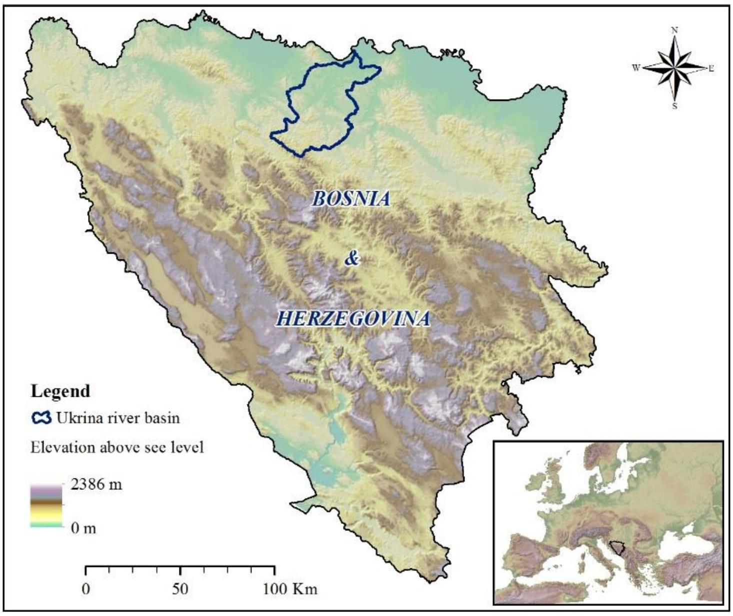

Fig. 1. Location of study area - Ukrina River Basin

Study area is characterized by complex geological features with the formations from Paleozoic, Mesozoic and Cenozoic. Paleozoic formations are connected to Motajica Mountain. Formations from Mesozoic are widely spread in the sedimentary, igneous and volcano-sedimentary facies.

Paleocene formations are composed of Paleocene-Eocene and Middle and Upper Eocene sediments. Neogene sediments occupy large areas in the Ukrina River Basin, correspond to Miocene and Pliocene age deposits, and are represented by low-lying and dispersed sediments created by erosion and denudation. Formations from Quaternary period are widespread in the river valleys in the forms of river terraces consisting of gravel and sand. Quaternary sediments occupy large areas in the Ukrina River Basin, in river valleys (Sofilj et al., 1985).

In terms of geomorphological characteristics of the basin, three smaller units can be distinguished. The first unit, the source part of the Ukrina River Basin, characterized by hilly relief with relatively wide valley sides. The second unit is the Neogene basin, characterized by the wide valley of the Ukrina River, as well as its valley sides and branches, and the third unit, where the Ukrina River crosses the wide alluvial plain of the Sava River. Climate is moderate continental with warm summers and wet winters. The annual precipitation in this area is 975 mm, and average temperature is 10.5°C, for period 1965–2010.

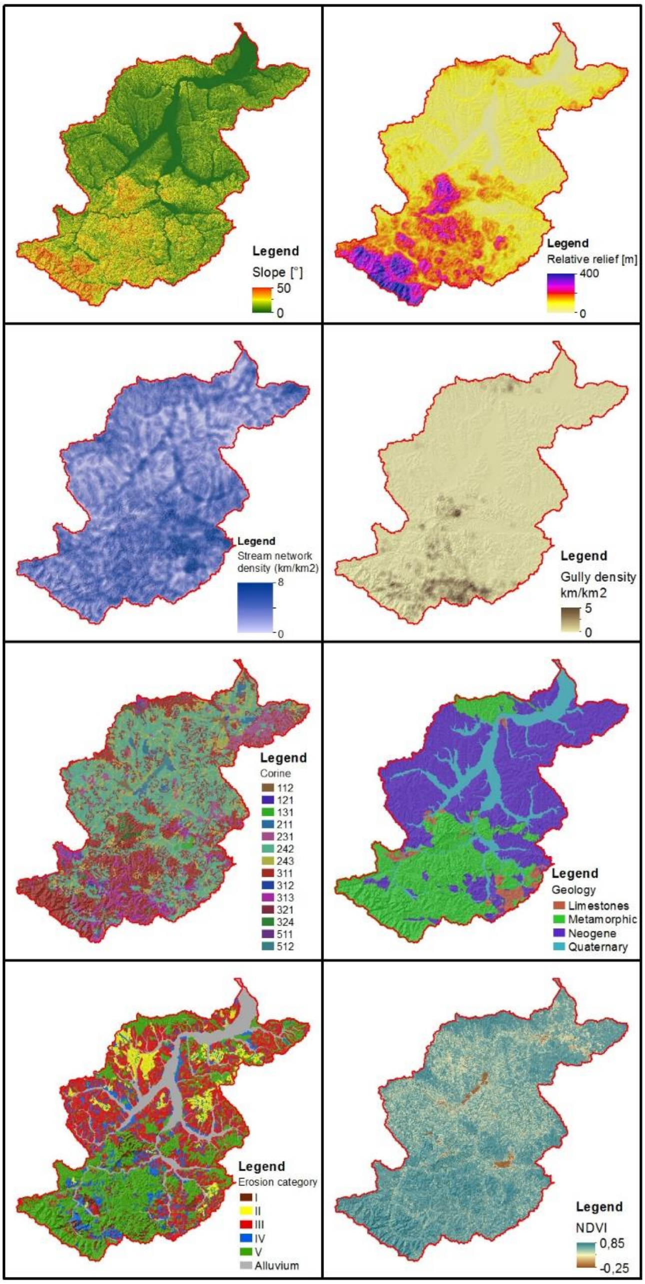

Fig. 2. Influence factors used for creating Torrential susceptibility models

Hydrographically, the catchment area of the Ukrina River is very developed with many tributaries, and the larger tributaries are the Vijaka, Lupljanica, Ilova and others. The average annual flow of the Ukrina River at the mouth is 19.8 m^3/s, while the maximum flow of the 100-year return period ($Q_{1/100}$) of the Ukrina River is 635.4 m^3/s (Tošić, 2006).

The following types of soil occur most commonly in the Ukrina River Basin: humus-silicate soil (rankers), eutric brown soil (eutric cambisol), distric brown soil (distric cambisol) and illimerized soil. Given the specific morphological characteristics of the area and the dominant soil types, the forests of sessile oak and common hornbeam dominate, with alternating beech forests, while the orographic elevations emphasize the communities of sessile oak, pine, fir and spruce fir. The areas under forests are mainly in the southern and hilly parts of the basin. The forests are in poor condition, degraded with a tendency to further decay. The coniferous to deciduous ratio is very uneven, close to 95% of forests are deciduous and only 5% are conifers. Land use data were obtained using a CORINE substrate (Land use/Land Cover 2012). Of the total surface area of the Ukrina Basin 611.59 km^2 is covered by forests, while 775.83 km^2 is agricultural land.

Methodology

Torrential (flash) flood susceptibility modeling (TFSM) is a fundamental, non-structural method implemented for sustainable land planning, protecting human lives, property etc. The main purpose of TFSM is to locate sites that are vulnerable to flash flooding in a particular area using a Geographic Information System (GIS) and the available topographic data. The general use of GIS-based torrential flooding assessments became possible for small catchments in the 1990s. GIS is always a useful tool for integrating multiple parameters of influence for torrential flood susceptibility mapping. On the other hand, in order to obtain accurate results, it is very important that all input factors retain spatial associations. Deterministic methods have been applied for flood susceptibility assessment over the years, such as multi-criteria evaluation, decision tree, analysis fuzzy theory, weight of evidence, logistic regression and others (Sahoo et al., 2006; Mukerji et al., 2009; Kia et al., 2012; Tehrany et al., 2013, 2014; Bajabaa et al., 2014; Zhang et al., 2015; Elkhrachy, 2015; Youssef et al., 2016; Tošić et al., 2018). These methods are widely used in natural hazards mapping. Several tools used by forecasters in assessing the potential occurrence of torrential flash floods have been developed worldwide (e.g. USA). The tools are used to upgrade Flash Flood Guidance (FFG), in terms of better understanding of the local physical-geographical conditions that contribute to the occurrence and development of flash floods.

The lack of data has determined a specific methodological approach to meet the goals set forth in this research, which relate to defining and identifying torrential basins in the Ukrina River Basin, and the development of the Torrential Flood Susceptibility Model (TFSM).

The field work was carried out to address the lack of relevant data on torrential basins and floods in the Ukrina River Basin. The field studies of torrential basins and streams in the Ukrina basin included: studying the basins and collecting data on factors that influence the formation of torrential floods; mapping erosion to define the source zones of sediments; studying sediment deposition zones; determination of hydraulic traces of flood flows formed during the passage of torrential flood waves; the frequency and extent of previous torrential flood waves; the type of torrential flood wave; the parameters of torrential flood wave (depth, width, hydraulic traces); causes of torrential flood wave (shower, long rainfall, sudden snow melt, etc.); the destructive force of the torrential flood wave (types of damage caused); identification of torrential basins, mapping with a GIS/GPS device; development of a Torrential Basins Cadastre.

The method used to determine susceptibility to the occurrence of torrential flood is Flash Flood Potential Index (FFPI). It was developed primarily because that torrential flood prediction, based on a survey of meteorological parameters, did not give adequate results and did not define connection between the occurrence of this disaster and certain physical-geographical characteristics of some territory. The structure and texture of the soil are characteristics that define water retention and infiltration. Slope and basin geometry determine the speed and concentration of runoff. Vegetation and structure of the canopy equalize the entering of the atmospheric water in the surface. Land use and urbanization in particular, have an important role in the infiltration of water, concentration and behavior of runoff. Together, these rather static qualities, provide information on the possibility of a torrential flood in a certain area (Smith, 2003). Of course, they are also subject to dynamic changes. For example, seasonal changes in the vegetation of deciduous forests significantly affect the possibility of the development of mentioned process, and forest fires, in addition to changes in the vegetation, adversely affect the soil, in which, due to the burning of organic matter infiltration power is reduced. The use of this method, as an evaluation methodology of the potential of flash-floods formation, has a special importance, because they represent actual issue in the contemporary society. The pragmatic result of the proposed index is in the spatial representation of the areas with a flash-flood risk, therefore, giving possibility to prevent the negative effects (Prăvălie & Costache, 2014). Calculation of FFPI is performed according to the formula (Smith, 2003):

$$FFPI = \frac{a_1 \cdot M + a_2 \cdot S + \ a_3 \cdot L + \ a_4 \cdot V}{\sum_{n=1}^{4} a_n}$$

Where M is slope index, S is soil type index, L is land use index, V is vegetation density index, and N is sum of weightings. Index values are within the range 1 to 10 (from least to most susceptible). As for weightings, soil type and land use are assigned value of 1. The vegetation density is the least important of the four parameters and the most susceptible to changes, so assigned value is 0.5, and surface slope is assigned a value of 2. This means that in this case the formula is:

$$FFPI = \frac{2M + S + \ L + \ 0.5V}{4.5}$$

The slope index is calculated in GIS, based on 20 m digital elevation model (DEM). At first slope is calculated, expressed in percentage, and then following formula is applied:

$$M = 10^{n/30}$$

Where n is slope in %. If n is greater or equal to 30%, then M value is always 10. Considering the fact, that there is no soil structure and texture database for investigated watershed, we used lithological type index calculation, certain lithological types are given values from 1 to 10, based on their characteristics which are significant for the emergence and development of torrential processes. Lithological type data are obtained by digitizing content from geological maps (scale 1:100,000). Land use index is calculated on the basis of CORINE Land Cover data (2012), where certain types of land cover were given values from 1 to 10, depending on the characteristics important for the emergence and development torrential processes. Vegetation density index is obtained by analysis of multispectral images from the satellite LANDSAT 8, and calculating NDVI (Normalized Difference Vegetation Index), which is calculated by formula:

$$NDVI = \frac{NIR - R}{NIR + R}$$

Where NIR is near infrared band value and R is red band value. Due to the fact that the vegetation density index is ranging from 1 to 10, and NDVI value is always between -1 and +1, the correlation between their values is designed, and the resulting formula is:

$$V = 10 \cdot \mathrm{e}^{-2{,}303 \cdot NDVI}, for\ NDVI > 0$$

$$V = NDVI + 1, for\ NDVI \leq 0$$

Then, based on the analysis of the obtained values of FFPI the classification of results on the four classes is made, according to the degree of susceptibility to torrential floods. The results indicate the possibility of a torrential flood in appropriate conditions. Will it really be so, depends on many factors, and for that reason it is only a predisposition or the susceptibility of territory for the occurrence and development of this natural disaster.

The definition and identification of adequate determination factors for torrential floods is the first step in the process of developing the Torrential Flood Susceptibility Model, i.e. the process of identifying certain areas and spaces which are differently susceptible to torrential floods (Tab. 1). Taking into account that physiographic parameters of a catchment have a large influence on time to peak and flood magnitude, we may assume that analysis of those parameters may be a valuable tool for the assessment of predisposition to torrent flood formation and identification of catchments more prone to torrent flood formation. Relief condition was characterized by the angle of the slope (S) and relative relief (RR), generated from the Digital Elevation Model (DEM), affects the timing of runoff and the infiltration process. The steeper the slope the quicker the flow response and the higher the peak flow. Hydrological conditions were characterized by the stream network density (SND) determined on the basis of the existing watercourses at the map scale of 1:25,000. This parameter is one of the most important characteristics for evaluating potential runoff. Higher stream density allows the landscape to drain more efficiently. Structure of land use/land cover influences on the runoff formation process, land use (LULC) determined on the basis of CORINE Land Cover (Coordination of Information on the Environment - EEA) supplemented with a digital orthophoto (DOF), erosion category (EC) determined by use of the Erosion Map of Ukrina River, lithological composition determined on the basis of geological maps (GM), density of gully (GD) determined on the basis of topographic maps, (Sofilj, 1985; Tošić et al., 2012; CLC, 2012).

Tab. 1. Established weight system and relative significance of various influence factors required for IBM method

Data layer	Weighting	Class	Rating value	Significance
Geology	0.35	Limestones	1	0.35
		Metamorphic rocks	4	1.40
		Neogene sediments	3	1.05
		Quaternary deposits	2	0.70
Slope (°)	0.20	0–5	1	0.20
		5–10	2	0.40
		10–15	3	0.60
		15–25	4	0.80
		>25	5	1.00
Relative relief (dH/km^2)	0.05	0–50	1	0.05
		50–100	2	0.10
		100–150	3	0.15
		150–250	4	0.20
		>250	5	0.25
Gully density (km/km^2)	0.09	0–0.2	1	0.09
		0.2–0.8	2	0.18
		0.8–1.4	3	0.27
		1.4–2.2	4	0.36
		>2.2	5	0.45
Stream network density (km/km^2)	0.05	0–1	1	0.05
		1–2	2	0.10
		2–3	3	0.15
		3–4	4	0.20
		>4	5	0.25
Land use/land cover	0.06	Cultivated land	4	0.24
		Urban area – built up	3	0.18
		Meadow and pastures	2	0.12
		Forest, transitional woodland - shrub	1	0.06
Erosion category	0.20	I	5	1.00
		II	4	0.80
		III	3	0.60
		IV	2	0.40
		V	1	0.20

The IBM method uses a simple ranking and rating technique for torrential flood susceptibility zonation. The first step in this method is to select influence factors in the study area. Each influence factor is then considered as a parameter map. The relative importance of each parameter map for occurrence of torrential flood is evaluated according to subjective expert's knowledge. On the basis of comparisons of different parameters, weight values are assigned to each parameter map. Subsequently, each parameter map is classified into several significant classes based on their relative influence on torrential flood, and rating values are assigned to each class depending on their influence. The rating values are also fixed according to expert opinions and estimates.

Finally, integration of the various factors and classes into a single torrential flood susceptibility index (TFSI) is achieved by a procedure based on the weighted linear sum (Voogd, 1983):

$$TFSI = \Sigma\,(Wj \cdot Wij)$$

In which TFSI is the torrential flood susceptibility index, W_j is the weight value of parameter j, w_{ij} is the rating value or weight value of class i in parameter j, and n is the number of parameters. All TFSI values were then separated into four classes using a natural break algorithm to present four categories (low, moderate, strong, and very strong) of the torrential flood susceptibility zone (TFSZ). Similar techniques can be found in many studies (Foumelis et al. 2004; Wati et al. 2010; Tošić et al., 2014). The collection and preparation of the data of the above specified factors used ArcGIS 10.4 software. All data prepared for the analysis have vector data format. They were reclassified depending on the type of data and histogram distribution of the analysed data.

Results and Discussion

Torrential floods are one of the most destructive natural disasters. According to available data (Barredo, 2007), between 1950 and 2006 almost 40% of flood events in Europe were torrential floods. The increase in precipitation at continental and global levels, in particular the occurrence of extreme (intensive) precipitation and the increase in the number of days with rainfall over 20 mm, has resulted in an increased number of torrential floods. Hydrometeorological data and historical flood information are most often available only for larger river basins, while smaller basins are very often without monitoring and historical data on flood events. Given their role in the formation of runoff and in determining the flood risk of a watercourse, they are increasingly subject to hydrological analysis. Intensive rainfall is a necessary but not a sufficient condition for the formation of a torrential flood. Because of this, the other conditions necessary to form a torrential flood in the basin were analysed. As already mentioned, the first attempt to analyse the potential for torrential flood was by Greg Smith (2003). Through the analysis of several influencing factors, his Torrential Flood Potential Index showed the potential of a certain area of a basin to develop torrential flooding. The selection of the parameters of the torrential flood susceptibility model in the Ukrina River Basin was based on the following criteria: that they were well documented in the literature as a factor with significant impact on the runoff and formation of torrential floods; that they allow the evaluation of the predisposition of the basin to torrential floods; that there is sufficient data to define those parameters and that they are of adequate spatial resolution; that they respect the specificities of geological and geomorphologic material, hydrography and vegetation characteristics of the Ukrina River Basin. Therefore, the development of the Torrential Flood Susceptibility Model for the Ukrina River Basin enabled identification of parts of the basin that have different characteristics of susceptibility to torrential floods.

The definition and identification of influencing factors for torrential floods is the first step in the process of developing the Torrential Flood Susceptibility Model (TFSM). In this study, as mentioned before, seven influencing factors were considered: geology, the angle of the slope, relative relief, gully density, stream network density, land use/land cover, and erosion category. After defining influencing factors, the Index based Method

(IBM) and Flash Flood Potential Method (FFPI) were used for generated Torrential Flood Susceptibility Models (Fig. 2). According to the Index based Method (IBM) 54.00% of the basin is within strong and very strong susceptibility category, while according to the FFPI method 40.86% of the basin is within strong and very strong susceptibility category (Tab. 2).

Tab. 2. The percentage share of torrential flood susceptibility categories in the Ukrina River Basin

Susceptibility category	**Index based method**		**Flash flood potential index**	
	Basin surface area		Basin surface area	
	[km²]	[%]	[km²]	[%]
Low	293.11	19.56	289.73	19.33
Medium	396.27	26.44	596.74	39.81
Strong	567.31	37.85	467.71	31.21
Very strong	242.12	16.15	144.63	9.65

The values of the strong and very strong sensitivity categories are closely related to the physical and geographical conditions in the basin, i.e. almost 70% of the basin is made of erosion-resistant rocks, while forests (mainly in the southern and higher parts of the basin - the Velika and Mala Ukrina Basins) are in poor condition, degraded and heavily thinned with a tendency to further deteriorate. It is particularly important to emphasize that there is a large presence of deciduous forests, and that about 95% of forests are deciduous, and only 5% are conifers. In the Ukrina River Basin, which is dominated by categories of strong and very strong erosion sensitivity (rinses and subsidence), surface erosion has taken a wider scale, while line erosion is expressed on the valley sides of large falls. Surface erosion is particularly intense on the surface of corneal diabase, which are easily decomposed, crushed, shredded, and put in a great deal of material transported during torrential floods. In many places in the basin (especially in the southern parts of the basin) where vegetation is very scarce, rills, water rails and ditches occur. The rills in watersheds can be seen on certain agricultural slopes, which are on higher slopes, while deep gullies are present in thinned and degraded forests. So, surface erosion is strongest in southern aspects, on bare terrain and often near settlements. Linear erosion is present in almost all torrential catchments, but to a lesser extent than surface erosion.

The values of medium and low sensitivity correspond to the area of the Prnjavor Neogene basin (the central parts of the basin) and the basin from Derventa to the estuary, which is dominated by Neogene sediments and Quaternary deposits, where terrain falls are very mild, and where erosion processes are characterized by middle and of lower intensity. Given the dominant erosion processes, most of the watercourses in the Ukrina River Basin belong to mixed types of torrential watercourses with a strong emphasis on surface erosion – sheet erosion.

The torrential watercourses in the mountains of the Ukrina River Basin are characterized by large gradients, large amounts of precipitation, impermeable rocks and sparse vegetation. Unlike the basins where the torrential flood regime is a consequence of land degradation and plant cover and where the erosion is surface and linear, in this high-altitude zone the erosion is concentrated only on river channels (dominant undermining). However, since the torrential floods in these basins do not directly threaten settlements and do not cause enormous damage to infrastructure, the monitoring and identification of torrential floods and other processes is virtually non-existent.

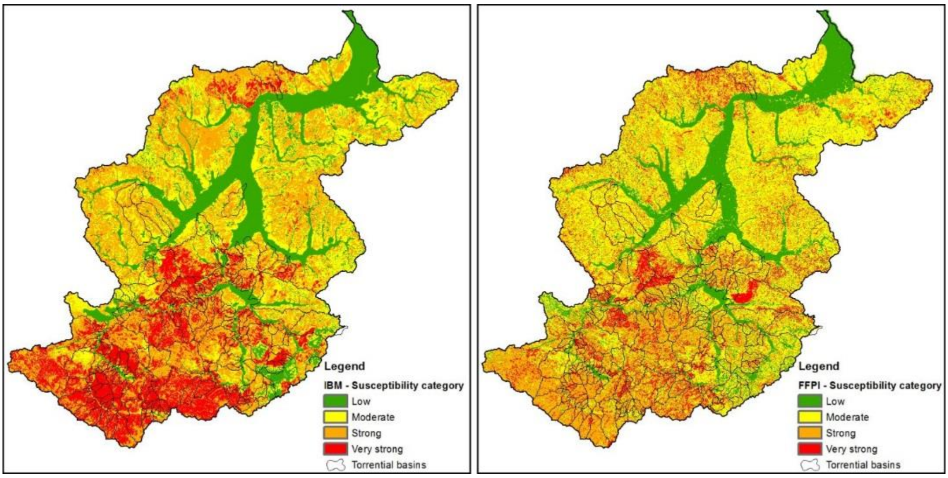

Fig. 3. Torrential susceptibility models based on the Index-Based Method (IBM) and Flash Flood Potential Index (FFPI) Method

The erosion material is present in almost all watercourses and is predominantly small. Significant amounts of sediment were deposited in the river beds of the Velika and Mala Ukrina, as well as in the main course of the Ukrina River, which caused the uplift and mantle formation and frequent flooding of the inundation area (Fig. 3).

Fig. 4. Riverbeds of the Velika and Mala Ukrina River

Through the detailed field survey, 154 torrential basins were identified in the Ukrina basin. The total surface area of the torrential basins is 551.37 km^2. The torrential basins are concentrated in the upper, southern parts of the basin, and along the Velika and Mala Ukrina River. In the Ukrina River Basin, 551.37 km^2 are made up of torrential catchments or 36.75% of the total catchment area, while 1,292.97 km^2 of the catchment area are affected by erosion and erosion processes (Fig. 2).

Susceptibility model can be validated through comparison with the data obtained from a terrain survey. The quality of the torrential susceptibility method can be ascertained using the same torrent basin data used for the estimate, or by using independent torrent basin information that was not used for the assessment (Guzzeti et al., 2006; Tošić et al., 2014). In order to select the final model of torrent susceptibility, a cross validation technique was used to compare known torrent basin location data with the torrent susceptibility model. In the study, we considered torrent basin prediction to be good if at least part of the torrent basin is in a strong or very strong susceptibility zone, and torrent susceptibility prediction to be bad if at least part of the torrent basin is in a low or moderate susceptibility zone. Furthermore, using the IBM method 78.11% area of the torrent basin observed belong to the strong and very strong susceptibility class, whereas using the FFPI method 60.45% area of the torrent basin observed belong to the strong and very strong susceptibility class (Tab. 3). Compared to the number of river basins examined, according to the IBM method, 138 is in the strong and very strong susceptibility class, and 16 in the low and moderate susceptibility class. Using Flash Flood Potential Index, 112 is in the strong and very strong susceptibility class and 16 in the low and moderate susceptibility class.

Tab. 3. Summary of the prediction accuracy of the final torrential susceptibility models

Susceptibility category	Index Based Method				Flash Flood Potential Index			
	Number of torrential basins observed		Area of torrential basins observed		Number of torrential basins observed		Area of torrential basins observed	
	Number	[%]	[km²]	[%]	Number	[%]	[km²]	[%]
Good	138	89.61	430.65	78.11	112	72.73	333.31	60.45
Bad	16	10.39	120.72	21.89	42	27.27	218.06	39.55
Total	154	100.00	551.37	100.00	154	100.00	551.37	100.00

The validation of our susceptibility assessment suggests that the application of a relatively simple methodology like IBM which is basically related to the subjectivity of the analysis, especially in defining weight coefficients for individual influenza factors gives good results as well as the application of the FFPI method. Regarding the reliability of this proposed susceptibility models, following the spatial analysis via GIS systems, but also following the direct observations on the field, we consider that these models (Index Based Method and Flash Flood Potential Index Method) succeed in delimiting the areas with strong susceptibility in the formation of torrent floods. The preparation of torrential susceptibility models are of great interest for preliminary hazard studies. Small scale regional surveys are low cost techniques by which large areas can be covered in a relatively short time permitting an economical and rapid hazard assessment. The improvement of such susceptibility models is possible with the definition of more objective weighting system. Examination of individual processes and factors controlling the occurrence of torrential flood by means of statistical analysis (e.g. multivariate, bivariate) provides more realistic results. The criticism relating the subjectivity of qualitative methodologies is not necessarily bad, considering that it is based on the opinion of the expert. Taking into account statistical techniques as complementary information to rank factors and not as a basis to establish the weighting system, allowed the reconsideration in some cases of the weights given.

Conclusion

The torrential basins in Bosnia and Herzegovina have not been hydrologically studied and are poorly researched. Measurements of rainfall, water level and discharge either relate to short periods or are non-existent. In forecasting of torrential floods, it is necessary to know not only the weather but also the geological-geomorphological features, erosion, soil and other conditions in the basin, which predispose the location and development of torrential floods. The hydrological susceptibility of a basin is conditioned by geological structure, relief (gradient, slope curvature, roughness, etc.), drainage network density, land use, vegetation density, state of erosion processes, and other factors that influence the runoff and create conditions for occurrence of torrential floods. The identification of torrential river basins and the formation of the torrential flood susceptibility model for the Ukrina basin commenced because of the lack of a torrential river basin register in B&H as a primary step in development of torrential floods risk maps. The basic characteristics of torrential watercourses in the Ukrina Basin are determined by the specific dynamics of torrents. If we look at the characteristics of this phenomenon, we will see that all torrential streams in the Ukrina Basin have specific geomorphological characteristics, that is, pronounced vertical relief dissection, great valley side and stream gradients, significant intensity of erosion processes (surface and linear), while the lower parts of the course are in alluvial planes where torrential watercourses flow into a larger river. In this study, the first task was to create the Torrential Floods Susceptibility Model for the Ukrina River Basin using Index Based Model and Flash Flood Potential Index Method. According to the results of these models, 54.00% and 40.86% of the Ukrina River Basin area are in the categories of strong and very strong susceptibility to torrential floods. The second task was to identify the torrential basins, that is, to create the Register and the Cadastre of Torrential Basins in the Ukrina River Basin. After detailed field reconnaissance and analyses, 154 torrential basins have been identified, occupying 551.37 km^2 of the Ukrina River Basin. According to the validation indicators of the Torrential Flood Susceptibility Model, 138 torrential basins are in the category of strong and very strong susceptibility according to the Index Based Method, while 112 torrential basins are in the same category of susceptibility to the Flash Flood Potential Index Method, which are very good results of the validation.

The used methodology based on IBM and FFPI method and used influence factors, show good results in determination of the area with strong and very strong susceptibility to torrential floods into the Ukrina basin. Its general conclusion is that the used methodological approach represents a good base for future research, and it has potential for the practical use and should be tested in other river basin in the Republic of Srpska/Bosnia and Herzegovina.

Acknowledgments

The research presented in this paper was performed as a part of the project "Mapping of Torrential Basins and Modelling of Torrential Susceptibility in the Ukrina River Basin" (Number: 19/6-010/14.3-16/18) funded by the Ministry for Scientific and Technological Development, Higher Education and Information Society of the Republic of Srpska.

References

Alcantara, A.I. (2002). Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries. *Geomorphology*, 47(2-4), 107-124.

Bajabaa, S., Masoud, M. & Al-Amri, N. (2014). Flash flood hazard mapping based on quantitative hydrology geomorphology and GIS techniques (case study of Wadi Al-Lith, Saudi Arabia). *Arabian Journal of Geosciences*, 7(6), 2469-2481.

Barredo, J.I. (2007). Major Flood Disasters in Europe: 1950-2005. *Natural Hazards*, 42, 125-148.

Blöschl, G., Hall, J., Viglione, A., Perdigão, R.A.P., Parajka, J., Merz, B., Lun, D., Arheimer, B., Aronica, G.T., Bilibashi, A., Boháč, M., Bonacci, O., Borga, M., Čanjevac, I., Castellarin, A., Chirico, G.B., Claps, P., Frolova, N., Ganora, D., Gorbachova, L., Gül, A., Hannaford, J., Harrigan, S., Kireeva, M., Kiss, A., Kjeldsen, T.R., Kohnová, S., Koskela, J.J., Ledvinka, O., Macdonald, N., Mavrova-Guirguinova, M., Mediero, L., Merz, R., Molnar, P., Montanari, A., Murphy, C., Osuch, M., Ovcharuk, V., Radevski, I., Salinas, J.L., Sauquet, E., Šraj, M., Szolgay, J., Volpi, E., Wilson, D., Zaimi, K. & Živković, N. (2019). Changing climate both increases and decreases European river floods. *Nature*, 573, 108-111.

CLC (2006). Technical Guidelines, 2007. EEA Technical report No 17/2007. Copenhagen: European Environment Agency, 1-65.

Elkhrachy, I. (2015). Flash Flood Hazard Mapping Using Satellite Images and GIS Tools: A case study of Najran City, Kingdom of Saudi Arabia (KSA). *The Egyptian Journal of Remote Sensing and Space Science*, 18(2), 261-278.

Foumelis, M., Lekkas, E. & Parcharidis, I. (2004). Landslide susceptibility mapping by GIS-based qualitative weighting procedure in Corinth area. *Bulletin of 10th International Congress of the Geological Society* 36-2. Thessalloniki

Guzzetti, F., Reichenbach, P., Ardizzone, F., Cardinali, M. & Galli, M. (2006). Estimating the quality of landslide susceptibility models. *Geomorphology*, 81(1-2), 166-184.

IPCC (2019). Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems. The Intergovernmental Panel on Climate Change, 1-41.

Kia, M.B., Pirasteh, S., Pradhan, B., Mahmud, A.R., Sulaiman, W.N.A. & Moradi, A. (2012). An artificial neural network model for flood simulation using GIS: Johor River Basin, Malaysia. *Environmental Earth Sciences*, 67(1), 251-264.

Kostadinov, S., Dragićević, S., Stefanović, T., Novković, I. & Petrović, A. (2017). Torrential flood prevention in the Kolubara River Basin. *Journal of Mountain Science*, 14(11), 2230-2245.

Minea, G., Iliescu, M. & Dedu, F. (2016). Temporal rainfall properties at events scale in the Curvature Subcarpathians (Romania). *Forum geografic*, 15 (Supplementary Issue), 115-123.

Mukerji, A., Chatterjee, C. & Raghuwanshi, N.S. (2009). Flood forecasting using ann, neuro-fuzzy, and neuro-ga models. *Journal of Hydrologic Engineering*, 14, 647-652.

Novković, I., Dragićević, S., Živković, N., Tošić, R. & Čvorović, Z. (2018). Vulnerability assessment of the Jošanička River Basin to torrential floods and forest fires. *Advances in GeoEcology*, 45 - Soil and water resources protection in the changing environment. CATENA, 65-48.

Prăvălie, R. & Costache, R. (2014). The analysis of the susceptibility of the flash-floods' genesis in the area of the hydrographical basin of Bâsca Chiojdului river. *Forum geografic*, 13(1), 39-49.

Ristić, R., Radić, B. & Vasiljević, N. (2009). Karakteristike velikih voda na bujičnim slivovima u Srbiji. *Glasnik Srpskog geografskog drustva*, 89(4), 161-189.

Sahoo, G.B., Ray, C. & De Carlo, E.H. (2006). Use of neural network to predict flash flood and attendant water qualities of a mountainous stream on Oahu, Hawaii. *Journal of Hydrology*, 327(3-4), 525-538.

Schmidt, T.P., Greiving, S., Kallio, H., Fleischhauer, M. & Jarva, J. (2006). Economic risk maps of floods and earthquakes for European regions. *Quaternary International*, 150(1), 103-112.

Smith, G. (2003). *Flash Flood Potential: Determining the Hydrologic Response of FFMP Basins to Heavy Rain by Analyzing Their Physiographic Characteristics*. Salt Lake City: NWS Colorado Basin River Forecast Center

Sofilj, J., Marinković, R., Pamić, J. & Đorđević, D. (1985). *Tumač za list Derventa L 33–120*, Sarajevo: RO Geoinžinjering

Spalevic, V., Lakicevic, M., Radanovic, D., Billi, P., Barovic, G., Vujacic, D., Sestras, P., & Khaledi Darvishan, A. (2017). Ecological-Economic (Eco-Eco) Modelling in the River Basins of Mountainous Regions: Impact of Land Cover Changes on Sediment Yield in the Velicka Rijeka, Montenegro. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 45(2), 602-610.

Tehrany, M.S., Pradhan, B. & Jebur, M.N. (2013). Spatial prediction of flood susceptible areas using rule based decision tree (dt) and a novel ensemble bivariate and multivariate statistical models in GIS. *Journal of Hydrology*, 504, 69-79.

Tehrany, M.S., Pradhan, B. & Jebur, M.N. (2014). Flood susceptibility mapping using a novel ensemble weights-of-evidence and support vector machine models in GIS. *Journal of Hydrology*, 512, 332-343.

Tošić, R. (2006). Erozija u slivu Ukrine. Banja Luka: Geografsko društvo Republike Srpske, *Posebna izdanja* knjiga 12.

Tošić, R., Dragićević, S. & Lovrić, N. (2012). Assessment of soil erosion and sediment yield changes using erosion potential method - Case study: Republic of Srpska – BiH. *Carpathian Journal of Earth and Environmental Sciences*, 7(4), 147-154.

Tošić, R., Dragićević, S., Zorn, M. & Lovrić, N. (2014). Landslide susceptibility zonation: A case study from Banja Luka Municipality (Bosnia and Herzegovina). *Acta geographica Slovenica*, 54(1), 189-202.

Tošić, R., Lovrić, N., Dragićević, S. & Manojlović, S. (2018). Assessment of torrential flood susceptibility using GIS matrix method: case study - Vrbas River Basin (B&H), *Carpathian Journal of Earth and Environmental Sciences*, 13(2), 369-382.

Toya, H. & Skidmore, M. (2007). Economic development and the impacts of natural disasters. *Economics Letters*, 94(1), 20-25.

Voogd, H. (1983). *Multi-criteria Evaluation for Urban and Regional Planning*. Delft: Delftsche Uitgevers Maatschappij

Wati, S. E., Hastuti T., Widjojo, S. & Pinem, F. (2010). Landslide susceptibility mapping with heuristic approach in mountainous area: A case study in Tawangmangu sub district Central Java, Indonesia. *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Science* 38-8. Kyoto

Youssef, A.M., Pradhan, B. & Sefry, S.A. (2016). Flash flood susceptibility assessment in Jeddah City (Kingdom of Saudi Arabia) using bivariate and multivariate statistical models. *Environmental Earth Sciences*, 75(1), 1-16.

Zhang, D.W., Quan, J., Zhang, H.B., Wang, F., Wang, H. & He, X.Y. (2015). Flash flood hazard mapping: A pilot case study in Xiapu River Basin, China. *Water Science and Engineering*, 8(3), 195-204.

Новица Ловрић[*], **Радислав Тошић**[*], **Славољуб Драгићевић**[**], **Иван Новковић**[**]

[*] *Универзитет у Бањој Луци, ПМФ, Бања Лука, Босна и Херцеговина*
[**] *Универзитет у Београду, Географски факултет, Србија*

ПРОЦЈЕНА ПОДЛОЖНОСТИ БУЈУЧНИМ ПОПЛАВАМА: СТУДИЈА СЛУЧАЈА – СЛИВ РИЈЕКЕ УКРИНЕ (БиХ)

Резиме: Бујичне поплаве су једне од најчешћих природних катастрофа које су заступљене у Републици Српској, односно у Босни и Херцеговини. Главни циљ овог истраживања је била процјена подложности одређених простора на појаву и развој бујичних поплава у сливу ријеке Укрине. У раду су коришћене Индексно базирана метода (IBM) и "Flash Flood" потенцијал метода (FFPI), које се у потпуности спроводе у ГИС окружењу.

Први корак у изради модела подложности на појаву и развој бујичних поплава (TFSM) био је дефинисање и идентификовање фактора који утичу на њихово појављивање. На основу добијених резултата обе коришћене методе, око 54% (IBM), односно 41% (FFPI) површине слива ријеке Укрине спада у категорије јаке и веома јаке подложности на појаву и развој бујичних поплава (сливова). Други важан задатак је био идентификовање бујичних водотока и њима припадајућих сливова и креирање регистра и катастра бујичних водотока у сливу ријеке Укрине. Након детаљно спроведених теренских истраживања и анализе прикупљених података, издвојено је 154 бујичних сливова који се простиру на површини од 551,37 km^2, што чини 36,79% слива ријеке Укрине. Према показатељима валидације добијених модела подложности на појаву и развој бујичних поплава, 138 (90%) бујичних сливова спада у категорију јаке и веома јаке осетљивости према IBM методи, док је према FFPI методи 112 (73%) бујичних сливова у истој категорији.

Овај рад представља значајан искорак ка бољем разумијевању настанка бујичних поплава у Републици Српској (Босни и Херцеговини). Резултати представљени у овом раду веома су значајни за многа практична питања, попут пројеката интегралног управљања водним ресурсима, просторног планирања, одрживог планирања коришћења земљишта и заштите тла, шумских екосистема и заштите животне средине, управљања ријечним наносом, пољопривредне производње и других људских активности.