Challenges of Modern Geomorphology

APPLICATION OF GIS IN THE ANALYSIS OF LANDSLIDE AND FLASH FLOOD VULNERABILITY ON THE EXAMPLE OF LUŽNICA RIVER BASIN

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Abstract

The application of GIS enables easier and more efficient spatial analysis, modelling of phenomena and processes, as well as predicting future events, and is especially important when investigating processes that degrade environment and endanger humans, other living beings and material goods. Landslides and flash floods are among the natural disasters that cause enormous consequences and often cause human casualties in the territory of the Republic of Serbia. In spite of this fact, for the most part of its territory vulnerability assessment zoning to these disasters was not carried out. The basin of Lužnica River, the right tributary of Vlasina River, is located in the southeast of Serbia, in one of the poorest parts of Serbia. The occurrence of the aforementioned disasters would further burden local communities, which is why a vulnerability analysis in order to reduce the risk is necessary. Using GIS, landslide and flash flood susceptibility zoning was carried out, and based on that, the vulnerability of settlements and road infrastructure was then analyzed. Very high landslide susceptibility was determined on 23.5% of the total basin area, while high landslide susceptibility have share of 20.5%. About 47.4% of the Lužnica River basin territory belongs to the classes of very high and high flash flood susceptibility. Territories of 19 settlements were determined to be of very high or high landslide vulnerability, and it is similar in the case of flash flood vulnerability. Almost 44% of total state roads length is in the very high and high landslide susceptibility classes, and almost all intersections between rivers and roads are considered to be in the class of very high and high flash flood vulnerability.

Keywords: GIS, Lužnica River, Landslide Susceptibility Index (LSI), Flash Flood Potential Index (FFPI), Probability Method (PM)

INTRODUCTION

Landslides and flash floods are the most significant natural hazards within the territory of the Republic Serbia. About 25% of its territory is affected by landslide process (Dragićević et al., 2011), and there are more than 12,000 torrential watercourses (Kostadinov, 2007). Even in recent past, this natural disasters have very often, directly and indirectly affected the environment, population, material and non-material goods. One of the major problems for natural disaster management in Serbia represents the fact that there is no landslide and torrential watercourses cadasters for the entire territory of the Republic of Serbia. In order to reduce risk from this disasters, and to manage hazard and risk in an adequate way, it is very important to allocate zones with a different degree of landslide and flash flood susceptibility and vulnerability. Both processes largely depend

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on natural conditions that are landslide-related and flood-related factors. GIS based analysis of those factors is very important and inevitable part of landslide and flash flood susceptibility assessment, which should mandatory be part of all spatial and urban plans, as well as other planning documents, from the state level to the level of local governments. It should also be part of river basin management, as is the case with the study area of this research.

The Vlasina basin is known for extreme torrential floods, and one of the most devastating occurred on the Vlasina River, on June 26, 1988. The rainfall in certain places in the basin reached up to 220 mm in 4 hours (Gavrilovic et al., 2004), when a third of the average annual amount of precipitation fell on the basin. This caused the formation of a torrent of catastrophic proportions, which carried large masses of surface sediments. The debris made congestion on all profiles of the bridges, which caused a pronounced slowdown in front of them. The flood wave destroyed about 500 houses, 80 km of regional roads, 32 bridges, a dam, a shopping center and a bus station in Vlasotince. (Dragicevic and Filipovic, 2016).

The paper represents a significant step towards for a better understanding of unfavorable natural conditions in the Luznica River Basin, and the obtained results are significant for numerous human activities in the study area, such as environmental protection, sustainable management of agricultural plots and road infrastructure, etc.

MATERIAL AND METHODS

Study area

The Lužnica River is the right tributary of Vlasina River, which is the right tributary of Južna Morava river. Its basin is located in the southeastern Serbia, on the area of 323.94 square kilometers. The highest point of basin has the altitude of 1406 m a.s.l., and lowest 305 m a.s.l., with an average basin altitude of 713 meters.

The territory of Lužnica River basin belongs to the municipalities of Babušnica, Vlasotince, Bela Palanka and Pirot. According to the census of 2011, it had a population of about 9,700 inhabitants, with a population density of about 30 inhabitant per km^2. It is located in one of the poorest parts of Serbia, with very big depopulation problem.

The occurrence of the landslides and flash floods would further burden local communities, which is why a vulnerability analysis in order to reduce the risk is necessary. Previous research, maps and terrain research determined that there are active and inactive landslides in Lužnica River basin that cover area of 49.45 km2, which is 15.24% of total basin area. Also, there were numerous flash flood occurrences in the past.

Methods

First step in determining landslide vulnerability, hazard and risk is landslide susceptibility zonation. For the landslide susceptibility zonation of the Lužnica River basin Probability method (PM) is used. It is based on the presumption that landslide occurrence is determined by landslide-related factors, and relationship between landslides occurring in an area and the landslide-related factors is expressed as a frequency ratio that represents the quantitative relationship between landslide occurrences and different causative parameters (Lee & Pradhan, 2006). The frequency ratio is defined in following formula:

$$W_{ij} = (A_{ij}' \cdot (A - A'))/(A' \cdot (A_{ij} - A_{ij}'))$$

Where: W_{ij} – the weight of class i in parameter j; A_{ij}' – landslide area in a class i of parameter j; A_{ij} – area of a class i of parameter j; A' – total landslide area in the entire study area; A – total study area. The greater the ratio above unity, the stronger the relationship between landslide occurrence and the given factor's attribute (Lee & Pradhan, 2006).

The application of the PM was carried out on the basis of data on lithology of the study area, terrain slope, aspect, curvature classes, distance from the watercourses, and Bare Soil Index (BSI). Lithology data was obtained by digitalization of contents from geological maps (scale 1:100,000) in QGIS software. Terrain slope, aspect and curvature were derived from the 25 m cellsize Digital Elevation Model – EUDEM of the European Environment Agency's Copernicus program. Slope values were classified to 6 classes, aspect values to 8 clasess (N, NE, E, SE, S, SW, W, NW), and curvature to 9 classes acording to values of planar and profile curvature, which can be convex (X), concave (V) or straight (Ge/Gr) (Wilson, 2018).

Distance from watercourses was obtained first by digitalization of all watercourses in the basin from topographic map (scale 1:25,000) in QGIS software, and then appropriate buffer zones were created.

BSI was obtained using the following formula (Diek et al., 2017) on the LANDSAT 8 multispectral imagery:

$$BSI = ((SWIR+R)-(NIR+B))/((SWIR+R)+(NIR+B))$$

Where SWIR is the shortwave infrared spectral channel, R is the red spectral channel, NIR is the near-infrared spectral channel, and B is the blue spectral channel.

Landslide susceptibility index (LSI) is equal to the sum of all parameters weighted values. After LSI value calculation, values were classified into four susceptibility classes (very high, high, medium and low susceptibility), and according to those values in QGIS software the entire Lužnice River basin area was classified to four zones of landslide susceptibility.

Based on and average values of LSI and the share of very high and high classes area in the total territory of the settlements on the territory of Lužnica River basin, classification of the settlement teritories on the four classes of landslide vulnerability (very high, high, medium and low) was performed.

Also, landslide susceptibility zones were intersected with state roads of first and second order in the Lužnica River basin for the determination of their vulnerability to landslide process.

For the flash flood vulnerability assessment the Flash Flood Potential Index method (Smith, 2003) was used, based on the following formula:

FFPI = (M+S+L+V)/4

Where M is terrain slope index, S represents soil type index, L is land use index and V represents vegetation density index. For every index values are within the range 1 to 10 (from least to most susceptible).

Terrain slope (M) index was obtained using GIS, based on a EUDEM and accordnig to folowing formula:

M = 10^(n/30)

Where n is terrain slope expressed in percentage. If n is greater than or equal to 30%, then the value of M is always 10.

Soil type index was obtained by digitizing content from geological maps (scale 1:100,000) in QGIS. Land use index is calculated on the basis of CORINE Land Cover 2018 database of Copernicus program, and vegetation type index is calculated from BSI. For indexes that were based on geological data, CORINE Land Cover data and BSI, values from 1 to 10 were given, depending on the characteristics important for the the emergence and development torrential processes.

Based on the analysis of the obtained values of FFPI the classification of results on the four classes was made (very high, high, medium and low), according to the degree of susceptibility to torrential floods. The results indicate the possibility of a torrential flood emergence in appropriate conditions. Will it be so, depends on many factors, and this is only a predisposition or the susceptibility of territory for the occurrence and development of this disaster (Novković et al., 2018).

Flash flood vulnerability of the settlements was determined based on the FFPI values on their territory and on the relation between watercourses and FFPI spatial distribution. Also, state roads vulnerability to flash floods was determined based on FFPI values upstream from road/river intersection

RESULTS AND DISCUSSION

Lithology is the primary factor of landslide process, because geological formation determines the possibility of landslide occurrence, as well as the process scale. Landslide hazard zones in Serbia are mostly developed on the slopes of Tertirary basins which consist heterogeneous sediment complexes, with complex hydrologic characteristics and unfavourable morphologic conditions (Dragićević et al., 2012). These sediments, occupy 28.6% of the Lužnica River basin, and 87% of the total landslide affected areas in the basin are located in these rocks (Table 1).

Most landslides occur in terrains that are inclined 5 to 10 degrees. In this slope class, which covers 27.6% of the total basin, there is 54% of total landslide area (Table 1). Most landslides are located on the slopes that are inclined to southwest, west and nortwest. On the surfaces of the Lužnica river basin that are 100 meters distant from the watercourses there is 36.9% of the total landslide area, and at a distance of 100 to 200 meters that share is 28.3%. In terrains that are 200 to 300 meters away from rivers there are 17.2% of a total landslide area (Table 1). Most landslides areas are located on the terrains that have BSI+1 value from 0.7 to 1.

Weighted values were used to calculate LSI, and after that classification to zones of different landslide susceptibility was performed. Very high susceptibility class is present on the 23.5% of the total river basin, and in the case of high susceptibility class that share is 20.5% (Table 2).

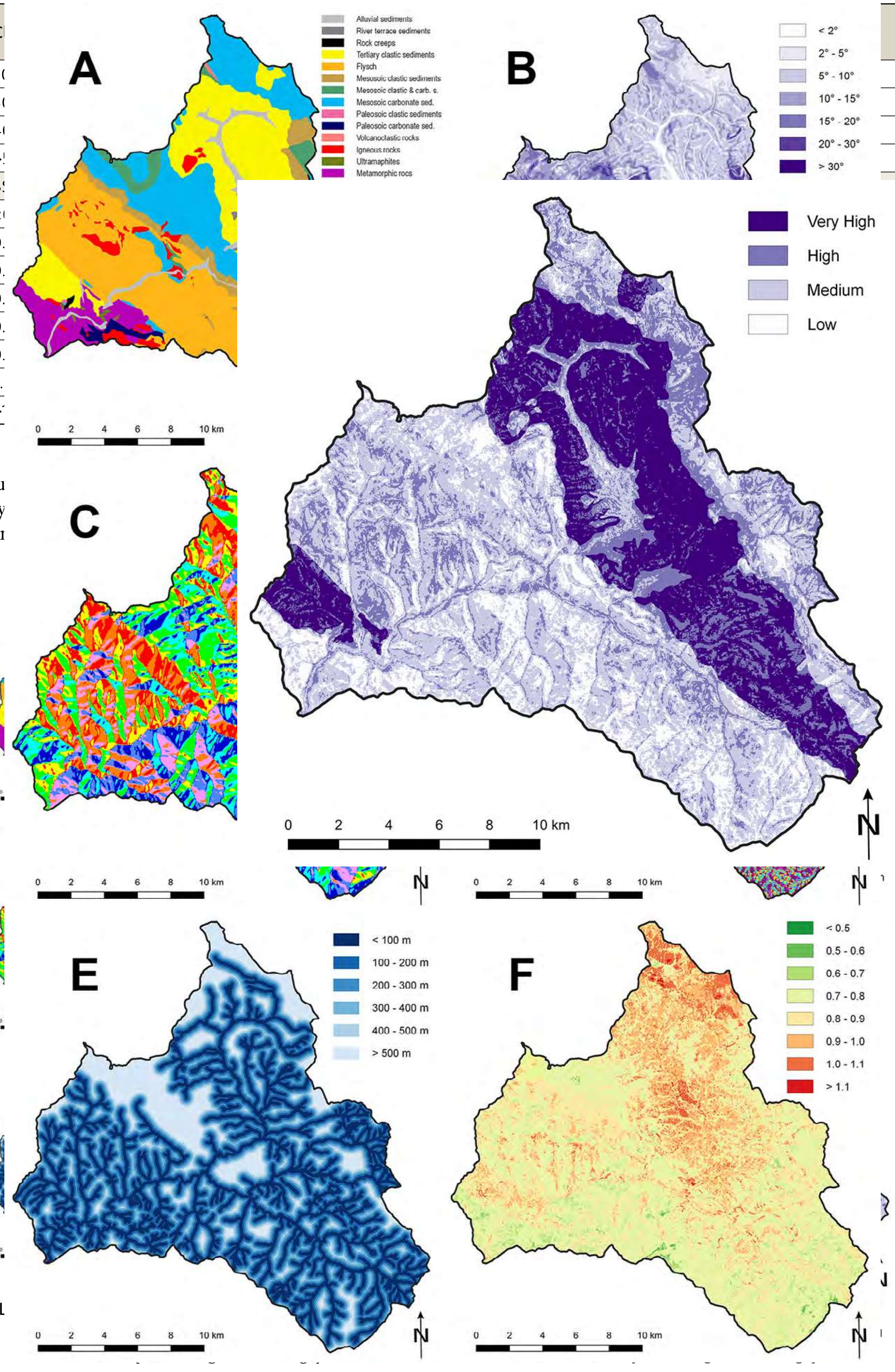
Table 2. Landslide susceptibility zones in the Lužnica River basin

Landslide susceptibility	km²	%
very high	76.12	23.50
high	66.29	20.46
medium	130.24	40.21
low	51.30	15.83
total	323.94	100.00

LSI and landslide susceptibility classes data were used to classify settlement territories of the on the

Table 1. Total area, landslide area, and weighted values of classes of parameters for LSI calculation

Classes of parameters	Total area		Landslide area		W_{ij}
	km²	%	km²	%	
Lithological types					
Alluvial sediments	13.04	4.02	0.26	0.53	0.1135
River terrace sediments	3.76	1.16	0.81	1.64	1.5290
Rock creeps	3.71	1.14	0.37	0.76	0.6240
Tertiary clastic sediments	92.76	28.59	43.07	87.10	4.8207
Flysch	94.63	29.17	2.05	4.14	0.1231
Mesozoic clastic sediments	22.98	7.08	1.52	3.06	0.3924
Mesozoic clastic and carb. sed.	7.88	2.43	0.62	1.24	0.4707
Mesozoic carbonate sediments	56.17	17.31	0.38	0.77	0.0381
Palaeozoic clastic sediments	3.72	1.15	0.00	0.00	0.0000
Palaeozoic carbonate sediments	2.14	0.66	0.00	0.00	0.0000
Volcanoclastic rocks	0.29	0.09	0.03	0.05	0.5590
Igneous rocks	9.67	2.98	0.34	0.69	0.2047
Ultramaphites	0.30	0.09	0.00	0.00	0.0000
Metamorphic rocs	13.37	4.12	0.00	0.00	0.0000
Slope [°]					
<2	9.26	2.85	0.80	1.61	0.5233
2-5	32.11	9.90	4.34	8.78	0.8690
5-10	89.59	27.62	26.68	53.95	2.3580
10-15	80.05	24.68	14.08	28.47	1.1864
15-20	63.43	19.55	2.95	5.97	0.2716
20-30	45.69	14.09	0.57	1.16	0.0706
>30	4.26	1.31	0.03	0.06	0.0378
Aspect					
N	37.38	11.52	5.28	10.69	0.9155
NE	40.89	12.61	4.23	8.55	0.6416
E	41.17	12.69	2.93	5.92	0.4256
SE	34.42	10.61	3.57	7.23	0.6439
S	39.94	12.31	6.04	12.21	0.9902
SW	51.73	15.95	11.43	23.11	1.5764
W	44.33	13.66	9.86	19.95	1.5917
NW	34.52	10.64	6.10	12.34	1.1941
Curvature classes					
1 - V/V	66.54	20.51	12.63	25.54	1.3028
2 - Ge/V	21.34	6.58	4.89	9.90	1.6545
3 - X/V	21.77	6.71	2.65	5.36	0.7712
4 - V/Gr	22.50	6.93	4.88	9.87	1.5412
5 - Ge/Gr	22.89	7.06	2.87	5.81	0.7978
6 - X/Gr	22.00	6.78	3.47	7.01	1.0408
7 - V/X	25.29	7.80	3.43	6.95	0.8739
8 - Ge/X	28.69	8.84	4.78	9.67	1.1129
9 - X/X	93.39	28.79	9.83	19.88	0.6542
Distance from watercourses [m]					
<100	98.91	30.49	18.26	36.92	1.2588
100-200	80.87	24.93	14.01	28.33	1.1650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Rock creeps
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Paleosoic clastic sediments
Paleosoic carbonate sed.
Volcanoclastic rocks
Igneous rocks
Ultramaphites
Metamorphic rocs
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2° - 5°
5° - 10°
10° - 15°
15° - 20°
20° - 30°
> 30°
C
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200 - 300 m
300 - 400 m
400 - 500 m
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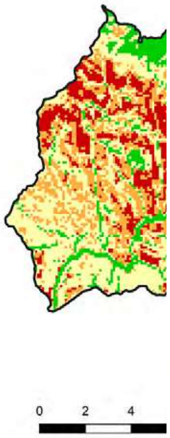

Figure 3. Flash
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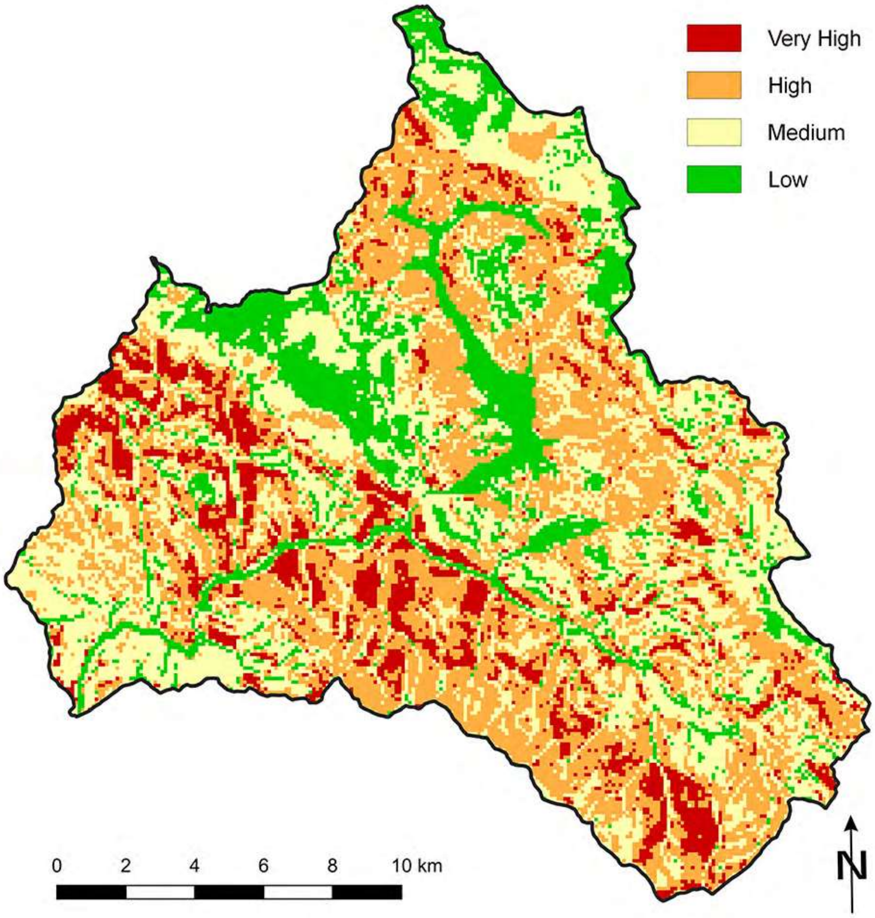

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II a	27.24
Total	59.86

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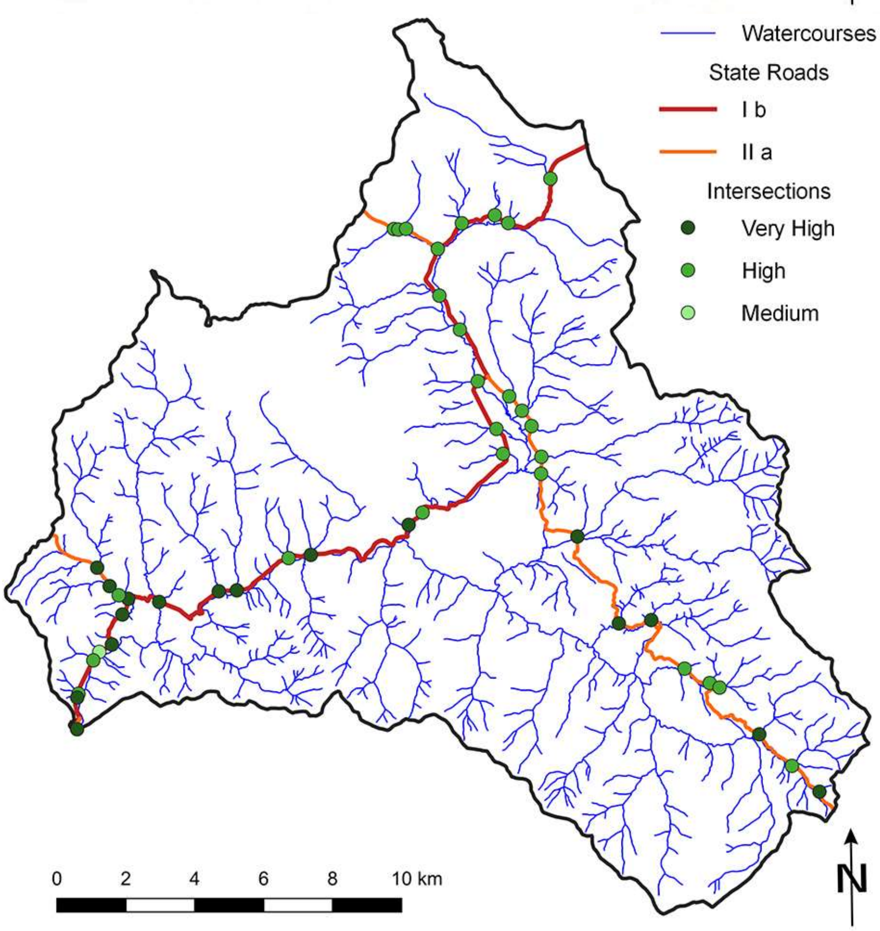

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Table 5. State road flash flood vulnerability in the Lužnica River basin

State road category	Low	Medium	High	Very high	Total locations
I b	0	1	14	9	24
II a	0	0	13	8	21
Total	0	1	27	17	45

CONCLUSION

The landslide and flash flood susceptibility and vulnerability assessment and zonation are very important elements of the decision making process in natural hazard management. They should represent mandatory part of all documents related to spatial planning and management, especially in vulnerable areas. Application of GIS in such cases is of utmost importance because it is the only possible way to integrate and analyze all relevant spatial data, and make decisions according to those analysis.

This research have shown that the Lužnica River basin is vulnerable to landslide and flash flood occurrence. Very high landslide susceptibility was determined on 23.5% of the total basin area, while high landslide susceptibility have share of 20.5%. In 19 settlement territories very high or high landslide vulnerability was determined, and large parts of state roads that run through basin are also in the classes of very high and high landslide susceptibility. Large part of teritory is also vulnerable to flash flood occurrence. About 47.4% of the Lužnica River basin territory belongs to the classes of very high and high flash flood susceptibility, there a lot of vulnerable settlements, and state road network is particularly vulnerable to occurrence of this disaster.

Obtained data must be taken into account when measures in the areas that are identified as vulnerable are conducted, when further development of the basin territory is being planned, all in order to prevent damage from this disasters in the future.

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