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GIS ANALYSIS OF THE VULNERABILITY OF FLASH FLOODS IN THE POREČKA RIVER BASIN (SERBIA)

Lukić Ana[1]

[1]*PhD student, University of Belgrade, Faculty of Geography and Public enterprise Roads of Serbia, Belgrade, Serbia, E-mail: analukic48@gmail.com*

ABSTRACT

The aim of this study is to identify and map the zones of different vulnerability to flash floods based on the geospatial analysis of natural conditions in the Porečka River basin (Republic of Serbia). The analysis covers the catchment area of the Porečka River (493.82 km^2). Geospatial analysis was conducted using GIS software (QGIS 3.18). The Flash Flood Potential Index (FFPI) was used to determine the terrain's predisposition to flash floods, where the input data for determining the value of the index were the values of the following coefficients: the terrain slope, the type of geological substrate, the way of land use, and the bareness of the terrain.

The analysis determined that 50.43% of the total territory of the basin belongs to the class of high and very high susceptibility to flash floods, and when looking at the length of watercourses in the basin, that percentage is 81.94%. The results of this study clearly indicate the advantages of using modern GIS technologies in the land use and risk management. Geospatial analysis is of particular importance in the field of managing regions that stand out as particularly vulnerable to some natural disasters.

Key words: *Flash floods, natural disasters, Porečka river, FFPI, GIS*

INTRODUCTION

Natural disasters are variations and extreme events which cause damage and destruction to human life safety, economic development, the living environment and resources [1]. Natural disasters are phenomena that disrupt the stability of natural systems by the action of natural processes, which have recently been significantly modified by anthropogenic influence [2]. Floods are natural hydrological disasters that cover with water areas that are not normally covered by water, whereby the consequences vary and can be catastrophic for the economic development of society, the environment, human lives, and health, as well as cultural heritage [3].

As a special type of flooding on watercourses, torrential floods are distinguished. Their occurrence is related to torrential watercourses, whose basic characteristic is a small amount of water during most of the year, but large flows after intense rainfall [2]. After intense rainfall, in addition to a large amount of water, a large amount of alluvial and other material (sand, gravel, mud, stones, leaves, branches, and even waste that previously reached the riverbeds) is carried by the riverbeds. A torrential mass formed in this way can negatively affect the environment.

The research area covers the Porečka River basin, which due to its natural features, which favor the occurrence of flash floods, is susceptible to the occurrence of such disasters. The Porečka River, like other rivers that belong to the Black Sea Basin in the territory of the Republic of Serbia, is characterized by upper flows that have the characteristics of mountain rivers, large falls, and significant water speed, while the lower part has a wide bed, smaller falls with frequent meanders. In river basins with these characteristics, water management problems are common, such as floods, and sometimes strong soil erosion with the occurrence of flash floods [2].

The main goal of this research is the data collection and creation of a database on the natural characteristics of the Porečka River basin area, the application of various methodological procedures and GIS, on the basis of which the geospatial analysis of the collected data was performed, then the identification and mapping of zones at different risk of flash floods.

STUDY AREA

The Porečka River basin is located in the eastern part of the Republic of Serbia (Map 1 and 2). Administratively, it belongs to the Bor district. The largest part of the basin is located in the territory of the municipality of Majdanpek (71.55 %), while a smaller part includes the areas of the municipalities of Bor (26.52%) and Negotin (1.93%). The river catchment area extends from the West 21° 56′ 36″ to na East 22° 15′ 04″ longitude, and from South 44° 09′ 52″ to North 44° 27′ 31″ latitute, Figure 1. The study area covers 493.82 km^2 in total.

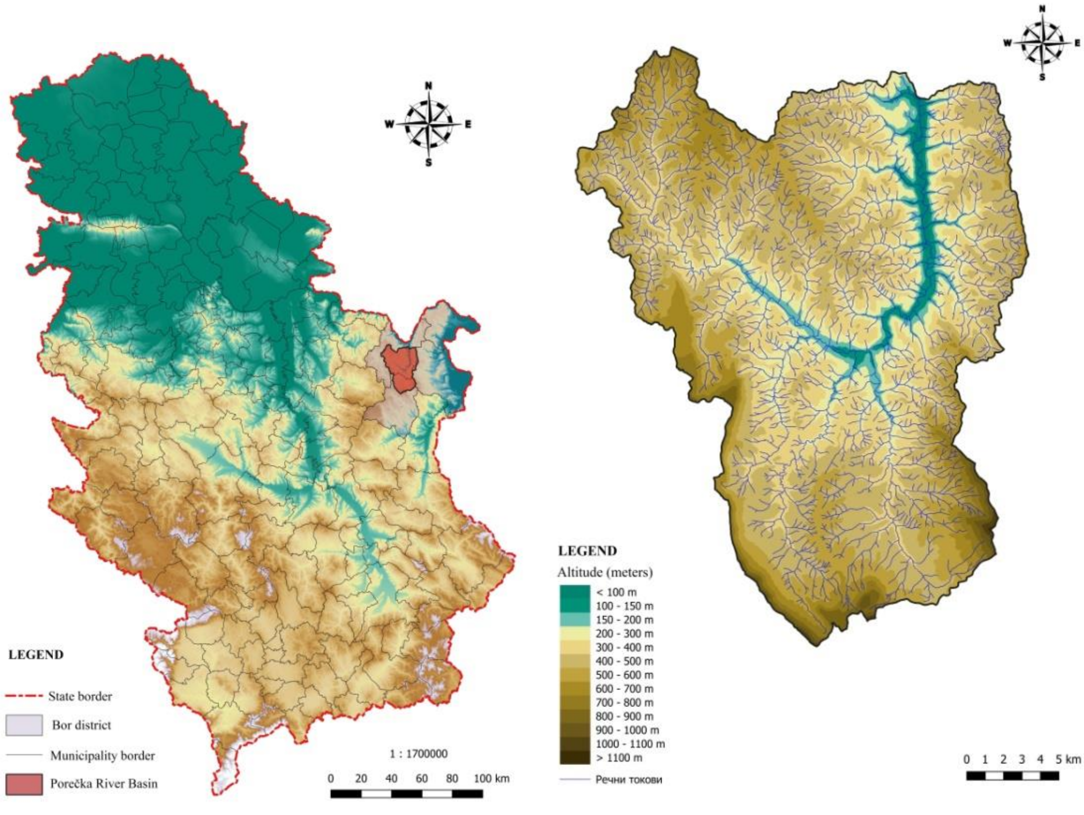

Figure 1. Map 1 and 2: Geographical location of the Porečka River Basin (Serbia)

The Porečka River, 21 km long, belongs to the Black Sea Basin and is a tributary of the Đerdap Lake (Danube River). It is formed by the joining of two rivers - Šaška (25.5 km) and Crnajka (18 km). The Crnajka River rises at the foot of the Deli Jovan mountain, and the Šaška River rises on the Liškovac mountain. The Porečka River flows through a wide valley plain where it meanders and receives 24 tributaries [5].

With the construction of HPP Đerdap I, its mouth was submerged and the Poreč Bay (4 km long) was formed, which is the largest bay of the Danube in the lower part of the course. The length of the watershed border is 122.60 km. The density of the river network is 2.34 km/km^2. The topography of the watershed is mainly hilly and mountainous and consists of mountains: Mali Krš, Veliki Krš, Deli Jovan, Stol i Liškovac.

The watershed area is characterized by a continental climate, but two characteristic microclimate areas are distinguished: the coastal belt of the Đerdap Lake with the Poreč Bay, with a moderate climate, and the hill-mountain belt with a colder climate and more snowfall [6]. The area of the watershed is largely covered by forest vegetation (68.04 % of the total area). The northeastern part of the Porečka River basin (7.63% of the total area) is located on the territory of the "Đerdap" National Park, which is considered to be very important from the point of preserving biodiversity and natural values.

MATERIAL AND METHODS

For the purpose of analyzing the risk of flash floods in the Poreč River basin, a method was used to determine the predisposition of the territory to the occurrence of flash floods - Flash Flood Potential Index (FFPI). The goal of the FFPI is a quantitative description of the risk of flash floods for a certain area, based on the characteristics of that area such as slope, type of soil (geological base), land use, and vegetation cover characteristics [7]. FFPI is calculated according to the formula [8]:

$$\text{FFPI} = \frac{M + S + L + V}{4}$$

Where: M – terrain slope coefficient, S – coefficient of the type of geological substratum, L – land use coefficient, V – terrain bareness coefficient. The values of the coefficients range from 1 to 10 (from the least susceptible to flooding to the most susceptible).

The terrain slope coefficient (M) was calculated on the basis of a DEM - Digital Elevation Model, with a resolution of 25 m. The DEM was taken from the database of the European Environment Agency (EEA) [9]. First, the slope is determined, which is expressed as a percentage, and then the following formula is applied:

$$M = 10^{n/3}$$

Where: n – slope (%) . If $n \geq 30\%$, then always M = 10.

To determine the coefficient of the type of geological substrate, data on the type of geological substrate obtained from basic geological maps were used, sheets: Donji Milanovac L34-129 [10], Bor L34-141 [11], Žagubica L34-140 [12] and Kučevo L34-128 [13]. Different types of rocks were assigned different coefficient values depending on their characteristics, and in connection with the susceptibility of such terrain to the occurrence and development of flash floods (Table 1).

Table 1: Coefficient values of the type of geological substrate

Type of rock	The value of the coefficient
Alluvial sediments	2
River terrace sediments	4
Deluvium-proluvium	8
Rock creep	8
Travertine	9
Tertiary clastic sediments	9
Volcanoclastic rocks	9
Igneous rocks	4
Mesozoic clastic sediments	8
Mesozoic carbonate and clastic sediments	7
Mesozoic carbonate sediments	5
Ultramafites	8
Paleozoic carbonate and clastic sediments	7
Paleozoic clastic sediments	8
Metamorphic rocks	7

The land use coefficient was obtained based on data from the digital database of the EEA - CORINE Land Cover (CLC, 2018) [14]. Each class is assigned values from 1 to 10, depending on the characteristics important for the occurrence and development of flash floods (Table 2).

Table 2: Land use coefficient values

CLC code	CORINE Land Cover class	The value of the coefficient
112	Discontinuous urban fabric	3
131	Mineral extraction sites	9
231	Meadows	6
242	Complex cultivation patterns	8
243	Land principally occuped by agriculture	7
311	Broad-leaved forests	4
313	Mixed forests	3
321	Natural grassland	5
324	Transitional woodland shrub	5
333	Sparsely vegetated areas	9
511	Water courses	1

The terrain bareness coefficient was obtained by analyzing multispectral images from the Sentinel-2 and Landsat 8 satellites taken from the Geological Topographic Institute in the USA [15]. BSI (Bare Soil Index) index was calculated for the researched area, according to the formula:

$$BSI = \frac{(SWIR+R)-(NIR+B)}{(SWIR+R)+(NIR+B)}+1$$

Where: SWIR - is the value of the short-wave infrared part of the spectrum, R - is the value of the red part of the spectrum, NIR - is the value of the near-infrared part of the spectrum, B - is the value of the blue part of the spectrum of electromagnetic radiation.

BSI is mainly used to distinguish between agricultural and non-agricultural land. The values of the BSI index range from 0 to 2 [16]. Given that the values of the bare terrain coefficient range from 1 to 10, in order to obtain such values, the dependence between the values was determined and a formula was obtained that was used for the final calculation of the coefficient:

$$V = 7.63 * \ln(BSI) + 8$$

After determining the value of each individual coefficient, the FFPI was calculated. Then, based on the analysis of the obtained FFPI values, the results were classified into four classes, according to the degree of susceptibility to floods. By analyzing the spatial distribution of FFPI values within the researched area, all watercourses were classified into 4 classes, which represent the possibility of flash floods occurring on them under appropriate conditions.

Geospatial analysis was conducted using GIS software (QGIS 3.18). The GIS method enables the wide application of quantitative methods and sophisticated technology. The availability of a large amount of data enables a deeper analysis of the landscape and more detailed land use planning. Computer technology, the application of GIS and various research methods have found wide application in the analysis of the natural conditions of the area, its susceptibility to natural disasters and finding solutions for the protection of the area and the repair of the resulting damage.

RESEARCH RESULTS

In order to identify the potential for the occurrence of flash floods, the determination of the FFPI was carried out, and as a prerequisite, the determination of the slope coefficients of the terrain, the type of geological substrate, the method of land use, and the bareness of the terrain was carried out. The values of the coefficients range from 1 to 10 (from the least susceptible to flash floods to the most susceptible).

Pronounced slopes in the hydrographic network and on the slopes of the watershed contribute to the intensification of rapid surface runoff, which shortens the time of water concentration in torrential flow [17], thus the slope of the terrain significantly affects the emergence and development of torrential flows and then torrential floods. Terrains with a slope coefficient of 10 occupy 33.37% of the total basin area. These are terrains with a slope of more than 16°, which are classified as very sloping and steep [18]. Terrains with a slope coefficient between 7 and 10 occur on 13.25% of the total area.

The spatial distribution of slope coefficient values and the distribution of slopes expressed in degrees (°) can be seen on Figure 2, and their percentage share in the total area of the basin is shown in Table 3.

The lithological composition of the terrain is considered an important modifier of natural processes in the watershed [19]. The geological structure is one of the factors that significantly influence the density of the hydrographic system and the size of the runoff. Very important characteristics of the geological substratum, on which the formation of conditions for the formation of torrential flows depend, are resistance and granulometric composition.

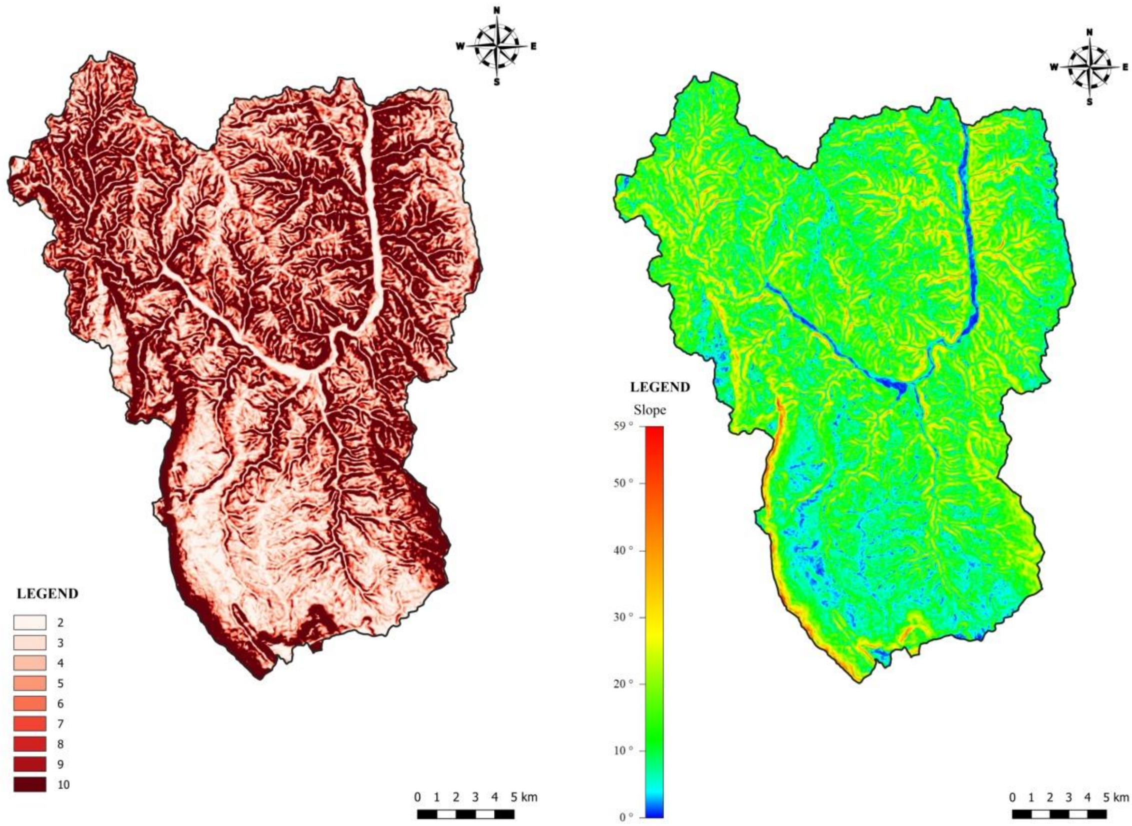

Figure 2. Map 3 and 4: Spatial distribution of slope coefficient values (3);
Terrain slope of the Porečka river basin (4)

Terrains assigned a value coefficient between 7 and 10 were evaluated as exceptionally susceptible types of geological substrate for the occurrence and development of torrential flows, and then floods. The coefficients were assigned according to the characteristics of the rocks, i.e. according to their susceptibility to torrential flows. Among them, the most common are metamorphic rocks, which occur at 36.44%. Other rock types rated as extremely vulnerable occupy 21.53% of the total area.

Therefore, highly susceptible terrains for the development of torrential flows occupy 57.97% of the total area of the basin. The spatial distribution of the types of geological substrate can be seen on Figure 3, while the percentage share in the total area of the basin is shown in Table 4.

Table 3: The value of the terrain slope coefficient and the terrain slope class of the Porečka River Basin

Coefficient value	Area (km^2)	Share in the total area (%)	Slope (°)	Area (km^2)	Share in the total area (%)
2	53.5	10.83	< 5	50.39	10.2
3	73.48	14.88	5 - 10	128.88	26.1
4	58.96	11.94	10 - 15	128.47	26.02
5	44.33	8.98	15 - 20	94.14	19.06
6	33.36	6.75	20 - 25	54.46	11.03
7	26.21	5.31	25 - 30	24.77	5.02
8	21.47	4.35	30 - 35	9.11	1.85
9	17.72	3.59	35 - 40	2.6	0.53
10	164.78	33.37	> 40	0.998	0.2

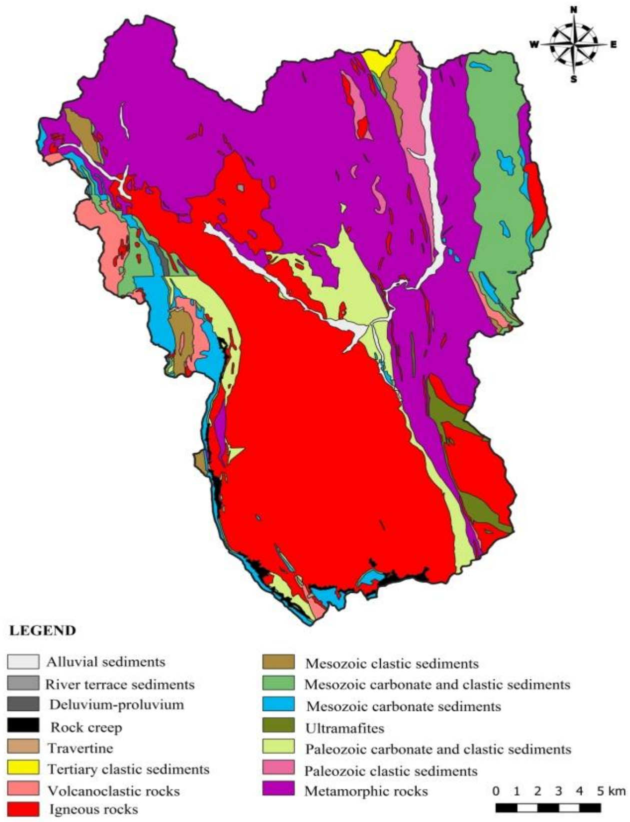

Figure 3. Map 5: Geological map of the Porečka River basin

Table 4: Geological structure of the Porečka River basin and coefficient values of the geological substratum

Type of rock	Area (km^2)	Share in the total area (%)	Coefficient values
Alluvial sediments	10.71	2.17	2
River terrace sediments	0.10	0.02	4
Deluvium-proluvium	0.52	0.11	8
Rock creep	3.51	0.71	8
Travertine	0.12	0.02	9
Tertiary clastic sediments	1.59	0.32	9
Volcanoclastic rocks	11.30	2.29	9
Igneous rocks	179.00	36.25	4
Mesozoic clastic sediments	7.42	1.50	8
Mesozoic carbonate and clastic sediments	38.33	7.76	7

Mesozoic carbonate sediments	17.73	3.59	5
Ultramafites	5.44	1.10	8
Paleozoic carbonate and clastic sediments	26.53	5.37	7
Paleozoic clastic sediments	11.61	2.35	8
Metamorphic rocks	179.94	36.44	7

Vegetation cover affects the process of emergence and formation of torrential water in different ways, considering that its presence improves the water regime of the soil and reduces surface runoff. In the case of the existence of forest cover, it is important to analyze its quality and composition, considering that degraded forests have less positive influence on the runoff regime compared to forests of good structure [19,20].

Vegetation increases unevenness on the land, which slows down the surface runoff of precipitation and increases the possibility of water infiltration into the soil [21]. Areas without or with very little vegetation, especially when they are under steep slopes, create the most favorable conditions for rapid surface runoff and the formation of torrential flood waves. However, areas under the forest cause weaker ascending currents, which increase the amount of precipitation by as much as 10% compared to the surrounding terrain [22]. On the contrary, barren areas and areas with scanty vegetation, especially when they are on steep slopes, create the most favorable conditions for rapid surface runoff and the formation of torrential flood waves. Proper forest management represents a significant contribution to a balanced runoff regime in the basin without the occurrence of frequent and catastrophic flash floods [20].

According to obtained results, mineral extraction sites and sparsely vegetated areas occupy 0.51% of the territory, followed by different types of agricultural land such as complex cultivation patterns (13.24%) and land principally occuped by agriculture (12.54%), which are represented 25.78% of the total area of the basin.

The spatial distribution of land use classes is shown on Figure 4, and the percentage share of different classes in the total area of the basin is given in Table 5.

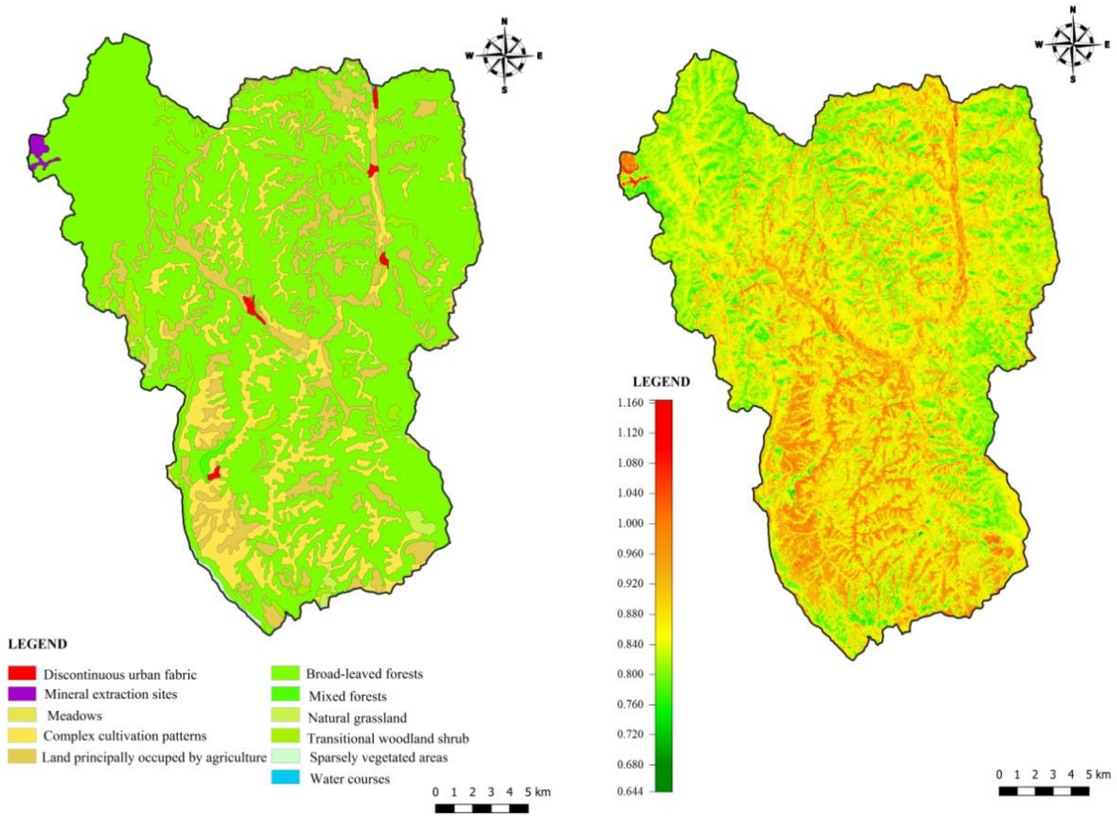

Figure 4. Map 6 and Map 7: Land use in the Porečka River basin (CORINE land cover) (6);
Spatial distribution of the soil bareness coefficient (7)

Table 5: Land use classes and land use coefficient values

CLC code	CORINE Land Cover class	Area (km^2)	Share in the total area (%)	Coeff. values
112	Discontinuous urban fabric	1.65	0.33	3
131	Mineral extraction sites	1.39	0.28	9
231	Meadows	7.153	1.45	6
242	Complex cultivation patterns	65.38	13.24	8
243	Land principally occuped by agriculture	61.91	12.54	7
311	Broad-leaved forests	334.96	67.83	4
313	Mixed forests	1.03	0.21	3
321	Natural grassland	4.28	0.87	5
324	Transitional woodland shrub	14.90	3.02	5
333	Sparsely vegetated areas	1.12	0.23	9
511	Water courses	0.05	0.01	1

The soil bareness coefficient indicates the difference between agricultural and non-agricultural land, that is, the magnitude of the change in bare soil. Agricultural areas, sparsely vegetated areas, mineral extraction sites, urban fabric areas, and in some places areas of meadows, lawns, and pastures have a higher value, while areas under forests and woody shrubby vegetation (Transitional woodland shrub) have lower values. The spatial distribution of the values of the soil bareness coefficient is shown on Figure 4, Map 7.

The values of all the mentioned coefficients were imported into the FFPI calculation formula [8] using GIS software (QGIS 3.18), and the spatial distribution of the obtained index is shown on Figure 5, Map 8. After the classification of the obtained FFPI values, it was determined that the class of very

high susceptibility is represented at 7.54%, and high susceptibility at 42.90% of the total area of the basin. The class of medium susceptibility occupies 36.62 %, and the low 12.94 % of the total area of the basin.

The spatial distribution of susceptibility classes for the occurrence of flash floods is given on Figure 5, Map 9, while the percentage share of classes in the total area is shown in Table 6.

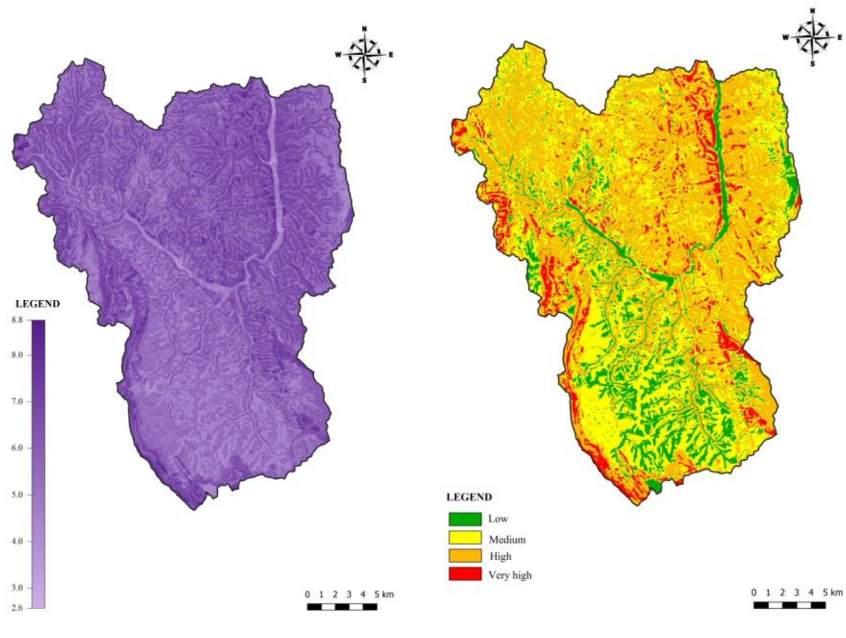

Figure 5, Map 8 and 9: Spatial distribution of FFPI in the territory of the Porečka River basin; Classes of susceptibility to flash floods in the Porečka River basin

Table 6: Share (%) of susceptibility classes to flash floods in the Porečka River basin

Susceptibility to flash floods	Area (km²)	Share in the total area (%)
Low	63.91	12.94
Medium	180.86	36.62
High	211.83	42.90
Very high	37.22	7.54

When it comes to the Šaška River basin, 7.23% of the total area of the basin belongs to the class of very high susceptibility, and 39.31% of the total area belongs to the class of high susceptibility. The class of medium susceptibility includes 38.92 %, and low 13.94 % of the total area of the basin. In the Crnajka River basin, 5.68% of the total area of the basin belongs to the class of very high risk, and 31.56% to the high class.

The class of medium susceptibility occupies 41.33 %, and low 21.43 % of the total area of the basin. In the part of the Porečka River basin downstream from the confluence of the Šaška River and the Crnajka River, the very high vulnerability class extends to 9.08% of the total area of that part of the basin, and the high susceptibility class to 53.97%.

By analyzing the obtained results, it can be concluded that the Šaška River basin is more susceptible to flash floods than the Crnajka basin, and data on the representation of susceptibility classes for these

two rivers can be seen in Table 7. When observing the entire basin of the Poreč River, the most susceptible to flash floods is the part downstream from the composition of the Šaška River and the Crnajka River. More detailed results can are shown in Table 8.

Given that the predisposition of the terrain for the occurrence and development of flash floods was determined through the calculation of the FFPI, in order to determine the susceptibility of the watercourses themselves for the transport of stormwater, the hydrographic network was overlapped with the previously obtained susceptibility classes.

Table 7: Share (%) of susceptibility classes to flash floods in the Saška River and Crnajka River basins

Susceptibility to flash floods	Area in the Šaška basin (km²)	Share in the total area of the Šaška basin (%)	Area in the Crnajka basin (km²)	Share in the total area of the Crnajke basin (%)
Low	32.88	13.94	20.55	21.43
Medium	91.78	38.92	39.64	41.33
High	94.11	39.91	30.26	31.56
Very high	17.06	7.23	5.44	5.68
Total	235.83	100.00	95.89	100.00

Table 8: The share (%) of flash flood susceptibility classes in the part of the Porečka river basin downstream of the Šaška and Crnajka River basins

Susceptibility to flash floods	The area of the part of the Porečka River basin downstream from the composition of the Šaška and Crnajka rivers (km²)	Share in the total area of the basin (%)
Low	10.46	6.46
Medium	49.38	30.49
High	87.41	53.97
Very high	14.71	9.08
Total	161.95	100.00

In addition, it was determined that 30.54% of the total length of streams in the territory of the basin belongs to the class of very high susceptibility to flash floods. On 51.4% of the total length of the streams, high susceptibility was determined. 14.45% of the total length belongs to the category of the medium, and 3.61% of the total length belongs to the category of low susceptibility to flash floods.

The spatial distribution of watercourses according to classes of susceptibility to flash floods is shown on Figure 6, and the percentage share of each class in the total length of the river network is shown in Table 9.

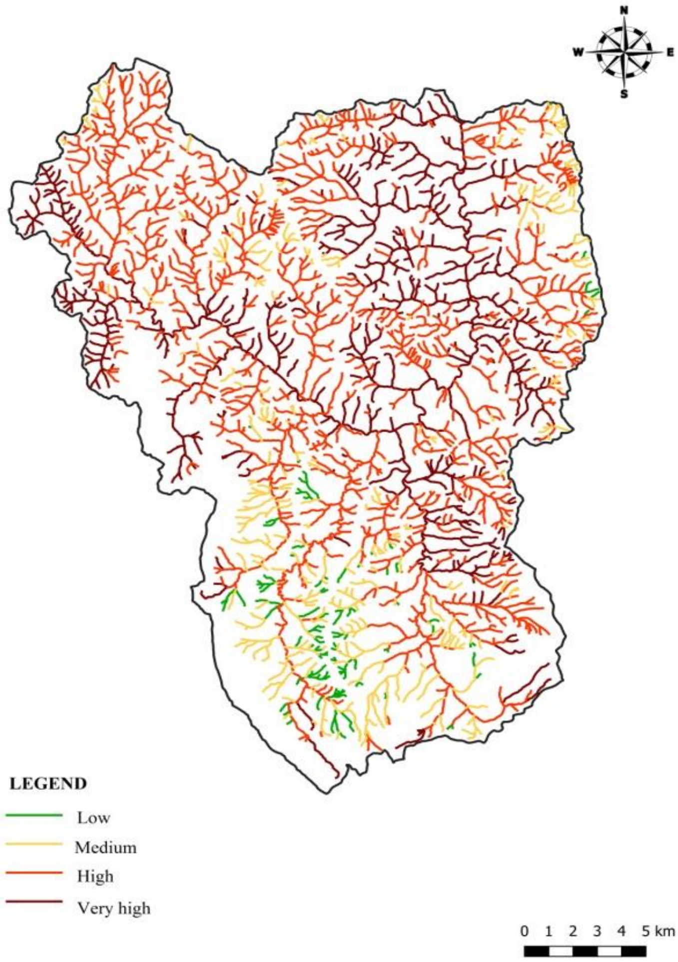

Figure 6. Map 10. Classes of susceptibility to flash floods in watercourses of the Porečka River basin

Table 9: Share (%) of susceptibility classes to flash floods in watercourses of the Porečka River basin

Susceptibility to flash floods	Length (km)	Share in the total length (%)
Low	41.81	3.61
Medium	167.29	14.45
High	594.89	51.4
Very high	353.42	30.54

CONCLUSION

The main goal of this paper was the geospatial analysis of the natural conditions in the Porečka River basin, and the identification and mapping of zones of different vulnerability to flash floods. In order to realize the aforementioned, it was necessary to collect numerous data, create a database on the natural characteristics of the researched area and apply different methodological procedures through the use of GIS software.

The results show the following: 7.54% of the total area belongs to the class of very high susceptibility to flash floods, and 42.90% of the basin belongs to high susceptibility class - that is, the two classes of highest susceptibility are represented on 50.43% of the total area. In addition, it was determined that 30.54% of the total length of streams belongs to the very high-risk class, and 51.4% of the total length belongs to the high-risk class.

This means that 81.94% of the total length of streams is extremely susceptible to the generation of torrential waters. As a result of the analysis of the susceptibility of the researched area to the occurrence of flash floods, maps were obtained on which the spatial distribution of susceptibility classes was presented. The data obtained from this analysis can represent a starting point in risk

management. Such analyzes can be used in the identification and assessment of risks. Furthermore, the results can be used to define and establish preventive protective measures, protection measures in the event of an accident, and measures to mitigate and eliminate the consequences of the accident.

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