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APPLICATION OF THE FLASH FLOOD POTENTIAL INDEX IN TORRENTIAL FLOODS RISK ASSESSMENT (FFPI): A CASE STUDY OF SVILAJNAC MUNICIPALITY

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Abstract: This paper analyses areas at risk of torrential floods in the municipality of Svilajnac. Flash floods are very important from the aspect of environmental protection and disaster management, considering that they can have serious consequences. Damage caused by floods results in the destruction of homes and infrastructure, as well as the displacement of people and loss of agricultural land, alteration of ecosystems and landscapes. For the purposes of this analysis data about geological structure, terrain slope, land cover and bare soil index were processed in the GIS environment. Flash Flood Potential Index (FFPI) was used to calculate the predisposition for flash flood occurrence in the study area. The obtained results indicate a high vulnerability to flash flood occurrence and they are classified into five vulnerability classes.

Keywords: torrential floods, disaster management, Flash Flood Potential Index (FFPI)

Introduction

Every year, numerous countries in the world are affected by floods, which unfortunately claim many innocent lives and leave catastrophic scenes and consequences. World Health Organization (WHO) estimates for the European Region, based on a combination of Emergency Event Database (EMDAT) and Dartmouth Flood Observatory (DFO) data, that more than 2,000 people were killed and 8.7 million people were affected by flooding during the period 2000-2014. (https://www.eea.europa.eu/data-and-maps/indicators/floods-and-health-1/assessment/#_edn1).

Between 1998 and 2017, more than 2 billion people worldwide were affected by flooding. People living in floodplains who do not have warning systems and awareness of the risk of flooding are most vulnerable, and in the last 10 years,

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80-90% of natural disasters were the result of floods, droughts, and severe storms (https://www.who.int/health -topics/floods#tab=tab_1).

Floods occur when water levels rise above normal due to heavy rainfall or snowmelt (Marchi et al., 2010; Dragićević et al., 2016). Flash floods are hydrological natural disasters characterized by sudden occurrence of maximum water volumes and intensive transport of floating and dragging sediments in the beds of torrents (Gavrilović, 1981; Petrović, 2021). There are over 12,000 torrent basins on the territory of Serbia (Petrović, 2021). Depending on the main cause, in our country there are floods caused by rain and snowmelt, ice floods, floods caused by the coincidence of floods, flash floods, floods caused by landslides, and floods caused by the collapse of dams (Gavrilović, 1981). Torrential floods can lead to long-term risks, such as the spread of water-borne diseases, increased risk of landslides, and severe erosion of the land. Flash floods are difficult to predict, but there are some warning signs to look for to prepare for a possible flood. These include monitoring for heavy rain, thunderstorms, and rapid snowmelt.

As one of the municipalities flooded in 2014, Svilajnac is an interesting example. For research purposes, the Flash Flood Potential Index (FFPI) was used. The data used in this work was processed using open-source software "QGIS". The aim of the research in this paper is to obtain a map of spatial distribution of flash flood hazard on the territory of municipality of Svilajnac. In addition to the hazard map, it is necessary to emphasize the importance of preventive measures and evacuation protocols in order to mitigate and, in the best case, prevent the consequences of such disasters.

Materials and methods

Study Area

The study area (Figure 1) is located in the northern part of Pomoravski district, between 44º19'10'' and 44º03'20'' north latitude and 21º08'' and 21º25'' east longitude. It is bordered to the north by the Municipality of Žabari, to the east by the Municipalities of Despotovac and Petrovac, to the south by the Municipality of Jagodina and to the west by the Municipalities of Batočina and Velika Plana. The area of the municipality is 326 km^2, and according to the 2022 census it has 25,802 inhabitants, while the average population density is 79.15 persons/km^2 (Republički zavod za statistiku, 2022). There are a total of 22 settlements in the municipality.

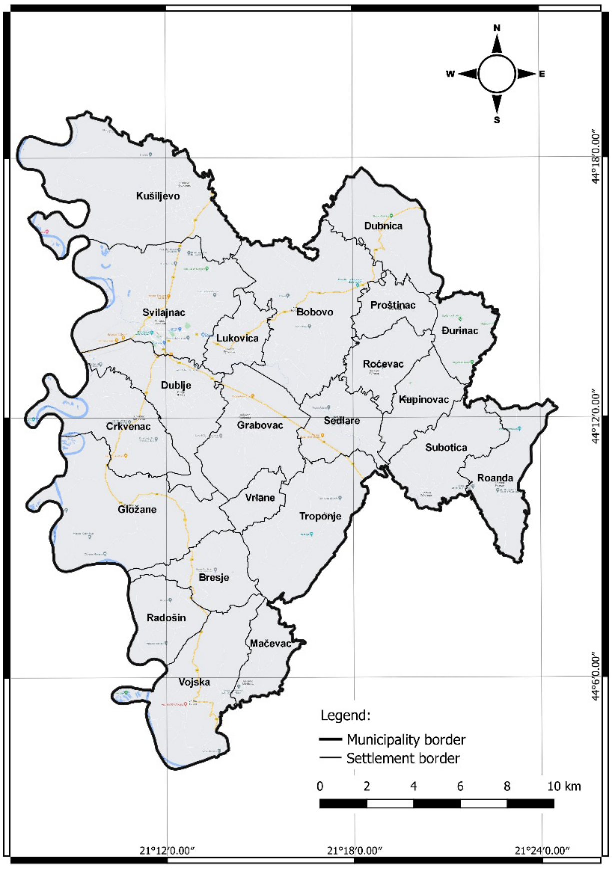

Figure 1. Position of the municipality of Svilajnac
Source: QGIS Quick Map Services plugin - Google maps

An administrative, economic and cultural center of the municipality is the village of Svilajnac with 9128 inhabitants (Republički zavod za statistiku, 2011) and an area of 27.78 km^2. The most important roads on the territory of the municipality are the state road of the second A-level with markings 160 and 162 (JP "Putevi Srbije", 2022a), the state road of the first B-level with number 27 (JP "Putevi Srbije", 2022b) and the state road of the second B-line with number 383 (JP "Putevi Srbije", 2022c).

On the territory of the municipality there are six immovable cultural properties (Zavod za zaštitu spomenika kulture, 2022): Zlatenac Monastery (cultural monument), Miljkov Monastery (cultural monument), Resava Library building in Svilajnac (cultural monument), old hospital building in Svilajnec (cultural monument), the building of the old high school in Svilajnac (cultural monument) and St. Nikola Church (cultural monument).

Methodology

A method for identifying flash flood potential areas (FFPI) was developed by Smith (2003) as part of the "West Region Flood Project", in the United States (Tincu et al., 2018). For research purposes, the FFPI was applied, which is calculated according to the formula (Smith, 2003):

$$FFPI = \frac{M+S+L+V}{4} \quad (1)$$

where *M* -, is the slope coefficient of the terrain, *S* -, is the coefficient of the geological base, *L* -, is the coefficient of land use and *V* -, is the coefficient of bareness of the terrain. The values of the coefficients of the parameters range from 1 to 10, i.e., from the terrain that is the least to the one that is most threatened by flash floods. This is the most commonly used method in the region (Minea et al., 2016; Ticnu et al., 2018; Marković et al., 2021).

The slope of the terrain (Table 1) is expressed by the size of the slope angle, which is the vertical angle that intersects the surface of the terrain with the horizontal plane and is expressed in degrees. The terrain slope coefficient (*M*) is calculated based on a digital elevation model with a resolution of 25 m and is expressed as a percentage, after which the formula is applied:

$$M = 10^{\frac{n}{80}} \quad (2)$$

where *n* – terrain slope in percent, and if *n* > 30%, then M is always equal to zero.

Table 1. Surfaces of terrain slope classes

Slope [°]	Area [km^2]
0 - 5	47,58
5-10	55.90
10 - 15	80.23
15 - 20	38.01
>20	99.20

Source:author

To determine the coefficient of the nature of the geological subsurface as a basis for digitization, geological base maps or open data on the representation and nature of the rocks in the area in question can be used. In order to determine the coefficient of the type of geological bedrock, in this work the geological base map - sheet L34 - 127 Lapovo, published by the Savezni geološki zavod in 1975, was used as a basis for digitization, using an interpreter for the analysis of the map content. Different coefficients were assigned to the represented rock types depending on their properties (e.g. strength, permeability, etc.), which were rated from 1 to 10 (Table 2).

Table 2. Display of coefficient values for the type of geological bedrock

Geological formation	The value of the coefficient
Alluvial sediments	2
Deluvium - Proluvium	7
Bedload sediments	4
Igneous rocks	3
Metamorphic rocks	6
Clastic sediments	7

Source: author

The land use coefficient is determined based on data from the European Environmental Protection Agency database - CORINE Land Cover (2018) or other relevant sources, and can also be determined for working purposes based on satellite imagery and existing land use documents. Land cover data can be used to identify areas of land that may be susceptible to natural disasters or other risks, such as flooding or landslides. The type of land use is very important from the point of vegetation, which can mitigate soil leaching and further erosion. Since trees root much deeper than grass and shrubs, densely vegetated areas were subjectively rated according to the class they represent. Vegetation also helps to improve water quality. Plants help to filter and absorb pollutants and contaminants, thus improving the water quality downstream. This is especially important in areas prone to torrential floods, as the amount of water flowing can increase the amount of pollutants and contaminants in the water. The coefficients are shown in Table 3.

Table 3. Display of the value coefficient for the land use

CORINE Land Cover class		The value of the coefficient
112	Settlements	4
121	Industrial and commercial areas	3
131	Mineral extraction sites	2
211	Non-irrigated arable land	5
221	Vineyards	8
231	Meadows	6
242	Complex agricultural areas	8
243	Agricultural areas with a significant proportion of natural vegetation	6
311	Deciduous forest	4
324	Transitional woodland-shrub	6
411	Inland marshes	1
511	Water courses	1
512	Water bodies	1

Source: author

The Bare Soil Index (BSI) is determined by analysing multispectral satellite images. BSI is calculated using the following formula (Diek et al., 2017):

$$BSI = \frac{(SWIR+R)-(NIR+B)}{(SWIR+R)+(NIR+B)} \quad (3)$$

where SWIR is the value of the shortwave infrared portion of the spectrum, R is the value of the red portion of the spectrum, NIR is the value of the near infrared portion of the spectrum and B is the value of the blue portion of the electromagnetic radiation. For easier calculation of the value without negative sign, the number one (+1) is added to the displayed formula. Shortwave infrared and red spectral channels are used to quantify mineral composition of the soil, while blue and near-infrared channels are used to highlight the presence of vegetation (https://www.geo.university/pages/spectralindices-with-multispectral-satellite-data).

Considering that the values for the coefficient of bare soil range from 1 to 10, to determine these values, the dependence between the values was determined and the following formula was established:

$$V = 7{,}68 * ln(BSI) + 8 \quad (4)$$

After determining the value of each coefficient, the FFPI index is calculated. Then, based on the analysis of the obtained values, a classification is made within the hazard classes, i.e., the susceptibility to the occurrence of flash floods. The results obtained in this way reflect the spatial arrangement of the phenomenon when it occurs, rather than the temporal intensity. Whether it will really happen depends on a variety of factors, which is why we talk about the predisposition, i.e., the susceptibility of the area to the occurrence and development of this natural disaster (Novković, 2016).

One of the main advantages of the FFPI is its ability to quickly assess the potential threat of flooding in areas that may have limited data or resources available. The FFPI can be applied to any location, regardless of whether or not it has access to high-resolution topographical data or sophisticated weather modelling. Additionally, the FFPI can be used to make comparisons between multiple locations, helping emergency managers to determine which areas are most likely to experience flooding. Additionally, the FFPI can be used to compare the relative risk of flooding in different regions, making it possible to prioritize emergency response and evacuation plans.

The basis of the calculations in the work is a raster digital elevation model with a resolution of 25 m, on the basis of which the data on the slope of the terrain were obtained, multispectral images of the Landsat 8 satellite downloaded from U.S. Geological Survey (USGS), on the basis of which the data on the bare soil index were obtained, the geological map from which geological formations were digitized, and then for the needs of the analysis were rasterized and land use downloaded from Corine Land Cover database that have been converted from vector to raster data type.

Results and discussion

Based on the applied formula, the FFPI index was determined with the values of ranging from 1.5 to 8.8 (Figure 2).

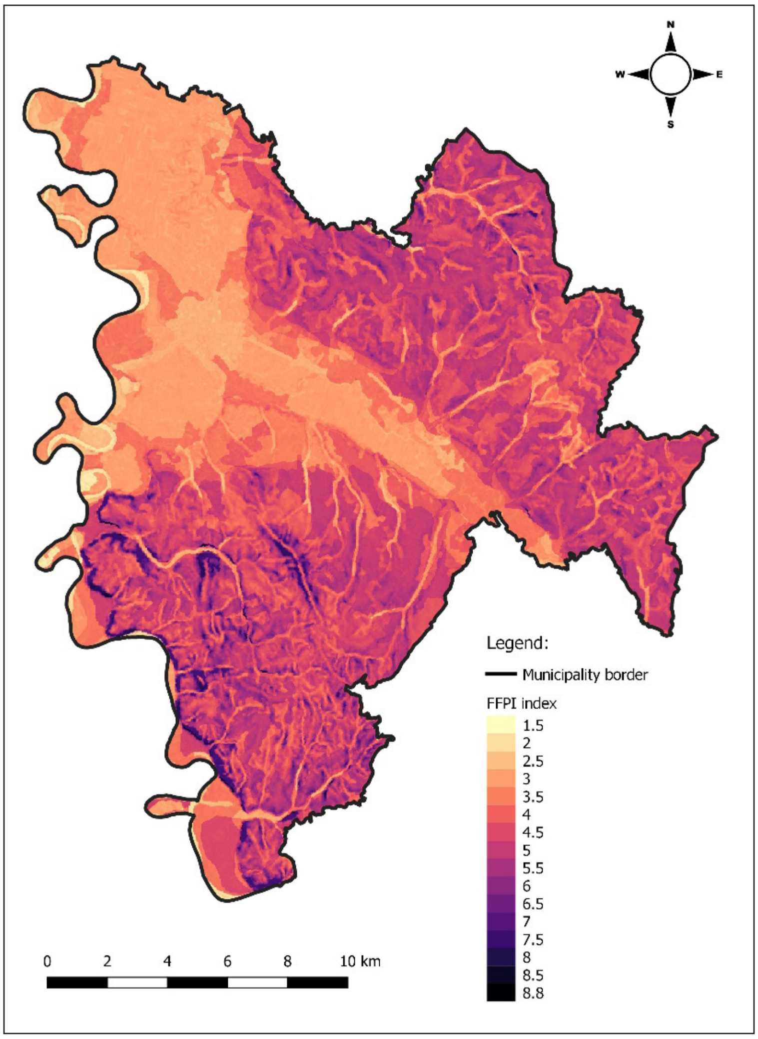

Figure 2. FFPI index
Source:author

The potential for flash flooding can be quite severe in some areas, and the index can help to inform both emergency response personnel and everyday citizens alike. By looking at the index, people can know what areas are more likely to experience flash flooding and can better plan for potential flooding events. The index also helps to inform the public of the potential risks associated with flash flooding, so that they can take any necessary precautions to protect themselves and their property. The FFPI index is an important tool for meteorologists, hydrologists and emergency response personnel because it provides information about the probability of flash floods occurring in a given area. This index can be used as a decision support tool for warning systems, emergency and evacuation plans and it is an essential tool for predicting the severity and likelihood of torrential flooding in an area.

FFPI can provide valuable insight into the factors which cause flash floods to occur. Terrain data is used to assess the slopes of the land and the amount of water that can flow through the area. Geological structure, land use and bare soil index data are used to determine how quickly water will be absorbed or runoff into the watershed.

After determining the index value, the classification was made into five vulnerability classes (Figure 3).

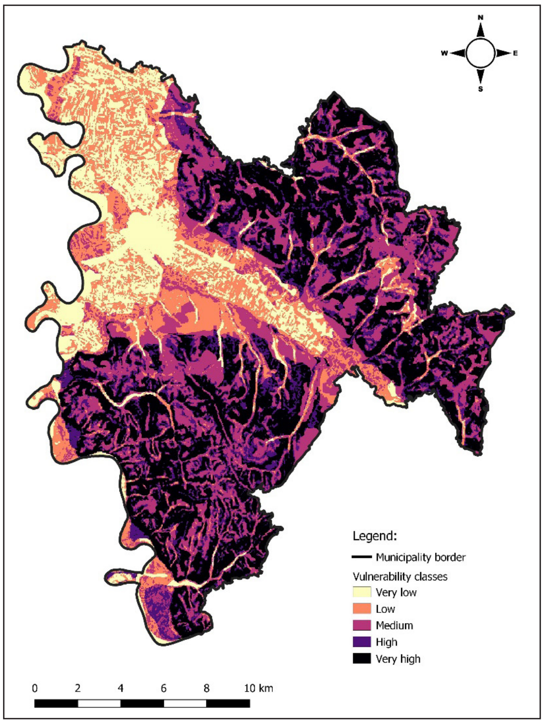

Figure 3. Vulnerability classes
Source: author

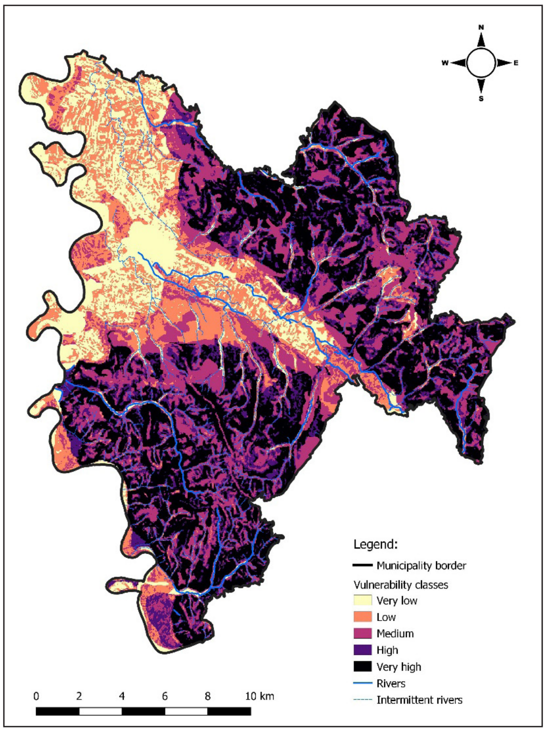

Figure 4. River network in vulnerability classes
Source: author

Areas classified as very low are unlikely to experience flash flooding, while areas classified as very high are at a greater risk of flash flooding.

Low vulnerability indicates that the area is relatively safe from flash floods, as the terrain, hydrology, and land cover are not conducive to flash flooding. Moderate vulnerability indicates that the area is partially at risk for flash flooding. The terrain, hydrology, and land cover are more conducive to flash flooding than those of low vulnerability areas. High vulnerability indicates that the area is very much at risk for flash flooding, as the terrain, hydrology, and land cover are all conducive to flash flooding. Areas in all vulnerability classes should be monitored closely and additional precautions should be taken in the event of a severe storm.

The spatial distribution is such that the north-eastern, eastern and southern parts of the study area are the most at risk because very high potential indicates the highest possibility of flash floods. The areas in the very low and low classes are located along the major river reaches, while the medium, high, and very high classes are found around the intermittent rivers (Figure 4). Moderate potential indicates that flash floods are possible, but unlikely, while high potential indicates that flash floods are likely to occur. These results can be used to make decisions related to land use and flood control measures such as levees or dams to reduce flood risk in sensitive areas, as well as in land use planning for construction of structures in the area.

Table 4 shows the areas by vulnerability classes. In the very low class, there are 44.58 km^2, which is 14.83% of the territory of the municipal area. The low class occupies 17.42% of the area, the medium class 25%, the high class 11.84% and the very high class 30.91%. It can be deduced that the largest part of the municipal area belongs to the low and medium class of vulnerability (57.25%). The smallest area is occupied by the high class and the largest by the very high class. Such a calculation could help municipalities to identify areas that are more vulnerable to flash floods and to take the necessary precautions to protect their inhabitants and infrastructure.

Table 4. Areas in vulnerability classes

Vulnerability class	Area [km^2]
Very low	44,58
Low	55.90
Medium	80.23
High	38.01
Very high	99.17

Source: author

From the obtained results it can be concluded that within the very low class there was a spatial overlap of the smallest coefficients of the parameters of the formula. Figure 5 shows the mean FFPI index by settlements.

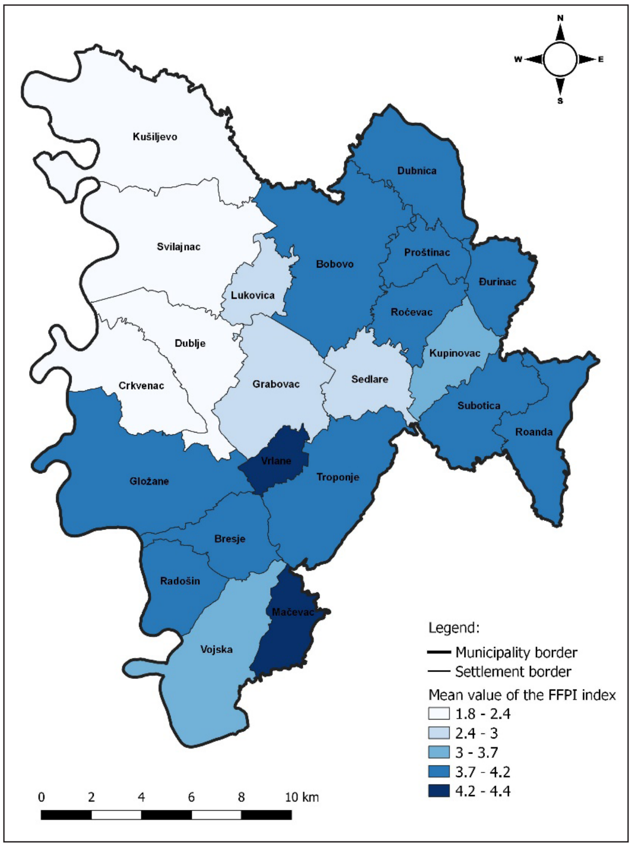

Figure 5. Mean value of the FFPI index by settlements

Source: author

This spatial arrangement of mean values should indicate places where it is necessary to strengthen precautionary measures and pay more attention to all factors preceding the occurrence of flash floods. The highest mean values were measured in the settlements of Mačevac and Vrlane (above 4.2), the lowest in the settlements of Svilajnac, Kušiljevo, Dublje and Crkvenac.

Conclusion

The flash flood risk analysis was performed using the Flash Flood Potential Index (FFPI) and showed that the probability of this natural disaster occurring in the territory of the Svilajnac municipality is significant. Although flash floods are usually triggered by heavy rainfall or sudden snowmelt, which cannot be influenced by humans, human negligence also plays a role in worsening the consequences of such a disaster. Precautionary measures should be strengthened, dams should be rebuilt or raised where needed, and a plan should be developed that includes prevention and remediation measures in the event of a flood.

The FFPI index can serve as an early warning of potential flash flooding so that communities can prepare in a timely manner. It also helps identify areas at risk of this disaster and allows for timely allocation of resources to mitigate potential damage.

According to the analysis, most of the municipality, more precisely 14.83% of the area, belongs to the very low vulnerability class, 17.42% to the low vulnerability class and 25% to the medium vulnerability class, and these areas are mostly located in areas where the low coefficients overlap within each member of the formula. In the high class there are 11.84% and in the very high 30.91% of the municipal territory. The most threatened settlements are Mačevac and Vrlane, which have the highest mean value of FFPI index, and the least threatened settlements are Svilajnac, Kušiljevo, Dublje and Crkvenac, while the mean coefficient of threat of flash floods for the whole municipality is 4.23.

Considering the changes in natural and anthropogenic factors relevant to these processes, it would be best to establish a system for occasional or permanent monitoring and control of the situation on the ground. With the help of new technologies, it is possible to collect detailed data from the surface that need to be analysed, and the use of GIS then allows data processing and the creation of a model of the future state. This type of analysis can prevent potential disasters, or at least mitigate their effects, and is therefore an important component of space analysis.

The FFPI index does not take into account other factors such as the amount of debris in riverbeds or landslides, which can also lead to flash flooding, nor does it take into account the effects of climate change, which can lead to more extreme weather events and increased potential for torrential flooding. Therefore, it is necessary to conduct analyses on a high-quality data set and use a combination of methods to compare results.

Each method has its advantages and disadvantages, but this does not preclude its importance for research. Using different methods can be a good way to achieve the desired goals. With so many methods available, it is important to find the one that is best suited for the task at hand. Different methods can be used in different situations and help increase efficiency and productivity in finding the optimal solution to the given problem, in this case, assessing the risk of flash flooding.

References

Diek, S., Fornallaz, F., Schaepman, M. & de Jong, R. (2017). *Barest Pixel Composite for Agricultural Areas Using Landsat Time Series*. Remote Sensing, 9, 1245, p.1-31.

Dragićević, S. & Filipović, D. (2016). *Prirodni uslovi i nepogode u planiranju i zaštiti prostora* (2. izd). Beograd: Univerzitet u Beogradu - Geografski gakultet.

European Environment Agency. (2018). *CORINE Land Cover (CLC)*. Retrieved from https://land.copernicus.eu/pan-european/corine-land-cover

European Environment Agency. (2021). *European Digital Elevation Model (EU-DEM),* version 1.1 Retrieved from https://land.copernicus.eu/imagery-in-situ/eu-dem/eu-dem-v1.1?tab=download

Gavrilović, Lj. (1981). *Poplave u SR Srbiji u XX veku – uzroci i posledic*e. Posebna izdanja SGD, br. 52. Beograd: Srpsko geografsko društvo.

Google (2022). *Google Maps*, retrieved on January 16th 2023. from https://www.google.com/maps

JP "Putevi Srbije". (2005-2023a). *II A – Spisak državnih puteva*. Retrieved on January 16th 2023. from https://www.putevi-srbije.rs/images/pdf/referentni-sistem/2.2.3_spisak_drzavnih_puteva_IIAreda.pdf

JP "Putevi Srbije" (2005 – 2023b). *IB Spisak državnih puteva*. Retrieved on January 16th 2023. from: https://www.putevi-srbije.rs/images/pdf/referentni-sistem/2.2.2_spisak_drzavnih_puteva_IBreda.pdf

JP "Putevi Srbije". (2005-2023c). *II B - Spisak državnih puteva*. Retrieved on January 16th 2023. from https://www.putevi-srbije.rs/images/pdf/referentni-sistem/2.2.4_spisak_drzavnih_puteva_IIBreda.pdf

Marchi, L.; Borga, M.; Preciso, E.; Gaume, E. (2010). *Characterisation of selected extreme flash floods in Europe and implications for flood risk management*. Journal of Hydrology. 394(1–2): 118-133.

Marković, M., Lukić, S. & Baumgerte, A. (2021). *Use of flash flood potential index (FFPI) method for assessing the risk of roads to the occurence of torrential floods - part of the Danube basin and Pek river basin.* International Journal for Traffic & Transport Engineering., Vol. 11 Issue 4, p543-553. 11p. DOI: 10.7708/ijtte2021.11(4).04

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.

Novković, I. (2016). *Prirodni uslovi kao determinante geohazarda na primeru slivova Ljiga, Jošaničke i Vranjskobanjske reke.* Doktorska disertacija. Beograd: Geografski fakultet - Univerzitet u Beogradu.

Petrović, A. (2021). *Bujične poplave u Srbiji.* Posebna izdanja SGD, knjiga 73. ISBN 978-86-82751-62-5. Beograd: Srpsko geografsko društvo.

Republički zavod za statistiku (2014). *Uporedni pregled proja stanovnika 1948, 1953, 1961, 1971, 1981, 1991, 2002, 2011*. Beograd: Republički zavod za statistiku

Republički zavod za statistiku (2022*). Prvi rezultati popisa stanovništva, domaćinstava i stanova 2022.* Beograd: Republički zavod za statistiku

Savezni geološki zavod (1975). *Osnovna geološka karta razmere* 1: 100 000, list L34 – 127 Lapovo

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

Tincu, R., Lazar, G. & Lazar, I. (2018). *Modified Flash Flood Potential Index in order to estimate areas with predisposition to water accumulation.* De Gruyter, 10, 593–606.

U.S. Geological Survey. (2021). *Earth Explorer*. Retrieved from https://www.usgs.gov/

Vojnogeografski institut, *Topogradske karte 1: 25,000*, listovi: Lapovo – 481_1_4, 481_2_3, 481_3_2, 481_3_4, 481_4_1 481_4_2, 481_4_3.

Zavod za zaštitu spomenika kulture (2023). *Informacioni sistem nepokretnih kulturnih dobara*. Retrieved on January 16th 2023. from https://nasledje.gov.rs/index.cfm?jezik=Serbian_CIR https://www.eea.europa.eu/data-and-maps/indicators/floods-and-health-1/assessment/#_edn1, retrieved on January 16th 2023.

https://www.who.int/health-topics/floods#tab=tab_1, retrieved on January 16th 2023.

https://www.geo.university/pages/spectralindices-with-multispectral-satellite-data, retrieved on January 16th, 2023.