

Research Article

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Multihazard susceptibility assessment: A case study – Municipality of Štrpce (Southern Serbia)

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Abstract: The municipality of Štrpce (Southern Serbia) is an area located within Šar Mountain National Park, which is of great ecological importance. Due to the vicinity of settlements, it is necessary to analyze the terrain's susceptibility to natural hazards. The main goal of this research was to determine locations that are highly vulnerable at times of natural hazards (such as earthquakes, erosion, torrential flooding, snow avalanches, and forest fires). The first step in this research was to analyze seismic hazards for a 475 years return period (VII–VIII MCS for the observed area), which was possible by means of Geographic Information Systems. The second step was to determine the intensity of erosion and total sediment production using the Erosion Potential Model. The third step was related to the analysis of the potential of torrential floods using the Flash Flood Potential Index. The Avalanches Potential Index method was used as the fourth step. The fifth step included the analysis of a terrain susceptibility to the occurrence of forest fires. Following the five criteria analysis, weight coefficients were assigned to each of the analyzed parameters by using the Analytical Hierarchy Process (AHP), which provided results of the total susceptibility to natural hazards of the territory of Štrpce. Results indicated that over 45% of the municipality is highly or very highly susceptible to various natural hazards. This article represents a significant step toward a better understanding of natural hazards and it provides a unique knowledge basis for establishing the

management and mitigation guidelines and measures, not only within the researched area but at regional and national levels as well.

Keywords: natural hazards, AHP, GIS, remote sensing, Šar mountain

1 Introduction

Serbia is a continental country located in Southeast Europe, in the Balkan Peninsula with an area of 88.361 km². Due to its specific geographical position in the southeast part of the Pannonian Basin, it was often faced with different types of natural disasters, for more than 100 years of observation. In the period from 1900 to 1940, there were 100 natural disasters in every decade. Between 1960 and 1970 there were 650 natural disasters, between 1980 and 1990 their number reached 2,000, while during the 10 year period between 1990 and 2000, the number of disasters increased to even 2,800 [1]. The investigation of Natural hazards has a long history. The term itself refers to various agents that encompass geological and hydro-meteorological processes in the area [2,3]. However, many authors define natural disasters as sudden events, caused by significant human activities [4,5].

Natural hazards may present a great threat for the community depending on the magnitude of events. The municipality of Štrpce is located in the southern part of the Province of Kosovo and Metohija. This location belongs to one of the most beautiful National Parks of Serbia. Unfortunately, this area was often hit by natural hazards in the past, especially by earthquakes and erosion processes. The diversity of flora and fauna in this area can be threatened by the effects of natural disasters, as well as by the anthropogenic impact. Recently, human activity is in connection with environmental impacts. The municipality of Štrpce, being the most important settlement in the area, would be seriously jeopardized by hazardous events. With the help of advanced Geographical Information System (GIS) methods and remote sensing, erosion, torrential floods, snow avalanches, and forest fires were analyzed [6–8].

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Multihazard techniques are very important for the analysis of hazardous events [9–14]. Another approach could be approved by probabilistic and deterministic stochastic processes [15]. These processes are implemented in the algorithms of Quantum Geographical Information Systems (QGIS). Earthquake magnitude and its effects are estimated by means of specific seismic hazard analysis [16,17].

The territory of Serbia has 86% of the area with a potential for soil erosion of different volumes and intensities [18–21]. Šar Mountain foothills are known as very seismically active zone. Štrpce municipality has 11,000–12,000 inhabitants and its settlements are distributed on different slopes and mountain areas. In this investigated area, soil erosion is the main factor that may cause a big problem for the settlements. According to Ristanović et al. [22], acceleration of the process of soil erosion can cause a potential problem for agriculture. The soil erosion may be doubled with an increase of slope and relative angle of terrain [23–26].

Torrential floods are recognized as one of the most devastating natural hazards affecting the lives of many people in central and southern Serbia [22]. The damage caused by floods is extremely difficult to assess because it is very difficult to measure it [27–33]. In the past, torrential floods caused great economic damage to the local population of the municipality of Štrpce, especially in the period between 1953 and 1979 [34]. On the Šar Mountain, snow avalanches often cause great economic damage to the local population in the tourist zone of Brezovica Ski Center.

According to the last climate changes variability in Serbia, the number of forest fires displays an increasing tendency in southeastern Europe and Serbia. Šar Mountain is very vulnerable in the case of forest fires. Spatial planning and protection of forests have become very important tasks [35]. GIS and spatial data modeling are very powerful tools for calculating and describing the data of hazardous effects [36–38].

This research develops a new methodology for the predisposition of terrain to snow avalanches by means of GIS algorithms and multicriteria analysis and it represents one of the first investigations for avalanches based on modern techniques. There are many research studies that included GIS and remote-sensing techniques and estimation of hazards. The GIS can help to reduce the impact of natural hazards [28,33].

GIS flood risk mapping may be very important for the analysis of flood risk. Multicriteria analysis was successful in estimating the flooding waves. A good example

is set through the case study of the Quang Tho Commune in Thua Thien Hue province, central Viet Nam [39]. Disasters vary drastically depending on the local context. Namely, the probability of a natural disaster having more devastating effects in one place than in another depends on the local vulnerability components of the affected society (cultural, social, and economic). The socio-economic indicators may be used for mapping the social vulnerability index after earthquake effects. The GIS approach was applied to identify the spatial variability of social vulnerability to seismic hazards. The example of seismic hazards after Volcano activity was performed by GIS numerical methods in Italy [40]. The Karmania Hazard Model is a GIS-based application for earthquake scenario development and disaster management. This model, created to solve earthquakes during the disaster response phase, motivated the design and implementation of a comprehensive, interactive, and user-friendly model [41]. The research gave new ecological and socioeconomic results. The main goal of this research is to predict hazardous events likely to happen in the future.

2 Methods and data

2.1 Study area

As already mentioned, the research area includes the municipality of Štrpce, which is located in the southernmost part of the Republic of Serbia, on the territory of the Autonomous Province of Kosovo and Metohija. The municipality includes 16 settlements: Brod, Ižance, Firaja, Drajkovce, Viča, Koštanjevo, Gotovuša, Gornja Bitinja, Donja Bitinja, Sušiče, Štrpce, Berevce, Brezovica, Vrbeštica, Jažince, and Sevce (Figure 1). Currently, the population of the municipality numbers between 11,000 and 12,000 people, who are mainly engaged in quaternary activities (education, healthcare, and administration), agriculture (raspberry growing), and tourism. Tourism relies on Brezovica Ski Center, offering ideal conditions for recreational and alpine skiing.

The municipality is located in the upper course of the Lepenac River basin, covering an area of approximately 248 km². In geographical terms, it is known as Sirinička župa. Morphologically and geographically, the municipality borders with Šar Mountain and its branches: Ošljak, Čerenački peak, Ostrvica, Žar, and Jezerska Mountain, which gives the impression of its natural isolation [34,42]. The lowest altitude in the municipality is 600 m, while the

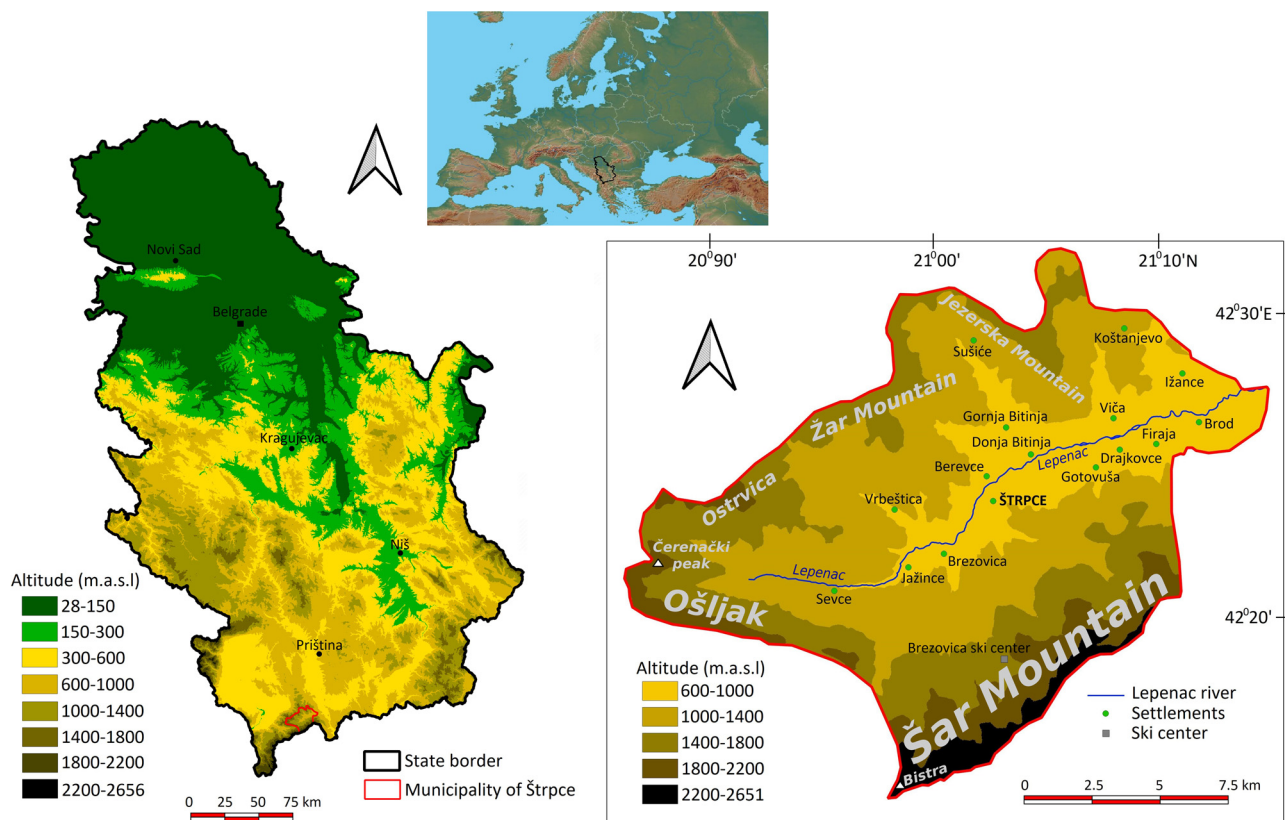


Figure 1: Geographical location of the municipality of Štrpce.

highest peak is Bistra (Peskovi), the second-highest peak in Serbia, with an altitude of 2,651 m. In terms of lithological composition, 13 types of rocks have been identified on the municipality's territory, out of which the most common are metamorphic rocks, diabase-hornstone formation, and Mesozoic carbonate rocks, together covering more than 77% of the municipality area. When it comes to pedological cover, various factors have contributed to creating numerous soil types and subtypes, with the most common being dystic cambisols, alluvial-diluvial soils, rankers, rendzinas, lithosols, kalkocambisols, diluviums, terra rossa, and brown soil on igneous rocks [34]. As far as land use is concerned, the area is dominated by deciduous forests and woody-shrubby vegetation. Nonirrigated agricultural areas, meadows, and agricultural plots with natural vegetation are frequent around the settlement. This area has a temperate-continental climate. Mean annual temperatures differ depending on the terrain morphometric characteristics. In the southern part of the municipality, at the peaks of Šar Mountain, the average annual temperature is less than 1°C, while in the lowest parts of the municipality, the average annual temperature reaches 11°C. The annual precipitation varies from 500 mm in the lowest, eastern part of the municipality, to 1,250 mm in the south, on the slopes and peaks of Šar

Mountain. During the winter months, the snow depth on Šar Mountain is often more than 1 m, with snow remaining until July and August in some parts. The Šar Mountain National Park is one of the most significant biogeographical areas in Europe. According to the Institute for Nature Conservation of Serbia, this area is inhabited by 1,800 plant species, of which 339 are Balkan endemics and 18 are local endemics. Moreover, 147 species of diurnal butterflies, 45 species of amphibians and reptiles, about 200 species of birds, and 32 species of mammals have been identified, making this area exceptionally valuable in terms of flora and fauna.

3 Methodology

By applying the previously defined multihazard methodologies, it was possible to conduct scientific research and analysis of the study area's susceptibility to natural hazards.

3.1 Seismic hazard

Seismic hazard data for the 475 year return period in the municipality of Štrpce was taken from the Serbian

Institute of Seismology database (<http://www.seismo.gov.rs>). In the GISs, the value was assigned based on intensity (VII–VIII and VIII MCS), which was later used for modeling the total susceptibility to natural hazards.

3.2 Soil erosion

Nowadays, depending on the database size and satellite images availability, it is possible to determine a degree of erosion intensity and total sediment production by the office work via GIS software packages and later confirm it by fieldwork. By applying an available database and by using the Erosion Potential Model (EPM) model, erosion risk for the territory of the municipality of Štrpce was assessed. By analyzing and processing the most up-to-date data for the researched area, an average erosion coefficient, as well as the total and specific sediment production, were obtained.

Specific annual production of erosion deposits in a catchment area was acquired by dividing the total production of erosion deposits by the catchment area.

As indicated by Ristanović et al. [22], the most widespread model in the Western Balkan countries is the so-called EPM, also known as the Gavrilovic method [43], because it corresponds well with the USLE model used for a wider area of Europe. For the analysis of the state of erosion and sediment production on the territory of the municipality of Štrpce, the applied formula was the one according to which the total sediment production in the catchment area is calculated by the following equation [43]:

$$W_{\text{annu}} = T \cdot H_{\text{annu}} \cdot \pi \cdot \sqrt{Z^3} \cdot F, \quad (1)$$

where W_{annu} represents the total sediment production (m^3/year), T the temperature coefficient, H_{annu} the average annual rainfall in mm, Z an erosion coefficient, and F the catchment area in km^2 .

The EPM model belongs to the group of regional methods, and in the widely spread literature, it is characterized as a semiquantitative method [44,45].

The temperature coefficient (T) is given by the following equation [43]:

$$T = \sqrt{\frac{t}{10} + 0.1}, \quad (2)$$

where t represents an average annual air temperature ($^{\circ}\text{C}$), obtained by analyzing the dependence of changes in temperature on the changes in altitude by using the data from relevant meteorological stations in the region of Metohija, based on the following equation [46]:

$$t = -0.005 \cdot H + 13.84, \quad (3)$$

where t represents an average annual air temperature and H represents a value (in m) obtained through the Digital Elevation Model (DEM).

The average annual precipitation of H_{annu} is obtained by analyzing the dependence of changes in precipitation from relevant precipitation stations in the municipality, based on the following formula [46]:

$$H_{\text{annu}} = 460 \cdot \ln H - 2,384, \quad (4)$$

where H_{annu} is an average annual rainfall and H (m) is a value obtained through the DEM. The erosion coefficient (Z) is calculated on the basis of the following formula [43]:

$$Z = Y \cdot X \cdot (\phi + \sqrt{I}), \quad (5)$$

where Z represents an erosion coefficient; Y the coefficient of soil resistance to erosion; X the coefficient of soil protection from atmospheric factors and erosion; ϕ the coefficient of a type of erosion; and I an average drop in the surface area for which erosion coefficient is calculated.

The coefficient of soil resistance to erosion (Y) was obtained by analyzing a pedological map on the scale of 1:50,000. Depending on the degree of pedological base resistance, the coefficient is classified in the range 0.1–1, with the lowest coefficients having the highest resistance, in this case, lithosol. The highest coefficient belongs to a bulk soil that is the most susceptible to erosion (Table 1).

The coefficient of soil protection from atmospheric factors and erosion (H) was obtained by processing and analyzing a geospatial database on land use – Corine Land Cover (2018), which is published by the European Environment Agency (EEA). In the range of 0.1–1, the highest coefficient is assigned to vegetation-free areas dominated by stronger types of erosion. Due to the extremely developed root system, the good composition of forests is contributing to a large amount of precipitation and to the reduction of erosion intensity. Nonirrigated

Table 1: Coefficient of soil resistance to erosion [43]

Soil type	Y
Fluvisol	0.55
Diluvium	0.80
Lithosol	0.40
Dystric cambisol	0.80
Kalkocambisol	0.60
Brown soil on igneous rocks	0.70
Ranker	0.80
Rendzina	0.65
Terra rossa	0.80

Table 2: Coefficient of land use types

Substrate protection coefficient	X
Discontinuous urban fabric	0.25
Nonirrigated arable land	0.80
Pastures	0.50
Land principally occupied by agriculture, with significant areas of natural vegetation	0.55
Broad-leaved forest	0.20
Coniferous forest	0.15
Mixed forest	0.15
Natural grasslands	0.40
Moors and heathland	0.50
Transitional woodland-shrub	0.40
Sparsely vegetated areas	0.90

agricultural areas and areas with sparse vegetation are very prone to erosion effects (Table 2).

The coefficient of a type of erosion (ϕ) was determined by using the Bare-Soil Index (BSI). Multispectral satellite images from Landsat 8 satellite, which belongs to the United States Geological Survey, were used for obtaining this index. Recordings for 2015, 2017, and 2019 were analyzed and so the final result represents an average BSI used to analyze the erosion intensity. The remote detection technique is very important in the field of regional soil erosion assessment [47–51]. This index enables easier and more efficient erosion intensity calculation. The BSI is obtained by using the following formula [52]:

$$BSI = \frac{(B6 + B4) - (B5 + B2)}{(B6 + B4) + (B5 + B2)}, \quad (6)$$

where B6 (Band 6) is a shortwave infrared spectral channel (SWIR 1), B4 (Band 4) is a red spectral channel, B5 (Band 5) is a near-infrared spectral channel (NIR), and B2 (Band 2) is a blue spectral channel.

An average slope of terrain (\sqrt{I}) was obtained by using the DEM with a resolution of 25 m, in the form of percentage expressed in decimals. EU-DEM was taken from the website of the EEA's Copernicus program [53]. It is important to note that in line with the slope increases, the slope stability decreases, while erosion intensity increases as well as torrential floods occurrence probability [54].

3.3 Torrential floods

For the area of the municipality of Štrpce, an analysis of terrain predisposition for the occurrence of torrents was conducted using GIS.

The method used for torrential floods was the Flash Flood Potential Index (FFPI). This method is most commonly used in the world and the region [55–57]. The method was developed at the Colorado Basin River Forecast Center. The FFPI is determined by using GIS software tools through a statistical approach based on the principle of established correlation between different factors and spatial distribution of particular basin drainage, or a research approach, i.e., indexing the weight factors or allocating weighting factor to each factor affecting the occurrence of torrential floods based on empirical experience [58–62]. It was developed primarily because predictions of torrential floods by means of meteorological parameters did not provide satisfactory results, while the connection between the occurrence of this disaster and certain physical–geographical characteristics of territory was not defined. Soil structure and texture are the main characteristics that define water retention and infiltration. Terrain geometry, primarily slope, determines the rate and concentration of the outflow. The percentage of atmospheric water retention on a surface primarily depends on the main characteristics of the vegetation. For example, seasonal changes in the vegetation of deciduous forests significantly affect the possibility of torrential flood development, while in addition to changes in vegetation, forest fires negatively affect the soil, where the power decreases due to the organic matter burning infiltration. Land use and especially urbanization play an important role in the process of water infiltration, concentration, and outflow behavior. Together, these natural conditions provide information on the possibility of torrents occurring in a particular area [58].

The following natural conditions were analyzed in order to identify the likelihood of torrential floods in the municipality of Štrpce: terrain slope, soil types, vegetation density, and land use type.

The FFPI method was obtained based on the following formula [58]:

$$FFPI = \frac{M + S + L + V}{4}, \quad (7)$$

where M is a terrain slope, S represents soil types, L is the land use, and V represents a BSI.

The terrain slope (M) was obtained by using GIS software packages, based on an EU-DEM with a spatial resolution of 25 m taken from the EEA's Copernicus program website. First, the slope was calculated, expressed as a percentage, and then the following formula was applied:

$$M = 10^{n/30}, \quad (8)$$

where n is a terrain slope expressed in %. If n is greater than or equal to 30%, then the M value is always 10. For

Table 3: Soil type coefficients

Soil type	<i>S</i>
Fluvisol	3
Diluvium	8
Lithosol	6
Brown soil on igneous rocks	5
Kalkocambisol	6
Dystric cambisol	7
Terra rossa	7
Ranker	7
Rendzina	6

the soil type (*S*) analysis, a pedological map was used on a scale of 1:50,000. The classification of soil types was analyzed depending on the soil type's susceptibility to torrents (Table 3).

The highest coefficient was assigned to a soil type that is most susceptible to a torrential flood occurrence.

The land use index (*L*) was calculated by using the data obtained from a geospatial database of the EEA – Corine Land Cover (2018), where certain land use classes were given values from 1 to 10, depending on the main significant characteristics for the occurrence and development of torrential floods. The most susceptible terrains are nonirrigated agricultural areas and areas with sparse vegetation, which were assigned a coefficient of 9 (Table 4).

The BSI was used for a vegetation density index *V*. Multispectral satellite images from Landsat 8 satellite were processed to obtain this index. In the field of the regional assessment of soil erosion and torrents, the remote detection technique has great potential and advantages [49,51]. The following formula was used to obtain the *V* coefficient:

Table 4: Land use coefficients

Land use	<i>L</i>
Discontinuous urban fabric	4
Nonirrigated arable land	9
Pastures	6
Land principally occupied by agriculture, with significant areas of natural vegetation	7
Broad-leaved forest	3
Coniferous forest	2
Mixed forest	3
Natural grasslands	5
Moors and heathland	6
Transitional woodland-shrub	5
Sparsely vegetated areas	9

$$V = 7.68 \cdot \ln(\text{BSI} + 1) + 8. \quad (9)$$

To avoid negative sums, a value of 1 has been added.

3.4 Snow avalanches

In the last 220 years, numerous human lives have been lost. With the tourism development of Brezovica Ski Center and by engaging the mountain rescue service, parts of terrain with a higher risk of avalanches have been marked as unfavorable and skiing-prohibited, in order to provide safety for tourists during the winter and spring period. All prerequisites for the occurrence of avalanches can be divided into two main groups. The first group includes invariable conditions of a position (altitude, relief, geological substrate, slopes and roughness of slopes, aspect, vegetation, and neotectonic activity), while the second group consists of variable, meteorological parameters, such as the current weather situation, snow cover condition, temperature, wind dynamics and direction, clouds, total snow depth, snow structure, etc. [34].

The following formula was used for the analysis of terrain susceptibility to avalanches, depending on the significance of parameters:

$$\text{AVAPI} = S^{(20-60^\circ)} \cdot \frac{1.5A + R + \text{SN} + 0.5V}{4}, \quad (10)$$

where *S* is the terrain slope, *A* is an aspect class, *R* is a terrain roughness class, *SN* is a snow depth class, and *V* is the vegetation.

The terrain slope is perhaps the most important parameter for the analysis of susceptibility to avalanches. Slope significantly affects the length and triggering of avalanches. Extremely flat and extremely steep terrains are very unsuitable for the formation of avalanches. Numerous authors stated that avalanches are most common on terrain slopes of 30–60° [63,64], 28–60° [65], and 30–50° [66]. On Šar Mountain, mapped avalanches also appeared at 20°, which is the main reason why the analysis of avalanches for this area included a slope of 20–60°. The terrain slope was obtained by using 25 m resolution DEM.

An important morphometric condition is the terrain aspect or exposure. Based on 25 m DEM, exposure plays a major role in retaining snow cover, depending on terrain insolation. Terrains facing south will be more susceptible to faster snow melting due to a longer effect of solar radiation, while the snow lasts much longer within northern exposure, which favors the formation of avalanches (Table 5).

Table 5: Terrain exposure and soil roughness classes

Aspect	Roughness	Value
Southwest, Southeast, South	50–100	1
West, East	25–50	2
North, Northwest, Northeast	0–25	3

Terrain roughness significantly affects the formation and movements of avalanches. Slopes that are overgrown with low (grassy) and sparse vegetation have the least roughness, while such terrains are most suitable for the movement of avalanches. The algorithm is derived from the GDAL DEM utility. Terrain roughness was determined and classified into three classes by using QGIS and DEM software packages. A value of 3 was assigned to terrains with a smooth surface dominated by low vegetation (Table 5).

The basic condition for the formation of avalanches is the existence of a snow cover. In the municipality of Štrpce, especially in Brezovica Ski Center, the snow depth in the winter months often exceeds 1 m. The snowfall on Šar Mountain and the surrounding mountains is frequent, so large amounts of newly fallen snow cannot stably bind to the existing snow, creating preconditions for the avalanche formation.

With increasing snow depth, snow stays on a surface longer and therefore the chances for formation and triggering of avalanches are greater. The 6 months (November–April) snow depth was analyzed for the period between 2007 and 2018 (Table 6). Data for the snow depth calculation were downloaded from the Snow-Forecast database. According to the available data, an average six-month amount of snow cover has been obtained by analyzing the dependence of changes in the amount of the snow cover from locations for which data were available.

Vegetation significantly affects the formation and movement of avalanches. Forests and woody–shrubby vegetation largely prevent the formation of avalanches, as well as the transport of surface loose material. The Normalized Difference Vegetation Index (NDVI) was used for the vegetation analysis based on the following formula [67–69]:

Table 6: Snow depth classes

Snow depth (cm)	Value
15–20	1
20–25	2
25–31	3

Table 7: Vegetation classes

NDVI value	Value
0–0.4	3
0.4–0.6	2
0.6–1	1

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})}, \quad (11)$$

where NIR is the near-infrared band and RED is the red infrared band.

Satellite images from Sentinel-2 satellites with a 10 m resolution were used. Analyzed recordings were from 2019. After index processing, classification was approached. Values of 0–0.4 represent grassy and sparse vegetation that is very highly suitable for avalanches' formation and movement (Table 7).

Values between 0.4 and 0.6 represent shrubby vegetation, while all values above 0.6 represent forest vegetation that is not suitable for avalanche formation.

3.5 Forest fires

In the territory of the municipality of Štrpce, forest fires (especially during summer) are a regular occurrence that has a negative impact on the state of the environment. Although the municipality is rich in forest ecosystems (50.54% of the entire area), the percentage of forest cover decreases every year due to anthropogenic impacts in the form of causing forest fires and illegal logging. Risk analysis for the occurrence of forest fires in the area would greatly contribute to determining adequate preventive measures for protecting the forests from fire.

For the forest fire hazard analysis, the following formula is used in order to determine the susceptibility to forest fires [70]:

$$\text{RC} = 7\text{VT} + 5(\text{S} + \text{A}) + 3(\text{DR} + \text{DS}), \quad (12)$$

where RC represents an index of susceptibility to forest fires, VT indicates a vegetation type with five classes, S is a slope factor with five classes, A is an aspect variable with five classes, and DR and DS indicate the distance from the road and settlements. The type of vegetation is the most important factor, followed by the slope and aspect, while the human factor expressed through distance from roads and settlements comes third. Each of these indices is assigned a value from 1 (minimum susceptibility) to 5 (maximum susceptibility), which are given in Table 8.

Table 8: RC index calculation classes [70]

Value	Vegetation	Slope (°)	Aspect	Distance from roads (m)	Distance from settlements (m)
1	Discontinuous urban fabric	<5	N	>600	>400
2	Complex cultivation patterns, nonirrigated arable land, sparsely vegetated areas	5–10	Unexposed	450–600	300–400
3	Pastures and natural grasslands, land principally occupied by agriculture, with significant areas of natural vegetation, moors, and heathland	10–25	E	300–450	200–300
4	Broad-leaved forest	25–35	W	150–300	100–200
5	Coniferous and mixed forest, transitional woodland-shrub	>35	S	<150	<100

The aspect was classified into four cardinal points, with an additional class representing unexposed areas. The greatest value was assigned to southern exposure due to the longest exposure to the Sun. Satellite images and topographic maps were used in order to calculate the index of distance from roads, settlements, and buildings, while appropriate contents were digitized, and finally, buffer zones of appropriate width were made.

The vegetation type index was obtained by using the Corine Land Cover geospatial database (2018). Areas were singled out by the type of vegetation represented within them and they were assigned the values from 1 to 5. The least susceptible are larger settlements, as the chances of a fire in such areas are extremely small. The terrain slope and exposure were obtained based on 25 m resolution DEM. The slope was expressed in degrees and divided into several classes, with terrains with a higher degree of slope having the greatest value due to greater inaccessibility, i.e., less availability.

3.6 Overall susceptibility to natural hazards

To model the overall susceptibility to natural hazards of the municipality of Štrpce, a hierarchy was established in relation to the probability of an occurrence in a certain area, the frequency of occurrence, and accompanying

consequences. Problems of decision-making are occurring every day, starting from elementary problems to very complex situations [71,72]. The AHP method is one of the most commonly used methods in decision-making, developed by Saaty. Its goal is to quantify a relative priority of the given set by an appropriate value scale. The multiple decision criteria method has been especially popular in the last few decades. It has been applied for the needs of rural development based on geological and geomorphological factors and also to assess the danger of floods in urban areas [73,74].

A concrete decision is usually based on the perception of an individual who should make the final decision and assess priorities by emphasizing the importance of consistency and correlation of alternatives that are compared throughout the decision-making process [75,76]. The total susceptibility of the terrain to natural hazards was estimated by using the AHP method and processed five criteria. The area of the municipality of Štrpce is not equally endangered by all natural hazards and so each was assigned a weighting factor, which was obtained by the AHP method (Table 9).

The criteria referred to in Table 9 are interrelated in matrix 1 to calculate the weighting coefficient for each criterion.

The mathematical operation of squaring the matrix yields a new matrix. In it, by summing the values for each

Table 9: Assigning values and comparison between all parameters

Criterion	Forest fires	Seismic hazard	Torrents	Snow avalanches	Erosion	Weight coefficient
Forest fires	1	1.5	2	2.5	3	0.339
Seismic hazard	0.667	1	1.5	2	2.5	0.251
Torrents	0.5	0.667	1	1.5	2	0.182
Snow avalanches	0.4	0.5	0.667	1	1.5	0.131
Erosion	0.333	0.4	0.5	0.667	1	0.097

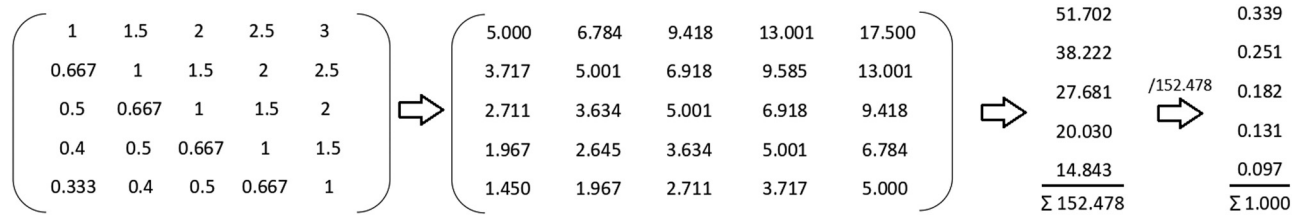


Figure 2: Matrix 1 and matrix 2.

row of the matrix (criterion) and dividing each sum of the row by the total sum, we get a coefficient, i.e., significance for each criterion (Figure 2).

In order to determine the validity of the matrix, the following parameter values are included:

$$\lambda_{\max} = 5.019; \quad CI = 0.004; \quad CR = 0.003, \quad (13)$$

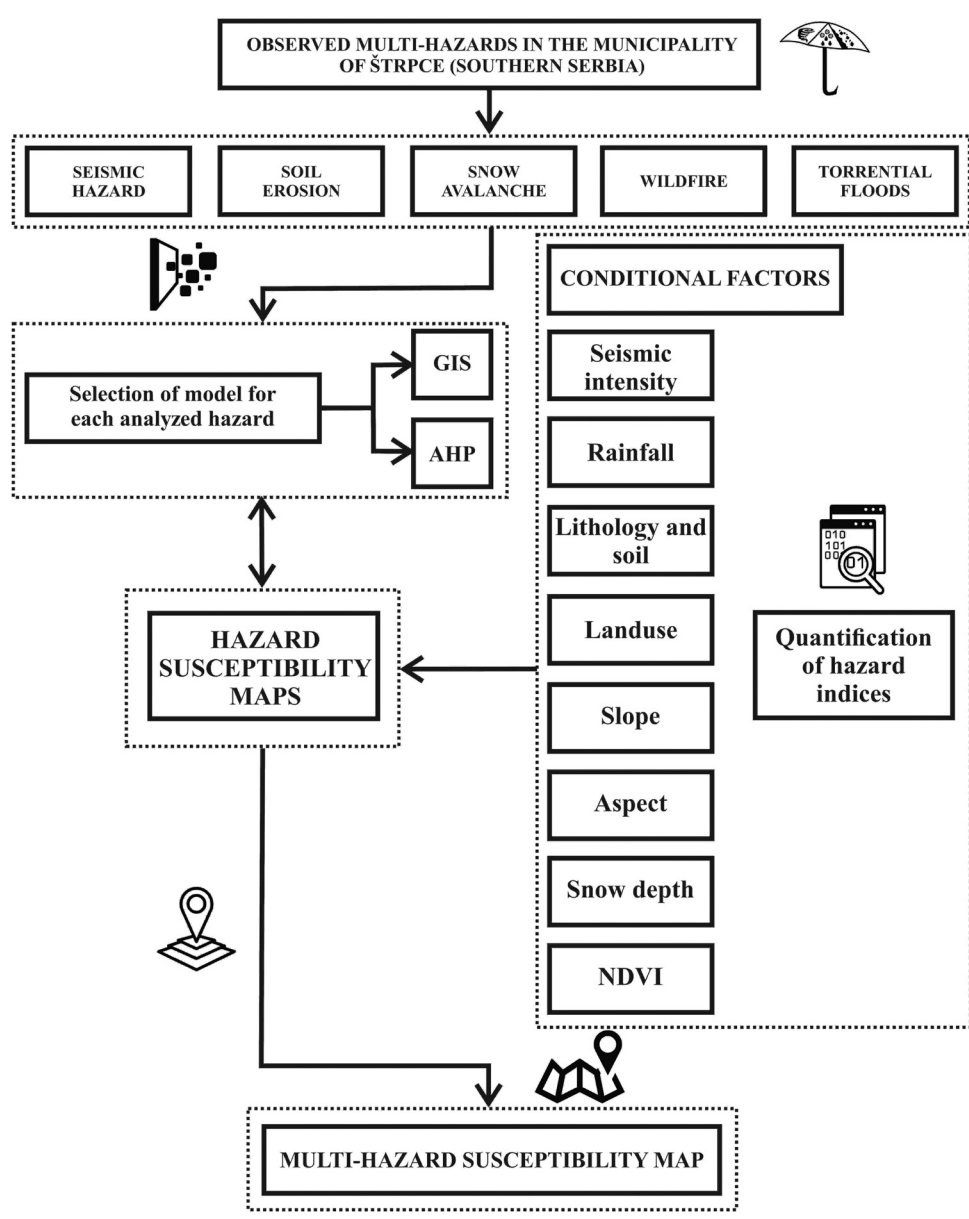


Figure 3: Flow chart of procedures used in this research.

where λ_{\max} is the maximum eigenvalue of the matrix; CI is the consistency index and CR is the consistency ratio.

Fires have the highest frequency of all natural disasters in Štrpce, which is the main reason why they were assigned the greatest weighting factor (0.339). During the summer months, tens to hundreds of hectares of land are affected by forest fires, mostly caused by human negligence. Earthquakes are rare in the municipality of Štrpce but this area is prone to intensive seismic activity of a magnitude up to VIII MCS. Therefore, this disaster was assigned a weighting factor of 0.251. The last major earthquake (VIII MCS) was recorded 99 years ago. Although there is potential, greater torrents in the municipality of Štrpce have not been recorded in the last 40 years, and therefore, were assigned a coefficient of 0.182. Avalanches represent a great threat to tourists and buildings located at high altitudes on Šar Mountain and hence avalanches were assigned a coefficient of 0.131. Soil erosion is an important factor for the entire analysis of natural disasters in this area; for the municipality of Štrpce, the weight coefficient for erosion is 0.097. In addition, a high degree of erosion carries away large amounts of soil and increases water retention on surfaces [77,78].

Intensive washing away and removal of particles from the loose substrate would significantly reduce agricultural productivity, which is at a satisfactory level in this municipality. Based on the obtained weight coefficients, total susceptibility to natural disasters was processed. Classes of each criterion are multiplied by weighting coefficients, and then their results are added up:

$$0.339 \cdot F + 0.251 \cdot Z + 0.182 \cdot T + 0.131 \cdot A + 0.097 \cdot E, \tag{14}$$

where F represents forest fires, Z the seismic hazard, T the torrential floods, A the snow avalanches, and E the erosion. After summarizing the research results, they were classified into four risk classes: low, medium, high, and very high.

All procedures and approaches used for the purpose of this research are presented in the flow chart given in Figure 3.

4 Results

4.1 Seismic hazard analysis

According to the obtained data, an area of 141.47 km² (60.8% share in the territory) has a potential intensity

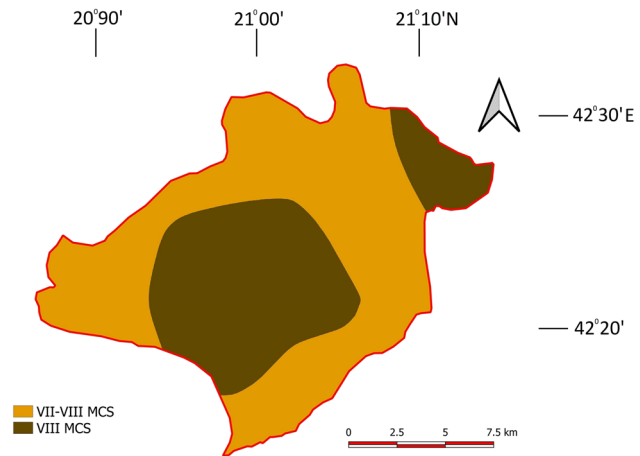


Figure 4: Seismic hazard for a 475 year return period.

MCS of 7–8, while at 91.07 km² (39.2% share in the territory), the estimated seismic hazard has a magnitude of 8 MCS.

Occurrences of autochthonous earthquakes have been registered in the northwestern, central, and southeastern part of the municipality, VII–VIII MCS, indicating that great attention regarding seismic hazards should be paid to the territories outside the municipality [34]. Based on a seismic hazard, the magnitude of potentially strongest earthquakes for the following 475 years would be VII–VIII and VIII MCS (Figure 4).

4.2 Erosion intensity

An erosion intensity map for the municipality of Štrpce was obtained by using the EPM model, as well as by analyzing and processing a terrain slope, land use type,

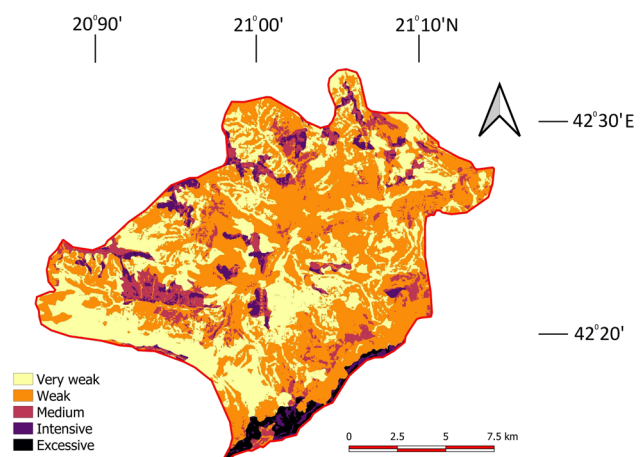


Figure 5: Erosion intensity map.

Table 10: Types of erosion intensities

Type of erosion	Area (km ²)	Share in the territory (%)
Very weak	78.40	33.67
Weak	116.50	50.03
Medium	24.47	10.51
Intensive	9.12	3.92
Excessive	4.38	1.88
Total	232.87	100.00

BSI, and pedological cover. The average erosion coefficient is 0.34 (Figure 5).

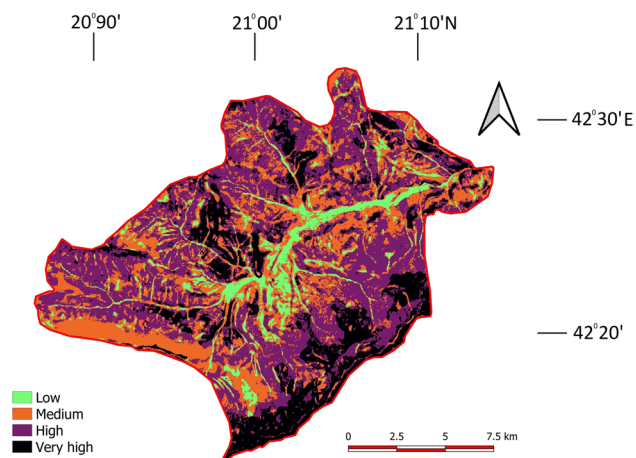
The erosion intensity situation in Štrpce is generally satisfactory. Most of the municipality (50.03%) is characterized by weak erosion. One-third of the municipality is affected by a very weak erosion (Table 10).

Excessive erosion occurs in the southern part of the municipality, on the slopes of Šar Mountain with sparse vegetation, pronounced terrain slope, and a large amount of precipitation.

In this area, it is necessary to consider the entire erosion situation on the ground, as well as to take appropriate anti-erosion measures in order to reduce the erosion intensity and therefore soil loss. The total sediment production in the municipality is 131.795 m³/year, while the specific sediment production is 565.96 m³/km²/year.

4.3 Susceptibility to torrential floods

By processing and analyzing the main characteristics of the terrain slope, land types, land use, and BSI, a map of the terrain's susceptibility to torrential floods was obtained (Figure 6).

**Figure 6:** Map of terrain susceptibility to torrential floods.**Table 11:** Terrain susceptibility to torrential floods

Susceptibility to torrents	Area (km ²)	Share in the territory (%)
Low	19.02	8.17
Medium	69.03	29.64
High	100.91	43.33
Very high	43.91	18.86
Total	232.87	100.00

A large part of the municipality of Štrpce has a high (43.33%) and very high (18.86%) susceptibility to the occurrence of torrential floods (Table 11). Low and medium susceptibility is mainly present in central (the Lepenac

**Figure 7:** Photographs from the field indicating susceptible areas due to great terrain slope, absence of forests, and presence of bare and loose soil (Photo: U. Durlević).**Figure 8:** Photographs from the field indicating areas most prone to torrents (Photo: U. Durlević).

valley) and southwestern parts of the municipality. Areas most prone to torrents are characterized by a great terrain slope, absence of forests, and bare and loose soil.

Due to large amounts of precipitation in a short period of time, the rivers flowing through such terrain can be extremely dangerous for the population and the environment (Figures 7 and 8).

It is necessary to determine and implement concrete protective measures against torrential floods through the combination of GIS software packages and field research in order to prevent their harmful effects. Local self-government units, in cooperation with provincial and state services, can provide funds for the implementation of biological and biotechnical measures that would significantly reduce high and very high torrential flood risk in a terrain.

4.4 Susceptibility to snow avalanches

By processing the available data in GIS software packages, a map of terrain susceptibility to avalanches was obtained (Figure 9). On a 9.1 km² of the municipality area, there are favorable conditions for the formation of avalanches, while chances for avalanches in other parts of the municipality are very small.

Susceptibility to avalanches occurs in southern and western parts of the municipality, on the slopes of Šar Mountain, on Ošljak ridge, Čerenački peak, and Ostrvica peak. Field research is needed in order to confirm the obtained results of the conducted office work and to prohibit any anthropogenic activity during the winter and spring period in avalanche-prone terrain. To prevent or mitigate the effects of avalanches, it is possible to afforest terrains at risk with species represented at high altitudes

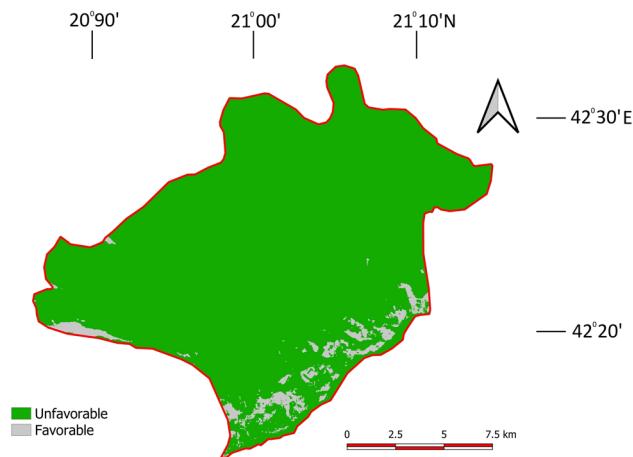


Figure 9: Map of susceptibility to snow avalanches.

(Heldreich’s pine and Balkan pine), in order to prevent the accumulation of large snow masses. Another method is to build special fences that restrict the movement of snow deposits.

4.5 Susceptibility to forest fires

Based on the analysis and processing of existing data in GISs, the susceptibility map of forest fires of the municipality of Štrpce was obtained. Susceptibility was divided into four classes: low, medium, high, and very high (Figure 10).

Due to a significant area under the forest cover (117.72 km²) and a relatively great terrain slope, the municipality generally has high susceptibility to forest fires (Table 12). Terrains with a large slope and southern exposure are the ones that are most vulnerable to forest fires. These are mostly coniferous or mixed forests that are relatively close to roads and settlements.

More than half of the municipality area is highly susceptible to forest fires, while the area of almost 20 km² has a very high susceptibility. Medium susceptibility occurs in

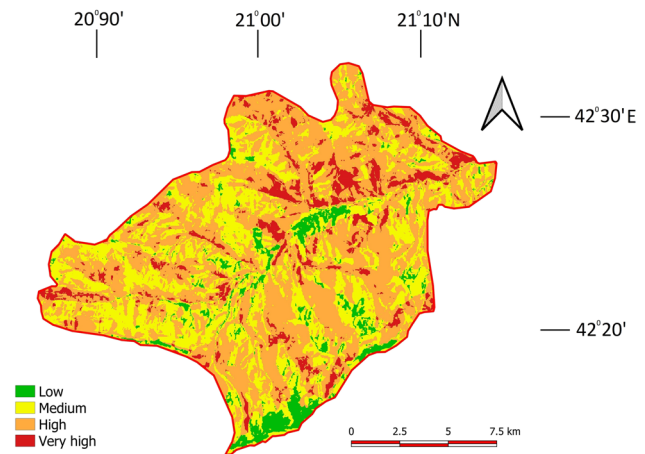


Figure 10: Map of terrain susceptibility to forest fires.

Table 12: Terrain susceptibility to forest fires

Susceptibility to forest fires	Area (km ²)	Share in the territory (%)
Low	13.49	5.79
Medium	77.67	33.35
High	122.01	52.40
Very high	19.79	8.50
Total	232.86	100.00

one-third of the territory, while low susceptibility is represented in 5.79% of the municipality.

4.6 Modeling the total susceptibility to natural hazards

Obtained results are of great importance for the local community and all institutions dealing with environmental protection and emergency management because they provide an overview of potentially most endangered locations in this area.

When considering the total susceptibility to natural disasters (Figure 11), the municipality is dominated by a medium and high susceptibility, found on 93% of the municipality.

Low susceptibility (5.23%) most often occurs in the central part of the municipality, while very high susceptibility occurs in central, southern, and eastern parts of the municipality, with a total share of 1.71% (Table 13).

For more efficient environmental management, it is necessary to identify areas within all settlements that have

a high and very high susceptibility to natural disasters and to implement concrete protective measures that would reduce the possibility of occurrence of all analyzed disasters.

5 Discussion

5.1 Seismic hazard

The area of Šar Mountain is an extremely seismically active area in Serbia. The municipality of Štrpce is not endangered by stronger autochthonous earthquakes but it is occasionally exposed to a seismic action with epicenters at greater or lesser distances. Contemporary earthquake data indicate that the occurrence of catastrophic earthquakes was registered in 1457 when an IX MCS earthquake hit the region near Prizren. A strong earthquake occurred in 1921 in the Uroševac-Vitina direction; in the municipality of Štrpce, it was registered with an intensity of VIII MCS. In the municipality of Štrpce, a seismic hazard was identified for a 475 years return period, relying on the official maps of the Seismological Survey of Serbia. The obtained results (VII–VIII MCS and VIII MCS) indicate that it is necessary to observe the modern seismic design standards to avoid or mitigate significant human and material losses.

5.2 Soil erosion

The main consequence of soil degradation is represented in the form of a significant reduction of soil productivity, which directly affects those whose employment depends on this natural resource [79].

In order to improve soil erosion management and help decision-makers in adopting appropriate remediation measures and mitigation strategies, the first step is to monitor and assess the system to obtain adequate and reliable information on soil erosion in the current climate and land use conditions [48,80]. In the southern, northern, and central territories of the municipality of Štrpce, 16.31% of the area is affected by medium, intensive or excessive erosion. Therefore, it is necessary to implement adequate agrotechnical measures on agricultural plots affected by stronger erosion and assess whether soil quality is suitable to pursue agricultural activities. For other territories not cultivated by man, it is also necessary to determine biological and technical measures to mitigate erosion effects (afforestation, grassing over).

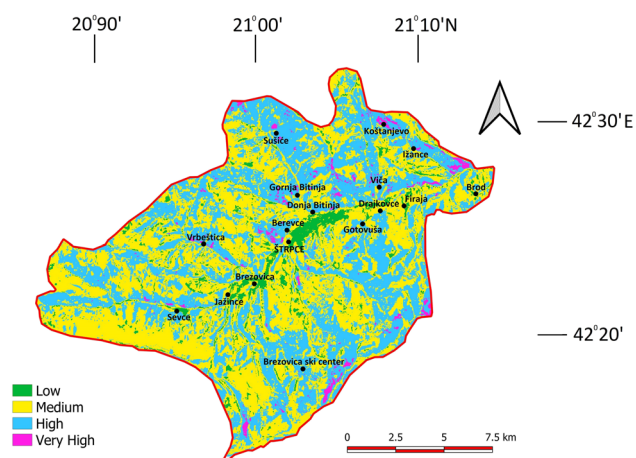


Figure 11: Map of the total susceptibility to natural hazards.

Table 13: Classes of total susceptibility to natural hazards

Susceptibility	Area (km ²)	Share in the territory (%)
Low	12.12	5.23
Medium	115.12	49.66
High	100.60	43.40
Very high	3.97	1.71
Total	231.80	100.00

5.3 Torrential floods

The emergence of natural and anthropogenic extremes around the world leads us to pay more attention to their impacts on the environment and the economy [81,82]. In all their various forms, floods are the most common type of natural disasters that are occurring worldwide [83,84]. Among the natural hazards with the highest risk for people and their activities, torrential floods are considered as the most common danger in Serbia [20,85] as well as the most significant in terms of great material damage and loss for humans lives. The frequency of these events, their intensity, and representation throughout the country make them a constant threat with serious consequences for the environment, economic, and social sphere [20]. In Serbia, more than 12,000 watercourses have been identified as having a torrential character [38]. Identifying locations that are the most susceptible to torrents is of great importance, as the largest part of arable land is located near rivers.

Due to the great ecological significance of this study area, it is necessary to continuously monitor the state of the environment. Large amounts of precipitation in a short period of time and a pronounced terrain slope are the main causes of the occurrence of torrential floods. In the last 100 years, great torrential floods have been recorded in 1953 and 1979, when the Lepenac River destroyed houses and bridges in the municipality. As with soil erosion, areas susceptible to torrential floods (very high and high susceptibility) need to be subjected to biotechnical and biological measures aimed at environmental protection.

5.4 Snow avalanches

Snow avalanches are one of the biggest threats for people, buildings, and roads and they are greatly affecting mountain ecosystems [86]. Snow avalanches that contain rocks, soil, broken trees, or ice, apart from snow, are characterized by short, local, dynamic occurrences in many mountainous areas [87].

The territory of the municipality is predisposed to the occurrence of snow avalanches if it is located on a suitable slope of terrain (20–60°), where a large amount of snowfall and the absence of woody vegetation (high mountain meadows and pastures) are recorded.

Terrains susceptible to avalanches are characterized by a high slope, north-facing aspects, a low degree of surface roughness, deep snow cover, and sparse vegetation. Such territories can be dangerous for tourists and

infrastructure within the Brezovica Ski Center. Therefore, it is necessary to implement avalanche protective measures, i.e., to afforest the terrain with particular species to maintain and increase snow load stability.

5.5 Fire hazards

Forest fires are one of the most common natural disasters. Apart from weather conditions, there are many other factors that influence the occurrence of forest fires [88]. Due to the increase in global temperature on the Earth, but also due to expressed human negligence, enormous areas are affected by fire each year, both in Serbia and in the world. In 97% of cases, forest fires are caused by humans; however, natural conditions determine a predisposition of territory for fires, and therefore, the analysis of natural conditions is the key for determining the level of endangerment of the concrete area [54]. The Republic of Serbia is covered by approximately 31.1% (27,480 km²) of the forest, The fires in the period 1990–2005 destroyed 43,000 ha of forest cover in Serbia [89].

Some settlements of the municipality of Štrpce are highly or extremely prone to fires. In addition to the impact on the population, fires have a significant negative impact on flora and fauna, which is exceptionally diverse in this part of Serbia. Therefore, satellite monitoring [90] of vegetation conditions and installing sensors in endangered areas would facilitate environmental management in this part of the Šar Mountain National Park.

5.6 Total susceptibility to natural hazards

Total susceptibility to natural hazards can provide a good overview of vulnerable zones aimed at protecting the environment, and natural and cultural heritage [69,91,92]. Based on the field experience, the weighting coefficients for each geohazard have been determined using the AHP method. Due to the highest frequency of forest fires, this hazard has been assigned the highest weighting coefficient. It is followed by seismic hazards, torrential floods, avalanches, and soil erosion. Processing the five criteria in GIS software gives the results of the total terrain's susceptibility to geohazards.

More than 45% of the municipality of Štrpce territory has been identified as susceptible or very susceptible to natural hazards. A large number of settlements belong to one of these two classes: Sušiče, Koštanjevo, Ižance, Viča, Gotovuša, Vrbeštica, Donja Bitinja, Berevce, Sevce, and Brezovica Ski

Center. In these places, it is first necessary to consider individually which natural hazard is the most dominant in order to implement adequate preventive measures.

6 Conclusion

Vulnerability analysis of the territories that are most sensitive to natural hazards will enable more adequate and efficient adoption of preventive measures and more correct environmental management actions by local, provincial, and state services. Due to its morphometric characteristics, geographical position, the richness of biodiversity and geodiversity, the municipality of Štrpce is an ideal territory for the analysis of natural hazards. In GISs, by using the relevant data for the entire researched area, the terrain was analyzed for susceptibility to forest fires, earthquakes, torrents, avalanches, and erosion. Forest fires are identified as the most common natural disaster in the municipality. More than 60% of the municipality area is susceptible or very susceptible to forest fires. As for earthquakes, Šar Mountain foothills are seismically very active, so larger magnitude earthquakes (VII–VIII MCS) might occur on the territory of Štrpce or in the surrounding municipalities. Assessing the seismicity of existing buildings and observing standards when constructing future buildings would significantly contribute to protecting the population from potential earthquakes.

Torrential floods have not been a problem in the municipality of Štrpce for the past 40 years, but nowadays more than half of the municipality's area is highly and very highly susceptible to torrential floods. More than 18% of the territory is very susceptible to torrential floods. During the winter and spring, snow avalanches could cause great damage in the form of casualties, damage to buildings, and natural devastation. The terrain area prone to avalanches is 9.1 km² and covers the area of the highest parts of Šar Mountain, Ošljak, Ostrvica, and Čerenački peak.

In the researched area, it was determined that the mean erosion coefficient is 0.34, which corresponds to the category of weak erosion. In addition to the increase in the erosion coefficient, only 5.8% of the municipality area is affected by strong and excessive erosion. By analyzing five disasters and by using the methods such as GIS and AHP, a map of the total terrain susceptibility to natural disasters was obtained, on which almost 105 km² of the municipality area is highly or very highly susceptible. In this area, which is a part of the Šar Mountain National Park, it is necessary to combine the obtained results with field research in order to greatly preserve

and improve the geodiversity and biodiversity of the area. Public companies dealing with nature protection, in cooperation with provincial and state environmental institutions and local environmental movements could take measures to protect and improve the territory by monitoring and auditing environmental elements in order to mitigate the risk of natural disasters in the municipality of Štrpce. Furthermore, standardization and implementation of the multihazard methodologies would be an important step toward more qualitative monitoring and identification of natural disasters at a local and regional scale in the Republic of Serbia. Such an approach would highlight the importance of the risk assessment and management programs, which are currently being developed in this part of Southeast Europe.

In the end, this research could be further extended by a larger investigation. This investigation may cover the entire territory of the Republic of Serbia. The maps and calculations from this research may serve as the basis of a potential project of hazardous events. Šar Mountain presents an area not investigated enough, with specific and very rare nature in this part of the Balkan Peninsula. After this research, we can find better ways for protecting this specific area. Environmental devastation in the future may be prevented by means of precise numerical and GIS analysis. Thus, the lives of people and properties may be saved and protected.

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