Multi-Hazard Susceptibility Assessment: Case Study – Municipality of Štrpce (Southern Serbia)

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Multi-hazard susceptibility assessment: Case study – Municipality of Štrpce (Southern Serbia)

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Abstract
The Municipality of Štrpce (Southern Serbia) is an area located within the Šar Mountain National Park, and due to its great ecological importance, it was necessary to analyze the terrain susceptibility to the occurrence of natural hazards. The main goal of this research is to determine the locations that are most susceptible to natural hazards (earthquakes, erosion, torrential flooding, snow avalanches and forest fires) on the territory of the municipality of Štrpce. By utilizing the geographic information systems (GIS), the first step was to analyze seismic hazard for a 475-year return period (VII-VIII MCS for the observed area). The second step was to determine the intensity of erosion and total sediment production using erosion potential model (EPM). The mean erosion coefficient is quantified to 0.34, and the total sediment production is 131.795 m^3/year. The third step was the analysis potential of torrential floods using the Flash Flood Potential Index (FFPI). This method indicated that 43.33% of the municipality is highly susceptible, and 18.86% is very highly susceptible to torrential floods. The Avalanches Potential Index (AVAPI) method was used for the fourth step which involved determining the area prone to the occurrence and movement of avalanches. It was determined that 9.1 km^2 of the municipality area is susceptible to this type of hazard. The fifth step included the analysis of the terrain susceptibility to the occurrence of forest fires. More than half of the municipal area (52.4%) is highly susceptible, and 8.5% is very highly susceptible to forest fires. Following the five criteria analysis, weight coefficients were assigned for each of the analyzed parameters using the analytical hierarchy process (AHP), giving the result of the total susceptibility of the territory of Štrpce to natural hazards. Results indicated that over 45% of the municipality is highly or very highly prone to various natural hazards. This paper presents a significant step towards better understanding and more adequate management and mitigation of natural hazards not only in the investigated area, but on regional and national levels as well.

Keywords GIS, seismic hazard, erosion, torrential floods, snow avalanches, forest fires

INTRODUCTION

As pointed out by Alcántara (2002), the term natural hazard is associated with the manifestation of a natural phenomenon which acts hazardously in spatio-temporal context. The term is referring to various agents who encompass geological and hydrometeorological processes (Keller and De Vecchio 2016). They are causally bonded to natural disasters, which, according to Kovačević-Majkić (2014) are defined as sudden events caused by high-magnitude natural processes which affect regular human activities, cause casualties, loss or damage of property to an extent that is surpassing the capacity of a certain community to cope with them.

Hence, natural hazards do not pose the greatest threat to humanity (Blaikie et al. 2014), but, depending on the magnitude of their impact and consequences, can affect an area to a greater or lesser extent (e.g. Lukić et al. 2013, 2016, 2017, 2018a; Lukić et al. 2018b; Durlević et al. 2019).

Serbia is a continental country located in Southeast Europe, in the Balkan Peninsula. Due to its specific geographical position on the border of the southeast part of the Pannonian Basin and the Balkan Peninsula, it has faced different types of natural disasters over the past more than 100 years. In the period from 1900 to 1940, there were 100 natural disasters every decade. Between 1960 and 1970 there were 650 natural disasters, between 1980 and 1990 their number reached 2.000, and during the ten-year period between 1990 and 2000, the number of disasters rose to 2800 (Lukić et al. 2013).

The investigated territory of the municipality of Štrpce (Southern Serbia) is part of the Šar Mountain National Park and research into the area's susceptibility to natural hazards is very important due to multi-level relationship between natural and social processes. Good knowledge of natural conditions in a particular territory is essential for adequate analysis of the natural disasters threat. The richness of flora and fauna in this area may be threatened by the effects of natural disasters and anthropogenic impact. In addition, beside environmental impact, these processes affect human communities and infrastructure as well. Using geographic information systems (GIS) and available databases, the municipality susceptibility was analyzed in regard to seismicity, erosion, torrential floods, avalanches and forest fires.

Seismic hazard analysis can be performed using a probabilistic and deterministic approach (Borges et al. 2020). In deterministic sense, seismic hazard analysis was estimated for specific earthquake magnitude (Anderson, 1997;

Krinitzsky, 2002; Hayashi and Yashiro 2019). The Šar Mountain foothills are known to be a very seismically active zone, so knowledge of seismic hazard is of great importance for the vulnerability assessment of this area.

As pointed out in numerous studies, soil erosion is regarded as one of the major global problems, which causes significant environmental and socio-economic impact (Eswaran et al. 2001; Manojlović et al. 2012; Ighodaro et al. 2013; Gomes de Souza et al. 2018). In Serbia, approximately 86% of the territory has the potential for soil erosion of different intensity. Stronger erosion categories are occurring on >35% of the Serbian territory south of the Sava and Danube rivers (Lazarević, 1983; Dragićević et al. 2011; Ristić et al. 2012; Kostadinov et al. 2018). According to Ristanović et al. (2019), soil erosion can be an issue in agriculture with the intensification of this process. Respective authors outline that several million hectares of arable land have been endangered along with numerous settlements in Central Serbia.

Torrential floods are recognized as one of the most devastating natural hazards affecting the lives of many people around the world and in central and southern parts of Serbia as well (e.g. Ristanović et al. 2019). The damage caused by floods is extremely difficult to assess (Alcántara, 2002; Schmidt et al. 2006; Toya and Skidmore 2007; Spalevic et al. 2017; Blöschl et al. 2019, Lovrić et al. 2019). In the past of the municipality of Štrpce, torrential floods have caused great economic damage to the local population, especially in 1953 and 1979.

Snow avalanches are causing great concern in all major mountain regions around the world (e.g., Schmidt-Thome, 2006), and mapping potentially risky areas is of great significance (Pistocchi and Notarnicola 2012). On the Šar Mountain, avalanches often caused casualties and great economic damage to the local population in the tourist zone of the Brezovica ski center.

Fire hazards are one of the most dangerous hazards in the world (Wang et al. 2018; Živanović et al. 2020). Due to climate variability, the number of forest fires is displaying rising tendency in the South-Eastern Europe and Serbia (Földi and Kuti 2016; Lukić et al. 2017), so environmental protection planning has become the primary task (Yan et al. 2011).

Knowledge of the areas that are the most susceptible to natural hazards could enable more adequate and efficient environmental management by local, provincial and state services responsible for nature protection and emergency management not only in the investigated area, but on regional and national levels as well. GIS and data modelling are very powerful tools for calculating and describing some data of hazard effects (Valjarević et al. 2018a; Valjarević et al. 2018b).

This paper develops a new methodology for the predisposition of terrain to snow avalanches using GIS and multi-criteria analysis and is one of the first articles in Serbia for avalanches based on modern data and information systems. The results of the research have ecological and socio-economic significance because the obtained data contribute to better geospatial analysis for nature protection, biodiversity conservation, existing infrastructure and reducing the risk of situations that could cause greater consequences for the local population.

MATERIAL AND METHODS

Study area

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, Sušiće, Štrpce, Berevce, Brezovica, Vrbeštica, Jažince and Sevce (Fig. 1).

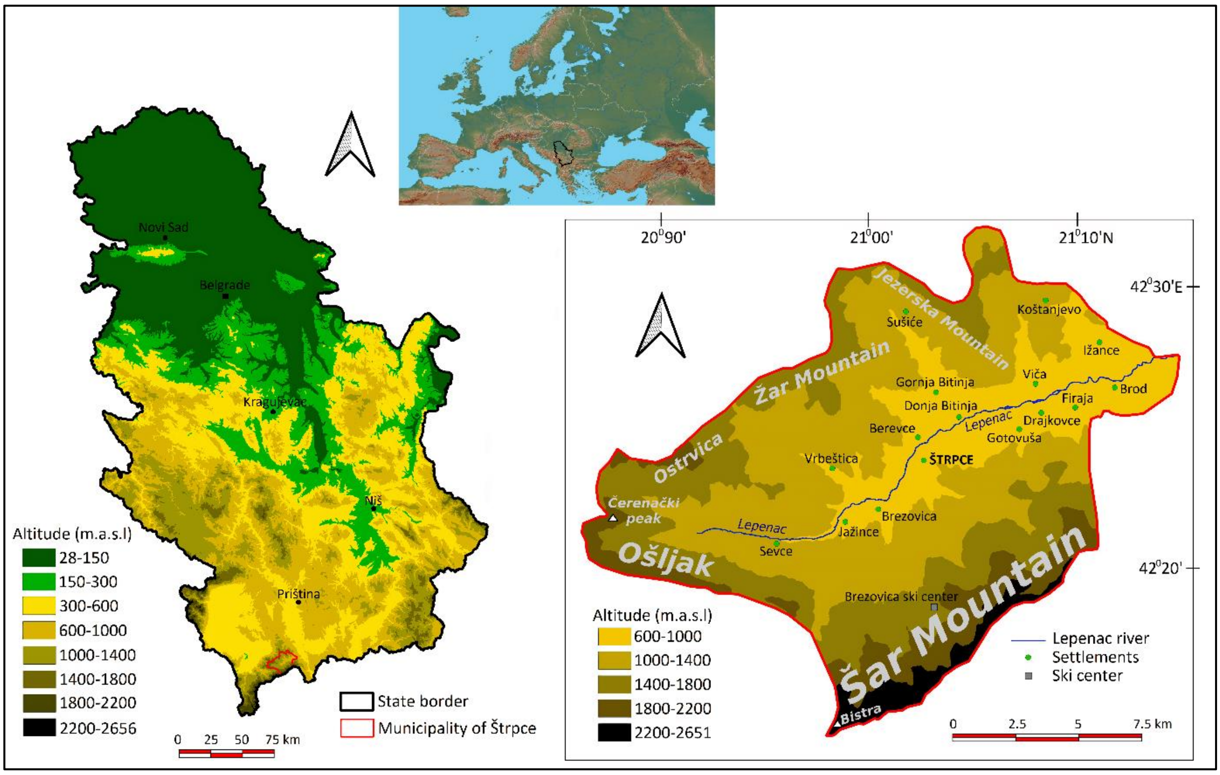

Fig. 1 Geographical location of the municipality Štrpce

The municipality is located in the upper course of the Lepenac river basin, covering an area of about 248 km^2. In geographical terms, it is known as Sirinićka župa. Physically and geographically, the municipality is bordered by Šar Mountain and its branches: Ošljak, Čerenački peak, Ostrvica, Žar and Jezerska Mountain, so one can get the impression of its natural isolation (Dinić, 1990). The lowest altitude in the municipality is 600 m, while the highest peak is Bistra (Peskovi), the second-highest peak in Serbia, with an altitude of 2651 m.

Metodology

By applying defined multi-hazard methodologies, it was possible to conduct scientific research and analysis of the investigated area's susceptibility to natural hazards. 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 geographic information systems, the value was assigned based on intensity (VII-VIII and VIII MCS) which was later used for modeling total susceptibility to natural hazards.

The main consequence of soil degradation is a significant reduction in soil productivity, whichdirectly affects those whose employment depends on this natural resource (Alam, 2014; Gocić et al. 2020).

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 current climate and land use conditions (Kirkby et al. 2008; Blanco and Lal 2010; Yin et al. 2018). In today's world, depending on the database size and satellite images availability, it is possible to determine the degree of erosion intensity and total sediment production by office work via GIS software packages and later confirm it by field work.

As indicated by Ristanović et al. (2019) the most widespread model in the Western Balkan countries is the Erosion Potential Model – EPM, also known as Gavrilovic method (Gavrilovic, 1972), because it corresponds well with the USLE model used for 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 following equation (Gavrilovic, 1972):

$$W_{anu} = T \cdot H_{anu} \cdot \pi \cdot \sqrt{Z^3} \cdot F \qquad [1]$$

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

The EPM model belongs to the group of regional methods, and in the world literature, it is characterized as a semiquantitative method (De Vente et al. 2005; Manojlović et al. 2017). Determining changes in soil erosion intensity using this method gives us the possibility to determine the characteristics of each of the above-mentioned factors that appear in the given equation (Mustafić, 2012).

The temperature coefficient (T) is given by the following equation (Gavrilovic, 1972):

$$T = \sqrt{\frac{t}{10} + 0.1} \qquad [2]$$

where: t - average annual air temperature (ºC), was obtained by analyzing the dependence of changes in temperature on changes in altitude by using data from relevant meteorological stations, based on the following equation (Živković, 2009):

$$t = -0.05 \cdot H + 13.84 \qquad [3]$$

where t represents the average annual air temperature, and H represents the value in meters obtained through the digital elevation model (DEM).

The average annual precipitation of H_{anu} was obtained by analyzing the dependence of the changes in precipitation from the relevant precipitation stations, based on the following formula (Živković, 2009):

$$H_{anu} = 460 \cdot \ln H - 2384 \qquad [4]$$

where H_{anu} is the average annual rainfall and H (m) the value obtained through the DEM. The erosion coefficient (Z) was calculated based of the following formula (Gavrilovic, 1972):

$$Z = Y \cdot X \cdot (\phi + \sqrt{I}) \qquad [5]$$

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

The coefficient of soil resistance to erosion (Y) was obtained by analyzing the pedological map in a scale of 1:50.000. Depending on the degree of pedological base resistance, the coefficient is classified 0.1 - 1, with the lowest coefficients having the highest resistance, in this case lithosol. The highest coefficient belongs to bulk soil that is most susceptible to erosion (Table 1).

Table 1. Coefficient of soil resistance to erosion (Gavrilovic, 1972)

Soil type	Y
Fluvisol	0.55
Diluvium	0.8
Lithosol	0.4
Dystric cambisol	0.8
Kalkocambisol	0.6
Brown soil on igneous rocks	0.7
Ranker	0.8
Rendzina	0.65
Terra rossa	0.8

The coefficient of soil protection from atmospheric factors and erosion (H) was obtained by processing and analyzing the geospatial database on land use (Corine Land Cover, 2018), which is published by the European Environment Agency [EEA]. In the range of 0.1 to 1, the highest coefficient is assigned to vegetation-free areas dominated by stronger types of erosion. Due to the extremely developed root system, good composition forests absorb a large amount of precipitation and reduce erosion intensity. Non-irrigated agricultural areas and areas with sparse vegetation are very prone to erosion effect (Table 2).

Table 2. Coefficient of land use types

Substrate protection coefficient	X
Discontinuous urban fabric	0.25
Non-irrigated arable land	0.8
Pastures	0.5
Land principally occupied by agriculture,	0.55

with significant areas of natural vegetation	
Broad-leaved forest	0.2
Coniferous forest	0.15
Mixed forest	0.15
Natural grasslands	0.4
Moors and heathland	0.5
Transitional woodland-shrub	0.4
Sparsely vegetated areas	0.9

The coefficient of type of erosion (ϕ) was determined using the bare-soil index (BSI). Multispectral satellite images from Landsat 8 satellite, which belongs to the United States Geological Survey (USGS) were used for obtaining this index. Recordings from the periods 2015, 2017 and 2019 were analyzed, so the final result was the average BSI used to analyze erosion intensity. Remote detection technique is very important in the field of regional soil erosion assessment (Vrieling, 2006; Le Roux et al. 2007; Mutekanga et al. 2010). This index enables easier and more efficient erosion intensity calculation. The bare-soil index was obtained using the following formula (Diek et al. 2017):

$$BSI = \frac{(B6+B4)-(B5+B2)}{(B6+B4)+(B5+B2)} \qquad [6]$$

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

The average slope of the terrain (√I) was obtained using the digital elevation model (DEM) with a resolution of 25 meters, in the form of a percentage expressed in decimals. EU-DEM was taken from the website of the European Environment Agency’s Copernicus program. As the slope increases, slope stability decreases, erosion intensity increases, and torrential floods occurrence probability increases (Novković, 2016).

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 (Guzzetti et al. 2005; Schmidt et al. 2006; Lerner, 2007). In all their various forms, floods are the most common type of natural disasters that occur worldwide (Berz et al. 2001; Barredo, 2007). Among the natural hazards with the highest risk to people and their activities, torrential floods are the most common danger in Serbia as well (Ristić and Nikić 2007; Ristić et al. 2012) and the most significant in terms of great material damage and loss of human lives. The frequency of these events, their intensity and representation throughout the country, make them a constant threat and have serious consequences for the environment, economic and social sphere (Ristić et al. 2012). Serbia was not included in recent studies examining floods risks in Europe and the world (Barredo, 2007; Mosquera-Machado and Dilley 2009). The importance of knowing the locations that are most susceptible to torrents is great, as the largest part of arable land is located near rivers.

As for torrential floods, the method used was the Flash Flood Potential Index (FFPI). This method is most commonly used in the world and the region (Minea, 2013; Tincu et al. 2018). The method was developed at the Colorado Basin River Forecast Center. The Flash Flood Potential Index is determined using GIS software tools through a statistical approach based on the principle of established correlation between different factors and the spatial distribution of particular basin drainage, or research approach, i.e. indexing of weight factors, or allocating weighting factor to each factor affecting the occurrence of torrential floods based on empirical experience (Smith, 2003; Ristić et al. 2009; Prăvălie and Costache 2014; Minea et al. 2016; Kostadinov et al. 2017; Novković et al. 2018). It was developed primarily because predictions of torrential floods using meteorological parameters did not give satisfactory results, and no connection between the occurrence of this disaster and certain physical-geographical characteristics of a territory was defined. Soil structure and texture are the characteristics that define water retention and infiltration. Terrain geometry, primarily slope, determines the rate and concentration of outflow. The percentage of atmospheric water retention on the surface depends on the vegetation. For example, seasonal changes in the vegetation of deciduous forests significantly affect the possibility of torrential floods development, and in addition to changes in vegetation, forest fires negatively affect soil, where due to organic matter burning infiltration power decreases. Land use and especially urbanization play an important role in water infiltration, concentration and outflow behavior. Together, these natural conditions provide information on the possibility of torrents occurring in a particular area (Smith, 2003).

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

The Flash Flood Potential Index method was obtained based on the following formula (Smith, 2003):

$$FFPI = \frac{M+S+L+V}{4} \qquad [7]$$

where M is terrain slope, S represents soil types, L is land use and V represents bare-soil index.

Terrain slope (M) was obtained using GIS, based on a EU-DEM with a spatial resolution of 25 m taken from the European Environment Agency's Copernicus program website. First, the slope was calculated, expressed as a percentage, and then the following formula was applied:

$$M = 10^{n/30} \qquad [8]$$

where n is terrain slope expressed in %. If n is greater than or equal to 30%, then the value of M is always 10. For the analysis of soil types (S), the pedological map was used, in a scale of 1:50.000. Classification of soil types was analyzed depending on the soil type susceptibility to torrents (Table 3).

Table 3. Soil type coefficient

Soil type	S
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 highest coefficient was assigned to the type of soil that is most susceptible to torrential flood occurrence.

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

Table 4. Land use coefficient

Land use	L
Discontinuous urban fabric	4
Non-irrigated 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

The bare-soil index (BSI) was used for the vegetation density index (V). Multispectral satellite images from Landsat 8 satellite were processed to obtain this index. In the field of regional assessment of soil erosion and torrents, remote detection technique has great potentials and advantages (Vrieling, 2006; Le Roux et al. 2007; Mutekanga et al. 2010; El Haj El Tahir et al. 2010, Durlević et al. 2019). The following formula was used to obtain the V coefficient:

$$V = 7.68 \cdot \ln(BSI + 1) + 8 \qquad [9]$$

In aim to avoid negative sums a value of 1 has been added.

Snow avalanches are one of the biggest threats to people, buildings and roads, and they greatly affect mountain ecosystems (Bebi et al. 2009). Snow avalanches that apart from snow also contain rocks, soil, broken trees or ice, are very short, local, dynamic occurrences in many mountainous areas (Aydin and Eker 2017).

In the last 220 years, dozens of human lives have been lost. With the development of the Brezovica ski center and by engaging the mountain rescue service, parts of the terrain with a higher risk of avalanches have been marked as unfavorable and skiing-prohibited, in order for the safety of tourists to be at an appropriate level during the winter and spring period. All prerequisites for the occurrence of avalanches can be divided into two groups. The first group includes invariable conditions of the position (altitude, relief, geological substrate, slopes and roughness of slopes, aspect, vegetation, neotectonic activity), while the second group consists of variable, meteorological parameters: current weather situation, snow cover condition, temperature, wind dynamics and direction, clouds, total snow depth, snow structure, etc. (Dinić, 1990).

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

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

where S is terrain slope, A is aspect class, R is terrain roughness class, SN is snow depth class, V is vegetation.

Terrain slope is the most important parameter for the analysis of susceptibility to avalanches. Slope significantly affects the length and triggering of avalanche. Extremely flat and extremely steep terrains are very unsuitable for avalanche formation. Numerous authors state that avalanches are most common on the terrain slopes of 30-60° (Maggioni and Gruber 2002; Pistocchi and Notarnicola 2012), 28-60° (Bühler et al. 2018) and 30-50° (McClung and Schaerer 2006). On the Šar Mountain, mapped avalanches also appeared at 20°, so the analysis of avalanches for this area included a slope of 20-60°. The terrain slope was obtained using 25 m resolution DEM.

An important morphometric condition is terrain aspect or exposure. Obtained based on 25-meter DEM, exposure plays a major role in retaining snow cover, depending on the terrain insolation. Terrains facing south will be more susceptible to faster snow melting due to the longer effect of solar radiation, while with northern exposure snow lasts much longer, 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 movement of avalanches. Slopes that are overgrown with low (grassy) and sparse vegetation have the least roughness, and such terrains are most suitable for the movement of avalanches. From the GDAL DEM utility the algorithm is derived. Using the QGIS and DEM software package, terrain roughness was determined and classified into 3 classes. The 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. With increasing snow depth, snow stays on the surface longer, therefore chances for the formation and triggering of avalanches are greater. The six-month (November-April) snow depth was analyzed for the period 2007-2018. (Table 6). Data for the calculation of snow depth were downloaded from the Snow-Forecast database. According to the available data the average six-month amount of snow cover has been obtained by analyzing the dependence of the change in the amount of snow cover from the locations for which data are available.

Table 6. Snow depth classes

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

Vegetation significantly affects the formation and movement of avalanches. Forests and woody-shrubby vegetation largely prevent the formation of avalanches and the transport of surface loose material. NDVI (Normalized Difference Vegetation Index) was used for vegetation analysis based on the following formula (Rouse et al. 1973; Tucker, 1979; Milanović et al. 2019):

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad [11]$$

where NIR is Near Infrared Band and RED is Red Infrared Band.

Satellite images from Sentinel-2 satellites with a 10-meter resolution were used. The 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 the formation and movement of avalanches (Table 7).

Table 7. Vegetation classes

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

Values of 0.4-0.6 represent shrubby vegetation, while all values over 0.6 represent forest vegetation that is not suitable for avalanche formation.

Forest fires are one of the most common natural disasters. Except weather conditions, there are many other factors that influence forest fires (Tošić et al. 2019). Because of the increase in global temperature on Earth, but also human negligence, every year enormous areas are affected by fire, both in Serbia and in the world. In 97% of cases, forest fires are caused by man; however, natural conditions determine the predisposition of a territory for fires, therefore the analysis of natural conditions is key for determining the endangerment of a area (Novković, 2016).

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 ecosystem (50.54% of the area), the percentage of forest cover decreases every year due to the anthropogenic impact 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 to protect forests from fire.

For forest fire hazard analysis, the following formula was used to determine the susceptibility to forest fires (Erten et al. 2004):

$$RC = 7VT + 5(S + A) + 3(DR + DS) \quad [12]$$

where: RC - the index of susceptibility to forest fires, VT - indicates vegetation type with 5 classes, S - the slope factor with 5 classes, A - the aspect variable with 5 classes, DR and DS indicate distance from road and settlement factors. 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.

Aspect was classified into 4 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. To calculate the index of distance from roads, settlements and buildings, satellite images and topographic maps were used, appropriate contents were digitized, and then buffer zones of appropriate width were made.

To model the overall susceptibility to natural hazards of the municipality of Štrpce, a hierarchy was established in relation to the probability of occurrence in a certain area, the frequency of occurrence and the consequences that disasters leave. The multiple decision criteria method has been especially popular in the last several decades. Problems of decision-making occur every day, from elementary problems to very complex situations (Atanasova – Pachemska et al. 2014). The analytical hierarchy process (AHP) method is one of the most commonly used methods in decision-making, developed by Saaty. Its goal is to quantify the relative priority of the given set by the appropriate value scale.

Table 8. RC index calculation classes (according to Erten et al. 2004)

Value	Vegetation	Slope [°]	Aspect	Distance from roads [m]	Distance from settlements [m]
1	Discontinuous urban fabric	< 5	N	> 600	> 400
2	Complex cultivation patterns, non-irrigated 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 vegetation type index was obtained using the Corine Land Cover geospatial database (2018). Areas were singled out by the type of vegetation represented on them and were assigned values from 1 to 5. The least susceptible are water surfaces and larger settlements, as chances of fire in such areas are extremely small. Terrain slope and exposure were obtained based on 25-meter resolution DEM. The slope was expressed in degrees and divided into classes, with terrains with a higher degree of slope having the greatest value, due to greater inaccessibility, i.e. less availability.

The decision is usually based on the perception of the individual who should make the final decision and assess the priorities, emphasizing the importance of consistency and correlation of alternatives that are compared throughout the decision-making process (Saaty, 1980; Saaty, 1990). The area of the municipality of Štrpce is not equally endangered by all natural hazards, so each was assigned a weighting factor, which was obtained by AHP (Table 9).

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

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

$$\lambda_{\max} = 5.019; CI = 0.004; CR = 0.003 \qquad [13]$$

where: λ_{max} – the maximum eigenvalue of the matrix; CI – Consistency Index; CR – Consistency Ratio.

Fires have the highest frequency of all natural disasters in Štrpce, and that is 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, which are most often 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, therefore they were assigned a coefficient of 0.182. Avalanches pose a great threat to tourists and buildings located at high altitudes on the Šar Mountain, hence avalanches were assigned a coefficient of 0.131. Soil erosion is an important factor for the analysis of natural disasters in this area; for the municipality of Štrpce, the weight coefficient for erosion is 0.097. In addition, high degree of erosion carries away large amounts of soil and increases water retention on surfaces (Langović et al. 2017; Doderović et al. 2020; Durlević, 2020).

Intensive washing away and removal of particles from 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 were multiplied by the weighting coefficients, and then their results were added up:

$$0.339 \cdot F + 0.251 \cdot Z + 0.182 \cdot T + 0.131 \cdot A + 0.097 \cdot E \qquad [14]$$

where: F - forest fires, Z - seismic hazard, T - torrents, A - snow avalanches and E - erosion. After summing the results, they were classified into 4 risk classes: low, medium, high and very high.

RESULTS AND DISCUSSION

Seismic hazard analysis

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 is occasionally exposed to 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.

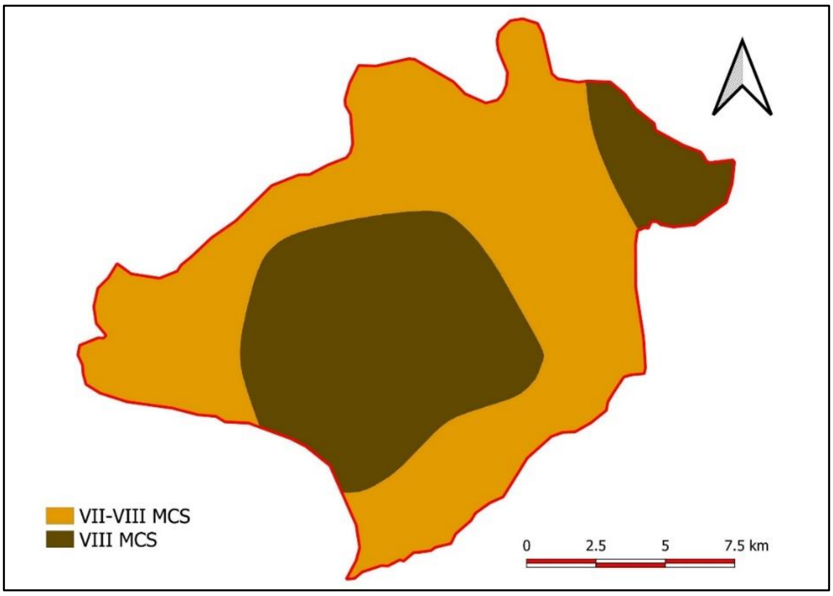

Fig. 2 Seismic hazard for a 475-year return period

A strong earthquake happened in 1921 in the Uroševac - Vitina direction; in the municipality of Štrpce, it was registered with an intensity of VIII MCS. Occurrences of autochthonous earthquakes were registered on northwestern, central and southeastern part of the municipality, of VII-VIII MCS, which indicates that they are of far greater importance for defining the seismicity of the area outside the municipality (Dinić, 1990). Based on seismic hazard, the magnitude of the potentially strongest earthquakes for the following 475 years would be VII-VIII and VIII MCS (Fig. 2).

According to the obtained data, the area of 141.47 km^2 (60.8% share in the territory) have 7-8 potential intensity MCS, while at 91.07 km^2 (39.2% share in the territory) the estimated seismic hazard has a magnitude of 8 MCS.

Erosion intensity

By applying the available database, and using EPM model, the erosion risk for the territory of the municipality of Štrpce was assessed. By analyzing and processing the most up-to-date data for the research area, the average erosion coefficient, as well as the total and specific sediment production was obtained.

The specific annual production of erosion deposits in the catchment area was acquired by dividing the total production of erosion deposits with the catchment area.

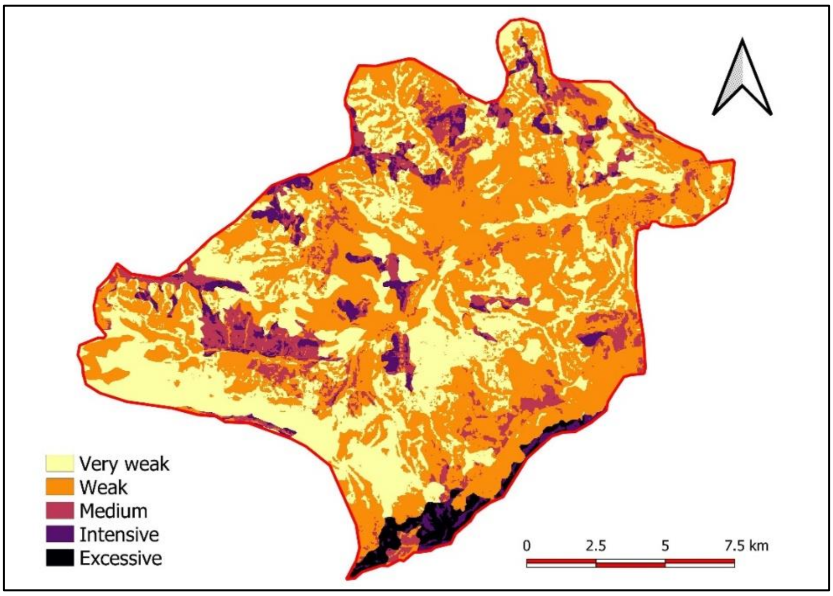

Fig. 3 Erosion intensity map

Using EPM model, analyzing and processing terrain slope, land use type, bare-soil index and pedological cover, an erosion intensity map for the municipality of Štrpce was obtained. The average erosion coefficient is 0.34 (Fig. 3).

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 very weak erosion (Table 10).

Table 10. Types of erosion intensity

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

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

In this area, it is necessary to consider the erosion situation on the ground, and take appropriate anti-erosion measures to reduce erosion intensity and therefore soil loss. The total sediment production in the municipality is 131.795 m^3/year, while the specific sediment production is 565.96 m^3/km^2/year.

Susceptibility to torrential floods

For the area of the municipality of Štrpce, an analysis of terrain predisposition for the occurrence of torrents was done using geographic information systems (GIS). Due to the great ecological significance of this research 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 was destroying houses and tearing down bridges in the municipality.

By processing and analyzing the terrain slope, land types, land use and bare-soil index, a map of the terrain's susceptibility to torrential floods was obtained (Fig. 4).

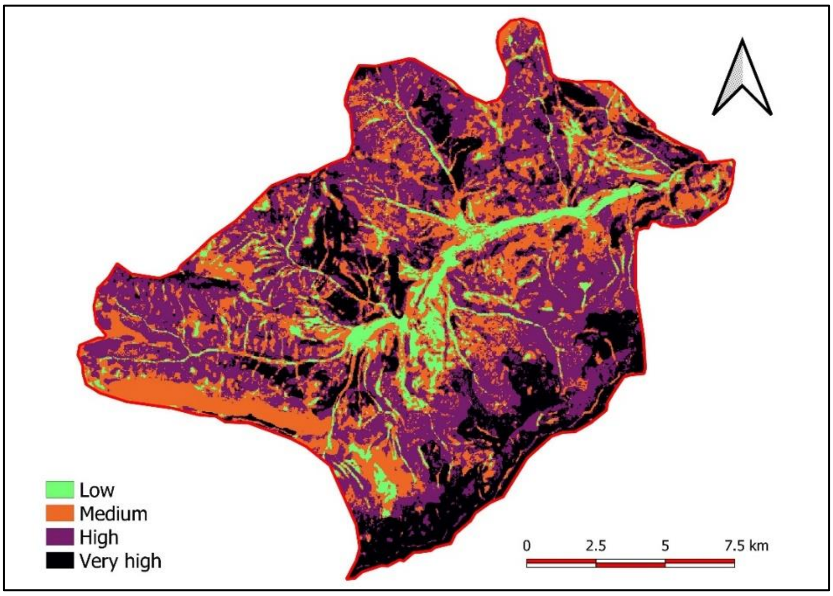

Fig. 4 Map of terrain susceptibility to torrential floods

A large part of the municipality of Štrpce has a high (43.33%) and very high (18.86%) susceptibility to occurrence of torrential floods (Table 11). Low and medium susceptibility is mainly present in the central (Lepenac valley) and the southwestern part of the municipality. The areas most prone to torrents are characterized by great terrain slope, absence of forests, 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.

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

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

Susceptibility to snow avalanches

By processing the available data in GIS, a map of terrain susceptibility to avalanches was obtained (Fig. 5). On 9.1 km^2 of the municipality area there are favorable conditions for the formation of avalanches, while the chances for avalanches in other parts of the municipality are very small. The territory is predisposed to the occurrence of snow avalanches if it is located on a suitable slope of the terrain (20-60^o), where a large amount of snowfall and the absence of woody vegetation (high mountain meadows and pastures) are recorded.

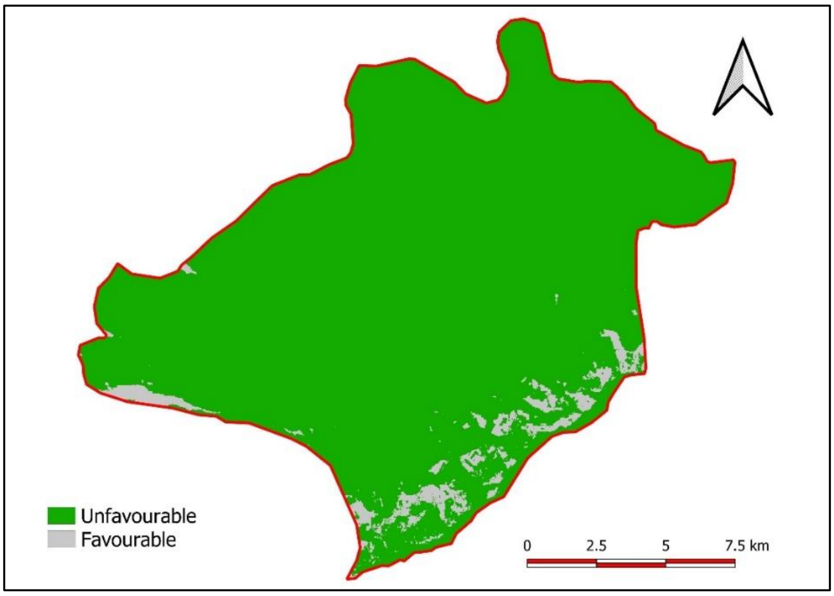

Fig. 5 Map of susceptibility to avalanches

Susceptibility to avalanches occurs in the southern and western part of the municipality, on the slopes of the Šar Mountain, on Ošljak ridge, Čerenački peak and Ostrvica peak. Field research is needed to confirm the results of office work and prohibit any anthropogenic activity during winter and spring 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 (Heldreich's pine and Balkan pine), in order to prevent accumulation of large snow masses. Another method is to build special fences that restrict the movement of snow deposits.

Susceptibility to forest fires

Based on the analysis and processing of existing data in geographic information systems, a forest fires susceptibility map of the municipality of Štrpce was obtained. Susceptibility was divided into four classes: low, medium, high, and very high (Fig. 6).

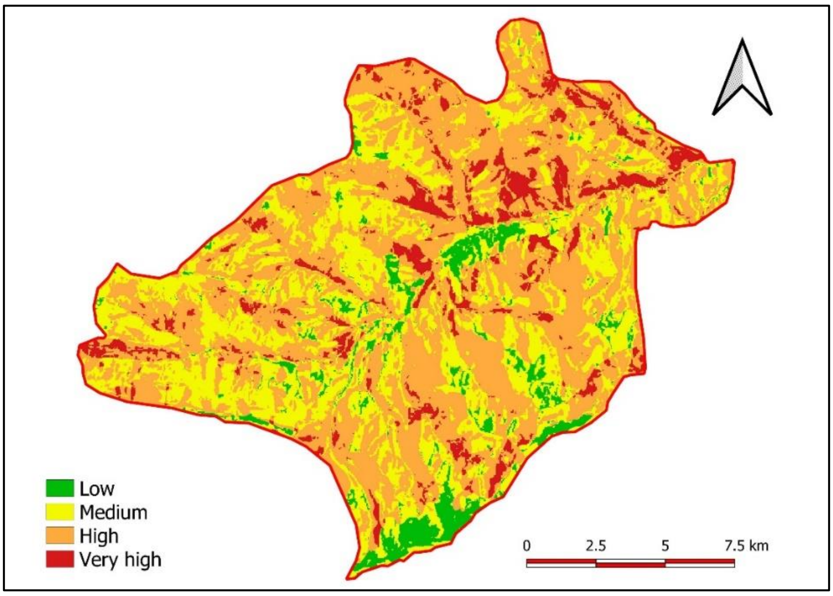

Fig. 6 Map of terrain susceptibility to forest fires

Due to the significant area under forest cover (117.72 km^2) and a relatively great terrain slope, the municipality generally has a high susceptibility to forest fires (Table 12). Terrains with a large slope and southern exposure are ones that are most vulnerable to forest fires. These are mostly coniferous or mixed forests that are relatively close to roads and settlements.

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

More than half of the municipality area is highly susceptible to forest fires, and almost 20 km^2 of territory has a very high susceptibility. Medium susceptibility occurs in one third of the territory, while low susceptibility is represented in 5.79% of the municipality.

Modeling total susceptibility to natural hazards

The total susceptibility of the terrain to natural hazards was estimated using the AHP method and the processed five criteria. The 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 the potentially most endangered locations in this area.

When considering the total susceptibility to natural disasters (Fig. 7), the municipality is dominated by medium and high susceptibility, found on 93% of the municipality.

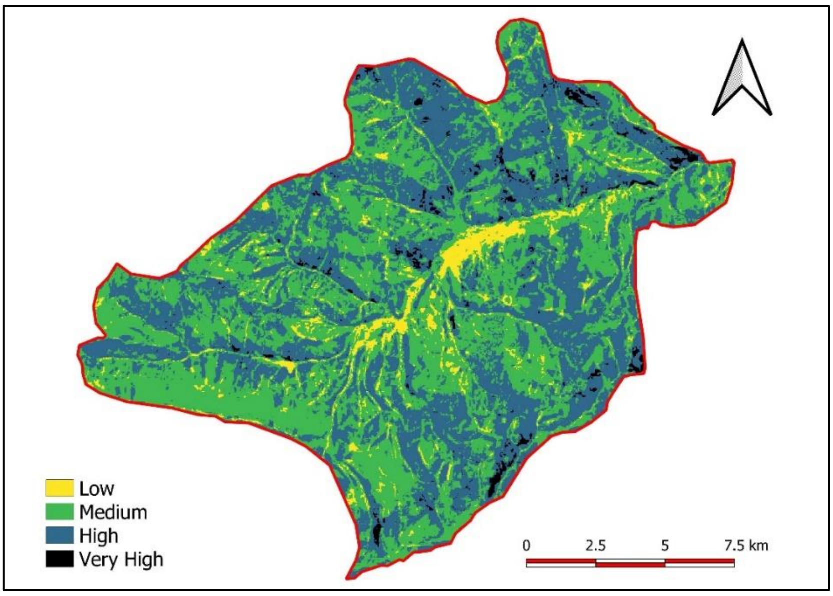

Fig. 7 Map of total susceptibility to natural hazards

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

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

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 implement protection measures that would reduce the possibility of occurrence of all analyzed disasters.

Conclusion

Vulnerability analyzing of the territories most sensitive to natural hazards will enable more adequate and efficient adoption of preventive measures and more correct environmental management by local, provincial and state services. Due to its morphometric characteristics, geographical position, richness of biodiversity and geodiversity, the municipality of Štrpce is an ideal territory for the analysis of natural hazards. In geographic information systems, using relevant data for a research area, the terrain was analyzed for susceptibility to: forest fires, earthquakes, torrents, avalanches and erosion. Forest fires are the most common natural disaster in the municipality. As for earthquakes, the Šar Mountain foothills are seismically very active, so larger magnitude earthquakes may occur on the territory of Štrpce or in the surrounding municipalities. Torrential floods have not been a problem in the municipality of Štrpce for the past 40 years, but today more than half of the municipality's area is highly and very highly susceptible to torrential floods. During the winter and spring, avalanches can inflict great damage in the form of casualties, damage to buildings and nature devastation. The terrain area prone to avalanches is 9.1 km^2 and covers the area of the highest parts of the Šar Mountain, Ošljak, Ostrvica and Čerenački peak.

In the research 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 the five disasters and using GIS and AHP methods, a map of the total terrain susceptibility to natural disasters was obtained, on which almost 105 km^2 of the municipality area is highly or very highly susceptible. In this area, which is 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 the provincial and republican environmental institutions and local environmental movements can take measures to protect and improve the territory, monitoring and auditing of environmental elements in order to mitigate the risk of natural disasters in the municipality of Štrpce. Furthermore, standardization and implementation of the multi-hazard methodologies would mean an important step towards more qualitative monitoring and identification of natural disasters on local and regional scale in the Republic of Serbia. Such an approach would highlight the importance of risk assessment and management programs, which are currently being developed in this part of South-East Europe.

Due to the specific management of the Šar Mountain National Park, ecosystems in this territory are more vulnerable compared to other protected areas in the Republic of Serbia. It is necessary to protect this area at the international level in order to mitigate further endangerment of the biodiversity and environmental devastation.

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Figures

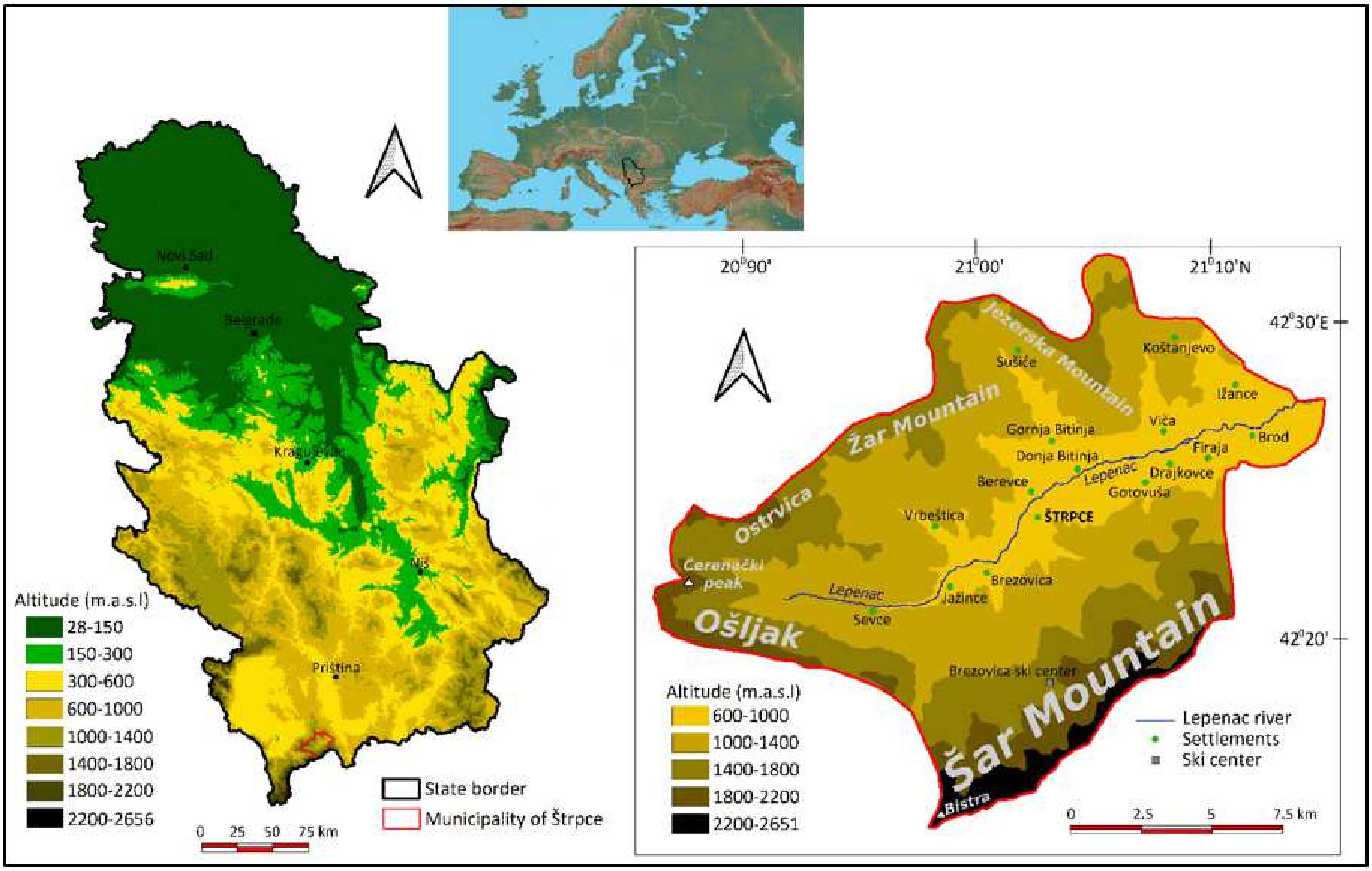

Figure 1

Geographical location of the municipality Štrpce Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

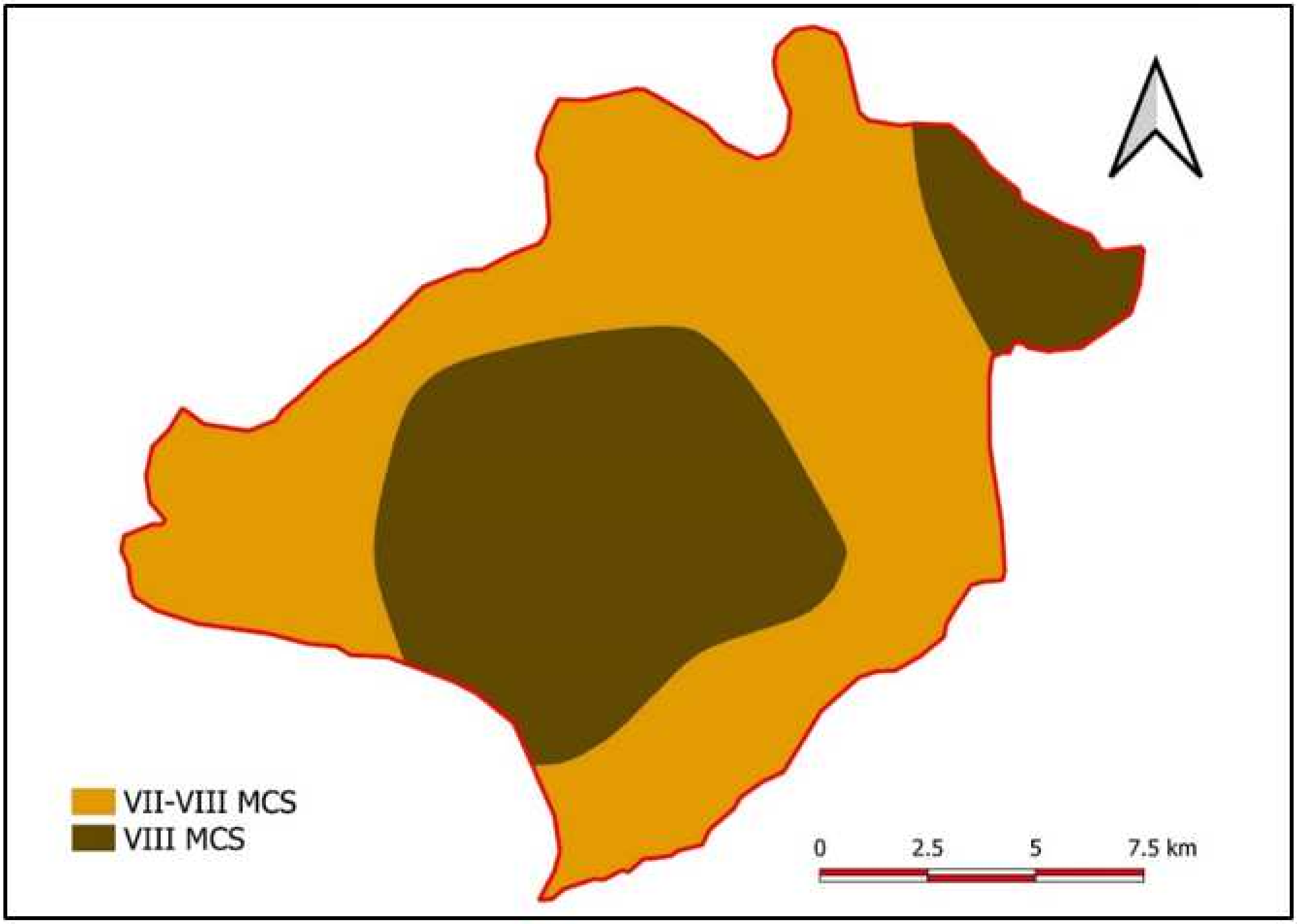

Figure 2

Seismic hazard for a 475-year return period Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

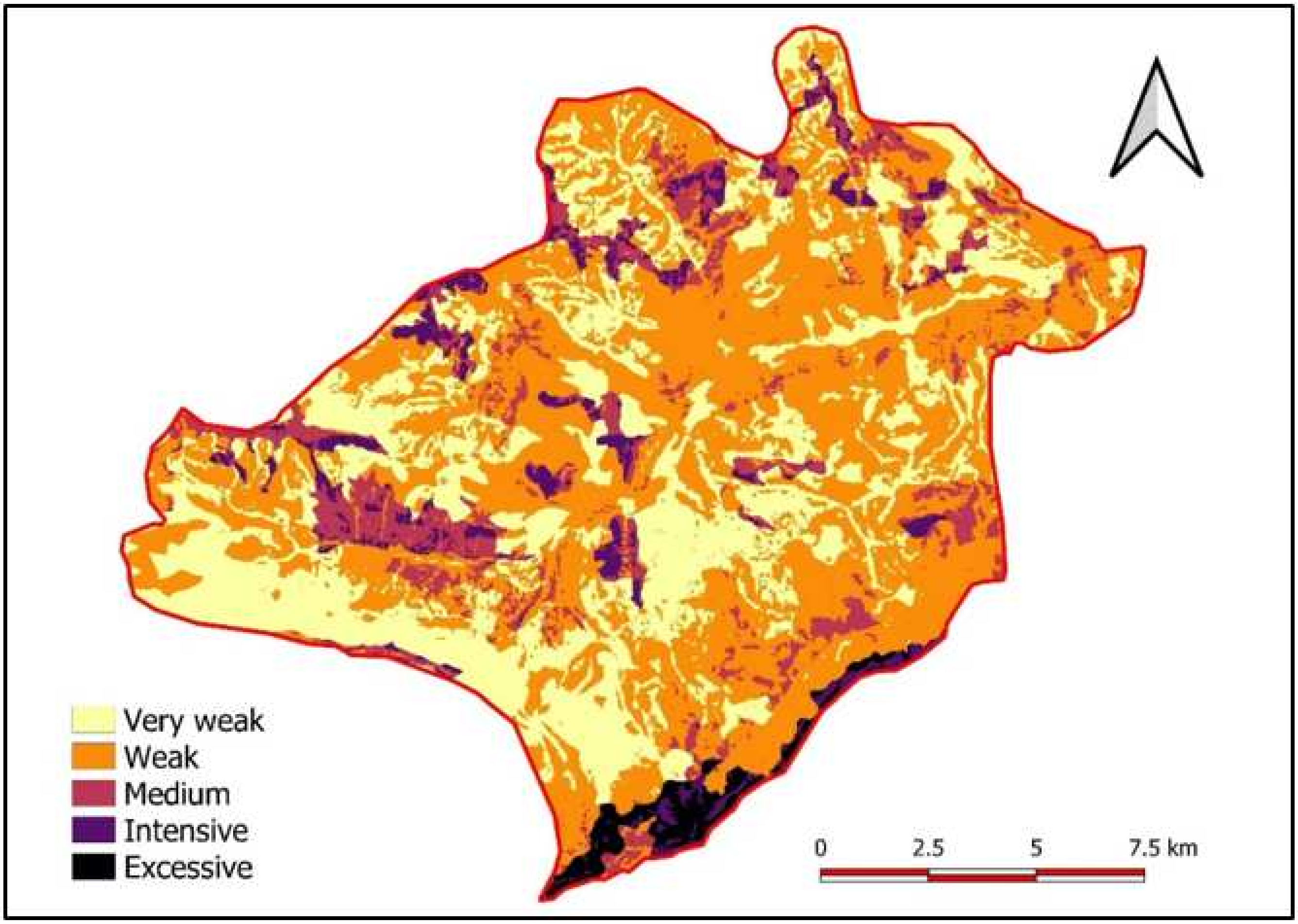

Figure 3

Erosion intensity map Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

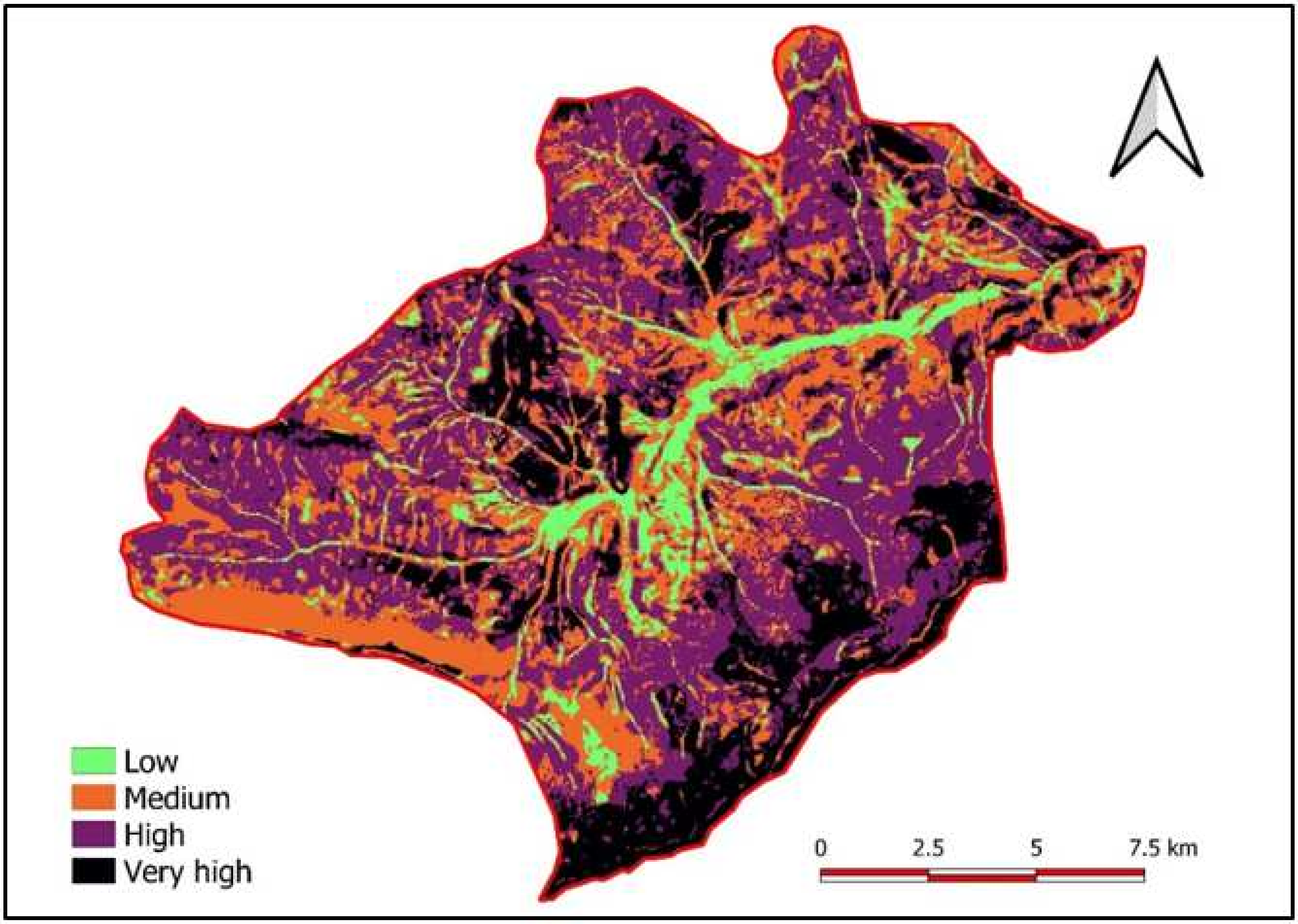

Figure 4

Map of terrain susceptibility to torrential floods Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

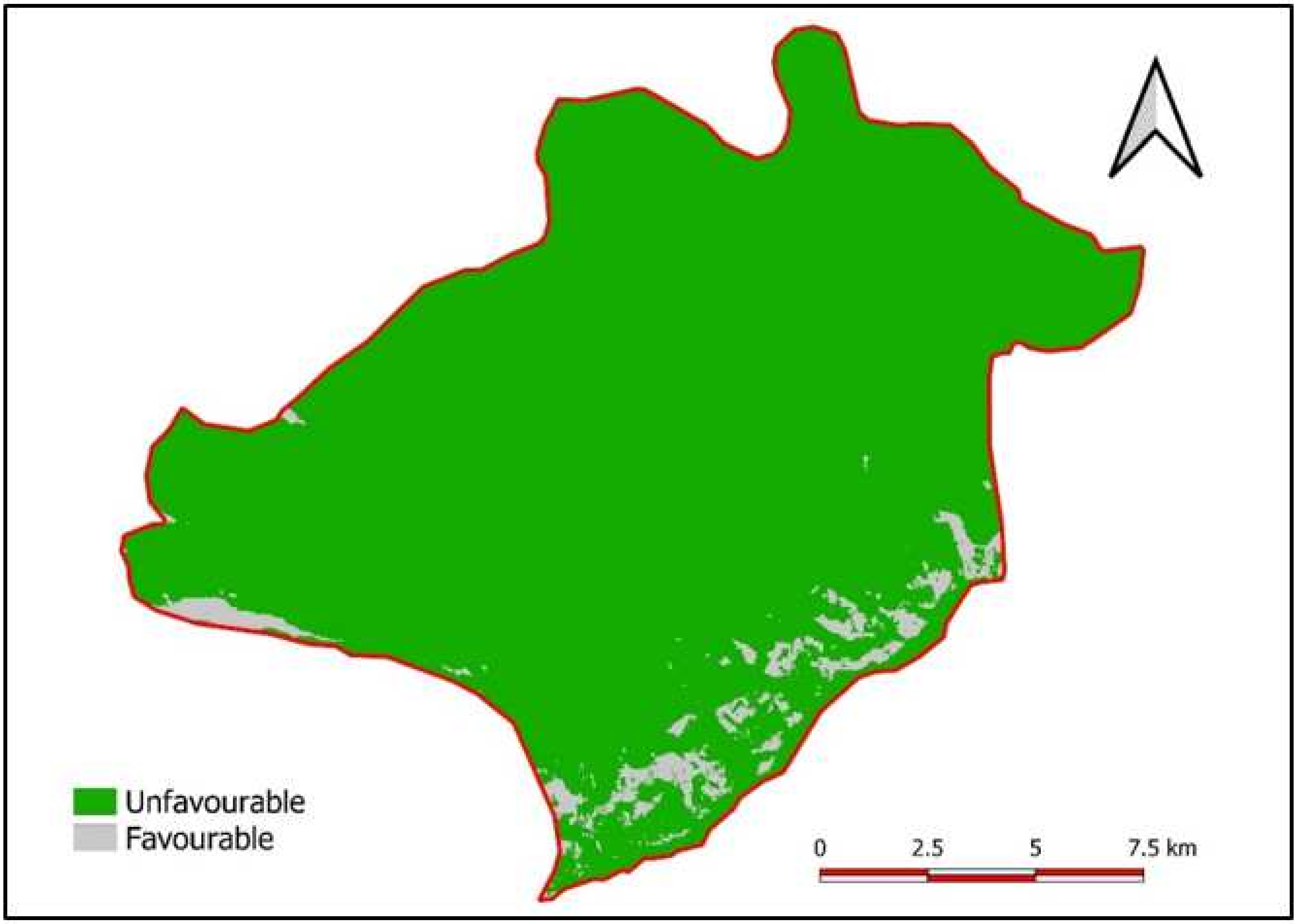

Figure 5

Map of susceptibility to avalanches Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

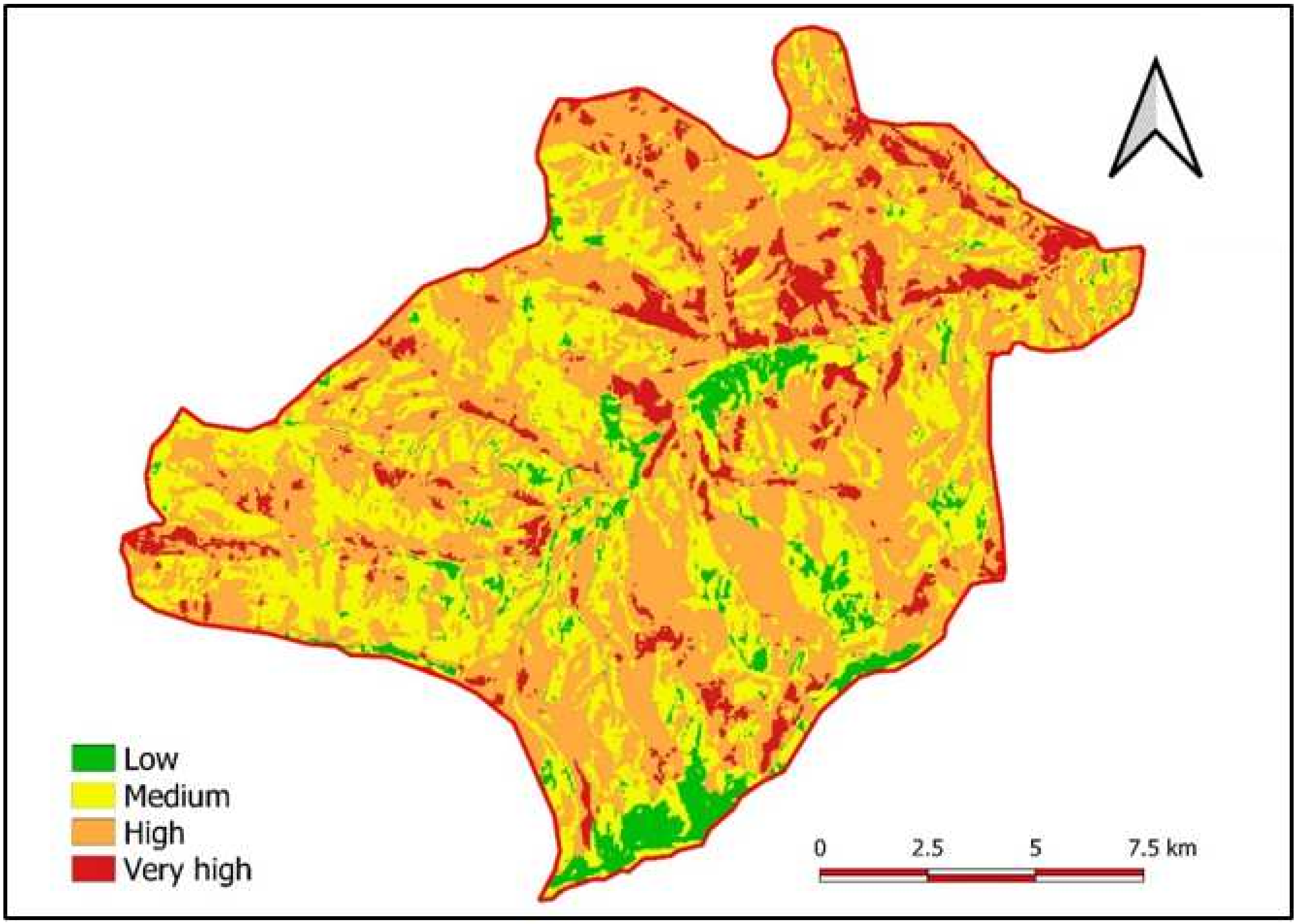

Figure 6

Map of terrain susceptibility to forest fires Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

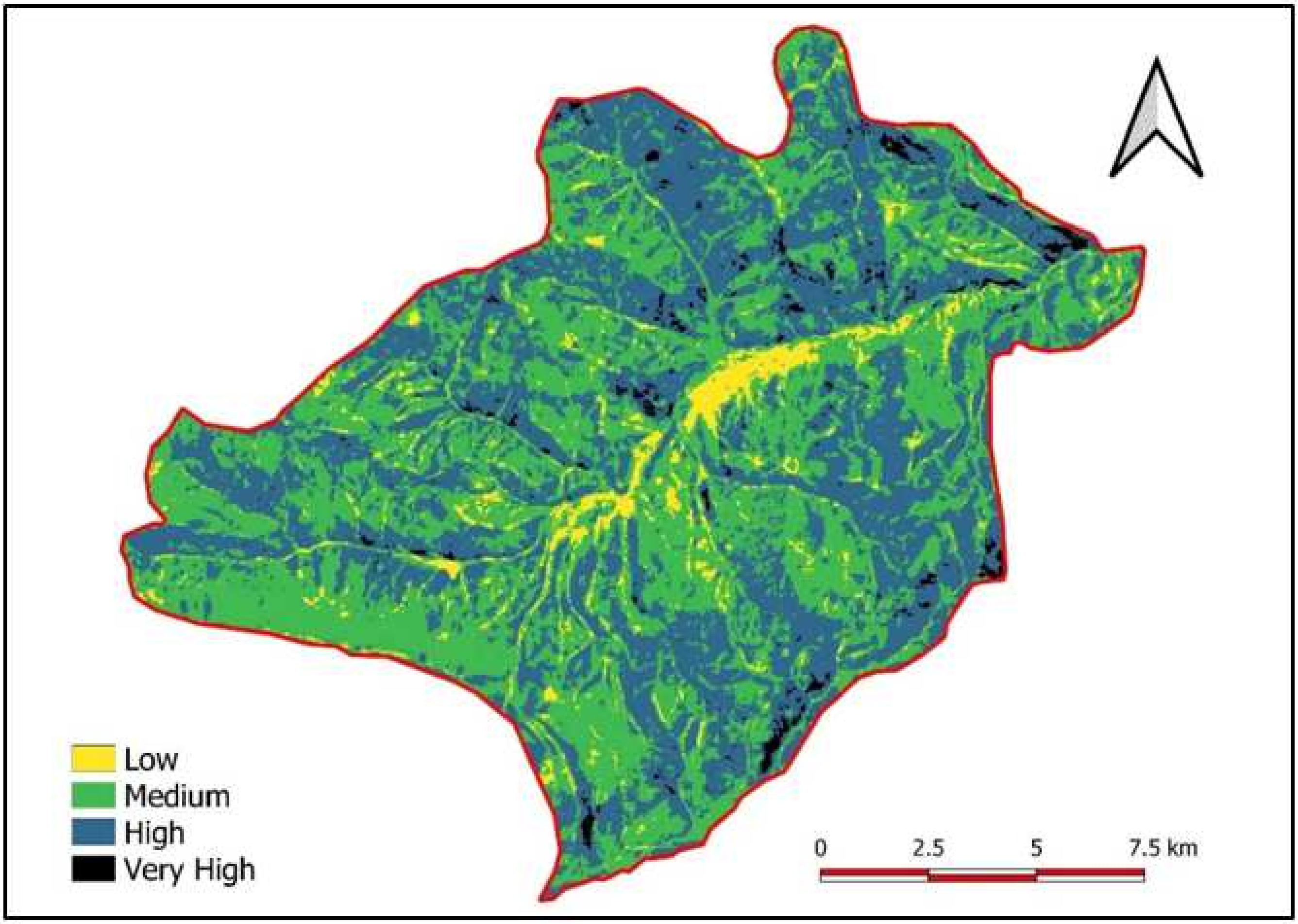

Figure 7

Map of total susceptibility to natural hazards Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.