Original Research

Vulnerability of National Parks to Natural Hazards in the Serbian Danube Region

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Abstract

The principal aim of this research was to determine the vulnerability of two national parks (Fruška Gora and Djerdap) along the Serbian Danube region, which are protected areas of great national and international significance, to major natural hazards. An analysis of the potential hazards to the protected natural and cultural-historical values was performed, and the adequacy of the allocation of protected zones was then examined according to the vulnerabilities of these values to natural hazards. The creation of a multi-hazard map is the first important task for the prevention and mitigation of natural hazards in the risk-prone area. This research represents an important step in completing the European database by including data from Serbia, a territory that was a blank area in previous hazard maps.

Keywords: multi-hazard mapping, vulnerability, protected areas, natural hazard mitigation, Serbia

Introduction

For various reasons, Serbia has not been included in most recent studies examining natural hazards within Europe [1-4] and globally [5-7]. Therefore, it was first necessary to create a preliminary multi-hazard map of the Serbian area. Previous research has indicated that the territory of Serbia is vulnerable to various types of natural hazards, and the risk is not uniform across the entire territory. Seismic hazards, landslides, excessive erosion, floods, torrential floods, rockfalls, droughts, and forest fires are examples of the significant natural hazards within the territory of Serbia [8]. These natural processes can directly and indirectly endanger the environment, population, and material goods. The International Strategy for Disaster Reduction [9] welcomes research to promote the protection of the environment in order to reduce vulnerability to disasters. In addition, previous research has demonstrated that protected areas can play an important role in preventing or mitigating disasters arising from natural hazards [10]. Although there is growing recognition that similar research can help to mitigate damage and disasters caused by vulnerability to hazards, we still do not have an inventory of natural hazards for Serbian territory for spatial and urban planning. In the field of implementation planning, zoning is a weak spot that needs to be improved in order to align the parks with the requirements of the internationally recognized categories [11]. Comprehensive understanding of natural systems coupled with the application of management tools such as environmental evaluation and risk assessment can make a major contribution to a reduction of risks and mitigation of any impacts. In this respect, there is a need to highlight the role

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that comprehensive environmental management and site planning can play in reducing the risk of disasters, and to mitigate the consequences if they should nevertheless occur both on human lives and on the broader ecology [12]. Negative consequences of natural hazards are the result of both the frequency and intensity of the hazard and the vulnerability of the society or element at risk exposed. Therefore, vulnerability assessment is an essential step to reduce these consequences and, consequently, natural hazard risk [13].

For the previously discussed reasons, the first aim of this research was to determine the vulnerability of two national parks (Fruška Gora and Djerdap) along the Serbian Danube region, which are important protected areas in Serbia, to the major types of natural hazards.

The main aim of the research was to identify the most vulnerable zones, and to then review the potential hazards to the protected natural resources and the complementary values of cultural and historical heritage (estimation of the protected values). According to the Law on Nature Protection in Serbia [14], the protection zones are distinguished in the protected area, where protection zones of degrees I, II, and III are implemented. Protection zone I includes the strict protection of areas of original, unmodified, or slightly modified ecosystems of great scientific importance. Protection zone II includes areas where ecosystems of great scientific and practical importance are partly modified, while zone III includes altered or modified ecosystems of scientific and practical importance. Accordingly, verification of the allocated protected zones was based on their vulnerability to natural hazards.

The result of the research is an overview of the Serbian protected areas that are affected by natural hazards. The importance of the integral multi-hazard vulnerability map of the Fruška Gora and Djerdap NPs expands beyond national interest because natural hazards strike irrespective of administration borders. Given the conterminous position of the selected national parks with Croatia and Romania, the research has regional and even European significance. Both national parks are part of the IBA, IPA, and PBA of international importance and the EMERALD network, as well as the integrated network of the Danube River Network of Protected Areas. The Djerdap NP is the only park in Serbia where the provisions of the Convention on the Protection and Sustainable Development of the Carpathians (Carpathian Convention) are applied.

Study Areas

The Danube is an international river that flows through 10 European countries. In Serbia, the length of its course is 588 km, of which 367 km is a river border with Croatia (137 km) and Romania (230 km). Therefore, this study has not only national but also regional significance. On the course of the Danube through Serbia, two national parks are located on its right bank, Fruška Gora and Djerdap, which are characterized by their distinct and complex natural resources, condition of conservation, and vulnerability. Considering that their morphological and biotic values are genetically diverse, the protection of these areas as well as their degree of vulnerability to natural hazards is not uniform.

The Fruška Gora NP covers an area of 266.72 km^2 (according to the most recent partial modification of the boundaries of Fruška Gora from 2011) and is located on the southern rim of the Pannonian basin, along the right bank of the Danube. This national park, established in 1960, is the oldest one in Serbia. Morphologically, the park covers the area of the Fruška Gora massif, which stretches in an east-west direction over 80 km parallel to the Danube course. Although the maximum height of Fruška Gora is only 538 m, it is morphologically dominant in the surrounding lowland of the Pannonian relief.

Fruška Gora is a unique natural phenomenon composed of rocks of almost all the geological periods, from the oldest Paleozoic to the Quaternary period. During the Quaternary period, heterogeneous tectonic movements gave way to denudational-accumulative processes, as evidenced by aeolian loess deposits. In the morphology of Fruška Gora, the mountain massif of the same name and the loess plateau of extremely uneven width are clearly distinguished. Namely, there is a distinct asymmetry in the width of the loess plateau, such that its northern part is much narrower than the southern portion. The loess plateau on the northern slope appears in the form of fragmented areas with steeper slopes towards the Danube, while on the southern slope, this morphological unit occurs as the continuing zone of much milder slopes.

These phenomena are the result of the tectonically predisposed direction of the mountain chain and the Danube course, but also of various local paleoecological conditions of the loess deposition on the northern and southern slopes [15]. A significant relief particularity of Fruška Gora is represented by numerous transverse (direction N-S) stream

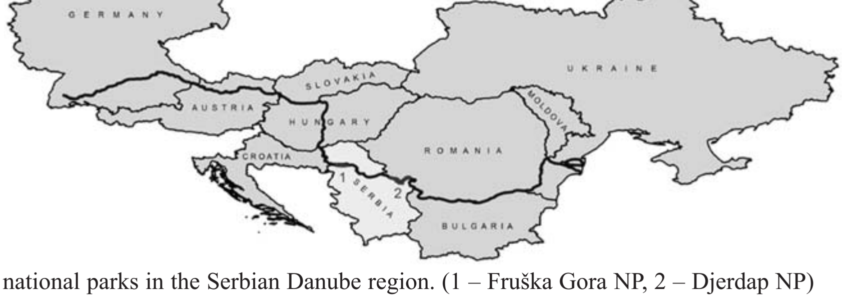


Fig. 1. Location of the national parks in the Serbian Danube region. (1 – Fruška Gora NP, 2 – Djerdap NP)

valleys formed by the erosive work of more than 50 streams that descend from the northern and southern mountain slopes.

The general climatic characteristics of Fruška Gora correspond to a moderate-continental climate of the Pannonian type. Because of the morphology, the precipitation regime is modified such that the central parts of the massif receive the greatest amount of rainfall: 780 mm [16]. The biotic values of the park are characterized by a remarkable diversity of flora and vegetation, which also has characteristics of refugia. The floristic richness of this area consists of more than 1,400 species, which compose a mosaic spread of meadow-steppe and forest communities. On the lower slopes of Fruška Gora and the loess plateaus, a steppe habitat community of *Festucion rupicola* alternates with communities of xerophile and mesophile forests. Altitudes over 300 m are dominated by mountain beech forests with lime (*Tilia-Fagetum submontanum*).

The basic characteristics of the faunal abundance and diversity of Fruška Gora are represented by the rare butterflies fauna (Lepidoptera), reptiles, avifauna (over 150 species of birds), of which the imperial eagle (*Aquila heliaca*) is particularly important; the only safe nesting area in Serbia has been identified solely on this mountain [17]. Because of the contact between the meadow-steppe and forest habitats, the fauna of mammals also is characterized by representatives where specific measures are needed for their protection (e.g., *Spermophilus citellus*).

Djerdap NP, with an area of 636.08 km^2, is the largest national park in Serbia and has been under protection since 1983. The territory of Djerdap is naturally predisposed by the course of the Danube, which has dissected the Carpathian mountain system and connected the Pannonian and Pontian basins. The Danube valley through Djerdap gorge is composite, polygenetic, polyphase, and transverse, with the dominant influence of tectonics in its formation.

The most striking geomorphological characteristic of the area of Djerdap is the grandiose Djerdap gorge, which is the longest and largest breakthrough gorge in Europe. The gorge consists of four small gorges and three valleys that alternate within a length of 100 km. The maximum height of the national park is located on Miroč Mountain (768 m) in the eastern part of the park. The hinterland of the gorge is divided by the erosive work of many short right tributaries of the Danube. The canyon of the Boljetina River is particularly important because the geological history of this part of Europe can be analyzed in it – from the Paleozoic to the Cenozoic eras. The eastern part of the park is represented by many explored caves, of which the Rakin Ponor pit was identified as the deepest pit in Serbia (285 m).

Average annual precipitation sums (1961-90) in the Djerdap sector of the Danube are in the range of 700-800 mm. Their hydrograph is typical of the continental regime.

The floristic and vegetative diversity of Djerdap is characterized by an exceptional richness of species (over 1,100) and phytocenoses (over 50). Among them, the recent communities of Italian (*Quercus frainetto*) and Turkish oak (*Quercus cerris*) on silicates, and the communities of Turkish oak (*Quercus cerris*) and eastern hornbeam (*Carpinus orientalis*) on limestone are dominant. During the Pleistocene, Djerdap gorge and the gorges and canyons of its tributaries represented a significant refuge area, which resulted in the appearance of a large number of relict species and communities (e.g., *Fago-colurnetum mixtim*, *Querco-colurnetum mixtum*, *Syringe-colurnetum mixtum*, and *Celto-juglandetum*) [18].

The main characteristic of the diversity of fauna in the Djerdap area is that it provides a wealth of bird fauna (out of 170 identified species, 110 are nesting birds), but the diversity of the insects, fish, reptiles, and mammals also is significant.

This area is on the tentative list that Serbia has proposed for entry in the list of sites under the protection of the UNESCO World Heritage Convention and the UNESCO MaB program, but also in the Ramsar List (List of Wetlands of International Importance of the Convention on Wetlands).

Both national parks also are areas that are unique in terms of items of cultural and historical heritage. For example, 17 active Orthodox monasteries, of which the oldest dates from the 13th century, are located in the territory of Fruška Gora NP. Complementary to the natural resources of Djerdap NP are its many anthropogenic values that have emerged during different periods of civilization in the area (e.g., the Neolithic archaeological site Lepenski Vir and medieval fortress Golubački Grad.).

Methodology and Experimental Procedures

Multi-hazard mapping is a useful approach for observing several hazards in one location, in which each hazard can be observed both separately and integrally [19]. Because natural disasters occur suddenly, independently of each other, or in a mutual relationship (synergy), it was necessary to assess the most significant natural hazards in the selected areas. The recent state of vulnerability of the national park territory to natural hazards was illustrated using analytic maps, and then a synthetic map was constructed. The areas that were vulnerable to some natural hazards were singled out, and their percentage shares of the total area of the national park were defined along with the total surface area that was vulnerable to natural hazards. By superposing the results, we determined the total vulnerability. In this study, vector-based geographic information system GIS was successfully integrated with multi-hazard zoning, with the aim of determining surfaces with different vulnerabilities.

Upper values of intensity for each natural hazard were determined, as this value represents the limiting factor on surface use for the given level. For seismic activity, for example, areas in which earthquake intensity was above VIII on the MCS-64 scale were singled out, followed by areas at risk of excessive erosion. A state map of seismic regionalization of the Republic of Serbia with a return period of 100 years and an approximately 63% probability of earthquake occurrence [20] was used to analyze the influence of seismic hazards.

The intensity of recent geomorphologic processes was assessed using the respective methods and previous field research data [21-26] and reference maps such as the soil erosion map of Serbia [27] and the Geomorphologic Map of Serbia [28]. According to the estimates, 25% of Serbia is affected by landslide processes, and landslides are a significant natural hazard within the country [8]. The areas that are potentially at risk for landslides in the research area were selected in several phases because the spatial distribution of landslides is a result of the interaction of many parameters. Landslide susceptibility zones in the study area were identified through the heuristic analysis of local topography, morphological and geological setting, and by examining existing and past landslides identified in the study area [29, 30].

Floods and torrential floods are the most frequent "natural risk" phenomena in Serbia. A total of 9,260 torrential watersheds were registered in Serbia through an investigation performed from 1930 to 1974 [31]. The characteristics of maximal discharges in Serbian torrential watersheds were studied by processing data from 128 control profiles, equipped with automatic water-level recorders [32]. Based on the previous research, a map was created with a spatial distribution of the most destructive torrential floods in the last 60 years for the Serbian territory as a result of an analysis of the characteristics of maximal discharges and some interesting cases of historic torrential floods reconstructed using the "hydraulic flood traces" method [33]. On the basis of the results from the previous research, we analyzed the torrential river length in the study area.

The final multi-hazard map of the study areas allows an overview of hazard and risk patterns potentially affecting the protected areas of the two national parks. The use of a multi-hazard approach is crucial because the occurrence of one hazard may trigger another one. In addition, it is also important to provide a multi-hazard assessment showing the comprehensive vulnerabilities and the hazard areas.

Results and Discussion

The results of a complex analysis of the vulnerability of the national park territories to natural hazards indicated that their surface areas are vulnerable to various types of natural hazards. The risk is not uniform across the entire territory but varies depending on the type of hazard and the expected potential damage.

Table 1. Areas vulnerable to natural hazards in Fruška Gora NP and Djerdap NP.

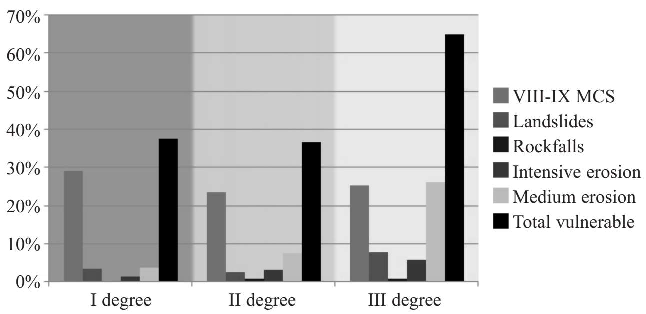
Hazard	Fruška Gora		Djerdap	
	Area (km^2)	%	Area (km^2)	%
VIII-IX MCS	64.89	24.33	31.21	4.91
Landslides	10.84	4.06	2.46	0.39
Rockfalls	0.44	0.17	2.43	0.38
Intensive erosion	9.88	3.70	15.78	2.48
Medium erosion	34.41	12.90	1.15	0.18
Total vulnerable	120.46	45.16	52.49	8.25

Hence, the recent state of vulnerability to major types of natural hazards in the national parks in the Serbian Danube region was analyzed, and it was determined that the areas affected by hazards in these two national parks are different, depending on the complexity of the natural conditions.

In Fruška Gora NP, 120.46 km^2 of the territory is vulnerable to natural hazards, representing 45.16% of its total area, while 52.49 km^2 of the area of the Djerdap NP (or 8.25% of its total area) is vulnerable (Table 1). Observed by the protection zones, out of the total area, 37.39% and 24.99% of the territory vulnerable to natural hazards in Fruška Gora and Djerdap, respectively, is characterized as zone I (Fig. 2). These are extremely high values for the first degree of protection.

In general, if one compares the two national parks, the vulnerability of Fruška Gora to natural hazards is extremely high and occupies more than half of its total area. The high degree of vulnerability is primarily caused by the seismic hazard that occupies more than 50% of all vulnerable areas. Particularly alarming is the vulnerability of the third degree of protection, where the hazards affect more than 65% of the area.

According to the seismological hazard map of Serbia from 2009 [34], which expresses the maximum expected intensity of an earthquake (modified by MCS-64 scale) for a return period of 100 years, the eastern part of Fruška Gora is the most endangered by a seismic hazard, with 29.2%, 23.7%, and 25.3% characterized under protected zones I, II, and III, respectively (Fig. 2). In the most vulnerable seismic



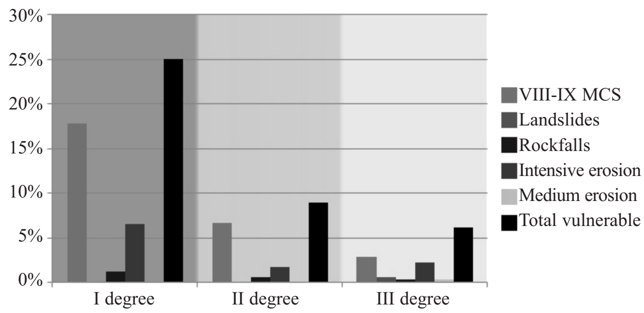


Fig. 2. Areas vulnerable to natural hazards in the protection zones of degrees I, II and III in Fruška Gora (left) and Djerdap (right) parks.

area, numerous natural resources are present, among which the forest ecosystems particularly stand out as zone I sites. Protected forest ecosystems of the region are important for its thermophilous properties (*Carpinoorientalis-Quercetum*), good preservation (*Festuco-Quercetum*, *Fagetum mixtum*, *Querco-Carpinetum*), limited spread (*Quercetum petrae farnetosum-cerris*), and its successive stage (*Musco-Fagetum submontanum* – in the final stage of degradation of the beech forests on Fruška Gora). In addition, the seismic movements endanger geological and geomorphological values represented by the important paleontological sites (Grgeteg and Papradine – rich findings of the fauna of molluscs from the Neogene period). In addition to the protected natural resources, numerous immovable protection zones II and III cultural items are also present in the most affected seismic area, including the Orthodox Monasteries, Novo Hopovo, Staro Hopovo, Grgeteg, and Velika Remeta, which are particularly distinguished for their values. The Staro Hopovo Monastery was damaged by strong earthquakes in 1740 and 1750.

An analysis of the seismic vulnerability of Djerdap indicates that the seismic hazard mostly threatens the western part of the park. Within the scope of the most vulnerable area, 17.8%, 6.7%, and 2.91% are considered to be in zones I, II, and III, respectively (Fig. 2). In the western part of Djerdap, numerous relict communities are represented (e.g., *Syringa-Carpinetum orientalis*, *Fagetum submontanum juglandetosum*), whose habitats would no doubt be significantly degraded by this hazard effect. Apart from the relict communities, numerous facilities that are part of the geological and cultural heritage in this region are threatened (such as the medieval fortress Golubački Grad). Although no earthquakes of a catastrophic intensity are expected, they can cause a synergistic effect and activate another natural disaster, in particular rockfalls or cover collapse.

Analysis of the erosion potential and existence of erosion areas in Fruška Gora indicated that these areas cover 16.60% (Table 1) and are most common on the periphery of the wooded area of the national park. In areas with developed forest vegetation located within the boundaries of the national park, the erosion potential is very weak, while treeless hills that surround these areas have an intensive erosion potential. In the eastern part of the national park, three zone I sites are located along the border of the national park itself and are partly affected by the increased intensity of erosion. The manifestation of the erosion potentials would particularly endanger the rare thermophilous woodland habitats of *Carpinoorientalis-Quercetum*, which is also an important complex community for the insect and bird fauna.

The protection of Fruška Gora is particularly important in the context of loess protection because its deposits, by their significance and attractiveness as well as their degree of erosion vulnerability, are distinguished as being particularly sensitive [35]. The same authors proposed an integrated loess protection in Vojvodina through the formation of the so-called Geopark, of which an essential part would be the territory of Fruška Gora.

In Djerdap, the erosion potential threatens 2.66% of the total area (Table 1), which is mainly located within zone I of protection. If this potential is intensified, the erosion would threaten relict thermophilous forests and bushy communities (such as *Fago-colurnetum mixtum juglandetosum*, *Fraxino-colurnetum mixtum*, *Syringe-colurnetum mixtum*, and *Carpino orientalis-Quercetum mixtum syringetosum*) or even a refuge community (*Celto-Juglandetum*). In addition, the erosion would threaten the palaeontological sites from the Jurassic and Cretaceous eras in the canyon of the Boljetina River.

The total length of the torrential streams in Fruška Gora NP is 34.3 km, while in Djerdap NP their total length is 34.2 km. The effects of the torrents can be considered relatively limited to the immediate surroundings of the streams, and therefore the areas affected by torrential floods do not cover large areas, but the destructive power of this phenomenon is nonetheless high. Frequent and severe torrents carry away much loose material in the affected areas and contribute to the filling in of the river channel and banks in the lower parts of the flow, and thus these torrents represent a serious threat to settlements and infrastructure within the protected zone of the national park. Fruška Gora has an extremely dense network of surface streams, of which the springs and upper parts of the flows are contained within the boundaries of the national park. The larger streams with more developed hydrographical systems that flow through the narrow valleys can easily function as paths of devastating torrential floods under certain conditions. Floods are easily formed on the slopes without mature forest vegetation, and it is therefore important to study the occurrence of torrential floods in correlation with the state of forests in the stream basins and insist upon the consistent application of protection measures as well as responsible and rational management of the forest stands.

Landslides cover large areas of Fruška Gora but are most common outside the boundaries of the national park (e.g., in the protected zone of the national park, they occupy approximately 45 km^2, or 8% of its total area, and are dominant in the coastal zone of the Danube).

The northern part of Fruška Gora and the Srem loess plateau is particularly prone to increased natural hazards caused by specific geologic, geomorphologic, hydrologic, and vegetative conditions and human activities. Important transport routes cross trough areas with increased landslide susceptibility and are often affected by mass movements [22].

Within the boundaries of Fruška Gora NP, approximately 10.84 km^2, or 4.06% of its total area, is vulnerable to landslides. Landslides occur in all three zones of protection (Fig. 2), threatening an area of 0.31 km^2 (3.27%), 4.33 km^2 (2.44%), and 6.21 km^2 (7.76%) within zones I, II, and III, respectively. Landslides generally occur on higher terrain, on steep valley sides, and in contact areas between the loose Quaternary and Tertiary sediments; however, some landslides also occur in low coastal areas of the Danube, such as in an allocated part of the national park at its farthest east. In terms of the most significant natural resources vulnerable to landslides, it is important to mention the sites in zone I where the important forest ecosystems *Tilio-Fagetum submontanum caricetosum silvaticae*, *Querceto-*

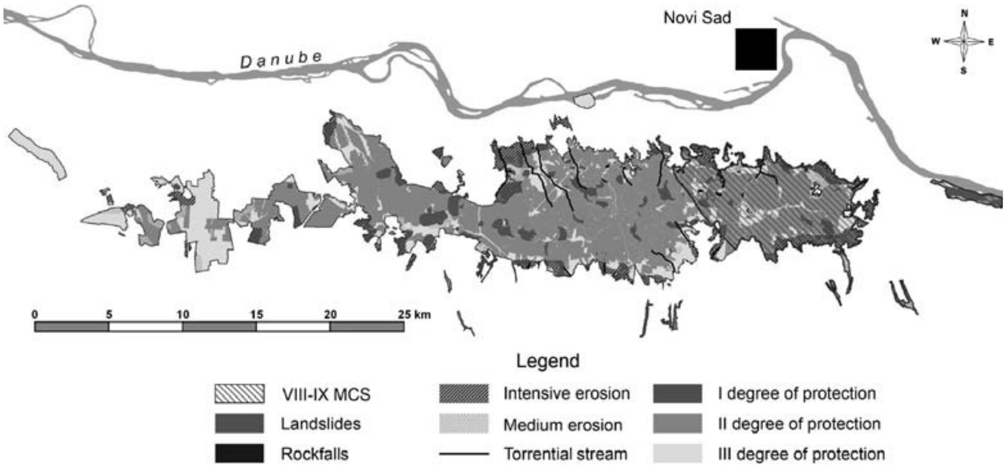


Fig. 3. Integral vulnerability map of natural hazards in Fruška Gora NP.

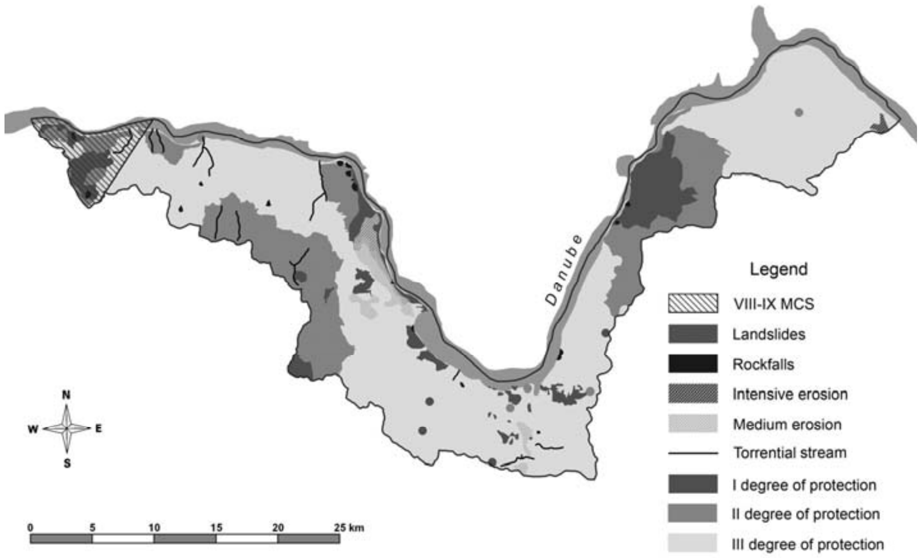


Fig. 4. Integral vulnerability map of natural hazards in Djerdap NP.

Fagetum, and *Querco-Carpinetum* are present, as well as habitats of importance for the bird fauna. Sliding of the surface layers on steep valley sides also affects smaller sites where trees are occasionally uprooted, which may contribute to the increased erosion of loose soil and the occurrence of gully erosion, which makes the natural regeneration of the forest layer more difficult. In addition to natural resources, the landslides also threaten certain cultural heritage, such as the Beočin Monastery on the northern periphery of the central part of the national park, located within zone III.

The area affected by landslides in Djerdap cover an area of approximately 2.46 km^2, or 0.39% of the total area of the national park (Table 1). All landslides occur within zone III and where the terrain is built of the Neogene sediments (the Porečka River). Because rocks of this type cover relatively small areas within the national park and, outside the mentioned locations, are not found on more than a few hectares, it can be concluded that despite the area they occupy, the landslides do not represent a significant hazard in the area, which is the subject of this research.

More than 80% of the rockfalls in Fruška Gora occur along roads, which are cut into the valley sides, the steep walls of the quarry, and on the steep slopes formed by natural processes. Rockfalls cover 0.44 km^2, or 0.17% of the total area of the park. Among the sites with the most important sources, rockfalls endanger the Zmajevac Reserve, an important forest ecosystem, in the eastern part of the national park the most, which is located in zone I. In addition, rockfalls threaten safe transport and occasionally park visitors.

Surfaces at risk of rockfalls affect 2.43 km^2 (or 0.38%) of the total territory of Djerdap. Among the most vulnerable areas is the largest reserve in the park (Veliki and Mali Štrbac), which is characterized by as many as 30 plant species, most of which are relict communities (e.g., *Fago-colurnetum mixtum*). Habitats vulnerable to this hazard are dominantly related to limestone rocks, where typical morphological karst forms were also developed. Nearly 80% of all areas affected by rock falls are near the Djerdap Highway, the main traffic artery that runs through the park, where construction is the cause of the activation of the falling process of the rock masses. The 115 km highway passes through the protected natural area and, currently, 11 locations are the most vulnerable despite security measures. Thus, Butler [36] points out that in areas where the passage of debris flow has produced scour to bedrock, a habitat amenable only to plants associated with the most rudimentary primary succession is created.

The potential collapse zones occur where there is a cover of limestone karst masses due to chemical erosion. In Fruška Gora, the limestone terrains have a limited distribution, and underground karst geomorphologic objects are rare. Only a few small and short caves that are not affected by potential collapse exist.

In Djerdap numerous pits and caves are found, and some might be prone to collapse due to natural factors, in particular earthquakes or anthropogenic effects. There are 11 sites that are most vulnerable to this hazard within the observed territory. This hazard should not be neglected because it threatens the speleological objects of the national park, which represent a significant part of the geological heritage of Serbia. The most significant are those located on Miroč mountain, located in the eastern zone of the NP.

Conclusions

The multi-hazard map is the first important task in the prevention and mitigation of natural hazards in a risk-prone area. Because of the synergetic effect, the hazard manifestation in the border area, where the border is the Danube River, may induce the activation of natural hazards in neighbouring countries that are also vulnerable to different hazards [37-41]. The conducted study suggests that this problem does not respect boundaries, which is necessary to create a vulnerability map of Southeast Europe in terms of natural hazards and thus fill in missing data for the final hazard map of Europe. Therefore, this study represents an important step in completing the European database by providing data from Serbia, a territory that was a blank area in previous maps.

The existing boundaries under the zones of different degrees of protection correspond to the established condition of natural resources. By applying protective measures, in particular those that prevent habitat degradation, it is possible to act preventively to the potential vulnerability to natural hazard areas such as landslides, rockfalls, and erosion. In all zones where these hazards were identified, it is necessary to intensify the implementation of measures that act toward protecting the indigenous phytocoenosis and conditions of their habitats. Particular sensitivity, in this context, is observed in the boundary areas of both national parks, regardless of their protected zone designation. On the basis of the obtained results, we propose a review of the usefulness of the existing measures in all parts of zone III of protection that are affected by these hazards, and where possible, their conversion to the zone II level of protection.

Considering the overall vulnerability to natural hazards in the area of research, the extreme disproportion between Fruška Gora and Djerdap NPs is evident. The natural hazards in Fruška Gora NP affect 45.16% of its total area, implying that their further study is fully justified. Continuous monitoring of the dynamics and magnitude of the observed hazards is just one of the possible activities that can accomplish the complex protection of these natural resources, cultural resources, and population.

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