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FOREST FIRE RISK MAPPING IN THE MUNICIPALITY OF BOLJEVAC

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Abstract: *The research was conducted in the Municipality of Boljevac, which geographically belongs to Eastern Serbia – Timočka Krajina, and administratively to the Zaječar District. Forest protection from fires in this area is of great importance as it can pose a threat. Spatial data within the Geodatabase are organised into the following thematic units: orographic characteristics (altitude, aspect, slope, soil erosion index, heat degrees by altitude, and thermal coordinates of aspect and slope), climate data (mean annual air temperatures, mean annual precipitation), geological and soil characteristics, vegetation (forest types, forest stands by degree of degradation, forest stands by age), fuel material (dead wood and stumps, forest edge on the boundary of forests/non-forests), isokeraunic map, human impact (human factor – human risk, history of fires and its impact on forest fire vulnerability, accessibility of the forest complex and hydrographic data, degree of organisation of areas designated for tourist and recreational activities, other biotechnical measures of protection). Based on 973,152 Geodatabase records grouped into 30,411 homogeneous units, zones were identified based on the degree of vulnerability to forest fires. An analysis of all parameters that affect the degree of vulnerability to varying extents revealed that 33.01% of the total forest area belongs to the first degree of vulnerability - very high vulnerability, 37.10% to the second degree - high vulnerability, while the third degree - moderate vulnerability is represented on 22.02% of the area, and the fourth degree - low vulnerability on 7.87% of the area. The fifth degree - no vulnerability to forest fires was not observed in the Municipality of Boljevac.*

Keywords: risk map, forest fire, geodatabase, Municipality of Boljevac

IZRADA KARTE RIZIKA OD ŠUMSKIH POŽARA NA PODRUČJU OPŠTINE BOLJEVAC

Sažetak: *Istraživanje je obavljeno na području Opštine Boljevac* koje *geografski pripada Istočnoj Srbiji – Timočkoj krajini, a administrativno Zaječarskom okrugu. Zaštita šuma od požara na ovom području ima veliki značaj.* Prostorni podaci unutar Geodatabaze *su organizovani po sledećim tematskim celinama: orografske karakteristike (nadmorske visine, ekspozicije, nagib, indeks spiranja zemljišta, stepeni toplote prema nadmorskoj visini*

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i toplotne koordinate ekspozicije i nagiba), klimatski podaci (srednja godišnja temperature vazduha, srednja godišnja količina padavina), geološke i pedološke karakteristike, vegetacija (tipovi šuma, sastojine po stepenu degradiranosti, sastojina po starosti), gorivi materijal (mrtvo drvo i panjevi, ivica šume na granici šuma/ne šuma), isokeraunička karta, antropogeni uticaji (antropogeni factor-rizik od čoveka, istorija požara i njen uticaj na ugroženost šuma od požara, otvorenost šumskog kompleksa i hidrografski podaci, stepen uređenosti prostora za turističe i izletničke aktivnosti, ostale biotehničke mere zaštite). Na osnovu 973.152 podatka Geodatabaze grupisanih u 30.411 homogenih celina izdvojene su zone po stepenu ugroženosti od šumskog požara. Analizom svih parametara koji u razuličitom stepenu utiču na stepen ugroženosti konstatovano je da 33.01% ukupne površine pod šumom pripada prvom stepenu ugoženosti – veoma velika ugroženost, 37.10% drugom spenu – velika ugroženost, trećem stepnu – srednja ugroženost zastupljena je na 22.02% površine i četvrtom stepenu – mala ugroženost na 7.87%. Peti stepen – nema ugroženosti šuma od požara nije konstatovana na području Opštine Boljevac.

Ključne reči: karta rizika, šumski požar, geodatabaza, opština Boljevac

1. INTRODUCTION

Global warming is accompanied by increasingly intense and prolonged forest fires in the northern parts of the world, resulting in additional carbon dioxide (CO_2) emissions and accelerating climate change. A decade-long monitoring revealed that much more carbon dioxide was emitted into the atmosphere during forest fires than forests could absorb during the process of photosynthesis in the Northern Hemisphere. This trend is expected to worsen in the coming years. Climate change alters the fire regime and leads to various environmental effects (Bowman et al., 2009). Forest fires cause significant economic losses (Lohman et al., 2007). At the Conference on Climate Change and Security (IES, 2012), Serbia was marked as an area with potentially dramatic changes in ecosystems, an increase in forest fires, and negative impacts on agriculture.

Forests, besides their ecological significance in preserving vital life cycles, have various other functions related to trade, tourism, economy, health and recreation, etc. Once, forests covered a much larger area of the planet than they do today. Forest fires are a crucial element in the Earth's system, linking climatic characteristics, human activity, and vegetation type (Ichoku et al., 2003). With 200 – 500 million hectares of burned areas per year, fires cause damage over larger areas and destroy biomass worldwide more than any other factors negatively affecting natural ecosystems (Lavorel et al., 2007; Ichoku et al., 2008).

Forest fire danger prediction is one of the fundamental tasks in forest fire prevention. It can minimise fire damage, while a well-developed system of detection, preparation for the fire season, good mobility and readiness can prevent the occurrence of forest fires. Assessments of the forest fire danger are based on scenarios of when and where a fire occurs and how it develops. Elements for determining the time of fire occurrence are defined by the fire season, i.e., the dynamics of forest fire occurrence defined by long-term monitoring. Risk mapping is of utmost importance for forest fire risk management (Ratknić, 2021).

2. MATERIAL AND METHODS

The research was conducted in the Municipality of Boljevac, located in eastern Serbia in the valley of the Black Timok River. The municipality covers an area of 827 km^2. Its territory geographically belongs to Eastern Serbia – Timočka Krajina, and administratively to the Zaječar District. The diverse composition of the soil has contributed to the richness of plant and animal species. Agricultural land accounts for 46%, while forests cover 51% of the total area. Broadleaved forests dominate in the forest complex. The most significant natural resources include an extensive forest area, water potential, climatic and soil conditions suitable for agricultural production (livestock farming, medicinal herbs, fruit growing, and vegetable cultivation), mineral resources (dolomite, clay – Bentonite, decorative stone), and conditions for the development of tourism and eco-tourism. For this reason, protecting forests from fires in this area is of utmost importance, as it can endanger the advancement of the municipality's tourism and other potentials.

The methodology presented in the dissertation entitled "Integrated Model for Protection and Management of Forest Fires in the Republic of Serbia (Ratknić T., 2018)" was utilised to create a forest fire risk map for the Municipality of Boljevac. Topographic maps at a scale of 1:25000 were used as a data source for the elevation representation of the terrain. To create the digital terrain model (DTM), contour lines were vectorised using a semi-automatic vectorisation method, and elevation points and structural lines were vectorised manually on the screen. The digital model was created in TIN format and then converted to GRID format, i.e., into a pixel matrix where each grid cell attributes the elevation in the state elevation system. The grid resolution was 15 m. A personal spatial database in mdb format was created for the Boljevac area. Spatial data within the Geodatabase are organised by thematic units and represented in cartographic form.

3. RESULTS

In the Boljevac area, 30,411 homogeneous units were identified using the method of visual interpretation of aerial images (and some high-resolution satellite images) (Map 1).

3.1. Orografic Characteristics

Orografic characteristics are decisive factors and modifiers of environmental conditions significant in the prevention and extinguishing of fires, cultivation of burned vegetation, and burned area rehabilitation. The minimum elevation in the Digital Terrain Model (DTM) is 185 m, and the maximum is 1550 m. It covers an area of 828 km^2 (Map 2). Orographic characteristics with the predominant influence are elevation, slope, and aspect. Sites with different elevations, aspects and slopes vary in the duration and intensity of sunlight, and consequently in the conditions for fuel material drying.

Elevation in lowland areas does not modify environmental conditions to a great extent, but in medium high and high areas, it is a decisive factor determining changes in macro and microclimates, soil composition, and vegetation composition.

For example, with a 100-meter elevation increase, air temperature decreases by 0.55°C (0.60°C in summer, 0.40°C in winter), and the growing season shortens by 11.5 days.

The difference in exposure to solar heat can be 1.5-2.5 times greater on southern than northern slopes. Fire incidences are more common on sun-exposed slopes, where they spread faster and with greater destructive power. Sun exposure is higher on slopes (mountains) compared to flat areas, as well as on steep sides than on levelled ones. Surface areas of homogeneous units based on elevation classes, exposure, slope, and points are presented in Table 1, as well as Maps 3, 4, and 5.

The slope of the terrain affects the soil moisture, the speed of water runoff, and the depth and duration of the snow cover. The degree of slope affects stability, erosion, deposition of weathering products, mineral formation, the thickness of the dead organic cover, as well as the depth and type of soil. Certain slopes are crucial for assessing hazards and contribute to significant variations in vulnerability, the rate of spread, intensity, and speed of forest fire movement.

Table 1. *Surface Areas of Homogeneous Units Based on Elevation Classes, Aspect, Slope, and Points*

Elevation				Aspect				Slope			
Elevation class (m a.s.l.)	Points	Area (ha)	%	Aspect class	Points	Area (ha)	(%)	Slope (%)	Points	Area (ha)	(%)
<500	15	41511	50.2	southern and plain	20	26768	32.3	≤15	5	59439	71.8
500-800	10	29794	36.0	eastern and western	10	27029	32.7	15-30	10	22705	27.4
>800	5	11454	13.8	northern	5	28962	35.0	31-45	15	615	0.7

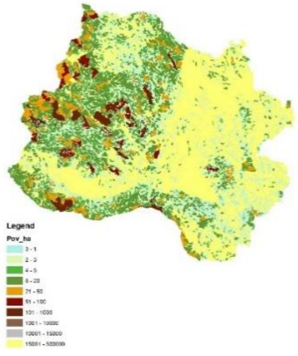
The slope of the terrain affects soil erosion. If soil erosion on a slope of 10% is designated with an index of 100, the erosion on other slopes is provided in Table 2 (Đorđević, G., 2012). Terrain erosion affects the type and quantity of combustible material on a specific surface area, as well as the potential for movement and communication in areas at risk or affected by fire (Map 6).

Table 2. *Soil Erosion Index Relative to Slope*

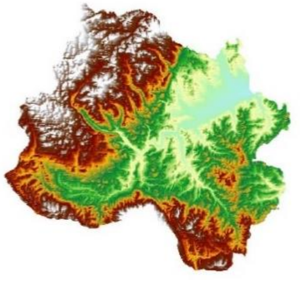
Slope %	1	2	5	10	15	20	25	30
Erosion index	10	12	33	100	186	256	312	354
Area	1448	1468	5257	12378	13674	12178	10023	26332
%	1.8	1.8	6.4	15.0	16.5	14.7	12.1	31.8

Heat degrees relative to elevation (Coordinate V). Coordinate V is dependent on the terrain's elevation. The highest value (18) is assigned to the heat coordinates of terrain with elevations up to 99 meters, while terrains exceeding 1800 meters in elevation have a value of 0 (Map 7).

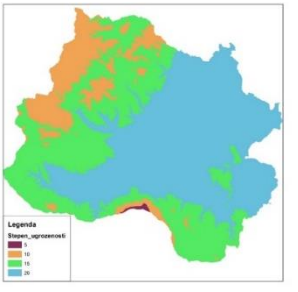
Heat coordinates of aspect and slope (Coordinate E). Coordinate E is derived from combinations of aspect and slope, grouped into nine heat degrees. The first group comprises combinations with the lowest annual solar radiation sum and is labelled 1. Groups with the highest annual solar radiation sum have heat coordinate value 9 (Lujić R., 1960) (Map 8). Together with the map of heat degrees (Coordinate E), they provide thermal conditions for each isolated homogeneous unit (Map 9).



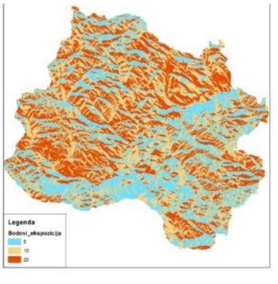
Map 1. *Homogeneous Units Grouped by Area*



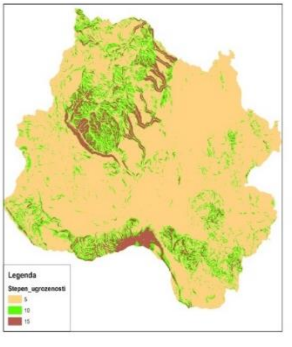
Map 2. *Digital Terrain Model*



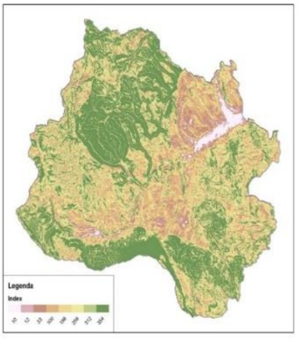
Map 3. *Elevation Classes by Points*



Map 4. *Aspect Classes by Points*



Map 5. *Slope Classes with Points*



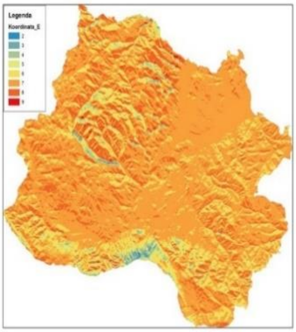
Map 6. *Erosion Index*

3.2 Climate Characteristics

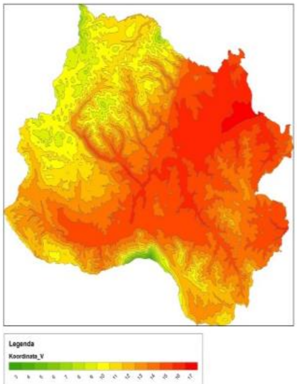
The climate interacts with all factors influencing forest fire vulnerability. Besides various climate parameters affecting the drying of combustible materials (air temperature, relative humidity, precipitation, wind, cloud cover, drought periods, etc.), three key parameters are used in assessing forest fire vulnerability: mean annual air temperature, mean annual precipitation, and mean annual relative humidity. When utilising these parameters, it is essential to incorporate the duration of drought periods and their distribution throughout the year in the assessment of the climate's impact on forest fire vulnerability (Table 3.).

Table 3. *Parameters of the Impact of Climate Elements on Forest Fires*

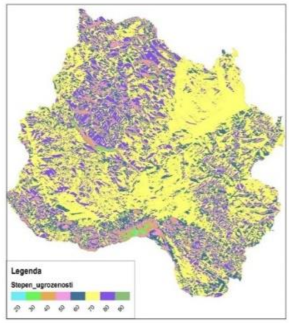
Mean Annual Air Temperature				Mean Annual Precipitation			
Category	Points	A(ha)	%	Category	Points	A(ha)	%
Over 12ºC	30			Up to 800 mm	30	81958	99.0
9.1-12.0 ºC	20	28720	34.7	801-1200 mm	20	800	1.0
Up to 9.0 ºC	10	54038	65.3	Over 1200 mm	10		



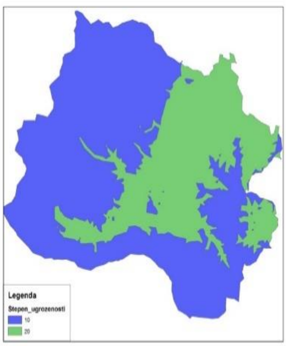
Map 7. *Coordinate V*



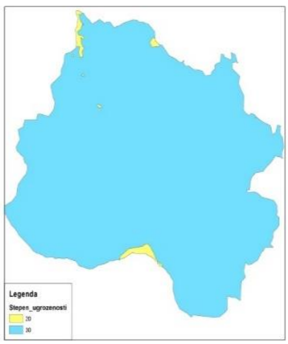
Map 8. *Coordinate E*



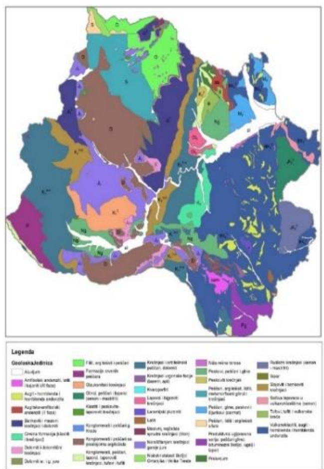
Map 9. *Corordinate E vulnerability*



Map 10. *Mean Annual Temperatures by Points*



Map 11. *Annual Precipitation by Points*



Map 12. *Geological Map*

3.3 Geological and Pedological Characteristics

Soil geological composition has a significant impact on both the occurrence of forest fires and firefighting conditions. Soils are formed from rocks that can be igneous, metamorphic or sedimentary. Depending on the region, tectonic damage to rocks and their mineral composition creates over time a pedosphere with surface soils of different compositions and thicknesses. The vegetation cover, i.e., plant communities that form on the surface, is developed depending on the type and characteristics of the soil, climate conditions, etc. Geological soil composition, alongside other elements, indirectly influences the formation of various types of vegetation, their characteristics, and their susceptibility to ignition and burning.

The flammability of vegetation on the soil surface depends on the dryness and aridity of the terrain, which is particularly high in the hottest months. Rainwater quickly filters into the underground layers when it encounters permeable rocks, leaving the surface dry and devoid of water. This increases the flammability of combustible materials and greatly favours the occurrence of fires. In such areas, firefighting is challenging because there are usually no water sources available for extinguishing. A better situation is observed in semi-permeable and impermeable petrographic areas, where the environments are moister, with surface waters and lush vegetation, reducing the risk of fire occurrence. However, even these areas are at risk of fire, especially in the summer months. These terrains hinder and slow the movement of vehicles, which can further complicate firefighting actions (Table 4.).

Table 4. *Soil Types and Their Impact on the Degree of Forest Fire Vulnerability*

Soil Type	Subtype	Points	Area (ha)	%
Leptosol	All Subtypes	80	3286	4.0
Colluvial Soils (Colluvium)	All Subtypes	80	1548	1.9
Limestone – Dolomite Black Soil (Kalkomelanosol)	All Subtypes	60	37465	45.3
Rendzina		80	886	1.1
Humus Silicate (Ranker)	Eutric	80	472	0.6
	Distric	60		
Vertisol (Smonica)	All Subtypes	60	14127	17.1
Brown Eutric Soil (Eutric Cambisol)	All Subtypes	40	968	1.2
Distric Brown or Acid Brown (Distric Cambisol)	Deep	40	18470	22.3
	Very Deep	20		
Brown Soil on Limestone and Dolomite (Kalkokambisol)	Shallow & Medium Deep	60	1498	1.8
	Deep	40		
Ilimerized or leached (Fluvisol	All Subtypes	40	3233	3.9
Pseudogley		40	419	0.5
Semigley		20	386	0.5

3.4 Vegetation

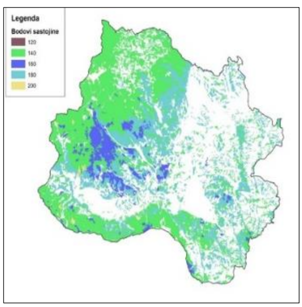
3.4.1 Vegetation by Forest Types

The vegetation, represented by the dominant tree species and the combustible material in the forest that gives rise to various types of combustible materials, forms the basis affected directly or indirectly by all other factors and resulting in varying degrees of susceptibility to fire. The main vegetation parameters determining the degree of forest fire vulnerability are presented in Table 5.

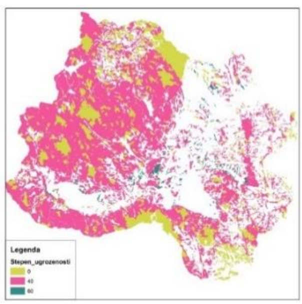
Table 5. *Vegetation Parameters Determining the Degree of Forest Fire Vulnerability*

FOREST TYPE	Points	Area (ha)	%
Category I – Xerothermic and Mesothermic Coniferous forests (natural and artificial) with higher resin content: natural and artificially-established Austrian pine forests; natural and artificially-established Scots pine forests	200	262	0.6
Category II - IIa - Xerothermic Broadleaved Forests: Downy oak forests, Manna ash forests, Oriental hornbeam forests, Turkey oak forests	180	16337	35.3
Category III – Mesophilic and Frigoriphilic Forests (natural and artificial) with lower resin content: Silver fir forests, Norway spruce forests, Serbian spruce forests, Macedonian pine forests, Artificially established larch stands, Artificially established Douglas fir stands, Artificially established Scots pine stands, Artificially established Abies grandis stands, Artificially established stands of other species with similar characteristics	160	122	0.3
Category IV			
IVa - Broadleaved and Coniferous Mesophilic and Frigoriphilic Mixed Forests (natural and artificial): Fir forests, Norway spruce forests, Beech forests IVb - Mixed Forests of Mesophilic and Mesothermic Broadleaved Species: Common hornbeam and sessile oak forests	140	26346	57.0
Category V – Forests Dominated by Mesophilic Deciduous Tree Species: Beech forests, Common hornbeam forests, Birch forests, Willow forests	120	3188	6.9

Map 13. *Soil Map by Points*



Map 14. Vegetation Units by Points



Map 15. *Map of Human Impact*

Forests can be classified in various ways (based on tree species, cultivation methods, age, purpose, etc.), but they are most commonly divided into coniferous forests, broadleaved forests, and mixed forests. Additionally, special forms such as scrubwood, thickets, maquis, garigue, and degraded forests are considered due to their specific susceptibility to fire. Artificially established stands (cultures) are categorised separately within the further classification of vegetation, irrespective of age, as age affects the vulnerability of forests to fire (increased age decreases the susceptibility to fire in natural forests). However, in cultures, this difference is negligible. Further classification of natural coniferous, mixed, and broadleaved forests is done based on light requirements and age, although there are other properties of specific forest types that contribute to their susceptibility to fire, such as resin, tannin, essential oil contents, forest density, and ground vegetation.

3.4.2 Stand Condition by Degree of Degradation

Degraded stands include forests with pronounced degradation of stands and habitats. This forest fire risk group includes scrubwooda and thickets, and partially xerothermic and mesothermic broadleaved forests on warmer slopes.

Table 6. *Stand Condition by Degree of Degradation*

Stand Condition by Degree of Degradation	Points	Area (ha)	%
Degraded stands	100	30625.58	66.2
Scrubwood and thickets	160	4042.07	8.7

3.4.3 Stand age

Regarding stand age, the age (in years) of the species identified in the homogeneous unit is entered. The age of trees is closely related to the fundamental parameters of stand structure, cultivation needs, and forest production characteristics. The age refers to the entire homogeneous unit, representing the average age for the entire set of trees of the homogeneous unit (Table 7).

Table 7. *Stand Age, Points, and Surface Area Representation*

Stand Age	Points	Area (ha)	%
Up to 30 years	80	1315	2.8
31 to 60 years	60	5859	12.7
Over 60 years	40	35039	75.8
Uncategorized		4042	8.7

3.5 Fuel Material

3.5.1 Dead Wood and Stumps

The quantity, condition, and structure of dead wood and stumps remaining in the forest are important ecological information indicating the degree of stand naturalness. It is also an essential basis for calculating carbon stocks in the forest ecosystem. The term "dead wood" includes physiologically dead trees or tree parts. Three categories of dead wood are distinguished: "lying" wood, dry branches and stumps, and thicker and thinner pieces of wood for which specific measurement procedures are defined. There are four degrees of decomposition of trees, stumps, and branches (wood is solid and hard; wood shows signs of decay; wood is in an advanced stage of decay, and wood is decomposed). Assessment is carried out for all categories of dead wood. The presence of dead wood (regardless of the stage of decomposition), with the points defining the risk of fire occurrence and spread, is divided into four groups (Table 8).

Table 8. *Presence of Dead Wood and Points*

Dead Wood Presence	Represented in m³/ha	Points	Area (ha)	%
Significant Presence	>10.0	20	2637	5.6
Present	7.22	10	31130	67.3
Minor Presence	<3.0	5	7956	17.2
Not Present	0	0	4532	9.8

3.5.2 Forest Edges at the Forest/Non-forest Boundary

The forest located on the border between the forest and non-forest land categories generally has a different internal structure. On the other hand, it represents a factor that contributes to the spread of fires to forest areas and the transition from surface to crown fires. The layered edge of the forest with a developed canopy cover (heterogeneous, sufficiently dense and irregular) is considered ecologically favourable. The presence of shrubs, along with the length, type, form, density, and composition of the forest edge, is determined for each homogeneous unit.

The presence of shrubs on the forest edge and their width are evaluated (the occasional presence of shrubs with coverage below 5% is not taken into account) (Table 9).

Table 9. *Presence Of Shrubs on the Forest Edge*

Presence of shrubs on the forest edge	Points	Area (ha)	%
No shrub belt	0	485	0,2
Shrub belt under 10 m	5	1178	0,5
Shrub belt over 10 m	10	647	0,3

Based on the way the "forest" category changes into the "non-forest" category, the forest edge can be classified into five types (Table 10).

Table 10. *Type of Forest Edge*

Forest edge type	Area (ha)	%
open area, plantation, young growth, or dwarf conifers at the upper forest boundary, etc.;		
trees with normally developed crowns (unbranched trees) without a shrub layer or only sporadically with shrubs;	134	5.8
forest edge composed of branched trees without a shrub layer or with sporadically present shrubs (partial canopy of tree crowns);	97	4.2
forest edge consisting of trees and shrubs (steep stand canopy)	608	26.3
layered forest edge, with a belt of lower trees and shrubs in front of taller trees (layered stand canopy)	1471	36.3

Shape of the forest edge. The forest edge can have different shapes (straight, irregular, and highly irregular) (Table 11).

Table 11. *Shape of the Forest Edge*

Forest Edge Shape	Area (ha)	%
Straight forest edge		
Irregular-shaped forest edge (undulating, rounded)	1529	66.2
Highly irregular-shaped forest edge	781	33.8

The density of the forest edge is determined to a depth of 10 m from the forest edge, viewed from the non-forest land into the interior of the stand. The percentage of the forest covered with shrubs and lower branches of trees up to a height of 2 m was assessed (Table 12).

Forest Edge Depth. The total depth of the forest edge, indicating a different structure from the interior of the stand, is assessed. If the estimated average depth of the forest edge is wider than 10 m, it is assigned 10 points (Ratknić, T., 2018). The presence of shrubs on the forest edge is also assessed (occasional presence of shrubs with coverage below 5% is not included), and a belt of 10 m in width is assigned 10 points (Ratknić, T., 2018).

Table 12. *Forest Edge Density*

Forest edge density	Points	Area (ha)	%
Open forest edge, 0-25% coverage	10	120	5,2
Sparse forest edge, 26-50% coverage	20	363	15,7
Moderately dense forest edge, 51-75% coverage	30	973	42,1
Dense forest edge, 76-100% coverage	40	855	37.0

Table 13. *Forest Edge Depth*

Forest Edge Depth	Points	Area (ha)	%
Forest edge is narrower than 10 m	10	784	34
Forest edge is wider than 10 m	20	1526	66

Effect of the Forest Edge and Adjacent Land on the Stand. Any potential impact on the forest land, along with activities carried out on it is assessed, including the impact of the forest edge itself, which can have a positive or negative influence on the condition, stability, and production of the stand. Positive effects include, for instance, wind protection, wildlife shelter, prevention of domestic animal entry into the forest, biodiversity protection, and similar benefits. The impact is considered negative when there are no such positive characteristics and when activities on the nearest non-forest environment cause damage to the forest land and stands (such as root damage from plowing, car or agricultural machinery parking, mushroom picking, waste dumping, livestock grazing, etc.). The assessment is complex, and the impact is classified into three categories (Table 14).

Table 14. *Effect of Forest Edge and Adjacent Land on Stand*

Effect of forest edge and adjacent land on stand	Area (ha)	%
Positive effect		
Negative effect	2310	100%
Very strong negative effect		

3.6 Isokeraunic Map

Although natural phenomena contributing to forest fires account for approximately 1% of all forest fire causes, this phenomenon should not be overlooked. There are areas that are affected by certain natural phenomena, and during specific periods, they can frequently be agents of forest fires. The most common natural phenomenon causing forest fires is atmospheric discharge or lightning strikes, as well as the effect of solar heat that can encounter a specific focus and lead to the ignition, usually of dry grass as fuel. Increasing attention is also given to the theory that many forest fires are caused by 'solar winds,' but this theory has not been scientifically proven and will not be considered in this methodology. Atmospheric discharge is a a natural phenomenon that causes forest fires. Table 15 presents the number of lightning strikes and the degree of danger expressed in points."

Table 15. *Number of Lightning Strikes and Degree of Danger Expressed in Points*

Number of Lightning Strikes	Danger Level	Points	Area (ha)	%
Up to 32	Low	0		
33 to 36	Moderate	10	46255	100
Above 36	Significant	20		

3.7 Anthropogenic Influences

3.7.1 Anthropogenic Factor – Human-Related Fire Risk

Nearly 98% of forest fires are directly or indirectly related to human activities. The presence of humans in the forest, including shepherds, tourists, fruit gatherers, and hunters, increases the risk of forest fires. The vulnerability increases if their activities involve the use of fire, such as burning stubble, plant residues, and using fire for any purpose in the forest. Therefore, the risk posed by humans is a significant indicator of forest fire vulnerability. Table 16 provides some indicators of the impact of human activities on the vulnerability of forests.

If reagarding the human-related forest fire risk, a forest can be classified into multiple risk categories, the impact of these factors on the vulnerability of forests to fires is expressed as the total number of points.

Table 16. *Parameters of Human Impact on Forest Fire Incidence*

Category	Points	Area (ha)	%
Category 1: Tourist and recreational forests, forests adjacent to agricultural land and waste disposal sites	60	7916	17.11%
Category 2: Forests traversed by public roads, power lines, or used for grazing	40	5272	11.40%
Category 3: Forests used for forest product gathering, hunting, fishing, and silviculture	20		
Uncategorized	0	33068	71.49%

3.7.2 Fire History and its Impact on Forest Fire Vulnerability

The history of fires, specifically the number of fires within a certain time interval in a particular area, affects the the degree of forest vulnerability to fires. The number of fires in the observed area indicates which part of the area is more susceptible to fire and the overall vulnerability of the forest to fires. Additionally, the combustible material is not the same in areas with frequent fire occurrences, as the weather conditions that affect the combustible material are prone to change in these locations. Table 17 presents some characteristics determining the degree of forest fire vulnerability related to the frequency of fires in the study area over a 10-year period.

Table 17. *Parameters of Fire History Influencing the Degree of Forest Fire Vulnerability*

Number of Fires in the Area in a 10-Year Period	Points
5 or more	40
2 to 4	20
Up to 2	10

3.7.3 Forest Complex Accessibility and Hydrographic Data

The accessibility of the forest complex through pathways is fundamental for the successful prevention of forest fires. This includes the maintenance of firebreaks by cleaning and pruning, thinning, and reduction of combustible material. The accessibility of the forest complex is depicted in Table 18.

Table 18. *Accessibility of the Forest Complex*

Accessibility of the Forest Complex	Points	Area (ha)	%
Forest complex is accessible (most areas are accessible via a developed road network; firebreaks are regularly maintained)	5		
Forest complex is partially accessible (large parts are poorly accessible, or accessible through forest roads unsuitable for firefighting vehicles; firebreaks are poorly maintained)	20		
Forest complex is not accessible, no firebreaks	40	46255.64	100

Map 16 shows the geodatabase of the road network of the Boljevac Municipality. Map 17 depicts the geodatabase for the hydrographic network and water sources.

3.7.4 Organisation of the Areas Designed for Tourist and Recreational Activities

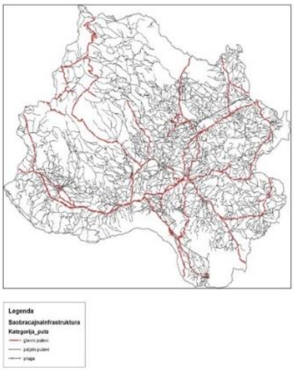
Due to the high number of people, campfires, and the use of various means of ignition, recreation areas pose a special danger and risk of fire occurrence. There are relatively few organised recreation areas that can meet all safety measures and reduce the risk of fire. An area is considered a designed recreational area if it is equipped with well-designed and designated places for casmpfire, firefighting equipment, and organised guard services to oversee and guide activities, as well as alert to activities that may cause a fire (Table 19). Map 18 displays geodatabases for natural and cultural values expressed through the locations of tourist facilities and protected natural assets.

3.7.5 Other Biotechnical Protection Measures

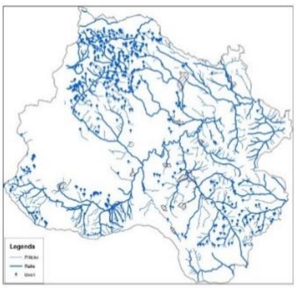
Other biotechnical measures for forest fire protection include planting mixed forests with less fire-prone fuel material, constructing and regularly maintaining firebreaks, building and maintaining water supply points, constructing observation points, establishing a forest surveillance system and developing and implementing a system of forest fire risk assessment (Table 20).

Table 19. *Degree of spatial organisation and number of points*

Degree of organisation	Points	Area (ha)	%
Forest complex is organised for tourist and picnicking activities (designated and secured fireplaces, sand bucket extinguishers in case of small fires in their initial stages, forest fire warning signs)	5	4626	10,0
Forest complex is partially organised for tourist and picnicking activities (forest fire warning signs)	20	10824	23.4
Forest complex is completely unsuitable for tourist and picnicking activities (no designated fireplaces or forest fire warning signs)	40	30806	66.6



Map 16. *Road Network*



Map 17. *Hydrological Network and Water Sources*

Map 18. *Tourist Facilities and Protected Natural Assets*

Table 20. *Biotechnical protection measures and points*

Degree of Organisation	Points	Area (ha)	%
Forest complex with biotechnical protection measures (mixed forests with less fire-prone fuel material, regularly maintained firebreaks, built and maintained water supply points, observation points, established forest surveillance system and implemented system of forest fire risk assessment)	5	2590	5,6
Forest complex without biotechnical protection measures	40	43665	94,4

3.8 Forests fire vulnerability risk: location of cameras and visibility zones

Based on the parameters for assessing the vulnerability of forests to fire, we calculated the sum of points for all represented parameters in the observed area. The degree of forest vulnerability to fire was determined based on the total number of points. Table 21 provides the categorisation of forest vulnerability to fire based on the number of points.

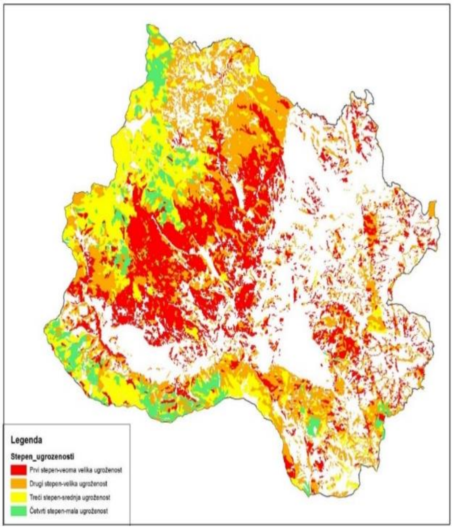
Table 21. *Categorisation of Forest Fire Vulnerability*

Degree of Forest Fire Vulnerability	Total Points	Colour	Area (ha)	%
First degree - very high vulnerability	> 681	red	15270	33.01%
Second degree - high vulnerability	601-681	orange	17160	37.10%
Third degree - moderate vulnerability	531-600	yellow	10186	22.02%
Fourth degree - low vulnerability	<531	green	3640	7.87%
Fifth degree - no vulnerability		blue		

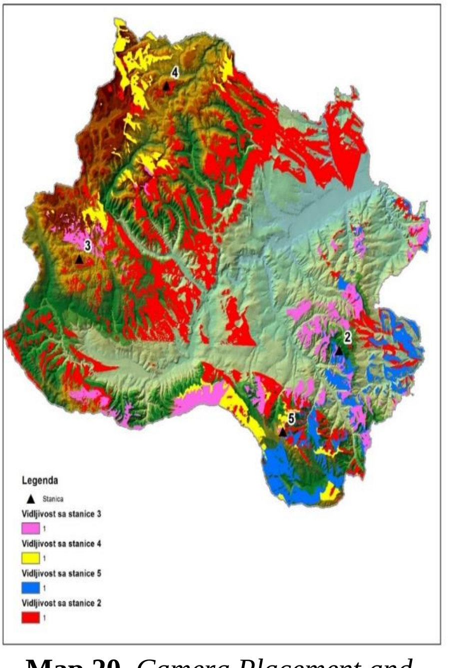
3.8.1 Camera Placement and Visibility Zones

Reducing damage caused by outdoor fires involves three prerequisites through the implementation of automatic observation and data collection systems, namely:

1. early detection of fires at their ignition;
2. timely and rapid implementation of necessary firefighting activities, requiring objective and relevant information;
3. detection and penalisation of deliberately set fires;



Map 19. *Categorization of Forest Fire Vulnerability*



Map 20. *Camera Placement and Visibility Zones*

A more technologically advanced method of monitoring open spaces is video surveillance, where an observer sits in a control center and simultaneously monitors multiple cameras. The automatic observation system aims at both preventive firefighting activities and activities related to fire extinguishment, encompassing two segments:

- preventive firefighting activities, which involve 24-hour observation in the visible and near-infrared spectrum, linked with an alarm expert system for early detection of outdoor fires based on recognising smoke and fire occurrences. This includes the capability of quickly transmitting and storing footage on a central device.
- activities related to firefighting involving remote video presence with camera control tailored to users, supporting fire monitoring and firefighting action management.

Map 20 displays the layout of locations for camera placement and visibility zones at different distance levels.

5. CONCLUSION

Based on 973,152 data points from the Geodatabase grouped into 30,411 homogeneous units, we identified zones by degrees of forest fire vulnerability. Through an analysis of all parameters that influence the degree of vulnerability to varying extents, it was observed that 33.01% of the total forest area falls into the first degree of vulnerability – very high vulnerability, 37.10% into the second degree – high vulnerability, the third degree – moderate vulnerability accounts for 22.02% of the area, and the fourth degree – low vulnerability for 7.87%. The fifth degree – no vulnerability to forest fires was not observed in the Boljevac Municipality area.

The installation of four cameras is planned to provide surveillance over all areas threatened by the occurrence of a forest fire. Such detection systems, enabling quick response and timely reporting of forest fires, are more acceptable from the financial aspects as as they incur lower costs, provide faster fire detection and notification regardless of the time of day and weather conditions. They allow for faster organisation and deployment of firefighting units, thus increasing the efficiency of firefighting. This method of fire monitoring allows for quicker response in the initial stages of a fire, requiring fewer personnel and less firefighting equipment. Connecting such integrated systems for forest fire detection with the forest fire hazard index and geographic information systems supporting the forest fire area opens up significant possibilities in both preventive and organisational forest fire protection.

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FOREST FIRE RISK MAPPING IN THE MUNICIPALITY OF BOLJEVAC

Tatjana DIMITRIJEVIĆ, Mihailo RATKNIĆ, Goran ĐORĐEVIĆ,
Sabahudin HADROVIĆ

Based on 973,152 data points from the Geodatabase grouped into 30,411 homogeneous units, we identified zones by degrees of forest fire vulnerability. Through an analysis of all parameters that influence the degree of vulnerability to varying extents, it was observed that 33.01% of the total forest area falls into the first degree of vulnerability – very high vulnerability, 37.10% into the second degree – high vulnerability, the third degree – moderate vulnerability accounts for 22.02% of the area, and the fourth degree – low vulnerability for 7.87%. The fifth degree – no vulnerability to forest fires was not observed in the Boljevac Municipality area. The installation of four cameras is planned to provide surveillance over all areas threatened by the occurrence of a forest fire. Such detection systems, enabling quick response and timely reporting of forest fires, are more acceptable from the financial aspects as as they incur lower costs, provide faster fire detection and notification regardless of the time of day and weather conditions. They allow for faster organisation and deployment of firefighting units, thus increasing the efficiency of firefighting. This method of fire monitoring allows for quicker response in the initial stages

of a fire, requiring fewer personnel and less firefighting equipment. Connecting such integrated systems for forest fire detection with the forest fire hazard index and geographic information systems supporting the forest fire area opens up significant possibilities in both preventive and organisational forest fire protection.

IZRADA KARTE RIZIKA OD ŠUMSKIH POŽARA NA PODRUČJU OPŠTINE BOLJEVAC

Tatjana DIMITRIJEVIĆ, Mihailo RATKNIĆ, Goran ĐORĐEVIĆ, Sabahudin HADROVIĆ

Na osnovu 973.152 podataka Geodatabaze grupisanih u 30.411 homogenih celina izdvojene su zone po stepenu ugroženosti od šumskog požara. Analizom svih parametara koji u razuličitom stepenu utiču na stepen ugroženosti konstatovano je da 33.01% ukupne površine pod šumom pripada prvom stepenu ugoženosti – veoma velika ugroženost, 37.10% drugom stepenu – velika ugroženost, trećem stepenu – srednja ugroženost zastupljena je na 22.02% površine I četvrtom stepenu – mala ugroženost na 7.87%. Peti stepen – nema ugroženosti šuma od požara nije konstatovan na području Opštine Boljevac. Predviđeno je postavljanje četiri kamere koje zonama vidljivosti obezbeđuju nadzor na svim površinama koje su ugrožene od nastanka šumskog požara. Ovakvi sistemi detekcije koji omogućuju brzo reagovanje i pravovremeno vršenje dojave šumskih požara su pre svega finansijski bolji, jer su troškovi manji, daju bržu detekciju požara i brzu dojavu, bez obzira na doba dana i vremenske uslove, što omogućuje bržu organizaciju, brži izlazak jedinica na gašenje požara što povećava efikasnost gašenja. Ovaj način nadgledanja požara omogućava brže reagovanje u početnoj fazi požara, potrebu za manjim brojem ljudi i potrebu za manjom količinom opreme za gašenje. Povezivanjem ovakvih integralnih sistema za detekciju šumskih požara sa indeksom opasnosti od nastanka šumskih požara i geografskim informacionim sistemima koji podržavaju oblast šumskih požara, otvaraju se velike mogućnosti i u preventivnoj i organizacionoj zaštiti šuma od požara