The influence of weather conditions on the fire hazard in nature in the protected areas of the Southern Carpathians

Živanović Stanimir[1], Nenad Radaković[2], Amalia Dumbrava[3] and Gocić Milena[4*]
1. Emergency Management Sector of Serbia, Belgrade, SERBIA
2. Djerdap National Park, Donji Milanovac, SERBIA
3. Iron Gates Natural Park, Orşova, ROMANIA
4. Department of Geography, Faculty of Sciences and Mathematics, University of Niš, Niš, SERBIA
*milena.j.gocic@gmail.com

Abstract
The protected areas in the Carpathians are sensitive to different types of natural hazards that threaten different systems. We investigated the possible influence of weather conditions that favour the ignition and spread of fires in protected areas in the Southern Carpathians. We focussed on the Djerdap National Park (Serbia) and the Iron Gates Natural Park (Romania). We used the calculation of climate indices based on the combination of air temperature, precipitation and humidity. The variability of the dynamics of fire occurrence in nature reserves was analysed depending on the change in the value of Forest Aridity Index (FAI), the De Martonne Aridity Index (I_{DM}), the Lang Rain Factor (L) and Angström index (I) in the period 2018-2023. The fire risk was assessed using statistical data on the occurrence of fires in Djerdap National Park and the Iron Gates Natural Park. The data on the period of fire occurrence show that the greatest risk of fire occurrence is in the period March-April (71.1% of the total annual number of fires), when air temperatures are not high.

Based on the value of the Angström Index (I), the risk of forest fires is highest in the period July-August. The results obtained show that there is a correlation between the number of fires and the climate indices, whereby the coefficient of determination for the annual values is significantly higher than for the monthly values. The correlation of the monthly dynamics of the occurrence of fires with the climate indices (L, I_{DM}) is stronger for the Djerdap National Park area than for the Iron Gates Nature Park.

Keywords: Fire, Climate Indices, Correlation, Protected Areas.

Introduction

National parks and nature parks are of great importance for the conservation of biodiversity and for the protection of various animal and plant species. The Carpathian region is one of the most important protected areas for biodiversity on European continent[35]. Carpathian forests are characterised by a high level of biodiversity and productivity and are a key element of the European carbon cycle[28]. The Carpathians are of fundamental importance for many endangered plant and animal species and the largest area in Europe covered with intact forests[19].

The negative effects of rising air temperatures and decreasing precipitation can be seen, among other things, in the drying out of forest vegetation. Climatic conditions in the Carpathian region have changed significantly in the last 50 years and that this is likely to continue in the coming decades[35]. High air temperatures pose a very pronounced and major threat to the occurrence of fires in nature[14,36]. Many studies[12,15,24,30] indicate the connection between extreme heat waves and fires in nature.

Changes that occur due to numerous natural and anthropogenic factors can lead to unfavourable conditions for the environment. The protected areas of the Southern Carpathians are threatened by various types of natural hazards and are particularly vulnerable to climate change[7]. Fires in nature significantly threaten its natural values and can affect various aspects of human life. The damaging consequences of fires can be significant, often unpredictable and far-reaching, depending on their intensity and duration[29]. As these areas are characterised by high biodiversity[21,26] and relatively good ecosystem conservation, an assessment of forest fire risk in this area is a current need.

The Carpathians were not affected by frequent fires in the past[21]. Forest fires are also not widespread in the Romanian Carpathians and are considered a negligible cause of ecosystem disturbance[13]. Many studies indicate that climate has a strong influence on fire activity in nature[6,11,20,25,34,37,40]. Climatic factors are generally considered to be the main driver of fire regimes[4]. Weather is the most variable and important factor influencing regional fires. The ignition and spread of fires depends on the interaction between climate, vegetation structure and land use at local and regional scales[18]. The results of this study can be used in designing and adopting appropriate strategies to avoid/minimize damage caused by fire in the protected areas and for the development and application of suitable strategies for the prevention/mitigation of fire damage in the research area.

Material and methods

The Carpathian Mountain system is located in the south-eastern part of Central Europe and the north-western part of

south-eastern Europe. The Carpathian Mountains are located in the south-eastern part of Central Europe and the north-western part of south-eastern Europe. The length of the mountain system reaches 1,500 kilometres and the maximum width 340 kilometres. The arch-shaped Carpathian massif extends across the territory of the Czech Republic, Slovakia, Poland, Ukraine, Romania and Serbia (Figure 1). The Djerdap National Park (NP) is located in the north-eastern part of Serbia, directly on the border with Romania. To the north of the Djerdap National Park, along the course of the Danube, there is the Iron Gates Nature Park (PP) on the Romanian side. Djerdap NP is the largest national park in Serbia and has its administration in Donji Milanovac (44° 31′ 44.2″ N 21° 58′ 33.1″ E).

The Iron Gates Natural Park is the second largest nature park in Romania. The administration is located in the town of Orsava (44° 43'31″ N 22° 23'46″ E). The area of Djerdap NP is 63,786.48 ha and the area of the Iron Gates Natural Park is 115,655 ha. The area of the NP and the PP is dominated by deciduous species with a pronounced richness and diversity of flora and fauna. The vegetation of Djerdap NP consists of over 50 plant communities, of which 35 are relict, with 1013 species and subspecies of vascular flora[26]. High quality beech forests are preserved in these areas and are the main feature[23]. The diversity of ecosystems and biodiversity is very high in PP Iron Gates. Many species of flora and fauna are protected by international, European and National regulations. Most of the area is slightly hilly and is characterised by river valleys.

The climatic conditions in the area of the Southern Carpathians are influenced by the Atlantic, Continental and Mediterranean climate. Climatic conditions are significantly influenced by solar radiation and PP tends to be on the sunny (warmer) side compared to NP. In order to consider the climatic characteristics of the NP and PP areas, we used data on the average monthly and annual values for air temperature, precipitation and humidity obtained from two important meteorological stations (Table 1) for the period from 2018 to 2023. The Veliko Gradište station is managed by the Hydrometeorological Service of the Republic of Serbia[27] and the Drobeta Turnu Severin station is managed by the National Meteorological Administration of Romania[10].

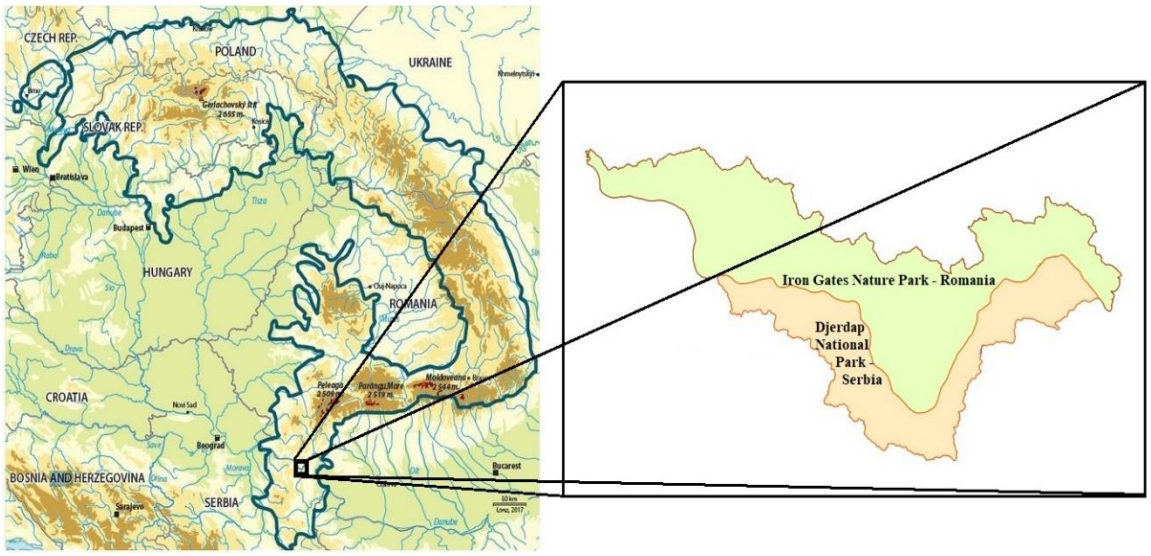


Figure 1: Geographical location of the study area

Table 1
Location of meteorological stations in the protected areas of the Southern Carpathians (latitude, longitude and altitude)

Protected areas	Meteorological station	Latitude (N)	Longitude (E)	Altitude (m)
Djerdap National Park	Veliko Gradište (VG)	44° 45’	21° 31’	82
Iron Gates Natural Park	Drobeta Turnu Severin (DTS)	44º 38’	22º 38’	77

Table 2
Monthly and annual mean (Ann) of air temperature (°C) at the meteorological stations in the protected areas of the Southern Carpathians during the period 2018-2023.

Met. station	Month												Ann.
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
VG	1.8	3.7	6.9	12.1	16.9	21.5	23.2	23.1	18.2	13.5	8.6	3.9	12.8
DTS	2.9	4.6	7.5	12.8	17.7	22.3	24.9	25.2	20.2	14.3	8.8	4.0	13.8

The annual values of the De Martonne aridity index (equation 1) I_{DM}[5], the Lang factor L[16] (equation 2) and the Forestry Aridity Index FAI[8] (equation 3) are obtained from the following equations:

$$I_{DM} = \frac{P}{T+10} \quad (1)$$

$$L = P/T \quad (2)$$

$$FAI = Cg * \frac{T_{VII-VIII}}{(P_{V-VII}+P_{VII-VIII})} \quad (3)$$

where P is the annual precipitation (mm), T the annual mean temperature (°C), $T_{VII-VIII}$ is the average temperature in July and August (°C), P_{V-VII} is the precipitation sum in the period from May to July (mm), $P_{VII-VIII}$ is the precipitation sum for the period July–August (mm) and Cg is 100 mm/°C, the constant.

The monthly drought index was determined using the adjusted index of the Lang factor[16] and De Martonne[5] (Im_{DM}). The data on fires collected for the period from 2018 to 2023 were obtained from the fire protection services in NP and PP. The Angström index (I) was used to assess the risk of forest fires, which is calculated based on the following equation[2,17]:

$$I = \frac{R}{20} + \frac{(27-T)}{10} \quad (4)$$

where R is relative humidity in % (0-100) and T is air temperature (°C).

Results and Discussion

Basic characteristics of air temperature: Average monthly and annual air temperature values in the protected areas of the Southern Carpathians are given in table 2. Based on the mean monthly and annual air temperatures in the protected areas of the Southern Carpathians, the following conclusions can be drawn:

- Higher annual air temperature values were measured in the Iron Gates PP (13.8 °C) and lower ones in the Djerdap NP (12.8 °C). The difference in average annual air temperatures of 1.0 °C could have an impact on the frequency and intensity of forest fires in the nature of Iron Gates PP and Djerdap NP.
- The highest average monthly air temperatures are recorded in July and August and the lowest in December and January.

Basic characteristics of precipitation: Precipitation in the areas of the Southern Carpathians is irregularly distributed in time and space, which is due to the characteristics of the relief. The amount and distribution of precipitation are important climatic elements influencing the occurrence of fires[31]. The number of fires decreases exponentially with the amount of precipitation. Precipitation, with its excess or deficiency, has a direct effect on the condition of the fuel in the forest and thus reduces the risk of fire and vice versa[3].

Table 3 shows the average monthly and annual precipitation values at the meteorological stations in the protected areas of the Southern Carpathians for the period from 2018 to 2023[10,27]. The average annual amount of precipitation is higher in the Djerdap National Park area (735.9 mm) and is lower in the Iron Gates Natural Park area (625.6 mm). Table 3 shows that most of the total annual precipitation falls in the month of June. Winter is drier than summer.

Dynamics of fire occurrence in the researched area: The dynamics of the occurrence of fires in open space on the territory of the Djerdap NP and the Iron Gates PP in the period 2018-2023 is shown in figure 2. It is noted (Figure 2a) that the highest number of fires was recorded in 2019 (34 fires) and the lowest in 2023 (2 fires). An extremely low number of forest fires occur in years with extreme precipitation[39]. It can be seen (Figure 2a) that there is a negative trend in the annual number of fires in the analysed period.

Air temperatures were extremely high and precipitation was unevenly distributed in 2019, which favoured the creation of suitable conditions for the occurrence and development of fires. Summer droughts and high air temperatures are the main factors in the interannual variability of fires in southern Europe[32,33]. The occurrence of fires in the eastern Mediterranean is correlated with the mean maximum and absolute maximum air temperature[15].

Looking at the dynamics of the occurrence of fires by month, the highest number is observed in the period March-April as in figure 2b. During the vegetation period, in the months of May and June, there were no fires. The largest number of forest fires occurred in March (39 fires – 47%). A significant number of fires occur in the months of April and October (38.5% of the total annual number of fires in Djerdap National Park (Djerdap NP) and the Iron Gates Natural Park (Iron Gates PP). There were no fires in the months of January, May, June and December.

Table 3
Monthly mean and annual mean rainfall (mm) at the meteorological stations in the protected areas of the Southern Carpathians during the period 2018-2023

Met. station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Ann.
VG	61.7	39.5	37.3	54.8	78.9	100.8	87.0	63.0	48.4	35.0	60.3	69.3	735.9
DTS	61.2	34.7	42.3	53.6	53.3	85.0	54.6	37.8	30.8	31.1	72.4	60.0	625.6

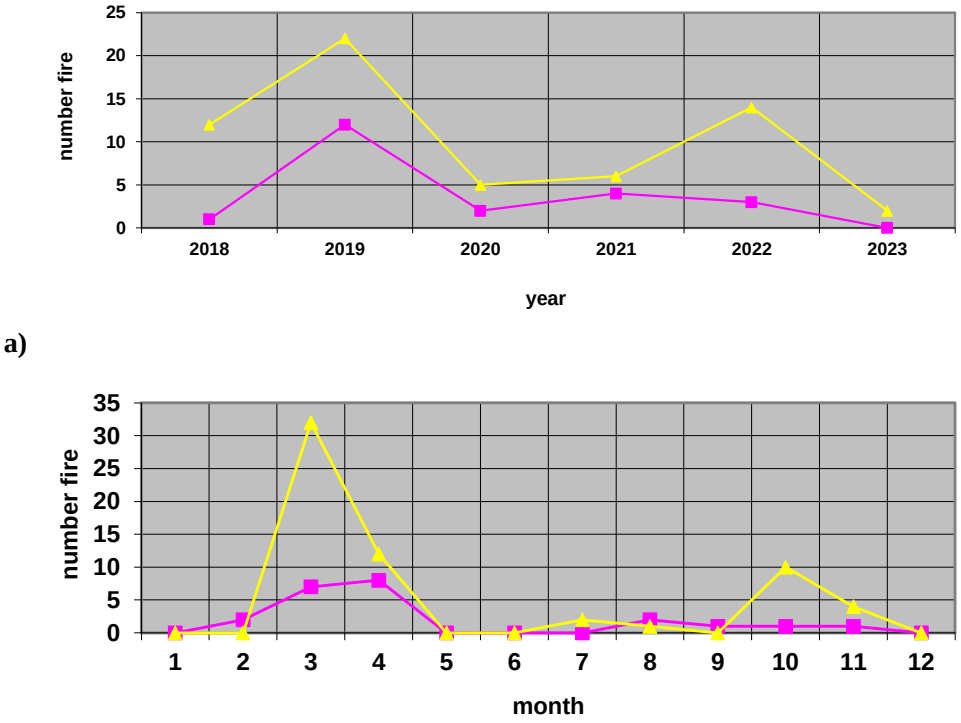


Figure 2: Number of fires in nature the Djerdap National Park and the Iron Gates Natural Park in the period 2018-2023, a) annual values, b) monthly values

Figure 2b shows that there are more fires in the first half of the year. The fire season lasts from February to November in Djerdap NP and from March to November in Iron Gates PP, indicating a long fire season. Most fires in the month of March were recorded in 2019 (5 fires in Djerdap NP and 13 in Iron Gates PP). For March 2019, 5.3 mm of precipitation was measured at the Veliko Gradište meteorological station and 1.02 mm at the Drobeta Turnu Severin meteorological station, which is well below the long-term average. The perennial precipitation (1961-1990) for March is 44.0 mm in Veliko Gradište (VG) and 53.3 mm in Drobeta Turnu Severin (DTS).

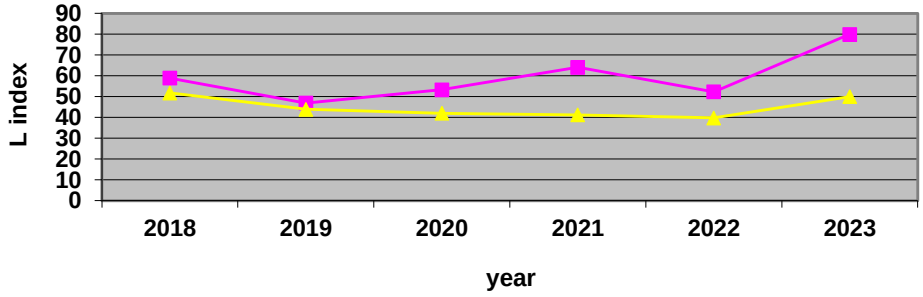
The aridity indices and the fire index: The results are structured to show the trend of the aridity indices and the fire danger index in the period from 2018 to 2023. Figure 3 shows the annual values of the aridity index and the fire danger index at meteorological stations in the protected areas of the Southern Carpathians. It is noted (Figure 3a) that based on the value of the Lang factor (L) for the Djerdap NP area, a semi-humid climate prevails in 2021 and 2023. Based on the FAI values (Figure 3b), the forests in the protected areas of the Southern Carpathians belong to the forest-steppe climate category. It is noted (Figure 3c) that the Iron Gates PP area has the characteristics of a Mediterranean climate type in 2021 and 2022.

Looking at the monthly aridity values (Figure 4), it can be seen that the month of August has the lowest value of the index. It is noted (Figure 4b) that according to the Im_{DM} index, October is the driest month in the Djerdap NP area and August is the driest month in the Iron Gates PP area. Based on the Lang factor[16] (Lm) value (Figure 4a), the climate in August, September and October is characterized as arid. Fire risk, based on Angstrom index values (Figure 4c), is highest in the period June-September for the Iron Gates PP and in the period July-August for the Djerdap NP.

According to the average value of the aridity index for the period 2018-2023, the value of the climate indices is shown in table 4. The climatic classification according to aridity indices for the VG station corresponds to the classification given in the study[40] for the period 2005-2021. Figures 3d and 4c show the values of the Angström index at the annual and monthly level for the period 2018-2023. It is noted (Figure 3d) that the fire risk in Iron Gates PP is higher than in Djerdap NP. At the annual level, the fire risk according to the I index was highest in 2019. The monthly values of the Angström index (I) (Figure 4c) indicate that there is a higher risk of fire in the Iron Gates PP compared to the Djerdap NP. Angström index (I) values are less than 4.0 in the period June-September for the Iron Gates PP and in the period July-August for the Djerdap NP.

Correlation between Fire Occurrence and Climate Indices: The prediction of climatic conditions suitable for the occurrence of fires in nature has long been the concern of many researchers worldwide[1,20,24,33,34]. The possible

relationship between the number of fires in the protected areas of the Southern Carpathians and the climate indices was analysed by linear correlation (Tables 5 and 6). Table 5 shows the linear correlations of the annual mean values of Lang rain factor[16] (L), De Martonne aridity index[5] (I_{DM}), FAI index, Angström index (I), precipitation (Prec) and air temperature (Temp) with the occurrence of fires in nature for the period from 2018 to 2023. Table 6 shows the linear correlations of the monthly mean values of Lang rain factor (L), De Martonne aridity index (I_{DM}), Angström index (I), precipitation (Prec) and air temperature (Temp) with the occurrence of fires by month for the period from 2018 to 2023.



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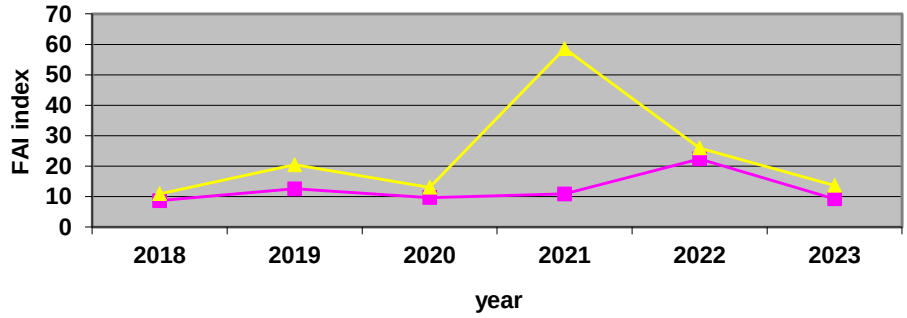

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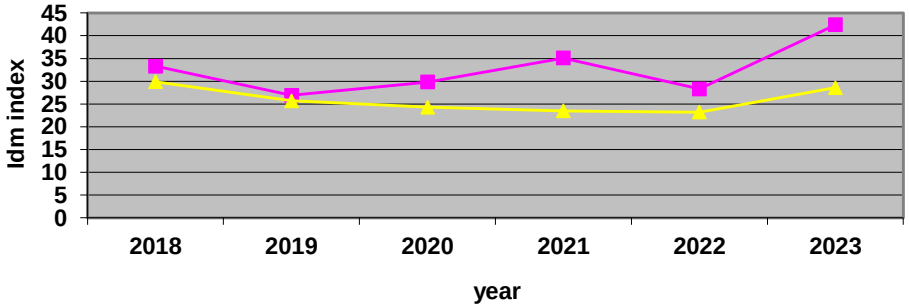

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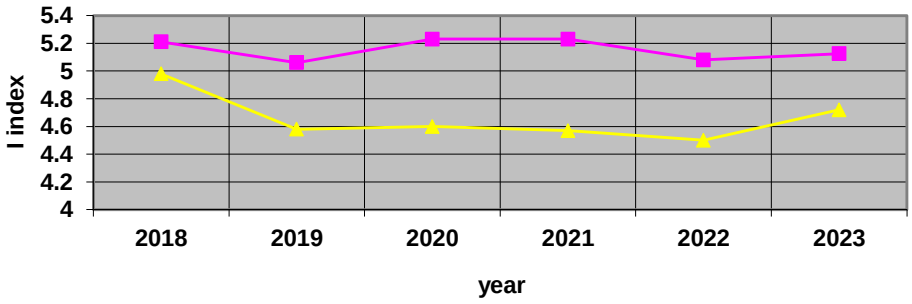
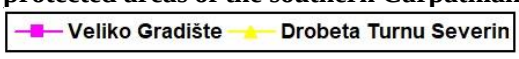
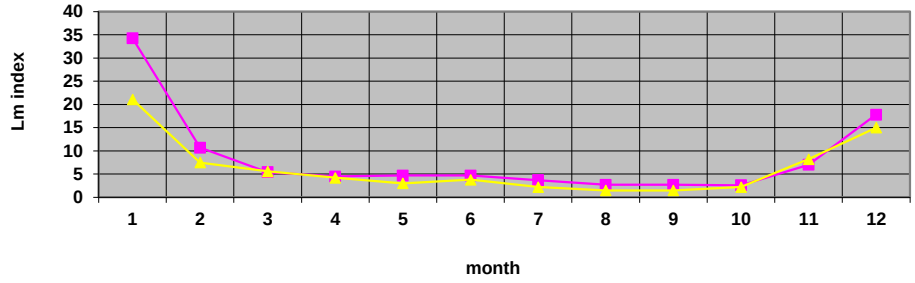


d)

Figure 3: a) Lang factor[16] (*L*), b) Forestry Aridity Index (FAI) c) De Martonne aridity index[5] (I_{DM}) d) Angström index (I) in the protected areas of the southern Carpathians during the period 2018-2023





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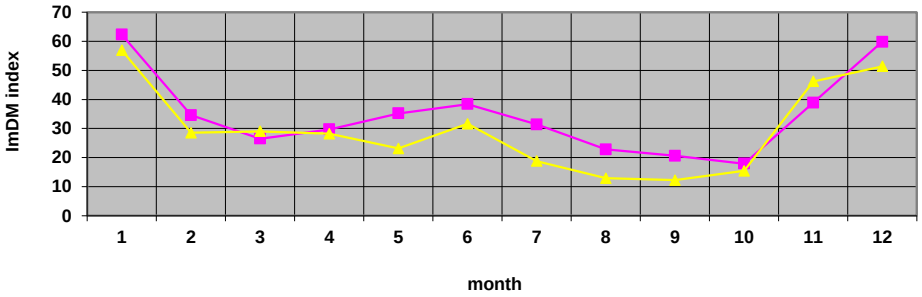

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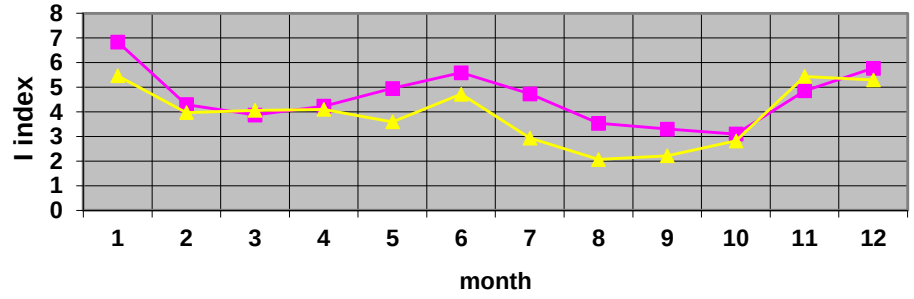

c)

Figure 4: Monthly values a) Lang factor (Lm), b) De Martonne aridity index (Im_{DM}), c) Angström index (I) in the protected areas of the Southern Carpathians during the period 2018-2023

Table 4
Climate classification according to the aridity indices

Climate Indices	Meteorological station	
	Veliko Gradište (VG)	Drobeta Turnu Severin (DTS)
Lang's rain factor (L)	Semi-arid (L = 57.5)	Semi-arid (L = 45.3)
De Martonne aridity index (I_{DM})	Humid (I_{DM} = 32.3)	Semi-humid (I_{DM} = 26.3)
Forest aridity index (FAI)	Forest-steppe climate (FAI = 11.1)	Forest-steppe climate (FAI = 17.6)

Based on the value of the Spearman correlation coefficient (Table 5), it was found that there is a positive relationship between the annual number of fires and air temperature (Temp). It is found (Table 5) that the correlation between the number of fires and De Martonne aridity index, Lang rain factor, Angström index and precipitation (Prec) is negative. Since a low correlation was found between the annual number of fires and the aridity index in the Iron Gates PP area, we tested the correlation between the monthly number of fires and the aridity index (Table 6). A significantly lower coefficient of determination is observed for the monthly values than for the annual values. The authors calculated a significantly higher coefficient of determination for monthly values compared to annual values at the meteorological station VG for the period 2005-2021[40]. It was found that there is a stronger correlation of fire occurrence with the I_{DM} index compared to the L index for the Djerdap NP area. The value of the Angström Index (I) at the monthly level is significantly lower compared to the values at the annual level.

Table 5
Results from linear regression models for number of forest fires in NP and PP with Forest aridity index (FAI), De Martonne aridity index (I_{DM}), Lang rain factor (L), Angström index (I), annual precipitation sum (Prec) and mean annual temperature (Temp)

Location	Equation	r	R^2	Predictor
Djerdap NP	y = - 0.2354x + 17.608	0.6383	0.4074	L
	y = 0.1526x + 1.7951	0.1819	0.0331	FAI
	y = - 0.4761x + 19.203	0.6264	0.3924	I_{DM}
	y = - 29.454x + 155.52	0.5265	0.2772	I
	y = - 0.0288x + 24.868	0.6653	0.4426	Prec
	y = 5.2586x - 63.819	0.4786	0.2291	Temp
Iron Gates PP	y = - 0.2445x + 21.115	0.1653	0.0273	L
	y = - 0.0383x + 11.077	0.0938	0.0088	FAI
	y = - 0.2354x + 16.257	0.0894	0.008	I_{DM}
	y = - 5.1999x +34.389	0.1229	0.0151	I
	y = - 0.0169x + 20.712	0.1908	0.0364	Prec
	y = 6.2651x - 76.5	0.2843	0.0808	Temp

Table 6
Results from linear regression models for the monthly number of fires in Djerdap NP and Iron Gates PP with Lang rain factor (L), De Martonne aridity index (I_{DM}), Angström index (I), monthly precipitation (Prec) and mean monthly temperature (Temp) during the period 2018-2023

Location	Equation	r	R^2	Predictor
Djerdap NP	y = 0.0766x + 2.4767	0.2565	0.0658	L
	y = - 0.0704x + 4.2851	0.3566	0.1272	I_{DM}
	y = - 0.9774x + 6.3203	0.3911	0.153	I
	y = - 0.0662x + 5.8925	0.4881	0.2382	Prec
	y = - 0.0628x + 2,6363	0.1780	0.0317	Temp
Iron Gates PP	y = - 0.2366x + 6.5781	0.1517	0.023	L
	y = - 0.0592x + 6.8311	0.0938	0.0088	I_{DM}
	y = - 0.016x + 5.1454	error	4E-06	I
	y = - 0.1245x + 11.48	0.2229	0.0497	Prec
	y = - 0.2583x + 8.6395	0.2256	0.0509	Temp

It is worth noting that the rainfall data showed a stronger correlation with the occurrence of fires than the air temperature for the Djerdap NP area (Table 6). For the Iron Gates PP area, the correlation of air temperature with the occurrence of fires is stronger than with the amount of precipitation.

Conclusion

The protected areas of the Southern Carpathians are prone to forest fires, which are one of the main factors of environmental degradation. The monitoring of meteorological conditions in a given area is increasingly recognised as a useful tool for the successful prediction and management of wildland fires. Assessing the impact of climate variability on the creation of conditions that may be suitable for the occurrence of fires is very important.

The results obtained show the dependence between the dynamics of the occurrence of fires in nature and weather conditions, which directly and indirectly affect the creation of conditions suitable for the ignition and spread of fires. Extremely wet periods reduce the risk of fires and thus the destruction of the geographical environment. Periods of pronounced high air temperatures and lower rainfall cause a greater risk of fire. However, there is relationship between forest fires and other climatic and fire risk indices.

Considering the negative demographic development in rural areas, which certainly affects the frequency of fires in protected areas, it is necessary to investigate the relationship between the occurrence of fires and human activities in nature. The results of this study are important for the development of a system for predicting fire activity in the protected areas of the Southern Carpathians.

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