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# Vulnerability of Central Serbian national parks to wildfires

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**Abstract**— National parks in Serbia are sensitive to various types of natural hazards that are becoming more frequent and having a significant negative impact on the environment. The present study examines the effects of weather conditions on wildfires in the national parks (NPs) Tara, Djerdap, and Kopaonik using data from meteorological stations and applying climate indices based on air temperatures and precipitation. It examines the variability of fire occurrence dynamics, which depend on changes in the forest aridity index (*FAI*), the De Martonne aridity index ($I_{DM}$), and the Lang's rain factor ($AI_{Lang}$) during the period 2005–2021.

The highest number of fire occurrences was recorded in NP Tara and NP Djerdap, and the lowest in NP Kopaonik. The risk of fire was greatest during September (27.5%) and August (18.1%), when air temperatures were high and precipitation was low. The fire season was longest in NP Djerdap (February–December) and NP Tara (March–November), and shortest in NP Kopaonik (April–August).

Due to the weak correlation between the annual number of fires and individual values of climate variables and climate indices, multiple linear regression (MLR) models were developed. The highest correlation and coefficient of determination were obtained using temperature, precipitation, $I_{DM}$, and $AI_{Lang}$ as predictors for NP Tara and NP Djerdap but not NP Kopaonik, where only three wildfires were recorded.

*Key-words:* climatic conditions, fire in nature, national park, Serbia

## *1. Introduction*

The natural resources of national parks are of exceptional importance, so more and more attention is being given to their preservation and protection. Protected natural areas contribute to society by preserving biological diversity and providing areas for recreation, science, and education. Efforts are, therefore, being made to ensure that this remains the case (*Rada* and *Marquina*, 2008).

The forest ecosystems of national parks are increasingly sensitive to changes that occur as a result of numerous natural and anthropogenic factors. The sustainability of a forest ecosystem depends to a significant extent on these influences. For instance, certain stress factors, by their intensity and frequency, can lead to a weakening of the vitality of certain plant species and eventually cause them to become extinct. As pointed out by the Centre for Research on the Epidemiology of Disasters (CRED), the Munich Reinsurance Company, and the Swiss Re Group, forest fires are generally classified into a group of natural climatological disasters, where wildfires are perceived as forest fires and land fires (*Lukić et al., 2*013). Therefore, wildfires are potentially the most destructive type of natural disaster in forested areas (*Bowman et al*., 2009). Climate conditions play a key role in the determination of the fire regime in the given area. The pronounced effects of climate change on forest fires were also highlighted by *Rosavec et al.* (2022). During 2022, the Intergovernmental Panel on Climate Change (IPCC) indicated that global warming effects tend to increase the number of forest fires around the world (*IPCC*, 2022), and there are many studies outlining the potential impacts of climate change on the risk of forest fires in the southeast Europe (e.g., *Novković et al.,* 2021).

According to *Gigović et al.* (2019), positive trends in both the number of forest fire events and burned areas have been confirmed in Europe during the last few decades. In relation with climate variability, during the high air temperature summer months, the number of forest fires in Serbia has been increasing as well (*Novković et al.,* 2021). Since forest area in the Republic of Serbia covers approximately 31.1% (27,200 km$^2$), protected natural areas are particularly vulnerable to forest fires and require special scientific attention (*Gigović et al.,* 2019).

National parks in Serbia are threatened by various natural hazards. *Dragićević et al*. (2011) state that this risk varies according to the territory. *Tošić et al*. (2019) point out that Serbia is susceptible to wildfires, and their number is increasing. Fires in nature often have unpredictable and far reaching consequences (*Tošić et al*., 2019). Several studies (*Abatzoglou* and *Kolden*, 2013; *Bessie* and *Johnson*, 1995; *Littell et al*., 2009) have shown that weather is the most variable and biggest driver of fire hazard. *Skvarenina et al*. (2003) claim that meteorological factors play a key role in affecting wildfire occurrence and behavior. For *de Angelis et al*. (2015), fire regimes are strongly related to weather conditions that directly and indirectly influence ignition and propagation.

Meteorological conditions such as long periods without precipitation help create conditions for the development of forest fires (*Cane et al*., 2008). The frequency, size, intensity, periodicity, and type of fire depend on the weather and climate, along with the structure and composition of the forest (*Dale et al.*, 2001). Weather alone can cause a forest fire, and when it does, can control its behaviour (*Van Wagner*, 1987).

*Flannigan et al*. (2016) suggest that weather and climatic elements (e.g., temperature, precipitation, wind, and atmospheric moisture) are critical aspects of fire activity. Climate has a strong influence on the activity, frequency, and probability of the occurrence of fire in nature (*Urbieta et al*., 2015; *Jolly et al*., 2015; *Pérez-Sánchez et al*., 2017).

Large forest fires are more frequent in areas with natural value. These have the highest level of state protection precisely because they are characterised by disasters. A case study of NP Djerdap in 2011 showed that the occurrence of large forest fires was strongly influenced by climatic conditions (*Živanović* and *Tošić*, 2020). When the dry season is longer, especially in periods when the air temperature is extremely high, the risk of fire is higher (*Živanović et al*., 2020b; *Živanović*, 2017, *Tošić et al*., 2020). By contrast, the danger of fire is lower during extremely wet periods (*Chandler et al*., 1983; *Dimitrakopoulos et al*., 2011; *Ćurić* and *Živanović*, 2013; *Tošić et al*., 2019; *Živanović*, 2021; *Živanović et al*., 2020).

The present study aimed to determine the vulnerability of national parks in the territory of Serbia from fires in nature based on the dynamics of forest fires and selected climate indices. It is hoped that the findings will help the relevant services to develop an effective forest fire prevention system.

## *2. Materials and methods*

### *2.1. Study area and data*

The territory of Serbia is located in the southeastern part of Europe and covers an area of 88 499 km$^2$. The total forest coverage in the Republic of Serbia is 29.1% (*Banković et al*., 2009), 1.8% of which comprises national parks. The present study examined parks in central Serbia: NP Djerdap, NP Tara, and NP Kopaonik (*Fig. 1*). Basic data on all three are presented in *Table 1*.


*Fig. 1*. Location of NP Tara, Djerdap, and Kopaonik in the Republic of Serbia.

*Table 1.* Basic data of selected national parks Djerdap, Tara and Kopaonik

| National park | Forest area (ha) | | Altitude (m) | Relative height (m) | Forest cover (%) |
|---|---|---|---|---|---|
| | Forest (all) | State forest | | | |
| Djerdap | 63 786 | 45 455 | 45 – 803 | 758 | 64 |
| Tara | 24 992 | 13 589 | 291 – 1591 | 1,300 | 80 |
| Kopaonik | 11 969 | 9 863 | 640 – 2 017 | 1 377 | 62 |

National park Djerdap is located in the northeastern part of central Serbia. It includes some of the Djerdap Gorge and the Severni Kučaj, Miroč, and Štrbac massifs. It covers the municipalities of Golubac, Majdanpek, and Kladovo (*Law on National Parks*, 2018).

National park Tara is located in the western part of Serbia. It covers an area limited by the Drina river, between Višegrad and Bajina Bašta, and includes the Zvezda, Crni vrh, and Ravna Tara mountains (*Law on National Parks*, 2018).

National park Kopaonik is located in the southern-central part of the country and covers the highest parts of the Kopaonik mountain and the basins of the Samokovska, Gobeljska, Brzećka, and Barska rivers. It extends to the municipalities of Raška and Brus (*Law on National Parks*, 2018).

The location of meteorological stations and their latitude, longitude, and altitude are listed in *Table 2*.

*Table 2*. Location of meterological stations in the national parks (latitude, longitude, and altitude)

| **National park** | **Meteorological station** | **Latitude (N)** | **Longitude (E)** | **Altitude (m)** |
|---|---|---|---|---|
| Djerdap | Veliko Gradište | 44° 45’ | 21° 31’ | 82 |
| Tara | Bajina Bašta | 43º 58’ | 19º 34’ | 270 |
| Kopaonik | Kopaonik | 43º 17’ | 20º 48’ | 1 711 |

To consider the climatic characteristics of the NPs, we used the average monthly and annual values of air temperature and precipitation from three main meteorological stations for the period 2005–2021. The data were retrieved from the Republic Hydrometeorological Service of Serbia (*RHSS*, 2021). Fire data were retrieved from the competent fire protection services in each of the NPs.

## *2.2. Methods*

### *2.2.1. Climate indices*

Selected climate indices such as the De Martonne aridity index ($I_{DM}$), Lang aridity index ($AI_{Lang}$) and the Forestry Aridity Index(*FAI*) based on air temperature and precipitation data were used since these indices are the most suitable for analysis of climate conditions over the territory of the Republic of Serbia (based on previous studies) (e.g., *Hrnjak et al.,* 2014; *Gavrilov et al*., 2019; *Radaković et al.,* 2018; *Bačević et al.,* 2017).

The annual values of $I_{DM}$ (*de Martonne*, 1925), $AI_{Lang}$ (*Lang*, 1920), and *FAI* (*Führer et al*., 2011), are obtained from the following equations:

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

$$AI_{Lang} = \frac{P}{T}, \quad (2)$$

$$FAI = \frac{T_{\text{VII–VIII}}}{P_{\text{V–VII}} + P_{\text{VII–VIII}}} c, \quad (3)$$

where $P$ is the annual precipitation (mm), $T$ is the annual mean temperature (°C), $T_{\text{VII–VIII}}$ is the average temperature in July and August (°C), $P_{\text{V–VII}}$ is the precipitation total from May to July (mm), $P_{\text{VII–VIII}}$ is the precipitation total for July–August (mm), and $c = 100$ mm/°C is the constant. The classification of climate according to Lang is given in *Table 3*. The classification of the $I_{DM}$ is given in *Table 4*. The *FAI* and the average weather conditions of four different climate categories are shown in *Table 5*. Unlike the $I_{DM}$, humidity rises with a decrease in the value of *FAI* and vice versa (*Gavrilov et al*., 2019). The monthly aridity index values are determined using $AI_{Lang}$ and $I_{DM}$ indices. $AI_{Lang}$ index is based on the hypothesis that warmer air temperatures lead to soil and air dryness if there is not enough precipitation and/or groundwater recharge. On the other hand, the $I_{DM}$ is one of the best known and widely used aridity/humidity indices in applied climatology for climate classification (*De Martonne* 1925; *Croitoru et al.,* 2012). The *FAI* is a very good parameter for presenting climate conditions during the yearly forests' growth, which is very important for forestry management (*Gavrilov et al*., 2019).

*Table 3*. Climate classification according to *Lang* (1920)

| **Value of $AI_{Lang}$** | **Types of climate** |
|---|---|
| 0 – 20 | Arid |
| 20 – 40 | |
| 40 – 60 | Semi-arid |
| 60 – 100 | Semi-humid |
| 100 – 160 | Humid |
| > 160 | Perhumid |

*Table 4*. The De Martonne index ($I_{DM}$) classification

| **Values of $I_{DM}$** | **Types of climate** |
|---|---|
| $I_{DM} < 10$ | Arid |
| $10 \le I_{DM} < 20$ | Semi-arid |
| $20 \le I_{DM} < 24$ | Mediterranean |
| $24 \le I_{DM} < 28$ | Semi-humid |
| $28 \le I_{DM} < 35$ | Humid |
| $35 \le I_{DM} < 55$ | Very humid |
| $I_{DM} > 55$ | Extremely humid |

*Table 5*. Meteorological features of forestry climate categories

| ***FAI* values** | **Forestry climate categories** |
|---|---|
| < 4.75 | Beech climate |
| 4.75 – 6.00 | Hornbeam-oak climate |
| 6.00 – 7.25 | The sessile oak/Turkey oak climate |
| > 7.25 | Forest-steppe climate |

### *2.2.2. Multiple linear regression (MLR) models*

Multiple linear regression models were used to establish the relationship between the number of fires and climate variables and indices. Meteorological variables and climate indices were used as predictors (independent variables), and the data on forest fires as the predicted variable. The models were calibrated for the first 10 years (from 2005 to 2015) and validated for the remaining five years (from 2016 to 2021). The model efficiency coefficient (*MEF*), Pearson's correlation coefficient (*r*), and coefficient of determination ($R^2$) were used to assess the predictive power of the model (*Cohen et al.*, 2002). The Nash–Sutcliffe efficiency can range from -∞ to 1. The model is perfect when the efficiency is 1 (*Nash* and *Sutcliffe*, 1970). The $R^2$ ranges from 0 to 1, with a perfect fit being equal to 1.

## *2.3. Climate characteristics of national parks*

### *2.3.1. Basic characteristics of air temperature*

The temperature regime is a basic feature of the climate of an area and has a direct and/or indirect influence on the values of other climatic elements. Periods of high air temperature represent a very pronounced danger for the occurrence of fires in nature (*Živanović et al.*, 2015). Average monthly and annual values of air temperature in Serbian NPs are given in *Table 6* (www.hidmet.gov.rs). The following conclusions can be drawn from the data on their mean monthly and annual air temperature values:

– The highest annual air temperature values were recorded in NP Djerdap (12.3 ºC) and the lowest in NP Kopaonik (4.6 ºC). The difference in average annual air temperatures of 7.7 ºC may have had a significant impact on the frequency and intensity of forest fires in both parks.

– The highest mean monthly air temperatures were during July in NP Tara (21.9 ºC) and NP Djerdap (23.2 ºC), and in August in NP Kopaonik (13.3 ºC).

*Table 6*. Mean monthly and annual air temperature in national parks of Serbia during the period 2005–2021

| Met. station | Month 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Veliko Gradište | 0.9 | 2.7 | 7.1 | 12.7 | 17.0 | 21.1 | 23.2 | 22.4 | 17.7 | 12.0 | 7.6 | 2.4 | 12.3 |
| Bajina Bašta | 1.2 | 3.5 | 7.3 | 12.2 | 16.2 | 20.0 | 21.9 | 20.4 | 16.4 | 11.8 | 7.1 | 2.4 | 11.9 |
| Kopaonik | -4.7 | -3.7 | -1.5 | 3.3 | 7.5 | 11.6 | 13.1 | 13.3 | 9.6 | 5.3 | 1.8 | -2.9 | 4.6 |

### *2.3.2. Basic characteristics of precipitation*

Precipitation was irregularly distributed in time and space with regard to atmospheric processes and relief features. *Trabaud* (1980) states that the amount and distribution of precipitation is an important climatic element that affects the occurrence of fires. The number of fires decreases exponentially with the height of precipitation. The latter, whether in surplus or deficit, directly influences the state of fuel material in the forest, thereby reducing the risk of fire and vice versa (*Ćurić et al.*, 2013). *Table 7* shows the mean monthly and annual precipitation total at meteorological stations in the NPs under study for the period 2005–2021 (www.hidmet.gov.rs). The annual precipitation totals, which reflected the differences in altitude, were highest in NP Kopaonik (1087.3 mm) and lowest in NP Djerdap (684.2 mm). *Table 7* shows that precipitation was at its highest during May and June. Winter was drier than summer in all three NPs.

*Table 7*. Mean monthly and annual precipitation in national parks of Serbia during the period 2005–2021

| Met. station | Month 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Veliko Gradište | 55.8 | 48.6 | 51.4 | 52.6 | 87.3 | 69.3 | 81.3 | 54.1 | 44.5 | 90.0 | 43.5 | 55.2 | 684.2 |
| Bajina Bašta | 46.2 | 60.0 | 65.4 | 55.6 | 95.6 | 94.8 | 74.1 | 70.8 | 58.2 | 66.1 | 52.8 | 66.4 | 720.3 |
| Kopaonik | 86.7 | 68.0 | 101.2 | 88.4 | 128.9 | 115.7 | 94.0 | 77.7 | 72.6 | 91.3 | 73.1 | 89.0 | 1087.3 |

## *3. Results and discussion*

### *3.1. Analysis of climate indices*

With the help of different drought indices, dry periods (in terms of humidity) can be determined, particularly, when the occurrence of forest fires is pronounced (*Živanović*, 2021). *Tošić et al*. (2020) argue that the risk of fire is greater when the dry season is longer, especially during periods, when the air temperature is extremely high. The values of the climate indices in terms of aridity for 2005–2021 can be seen in *Table 8*.

*Table 8*. Climate classification according to the aridity index

| Climate index | Meteorological station | | |
|---|---|---|---|
| | **Veliko Gradiše** | **Kopaonik** | **Bajina Bašta** |
| Lang's rain factor ($AI_{Lang}$) | Semi-arid ($AI_{Lang}$ = 57.1) | Perhumid ($AI_{Lang}$ = 244.8) | Semi-humid ($AI_{Lang}$ = 68.6) |
| De Martonne aridity index ($I_{DM}$) | Humid ($I_{DM}$ = 31.3) | Extremely humid ($I_{DM}$ = 74.9) | Very humid ($I_{DM}$ = 37.2) |
| Forest aridity index (*FAI*) | Forest-steppe climate (*FAI* = 7.6) | Beech climate (*FAI* = 3.0) | Forest-steppe climate (*FAI* = 6.0) |

*Figs. 2, 3*, and *4* show the values of the climate indices during the period 2005–2021. The multiannual values of the drought index for the period 2005–2021 indicate an exceptional diversity of climatic conditions and a relatively large variation in values during certain years. On the basis of $AI_{Lang}$ (*Fig. 2*), it may be concluded that a semi-arid climate prevailed in NP Djerdap during 2005–2021. The lowest values of this index were recorded in NP Djerdap in 2011 ($AI_{Lang}$ = 33.4), and the highest in NP Kopaonik in 2005 ($AI_{Lang}$ = 340.5).

High *FAI* values were recorded in 2012, 2013, and 2015 (*Fig. 3*), and small values in 2014. The *FAI* values were extremely high for NP Kopaonik, which indicates that its forest ecosystems were the least affected of the three.

*Fig. 4* shows that the $I_{DM}$ was low for 2011 indicating extremely dry conditions. Extremely wet conditions pertained in 2014, with $I_{DM}$ values ranging from 41.8 in Veliko Gradište to 89.5 in Kopaonik (*Fig. 4*). According to the De Martonne's aridity index, the humidity conditions for 2011 corresponded to the conditions of a semi-arid climate at the Veliko Gradište measuring site (*Fig. 4*). In NP Kopaonik, 2011 was extremely humid.

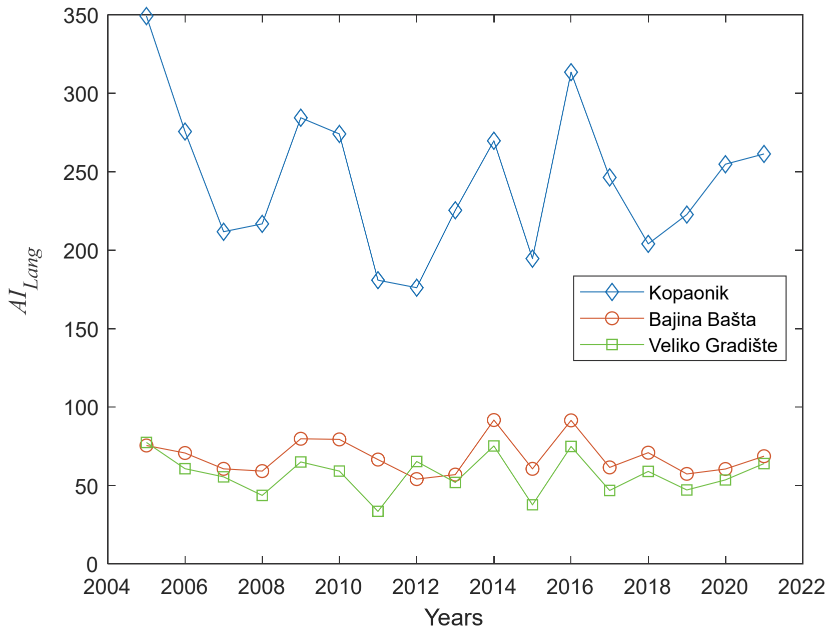


*Fig. 2*. Values of the Lang's rain factor (*$AI_{Lang}$*) at the meteorological stations in the national parks of Serbia during the period 2005–2021.

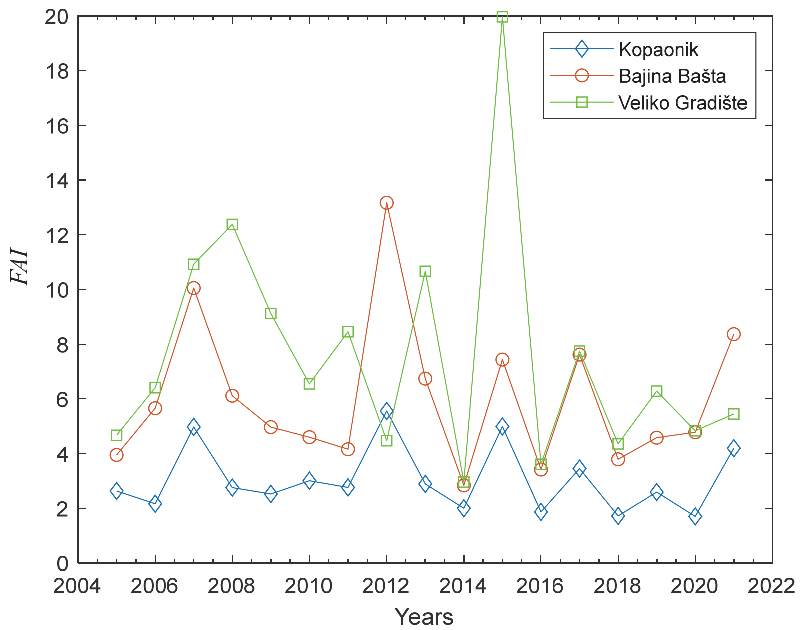


*Fig. 3*. Values of the forest aridity index (*FAI*) at the meteorological stations in the national parks of Serbia during the period 2005–2021.

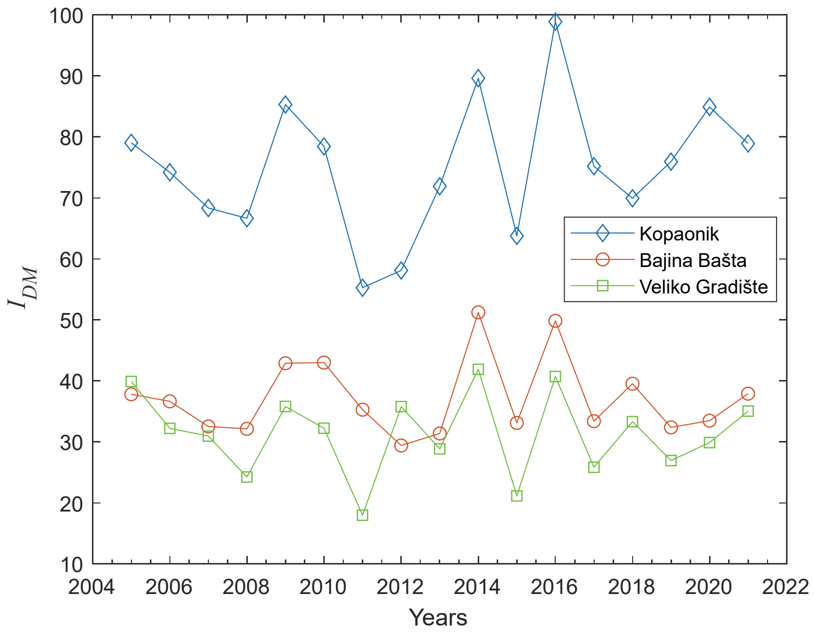


*Fig. 4*. Values of the De Martonne aridity index ($I_{DM}$) at the meteorological stations in the national parks of Serbia during the period 2005–2021.

*Figs. 2, 3*, and *4* show that favorable conditions for fire existed in 2007, 2012, and 2015. These were warm years, as was confirmed by the climatic conditions on the synoptic scale (*Fig. 5*). Annual temperature anomalies across Serbia were positive: 0.9 °C in 2007 (*Fig. 5a*), 1 °C in 2012 (*Fig. 5c*), and 1.25 °C in 2015 (*Fig. 5d*) when compared with the period as a whole. The only negative temperature anomaly was in 2011 (*Fig. 5b*). In the same year, a negative precipitation anomaly was registered over the central area of the Balkans (up to −40 mm), and −20 mm in Serbia (*Fig. 6a*). In contrast with 2011, conditions in 2014 did not favor the development of fires: excessive precipitation was registered over the Balkans (more than 40 mm), as well as in Serbia itself (along the Sava and Danube river valleys; *Fig. 6b*).

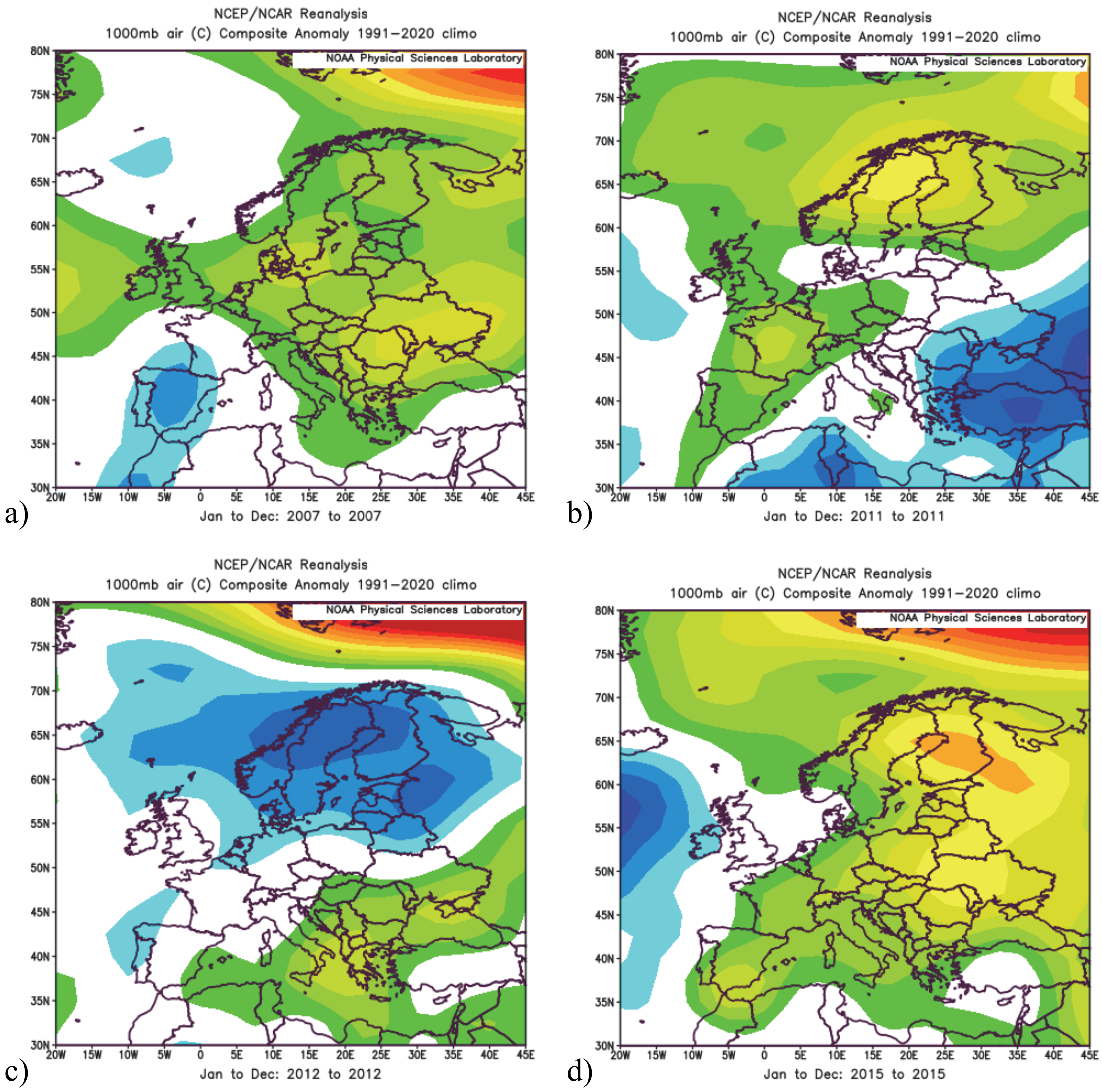


*Fig. 5*. Composite anomaly of 1000 hPa air temperature (°C) for: a) 2007, b) 2011, c) 2012, and d) 2015 compared to the period 1991–2020.

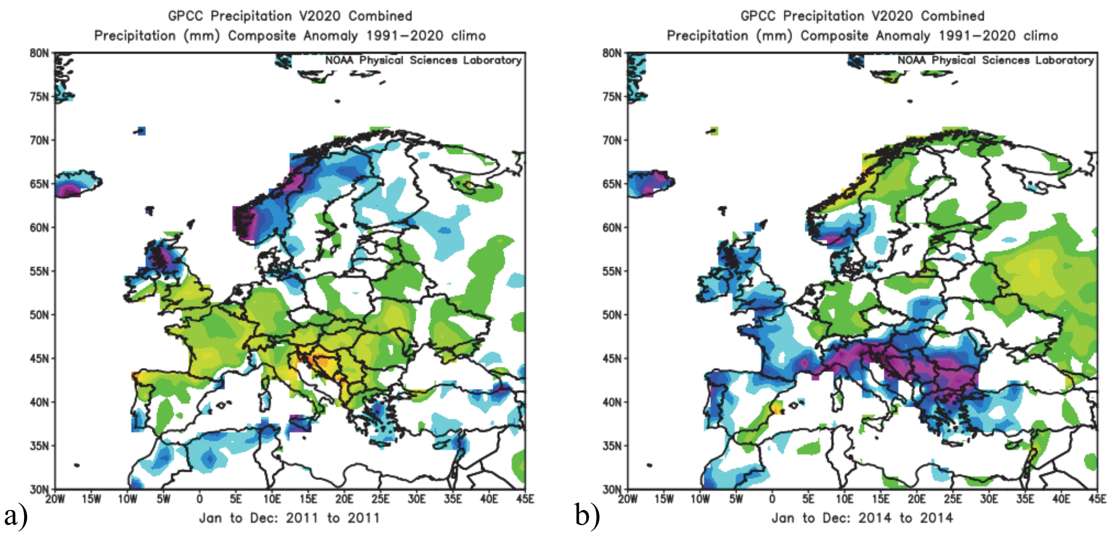


*Fig. 6*. Composite anomaly of precipitation (mm) for: a) 2011 and b) 2014 compared to the period 1991–2020.

According to *Gračanin* (1950), the adjusted $AI_{Lang}$ for monthly values of precipitation and air temperature indicates that in each of the meteorological stations, the highest values are during the cold period of the year (*Fig. 7*). The lowest values of the monthly rain factor are in summer, that is, the growing season, when plants are in most need of precipitation. It should be noted that August and September were arid in the NP Djerdap area (Veliko Gradište). Based on the multiannual mean for NP Kopaonik, each month was defined as humid, and April, May, October, and November as perhumid.

The monthly values of the De Martonne ($I_{DM}$) aridity index (*Fig. 8*) indicate that the driest month was August. Values of $I_{DM}$ for NP Tara and NP Djerdap for July, August, and September indicate a Mediterranean type of climate. A humid type of climate was determined for NP Kopaonik during all months.

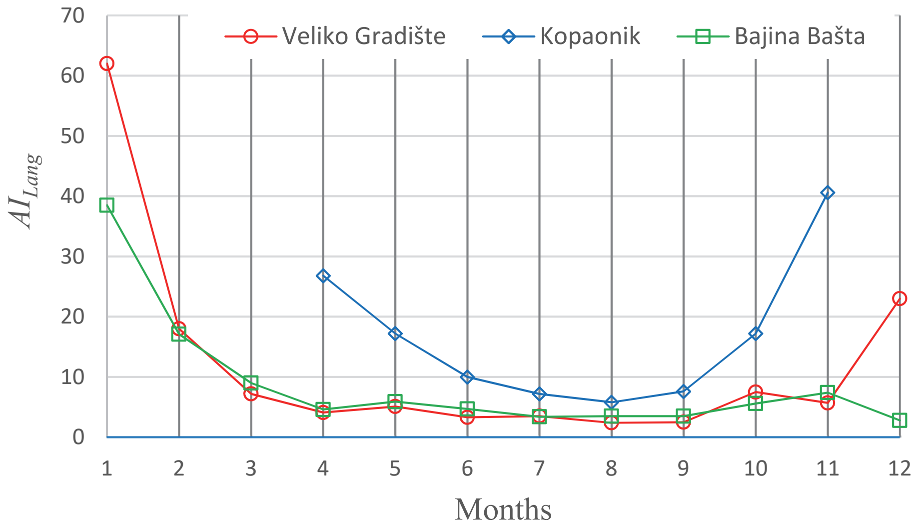


*Fig. 7.* Monthly values of the $AI_{Lang}$ index during the period 2005–2021.

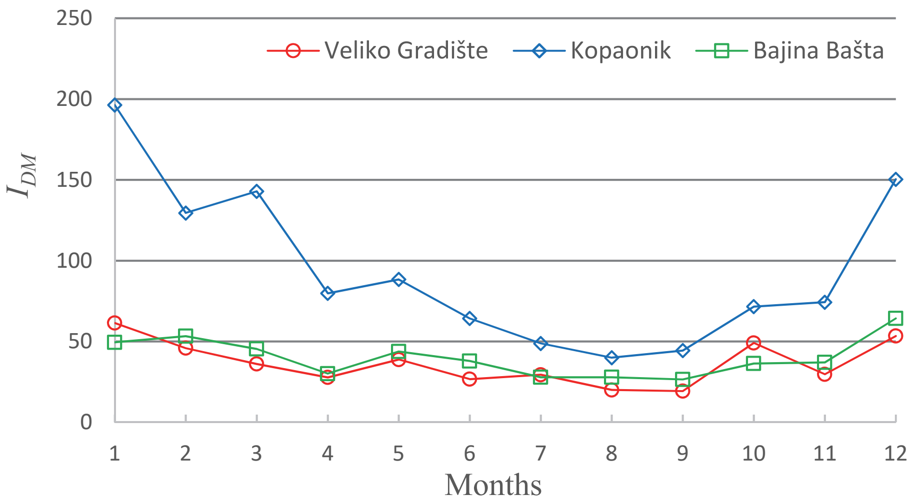


*Fig. 8.* Monthly values of the $I_{DM}$ index during the period 2005–2021.

*3.2. Dynamics of fire occurrence*

The dynamics of the occurrence of fires in open spaces in the NPs between 2005–2021 can be seen in *Fig. 9*. The largest number of fires occurred in NP Tara (272 fires, that is, 58.2% of the total number). The lowest number of fires occurred in NP Kopaonik (three fires, that is, 0.6% of the total number of fires). The highest number of fires was recorded in 2007 (85 fires), and the lowest in 2018 and 2020 (four fires). Air temperatures were extremely high and precipitation was unevenly distributed during 2007, which affected the drying of fuel material in the forest and on forest land, creating suitable conditions for the occurrence and development of fires. The heat waves in Serbia that lasted 6–12 days in 2007 were extreme climatic events.

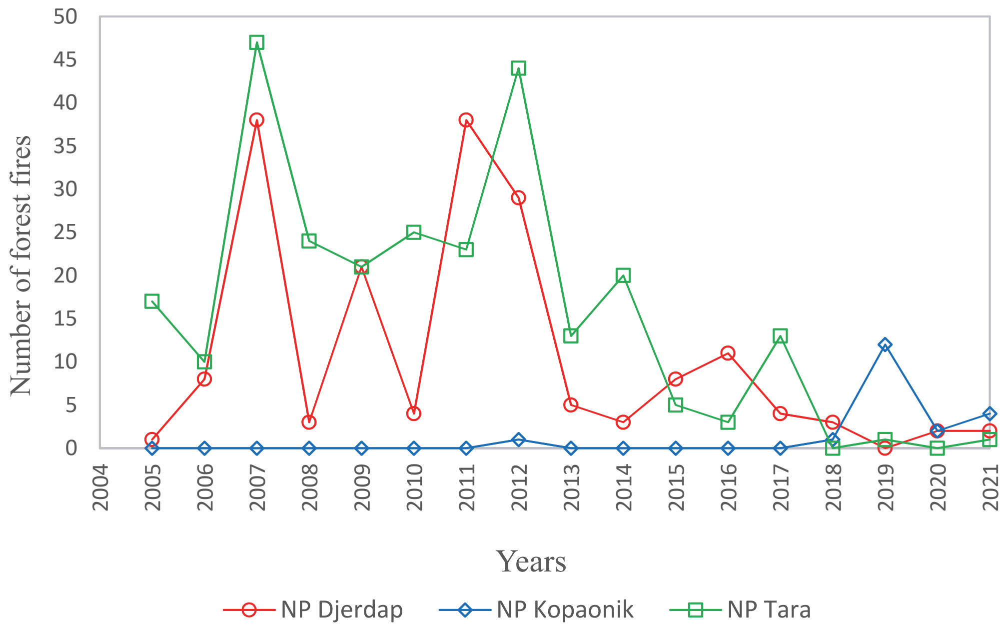


*Fig. 9.* Number of forest fires per year during the period 2005–2021.

Characteristic fires (in terms of intensity and duration) occurred between September 13 and September 16, 2011 in NP Djerdap and between August 23 and September 5, 2012 in NP Tara. *Lukić et al*. (2017) recorded a significant correlation between meteorological parameters and forest fires on Tara Mountain. In case study of NP Djerdap in 2011, *Živanović* and *Tošić* (2020) stated that the occurrence of fires was strongly influenced by climatic conditions.

The highest degree of vulnerability to fire was in September (27.5% of the total annual number of fires) and August (18.1%; *Fig. 10*). There was a significant frequency of fires occurring in March and April, though the air temperature was not high. No fires occurred in any of the NPs in January. The longest fire periods were in NP Djerdap (February–December) and NP Tara (March–November), and the shortest in NP Kopaonik (April–August). The frequency of fires at the beginning and the end of these seasons suggest that the fire season may last longer in the future.

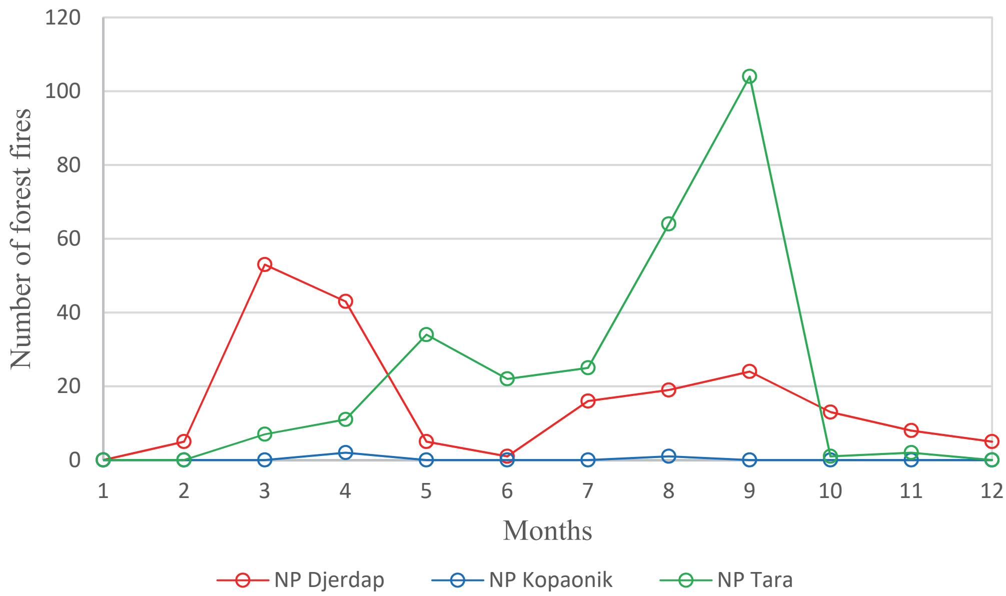


*Fig. 10.* Number of forest fires in national parks according to months of origin during the period 2005–2021.

The high number of fires in September 2011, 2012, 2015, and 2018 may be explained by the very warm conditions that prevailed. *Fig. 11a* shows that the temperature anomaly in September 2011 was around 3 °C higher in the Balkans and Serbia, while in 2012, the maximum temperature was in northeast Serbia (where the anomaly was 2.5 °C) (*Fig. 11b*). September 2015 and 2018 were less warm than in 2011 and 2012. In September 2015, the positive temperature anomaly was about 2 °C (*Fig. 11c*), while in 2018, it was about 1.0 °C (*Fig. 11d*).

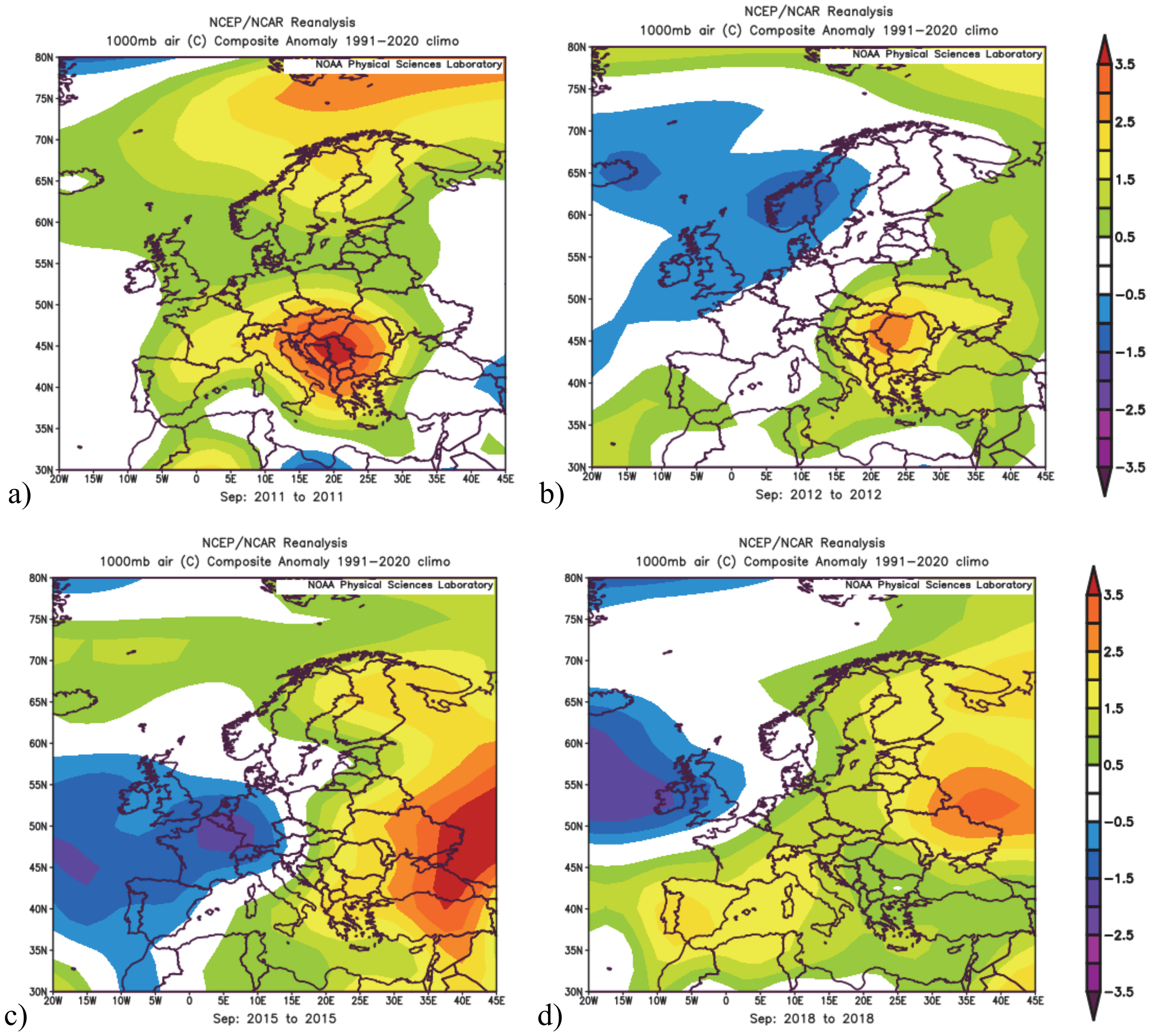


*Fig. 11.* Composite anomaly of 1000 hPa air temperature (°C) for: a) 2011, b) 2012, c) 2015, and d) 2018 compared to the period 1991–2020.

### *3.3. Correlation between fire occurrence and climate indices*

A possible connection between the number of fires and climate indices during 2005–2021 was investigated using linear correlations. *Table 9* shows the linear correlations of the mean annual values of temperature, precipitation, $AI_{Lang}$, $I_{DM}$, and *FAI* with the occurrence of forest fires.

The results are shown for NP Djerdap and Tara and not for NP Kopaonik, because only three fires were recorded in the latter (in 2012, 2019, and 2021). There was a positive relationship between the annual number of fires and *FAI* and a negative relationship for other predictors. The strongest correlation between the number of fires and *FAI* was found in NP Tara (0.5503), while for NP Djerdap, the strongest correlation was between the number of fires and precipitation (*Table 9*). The $R^2$ for NP Tara was 0.3029, which means that 30.29% of the variation in the number of forest fires was explained by *FAI* alone.

*Table 9*. Results from linear regression models for the number of forest fires in national parks of Serbia with annual precipitation sum (*Prec*), mean annual temperature (*Temp*), forest aridity index (*FAI*), De Martonne aridity index ($I_{DM}$), and Lang's rain factor ($AI_{Lang}$)

| Location | Equation | *r* | $R^2$ | Predictor |
|---|---|---|---|---|
| NP Djerdap | y = -2.818x + 727.8 | -0.2438 | 0.0594 | *Prec* |
| | y = -0.003x + 12.27 | -0.0600 | 0.0036 | *Temp* |
| | y = -0.241x + 59.83 | -0.2355 | 0.0554 | $AI_{Lang}$ |
| | y = -0.129x + 32.8 | -0.2399 | 0.0576 | $I_{DM}$ |
| | y = 0.050x + 7.013 | 0.1495 | 0.0224 | *FAI* |
| NP Tara | y = -2.463x + 853.2 | -0.2390 | 0.0571 | *Prec* |
| | y = -0.015x + 12.13 | -0.3081 | 0.0949 | *Temp* |
| | y = -0.127x + 70.6 | -0.1524 | 0.0232 | $AI_{Lang}$ |
| | y = -0.088x + 38.59 | -0.1952 | 0.0381 | $I_{DM}$ |
| | y = 0.105x + 4.337 | 0.5503 | 0.3029 | *FAI* |

Because low correlation was found between the annual number of fires and individual indices, MLR models were developed for the stations in NP Djerdap (*Table 10*) and NP Tara (*Table 11*). They were evaluated using three goodness-of-fit estimates (*r*, $R^2$, and *MEF*). First, in the case of NP Djerdap, both climate variables, temperature and precipitation, were kept as predictors, but the result did not improve (*Table 10*). The contribution of all climate indices was then examined, and again there was no change. However, the inclusion of $AI_{Lang}$ along with temperature and precipitation increased the correlation to –0.8171, as well as $R^2$ to 0.6677. In addition, an improvement was noted when the $I_{DM}$ was included in combination with precipitation and temperature ($r$ = –0.9111, $R^2$ = 0.8301). The highest coefficients of correlation and determination ($r$ = –0.9128, $R^2$ = 0.8333) were obtained using temperature, precipitation, $I_{DM}$, and $AI_{Lang}$ as predictors

(*Table 10*). This indicates that about 83.3% of the forest fire variability in NP Djerdap could be explained by these four variables. For all three cases, values of MEF (model officiency coefficient) were about −4, also indicating the best estimates.

*Table 10*. Results from multiple linear regression models for the number of forest fires in NP Djerdap with retained predictors: annual precipitation total (*Prec*), mean annual temperature (*Temp*), forest aridity index (*FAI*), De Martonne aridity index ($I_{DM}$), and Lang's rain factor ($AI_{Lang}$)

| Location | Predictor | *r* | $R^2$ | *MEF* |
|---|---|---|---|---|
| | *Temp, Prec* | 0.0265 | 0.0070 | -10.60 |
| | $I_{DM}$, $AI_{Lang}$ | -0.0290 | 0.0080 | -10.70 |
| | $I_{DM}$, *FAI* | -0.1202 | 0.0145 | -8.36 |
| | $AI_{Lang}$, *FAI* | -0.1817 | 0.0330 | -9.96 |
| | $I_{DM}$, $AI_{Lang}$, *FAI* | -0.2293 | 0.0526 | -13.17 |
| | *Temp*, $AI_{Lang}$ | -0.0007 | 0 | -10.17 |
| | *Temp, FAI* | 0.1900 | 0.0361 | -6.81 |
| NP Djerdap | *Prec*, $AI_{Lang}$ | -0.0270 | 0.0007 | -10.73 |
| | *Prec, FAI* | -0.0265 | 0.0007 | -6.90 |
| | *Temp, Prec*, $I_{DM}$ | -0.9111 | 0.8301 | -4.45 |
| | *Temp, Prec*, $AI_{Lang}$ | -0.8171 | 0.6677 | -4.27 |
| | *Temp, Prec, FAI* | -0.1547 | 0.0239 | -14.79 |
| | *Temp, Prec*, $I_{DM}$, $AI_{Lang}$ | -0.9128 | 0.8333 | -4.72 |
| | *Temp, Prec*, $AI_{Lang}$, *FAI* | -0.2198 | 0.0483 | -7.05 |
| | *Temp, Prec*, $I_{DM}$, $AI_{Lang}$, *FAI* | -0.2782 | 0.0774 | -5.68 |

According to *Table 11*, a stronger relationship between the number of fires and the combination of *FAI* and $I_{DM}$ was observed for NP Tara ($r$ = 0.4268, $R^2$ = 0.1822), that is, *FAI* and $AI_{Lang}$ ($r$ = 0.4441, $R^2$ = 0.1972), compared with NP Djerdap. A higher correlation ($r$ = 0.4356) was obtained using *FAI* with temperature and precipitation as predictors, as well as with added the $AI_{Lang}$ and $I_{DM}$ ($r$ = 0.5934; Table 11). As was the previous case with NP Djerdap, the highest correlation ($r$ = 0.7452) and $R^2$ (0.5553) were obtained using temperature, precipitation, $I_{DM}$, and $AI_{Lang}$ as predictors (*Table 11*).

*Table 11*. Results from multiple linear regression models for the number of forest fires in NP Tara with retained predictors: annual precipitation total (*Prec*), mean annual temperature (*Temp*), Forest aridity index (*FAI*), De Martonne aridity index ($I_{DM}$), and Lang's rain factor ($AI_{Lang}$)

| Location | Predictor | *r* | $R^2$ | *MEF* |
|---|---|---|---|---|
| NP Tara | *Temp, Prec* | -0.1032 | 0.0107 | -39.06 |
| | $I_{DM}$, $AI_{Lang}$ | -0.0427 | 0.0018 | -38.06 |
| | $I_{DM}$, *FAI* | 0.4268 | 0.1822 | -22.97 |
| | $AI_{Lang}$, *FAI* | 0.4441 | 0.1972 | -21.30 |
| | $I_{DM}$, $AI_{Lang}$, *FAI* | 0.4258 | 0.1813 | -23.10 |
| | *Temp*, $AI_{Lang}$ | -0.0734 | 0.0054 | -38.44 |
| | *Temp, FAI* | 0.4064 | 0.1651 | -26.84 |
| | *Prec*, $AI_{Lang}$ | -0.0513 | 0.0026 | -38.21 |
| | *Prec, FAI* | 0.4156 | 0.1728 | -24.58 |
| | *Temp, Prec*, $I_{DM}$ | 0.2235 | 0.0499 | -30.10 |
| | *Temp, Prec*, $AI_{Lang}$ | 0.5818 | 0.3385 | -21.99 |
| | *Temp, Prec, FAI* | 0.4356 | 0.1897 | -22.29 |
| | *Temp, Prec*, $I_{DM}$, $AI_{Lang}$ | 0.7452 | 0.5553 | -18.57 |
| | *Temp, Prec*, $AI_{Lang}$, *FAI* | 0.5780 | 0.3341 | -16.67 |
| | *Temp, Prec*, $I_{DM}$, $AI_{Lang}$, *FAI* | 0.5934 | 0.3521 | -15.80 |

Lower correlation and determination coefficient values were obtained for NP Tara, except when *FAI* was used as a predictor. Lower values were also obtained for *MEF* (*Table 11*), which means that a better model was obtained for NP Djerdap.

The results of the study suggest a connection between fires in nature and weather conditions. This accords with the findings of *Flannigan* and *Harrington* (1988), *Viegas* and *Viegas* (1994), *Westerling et al*. (2006), *Won et al*. (2010), amongst others.

## *4. Conclusions*

The present study has revealed that the NPs were at different levels of vulnerability from wildfires during the period in question. The findings indicate that the highest degree of threat occurred during the months of August and September.

Data on the number of fires for the period 2005–2021 indicated that the highest number of fires was recorded in NP Tara and the lowest number in NP

Kopaonik. The number of registered fires was higher in the NPs at a lower altitude. Climate variables, as well as climate indices calculated using air temperature and precipitation, correlated with the dynamics of fire occurrence. The correlation with *FAI* was positive and it was negative for precipitation, temperature, $AI_{Lang}$, and $I_{DM}$. A linear correlation of 0.5503 was obtained between the number of fires and *FAI* for NP Tara and –0.2438 between the number of fires and precipitation for NP Djerdap. The best MLR model was obtained using temperature, precipitation, $I_{DM}$, and $AI_{Lang}$ as predictors for both NP Djerdap (where the coefficient of correlation was –0.9128) and NP Tara (where it was –0.7452).

Obtained results by this study can be applied for adequate forest fire risk management and monitoring in the Republic of Serbia. Future investigation should strive to derive forest fire susceptibility maps which can be used by decision makers for better preparedness, coordination, and intervention in the national parks area vulnerable to wildfires.

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