Influence of forest humidity on the distribution of forest fires in the territory of Serbia

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Abstract

In this study, we examined the dependence of the influence of forest humidity conditions on the variability of forest fires in Serbia. The changes in values of the Forest Aridity Index (FAI) and the De Martonne Drought Index (I_{DM}) in the period 2009-2018 were analyzed, with an emphasis on 2012 and 2014. Data from ground meteorological measurements at 14 main meteorological stations on the territory of Serbia were used. The analysis of the FAI index determines a positive correlation on the activity of forest fires in the territory of Serbia. FAI values indicate marked increases for 2012 and 2017 when the largest number of forest fires was registered in Serbia. The lowest values of this index are for 2014, when we registered the smallest occurrence of forest fires in Serbia.

Decrease in the value of the I_{DM} index was observed during 2011, 2012 and 2017 correlated with a larger number of forest fires in the period. The greatest threat to forests from fire is in the administrative district of Kragujevac (region of Šumadija and Western Serbia) and Vranje (region of Southern and Eastern Serbia) and the lowest in the area of Sombor and Kikinda (region of Vojvodina). At nine of the fourteen meteorological stations, the De Martonne Drought Index (I_{DM}) showed stronger connection with the occurrence of forest fires compared to the Forest Aridity Index (FAI).

Keywords: Aridity, Aridity indices, Forest fire, Serbia.

Introduction

The territory of Serbia is sensitive to different types of natural hazards and the risk is not the same across the entire territory[8]. Forest fires occurred in this teritory seriously endangered the safety of people and material goods. The number of fires varies from year to year and that depends on weather conditions.

Forest humidity conditions are variable during the year which is determined by air temperature and precipitation. Long dry periods adversely affect the development and condition of vegetation and cause instability of forest ecosystems.

Živanović[34] stated that by drying out the vegetation and reducing the moisture content in the fuel material, conditions are created that are suitable for the occurrence and spread of fires in the forest. Analyzes confirmed drought as an important initiator of both occurrences and fire size[19].

Many authors[14,17,20,30] have identified drought as an important influence on fire regimes. The occurrence of drought is a common natural danger in Serbia and its harmful impact is increasingly pronounced in the 21st century. Spasov[27] states that the area of Serbia is exposed to changes in humidity conditions, especially during the warmer half of the year.

It is known that vegetation depends on the amount of precipitation and air temperature. For these reasons, one quantity is taken as the drought index, which is the function of air temperature and precipitation. Drought periods can be determined for a certain area in terms of humidity with the help from different drought indices. The occurrence of forest fires is also expressed. Gavrilov and associates[12] stated that the Forestry Aridity Index (FAI) is one of the most appropriate indicators for analyzing the interaction of climatic and vegetative averages, especially in forestry. The De Martonne aridity index[6] is one of the best known and most widely used aridity/ humidity indices in applied climatology[3,5,21,26].

Climate and weather play an important role in shaping fire activity patterns by controlling fuel productivity and fire spread respectively[31]. Flannigan and associates[10] stated that fire activity is strongly linked to the weather. The risk of fire is lower during extremely wet periods[7,28,36-38].

Dragicevic and associates[8] stated that forest fires mostly occur in dry years. Tosic and associates[29] stated that the danger of fire is higher if the dry season is longer, especially during the period when the air temperature is extremely high. The aim of this study is to determine the impact of humidity conditions on the risk of forest fires in Serbia. Understanding the weather and climate impacts on the distribution of forest fires should help the competent services to prevent forest fires in the future.

Study area and Data

The territory of Serbia consists of the geographical area of Southeast Europe (central part of the Balkan Peninsula) between 18° 39' and 23° 01' in the latitude and 41° 51' and 46° 11' north longitude in the area of 88 361 km^2. The total forest cover in Serbia is about 29.1% of the territory with a dominant deciduous forest. The climate in Serbia is temperate-continental[9] with differently expressed local characteristics. Summers in Serbia are warm and winters are

short and cold. July is the warmest month while January is the coldest. The average altitude of the territory of Serbia is 473 m. The degree of aridity was estimated based on the value of the forest moisture index (FAI) and the De Martonne Drought Index (I_{DM}). The Forest Aridity Index[11] links the temperature, precipitation and distribution of forests based on equation (1):

$$FAI = C_g \times T_{VII-VIII} / (P_{V-VII} + P_{VII-VIII}) \quad (1)$$

where $T_{VII-VIII}$ represents the average monthly temperatures for July and August (°C), $P_{V-VII} + P_{VII-VIII}$ is sum of precipitation amounts for the two periods May, June and July and July to August (mm) and C_g is a constant with dimensions $C_g = 100$ mm/°C.

Forest aridity index is interpreted as:

FAI> 15.0 - High
9.0 ≤ FAI ≤ 15.0 - Medium and
FAI <9.0 - Low.

The De Martonne Drought Index (I_{DM}) is calculated according to the following expression:

$$I_{DM} = P/ (T+10) \quad (2)$$

where P = annual rainfall (mm), T = annual air temperature (°C) and 10 is the coefficient that is added to get positive index values. The classification of I_{DM} values is given in table 1.

In this research we used data for air temperature and precipitation from 14 meteorological stations (Figure 1) for the period from 2009 to 2018. Meteorological stations Zrenjanin, Kikinda, Novi Sad (Rimski Šančevi), Sombor and Sremska Mitrovica were used for the region of Vojvodina. The stations Zaječar, Niš, Vranje and Leskovac were used for the region of Southern and Eastern Serbia. The stations Valjevo, Kragujevac, Kraljevo and Kruševac were used for the region of Šumadija and Western Serbia while the station in Belgrade (observatory) was used for the Belgrade region. These meteorological stations are the database managed by the Republic Hydrometeorological Institute of Republic of Serbia.

The endangerment of forests by fire was assessed on the basis of statistical data from the Sector for Emergency Situations of the Ministry of the Interior of the Republic of Serbia on the registered number of forest fires in 14 administrative districts in Serbia for the period from 2009 to 2018.

Table 1
De Martonne index climatic classification

Values of I_{DM}	Types of climate
I_{DM} <10	Arid
10≤I_{DM} <20	Semiarid
20≤I_{DM} <24	Mediterranean
24≤I_{DM} <28	Semi-humid
28≤I_{DM} <35	Humid
35≤I_{DM} ≤55	Very humid
I_{DM} >55	Extremely humid

Annual mean temperature (°C) and precipitation (mm) for 14 stations in Serbia during the period 2009–2018 are shown in table 2.

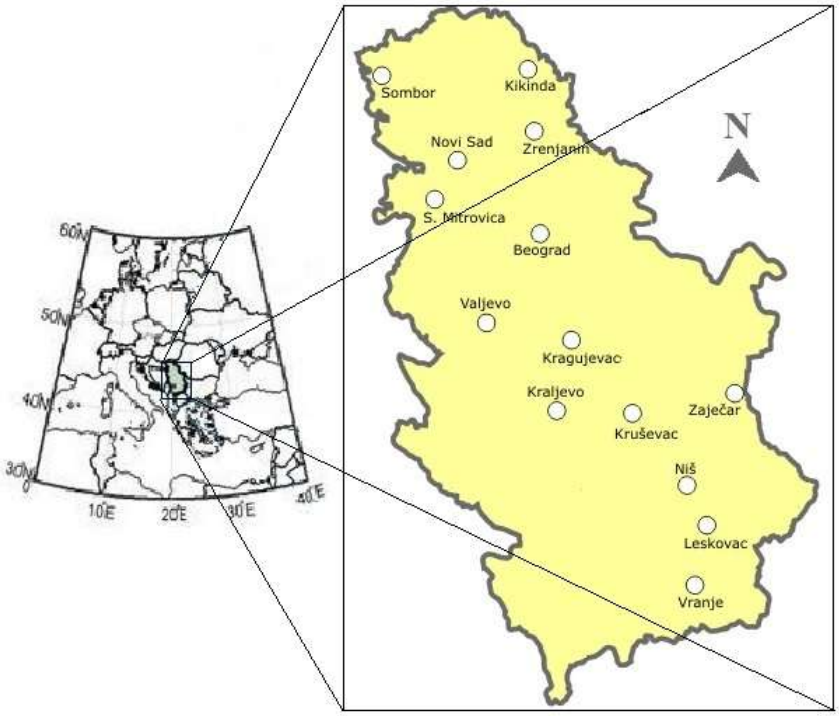

Fig. 1: Administrative districts in Serbia and location of meteorological stations

Table 2
Abbreviations (Abb) of stations with their latitude, longitude and altitude (m) and mean annual temperature (°C), precipitation (mm) during the period 2009-2018

Abb	Meteorological station	Latitude (N)	Longitude (E)	Altitude (m)	*T* (°C)	*P* (mm)
VA	Valjevo	44º 17’	19º 55’	174	12.6	848.0
VR	Vranje	42º 33’	21º 55’	433	12.1	669.6
ZA	Zaječar	43º 53’	22º 17’	144	11.6	604.6
ZR	Zrenjanin	45º 24’	20º 23’	80	12.7	607.3
KI	Kikinda	45º 51’	20º 28’	81	12.4	590.1
KG	Kragujevac	44º 02’	20º 56’	181	12.5	693.4
KR	Kraljevo	43º 43’	20º 42’	219	12.4	787.1
KŠ	Kruševac	43º 34’	21º 20’	166	12.3	715.8
LE	Leskovac	42º 59’	2º 57’	231	12.0	707.9
NI	Niš	43º 20’	21º 54’	202	12.9	657.6
NS	Novi Sad	45º 19’	19º 50’	86	12.5	680.5
SO	Sombor	45º 46′	19º 09’	87	12.1	649.6
SM	Sremska Mitrovica	45º 01’	19º 33’	81	12.3	607.3
BG	Beograd	44º 48’	20º 28’	132	13.8	699.1

The frequency of forest fires in 14 administrative districts was compared with the values of the Forest Aridity Index (FAI) and the De Martonne Drought Index (I_{DM}) for the period 2009–2018 and correlations were determined between these values. The correlation between the time series of the number of forest fires and the drought index was determined by applying the Pearson correlation coefficient (r).

The coefficient of determination (R^2) was used as an indicator to determine how much changes in one variable were caused by the changes in the other variable. If the value of the Pearson correlation coefficient is in the range between ± 0.10 and ± 0.29, it is concluded that the correlation is low. The correlation of the mean degree for the values of the coefficients in the interval between ± 0.30 and ± 0.49 and the high degree between ± 0.50 and ± 1.00 is considered. If the value of Pearson's correlation coefficient is zero, it is concluded that there is no correlation. There is a positive correlation when one variable increases and the other variable increases. Correlation is negative when one variable increases and the other variable decreases (Pearson’s Correlation Coefficient - Statistics Solutions, 2017). Significance level ($p < 0.05$) was determined, $\chi 2$ test was used as a non-parametric method.

Results and Discussion

Basic characteristics of humidity conditions in the investigated area: The concept of humidity conditions is an official term in agrometeorology and it is determined by certain indicators (indices) based on which the occurrence of drought in a certain area is monitored in a certain period of time. Nastos and associates[22] stated that the dryness index is a numerical indicator of the degree of dryness of the climate at a given location. According to the interpretation of the American Meteorological Society[1], in the climatic sense of the term, dryness is the opposite of humidity. Barakat[4] defines aridity as the lack of moisture in average climatic conditions. According to the World Meteorological Organization[39], drought is a prolonged absence and pronounced deficit or poor distribution of precipitation.

Many authors in their studies[2,12,13,15,16,18,23,24,32] analyzed aridity in certain areas in Serbia. The values of the Forest Humidity Index (FAI) and the De Martonne Drought Index (I_{DM}) for certain areas in Serbia are shown in tables 3 and 4 where the humidity conditions were calculated for the period 2009–2018.

Time distribution for the mean annual values of the Forest Aridity Index (FAI) and the De Martonne Drought Index (**I_{DM}**) on the territory of Serbia indicates a significant variability in its value. On the territory of Serbia, high values of the Forest aridity index (FAI> 15.0) were recorded in the years 2012, 2015 and 2017. The low values of this index (FAI <9.0) are for 2014. The amount of precipitation during 2014 at most measuring points in Serbia is two to three times higher than the average values[25].

For the territory of Serbia, the FAI index is 18.8 for the region of Southern and Eastern Serbia, 16.5 for the Belgrade region and for the region of Vojvodina and 14.1 for the region of Šumadija and Western Serbia. This indicates that due to the effects of drought, forest ecosystems in the south and east of Serbia are the most affected.

It is noted in table 4 that the De Martonne Drought Index (I_{DM}) has small value for the years 2011, 2012 and 2017 which indicates extremely dry conditions. Extremely humid conditions in Serbia were in 2014 with I_{DM} values from at least 28.0 in Kikinda to the highest from 58.2 in Valjevo (Table 4). It is noted that according to the De Martonne drought index, the humidity conditions for 2011 correspond to the conditions of the semi-arid climate at 10 measuring

points (Table 4). Very humid conditions in 2014 were at 9 locations and conditions had extremely humid climate at one location.

The minimum value of the De Martonne drought index (I_{DM} = 15.8) was calculated for 2011 for the Vranje area (VR). Extremely humid conditions were recorded for the Valjevo area (VA) in 2014 (I_{DM} = 58.2). These values of the drought index indicate an exceptional diversity of climatic conditions. It is noticed that the variability of the FAI and I_{DM} indices is not conditioned geographically with the latitude and absolute altitude of the meteorological station in the territory of Serbia.

Dynamics of fire occurrence in the investigated area: The occurrence of forest fires in Serbia is pronounced almost every year and it is a limiting factor for sustainable forest management[35]. Great part of the territory of Serbia is relatively high sensitive to forest fires[33]. Figure 2 presents the dynamics of fire occurrence on forest areas in Serbia in the period from 2009–2018. Based on this picture, it is determined that the largest number of fires was noted during 2012 and 2017. The lowest number of fires occurred during 2014.

The linear trend in a ten-year series shows negative trend in the number of forest fires in Serbia (Figure 2). The equation of the linear trend – number of forest fires in the territory of Serbia – has the following form:

$$y = - 18.697x + 596.13 \quad (3)$$

The number of forest fires in certain administrative districts and in the area of the city of Belgrade is shown in figure 3. It is noted that for the period 2009–2018, the highest number of fires occurred in the area of Kragujevac (KG), Vranje (VR) and Kruševac (KŠ). The lowest number of forest fires is in the districts Kikinda (KI), Sombor (SO), Zrenjanin (ZR), Novi Sad (NS) and Sremska Mitrovica (SM) which are located in the area of Vojvodina where there is the least forest cover about 6.5%.

Table 3
Forest aridity index (FAI)) for the period 2009–2018

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
VA	9.8	7.1	11.8	27.4	14.8	4.4	19.9	9.4	16.7	8.4
VR	17.7	23.5	23.4	29.2	19.7	10.2	41.5	10.9	24.9	15.5
ZA	18.7	17.1	19.1	18.8	40.6	8.5	42.4	13.6	19.3	12.5
ZR	13.1	8.3	17.6	34.2	19.8	7.6	30.6	10.0	44.4	15.0
KI	15.6	7.5	15.5	26.2	19.0	10.0	39.8	12.0	30.0	10.0
KG	15.5	14.9	18.3	22.9	13.7	6.7	16.3	11.3	21.7	5.7
KR	11.0	12.1	18.4	30.0	16.0	6.3	20.5	14.3	18.9	5.9
KŠ	18.5	13.2	13.5	20.3	27.5	9.2	24.9	8.7	23.6	8.1
LE	13.9	24.3	23.2	14.8	18.3	10.7	28.3	11.1	24.6	11.2
NI	16.6	19.6	18.8	20.3	27.1	7.3	29.9	13.3	27.8	16.9
NS	14.6	6.9	20.1	27.9	13.3	7.1	15.3	10.7	25.8	10.4
SO	17.4	7.7	15.6	37.2	16.3	9.8	16.3	9.1	19.2	10.8
SM	23.7	9.6	13.7	27.4	15.6	9.8	20.1	14.1	17.3	10.6
BG	12.3	12.0	15.6	23.5	24.3	5.0	27.8	13.2	24.6	14.8

Table 4
De Martonne Drought Index (I_{DM}) for the period 2009–2018

	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
VA	40.7	48.3	27.4	26.9	29.9	58.2	33.4	43.6	32.5	34.3
VR	33.1	37.8	15.8	24.8	27.0	40.1	30.5	36.8	28.0	28.8
ZA	36.7	38.0	18.0	28.0	24.6	49.0	23.7	36.1	26.5	33.1
ZR	27.8	41.6	17.9	22.6	26.0	34.6	22.3	33.4	16.1	26.0
KI	24.7	47.4	17.4	20.1	27.6	28.0	18.6	32.1	17.5	30.6
KG	35.3	32.7	19.7	26.2	31.7	42.7	30.0	36.7	25.1	27.9
KR	38.6	36.4	23.7	26.4	29.9	50.5	34.6	37.6	30.5	43.5
KŠ	32.8	34.2	22.6	29.2	26.7	44.0	27.5	42.4	25.8	35.2
LE	37.6	33.8	19.1	27.9	25.7	40.3	31.6	37.0	33.2	34.7
NI	31.3	29.7	18.6	27.3	25.0	41.1	25.6	34.1	26.6	27.4
NS	28.3	48.4	17.8	21.6	33.2	35.6	30.7	34.6	22.7	30.8
SO	23.7	49.1	18.8	20.3	31.6	34.5	27.4	34.8	24.7	29.6
SM	24.8	38.9	19.9	20.2	27.8	33.5	27.7	27.8	24.0	28.2
BG	33.9	37.5	21.5	23.4	25.5	45.4	48.2	32.3	21.3	24.5

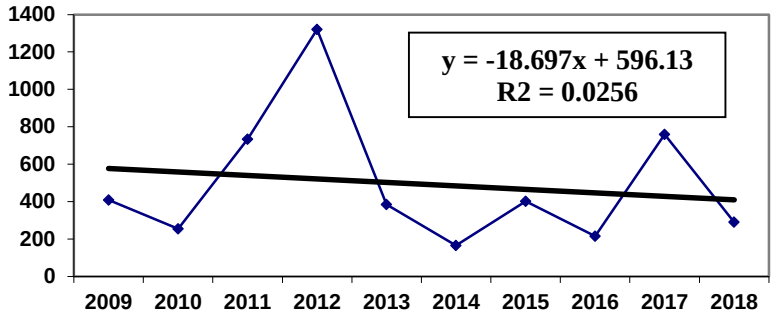

Fig. 2: Number of forest fires and linear trend curve from 2009 to 2018 in the Republic of Serbia

Table 5
Results from stepwise regression models for number of forest fires in of meteorological stations Serbia with the Forest aridity index (FAI) and the De Marton drought index (I_{DM}) retained as predictor

Location	Correlation equation	r	R^2	Predictor variables
Valjevo	y = 2.308x – 11.635	0.8312	0.6909	FAI
	y = -1.1618x – 61.89	0.6085	0.3703	I_{DM}
Vranje	y = 0.8724x +6.7115	0.3518	0.1238	FAI
	y = -2.1815x +91.936	0.6832	0.4668	I_{DM}
Zaječar	y = - 0.0128x +8.6701	0.0200	0.0004	FAI
	y = - 0.4753x +23.311	0.5999	0.3599	I_{DM}
Zrenjanin	y = 0.1038x +0.1177	0.3584	0.1285	FAI
	y = - 0.1146x +5.2744	0.2516	0.0633	I_{DM}
Kikinda	y = 0.0294x +0.455	0.2893	0.0837	FAI
	y = - 0.0424x +2.1204	0.3696	0.1366	I_{DM}
Kragujevac	y = 4.0586x – 29.262	0.7226	0.5221	FAI
	y = - 3.2028x +129.05	0.6587	0.4339	I_{DM}
Kraljevo	y = 1.7753x – 4.2337	0.7683	0.5903	FAI
	y = - 1.6666x +81.615	0.8067	0.6507	I_{DM}
Kruševac	y = 1.3727x +2.9067	0.4865	0.2367	FAI
	y = - 1.6608x +79.112	0.5800	0.3364	I_{DM}
Leskovac	y = 0.0032x +10.843	0.0014	2E-06	FAI
	y = - 1.1416x +47.534	0.5025	0.2525	I_{DM}
Niš	y = 0.2195x +5.1618	0.2267	0.0514	FAI
	y = - 0.2131x +15.609	0.2929	0.0858	I_{DM}
Novi Sad	y = 0.3503x – 1.8283	0.6381	0.4072	FAI
	y = - 0.2569x +11.303	0.5560	0.3091	I_{DM}
Sombor	y = 0.0066x +1.295	0.0346	0.0012	FAI
	y = 0.0242x +0.6867	0.1356	0.0184	I_{DM}
Sremska Mitrovica	y = 0.9283x -9.9294	0.7864	0.6184	FAI
	y = - 0.631x +22.315	0.5108	0.2609	I_{DM}
Beograd	y = 0.4507x +12.798	0.2207	0.0487	FAI
	y = - 0.7532x +44.214	0.4955	0.2455	I_{DM}

Correlation of aridity index and fire occurrence: Table 5 shows the linear correlations of the Forest Aridity Index (FAI) and the De Martonne Drought Index (I_{DM}) with the occurrence of forest fires for the period from 2009–2018.

The data in table 5 indicates that there is connection between the occurrence of forest fires and the aridity index in the observed period. Based on the values of Spearman's correlation coefficients, a high degree of correlation (r) and coefficient of determination (R^2) were determined for the areas of Valjevo, Vranje, Kragujevac, Kraljevo, Kruševac and Sremska Mitrovica. It is noticed that there is a stronger correlation of forest fires with FAI index in 5 administrative districts (VA, ZR, KG, NS, SM) and with I_{DM} index in 9 administrative districts (VR, ZA, KI, KR, KŠ, LE, NI, SO, BG).

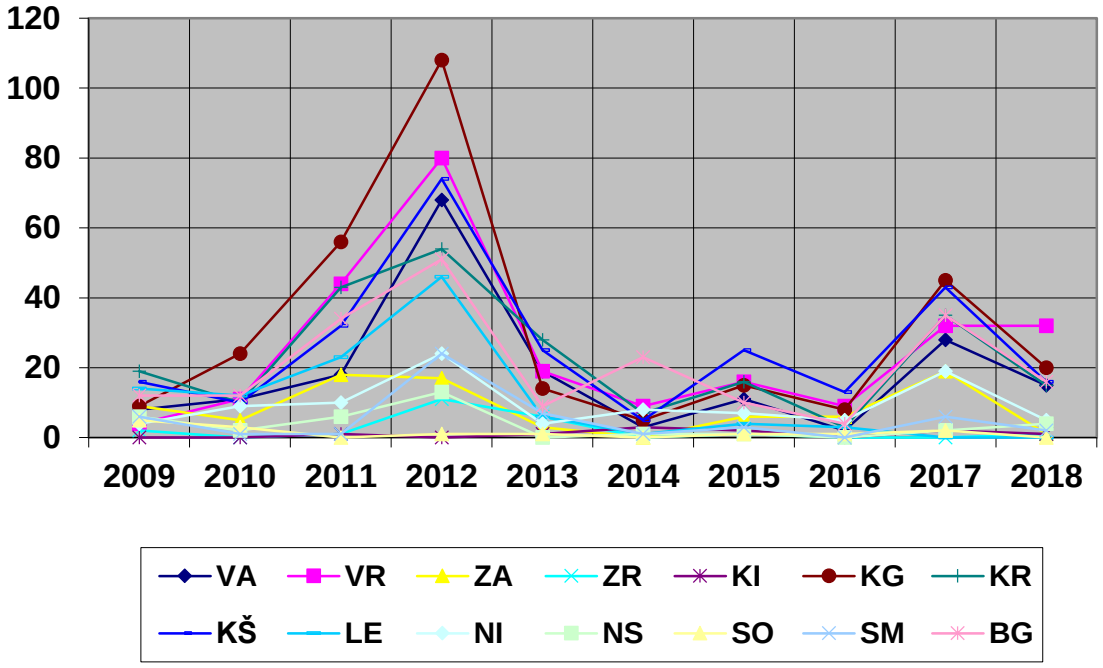

Fig. 3: Number of forest fires during the period 2009–2018

Conclusion

Weather conditions on the territory of Serbia are important aspects for creating conditions that are suitable for the occurrence and spread of forest fires. Reduced forest humidity in certain years has an adverse effect on vegetation and causes high natural vulnerability of forests. There is a connection between the analyzed aridity indices and forest fires on the territory of Serbia for the period 2009–2018. The values of the FAI index and the De Martonne drought index indicate that 2011, 2012 and 2017 were extremely dry which correlates with a large number of forest fires. At all meteorological stations, extremely humid conditions were present during 2014 and 2016 correlated with the small number of forest fires.

According to I_{DM} indicators, the semi-humid climate is in most of the region of Vojvodina and the humid climate is in the region of Southern and Eastern Serbia. For the region of Šumadija and Western Serbia, the climate is semi-arid while in the region of Belgrade, the Mediterranean climate prevails. Forest moisture index (FAI) indicators indicate that the highest values of drought are for the area of Vranje and the lowest for the area of Valjevo. Forest protection decision makers can use the results of this research to prevent and control harmful events in the future.

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