UDK 630* 431
https://doi.org/10.31298/sl.147.9-10.6

Pregledni članci – Reviews
Šumarski list, 9–10 (2023): 477–484

DETERMINING THE FIRE SEASON BY ANALYZING CLIMATIC CONDITIONS IN NORTHEASTERN SERBIA

ODREĐIVANJE SEZONE ŠUMSKIH POŽARA ANALIZOM KLIMATSKIH UVJETA NA PODRUČJU SJEVEROISTOČNE SRBIJE

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SUMMARY

The territory of Serbia is sensitive to forest fires, which endanger various systems and play an important role in shaping the ecosystem. The probability of the occurrence and spread of forest fires in the area of northeastern Serbia was examined, depending on the influence of climatic conditions. Changes in climatic conditions are investigated at the annual and monthly level of air temperature, precipitation and air humidity values recorded at three main meteorological stations (Zaječar, Negotin, Crni Vrh) in the area of northeastern Serbia. Changes in climatic conditions in the period 2009-2022 compared to the period 1961-1990 were analyzed, with an emphasis on 2012 and 2014.

The length of the average fire season was determined through a modified version of Thornthwaite's evapotranspiration index. The fire season is longer in the area of Negotin and Zaječar than in the area of Crni Vrh. On the basis of the monthly humidity indices, a significantly longer fire season was determined in 2012 compared to 2014, as well as the multi-year period 1961-1990.

An analysis of the value of the Burning Index (B) for the period 2009-2022 was performed and a correlation was established with the data on the number of forest fires. The burning index in the area of northeastern Serbia is the highest during the months of July, August and September. Significantly higher values of the burning index are for 2012 compared to 2014, which is correlated with the occurrence of forest fires in this period.

KEY WORDS: Thornthwaite's evapotranspiration index, Burning index, forest fire, fire season, northeastern Serbia

INTRODUCTION
UVOD

Available climate data provide information on forest fire potential in any area of the world (Chandler *et al.*, 1983). Tošić et al. (2019) state that the most favorable conditions for the occurrence of fires in Serbia are high air temperatures, low relative humidity and lack of precipitation. There is a need for a better understanding of the influence of weather conditions on the occurrence of forest fires in the area of northeastern Serbia.

Climatic data, which are variable during a certain period of time (Kolić, 1988; Milosavljević, M., 1990), influence creating the conditions favorable for the occurrence of forest fires. The accumulation of plant cover is mostly a function of winter temperatures and spring humidity (Chandler *et al.*,1983; Bonan, 2002). Jolly et al. (2015) state that global fire activity is strongly influenced by climate. De Angelis et al. (2015) indicate a strong connection between fire regimes and weather conditions. Climate determines the length of the fire season (Carvalho *et al.*, 2011; Jiménez-Ruano *et al.*,

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2019), and in the short term, time drives fire behavior and spread (Wotton *et al*., 2007). Flannigan et al. (2016) state that fuel moisture is time dependent. The condition of the plant cover during the growing season is determined by the intensity and frequency of the dry season. The distribution and amount of precipitation affect the increase in the humidity of the fuel material, and thus the decrease in the risk of fire and vice versa (Vučetić, 2001; Ćurić *et al*., 2013). Heikkilä et al. (2007) state that the moisture content of the fuel is a very important condition for combustion. Many authors in their studies (Dimitrakopoulos *et al*., 2001; Aguado *et al*., 2007) state that moisture content was the most significant factor affecting the flammability of Mediterranean forest fuels. Garcia et al. (2008) they state the moisture content of the fuel is correlated with the ignition and spread of fire. Xystrakis et al. (2014) believe that the rate at which fuel dries depends on air humidity and temperature. Fuel material with reduced moisture content is suitable for the occurrence and spread of forest fires (Vasić, 1992; Živanović, 2017; Živanović *et al*., 2018). If the moisture content is high enough, the amount of available combustible material will decrease and thus the risk of ignition (Burgan, 1979). Gaulton et al. (2013) state that fuel moisture is an important indicator of fire risk. Fuel moisture content is a critical parameter in predicting fire behavior (Zhenxing *et al*., 2017) and is largely determined by precipitation and air temperature. Živanović (2012) states that the value and variability of climatic elements indicate when and to what extent there is a danger of the occurrence and spread of forest fires. Wotton (2009) claims that weather conditions primarily determine the severity and strength of a forest fire.

The aim of this work is to determine the areas and periods of increased risk of forest fires based on the climatic conditions on northeastern Serbian teritory.

MATERIALS AND METHODS
MATERIJALI I METODE

Northeastern Serbia is a geographic area between 21°40´ and 22°46´ east latitude and 43°20´ and 44°42´ north longitude. The forested area of northeastern Serbia is 3014.79 km^2 or about 42.28% of the territory (total area 7130 km^2), and deciduous species dominate (beech, oak, hornbeam). Winters in the area of northeastern Serbia are short and cold, and summers are warm. According to Keppen's climate classification system (Wladimir Köppen, 1846–1940), the climate formula for Negotin is Cfs"w"ax, Zaječar Cfs"w"bx and Crni Vrh Cfwbx, period 1951-2010. The location of the area of northeastern Serbia is shown in Figure 1.

Data from ground meteorological measurements from three meteorological stations in the area of northeastern Serbia were used to analyze the change in climate conditions (Figure 1). Thresholds of air temperature, amount of precipitation and air humidity in the period 2009-2022. were calculated from the common base period of 1961-1990. Data series are complete (i.e. no missing values). The data were retrieved from the Republic Hydrometeorological Service of Serbia (RHSS, 2023)

Figure 1. The area of northeastern Serbia
Slika 1. Područje sjeveroistočne Srbije

The distribution of moisture throughout the year can be determined by a modified version of Thornthwaite's evapotranspiration index (Thornthwaite, 1948):

$$M = (PR) - F \quad (1)$$

where:

M – Monthly moisture index

P – Total monthly precipitation (cm)

R – Total monthly days with precipitation, and

F – Evapotranspiration factor.

The evapotranspiration factor can be represented by the formula:

$$\ln F = \frac{0{,}14 \cdot T^{0{,}89}}{12} \cdot L \quad (2)$$

where:

T – Mean monthly air temperature (°C), and

L – Mean monthly day length (h).

Table 1. The Burning index (B) classification
Tablica 1. Klasifikacija indeksa gorenja (B)

Burning index values *Vrijednosti indeksa gorenja*	Fire behavior *Ponašanje pri požaru*
1≤B≤19	Creeping fire only
20≤B≤39	Surface fire only
40≤B≤59	Running fire, occasional torching of tree crowns
60≤B≤79	Hot running fire, spot fires, and torching common
80≤B	Crown fire likely

The evapotranspiration factor and the monthly moisture index are equal to "0" for every average monthly temperature ≤0 °C. The monthly moisture index is limited to max. a value of 100 (all values > of 100 are taken as a value of 100), (Chandler *et al.*,1983).

The length of the average fire season was obtained by simply counting months with negative wetness indices. Positive monthly moisture index indicate fire-free seasons. Period one to four months with a negative monthly moisture index is a short fire season, and five to 12 months is a long fire season (Chandler *et al.*,1983).

The burning index is determined by the formula

$$B = \frac{IS}{60} \quad (3)$$

where:

B – Burning index

I – Intensity component

S – Spread component

and

$$I = (110 - 1{,}373\ H) - (20{,}4 - 0{,}054\ T) \quad (4)$$

where:

H – Humidity Index

T – Monthly mean maximum temperature (°C)

and

$$S = 124 \cdot 10^{-0{,}0142H} \quad (5)$$

where:

$H = 100 \cdot (10^{0{,}0308D} / 10^{0{,}0308T})$

D – Monthly mean dew point temperature (°C).

The burning index is correlated with the fire behavior, which is determined based on the data from table 1.

For this research, statistical data from the Department for Emergency Situations (MUP of the Republic of Serbia) on the registered number of forest fires in the area of northeastern Serbia for the period from 2009 to 2022 were used. The Pearson correlation coefficient (r) was used to examine the possible relationship between the time series of the number of forest fires and the burning index.

RESULTS
REZULTATI

Climate conditions – *Klimatski uvjeti*

In the area of northeastern Serbia, the average annual air temperature ranges from 6.4 °C at Crni Vrh to 11.1 °C in Negotin (RHSS, 2023). Significantly lower air temperature values in the area of Crni Vrh are conditioned by the higher altitude of this place where the meteorological station is located (1027 m asl.). In relation to the multi-year average of mean annual air temperatures, Table 2 shows that at all meteorological stations there was an increase in air temperature in all years during the period 2009-2022. The deviation of the average annual air temperature compared to the reference period was the most pronounced in 2019.

In the area of northeastern Serbia, the hottest month is July, with an average daily temperature of 16 °C at Crni Vrh to 22.1 °C in Negotin. The coldest month is January with an average daily temperature of -4.2 °C at Crni Vrh to -1.4 °C in Zaječar (RHSS, 2023). In July 2012, the mean monthly air temperatures in Negotin were 5.1 °C higher than the multi-year average (RHSS, 2023). Tošić et al. (2014) state that 2012 was one of the warmest years in Serbia. For the period 2009-2022. every month of the vegetation period in the area of Negotin had higher air temperature values than the multi-year average.

In the area of northeastern Serbia, the multi-year average amount of precipitation is from 610.5 mm in Zaječar to 810.1 mm in the area of Crni Vrh (RHSS, 2023) (table 3).

For the period 2009-2022, in the area of northeastern Serbia, the least amount of precipitation was measured in 2011,

Table 2. Temperature mean values in the northeastern Serbia area during different periods, (mm)
Tablica 2. Srednje vrijednosti temperature zraka na području sjeveroistočne Srbije za različita razdoblja, (mm)

Weather station	Year *Godina*														
Meteorološka postaja	1961-1990	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Zaječar	10.4	11.5	11.2	11.2	11.7	11.8	11.4	12.2	11.6	11.6	11.7	12.3	12,0	11,6	12,2
Negotin	11.1	12.8	12.2	12.3	13.2	12.9	12.7	13.7	13.2	13.2	13.1	13.9	13,7	13,1	13,9
CrniVrh	6.4	7.5	6.7	7.1	7.9	7.7	7.4	8.2	7.6	7.6	8.0	8.7	8,0	7,6	8,5

Table 3. Mean values of precipitation in the northeastern Serbia area during different periods, (mm)
Tablica 3. Srednje vrijednosti oborina na području sjeveroistočne Srbije za različita razdoblja, (mm)

Weather station / *Meteorološka postaja*	Year / *Godina*														
	1961-1990	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Zaječar	610.5	790.6	806.4	375.6	608.7	535.5	1048.3	525.4	781.6	574.0	719.3	575.3	752,1	612,1	534,6
Negotin	646.0	779.8	737.1	352.4	532.5	700.1	1237.2	732.1	744.7	565.5	738.6	569.3	571,6	590,9	559,2
CrniVrh	810.1	988.3	1024.4	590.2	759.1	695.5	1137.4	764.9	904.5	623.1	857.1	740.0	781,2	708,3	694,6

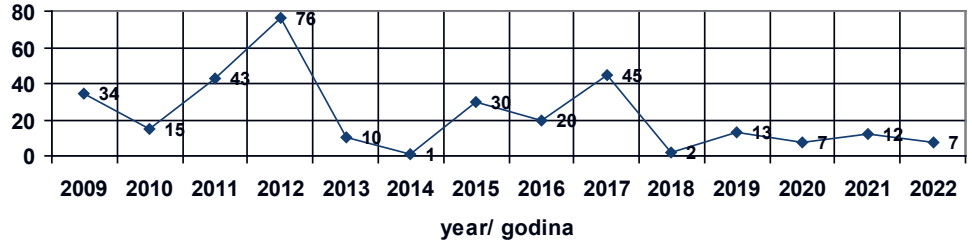

Figure 2. The number of forest fires in the area of northeastern Serbia, period 2009-2022.
Slika 2. Broj šumskih požara na području sjeveroistočne Srbije, razdoblje 2009.-2022.

while the rainiest was in 2014 (table 3). The year 2014 was one of the wettest (Tošić *et al.*, 2017) with significant amounts of precipitation during the growing season. Table 3 shows that at all meteorological stations, the years 2011, 2012, 2017,2019 and 2022 have a lack of precipitation. Deficit precipitation caused a pronounced decrease in the humidity of the surface layer of the soil, as well as a decrease in the humidity in the deeper layers. Excess precipitation in this area was recorded in 2009, 2010, 2014, 2016 and 2018 (table 3). Table 3 shows that in 2014 the amount of precipitation was higher than the multi-year average by 327.3 mm at Crni Vrh, i.e. 591.2 mm in Negotin and 437.8 mm in Zaječar.

The dynamics of forest fire outbreaks in the area of northeastern Serbia – Dinamika izbijanja šumskih požara na području sjeveroistočne Srbije

Fire season in the area of northeastern Serbia varies significantly from year to year. Figure 2 shows the number of forest fires during the period 2009-2022. years. The year with the highest number of forest fires (2012) is characterized by extreme fire weather conditions, especially a combination of long periods of drought and high air temperatures. The lowest number of forest fires (in 2014) (Figure 2) is in years with precipitation that is significantly above multi-year average values, which then create wet conditions and reduce the risk of fire occurrence.

The number of forest fires in the area of northeastern Serbia is the highest during the months of March (24.1%) and September (15.2%), Figure 3. Fires occur in the period from January to December, which also constitutes the fire period in the area of northeastern Serbia. The defined period of occurrence of forest fires of 12 months during the year in-

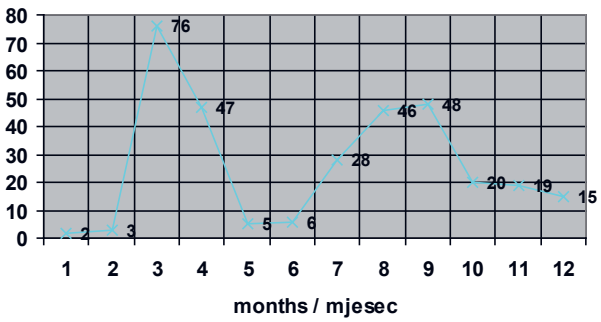

Figure 3. Number of forest fires per months in the period 2009-2022.
Slika 3. Broj šumskih požara po mjesecima za razdoblje 2009.-2022.

dicates that there is a long fire season in the area of northeastern Serbia. Figure 3 shows that the number of fires is greater in the second half of the year.

The monthly occurrences of forest fires in 2012 and 2014 is shown in Table 4. Table 4 shows a large number of fires that occured in March 2012, which is correlated with the negative monthly moisture index and high values of the burning index (B) for the month of March.

The monthly moisture index for the area of northeastern Serbia for different periods is shown in table 5. It is noticeable (table 5) that for the period 1961-1990. at Crni Vrh, a positive monthly moisture index was. The area of Zaječar and Negotin has a negative monthly moisture index for the months of July, August and September, when forest fires are likely to occur. Table 5 shows a significantly longer fire season in 2012 compared to 2014 at all stations.

The values of the burning index are shown in table 6. The presented tabular data indicate that running fire, occasional torching of tree crowns ($40 \leq B \leq 59$) is possible during the

Table 4. Number of forest fires in the area of northeastern Serbia in (year) 2012 and 2014
Tablica 4. Broj šumskih požara na području sjeveroistočne Srbije u 2012. i 2014. godini

Year *Godina*	Month *Mjesec*												Total *Ukupno*
	1	2	3	4	5	6	7	8	9	10	11	12	
2012	1	0	32	4	1	0	10	11	10	1	0	6	76
2014	1	0	0	0	0	0	0	0	0	0	0	0	1

months of July, August and September in the area of Negotin and Zaječar. Surface fire only (20≤B≤ 39) is possible in the period March-April in the area of Negotin and Zaječar. During the period December-February, the occurrence of fires is unlikely in the area of Crni Vrh. Table 6 shows a significantly higher value of the burning index in 2012 compared to 2014 at all stations.

The correlation between the value of the burning index and the number of forest fires in 2012 is shown in Figure 4. It is noted that there is a connection between the value of the burning index and the occurrence of forest fires in the observed period. For the region of northeastern Serbia, the correlation is of medium intensity ($r = 0.48$; $R^2 = 0.23$), but it is not statistically significant ($p > 0.05$).

The results of this study confirm the findings (Živanović, 2017; Tošić *et al.*, 2019; Živanović *et al.*, 2020; Tošić *et al.*, 2020) that there is a coincidence of the largest number of fires in nature in Serbia with periods with high air temperatures and daily and monthly reduced moisture content in soil and fuel material. Ćurić and Živanović (2013) and Živanović (2020) pointed out that there is connection between the dynamics of fire occurrence and the distribution and amount of atmospheric precipitation. Several studies have found that summer droughts and high temperatures are the primary determinant of interannual fire variability in Southern Europe (Turco *et al.*, 2013; Pereira *et al.*, 2013; Turco *et al.*, 2017). Koutsias et al. (2013) state that fire occurrence in the eastern Mediterranean region is

Table 5. Monthly moisture index for the area of northeastern Serbia for different periods
Tablica 5. Mjesečni indeks vlage za područje sjeveroistočne Srbije za različita razdoblja

Weather station *Meteorološka postaja*	Period *Razdoblje*	Month *Mjesec*											
		1	2	3	4	5	6	7	8	9	10	11	12
Negotin 42 m asl.	1961-1990	+	+	+	+	+	+	-	-	-	+	+	+
	2012	+	+	-	+	+	-	-	-	-	+	+	+
	2014	+	-	+	+	+	+	+	+	+	+	+	+
Zaječar 144 m asl.	1961-1990	+	+	+	+	+	+	-	-	-	+	+	+
	2012	+	+	-	+	+	-	+	-	-	+	+	+
	2014	+	+	+	+	+	+	-	+	+	+	-	+
Crni Vrh 1027 m asl.	1961-1990	+	+	+	+	+	+	+	+	+	+	+	+
	2012	+	+	-	+	+	-	+	-	-	+	+	+
	2014	+	+	+	+	+	+	+	+	+	+	+	+

Table 6. Burning Index by month for the area of northeastern Serbia for different periods (1961-1990, 2012, 2014)
Tablica 6. Indeks gorenja po mjesecima za područje sjeveroistočne Srbije za različita razdoblja (1961-1990, 2012, 2014)

Weather station *Meteorološka postaja*	Period *Razdoblje*	Month *Mjesec*											
		1	2	3	4	5	6	7	8	9	10	11	12
Negotin	1961-1990	0.7	1.2	7.9	14.8	15.3	19.2	23.5	22.3	19.1	11.8	2.3	0
	2012	6.1	1.8	39.0	23.0	15.3	28.1	46.7	56.1	40.6	14.9	0	0
	2014	0	1.4	12.2	6.3	9.8	16.1	17.8	19.5	7.2	4.2	0	0
Zaječar	1961-1990	1.7	2.7	7.8	12.3	14.4	14.8	20.7	16.6	19.2	12.2	4.3	0.6
	2012	8.1	4.6	30.0	24.2	15.9	31.6	41.5	53.9	41.2	22.1	1.5	1.1
	2014	3.1	8.2	16.6	7.2	12.6	17.6	14.7	18.3	7.7	5.6	0	0.9
Crni Vrh	1961-1990	0	0	2.1	5.8	7.0	7.2	9.5	9.4	7.0	3.3	0.7	0
	2012	0	0	7.3	11.4	2.7	12.6	22.3	36.3	18.3	4.8	0	0
	2014	0	0	2.6	0.3	0.8	2.4	1.7	3.2	0	0	0	0

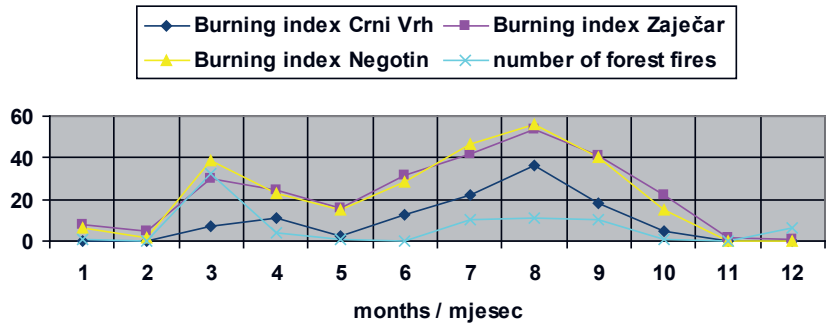

Figure 4. Burning index and occurrence of fires in 2012
Slika 4. Indeks gorenja i pojava požara u 2012. godini

correlated with mean maximum and absolute maximum air temperature, and that the total burning area is strongly negatively related to precipitation in the fire season.

DISCUSSION AND CONCLUSIONS
RASPRAVA I ZAKLJUČCI

Changes in climatic conditions in the area of northeastern Serbia affect the increased risk of forest fires and represent a challenge for decision makers. Identifying periods of the year with a high degree of threat from forest fires is useful in making appropriate decisions. Understanding the connection between climate conditions and the time frequency forest fire occurence can be of great help to the competent services for forest fire protection. Years with pronounced high air temperatures and reduced amounts of precipitation have the highest number of forest fires. A markedly small number of forest fires occur in years with extremely wet conditions. Data analysis of monthly moisture index in the area of northeastern Serbia indicates that, based on a longer period of time, the most critical months of the year are July, August and September. In certain years, such as 2012, due to the lack of precipitation and high air temperatures, fires also occurred in March. The number of forest fires in the northeastern Serbia area was higher in areas at a lower altitude. The risk of fire is significantly higher in the area of Zaječar and Negotin than in the area of Crni Vrh. Based on the burning index occasional torching of tree crowns in the area of northeastern Serbia is possible during the months of July, August and September. The obtained results show a good correlation between the values of the burning index and the temporal distribution of fires.

Based on the value of Spearman's correlation coefficients, the medium intensity of correlation (r) and the coefficient of determination (R^2) were determined, but not statistically significantly ($p > 0.05$). The results from this study can be used to develop forest protection plans and reduce the risk of forest fires in the future. It is necessary to continue research and look at geophysical and anthropogenic factors that can affect the occurrence of forest fires.

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SAŽETAK

Teritorija Srbije je osjetljiva na šumske požare koji ugrožavaju različite sustave i igraju važnu ulogu u oblikovanju ekosustava. Ispitana je vjerojatnost nastanka i širenja šumskih požara na području sjeveroistočne Srbije, ovisno o utjecaju klimatskih uvjeta. Promjene klimatskih prilika istražuju se na godišnjoj i mjesečnoj razini vrijednosti temperature zraka, oborina i vlažnosti zraka zabilježenih na tri glavne meteorološke postaje (Zaječar, Negotin, Crni Vrh) na području sjeveroistočne Srbije. Analizirane su promjene klimatskih uvjeta u razdoblju 2009.-2022. u odnosu na razdoblje 1961.-1990., s naglaskom na 2012. i 2014. godinu. Duljina prosječne požarne sezone određena je modificiranom verzijom Thornthwaite-ovog indeksa evapotranspiracije. Požarna sezona duža je na području Nego-

tina i Zaječara nego na području Crnog Vrha. Na temelju mjesečnih indeksa vlažnosti utvrđena je značajno duža sezona požara u 2012. u odnosu na 2014., kao i višegodišnje razdoblje 1961.-1990. Provedena je analiza vrijednosti indeksa gorenja (B) za razdoblje 2009. – 2022. te je utvrđena korelacija s podacima o broju šumskih požara. Indeks gorenja na području sjeveroistočne Srbije najveći je u srpnju, kolovozu i rujnu. Značajno veće vrijednosti indeksa gorenja su za 2012. godinu u odnosu na 2014. godinu, što je u korelaciji s pojavom šumskih požara u ovom razdoblju.

KLJUČNE RIJEČI: Thornthwaite-ov indeks evapotranspiracije, indeks gorenja, šumski požar, sezona požara, sjeveroistočna Srbija