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Influence of extreme climate conditions on the forest fire risk in the Timočka Krajina region (northeastern Serbia)

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Abstract—The dependence of the influence of extreme climate conditions on the variability of forest fires in the Timočka Krajina region of northeastern Serbia was studied. The impact of extreme conditions was investigated with extreme climate indices using air temperature, relative humidity, and precipitation measured at three meteorological stations in northeastern Serbia. The De Martonne index was used to analyze climate conditions as a measure for aridity. The study analyzes trends in extreme climate indices with an emphasis on the two contrasting years, 2012 and 2014, and compares them to the baseline period 1961–1990. The year 2012 was very warm and dry, while 2014 was one of the wettest recorded in Serbia. There was an increase (decrease) in warm (cold) temperature indices. Non-significant increases in extreme precipitation indices were observed, while the number of precipitation events greater than 1 mm decreased, as did relative humidity.

Ångström index values were used as an index for assessing the risk of forest fires. These indices were analyzed and a correlation between them and forest fires in northeastern Serbia was established. The aridity index was low during the years 2012, 2011, and 2017, correlating with the large number of forest fires. High values of the Ångström index in 2013 and 2014 were associated with a minimum number of registered forest fires. As an improved indicator for the number of forest fires, the modified Ångström index using daily maximum temperature is proposed.

pKey-words: extreme climate indices, air temperature, precipitation, forest fires,
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1. Introduction

There is a general agreement that changes in the frequency or intensity of extreme weather and climate events will have profound impacts on both human society and natural environment (*Easterling et al.*, 2000). Every region of the world is already experiencing extreme events (e.g., *Yan et al.*, 2002; *Bartholy and Pongrácz*, 2007; *Santos et al.*, 2011; *Finkel and Katz*, 2018).

Forest resources are becoming increasingly sensitive to extremes and climatic conditions. The interest of the competent services for the protection of forests from fires usually focuses on extreme indicators of fire danger. The territory of Serbia is exposed to extreme climate conditions, which are more pronounced in the 21st century (*Vuković et al.*, 2018). The Fourth Assessment Report (AR4) from the Intergovernmental Panel on Climate Change (*IPCC*, 2007) defines an extreme event as rare at a particular place and time during the year. The implications of extreme climatic events depend on their intensity, duration, and frequency of occurrence. Heat waves, droughts, and storms can have a devastating and a wide range of impacts on forest resources. Fire danger is greater if the dry season is longer, especially during periods when the air temperature is extremely high. Many studies (e.g., *Moritz*, 2003; *McKenzie et al.*, 2004; *Keeley*, 2004) indicate that prolonged drought combined with extreme weather conditions, such as high air temperature, wind speed, and low relative humidity, often lead to fires. Drought is relatively common in the northeastern region of Serbia (*Aleksić et al.*, 2004) and it increases the risk of fires of combustible materials. Applying the De Martonne aridity index for 26 meteorological stations in central Serbia, *Radaković et al.* (2018) showed that humidity decreases towards the east. Vegetation drying that reduces the moisture content in fuel material creates conditions favorable for the occurrence and spread of fire (*Živanović*, 2017). Studies from domestic and foreign authors (*Popović et al.*, 2005, 2008; *Kadović and Medarević*, 2007; *Seidling*, 2007; *Carnicer et al.*, 2011; *De la Cruz et al.*, 2014) suggest that the impacts of climate change extremes, such as heat waves and droughts, significantly contribute to the exposure and vulnerability of certain ecosystems. The predicted changes in temperature and precipitation regime in Serbia (*Djurđević et al.*, 2015; *Vuković et al.*, 2018) suggest that climate changes in the near or distant future may have even stronger impacts on forest ecosystems and the whole environment.

The appearance of fire in Serbia changes from period to period and largely depends on weather conditions and the humidity of combustible materials (*Tabaković-Tošić et al.*, 2009; *Živanović et al.*, 2018). Variability in climate elements indicates when and to what extent there is a risk of the emergence and spread of fire in the forest (*Živanović*, 2012; 2015).

Air temperatures over 25 °C present an elevated risk for the occurrence and spread of forest fires. Some areas in the northeastern territory of Serbia can

experience more than 26 days a month when air temperature is over 25 °C, creating favorable conditions for the occurrence of forest fires (Vasić, 1992). Particularly dangerous forest fire risk is present during days without atmospheric precipitation and air temperature greater than 30 °C (Živanović *et al.*, 2015). Some areas in the summer months can experience more than 15 consecutive days with air temperatures greater than 30 °C, greatly exacerbating the danger for forest fires.

The aim of this study is to determine the vulnerability of forest resources to fire on the basis of extreme climate conditions in the Timočka Krajina region. The results are useful as planning criteria to manage adaptation to extreme climate conditions and reduce the future risk of forest fires.

2. The study area

Timočka Krajina is located in the northeastern (NE) region of the Republic of Serbia, between 21° 40' to 22° 46' E, and 43° 20' to 44° 42' N (*Fig. 1*). Timočka Krajina is the geographic area from which the water is flowing into all five Timok (Svrljiški, Trgoviški, Beli, Crni Timok, and Veliki Timok) originates. The Timok region is separated by several natural boundaries, including on the Danube River on the north, the Stara Planina (Old Mountain) and Veliki Timok River to the east (with Bulgaria), the mountain range from Gramade and Svrljiške mountains to Midžor to the south, and the Severnokučajske Mountains to the west (*Manojlović*, 1986). In the area of Timok region (7,130 km²), there are two administrative-territorial units, the Bor and Zaječar districts. Specific places and their locations and altitudes are listed in *Table 1*. There are 249,959 residents in this area.

The Timok forested area in 2008 was 3014.79 km² covering 42.28% of the territory. Forest cover ranges from a minimum of 25.28% in Negotin to 86.47% in the municipality of Majdanpek. The northeast part of the Republic of Serbia is the Djerdap National Park with nearly untouched flora and fauna. The forest cover stock is large (over 64%) and has an extremely rich and diverse flora (more than 1,100 plant species) and fauna, which carries all the marks of relictness.

The forests are primarily hardwood (76.13%) consisting of 38% beech wood, which is the dominant forest type. Coniferous forests are underrepresented and occupy less than 5% of the forest fund (*RZS*, 2008). In accordance with general European floras, floral elements of the area belong to a pontic South-Siberian group within the Pannonian-Vlach subregion, though some other groups (e.g., sub-Mediterranean, Central European) are represented as a result from migration processes (*Stevanović*, 1999).

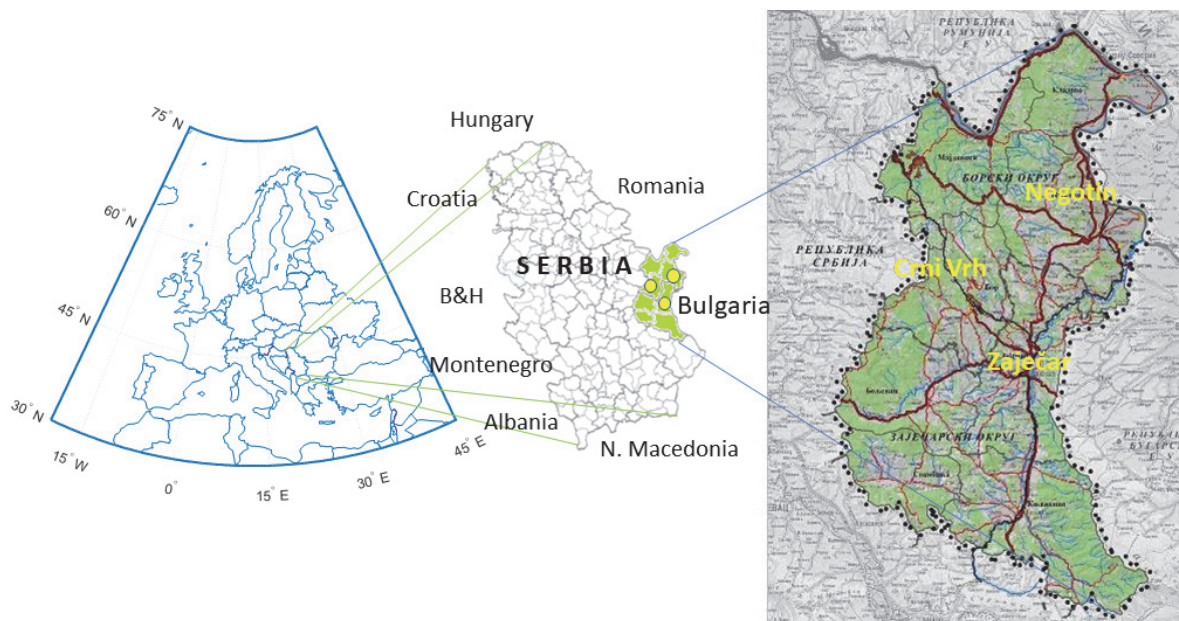


Fig. 1. Timočka Krajina region in northeastern Serbia with location of meteorological stations: Zaječar, Negotin, and Crni Vrh.

Table 1. Geographical location of places in Timočka Krajina with altitude

Place	Latitude (φ)	Longitude (λ)	Altitude [m]
Crni Vrh	44° 07' N	21° 57' E	1037
Negotin	44° 13' N	22° 31' E	42
Zaječar	43° 53' N	22° 18' E	144
Bor	44° 05' N	22° 06' E	378
Knjaževac	43° 30' N	22° 06' E	276
Sokobanja	43° 39' N	21° 52' E	400
Kladovo	44° 37' N	22° 37' E	45
Boljevac	43° 50' N	21° 58' E	349
Majdanpek	44° 25' N	21° 56' E	340
Timočka Krajina region	43°20' – 44°42' N	21°40' – 22°46' E	35 – 1978

Orographic characteristics of this area in northeastern Serbia are shown in Table 2. The largest surface area is found at altitudes from 200 to 500 m. At higher altitudes above 500 m, mountain slopes are very steep. Quality beech wood is preserved in this region (Manojlović, 1986).

Table 2. Surface elevation zones of Timočka Krajina (%)

Place	0–200 (m)	200–500 (m)	500–1000 (m)	1000–1500 (m)	1500–2000 (m)
Bor	1.38	57.22	38.96	2.44	0.00
Kladovo	51.54	46.79	1.67	0.00	0.00
Majdanpek	9.63	58.33	32.04	0.00	0.00
Negotin	43.51	52.68	3.80	0.01	0.00
Zaječar	21.10	71.37	7.39	0.19	0.00
Boljevac	1.16	49.40	48.35	1.10	0.00
Knjaževac	1.26	33.17	57.32	7.03	1.23
Sokobanja	0.00	32.81	61.28	5.90	0.00

3. Data and methods used

3.1. Data

Daily air temperature [maximum (TX), mean (TG), and minimum (TN)], precipitation, and relative humidity obtained from three meteorological stations in northeastern Serbia (*Fig. 1*) were analyzed and compared in order to assess changes in climatic conditions. Data were available from 1961 to 2017 for the meteorological stations in Zaječar and Negotin, and from 1982 to 2017 for the Crni Vrh meteorological station situated at the altitude of 1,037 m (*Table 1*). Measurements were performed every day without a break using the same type of instruments. The Serbian Meteorological Service made technical and quality control of these measurements.

3.2. Methods

As a numerical indicator of the degree of dryness of the climate at a given location, annual values of the De Martonne aridity index (Is) were determined as (*De Martonne, 1925*):

$$Is = RR / (T + 10), \quad (1)$$

where RR is the annual sum of precipitation (mm) and T is the mean annual air temperature (°C). Humidity reduces with the decrease in value of Is , and vice versa. Climatic classification according to the De Martonne aridity index is shown in *Table 3*. The De Martonne aridity index was shown to give good results for northern Serbia (*Hrnjak et al., 2014*) and central Serbia (*Radaković et al., 2018*), as well as for Greece (*Baltas, 2007*), Romania (*Croitoru et al., 2013*), and Spain (*Moral et al., 2017*).

Table 3. De Martonne index climatic classification

Values of I_S	Climate
$I_S < 10$	Arid
$10 \leq I_S < 20$	Semi-arid
$20 \leq I_S < 24$	Mediterranean
$24 \leq I_S < 28$	Subhumid
$28 \leq I_S < 35$	Humid
$35 \leq I_S \leq 55$	Very humid
$I_S > 55$	Extremely humid

The Ångström index (I) was used to assess the risk of forest fires and was calculated as (Chandler *et al.*, 1983):

$$I = RH / 20 + (27 - T) / 10, \quad (2)$$

where RH is the relative humidity (%) and T is the annual mean air temperature (°C). A reduced index indicates a higher risk of fire (Lukić *et al.*, 2017). The values for I were translated into fire risk as follows:

- when $I > 4.0$, fire occurrence was unlikely;
- when $2.5 < I \leq 4.0$, fire conditions were unfavorable;
- when $2.0 < I \leq 2.5$, fire conditions were favorable; and
- when $I \leq 2.0$, fire occurrence was very likely.

Although the Ångström index is a simple day-to-day fire danger indicator, it was successfully applied for different regions in the central part of Europe: Slovakia (Skvarenina *et al.*, 2003), southern Germany (Schunk *et al.*, 2013), Austria (Arpaci *et al.*, 2013), Serbia (Lukić *et al.*, 2017), etc. The Ångström index might be a good indicator if there are rapid changes in weather situations, which increase the fire danger situation so quickly, that fuel or soil moisture models are not able to capture that moment (Arpaci *et al.*, 2013).

For this study, we used statistical data about forest fires from the Department for Emergency Situations, Ministry of the Republic of Serbia for the period from 2009 to 2017.

To assess extreme fire danger conditions, we used extreme climate indices selected from the list recommended by the World Meteorological Organization (WMO) – Commission for Climatology and the Research Programme on Climate Variability and Predictability (CLIVAR). This paper concentrates on indices that refer to climate change estimates (conditions suitable for the

development of fire): the number of summer days (*SU25*), number of tropical days (*SU30*), number of tropical nights (*TR20*), annual maximum of daily maximum temperatures (TX_x), annual minimum of daily minimum temperatures (TN_n), precipitation sum (mm), relative humidity (*RH*), wet days (*RR1*), heavy precipitation days (*RR10*), maximum number of consecutive dry days (*CDD*), maximum number of consecutive wet days (*CWD*), and growing season length (*GSL*). Definitions of extreme climate indices are given in *Alexander et al.* (2006) and defined here as follows:

SU25 - number of summer days: annual count of days with $TX > 25$ °C;

SU30 - number of tropical days: annual count of days when $TX > 30$ °C;

TR20 - number of tropical nights: annual count of days when $TN > 20$ °C;

TX_x - annual maximum value of daily maximum temperature;

TN_n - annual minimum value of daily minimum temperature;

RR1 - wet days: annual count of days with $RR \geq 1$ mm;

RR10 - heavy precipitation days: annual count of days when $RR \geq 10$ mm;

RRsum - annual precipitation sum;

RH - annual mean relative humidity;

CDD - maximum number of consecutive dry days;

CWD - maximum number of consecutive wet days, and

GSL - growing season length, annual count between first span of at least 6 days with $TG > 5$ °C and the first span after July 1 of 6 days with $TG < 5$ °C.

4. Results

4.1. Climate analysis

The climate of northeastern Serbia is determined by geographic location, distance from the sea, relief, and forest cover. The climate can be described as moderate-continental with major or minor variations. In the lowest parts of the Negotin region and along the Danube and Timok rivers, there is steppe-continental climate. The characteristics of continental climate are determined by the increase in altitude (*Rakićević*, 1976). Continentality of the area is reflected in extreme temperatures. During the winter months, air temperature below -10 °C can last longer than 10 days.

The average annual temperature is 10.8 °C in Zaječar, 11.5 °C in Negotin, and 6.6 °C in Crni Vrh. The warmest month is July and the coldest month is January (*Table 4*). Mean annual precipitation is 606.9 mm in Zaječar, 639.5 mm

in Negotin, and 768.2 mm in Crni Vrh. Maximum precipitation occurs in June or May, while the minimum occurs in January or February (*Table 4*). Mean annual relative humidity is about 75 %, with maximum *RH* in December and minimum in July or August.

Table 4. Monthly values of mean temperature (*T*), precipitation sum (*RR*), and relative humidity (*RH*) in: Zaječar (ZA), Negotin (NE), and Crni Vrh (CV)

Month	Station								
	ZA	NE	CV	ZA	NE	CV	ZA	NE	CV
	<i>T</i> (°C)			<i>RR</i> (mm)			<i>RH</i> (%)		
1	-0.9	-0.4	-3.3	41.6	44.4	47.7	80.1	80.4	85.2
2	1.2	1.6	-2.6	41.1	48.8	47.2	77.5	77.6	83.7
3	5.7	6.3	1.0	45.0	51.4	51.2	72.5	71.1	79.0
4	11.4	12.0	6.4	54.3	54.4	70.6	70.0	66.7	73.8
5	16.4	17.2	11.2	65.1	60.6	83.6	71.3	66.7	74.4
6	20.0	20.8	14.5	63.8	63.9	85.0	70.4	64.5	75.3
7	21.8	22.7	16.8	56.8	52.0	69.2	66.7	61.3	70.9
8	21.2	21.9	16.8	41.2	40.8	61.6	67.6	63.0	69.5
9	16.5	17.3	12.2	43.1	50.3	66.9	72.3	68.8	75.4
10	10.6	11.2	7.0	48.6	53.5	70.0	78.2	76.1	82.3
11	5.3	5.8	1.9	53.0	59.5	59.0	81.2	80.7	85.1
12	0.7	1.3	-2.0	53.2	59.8	56.1	82.1	81.7	85.7
Average	10.8	11.5	6.6	606.9	639.5	768.2	74.1	71.6	78.4

The number of days with an average temperature above 10 °C, namely with temperature conditions suitable for the occurrence of forest fires, is about 200 days in Zaječar and Negotin and about 150 days at Crni Vrh. Mean temperatures above 20 °C occur in the summer months for about 94 days in Negotin, 65 days in Zaječar, and 21 days in Crni Vrh.

Annual values of the De Martonne index are presented in *Table 5*. Values of the De Martonne aridity index (*Is*) point to particularly pronounced low annual values in 2011, when for Zaječar and Negotin, *Is* values were less than 20, which characterizes these areas as semi-dry. The year 2014 was very humid with *Is* values greater than 49 (*Table 5*). 2011 and 2017 were dry years. Very few fires were recorded when conditions were extremely wet, as in 2014. From 2011 to 2013, *Is* were extremely low, particularly during the active growing season when the occurrence of forest fires is observed.

Climate indices for Negotin, Zaječar, and Crni Vrh for the base period 1961–1990 and the two years 2012 and 2014 are presented in *Table 6*.

Table 5. Annual aridity index (*I_s*) according to the De Martonne index

Station	Year								
	2009	2010	2011	2012	2013	2014	2015	2016	2017
Zaječar	36.7	38.0	18.0	28.0	24.6	49.0	23.7	36.1	26.5
Negotin	34.2	33.2	15.8	22.9	30.6	54.7	30.8	32.1	24.4
CrniVrh	56.5	61.3	34.6	42.3	39.3	65.4	42.0	51.3	35.4

Table 6. Climate indices for Negotin, Zaječar, and Crni Vrh for the base period (1961–1990), 2012 and 2014

Parameter	Negotin			Zaječar			Crni Vrh		
	1961-1990	2012	2014	1961-1990	2012	2014	1961-1990	2012	2014
Mean temperature	11.1	13.2	12.7	10.4	11.7	11.4	6.4	7.9	7.4
Absolute maximum temperature TX_x	41.2	40.4	34.3	41.9	40.8	33.7	33.8	32.9	27.0
Absolute minimum temperature TN_n	-28.5	-27.5	-13.1	-29.0	-25.6	-16.6	-22.2	-22.1	-20.2
Precipitation sum	646.0	532.5	1244.8	610.5	608.7	1046.1	810.1	758.2	1137.4
Tropical nights $TN > 20^\circ\text{C}$	1.7	13	6	0.13	1	0	1.6*	12	2
Tropical days $TX > 30^\circ\text{C}$	29.1	80	32	28.0	80	22	0.8	11	0
Summer days $TX > 25^\circ\text{C}$	95.9	146	99	93.8	144	89	13.7*	49	5
Relative humidity	73.1	64.3	76.5	75.6	68.5	77.9	81.8	74.1	84.9
Daily maximum of precipitation	116.3	42.8	161.3	83.1	40.5	46.5	107.0	64.7	85.8
Number of days $RR > 1.0$ mm	82.0	66	97	82.2	78	111	96.7*	96	125
Number of days $RR > 10.0$ mm	19.4	14	39	19.1	17	37	23.8	22	33
Sunshine length	2035.9	2582.8	1897.8	2050.2	2144.2	1527.4	2016.1	2400.2	1785.3
Number of clear days	77	133	68	66.1	90	32	55.7	107	51
Number of cloudy days	110	87	135	113.1	101	161	141.5	113	152
Consecutive dry days CDD	29.5	50	21	29.5	46	18	27.8*	25	21
Consecutive wet days CWD	6.4	6	10	5.7	7	5	5.3*	7	7
Growing season length GSL	247.6	265	280	245.7	263	281	200.9*	236	219

Numbers with asterics for Crni Vrh are calculated during the period 1982–1990.

During 2012, a high number of tropical days (about 80) and summer days (about 145) were recorded in Negotin and Zaječar. The number of consecutive dry days (*CDD*) in 2012 was almost double that of the 1961–1990 baseline period. In contrast to the dry 2012, precipitation sums in 2014 were greater than 1000 mm, which was high even compared to the 600 mm 1961–1990 annual baseline. The observed maximum daily precipitation was 161.3 mm in Negotin 2014 (*Tošić et al.*, 2017). The number of days when daily precipitation was greater than 10.0 mm in 2014 was double that of the 1961–1990 baseline (*Table 6*).

Climate parameters (*Table 6*) were most impactful to forest ecosystems in 2012 when mean temperature, the number of tropical nights, the number of tropical days (*SU30*), and the number of summer days (*SU25*) were highest, and simultaneously the precipitation sum (*RRsum*), minimum number of wet (*RR1*) and heavy precipitation (*RR10*) days were lowest. The number of consecutive dry days (*CDD*), as well as sunshine length and the number of clear days were highest in 2012. The greatest precipitation, maximum daily precipitation (*RRdmax*), relative humidity (*RH*), and number of cloudy days were observed in 2014 at all three stations (*Table 6*).

Trends for 12 climate indices for Zaječar, Negotin, and Crni Vrh are presented in *Table 7*. Several indices increased at the 5% significance level, including *SU25*, *SU30*, *TX_x*, *GSL*. Negative trends in *RR1* and *RH* were observed in Zaječar and Negotin. Significant positive trends in *SU25*, *RR10*, *RRsum*, and *RRdmax* were found at Crni Vrh, which is located at an altitude of 1,037 m.

Table 7. Trend coefficients of climate indices for Zaječar, Negotin, and Crni Vrh

Index	Zaječar (1961-2017)	Negotin (1961-2017)	Crni Vrh (1982-2017)
<i>SU25</i>	0.5566	0.4821	0.5033
<i>SU30</i>	0.6781	0.6266	0.0400
<i>TX_x</i>	0.0588	0.0520	0.0147
<i>TN_n</i>	0.0178	0.0537	-0.0393
<i>RR1</i>	-0.0731	-0.2568	0.3921
<i>RR10</i>	0.0152	0.0573	0.2956
<i>RRsum</i>	0.3722	0.5831	6.6343
<i>RRdmax</i>	0.0914	0.4934	0.7724
<i>RH</i>	-0.0930	-0.0978	-0.0137
<i>CDD</i>	-0.0006	0.1121	-0.2045
<i>CWD</i>	0.0091	-0.0031	0.0556
<i>GSL</i>	0.4934	0.8131	0.4082

Coefficients being significant at the 5% level are indicated by bold.

4.2. Analysis of forest fires in Timočka Krajina

The occurrence of forest fires in the Timočka Krajina region changes from period to period. The number of forest fires in the territory of Timočka Krajina and Zaječar during the period 2009-2017 is shown in *Fig. 2*. There was a marked difference in the number of fires in 2012 compared to 2014. Namely, during 2014 only one/zero fire was registered in the Timočka Krajina region/Zaječar, while in 2012, 69/17 fires were recorded.

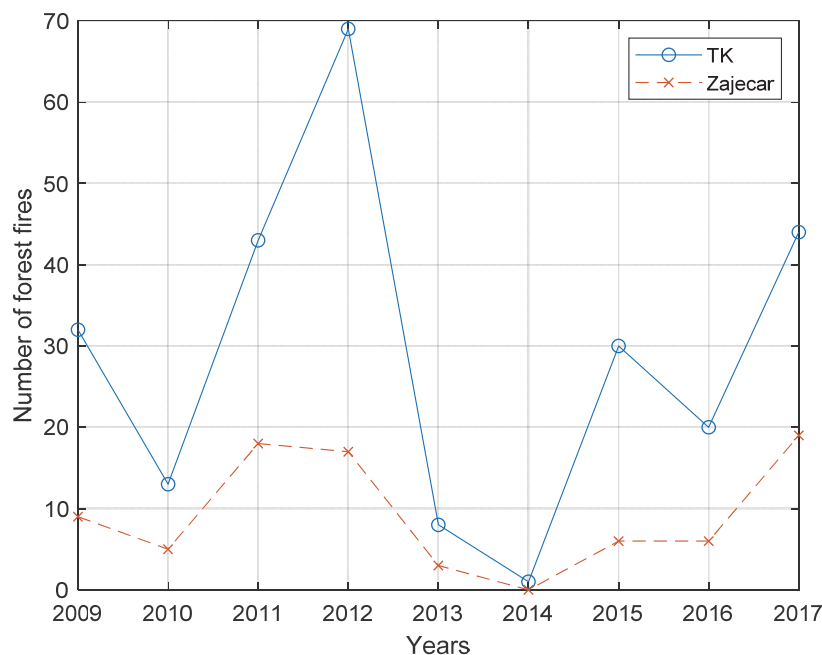


Fig. 2. Number of total forest fires at the territory of Timočka Krajina (TK) and Zaječar during the period 2009-2017.

Daily fluctuations of the Ångström index for Negotin, Zaječar, and Crni Vrh in 2012 and 2014 are presented in *Fig. 3*. The Ångström index was lower during 2012 indicating that the risk of fire was elevated. For a long period during the growing season of 2012, the Ångström indices were lower than 2.5. The lowest value of the Ångström index (1.02) was observed on September 2, 2012 at Crni Vrh. The longest period with an Ångström index less than 2.5 was in the period from June 21 to July 22, 2012 in Negotin. The Ångström index in 2014 was above 3, which means that the risk of fire was significantly lower in 2014 (*Fig. 3*).

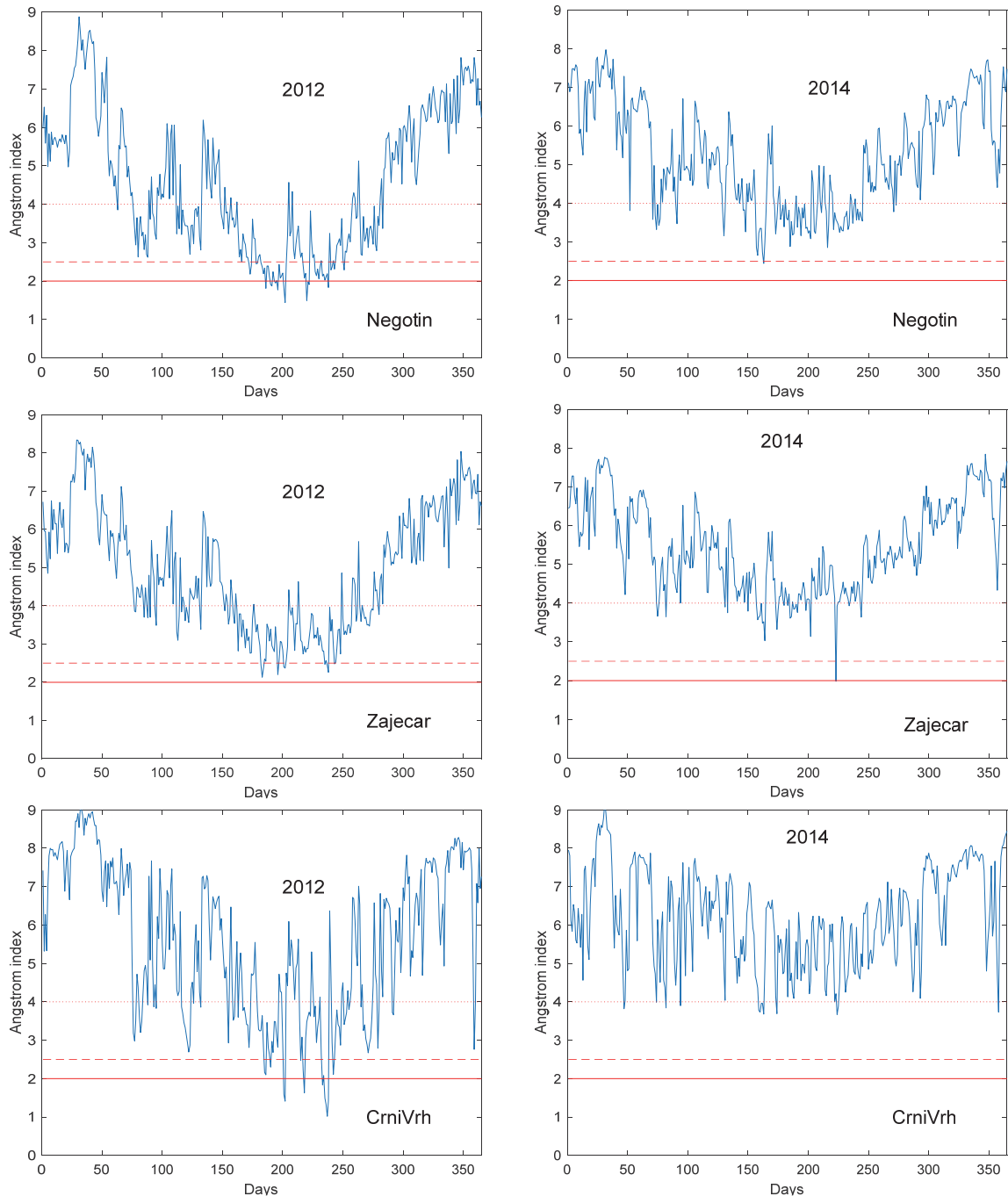


Fig. 3. Time series of the Ångström index for Negotin, Zajecar, and Crni Vrh in 2012 (left) and 2014 (right) with fire danger classes $I=2.0$ (noted by horizontal solid line), $I=2.5$ (dashed line), and $I=4.0$ (dotted line).

5. Discussion

This study was motivated by an interest in examining the influence of extreme climate conditions on forest fire risk in northeastern Serbia. A significant increase in summer and tropical days, absolute maximum temperature, and growing season length, and a significant decrease in relative humidity was found

in Zaječar and Negotin. A significant increase in summer days and precipitation indices was found for Crni Vrh. According to the meteorological station in Crni Vrh, this location was considered very humid, which is explained by the high altitude of the station in the Carpathian Mountains (*Radaković et al.*, 2018).

Previous studies of changes in air temperature in Serbia, both average annual and seasonal air temperatures, have clearly indicated an increase (e.g., *Gavrilov et al.*, 2016). The observed warming was also confirmed by the increased frequency of warm extremes (*Unkašević and Tošić*, 2013). The changes taking place were also documented for the whole of Europe (*Klein Tank and Können*, 2003; *Della-Marta et al.*, 2007; *Shevchenko et al.*, 2014; *Tomczyk et al.*, 2019) and globally (e.g., *Alexander et al.*, 2006).

The highest number of tropical nights, number of tropical days, number of summer days, number of consecutive dry days, and the lowest precipitation sums, minimum number of wet and heavy precipitation days were registered in 2012. All these conditions were favorable for the development of fires. The Balkans and the central part of Europe were affected by unprecedented drought in the summer of 2012 (*Unkašević and Tošić*, 2015). The longest heat waves, caused by the flow of warm and dry air from North Africa towards southeastern Europe, were observed during the summer of 2012 in Serbia at ten out of 15 stations (*Unkašević and Tošić*, 2015). More than 1,000 forest fires occurred in Serbia in 2012 (*Lukić et al.*, 2017). The highest number of fires was recorded in 2012, creating the greatest damage with 7,460 ha and 63,118 m³ wood mass burned (*Šorak and Rvović*, 2016).

The year 2014 was one of the wettest recorded in Serbia (*Tošić et al.*, 2017). The highest values of precipitation sums, daily maximum of precipitation, relative humidity, and number of cloudy days were observed in 2014 at all three stations considered. Precipitation was high during the vegetation period in 2014, and the number of forest fires was smallest.

As a measure of fire risk, the Ångström index provides good results even when using only meteorological variables. Ångström index values in 2012 were below 2.5, indicating favorable fire conditions, while in 2014 they were above 3, indicating that the risk of fire was significantly lower. Replacing *TX* instead of *TG* in definition of the Ångström index provides better results. Values of the Ångström index were below 2 for Zaječar (*Fig. 4*), indicating very favorable fire conditions during the summer of 2012 when 17 forest fires were recorded (*Fig. 3*). In addition, the minimum Ångström index value was not below 2 (*Fig. 4*) compared to 2014 (*Fig. 3*) when no forest fires were registered in Zaječar (*Fig. 2*).

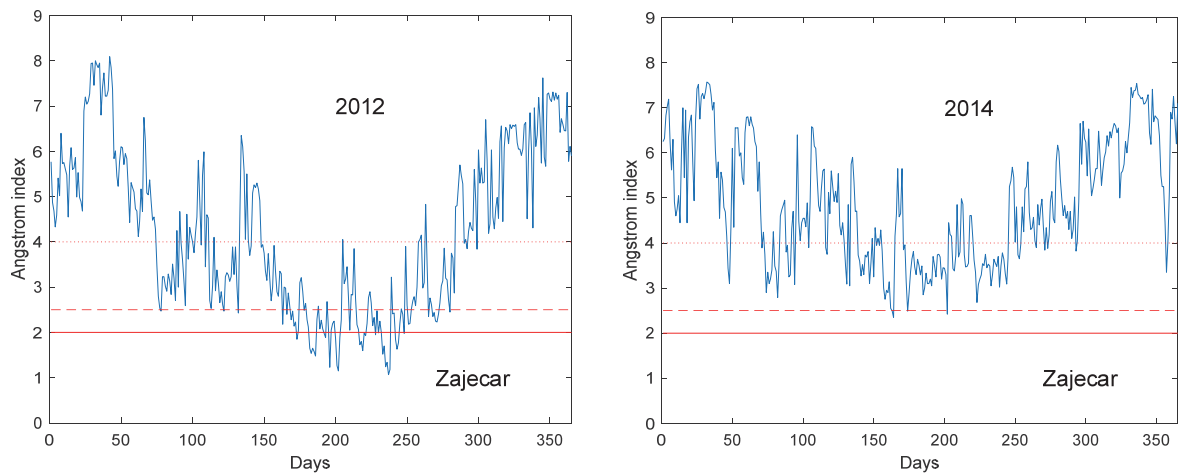


Fig. 4. Time series of the Ångström index (with TX instead of TG) for Zajecar in 2012 (left) and 2014 (right) with fire danger classes $I=2.0$ (noted by horizontal solid line), $I=2.5$ (dashed line), and $I=4.0$ (dotted line).

Živanović *et al.* (2020) suggested that increased air temperature and reduced precipitation in the period 1981–2010 compared to the period 1961–1990 had substantial influence on the probability of fire occurrence in Serbia. They have also concluded that particular attention has to be paid to the eastern and southern parts of Serbia, where the decrease in precipitation was greatest.

6. Conclusions

Extreme climate conditions are crucial for forecasting and managing forest potential in Serbia, and posing a challenge for policy makers. If extreme climate effects are implemented in risk assessments of forest fires, adverse effects can be minimized. Many climate scenarios predict further increases in the frequency of climate extremes in the future, and it is necessary to take adequate measures to adapt.

Our research reveals that understanding extreme climate conditions and their impact on the occurrence of forest fires are important variables to consider when selecting adaptation strategies. Determining priorities for adaptation measures and their implementation are of great importance. Forest protection should be based on good organization and a hierarchy of responsibility for planning and implementing preventive and repressive measures to protect forests from fire. Evaluation of impacts of extreme climate conditions that are conducive to the emergence and spread of forest fires has particular importance. Synoptic situation unfavorable to the occurrence of forest fires are those that

occur because of long dry periods with high air temperatures and low relative humidity. Our study showed that the Ångström index calculated with meteorological variables only provided a good indicator for forecasting forest fires. Better results were obtained when the daily maximum temperature instead of daily mean temperature were included in the definition of the Ångström index. The competent authorities for the protection of forests against fire in Serbia should define indices to assess climate extremes that can be used to estimate conditions indicative of extreme fire danger (with the levels of risk of danger). Successful implementation of the strategies for adaptation to extreme climate conditions should lead to the active promotion and education of the population by the competent institutions.

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