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Influence of air temperature and precipitation on the risk of forest fires in Serbia

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Abstract
Official reports indicate that the number of forest fires and areas affected by fire in Serbia is increasing. Changes in temperature and precipitation, important factors in fire behaviour, were determined by comparison between the standard climatological period (1961–1990) and the period 1981–2010. The study processed and compared the data from 26 meteorological stations on the territory of Serbia. In order to determine the risk of fires, values of the Lang precipitation factor and Ångström index are calculated. It is found that the mean values of temperature significantly increased during the second period at all stations in Serbia. The small values of the precipitation factor are recorded during summer, but also in the spring months. Research has shown that an increase in air temperature and reduction of precipitation in the examined period has a great influence of the possibility of fire occurrence. It is concluded that there is a higher fire danger risk during the summer months in Serbia. It is found that eastern and southern Serbia are particularly vulnerable to forest fires because of small values of the Lang precipitation factors.

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1 Introduction

Forecasting the fire risk is the basis for taking necessary measures against forest fires. Fire hazards are considered to be one of the most dangerous hazards in the world (Wang et al. 2018). Some studies (Živanović 2010) indicate that, in addition to vegetative cover, terrain characteristics and values of climate elements also contribute to an increased risk of forest fire. The possibility of vegetative cover catching fire depends on the level of moisture present in combustible materials, soil and air, which is more or less affected by the values and changes of climate elements. Experts from the Canadian Forest Service in Ontario have concluded in their study on the relationship between meteorological parameters and the occurrence of forest fires, "The weather can cause a forest fire, and when it does, the weather controls its behaviour" (Wagner 1987).

Weather variables are often combined in specific meteorological fire danger indices that provide estimations of fire danger level of a given time (e.g. Skvarenina et al. 2003; Li et al. 2014). Forest vegetation is sensitive and vulnerable to fires. According to the Intergovernmental Panel on Climate Change report (IPCC 2007), this sensitivity should be defined, as well as the way in which a system responds to given climate changes. A system vulnerable to climate change can adapt spontaneously.

The sensitivity, adaptability, and vulnerability of forests depend on the uncertainty of future climate conditions. A vulnerable system can be measured by the unavoidable damage, but also, by its ability to adapt to new climate conditions. Sekulić et al. (2012) report in their study that fires can pose a serious threat to certain ecosystems and species.

Plant life is dependent on climate conditions, and any change in the ecosystem primarily affects the vegetation. Phenological stages of plants, from the beginning to the end of their vegetation period, are changing, which points to the variability of weather conditions. Thuiller (2007) estimates that every 1 °C of air temperature change moves ecological zones on Earth by about 160 km. Pauli et al. (2012) believe that, due to climate change, there has been a significant shift in the distribution of plants on high mountain tops in Europe. In addition to these effects, it is expected that the appearance of certain disease-causing agents in trees will become more frequent (Karadžić 2007), thereby increasing their susceptibility to fire. There are many studies which analyse the impact of climate elements on forest fire risks in various parts of the world (e.g. Flannigan et al. 2000, 2009; Moriondo et al. 2006; Hessl 2011) as well as in Serbia (Ćurić and Živanović 2013; Živanović et al. 2015; Marković et al. 2016; Živanović 2017; Tošić et al. 2019). Flannigan et al. (2000) examined the impacts of climate change on forest fires and described how this, in turn, will impact on the forests of the United States. They concluded that the change in the fire regime has the potential to overshadow the direct effects of climate change on species distribution and migration. Moriondo et al. (2006) investigated the effects of climate change on fire risk (number of days with fire risk, length of fire risk season, etc.) for the EU Mediterranean countries. Their results indicated a general increase in fire risk in both future scenarios over the whole study area. Flannigan et al. (2009) noted that fire activity is strongly linked to weather and concluded that increased fire activity due to climate change has already occurred. According to Hessl (2011), identifying generalizable pathways through which climate change may alter fire regimes is a critical next step for understanding, measuring, and modelling fire under a changing climate.

In recent years, forest fires on the territory of Serbia appear to be increasingly more frequent, seriously threatening the safety of people and material goods (Sekulić et al. 2012).

In this study, the influence of air temperature and precipitation on the risk of forest fires in Serbia will be investigated. Our paper is organized as follows: Sect. 2 presents data and methods used in this study; the obtained results are presented in Sect. 3; and discussion and conclusions are given in Sects. 4 and 5, respectively.

2 Data and methods

2.1 Data

For the purposes of analysis, meteorological measurements of temperature, precipitation, and relative humidity collected at synoptic stations on the territory of Serbia were used. These stations are operated by the Republic Hydrometeorological Service of Serbia (https://www.hidmet.gov.rs/). The study processed and compared the data from 26 meteorological stations which cover most of the territory of Serbia (Fig. 1).

2.2 Methods

2.2.1 The Ångström index

The Ångström index (*I*) was calculated (Ångström 1936; Langholz and Schmidtmayer 1993) using Eq. (1), where *R* is relative humidity in percent and *T* is temperature in ºC:

$$I = \frac{R}{20} + \frac{(27 - T)}{10}. \tag{1}$$

Its values are high in times of low danger/flammability and low in times of high danger/flammability (Schunk et al. 2013). The index provides an indication of the likely number of fires on any given day. A reduced index indicates a higher risk of fire (Lukić et al. 2017). The use of the index for risk categorisation is shown in Table 1.

2.2.2 The Lang precipitation factor

Recognizing temperature as the major factor for evaporation, Lang (1920) used a coefficient of humidity which is defined as the ratio of precipitation to the mean temperatures of the frost-free months:

$$L_a = \frac{P_a}{T_a}, \tag{2}$$

where P_a is the annual mean precipitation sum (mm) and T_a is the annual mean temperature (ºC). The ratio is related directly to precipitation and inversely to temperature. According to the strength of the precipitation factor, bioclimate areas are classified as set out in Table 2.

Monthly values of the Lang precipitation factor are calculated as follows:

$$L_m = \frac{P_m}{T_m}, \tag{3}$$

where P_m is the mean monthly precipitation sum (mm) and T, is the mean monthly temperature (ºC). Climate classification system following Eq. (3) is presented in Table 3.
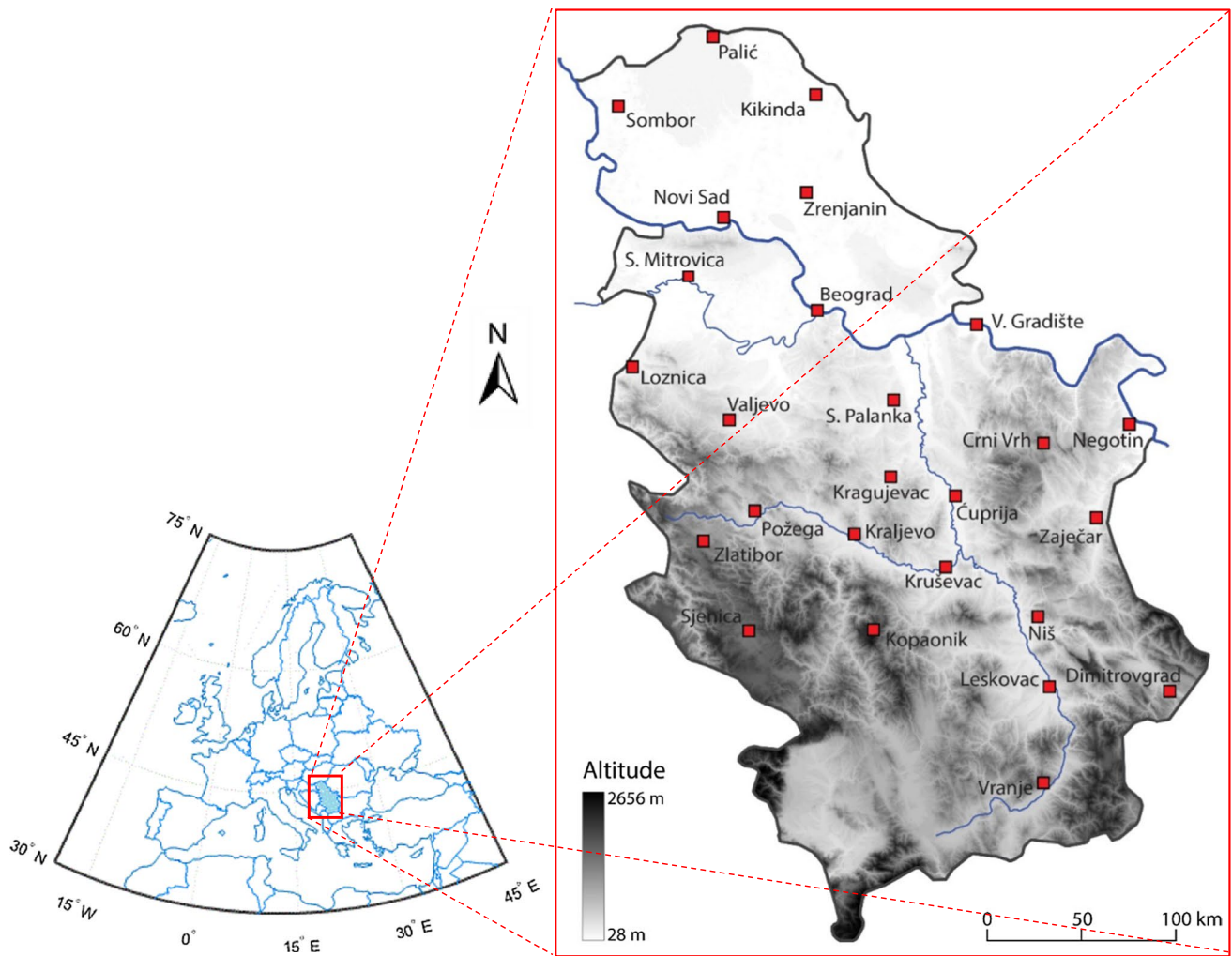
Fig. 1 Position of Serbia in Europe and location of meteorological stations in Serbia

Table 1 Values of the Ångström index (*I*) translated into fire risk probability of fire (Skvarenina et al. 2003; Shetinsky 1994)

Angstrom index (*I*)	Probability of fire
I > 4.0	Fire occurrence unlikely
4.0 < *I* < 3.0	Fire occurrence unfavourable
3.0 < *I* < 2.5	Fire conditions favourable
2.5 < *I* < 2.0	Fire conditions more favourable
I < 2.0	Fire occurrence very likely

Table 2 The classification system according to the annual Lang precipitation factor (Lang 1920)

L_a value	Bioclimatic areas	Climate class
0–20	Desert	Arid
20–40	Semi desert	
40–60	Steppes and savannas	
60–100	Low forests	Humid
100–160	High forests	
> 160	Barrens and tundra	Perhumid

2.2.3 The Student's *t* test

The Student's *t* test was used to determine possible differences between the means of temperature and precipitation in the following periods: 1961–1990 and 1981–2010 for all stations in Serbia. This test statistic is determined as follows:

Table 3 The classification system according to the monthly Lang precipitation factor (Lang 1920)

L_m value	Climate class
< 3.3	Arid
3.3–5.0	Semi-arid
5.0–6.6	Semi-humid
> 6.6	Humid

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\frac{[N_1 S_1^2 + N_2 S_2^2]\left[\frac{1}{N_1} + \frac{1}{N_2}\right]}{[N_1 + N_2 - 2]}}}, \tag{4}$$

where $(\overline{X}_1 - \overline{X}_2)$ represents the difference in group means of data, N_1 and N_2 are the number of cases within each subsample, and S_1 and S_2 are the standard deviations in the subsamples. If the calculated t value is greater than the table value at the significance level of 0.05, a significant shift in the mean is assumed (Unkašević et al. 2004).

2.2.4 The Mann–Kendall test

The Mann–Kendall test (Kendall and Stuart 1961) is used to investigate presence or absence of trend. It is a non-parametric test and does not require the data to be normally distributed (e.g. Tabari et al. 2011).

Linear trend has been determined by conventional least squares regression analysis. In trend evaluation, the 5% level of significance has been taken for the rejection of the null hypothesis of no trend for individual sets of data.

2.3 Climate of the studied area

The mean temperatures (Fig. 2) and precipitation (Fig. 3) were determined for the standard climatological period, 1961–1990 (left), and the period 1981–2010 (right). The annual mean temperatures ranged from 10 to 11 °C at the majority of stations, i.e. in northern Serbia and in the lowlands along the Velika Morava, Zapadna Morava, and Južna Morava rivers, during the period 1961–1990. Požega (310 m a.s.l.) at the west and Dimitrovgrad (450 m) at the east of Serbia have annual mean temperatures around 9 °C. Annual mean temperatures at meteorological stations with altitudes higher than 1,000 m are around 6 °C, i.e. Sjenica (1038 m, 6.1 °C) and Zlatibor (1028 m, 7.1 °C) at the west and Crni Vrh (1037 m, 6.4 °C) at the east of Serbia. The minimum temperature in value of 2.7 °C is recorded at Kopaonik (1,710 m). The annual mean temperatures increased during the period 1981–2010 (Fig. 2, right) in the range from 0.2 to 0.9 °C (Table 4). Belgrade is the only station with the annual mean temperature higher than 12 °C during the period 1981–2010 (12.5 °C). An increase of the mean temperature of about 0.5 °C was at the majority of stations (Table 4).
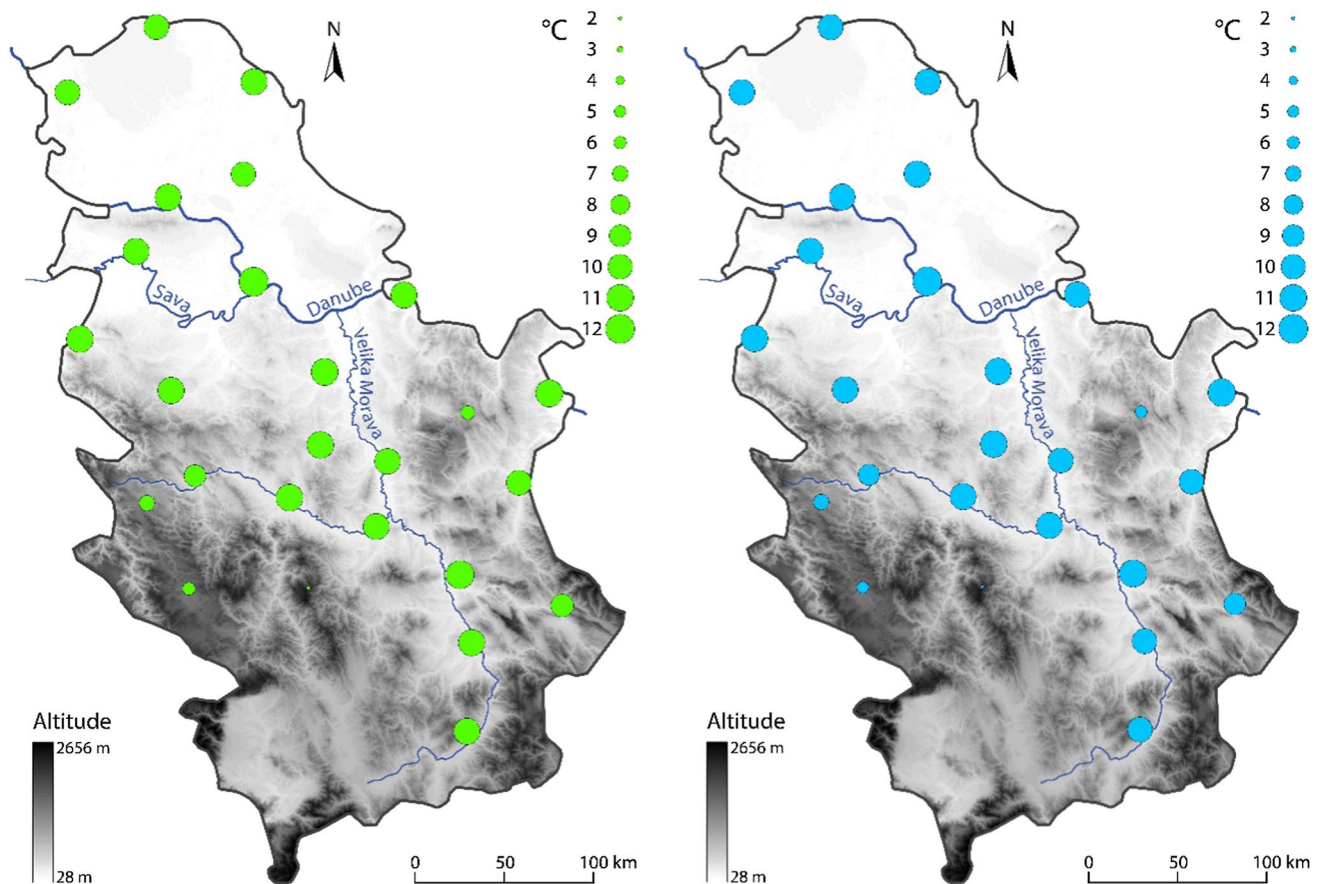

Fig. 2 Mean air temperature (°C) in Serbia during two periods: 1961–1990 (left) and 1981–2010 (right)
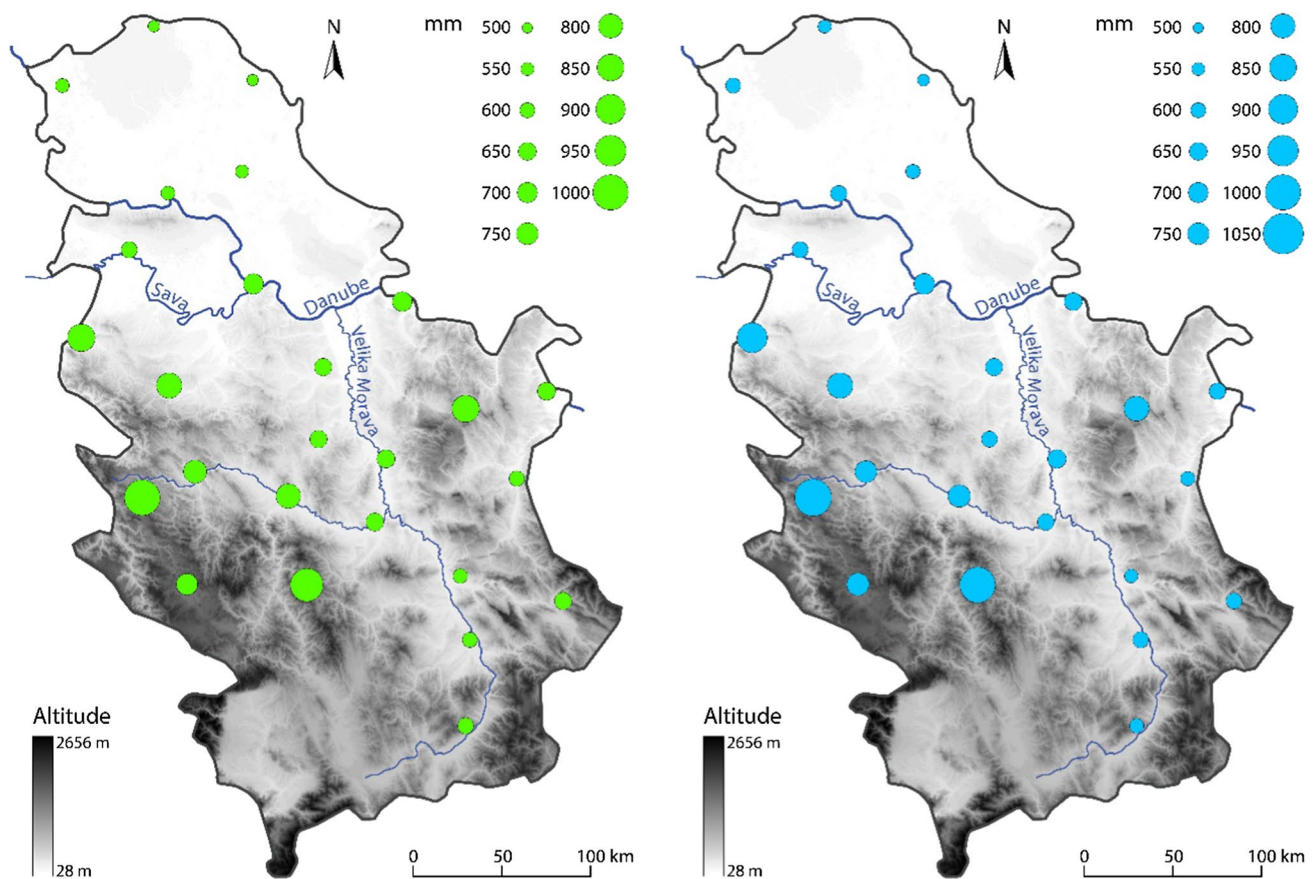
Fig. 3 Mean precipitation (mm) in Serbia during two periods: 1961–1990 (left) and 1981–2010 (right)

The greater part of Serbia has a continental precipitation regime with the exception of southwestern Serbia which is subjected to a Mediterranean rainfall regime (Luković et al. 2014). The northern part of the country received less than 550 mm per year, while most stations received between 600 and 700 mm during the period 1961–1990. Precipitation increased to the southwest (Fig. 3). The highest precipitation exceeding 900 mm per year is in the southwestern mountains of Serbia, i.e. 964.3 mm at Zlatibor and 920.8 mm at Kopaonik (Fig. 3, left). Zlatibor with precipitation of 1017.3 mm is the only station with average precipitation higher than 1,000 mm during the period 1981–2010. Precipitation increased in the second period 1981–2010 at 14 stations, while it decreased at 12 stations in eastern Serbia (Table 4).

3 Results

3.1 Analysis of temperature and precipitation changes

Differences in air temperature and precipitation between two periods (1961–1990 and 1981–2010) are presented in Table 4. The stations in northern, northeastern, and western Serbia have a higher increase in temperature (Kopaonik 0.9 °C; Palić, Sombor, Negotin 0.7 °C) than stations in the rest of the country. The slightest increase was in southern and eastern Serbia (Crni Vrh 0.2 °C; Dimitrovgrad, Vranje, Leskovac 0.3 °C). The mean value of the air temperatures of all stations in Serbia increased by 0.4 °C. The differences in the temperature of the two observed periods are in the range of 0.3–0.9 °C (Table 4). Results show that percentage values better represent the intensity of changes of temperatures than numerical values. The greatest increase is observed at the mountain Kopaonik with a value of 33.3%. Differences in percentage were from 2.8% at two stations at the south (Leskovac and Vranje) to 9.8% in Sjenica at the southwest.

The Student *t* test is applied to the temperature and precipitation data to determine if two sets of data for the period

Table 4 Values of differences in mean air temperature and precipitation between two periods of observation in units of measure and percent (%)

Station	Temperature		Precipitation	
	Diff. (°C)	Diff. (%)	Diff. (mm)	Diff. (%)
Palić	0.7	6.7	31.8	5.9
Sombor	0.7	6.7	38.9	6.8
Novi Sad	0.5	4.6	70.5	12.2
Kikinda	0.5	4.6	21.1	3.9
Zrenjanin	0.6	5.5	21.1	3.8
Sremska Mitrovica	0.5	4.6	− 0.4	− 0.1
Beograd	0.6	5.0	6.6	1.0
Loznica	0.6	5.5	47.7	5.8
Valjevo	0.5	4.6	5.5	0.7
Kragujevac	0.6	5.5	− 13.7	− 2.2
Požega	0.4	4.3	− 13.5	− 1.8
Smederevska Palanka	0.5	4.5	1.0	0.2
Veliko Gradište	0.4	3.7	− 21.8	− 3.2
Crni Vrh	0.2	3.1	− 41.0	− 5.1
Negotin	0.7	6.3	− 32.4	− 5.0
Zlatibor	0.6	8.5	53.0	5.5
Sjenica	0.6	9.8	36.9	5.2
Kraljevo	0.5	4.5	− 20.7	− 2.7
Kopaonik	0.9	33.3	63.6	6.9
Ćuprija	0.4	3.7	6.7	1.0
Kruševac	0.6	5.6	− 19.4	− 3.0
Niš	0.5	4.4	− 9.3	− 1.6
Zaječar	0.6	5.8	− 29.1	− 4.8
Dimitrovgrad	0.3	3.1	− 10.8	− 1.7
Leskovac	0.3	2.8	30.8	5.2
Vranje	0.3	2.8	− 35.7	− 5.8
Serbia	0.4	4.0	7.2	1.1

1961–1990 and 1981–2010 are significantly different at the 5% level of significance from each other. It is found that the mean values of temperature significantly increased during the second period at all stations in Serbia.

To better present the increase of temperature, mean annual temperatures for selected stations for two periods are shown in Fig. 4. It can be seen that the increase of temperature is stronger in the second period 1981–2010 than during the first period 1961–1990. Applying the Mann–Kendall test, it is found that positive trends in the period 1981–2010 are statistically significant at the 5% level of significance.

The average annual amount of precipitation, for the entire territory of Serbia, is slightly increasing by about 7.2 mm (Table 4). However, in the northern and western parts of Serbia, there is a greater increase in precipitation (Novi Sad 70.5 mm, Kopaonik 63.6 mm, Zlatibor 53.0 mm). According to Table 4, there is a decrease in precipitation in eastern, central, and southern Serbia (Crni Vrh 41.0 mm, Vranje

35.7 mm, Negotin 32.4 mm). The highest increase of precipitation of 12.2% is found in Novi Sad at the north, while a decrease of − 5.8% is in Vranje at the south.

Applying the Student t-test, a significant increase is not found between the mean values of precipitation for two periods at any station in Serbia. Precipitation for selected stations in Serbia during two periods: 1961–1990 and 1981–2010, are shown in Fig. 5. There is a non-significant decrease of precipitation at the majority of stations during the period 1961–1990 (Fig. 5). A non-significant increase of precipitation is observed at most stations from 1981 to 2010 (Fig. 5).

3.2 Analysis of fire indices

The Ångström index is calculated according to Skvarenina et al. (2003), which uses air temperature and relative humidity. The Ångström index (I), is used in the fire risk assessment (e.g. Willis et al. 2001). According to Table 5, the Ångström index shows that there is a risk of fire over the whole territory of Serbia, increasing especially in the summer months (June, July, and August). Particularly, there is a risk in isolated areas of eastern (Negotin), northern (Palić, Sombor), and southern Serbia (Leskovac, Vranje, Niš). The Ångström index values indicate that the period 1981–2010 is in higher risk for the spread of fire than the period 1961–1990. The results show that at considered stations index is between 3.0 and 4.0 over a period when most fires occur (April–October). Daily values of the Ångström index for three selected stations in northern Serbia (Novi Sad), central Serbia (Zaječar), and southern Serbia (Vranje) are presented in Fig. 6. It can be seen that the values of the Ångström index $I < 2.0$, indicating a very probable occurrence of fire, appear more frequently after the 1990s in northern Serbia (Fig. 6a) and after 1984 in central (Fig. 6b) and southern Serbia (Fig. 6c).

In order to explain increased probability of fires, the Lang factor is examined. Based on temperature and precipitation data, the annual (L_a) and monthly (L_m) values of the Lang precipitation factors are calculated. The annual values of L_a show that Serbia is at the lower limit of a semi-humid climate. In the period 1981–2010, the Lang precipitation factor values decrease at 22 stations and increase at 4 (Table 6).

With regard to the standard climatological period (1961–1990), during the period 1981–2010, at most stations, there is a decrease of monthly values of L_m in the first half of the year, i.e. in the period March–August (Table 7). A slight increase is evident during the autumn and winter months. At most stations, values of an arid climate exist for 4–5 months. This was caused by smaller amounts of precipitation and higher air temperatures, which also led to increased evapotranspiration. Based on the processed data of precipitation and air temperature, it can be concluded that
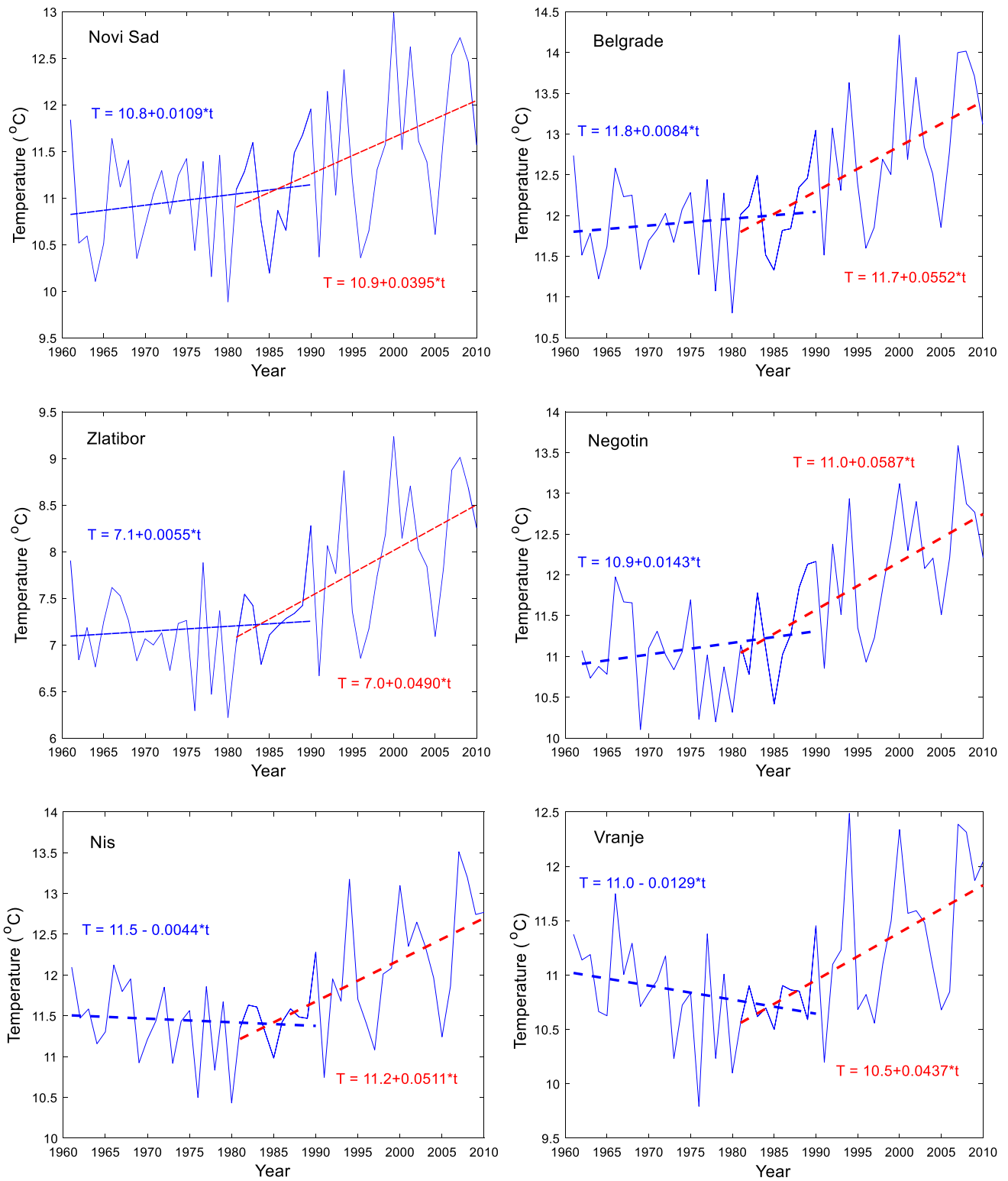
Fig. 4 Mean annual temperature (°C), trend equations, and trend lines for selected stations in Serbia during two periods: 1961–1990 and 1981–2010
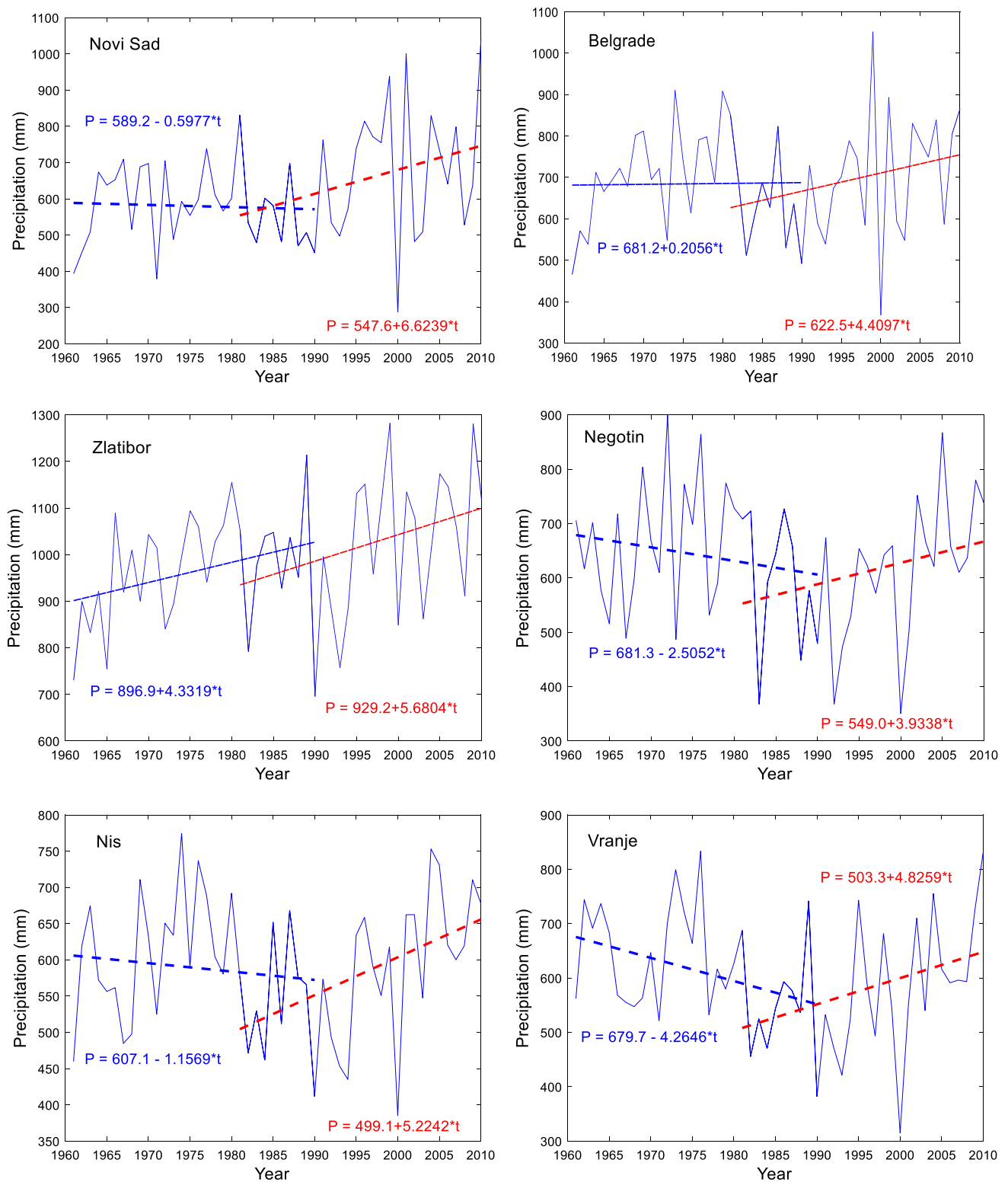
Fig. 5 Annual precipitation (mm), trend equations, and trend lines for selected stations in Serbia during two periods: 1961–1990 and 1981–2010

most of the territory of Serbia has the elements of an arid climate. In fact, all the meteorological stations in Vojvodina (northern Serbia) show the elements of a semi-arid climate, as in the steppes and Savannas ($40 < La < 60$). Other areas with lower altitudes, together with the parts in the south and east, also have the elements of this climate. The same results

Table 5 The monthly Ångström index at 26 stations in Serbia for two periods: 1961–1990 and 1981–2010

Station	Period	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Palić	1961–1990	7.14	6.65	38.79	4.97	4.44	4.12	3.85	4.07	4.62	5.36	6.34	6.98
	1981–2010	6.99	6.52	5.65	4.84	4.17	3.86	3.57	3.73	4.52	5.31	6.26	6.97
Sombor	1961–1990	7.09	6.64	5.82	5.045	4.48	4.24	4.08	4.26	4.82	5.44	6.36	6.94
	1981–2010	6.91	6.46	5.58	4.84	4.19	3.93	3.71	3.87	4.60	5.32	6.26	6.89
Novi Sad	1961–1990	7.08	6.59	5.74	4.98	4.44	4.23	3.95	4.07	4.62	5.28	6.245	6.91
	1981–2010	6.93	6.49	5.61	4.87	4.27	4.14	3.91	3.94	4.61	5.32	6.21	6.85
Kikinda	1961–1990	7.12	6.66	5.76	4.98	4.42	4.20	3.94	4.12	4.59	5.30	6.32	6.96
	1981–2010	7.02	6.56	5.62	4.81	4.17	3.97	3.67	3.78	4.56	5.29	6.24	6.94
Zrenjanin	1961–1990	7.00	6.50	5.68	5.02	4.44	4.31	4.04	4.12	4.64	5.32	6.28	6.88
	1981–2010	6.94	6.44	5.56	4.80	4.21	4.02	3.78	3.82	4.54	5.21	6.15	6.86
Sremska Mitrovica	1961–1990	7.06	6.56	5.75	5.05	4.56	4.42	4.22	4.40	4.90	5.48	6.34	6.93
	1981–2010	7.04	6.59	5.71	4.97	4.38	4.26	4.10	4.13	4.79	5.43	6.37	6.96
Belgrade	1961–1990	6.58	6.08	5.24	4.54	4.15	3.96	3.67	3.76	4.34	4.97	5.81	6.46
	1981–2010	6.46	5.94	5.09	4.46	3.94	3.75	3.45	3.48	4.25	4.96	5.74	6.38
Loznica	1961–1990	6.83	6.42	5.66	5.02	4.63	4.40	4.18	4.36	4.92	5.56	6.16	6.68
	1981–2010	6.77	6.36	5.56	4.97	4.45	4.25	3.97	4.11	4.82	5.51	6.17	6.68
Valjevo	1961–1990	6.82	6.40	5.65	5.04	4.64	4.40	4.11	4.26	4.82	5.46	6.12	6.68
	1981–2010	6.74	6.30	5.54	4.94	4.42	4.21	3.86	4.01	4.72	5.43	6.09	6.61
Kragujevac	1961–1990	6.66	6.28	5.58	4.96	4.58	4.36	4.11	4.19	4.68	5.31	5.96	6.56
	1981–2010	6.56	6.22	5.49	4.88	4.43	4.10	3.76	3.09	4.61	5.26	5.91	6.54
Požega	1961–1990	7.22	6.66	5.88	5.18	4.91	4.71	4.50	4.65	5.16	5.76	6.48	7.13
	1981–2010	7.16	6.66	5.87	5.23	4.83	4.62	4.40	4.50	5.14	5.78	6.54	7.09
Smederevska Palanka	1961–1990	6.76	6.36	5.55	4.88	4.52	4.30	4.02	4.13	4.64	5.32	6.04	6.67
	1981–2010	6.68	6.24	5.45	4.82	4.35	4.09	3.80	3.84	4.62	5.28	5.98	6.61
Veliko Gradište	1961–1990	6.86	6.47	5.64	4.95	4.58	4.36	4.15	4.17	4.64	5.22	6.08	6.76
	1981–2010	6.84	6.40	5.53	4.87	4.40	4.21	3.91	3.90	4.62	5.23	6.00	6.71
Crni Vrh	1961–1990	7.47	7.36	6.68	5.85	5.43	5.29	4.97	4.97	5.42	6.09	6.86	7.36
	1981–2010	7.30	7.20	6.57	5.78	5.18	4.98	4.61	4.05	5.33	6.07	6.79	7.23
Negotin	1961–1990	6.86	6.60	5.87	4.94	4.44	4.02	3.67	3.85	4.43	5.38	6.17	6.68
	1981–2010	6.67	6.26	5.49	4.78	4.23	3.72	3.35	3.52	4.39	5.34	6.20	6.74
Zlatibor	1961–1990	7.245	6.925	6.265	5.57	5.16	4.995	4.705	4.665	5.13	5.72	6.425	7.12
	1981–2010	7.06	6.78	6.16	5.48	4.97	4.81	4.48	4.45	5.14	5.72	6.38	7.07
Sjenica	1961–1990	7.44	7.12	6.52	5.74	5.28	5.14	4.92	4.97	5.45	5.99	6.56	7.21
	1981–2010	7.16	6.97	6.37	5.65	5.15	4.88	4.65	4.73	5.41	5.87	6.53	7.11
Kraljevo	1961–1990	6.80	6.30	5.54	4.82	4.58	4.41	4.14	4.16	4.72	5.35	6.06	6.72
	1981–2010	6.72	6.22	5.47	4.82	4.48	4.22	3.92	3.95	4.72	5.37	6.05	6.69
Kopaonik	1961–1990	7.35	7.46	7.18	6.55	6.06	5.88	5.46	5.44	5.82	6.21	6.89	7.20
	1981–2010	7.21	7.36	7.02	6.50	5.92	5.59	5.18	5.12	5.83	6.20	6.75	7.25
Ćuprija	1961–1990	6.86	6.45	5.69	4.99	4.62	4.44	4.22	4.26	4.77	5.40	6.12	6.76
	1981–2010	6.78	6.39	5.64	4.95	4.48	4.23	3.95	3.92	4.70	5.41	6.07	6.70
Kruševac	1961–1990	6.98	6.54	5.83	5.12	4.74	4.50	4.26	4.25	4.80	5.50	6.24	6.88
	1981–2010	6.93	6.45	5.69	5.07	4.62	4.30	4.02	4.00	4.72	5.49	6.16	6.79
Niš	1961–1990	6.71	6.21	5.42	4.70	4.35	4.12	3.77	3.75	4.43	5.12	5.96	6.62
	1981–2010	6.64	6.16	5.30	4.63	4.24	3.91	3.05	3.52	4.41	5.12	5.91	6.54
Zaječar	1961–1990	6.86	6.59	5.96	5.14	4.74	4.44	4.08	4.14	4.72	5.54	6.26	6.76
	1981–2010	6.67	6.33	5.66	5.01	4.47	4.06	3.66	3.83	4.59	5.52	6.27	6.73
Dimitrovgrad	1961–1990	6.80	6.44	5.70	4.99	4.69	4.49	4.10	4.10	4.62	5.28	6.10	6.70
	1981–2010	6.82	6.49	5.70	5.04	4.66	4.38	3.99	4.02	4.72	5.40	6.15	6.72

Table 5 (continued)

Station	Period	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Leskovac	1961–1990	6.97	6.53	5.83	5.17	4.72	4.51	4.16	4.22	4.88	5.54	6.28	6.89
	1981–2010	6.80	6.38	5.56	4.96	4.51	4.13	3.79	3.88	4.72	5.43	6.20	6.71
Vranje	1961–1990	6.88	6.36	5.60	4.86	4.49	4.22	3.78	3.76	4.40	5.19	6.14	6.80
	1981–2010	6.76	6.27	5.41	4.78	4.35	4.00	3.59	3.54	4.36	5.17	6.08	6.73

are obtained by Hrnjak et al. (2014) and Radaković et al. (2018), who applied the De Martonne index and analysed aridity in Vojvodina (northern Serbia) and central Serbia, respectively. The western part of Serbia, as well as the areas with higher altitudes, has the features of a semi-humid climate. The decrease in L_a will certainly increase the risk of fire. Particular attention should be paid to the east and south of Serbia where the decrease in the precipitation factor is the highest. The summer period (Table 7) is particularly risky because the value of the Lang factor is considered arid on the entire territory of Serbia (L_m is less than 3.3). In the eastern and southern parts of Serbia, this period begins as early as May and lasts until October. Therefore, in these regions, the increased risk of forest fires can last for 5–6 months.

4 Discussion

Temperature and precipitation were calculated in Serbia for two periods, since these values characterize the climate of a certain area. The significant increase of the mean temperature was registered at all stations during the second period (1981–2010). An increase in temperature and reduction of precipitation could influence the number and size of fires.

According to daily values of the Ångström index, 2000 and 2007 appear as years very probable for fire occurrence. A severe drought was recorded in Serbia in 2000, except at Loznica and Novi Sad (Tošić and Unkašević 2014). A deficit of precipitation made favourable conditions for fire occurence. Air temperatures were extremely high in 2007, while precipitation was unevenly distributed throughout the year. In July, a number of stations measured the highest temperature ever since regular measurements began in Serbia in 1848 (Unkašević and Tošić 2011). The total number of fires on the territory of Serbia from 2000 to 2010 is presented in Table 8. It can be seen that the largest number of fires (28,546) happened in 2007. During the period 2004–2010, the largest area (22,161 ha) affected by fire on the territory of Serbia was in 2007 (Fig. 7), which is about 0.3% of the territory of Serbia. Analysing the number of forest fires, Lukić et al. (2017) found that the number of forest fires increased in Serbia during the period 2000–2012, but was non-significant. They pointed out that a significant correlation existed between meteorological parameters and forest fire occurrence.

The frequency, duration, and intensity of droughts causes the drying of combustible materials, leading to an increased risk of fire. According to Trabaud (1980), the amount and distribution of precipitation is an important climatic factor influencing the occurrence of fire; the number of fires decreases exponentially with increase of precipitation.

Marković et al. (2016) investigated impact and hazard of drought and drought-related wildfires in Kanjiža municipality in Serbia and associated risk. They found that the areas of highest wildfire hazard correspond very well with the areas of high drought hazard and impact.

The complex influence of high temperatures and drought on vegetation (Spasov 2003) causes it to become physiologically weaker and dried. This harmful effect is less pronounced in younger trees. Middle-aged trees, however, have a higher need for water, making the effect more pronounced. Among forest tree species that are the first to take a hit are conifer species with shallow plate-like roots, such as the spruce.

The most vulnerable are the communities and species which have limited opportunities for adaptation. In Serbia, these are mountaneous communities and endemic species, as well as the species with slow and difficult reproduction.

5 Conclusions

The increase in air temperature and decrease in annual precipitation lead to increased aridity in the territory of Serbia. According to the analysis of the Ångström index, it is shown that on the entire territory of Serbia during the summer months there was a higher fire danger risk. The small values of the precipitation factor not only during summer, but also in the spring months, affect the increased risk of forest fires.

Estimates of future climate suggest that Serbia can expect a warmer climate (Kržič et al. 2011), which increases the danger of fire emergence and spreading. The season of fires will start earlier and will end later in the year. Shifts of the fire season will be more pronounced in the spring months. The analysis shows an expansion of the areas with increased forest fire risks from the south to the north of Serbia. Results
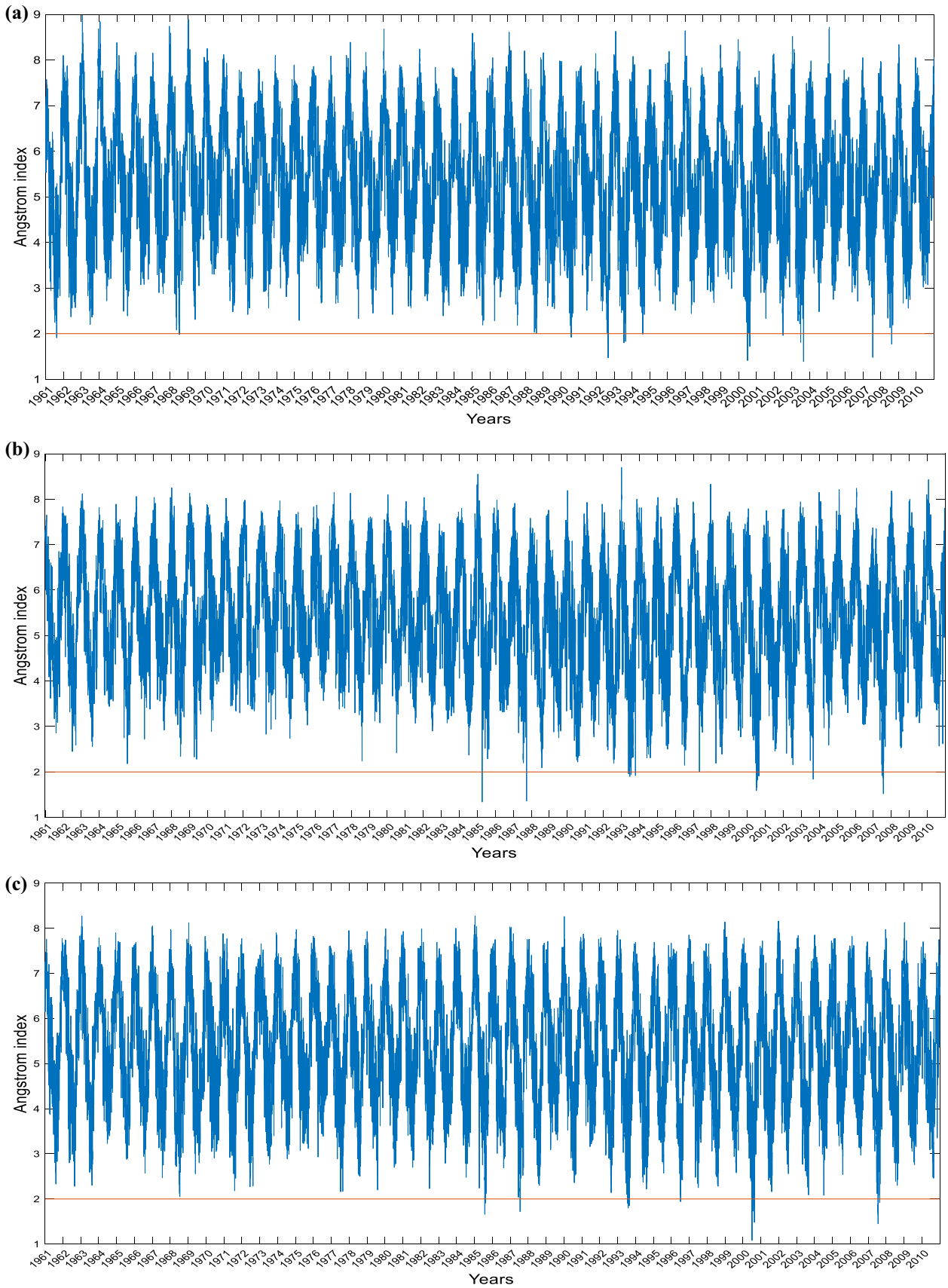
Fig. 6 Daily values of the Ångström index for: **a** Novi Sad, **b** Zaječar and **c** Vranje

Table 6 The annual Lang precipitation factor (L_a) at 26 stations with their altitude (h) in Serbia for two periods: 1961–1990 and 1981–2010

Station		L		Type of climate		Bioclimatic area	
	h (m)	1961–1990	1981–2010	1961–1990	1981–2010	1961–1990	1981–2010
Palić	102	51.4	51.0	Arid	Arid	Steppes and savannas	Steppes and savannas
Sombor	87	54.6	54.7	Arid	Arid	Steppes and savannas	Steppes and savannas
Novi Sad	84	52.9	56.8	Arid	Arid	Steppes and savannas	Steppes and savannas
Kikinda	81	49.6	49.2	Arid	Arid	Steppes and savannas	Steppes and savannas
Zrenjanin	80	51.6	50.7	Arid	Arid	Steppes and savannas	Steppes and savannas
Sremska Mitrovica	82	56.9	54.4	Arid	Arid	Steppes and savannas	Steppes and savannas
Belgrade	132	57.5	55.3	Arid	Arid	Steppes and savannas	Steppes and savannas
Loznica	121	74.6	74.8	Humid	Humid	Low forests	Low forests
Valjevo	388	71.8	69.1	Humid	Humid	Low forests	Low forests
Kragujevac	185	57.5	53.3	Arid	Arid	Steppes and savannas	Steppes and savannas
Požega	310	79.6	74.9	Humid	Humid	Low forests	Low forests
Smederevska Palanka	121	57.8	55.4	Arid	Arid	Steppes and savannas	Steppes and savannas
Veliko Gradište	80	61.9	57.8	Humid	Arid	Low forests	Steppes and savannas
Crni Vrh	1027	126.6	115.2	Humid	Humid	High forests	High forests
Negotin	42	58.2	52.0	Arid	Arid	Steppes and savannas	Steppes and savannas
Zlatibor	1028	135.8	132.1	Humid	Humid	High forests	High forests
Sjenica	1038	116.8	111.9	Humid	Humid	High forests	High forests
Kraljevo	215	69.2	64.4	Humid	Humid	Low forests	Low forests
Kopaonik	1711	341.0	273.4	Perhumid	Perhumid	Barrens and tundra	Barrens and tundra
Ćuprija	123	60.9	59.3	Humid	Arid	Low forests	Steppes and savannas
Kruševac	166	60.0	55.1	Humid	Arid	Low forests	Steppes and savannas
Niš	204	51.7	48.8	Arid	Arid	Steppes and savannas	Steppes and savannas
Zaječar	144	58.7	52.9	Arid	Arid	Steppes and savannas	Steppes and savannas
Dimitrovgrad	450	65.5	62.5	Humid	Humid	Low forests	Low forests
Leskovac	230	55.0	56.3	Arid	Arid	Steppes and savannas	Steppes and savannas
Vranje	432	56.8	52.1	Arid	Arid	Steppes and savannas	Steppes and savannas
Serbia	333.2	78.2	72.8	Humid	Humid	Low forests	Low forests

of air temperature and precipitation show that there has been a significant rise in air temperature observed in the second period (1981–2010), which leads to the conclusion of an increased risk of forest fires in Serbia.

The coincidence of periods of drought and high temperatures leads to reduced tree vitality, thereby creating optimal conditions for the incidence and development of fires. The direct and indirect damage to forests is significant; it is often also unpredictable and has far-reaching consequences. In the following period, due to lack of available soil moisture, and increased air temperature, which can be extreme in some years, it is necessary to take certain measures against forest fires. Taking steps to implement precautionary procedures could be useful now but most likely necessary in the future. Managing forest resources should reduce vulnerability and enhance recovery.

Education and awareness raising should be of primary importance, since, most of the time, forest fires are caused by the negligence of the local population. The greatest challenge of forest management is to perform control checks with the aim of minimizing fire risks, as well as to implement a risk mitigation strategy. The inadequacy of forestry funds and the slow process of natural recovery from forest fires does not ensure the realization of a sustainable forestry strategy.

Table 7 The monthly Lang precipitation factor (L_m) at 26 stations in Serbia for two periods: 1961–1990 and 1981–2010

Station	Period	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Palić	1961–1990	–	28.5	6.0	3.8	3.4	3.8	2.7	2.7	2.2	2.5	8.9	65.7
	1981–2010	–	23.3	5.7	3.8	3.2	3.9	2.6	2.4	3.0	3.5	8.9	58.1
Sombor	1961–1990	–	24.4	6.3	4.6	3.5	4.1	2.9	2.6	2.3	3.4	9.8	48.3
	1981–2010	–	21.4	5.9	3.9	3.5	4.0	3.0	2.5	3.3	4.2	9.9	43.1
Novi Sad	1961–1990	–	23.2	6.8	4.1	3.4	4.2	2.9	2.7	2.1	3.0	7.8	36.8
	1981–2010	195.5	19.6	6.6	4.2	3.6	4.5	2.9	2.7	3.2	4.5	9.1	32.5
Kikinda	1961–1990	–	26.2	5.9	4.1	3.2	3.9	2.4	2.5	2.2	2.8	7.9	50.7
	1981–2010	–	19.1	5.3	3.7	3.1	3.7	2.5	2.3	3.0	3.5	8.1	42.3
Zrenjanin	1961–1990	–	17.6	5.9	4.1	3.4	4.5	3.0	2.3	2.4	3.3	7.6	29.5
	1981–2010	359	18.8	5.8	3.6	3.2	4.4	2.7	2.1	2.9	3.7	8.0	32.4
Sremska Mitrovica	1961–1990	–	20.7	6.6	4.4	3.5	4.4	3.1	2.7	2.7	3.4	9.1	41.2
	1981–2010	379	18.3	6.3	4.1	3.3	4.2	2.9	2.5	3.0	4.7	9.1	32.6
Belgrade	1961–1990	–	15.9	6.9	4.7	4.1	4.5	3.0	2.4	2.9	3.2	7.8	25.0
	1981–2010	33.5	12.9	6.5	4.3	3.2	4.8	2.7	2.6	3.1	3.9	7.8	21.3
Loznica	1961–1990	–	21.4	8.9	6.1	5.1	5.2	4.1	3.8	3.7	4.8	11.3	35.3
	1981–2010	74.1	19.2	9.5	5.3	4.6	5.4	3.9	3.5	4.1	6.2	11.8	31.6
Valjevo	1961–1990	–	23.1	8.6	5.7	5.5	5.7	3.7	3.4	3.6	4.3	9.8	39.6
	1981–2010	83.2	22.3	8.8	5.2	4.3	5.5	3.2	3.3	3.9	5.4	10.3	31.9
Kragujevac	1961–1990	–	17.6	7.0	4.4	4.6	4.5	3.3	2.6	2.7	3.3	7.5	26.4
	1981–2010	42.1	16.1	6.4	4.6	3.5	3.8	2.6	2.7	3.1	4.1	7.7	21.8
Požega	1961–1990	–	60.6	9.7	5.7	5.8	4.7	4.2	3.2	3.9	5.0	14.5	–
	1981–2010	–	104.8	8.6	5.7	4.9	4.8	3.8	3.1	4.4	5.6	15.5	–
Smederevska Palanka	1961–1990	–	20.0	7.4	4.3	4.3	4.7	2.8	2.3	2.8	3.5	8.5	30.5
	1981–2010	60.6	18.7	6.7	4.2	3.2	3.9	2.8	2.7	3.4	4.4	8.1	27.3
Veliko Gradište	1961–1990	–	28.8	7.3	4..8	4.5	4.5	3.3	2.8	3.0	3.6	7.9	48.8
	1981–2010	450	28.1	6.7	4.8	3.5	4.1	2.8	2.6	3.4	4.4	8.1	36.2
Crni Vrh	1961–1990	–	–	52.2	9.9	9.1	8.6	5.6	4.1	5.0	7.3	32.4	–
	1981–2010	–	–	62.8	11.3	6.6	6.3	4.1	3.6	5.6	9.1	38.5	–
Negotin	1961–1990	–	0.7	10.3	5.3	4.0	3.3	2.2	1.9	2.4	4.3	11.3	42.9
	1981–2010	139.3	23.2	7.2	4.4	2.9	2.8	2.1	2.1	2.6	4.3	10.6	60.4
Zlatibor	1961–1990	–	–	32.0	11.6	8.7	7.6	5.9	4.8	6.4	7.9	26.7	–
	1981–2010	–	–	30.6	11.0	7.7	7.2	5.6	4.5	7.5	8.9	28.8	–
Sjenica	1961–1990	–	–	29.7	8.0	6.8	6.2	4.5	4.5	5.1	8.2	31.1	–
	1981–2010	–	–	25.8	8.6	6.2	5.4	4.1	3.8	6.4	8.0	33.7	–
Kraljevo	1961–1990	–	21.3	8.2	5.2	5.7	5.0	3.6	2.8	3.4	4.0	9.7	43.4
	1981–2010	150.3	19.7	7.8	5.3	4.3	4.7	3.5	3.0	3.5	4.9	9.4	35.1
Kopaonik	1961–1990	–	–	–	62.2	17.0	13.9	8.1	8.3	8.1	11.3	–	–
	1981–2010	–	–	–	44.4	15.1	10.1	7.2	6.3	9.8	13.6	–	–
Ćuprija	1961–1990	–	25.6	7.7	4.6	4.9	4.6	3.0	2.2	2.9	3.4	9.0	42.8
	1981–2010	230.5	28.4	7.4	5.3	3.8	4.1	2.7	2.2	3.2	4.4	9.3	37.7
Kruševac	1961–1990	–	20.7	7.2	4.9	4.9	4.5	2.8	2.2	2.7	3.4	9.8	45.8
	1981–2010	201.5	19.6	7.3	4.8	3.4	3.6	2.5	2.3	3.0	4.3	9.5	34.4
Niš	1961–1990	–	16.1	6.8	4.3	4.0	3.6	2.0	2.1	2.5	2.9	8.9	31.5
	1981–2010	64.7	15.3	6.1	4.6	3.4	2.8	2.0	2.1	2.8	3.7	8.6	24.5
Zaječar	1961–1990	–	55.0	9.4	5.0	4.5	3.7	2.6	1.8	2.3	3.9	11.2	64.4
	1981–2010	–	33.2	6.9	4.7	3.1	2.8	2.5	2.0	2.7	4.4	10.9	77.1
Dimitrov-grad	1961–1990	–	45.0	9.5	5.1	5.1	5.0	3.1	2.3	2.5	3.8	11.8	70.9
	1981–2010	–	63.5	8.0	5.4	4.5	3.8	3.0	2.7	3.4	4.8	10.6	58.6

Table 7 (continued)

Station	Period	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Leskovac	1961–1990	–	22.4	7.9	4.4	3.5	3.9	2.1	2.1	2.8	3.1	11.1	50.2
	1981–2010	–	26.9	7.2	5.3	3.4	3.3	2.0	2.2	3.2	4.6	11.3	39.4
Vranje	1961–1990	–	21.7	7.5	4.7	4.2	3.8	2.4	1.9	2.7	4.0	10.7	52.0
	1981–2010	–	21.3	6.0	4.6	3.5	3.2	2.1	2.0	2.8	4.4	10.1	42.1

Table 8 Registered number of fires on the territory of Serbia (Official Gazette of the Republic of Serbia 2011)

Year	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Number of fires	21,688	11,728	14,841	19,271	15,061	14,670	17,847	28,546	24,450	21,569	17,254
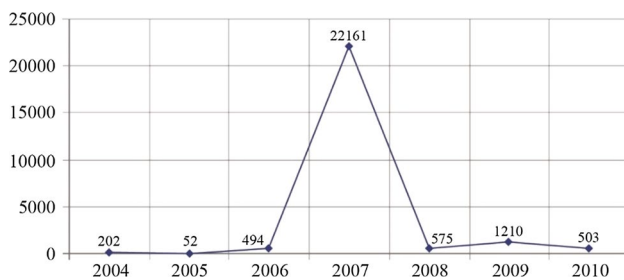
Fig. 7 Burnt forest areas (ha) in the period 2004–2010 on the territory of Serbia (https://publikacije.stat.gov.rs/G2011/Pdf/G20112002.pdf)

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Humand and animal rights This study does not involve human subjects, human material, or human data.

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