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Potential influence of meteorological variables on forest fire risk in Serbia during the period 2000–2017

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Abstract: To examine potential relationships between meteorological variables and forest fires in Serbia, daily temperature, precipitation, relative humidity and wind speed data for 15 meteorological stations across Serbia were used to construct fire indices. The daily values of the Ångström and Nesterov indices were calculated for the period 2000–2017. A high number of forest fires occurred in 2007 and 2012 in Serbia, during a period of extremely high air temperatures in 2007, followed by the longest heat wave and the worst drought in 2012.

In order to identify the ideal weather conditions for fire break outs, different combinations of input variables, e.g., meteorological variables (mean temperature, precipitation, relative humidity, maximum temperature, minimum temperature and wind speed), fire danger indices or a combination of both, for the Belgrade area during the period 1986–2017, were tested. It was found that using relative humidity or precipitation as a predictor only generates a satisfactory model for forecasting of number of forest fires.

Keywords: meteorological variables, forest fire risk, fire indices, stepwise regression, Serbia

1 Introduction

Based on the definition and classification of natural disasters that are listed in the annual statistical examination by the Centre for Research on the Epidemiology of Disasters (CRED) [1] with its database EM-DAT (<http://www.cred.be/em-dat>), forest fires are classified into a group of natural climatological disasters [2]. The CRED and the classification of natural disasters of Munich Reinsurance Company [3] with its database NatCat-SERVICE (<https://www.munichre.com/en/reinsurance/business/non-life/natcatservice/index.html>) [4] also consider wildfires as climatological disasters but divide them into two categories: forest fires and land fires.

The danger of fire is a complex topic, influenced not only by weather but also by a number of factors. The intensity and size of the area affected by forest fires, to a large extent, depends on the values of meteorological elements. The importance of weather conditions to the behaviour and rate of spread of a wildfire is well documented [5–9]. Weather elements are recognized as major determinants of the exposure to fire risk and the spread of fire [10–12]. The most important climatic factors that influence the degree of risk of forest fires are air temperature, precipitation, relative humidity, wind and droughts. Based on these values and the variability of weather, different models have been constructed to determine the index of fire risk. Fire-danger indices usually combine information about weather and drought. For several decades, fire-weather indices have been used all over the world as proxies to estimate the dryness of the vegetation [13–15]. Some include very simple algorithms combining temperature and humidity [16, 17], while others are sophisticated tools which can be used to estimate not only the probability of a fire but also its rate of spread and severity [18, 19]. In general, ignition of a fire is related to both the prevailing atmospheric conditions and the local geomorphological structure, among any number of other anthropogenic factors that are not easily quantified [20].

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The annual number of deaths due to fire hazards exceeds 10,000 worldwide, according to the United Nations World Fire Statistics Centre [21, 22]. The territory of Serbia is vulnerable to fires in nature, the number of which is increasing. These fires, depending on their intensity and duration, often have unpredictable and far-reaching consequences. In Serbia, there is a more common threat to people, the environment and property from catastrophic fires in open spaces, especially in forests. Particularly disturbing is the number of mortalities (53 persons) in fires in open spaces from 2009 to 2015 in the territory of Serbia according to the Sector for Emergency Situations of the Ministry of Internal Affairs of the Republic Serbia (MUP RS). This institution was in charge of recording all fire events in Serbia.

The total forested area in Serbia amounts to 2,252,400 ha, i.e. 29.1% of its territory [23]. Three main climate types are recognized in Serbia: continental, moderate continental and modified Mediterranean climate [24]. Northern Serbia is characterized by arid climate [25, 26]. The western part of Serbia has humid climate characteristics [27], as well as areas with higher altitude [28]. The combination of climate and forest coverage leads to a high potential danger for fire in southern and eastern Serbia, especially in the warmest and driest months of the year, which are July and August. The significance of the impact of climate change on forest-fire risk is greatest for Belgrade and minimal for the area of Kopaonik and Zlatibor [29].

Consideration of the impact of climate conditions on the occurrence of forest fires in Serbia is becoming more and more important. Previous studies have faced the impact of climate conditions on the occurrence of forest fires in certain areas [28, 30]. The examinations did not cover all input variables of importance to the creation of favourable conditions for the occurrence of forest fires, and it is necessary to identify the meteorological variables that affect forest fires in Serbia.

The aim of this study is to examine potential relationships between meteorological variables and wildfire occurrence in Serbia. Identifying the most important meteorological fire drivers is fundamental to the management of forest-fire risk in Serbia.

2 Materials and methods

2.1 Study area and data

The republic of Serbia covers 88,361 km², with an average altitude of 470 m. Serbia is located between central and

southern Europe and is characterized by a complex topography. Forest coverage in Serbia is around 29.1% of the territory, with a predominance of deciduous forest, of which 660,400 ha (29.3%) is occupied by beech forests [31].

The average daily air temperature, precipitation, relative humidity, maximum temperature, minimum temperature and wind speed data from 15 meteorological stations (Table 1) in Serbia were used. The location of the 15 stations are presented in Fig. 1. These stations are operated by the Republic Hydrometeorological Service of Serbia (<http://www.hidmet.gov.rs/>). Data series are complete (i.e. no missing values). Annual mean temperature (°C), precipitation (mm) and relative humidity (%) for the 15 stations during the period 2000–2017 are shown in Table 1. Mean temperatures in Serbia are around 11°C, with the highest average annual air temperature observed in Belgrade (13.4°C), and the lowest average annual air temperature in Zlatibor (8.5°C), the mountainous range in southwestern Serbia. The annual mean precipitation increases from north (~600.0 mm) to southwest, with the maximum in Zlatibor (1049.6 mm). Relative humidity is around 70% in Serbia (Table 1).

For this study, we used statistical data from the Sector for Analytics, Telecommunications and Information Technology (Sector ATIT) and the Sector for Emergency Situations of the MUP RS about a registered number of fires in open space and burnt areas in the territory of the Republic of Serbia. Statistical data of the number of fires in open space are classified into six groups (forest fires, grain fires in meadows and pastures, orchard fires, fires in garbage dumps (waste) and other fires in open space). Fire hazards (total number of all types of fires) occurred more than 503,870 times in Serbia during the period 2000–2017, leading to 1,574 fatalities, with more than 6,000 people injured and economic losses of about a million euros.

The vegetation cover of Serbia was determined by CORINE Land Cover 2012, which is a free access map of 44 land classes in over 39 countries, with a minimum mapping unit of 25 ha. For the purpose of this study, 16 major land classes in Serbia are represented in Fig. 1, by using the software ArcGIS 10.1.

2.2 Daily fire-weather index

Selected fire danger indices are based on standard meteorological observations.

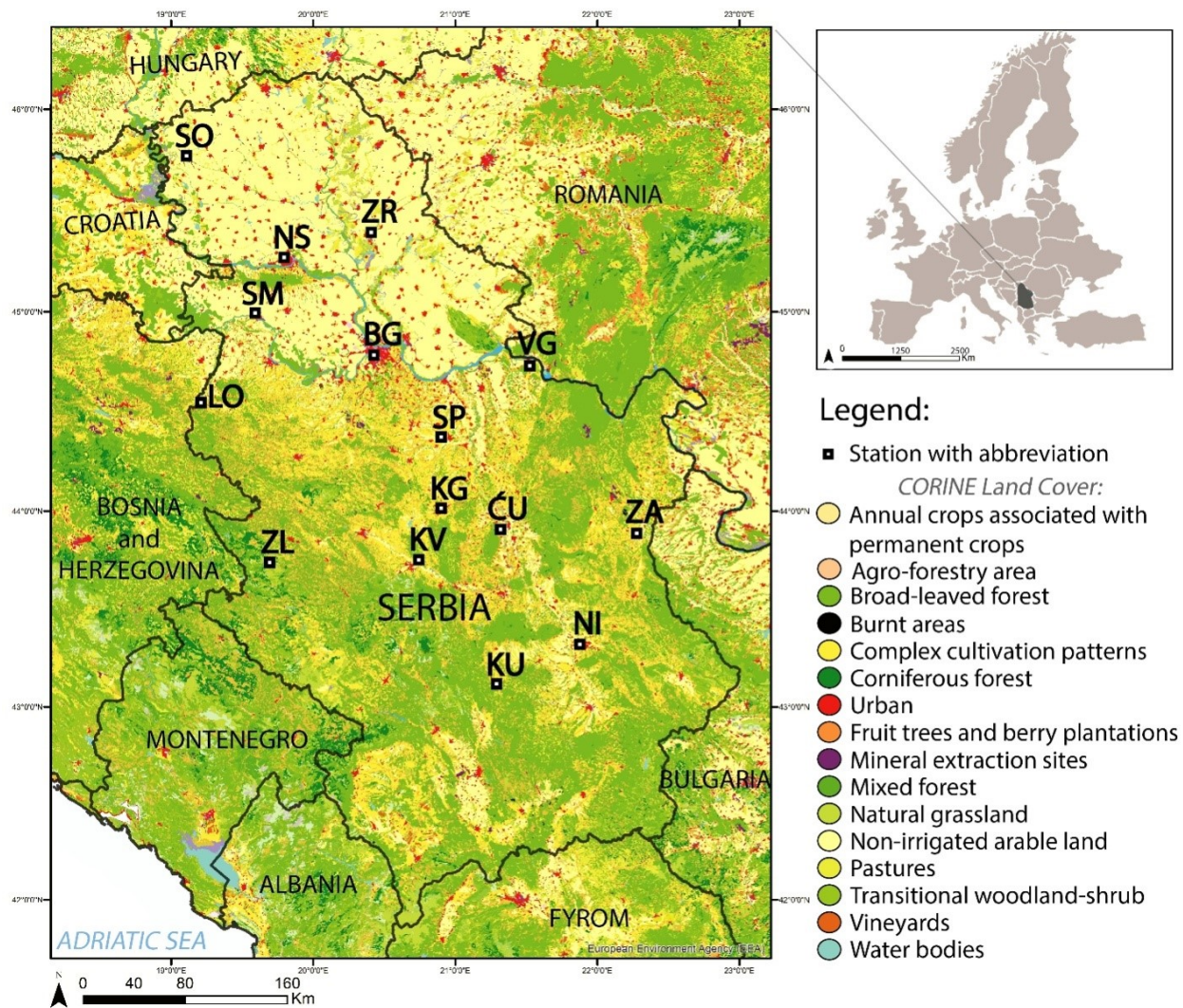


Figure 1: Regional position of Serbia, and CORINE Land Cover with overlaid climatic stations used in this study.

2.2.1 The Ångström index

The Ångström index, I , is calculated [32] using Eq. (1), where RH is relative humidity in percent and T is temperature in $^{\circ}\text{C}$

$$I = \frac{RH}{20} + \frac{(27 - T)}{10} \quad (1)$$

Its values are high in times of low danger/flammability and low in times of high danger/flammability [33]. The use of the index for risk categorization is shown in Table 2.

2.2.2 The Nesterov index

Nesterov proposed a fire-risk rating index, NI , in 1949 [14]. This index establishes a range of discrete fire-risk levels.

The Nesterov Index is calculated as follows:

$$NI = \sum_{i=1}^w (T_i - T_i^{dew}) T_i \quad (2)$$

where, w is the number of days since the last rainfall exceeding 3 mm per day, is the temperature ($^{\circ}\text{C}$) on a given day i and T_i^{dew} is the dew-point temperature ($^{\circ}\text{C}$) on the same day. NI is reset to zero when the daily rainfall exceeds 3 mm per day [34]. The original risk levels proposed by Nesterov are shown in Table 3.

2.2.3 The Lang precipitation factor

Recognizing temperature as the major factor in evaporation, Lang [35] used a coefficient of humidity, defined as

Table 1: Abbreviation (Abb) of meteorological stations with their latitude, longitude and altitude (m), and annual mean values of temperature (°C), precipitation (mm) and relative humidity (%) during the period 2000-2017.

Abb	Station	Latitude	Longitude	Altitude (m)	T (°C)	P (mm)	RH (%)
SO	Sombor	45°47'	19°05'	88	11.8	639.4	71.8
ZR	Zrenjanin	45°24'	20°21'	80	12.3	593.1	73.6
NS	Novi Sad	45°20'	19°51'	84	11.2	761.9	75.0
SM	Sremska Mitrovica	44°58'	19°38'	82	11.9	617.7	76.6
BG	Belgrade	44°48'	20°28'	132	13.4	710.1	67.1
VG	Veliko Gradište	44°45'	21°31'	82	12.0	678.7	73.8
LO	Loznica	44°33'	19°14'	121	12.4	884.7	74.5
SP	Smederevska Palanka	44°22'	20°57'	121	12.2	687.7	72.3
KG	Kragujevac	44°02'	20°56'	185	12.3	667.5	72.1
CU	Čuprija	43°56'	21°23'	123	11.8	717.9	74.2
ZA	Zaječar	43°53'	22°17'	144	11.5	632.9	73.4
KV	Kraljevo	43°44'	20°41'	215	12.1	753.0	72.9
ZL	Zlatibor	43°39'	19°41'	1028	8.5	1049.6	75.3
NI	Niš	43°20'	21°54'	202	12.6	641.0	70.7
KU	Kuršumlija	43°08'	21°16'	384	11.0	688.1	78.3

Table 2: Values of the Ångström index (I) translated into fire-risk probability [34]

Ångström index (I)	Probability of fire
$I > 4.0$	Unlikely
$4.0 < I < 3.0$	Unfavourable
$3.0 < I < 2.5$	Favourable
$2.5 < I < 2.0$	More favourable
$I < 2.0$	Very likely

Table 3: Values of the Nesterov index (NI) translated into fire-risk probability [34]

Nesterov index (NI)	Probability of fire
$NI < 300$	No risk
$301 < NI < 1000$	Low risk
$1001 < NI < 4000$	Medium risk
$4001 < NI < 10000$	High risk
$NI > 10000$	Extremely high risk

the ratio of precipitation to the mean temperatures

$$L = \frac{P}{T} \quad (3)$$

where P is the annual mean precipitation (mm), and T is the annual mean temperature (°C).

2.3 Stepwise regression

Stepwise regression (SR) is a systematic method for adding and removing terms from a multilinear model based on their statistical significance in a regression [36]. A stepwise regression analysis generates a linear equation that predicts a dependent (predicted) variable as a function of several independent (predictor) variables. Each variable is entered in sequence and its value assessed. If adding the variable contributes to the model, it is retained, and all other variables in the model are then re-tested to see if they still contribute to the success of the model. If they no longer contribute significantly, they are removed. In this paper the number of forest fires was selected as the dependent variable, while the independent variables were the annual mean values of temperature, precipitation, relative humidity, maximum temperature, minimum temperature and wind speed.

The model efficiency coefficient (MEF) [37], Pearson's correlation coefficient (r) and coefficient of determination (R^2) are used to assess the predictive power of the regression model. The Nash–Sutcliffe efficiency can range from $-\infty$ to 1. The model is perfect when the efficiency is 1 [38]. An efficiency of 0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency lower than 0 occurs when the observed mean is a better predictor than the model. The coefficient of determination ranges from 0 to 1, with a perfect fit being equal

to 1. The lower the root mean square error (RMSE), the better the performance of the model.

3 Results

3.1 Analysis of fires in Serbia

The number of outdoor fires in Serbia during the period 2000–2017 is presented in Fig. 2. The maximum number of fires was observed in 2012, followed by 2007, 2011 and 2017. Figure 3 shows the number of forest fires and size of the burnt area (ha) in Serbia. It can be seen that 2007 was the year with the highest number of forest fires (1627) and the largest burnt area (22161 ha) in Serbia. Table 4 shows the total number of fires in open space and the number of fires by group during the period 2000–2017. Fires in open space comprised approximately 46.34% of all fires. This analysis shows that the highest proportion of fires (50.67%) occurred in the group ‘other fires in open space’.

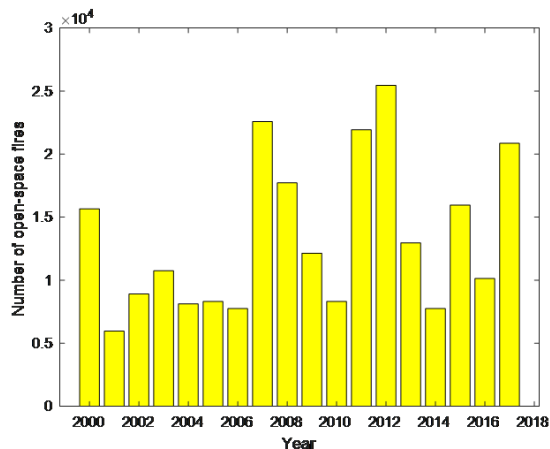


Figure 2: Number of open-space fires in Serbia during the period 2000–2017.

Monthly number of forest fires in Serbia during the period 2009–2017 is presented in Fig. 4. About 70% of all fires is registered in four months; the highest number of fires is observed in August (980), followed by April (891), March (812), and September (725). The dynamics of forest fires in Serbia indicates that most frequently forest fires occurred in early spring and during the summer months. Forest fires usually occur in the season of agricultural works in spring, and in summer due to high temperatures and drought. Annual number of forest fires for selected municipalities is

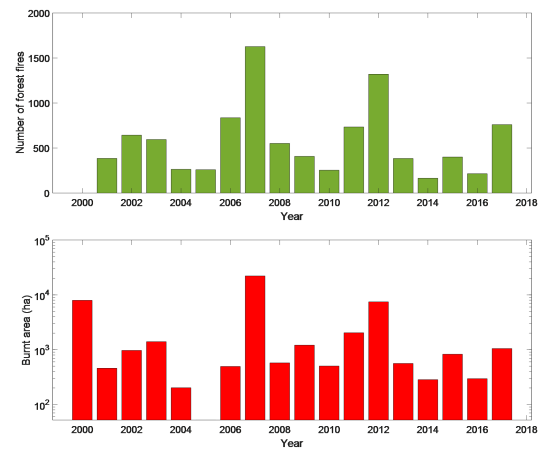


Figure 3: Number of forest fires (upper panel) and burnt area (ha, lower panel) in Serbia during the period 2000–2017.

presented in Table 5. The highest number of forest fires is recorded in all areas in 2012.

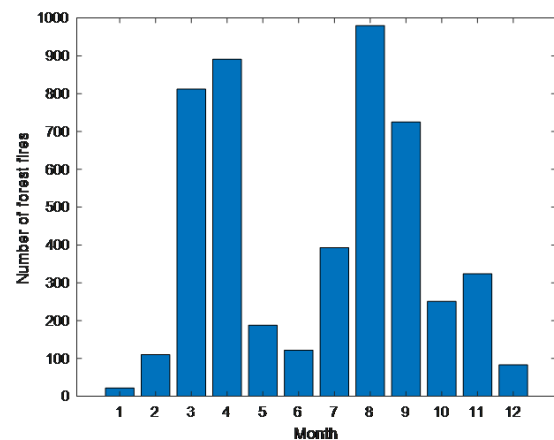


Figure 4: Monthly number of forest fires in Serbia during the period 2009–2017.

The daily values of the Ångström index for six selected stations (Novi Sad, Belgrade, Kragujevac, Zaječar, Kuršumlija and Niš) during the period 2000–2017 are presented in Fig. 5. It can be seen that values of $I < 2.0$, indicating a high likelihood of occurrence of fire, appeared in 2000, 2003, 2007 and 2012 at all selected stations, except in Kuršumlija. In Belgrade (Fig. 5b), all years after 2007 appeared (except 2014) to have a high probability of fire occurrence. According to the Ångström index (Fig. 5c), 2001 and 2008 were years of probable fire occurrence in Kragujevac (central Serbia). Zaječar (Fig. 5d) is the only station in eastern Serbia where the values of the Ångström index were not lower than 2 in 2012. In Kuršumlija (Fig. 5e) in

Table 4: Total number of fires in open space and fire by groups during the period 2000-2017.

Category of fire	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Outdoor fires	15,663	5,961	8,903	10,745	8,126	8,314	7,749	22,584	17,720	12,141	8,315
Forest fires	/	385	643	595	264	259	837	1,627	552	408	254
Cereals fires	/	189	221	175	213	62	62	147	200	286	98
Grass and meadows fires	/	1,877	2,919	3,820	2,311	1,936	2,831	10,273	6,339	4,159	2,789
Orchard fires	/	51	91	90	55	32	92	299	140	129	70
Garbage dump (waste) fires	/	811	1,273	2,031	1,797	2,215	3,073	4,060	4,554	1,212	755
Other fires in open space	/	2,837	3,756	4,034	3,486	3,810	4,721	6,178	5,935	5,947	4,349
Category of fire	2011	2012	2013	2014	2015	2016	2017	Mean	Sum		
Outdoor fires	21,931	25,455	12,966	/	15,958	10,129	20,854	12,973	233,514		
Forest fires	734	1,321	384	165	401	215	760	544	9,804		
Cereals fires	721	416	228	65	112	118	179	194	3,492		
Grass and meadows fires	9,814	11,665	4,596	2,049	4,835	3,079	9,281	4,698	84,573		
Orchard fires	332	349	109	24	103	42	228	124	2,236		
Garbage dump (waste) fires	1,671	1,663	948	2,717	997	584	3,894	1,903	34,255		
Other fires in open space	8,659	10,041	6,701	2,728	7,182	6,091	6,512	5,164	92,967		

Table 5: Annual number of forest fires in: a) Novi Sad (NS), b) Belgrade (BG), c) Kragujevac (KG), d) Zaječar (ZA), e) Kuršumljia (KU) and f) Niš (NI) during the period 2009–2017.

Year	NS	BG	KG	ZA	KU	NI
2009	6	12	9	9	46	4
2010	2	12	24	5	10	9
2011	6	34	56	18	65	10
2012	13	51	108	17	111	24
2013	0	9	14	3	40	4
2014	1	23	5	0	28	8
2015	1	10	15	6	22	7
2016	0	2	8	6	20	5
2017	2	35	45	19	36	19

southern Serbia, 2007 and 2012 were years of very probable fire occurrence. In Niš (Fig. 5f) in southern Serbia, all years after 2010 were determined to have a very high likelihood of fire.

Large-scale forest fires are recorded at 8 locations in July 2007 and at 20 locations in August 2012 in Serbia. Favourable conditions for wildfires have also obtained by simulation using the Ångström index (except for Zaječar in 2012). A good agreement existed between number of fires (Table 5) and values of the Ångström index for Novi Sad (Fig. 5a). The only exception appeared in 2017, when 2 forest fires are registered. Good results are obtained for Belgrade (Fig. 5b) and Kragujevac (Fig. 5c) for 2011, 2012 and 2017, but not for 2013 and 2015. The highest discrepancy between observed and simulated data is noted for Zaječar (Fig. 5d). Comparing data about forest fires (Table 5) and values of the Ångström index, a good agreement is obtained for Kuršumljia (Fig. 5e) and Niš (Fig. 5f).

Figure 6 shows daily values of the Nesterov index for six selected stations. In Novi Sad (Fig. 6a), Belgrade (Fig. 6b), Kragujevac (Fig. 6c), Zaječar (Fig. 6d), Kuršumljia (Fig. 6e) and Niš (Fig. 6f), 2012 appeared as the year with the highest probability of fires, because the values of the Nesterov index were higher than 10,000. In addition, 2000 in Novi Sad (Fig. 6a), 2003 and 2013 in Belgrade (Fig. 6b), 2000, 2013 and 2015 in Zaječar (Fig. 6d) and 2007 and 2013 in Niš (Fig. 6f) were years with fires most likely to occur.

Comparing data about number of forest fires (Table 5) and values of the Nesterov index (Fig. 6), it can be seen that a good agreement existed for Novi Sad (Fig. 6a). Using the Nesterov index, fires in 2011 and 2017 are not reproduced for Belgrade (Fig. 6b) and Kragujevac (Fig. 6c). A wrong number of fires is obtained for Zaječar in 2013, 2015 and 2017 (Fig. 6d). Applying the Nesterov index, good results are obtained for Kuršumljia (Fig. 6e) and Niš (Fig. 6f), except for Niš in 2013.

3.2 Stepwise regression models

Stepwise regression models (SRMs) were applied to Belgrade, for which data on forest fires, fire indices and meteorological variables were available from 1986 to 2017. The models were calibrated for the first 25 years (15 years in the second case and 10 years in the third case) and validated for the remaining 7 years (17 and 22 years).

Table 6 shows the results of regression models for the number of forest fires in Belgrade. The annual mean values of temperature, precipitation, relative humidity, maximum temperature, minimum temperature and wind speed were designated as independent variables. Three SRMs for three periods were evaluated using four goodness-of-fit estimates. Results are presented for three periods: 2001–2017, 2006–2017 and 2011–2017. From Table 6, it can be seen that the highest coefficients of correlation and determination ($r = 0.6556$, $R^2 = 0.4298$) were for the period 2001–2017. This indicates that about 43% of the forest-fire variability in Belgrade could be explained by relative humidity alone. The MEF values were positive for the first two periods and negative for the period 2011–2017. According to the estimates (Table 6), the model for the period 2006–2017 was more efficient, because the RMSE was lower, although MEF was closer to 1 in the period 2001–2017.

Table 7 shows results from stepwise regression models for the number of forest fires for Belgrade with the Ångström index (I), Nesterov index (NI) and Lang factor (L) included as predictors. For the first two periods, the Ångström index was retained only for a significance level (p) of 0.05, while for the evaluation period 2011–2017, L was only retained (Fig. 6b). According to the evaluation estimates, very similar results were obtained for the evaluation periods 2001–2017 and 2006–2017 when the Ångström index was retained as predictor.

Table 8 presents results of the regression models obtained when a combination of meteorological variables

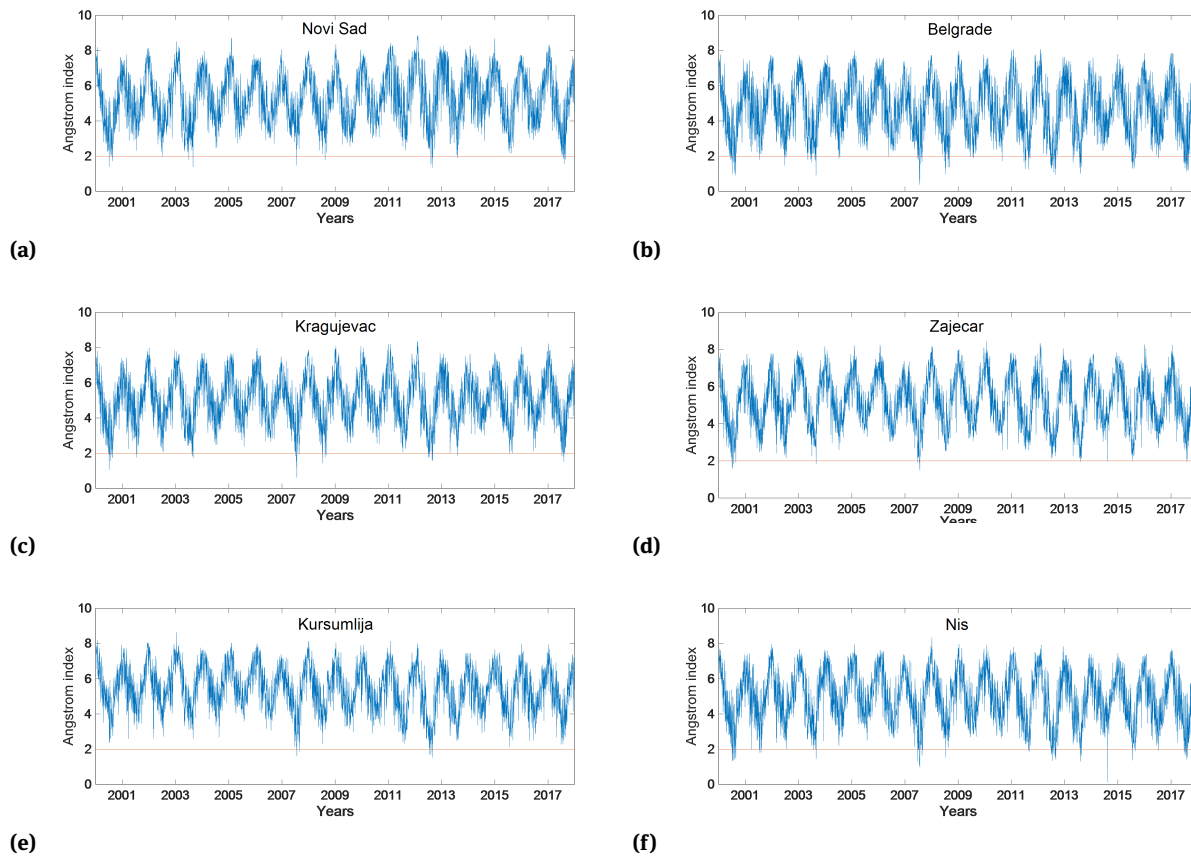


Figure 5: Daily values of the Ångström index for: a) Novi Sad, b) Belgrade, c) Kragujevac, d) Zaječar, e) Kuršumlija and f) Niš during the period 2000–2017.

Table 6: Results from stepwise regression models for number of forest fires in Belgrade with retained predictor (meteorological variables: relative humidity- RH , precipitation- P)

Evaluation period	r	R^2	RMSE	MEF	Predictor
2001–2017	0.6556	0.4298	1.1891	0.2681	RH (%)
2006–2017	0.6272	0.3933	0.8984	0.1703	RH (%)
2011–2017	0.3687	0.1359	0.8054	-0.3577	P (mm)

Table 7: Results from stepwise regression models for number of forest fires in Belgrade with the Ångström index (I) and the Lang index (L) retained as predictor

Evaluation period	r	R^2	RMSE	MEF	Predictor
2001–2017	0.5442	0.2962	1.2929	0.0297	I
2006–2017	0.5514	0.3040	0.8633	0.0019	I
2011–2017	0.3912	0.1530	0.7012	-0.3073	L

and fire-weather index were used as inputs. For two periods, 2006–2017 and 2011–2017, the same results were obtained as when only meteorological variables were used. For the evaluation period 2001–2017, three predictors were retained for p values of 0.05: relative humidity, wind speed

and the Ångström index. In this case, estimates were somewhat worse compared with the results obtained for the same period when relative humidity (Table 6) and Ångström index were retained (Table 7). It should be noted that all retained predictors had negative coefficients, ex-

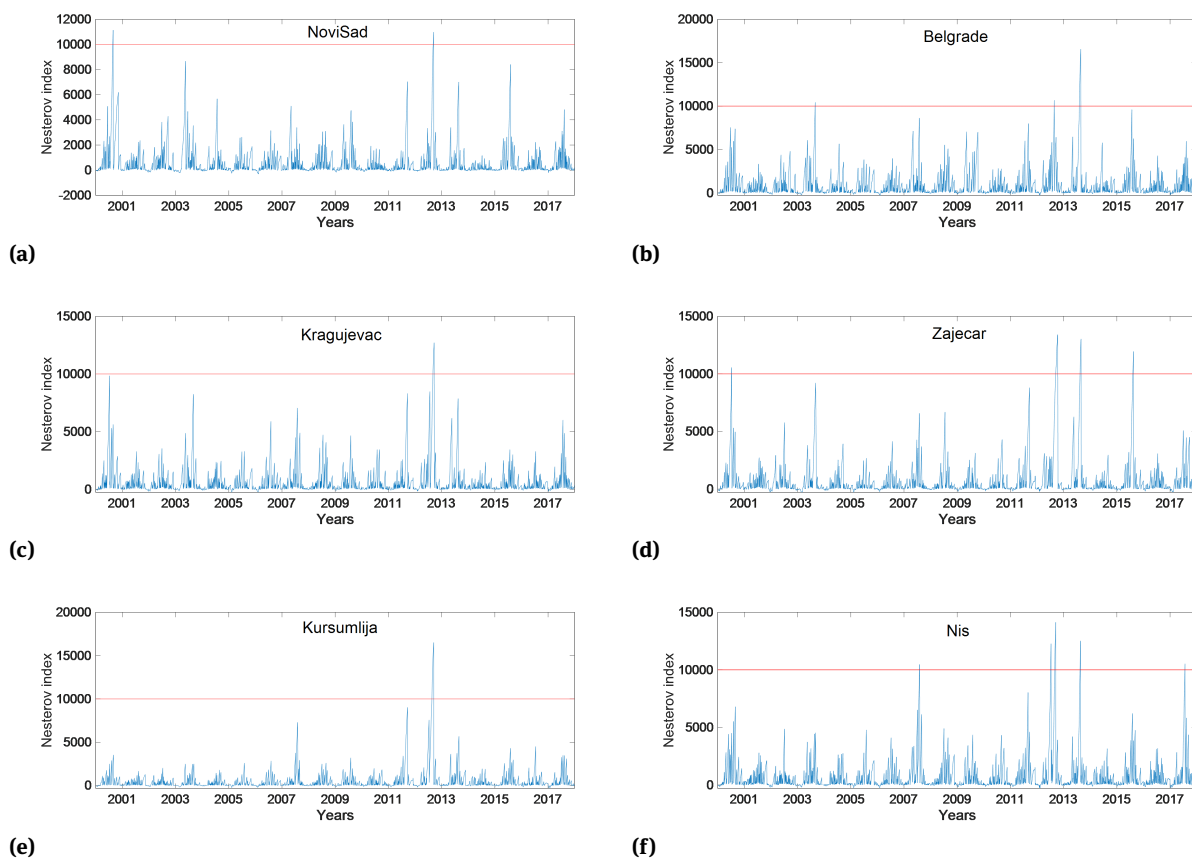


Figure 6: Daily values of the Nesterov index for: a) Novi Sad, b) Belgrade, c) Kragujevac, d) Zaječar, e) Kuršumlja and f) Niš during the period 2000–2017.

cept wind speed, which had a positive regression coefficient.

The time series of the modelled (with different combinations of input variables) and observed annual number of forest fires in Belgrade for the evaluation period 2011–2017 are presented in Fig. 7. Figure 7a shows the model for forest fire occurrence with precipitation (P) retained as a predictor; no other single predictor contributed to the success of the model at a significance level of 0.05. A model with fire indices as predictors, from which the Lang factor (L) was retained, is presented in Fig. 7b. Results show that the modelled number of forest fires followed the observed number of forest fires during the period 2011–2017, and the model captured the maximum value in 2012 well, but not the secondary maximum in 2014. Difference between the model and observations could be explained by the small number of data points.

4 Discussion

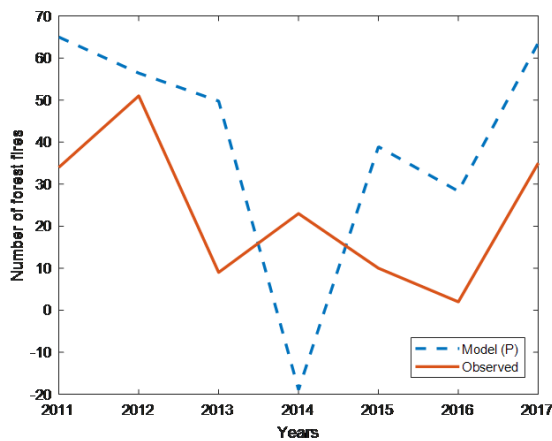
The aims of this study were to examine possible relationships between forest fires and meteorological variables and to model fire occurrences in Serbia using meteorological variables, fire indices or a combination of both. Our results confirm that interannual variability in climate has impact on fire activity.

The number of forest fires increased in Serbia after 2000. Lukić et al. [30] found a positive trend in the number of forest fires in Serbia during the period 2000–2012. Our results agree with Moriondo et al. [40], who observed both an increase in the length of the fire season and an increase in the number of extreme events in Mediterranean countries. They found that the Alps region in Italy, the Pyrenees in Spain and mountains of the Balkan region, where forest cover is very high (>50%), were principally affected.

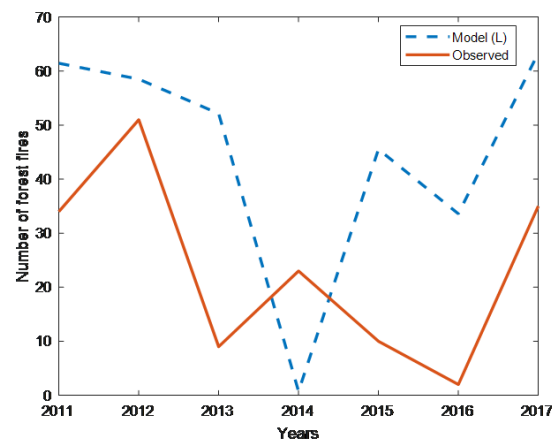
Monthly analysis indicated that the highest number of fires is observed in August, followed by April, March, and September. Our results are in accordance with Tabaković-Tošić et al. [40], who found three critical periods of forest

Table 8: Results from stepwise regression models for number of forest fires in Belgrade with retained predictor (meteorological variables: relative humidity- RH , precipitation- P and wind speed- V , and fire index)

Evaluation period	r	R^2	RMSE	MEF	Predictor
2001-2017	0.5187	0.2690	0.5797	-0.0046	RH (%), V (m/s), I
2006-2017	0.6272	0.3933	0.8984	0.1703	RH (%)
2011-2017	0.3687	0.1359	0.8054	-0.3577	P (mm)



(a)



(b)

Figure 7: Modeled (dashed line) and observed (solid line) annual number of forest fires in Belgrade for the evaluation period 2011-2017: a) using meteorological variables (retained precipitation – P (mm) as predictor, and b) using fire indices (retained L as predictor).

fires, based on the fifty-year monitoring: the early spring (from March to mid-April), summer (from mid-July to late August), and autumn (from the early September to mid-October). They indicated that agricultural producers clean the fields prior to spring sowing by burning, causing the spread of fires in spring. There is a real risk of large forest fires during the period of high air temperatures and lack of

precipitation over an extended period of time in summer. Tourists and hikers (wildfire initiators) usually visit forests in summer and from the early September to mid-October, contributing to spread of fires [40].

The rate of fire occurrence in Serbia was particularly high in two years, 2007 and 2012. Air temperatures were extremely high in 2007 in Serbia. Record high values of maximum temperature affected the territory of Serbia during the summer of 2007, and the previous absolute maximum temperature records dating back to the middle of the twentieth century were exceeded at almost all meteorological stations [41]. According to Šorak and Rvović [42], who analysed the period 2010–2014, the highest number of fires in Serbia was recorded in 2012, characterized by the greatest damage (7,460 ha of burned area and 63,118 m³ of damaged wood mass). The year 2012 had the longest heat waves and the worst drought since the beginning of observations in Serbia [43].

The Ångström and Nesterov indices, as fire occurrence likelihood measures, were used to study number of forest fires in several cities in Serbia. Applying the Ångström and Nesterov indices, we pointed out that the risk of fire was very high after 2011 in Serbia. Good results are obtained for forest fires occurrences using the Ångström index, which includes air temperature and relative humidity. According to Arpaci et al. [44], when looking at fires >1,000 m², the simple indices like the Ångström index, showed a better performance than complex ones, since larger fires occur under conditions that are fire prone.

A stepwise regression model was used to study how much of the variability in the number of forest fires can be explained by meteorological variables. Several models using meteorological variables, fire indices or a combination of both as inputs (predictors) were examined. Among the following meteorological variables: temperature, relative humidity, precipitation, maximum temperature, minimum temperature and wind speed, only precipitation and relative humidity were retained as predictors with a negative coefficient, and wind speed as a predictor with a positive regression coefficient. The Ångström and Lung indices were retained with a negative regression coefficient. The model's performance for Belgrade was found to be rea-

sonable, including only precipitation or relative humidity as predictors. Our results are in accordance with the findings of De Angelis et al. [45], who demonstrated that, surprisingly, even using meteorological variables only allows a similar or better performance than using the complex Canadian Fire Weather Index (FWI).

5 Conclusions

In this study, the potential influence of meteorological variables on forest fire risk in Serbia was examined. The obtained results indicated that forest fires interact with climate dynamics. The most favourable conditions for the occurrence of the wildfires are high air temperatures, low relative humidity, and lack of precipitation. Monthly analysis indicated that most frequently, forest fires in Serbia occurred in August, March-April, and September. A particularly high number of wildfires occurred in Serbia in 2007 and 2012. The maximum number of forest fires was 1627, while the burnt area was 22161 ha in 2007 in Serbia. Air temperatures were extremely high in 2007, while the longest heat waves and the worst drought since the beginning of observations were recorded in 2012 in Serbia.

The Ångström and Nesterov indices were used to estimate a risk of fires. Better results were obtained using the Ångström than the Nesterov index, since the Ångström index includes relative humidity and temperature, while the Nesterov index includes only temperature and dew-point temperature. Further investigation which of fire indices are best suited for forest fire risk analysis is necessary.

In order to identify the meteorological variables responsible for forest fires, different combinations of input variables (meteorological variables, fire danger indices or a combination of both) were tested. The performance of the stepwise regression model for Belgrade was found to be reasonable, including only precipitation or relative humidity as predictors. Our results are in accordance with those obtained by other researchers.

Monitoring climatic conditions in a given area is increasingly recognized as a useful tool for the successful prediction and management of forest resources. Values of climate elements and their variability indicate when and to what extent there is a risk of the emergence and spread of fire in the forest. Understanding the effects of climate elements on forest fire is essential to preparing for climate change impacts on future forest fires, when an increase in temperature is expected.

This examination of fires and meteorological variables serves as a starting point for understanding the role of fire

in Serbia. Further understanding of how climate variability affects wildfire activity is needed to guide managers and policy makers as they face difficult decisions regarding issues such as fuel management, firefighting, and post-fire rehabilitation practices under varying scenarios of climate and land-use changes.

Conflict of interest: The authors of this manuscript declare no conflict of interest.

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