INFLUENCE OF CLIMATIC CONDITIONS ON FIRE RISK IN DJERDAP NATIONAL PARK (SERBIA)
A Case Study of September 2011

by

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The Djerdap National Park in Serbia is vulnerable to fires. The variability of a fire in the Djerdap National Park is studied depending on the impact of climatic conditions. The influence was investigated on a yearly, monthly, and daily basis using data recorded at the meteorological station Veliko Gradiste. Data were analyzed for two periods: 1961-1990 and 1991-2017, and for the year of 2011. Special attention is devoted to the conditions for the emergence of the largest forest fire in the Djerdap National Park in September 2011. In this study, the Angstrom index, the Nesterov index, and method of deficit and surplus of precipitation are used to predict the risk of fire. There was an increased danger of fire in the forests in the period of 1991-2017 compared to the period of 1961-1990. Indices showing fire risk are increased for the months of June, July, and August. The September 2011 is characterized by an increase of average monthly air temperature by 3.7 °C and a reduction of the total monthly rainfall of 32.3 mm compared to a long-term average value which favorable influenced to the occurrence of large forest fires.

Key words: *climate change, risk, fire, forestry, the Djerdap National Park, Serbia*

Introduction

Developing a system for assessing the risk of fire in order to identify the climatic conditions suitable for the emergence and development of fires in nature is an important step in the proactive management of fire and resources. The development of such a system relies on a long-term record of the occurrence of fires, as well as on numerous sources of information about past and present values of climate variables in a certain area. It is expected that climate change will significantly affect the intensification of forest fires [1], and that it will further increase the already high risk of natural disasters in Serbia [2].

The Djerdap National Park (from now on referred to simply as Djerdap) in Serbia, is vulnerable to wildfires [3], which are frequent and lead to significant degradation of the environment. Proper management of forest potential should reduce vulnerability and improve recovery. The sensitivity, adaptability and vulnerability of vegetation (forest) to fire depend on climate conditions. Assessment of the risk of fire in nature should give answers to the causes, how much and in what way affect the vulnerability of forests against fire. Many studies around the world [4-7] pointed out the importance and influence of climatic conditions on the emergence and development of fire in nature. There have been several studies about the impact of

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climate change on forest fire risk in Serbia. The effect of deficit and surplus of precipitation, and air temperature on forest fire risk is examined in the municipality of Negotin [8, 9]. A significant correlation between meteorological parameters and forest fire occurrence is found in the Tara region of Serbia [10]. The risk of forest fires caused by the drought is the greatest in August and July in Serbia [11]. To examine potential relationships between meteorological variables and forest fires in Serbia, daily temperature, precipitation, relative humidity, and wind speed data for fifteen meteorological stations across Serbia are used [12]. They found that using relative humidity or precipitation as a predictor only generates a satisfactory model for forecasting of number of forest fires (NFF).

The focus of this study is to determine Djerdap's vulnerability to wildfires based on climatic conditions. The results of this work can be used to estimate the extreme fire danger conditions defining thresholds that may be relevant to the heritage of the national park.

Materials and methods

Study area and data sources

Djerdap is located in the southeastern part of Europe, in the northeastern part of the Republic of Serbia, fig. 1. The total area of the national park is 63608.45 ha wherein forest cover makes up about 70% (www.npdjerdap.org). Djerdap is open to the east and to the Wallachia Plain, which is located between the Carpathian Mountains in the north and the Old Mountains in the south.

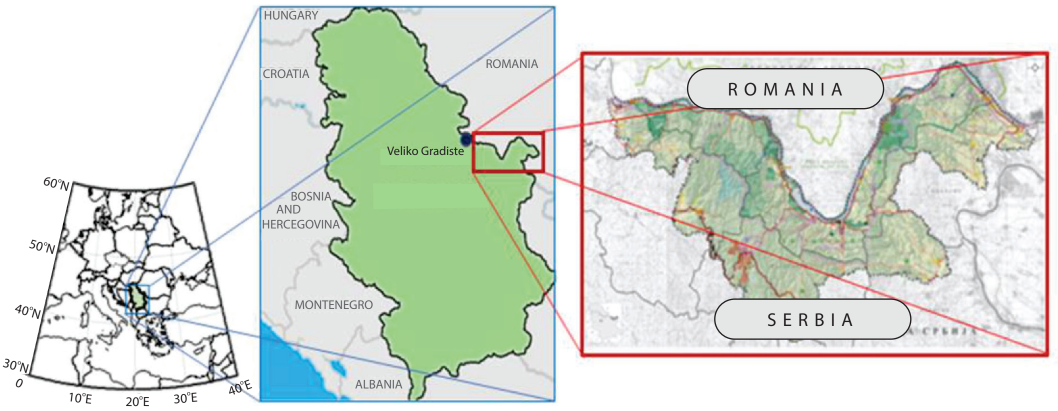

Figure 1. Location of Serbia in Europe and map of the National Park Djerdap in Serbia

The observations were taken at the meteorological station Veliko Gradiste (φ = 44°45' N, λ = 21°31' E, H = 82 m), located next to Djerdap. The main air masses coming from the northwest and southeast [13]. The coldest month is January, and the warmest July.

To consider the climate characteristics in the area of Djerdap, we used a daily series of air temperature, precipitation and relative humidity observations from the main meteorological station of Veliko Gradiste for the period 1961-2017, operated by the Republic Hydrometeorological Service of Serbia [14].

Changes in air temperature and precipitation are determined by comparison between the standard climatological period (1961-1990) and the study period (1991-2017). Based on these data, the annual, monthly and daily values of precipitation deficit or excess are calculated, from which a period of fire risk is determined. Risk assessment of fire occurrence in nature is presented on the basis of statistical indicators of registered number of fires in the open air at Djerdap in the period 1991-2017.

Methods

The Angstrom index

For assessment of the risk of forest fires, the Angstrom index, I, is used [15, 16]:

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

where I is the Angstrom index, R [%] – the relative humidity, and T [°C] – air temperature. The values for I translate into fire danger:
- fire occurrence unlikely, $I > 4.0$,
- fire conditions unfavorable, $4.0 < I < 2.5$,
- fire conditions favorable, $2.5 < I < 2.0$, and
- fire occurrence very likely, $I < 2.0$.

In this study, the daily, monthly and annual values of the Angstrom index are analyzed at the meteorological station Veliko Gradiste. Based on these parameters, we can analyze the impact of climate conditions on the number and size of fires in nature.

The Nesterov index

The Nesterov index, NI, is calculated according to [17]:

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

where w is the number of days since the last rainfall exceeding 3 mm per day, T_i [°C] – the temperature on a given day i , and T_i^{dew} [°C] – the dew-point temperature on the same day. The NI is reset to zero when the daily rainfall exceeds 3 mm per day [18]. The original risk levels proposed by Nesterov are:
- no risk, $NI < 300$,
- low risk , $301 < NI < 1000$,
- medium risk, $1001 < NI < 4000$,
- high risk, $4001 < NI < 10000$, and
- extremely high risk, $NI > 10000$.

Method of deficit and surplus of precipitation

Using the method of deficit and surplus of precipitation (DSP), the duration of the dry and wet periods can be determined. The DSP method is based on the analysis and comparison of the observed precipitation and a mean expected amount of precipitation. The difference between the observed, P, and the potentially expected, $\overline{P}$, amount of rainfall is a continuous function of time [19]:

$$(R_d)_i = (P_d - \overline{P}_d)_i \tag{3}$$

where d is the daily value and i – the Julian day.

Monthly deficit or surplus of precipitation can be determined:

$$(D_m)_j = T_m + \sum_{j=1} (P_m - \overline{P}_m)_j \tag{4}$$

where $j = 1, 2, ..., m$, $m = 12$ and T_m [mm] is the monthly deficit or surplus of precipitation transferred from the previous month.

Correlation

A Pearson correlation coefficient, *r*, between time-series of number of the fires, and the air temperature, precipitation and fire indices are produced to investigate the possible connection. The significance level of the correlation is computed by transforming the correlation to create a *t* statistic having *N*-2 degrees of freedom, where *N* is the length of the series [20].

Multiple linear regression attempts to model the relationship between two or more explanatory variables and a response variable by fitting a linear equation to observed data [21]. The coefficient of determination, R^2, is a statistical metric that is used to measure how much of the variation in outcome can be explained by the variation in the independent variables.

Results and discussion

Climate characteristics of Djerdap National Park

Temperature regime provides a basic feature of the climate of Djerdap. Periods of high air temperatures represent a very pronounced high risk for the occurrence of wildfires [9]. Table 1 shows monthly mean and annual mean air temperatures for different periods. Taking into consideration values of the mean air temperature in the period 1991-2017, tab. 1, the increase in annual average of 0.8 ºC can be observed relative to the last standard climatological normal (1961-1990). Monthly mean air temperatures during the vegetation period (April-September) of 2011 are above the long-term average, tab. 1.

Table 1. Monthly mean and annual mean (Ann) air temperature [°C] at the Meteorological station Veliko Gradiste for different periods of analysis

	Month												
Period	1	2	3	4	5	6	7	8	9	10	11	12	Ann
1961-1990	–0.8	1.5	6.0	11.6	16.4	19.3	20.8	20.4	16.8	11.6	6.0	1.2	10.9
1991-2017	0.4	2.0	6.7	10.2	13.1	19.9	22.7	22.1	17.0	11.7	6.7	1.4	11.7
2011	0.2	-0.8	6.3	12.9	16.7	21.2	22.6	22.7	20.5	10.4	2.6	3.4	11.6

During the vegetation period of 2011, the average temperature is 19.4 °C which is 1.9 °C higher compared to the long-term average. The largest increase in the monthly mean air temperature is 3.7 °C during the month of September. It is observed that the average monthly air temperature is above 20 °C during the period June-September in 2011, tab. 1. The trend of

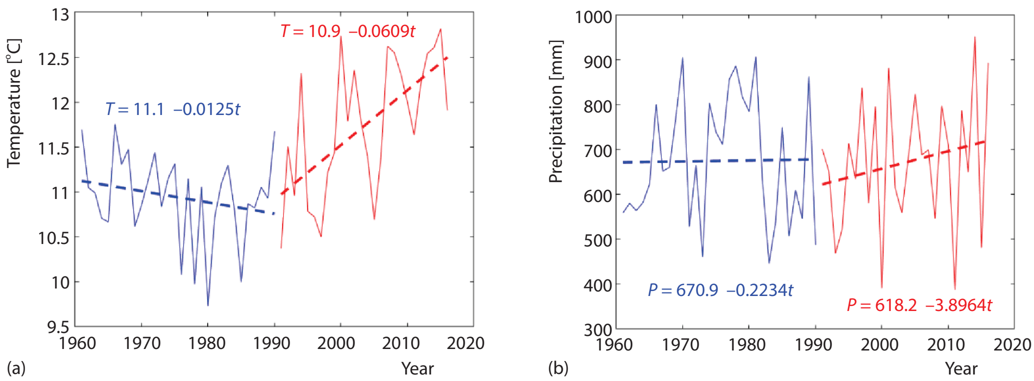

Figure 2. (a) Annual mean air temperature and (b) annual precipitation sums in Veliko Gradiste during the periods 1961-1990 and 1991-2017; linear trend is presented by dashed line

annual air temperature at the meteorological station of Veliko Gradiste is shown in fig. 2(a). The decrease of the annual mean temperature is observed in the period 1961-1990, and an increase in the period 1991-2017. Applying the Mann-Kendall test, it is found that a positive trend in the period 1991-2017 is statistically significant at the 1% level of significance.

According [22], the amount and distribution of rainfall is an important climatic factor affecting the spread of fire, so that the number of fires decreases exponentially with precipitation. Distribution and amounts of precipitation affect the increase in moisture content of the fuel material [8], and thereby reducing the risk of fire or *vice versa*. Table 2 shows the values of the mean monthly and annual precipitation in different periods of the analysis.

Taking into account the value of the precipitation amount in 2011, tab. 2, a significant reduction in the annual average of 287.2 mm can be observed compared to the last standard climatological normal (1961-1990). Table 2 shows that the monthly mean amount of precipitation during the vegetation period of 2011 is significantly below the long-term average. During the vegetation period (April-September) of 2011, the precipitation is measured to be 211.4 mm, which is 180.4 mm lower than the long-term mean. A pronounced increase in rainfall was observed in July, while the reduction in rainfall is obvious during the remaining months.

A deficit in precipitation in 2011 has caused a marked reduction of topsoil moisture as well as a significant deterioration of moisture in the deeper layers. The trend of annual precipitation sum at the meteorological station of Veliko Gradiste is shown in fig. 2(b). A non-significant increase of precipitation is observed for both periods, with a greater increase seen from 1991 to 2017. The lowest precipitation amounts are recorded in 2000 and 2011.

Table 2. Mean monthly and annual (Ann) precipitation [mm] at the meteorological station Veliko Gradiste for different periods of analysis

	Month												
Period	1	2	3	4	5	6	7	8	9	10	11	12	Ann
1961-1990	48.8	43.2	44.0	55.9	73.6	87.6	67.7	56.7	50.3	41.2	47.3	58.5	674.8
1991-2017	43.9	41.9	40.9	58.8	68.9	70.0	75.3	53.8	62.6	55.8	46.5	66.3	668.2
2011	44.8	36.1	21.1	28.1	29.5	26.6	102.5	6.7	18	20	0.0	54.2	387.6

Analysis of the fire indices

The Angstrom and Nesterov indices are used to assess the risk of fire [23]. In 2011, the largest decrease of the Angstrom index (0.84), and thereby an increase in the risk of fire, is registered in September.

From August 1st to September 30th 2011, according to the values of the Angstrom index, fig. 3(a), the risk of fire was very high (the index value was less than 2.0) on September 5th 2011. The days with favorable conditions for the occurrence of fire (values of the Angstrom index were between 2.0 and 2.5) are registered on 8, 25, 26, and 27 August, and 12 and 18 September. Values of the Angstrom index between 2.5 and 3.0 are registered on 7 and 24 August, and 4 and 19 September 2011. Otherwise, the Angstrom index values are above three, which means unfavorable fire conditions.

According to the values of the Nesterov index, fig. 3(b), the high risk of fire (the index values were between 4001 and 10000) was from August 27th to September 1st 2011. The days with the medium risk for the occurrence of fire (the index values were between 1001 and 4000) are registered from 12th to 20th September, including 14th September when the forest fire occurred.

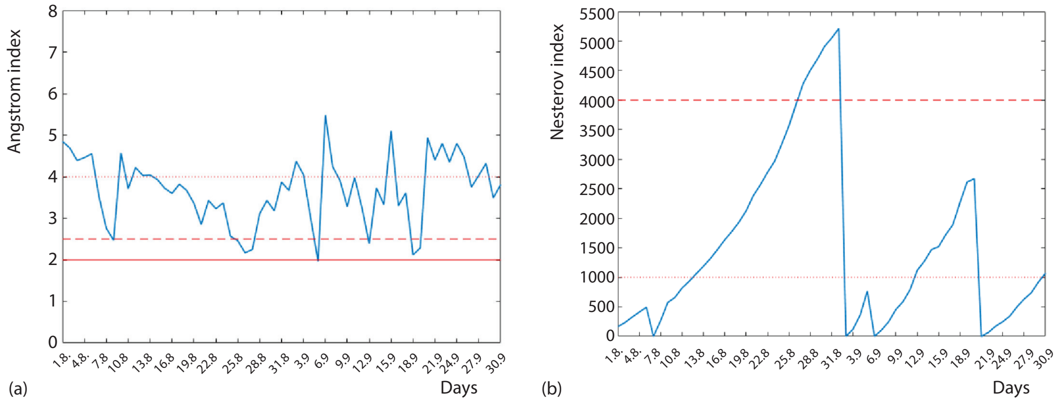

Figure 3. (a) Daily fluctuation for Veliko Gradiste from August 1st to September 30th 2011 of the Angstrom index with fire danger classes: *I* = 2.0 (noted by horizontal solid line), *I* = 2.5 (dashed line), *I* = 4.0 (dotted line), and (b) Nesterov index with fire danger classes: *NI* = 4001 (dashed line) and *NI* = 1000 (dotted line)

The DSP analysis

Results for monthly DSP, based on eq. (4), at the meteorological station Veliko Gradiste are given in tab. 3. From this table it can be seen that there is a deficit of precipitation over 10 months and an excess of precipitation for two months. During the year, over all months, except in January, a lack of rainfall $D_m < 0$ exists, because the deficit in 10 months could not be recovered by the excess of the other two months. From tab. 3 it can be seen that for September of 2011, the monthly precipitation is 18 mm. The expected mean monthly precipitation is 62.6 mm, by which the lack of precipitation –44.6 mm is determined. A lack of rainfall occurs in the month of August, with only 6.7 mm being recorded, down from the expected 53.8 mm.

Table 3. Monthly deficit or surplus of precipitation (mm) in Veliko Gradiste in 2011

Month, (*j*)	$(P_m)_i$	$(\bar{P}_m)j$*	$(R_m)_j$	$(D_m)_j$
January	44.8	43.9	0.9	0.9
February	36.1	41.9	–5.8	–4.9
March	21.1	40.9	–19.8	–24.7
April	28.1	58.8	–30.7	–55.4
May	29.5	68.9	–39.4	–94.8
June	26.6	70.0	–43.4	–138.2
July	102.5	75.3	27.2	–111.0
August	6.7	53.8	–47.1	–158.1
September	18.0	62.6	–44.6	–202.7
October	20.0	55.8	–35.8	–238.5
November	0.0	46.5	–46.5	–285.0
December	54.2	66.3	–12.1	–297.1
∑	387.7	668.2	–280.5	

* Expected monthly amount of precipitation based on the period 1991-2017

The long dry season from August 7 to September 2 with no precipitation is observed in 2011, tab. 4. In addition, the dry season with no precipitation is recorded from 8-20 September which, along with high air temperatures, were conducive to the spread of fire.

Table 4. Daily deficit of precipitation [mm] from August 1 to September 30 2011

Date	$(R_d)_i$	$(\bar{P}_d)_i$*	$(D_d)_i$	Date	$(R_d)_i$	$(\bar{P}_d)i$*	$(D_d)_i$
01/08	0.0	1.73	–1.73	01/09	0.0	2.1	–49.03
02/08	0.0	1.73	–3.46	02/09	4.7	2.1	–46.43
03/08	1.1	1.73	–4/09	03/09	0.0	2.1	–48.53
04/08	0.0	1.73	–5.82	04/09	0.0	2.1	–50.63
05/08	0.0	1.73	–7.55	05/09	0.0	2.1	–52.73
06/08	5.5	1.73	–3.78	06/09	5.7	2.1	–49.13
07/08	0.0	1.73	–5.51	07/09	2.8	2.1	–48.43
08/08	0.0	1.73	–7.24	08/09	0.0	2.1	–50.53
09/08	0.0	1.73	–8.97	09/09	0.0	2.1	–52.63
10/08	0.0	1.73	–10.70	10/09	0.0	2.1	–54.73
11/08	0.1	1.73	–12.33	11/09	0.0	2.1	–56.83
12/08	0.0	1.73	–14.06	12/09	0.0	2.1	–58.93
13/08	0.0	1.73	–15.79	13/09	0.0	2.1	–61.03
14/08	0.0	1.73	–17.52	14/09	0.0	2.1	–63.13
15/08	0.0	1.73	–19.25	15/09	0.0	2.1	–65.23
16/08	0.0	1.73	–20.98	16/09	0.2	2.1	–67.13
17/08	0.0	1.73	–22.71	17/09	0.0	2.1	–69.23
18/08	0.0	1.73	–24.44	18/09	0.0	2.1	–71.33
19/08	0.0	1.73	–26.17	19/09	0.0	2.1	–73.43
20/08	0.0	1.73	–27.90	20/09	0.4	2.1	–75.13
21/08	0.0	1.73	–29.63	21/09	4.2	2.1	–73.03
22/08	0.0	1.73	–31.36	22/09	0.0	2.1	–75.13
23/08	0.0	1.73	–33.09	23/09	0.0	2.1	–77.23
24/08	0.0	1.73	–34.82	24/09	0.0	2.1	–79.33
25/08	0.0	1.73	–36.55	25/09	0.0	2.1	–81.43
26/08	0.0	1.73	–38.28	26/09	0.0	2.1	–83.53
27/08	0.0	1.73	–40.01	27/09	0.0	2.1	–85.63
28/08	0.0	1.73	–41.74	28/09	0.0	2.1	–87.73
29/08	0.0	1.73	–43.47	29/09	0.0	2.1	–89.83
30/08	0.0	1.73	–45.20	30/09	0.0	2.1	–91.93
31/08	0.0	1.73	–46.93				

* Expected daily amount of precipitation based on the period 1991-2017

The daily values of DSP (noted by the bars) for the period August 1 – September 30 2011 are shown graphically in fig. 4. This figure shows a long period with a deficit of precipi-

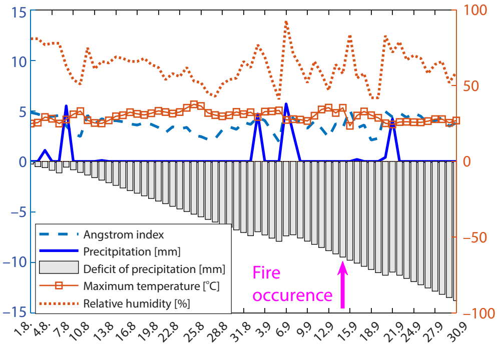

Figure 4. Deficit of precipitation (bar), the Angstrom index (dashed line), precipitation (solid line), maximum temperature (square), and relative humidity (dotted line) in August and September 2011

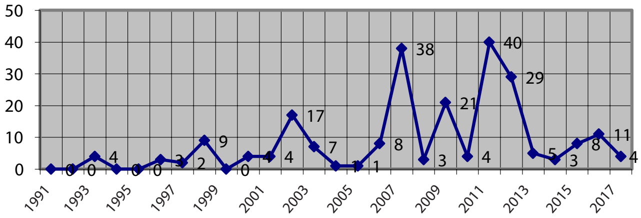

Figure 5. The NFF per year in the period 1991-2017

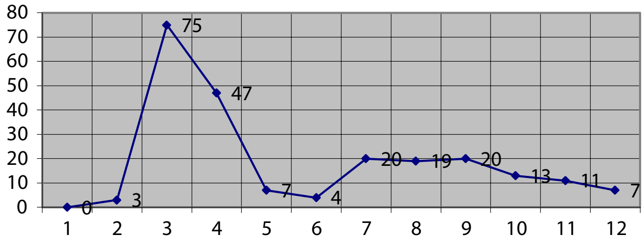

Figure 6. Registered number of fires on the monthly bases from 1991 to 2017

tation and that there are no periods with surplus of precipitation. The period with a deficit of precipitation coincides with the period of fire (14/09/2011).

The dynamics of the fire occurrence

In recent years, the more frequent occurrence of fire in nature is noted in the area of Djerdap. The trend of the increase of fire numbers arises in particular in the years when there are increased values of air temperature and reduced precipitation amounts are observed. Figure 5 presents the dynamics of fire in the open air within Djerdap in the period 1991-2017. The largest number of fires was in 2011 (40) and 2007 (38). From fig. 5 it can be determined that the lowest number of fires was during the years 1991, 1992, 1994, 1995, and 1999.

Looking at the dynamics of fire on a monthly basis, the highest number is observed during the period March-April, fig. 6. From the growing season period, the lowest number of fires was during the months of May and June. The largest NFF in the national park appeared in March (75 fires – 33.2%), then in April (47 fires – 20.8 %). After these two months, according to the frequency of fire, they are: July and September with 20 fires (8.8%), August with 19 fires (8.4%) and October with 13 fires (4.9%). Considerably fewer fires were observed during the remaining months, with no registered fires in January. The month of March (17) had the most recorded in 2012 [24]. March of 2012 is characterised by the low precipitation of 16.0 mm from the expected 40.9 mm, mean monthly air temperature was 7.4 °C while the long-term mean for March is 6.0 °C (1961-1990), and by two dry periods, a short one from 4 to 11 March, and a longer one from 13 to 29 March in 2012.

Among the registered number of fires in nature for the reporting period of 1991-2017, according to the affected area and intensity, the largest fire started in September 2011. Namely, the fire originated on the September 14th in 2011 at around noon in the municipality of Majdanpek at the mountain of Somrda (803 m, 44°32′23″ N, 21°58′32″ E) and affected 100 hectares of old oak forest. On the day of the fire, the mean daily air temperature was 22.7 °C, maximum air temperature 35.4 °C, relative humidity 58%, and there was no precipitation.

Correlation with forest fires

Possible connection between the annual number of fires and climatic factors during the period 1991-2017 is examined using the linear correlation, fig. 7(a). Non-significant negative correlation is found between the annual number of fires and precipitation ($r = -0.1275$), and a positive one with temperature ($r = 0.3292$). Air temperature was high and precipitation very low (marked by the filled circle) in 2011, fig. 7(b). It is found that a negative relationship exists between the annual number of fires and the Angstrom index ($r = -0.2785$), and a positive one with the Nesterov index ($r = 0.2862$) for the period 1991– 2017. Since a low correlation is found between the number of fires and precipitation/temperature, a multiple linear regression model is made. We tested several combinations of meteorological variables as explanatory variables, and obtained a very high (absolute) value of the correlation coefficient $r = -0.6835$ when mean temperature, relative humidity and precipitation are included in the model. The coefficient of determination, R^2, is 0.4672, meaning that 46.72% of the variation in NFF can be explained by the variation in the following variables: annual mean temperature, T, annual mean relative humidity, R, and annual precipitation, P. In this case, regression equation for NFF:

$$NFF = -115.0747 + 8.1750T + 0.2835R + 3.6879P \tag{5}$$

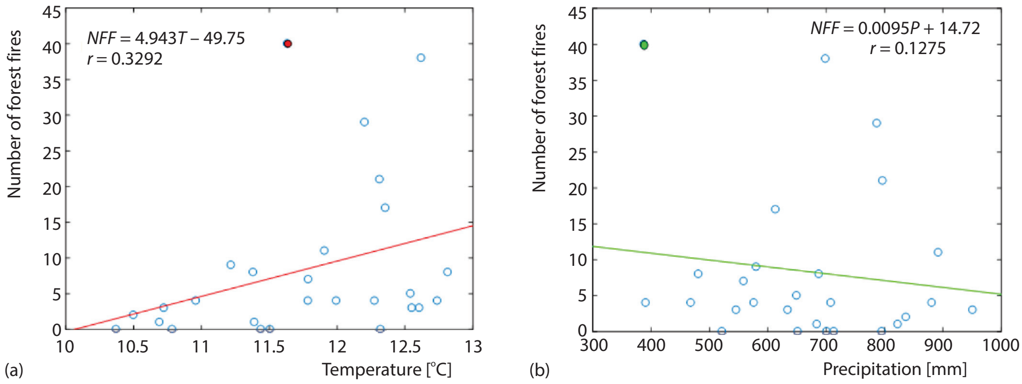

Figure 7. (a) Linear correlation during the period 1991-2017 between the annual NFF and temperature and (b) NFF and precipitation

A positive correlation is found between the annual NFF and the Nesterov index, because this index is proportional to the temperature. The Nesterov index is calculated by using temperature and dew-ponit temperature, while the Angstrom index by combining temperature and humidity. Both indices are simple fire danger indicator, but they can be very successful. Studies [10, 12] showed that the relationship between forest fires and fire indices existed in different regions of Serbia. In order to improve the wildfire risk assessment, the Angstrom index was modified, and a significant correlation with the forest fires is found in southern Serbia [25]. Beside the fire indices, the raw climate data can be used to estimate fire occurrence. The mean daily temperature is found to be a good proxy for fire danger in seven out of 18 ecoregions in Austria during the summer [26]. In Germany, [27] found relative humidity to be a good indicator of fire danger. In the case of the Djerdap National Park, the best results for number of fires are obtained by inclusion of temperature, relative humidity and precipitation.

Conclusions

Case study for the Djerdap National Park in 2011 showed that the occurrence of large forest fires was strongly influenced by climatic conditions. It was evident, based on the analysis of weather conditions, that extremely hot weather with long heat wave was recorded in September 2011. The occurrence of the heat waves was recorded also in the month of August with a reduced amount of rainfall conducive to drying out of the fuel material in the wood, thereby increasing the level of their flammability.

It can be concluded that is possible to determine the level of risk of fire by applying mathematical models, which are based on weather data. Using the Angstrom and Nesterov index values, and method of deficit and surplus of precipitation were presented and graphically illustrated by an example of forest fire at the mountain of Somrda (Serbia). A negative (positive) correlation is found between the number of fires and precipitation (temperature). Among the several multiple linear regression models for fires occurrences, the best results were obtained when the mean temperature, relative humidity and precipitation were used as explanatory variables. Results obtained by a method of the Angström and Nesterov indices, and deficit and surplus of precipitation, indicated periods when there was a greater risk of fire. In the case of forest fire in September 2011, there were favorable conditions for the occurrence of fire according to the values of the Nesterov index. The application of proposed models can serve as a starting point for predicting and managing fires in the forest. Protection of forests against fire should be given special attention in order to mitigate the negative effects of climatic conditions on the formation and development of forest fires.

Acknowledgment

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Nomenclature

D_d – daily deficit/surplus of precipitation, [mm]
D_m – monthly deficit/surplus of precipitation, [mm]
I – Angstrom index
NI – Nesterov index
NFF – number of forest fires
P – precipitation, [mm]
P_d – observed daily precipitation, [mm]
$\bar{P}_d$ – expected daily precipitation, [mm]
P_m – observed monthly precipitation, [mm]
$\bar{P}_m$ – expected monthly precipitation, [mm]
R – relative humidity, [%]
r – correlation coefficient
T – air temperature, [°C]
t – mean annual temperature

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