DEVELOPMENT OF A NATIONAL INDEX FOR THE PURPOSE OF FOREST FIRE RISK ASSESSMENTS ON THE EXAMPLE OF SOUTHERN SERBIA

by

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The paper presents the results on the study of the possible application of the Canadian Forest Fire Weather Index (FWI) and the Modified Angstrom Index (Mod Ang) in forest fire risk assessments. The daily values of these indices for the period 2005-2015 were related to the forest fire database. It was found that there is a relatively weak to moderate correlation between forest fires and the values of the Canadian Forest Fire Weather Index (FWI). In order to improve the wildfire risk assessments (including forest fires), the index was modified. The modified index has a significantly greater correlation with the actual events of forest fires and consequently a much wider application in southern Serbia. The modified index can be of great importance in the future concepts of forest fire risk management.

Key words: *forest fire, assessment, risk, modified index, Serbia*

1. Introduction

Apart from their ecological role in the maintenance of important life cycles, forests have other functions related to the economy, tourism, trade, recreation and health, etc. However, forests used to cover much larger surface areas of the Earth than today.

Forest fires are a key element of the Earth's system that correlates with climate characteristics, human activity, and type of vegetation [1]. With 200 - 500 million hectares of burned area a year, forest fires damage larger areas and destroy more biomass around the world than any other adverse factor affecting natural ecosystems [2,3].

Weather conditions have a dominant role in the outbreak of fires in a particular area [4]. High temperatures and low relative air humidity are the basic factors in the fire triangle expressed through the heat and moisture content in the fuel material.

The assessment of the risk of forest fire outbreak is one of the most important tasks undertaken as preventive action of forest fire protection. In this way, fire damage can be minimized, while a good fire detection system, pre-fire season preparation, good mobility and preparedness can prevent the occurrence of forest fires. Forest fire risk assessments imply scenarios which include when and where a fire will occur and how it will develop. The elements needed to predict the time of fire occurrence are defined by the fire season, i.e., the dynamics of forest fire outbreak which is determined by long-term monitoring.

The criteria applied when assessing where a fire will occur are determined by the area, the type of fuels in the area, orographic and climatic conditions and the availability of fuels. These parameters determine the way a fire will develop and measures to be taken for its suppression.

Some specific studies have determined the correlation between solar activity and forest fires [4-10], but results of this study are still in the research phase.

In Portugal, the Canadian Forest Fire Weather Index (FWI) has shown great variability within individual districts and relative applicability in the areas where no meteorological data are available [11].

Since the data of daily measurements are presented in the Meteorological Yearbook of the Republic Hydrometeorological Service of Serbia, the issue of the possible use of the Canadian Forest Fire Weather Index (FWI) has become increasingly pronounced. Its application is hindered by distinct orographic characteristics of the area of Serbia which require very extensive research in order to develop correction parameters [12] and a different risk scale. Therefore, we have developed a modified Angstrom index which provides a simpler way of determining the degree of forest fire vulnerability [13].

The differences in the characteristics of these two indices also stem from the differences in the characteristics of the areas in which they were created. The Canadian Forest Fire Weather Index (FWI) was created in the conditions of a humid area with high sums of precipitation during the summer and cold winters, thus representing a cumulative index complicated to measure. The Modified Angstrom Index (Mod Ang) is adapted to the conditions of Serbia, i.e., dry and warm springs and summers and autumns with low precipitation. This is a daily index easy to measure.

The method of determination and the simplicity of its application should be a parameter to enable the creation of climate change scenarios and their impact on the increasing forest fire risk on smaller territorial units within regions.

2. Research method

The study of climate characteristics and their effects on the occurrence of forest fires included the following: air temperature, relative humidity, precipitation and wind. The daily values for the period 2005 - 2015 were studied and correlated with the forest fire databases in this period. The databases contain daily measurements and show the number of fires, the affected area and the location of fires.

The analysis includes the Canadian Forest Fire Weather Index (FWI) and the Modified Angstrom Index and their relationships with climate factors and the actually existing forest fire events. A comparison of these two indices was made and the possibility of their application in the territory of southern Serbia was assessed.

The Canadian Forest Fire Weather Index (FWI) is based on the model of estimating the flammability of forest fuels and its dependence on past and current weather conditions [13].

It consists of six components: three primary components (Fine Fuel Moisture Code - FFMC, Duff Moisture Code - DMC and Drought code - DC) two indirect components (Initial spread index - ISI and Buildup index – BU) and one that denotes the intensity of an individual fire in the standard type of fuel (The Fire Weather Index (FWI)).

The Fine Fuel Moisture Code (FFMC) is a numeric rating of the moisture content of forest litter and other fine fuels in the forest. This code is an indicator of the relative ease of ignition and the flammability of fine fuel. It typically refers to a 2-3 cm thick layer of dead organic forest litter, weighing about 5 t/ha [14].

The calculation of the Fine Fuel Moisture Code is based on daily temperatures, relative humidity and wind speed.

The precipitation over the past 24 hours greater than 0.6 mm points to the moisture of fuels by the early afternoon in the hottest part of the day. This value is most adequate for the estimation of inflammability. The wind is used to calculate the initial fire spread index in meters per minute.

The Fine Fuel Moisture Code - FFMC is calculated using the formula (1,2):

$$FFMC=59.5\ (250-m) \tag{1}$$

$$m=147.2\ (101-FFMC)/(59.5+FFMC) \tag{2}$$

where: m - fine fuel moisture content obtained as a function of air humidity.

Duff Moisture Code - DMC is a numeric rating of the average moisture content of loosely compacted organic layers of moderate depth and the medium-size wood material. This code refers to 5-10 cm thick layer of dead organic forest litter, weighing about 50 t/ha. It is the primary source of energy that ignites a fire in most types of fuels.

The calculation of this code is based on air temperature, relative humidity, 24-hour precipitation greater than 1.5 mm and the day length.

DMC is an indicator of moisture at a depth of 5-10 cm obtained according to the following formula (3,4):

$$DMC=DMCo\ (or\ DMCr) + 100\ K \tag{3}$$

$$K=1.894\ (T'+1.1)\ (100-H)\ Le\ 10-6 \tag{4}$$

where: DMCo = DMC of the previous day; DMCr = DMC if it is raining; T' = air temperature at 12 o`clock; H = relative air humidity at 12 o`clock; Le = the length of the visible part of the day; r = 24-hour rainfall in mm.

The Drought Code - DC is a numeric rating of the average moisture content of deep, compact organic layers and large wood material. In the coarse deep layer of dead forest litter, the layers can contain up to 350-400% of water compared to the weight of dry fuels. In places where coarse combustible material burns, the fire is difficult to extinguish and control.

The calculation of this code is based on air temperature, 24-hour rainfall greater than 2.9 mm, the current month for the calculation of the value describing the moisture content in the layer 10-20 cm below the dead forest litter weighing 440 t/ha [14].

These moisture codes (modules of the meteorological fire indices) have the following meanings regarding the inflammability and fire durability: FFMC - inflammable; DMC - durable and wind power; DC – difficult to extinguish and control.

The Drought Code - DC is derived from the following relationship (5):

$$DC = DCo\ (or\ DCt) + 0.18\ (T + 2.8) + 0.5\ Le \tag{5}$$

where: DCo = DC of the previous day; DCt = DC after rain; T = air temperature at 12 o'clock; Le = the length of the visible part of the day; r = 24-hour rainfall in mm.

The DC value is a long-term indicator that is sensitive to seasonal drying that can last for 2, 3 and 4 months.

The Initial spread index – ISI combines the effects of wind speed and the Fine Fuel Moisture Code. It is used as a numeric rating of the expected rate of fire spread immediately after it has broken out. To determine the Initial Spread Index, wind speed data at a height of 10 m are needed. The Initial Spread index uses four classes of ROS (Rate of Spread).

The Buildup Index - BU combines the Duff Moisture Code – DMC and the Drought Code - DC. It is a numeric rating of the total amount of fuel available for combustion. The numeric value of this index ranges from 0 to 400.

The Initial Spread Index – ISI and The Buildup Index – BU are represented by equations (6,7).

$$ISI = 0.208\ f(W)\ f(F) \qquad (6)$$

$$BUI = 0.8\ DMC \times DC/(P+0.4\ DC) \qquad (7)$$

where: f (W) = wind function; f (F) = fine fuel moisture function; DMC = The Duff Moisture Code; DC = The Drought Code.

The Fire Weather Index (FWI) combines the Initial Spread Index with the Buildup Index. This index is a numeric rating of the potential intensity of a fire in the standard fuel type and indicates the degree of energy produced per unit of fire front length. The value of the Fire Weather index depends only on meteorological elements and it is calculated on a daily basis. The values obtained point to the risk of fire in a given area in the time interval around noon. This method allows temporal and spatial comparisons of this index. It shows the range of localization, the size of spread, and the degree of the damage that may occur. The Fire Weather Index, as the final index, is used in all planning activities.

Tab. 1. presents numeric values that determine the Fire Weather Index (FWI) on the basis of which the degree of forest fire risk is determined.

Table 1.Forest fire risk according to FWI

FWI	Forest fire risk
from 0 to 5.2	VLR – Very low risk
from 5.2 to 11.2	LR - Low risk
from 11.2 to 21.3	MR – Moderate risk
from 21.3 to 38.0	HR – High risk
from 38.0 to 50.0	VHR – Very high risk
50.0 and more	ER – Extreme risk

In order to improve the wildfire risk assessment, the Angstrom index was modified [12] in the following way:

1. the mean air temperature was replaced with the maximum air temperature in the formula

2. the mean relative air humidity was replaced with the minimum relative air humidity in the (formula.

By incorporating these parameters, the formula has the following form:

$$Mod\ I = R_{min}/20 + (27-T_{max})/10 \qquad (8)$$

Tab. 2. presents numeric values that determine the Modified Angstrom index (Mod Ang) on the basis of which the degree of forest fire risk is determined

3. Research results

3.1 *Climate characteristics*

The explored area belongs to Climate Zone III, with pronounced continental characteristics and subarea III d as the driest part of Zone III [15]. The hottest months are July and August at all stations (Vranje climatological station), and the coldest are February (Vlasina, -3.2^{0}C) and January (Kukavica, -3.1^{0}C).

Table 2. Forest fire risks according to Mod Ang

Mod Ang	Forest fire risk
<2.0	EC1 – Extreme forest fire conditions1
2.0 – 2.5	EC2 - Extreme forest fire conditions 2
2.5 – 3.0	VH1 – Very high risk 1
3.0 – 4.0	VH2 – Very high risk 2
4.0 – 5.0	HR – High Risk
5.0 – 6.0	MR – Moderate Risk
6.0 - 7.0	LR – Low risk
> 7.0	VLR – Very low risk

The mean winter air temperatures range from -2.5^{0}C at Kukavica to 0.9^{0}C in Leskovac and Vranje, while the summer temperatures range from 13.7^{0}C inVlasina to 20.4^{0}C in Vranje, spring temperatures from 5.2^{0}C in Vlasina to 11.2^{0}C in Leskovac and autumn temperatures from 6.6^{0}C in Vlasina to 11.4^{0}C in Vranje.

The mean monthly minimum air temperatures are the lowest in February (Vlasina and Kukavica climatological stations). Mean monthly maximum air temperatures are the highest in July and August and the lowest in January.

Precipitation of the research area is determined by the physical-geographical characteristics, the character of atmospheric circulation during the year and local factors.

The annual precipitation totals in the research area range from 564.1 (Klenike) to 999.4 mm (Kriva Feja). The highest amount of precipitation during the growing period was recorded at Kukavica (547.6 mm or 58.6% of the total precipitation).

The wind is an important element of climate that affects temperature relationships and humidity. It determines the precipitation and cloudiness. The distribution of wind depends mainly on the distribution of air pressure. The direction and speed of wind are affected by the topography.

In the Vranje area, the most prevailing wind blows from the northeastern direction over the whole year. Wind speed with Beaufort scale number 2.2 has been registered for this direction. The winds blowing from the southeast, south and northwest are less frequent in the area. Southeastern (Beaufort scale number 1.8) and southern (Beaufort scale number 2.1) winds have the lowest speed. The highest speed with Beaufort scale number 2.5 was recorded in the winds blowing from the north, and somewhat smaller (Beaufort scale number 2.4) from the east, west and northwest. The northeastern and southwestern slopes are most affected by these winds. They are followed by the northern, eastern, western and northwestern aspects, while the southern and southeastern aspects are not endangered.

3.2 The number of fires and the burned area

Between 2005 and 2015, a total of 621 fires were recorded while the burned area amounted to 5662.5 ha. The mean fire burned area was 9.1 ha tab.3.

Table 3. The number of fires, burned area, mean fire burned area by years of the study period

Year	Number of fires	%	Burned area (ha)	%	Mean burned area (ha)
2005	-	-	-		-
2006	1	0.2	108.0	1.9	108.0
2007	33	5.3	198.3	3.5	6.0
2008	12	1.9	4.5	0.1	0.4
2009	-		-		-
2010	11	1.8	317.6	5.6	28.9
2011	70	11.3	412	7.3	5.9
2012	483	77.8	4520.7	79.8	9.4
2013	-		-		-
2014	7	1.1	94.6	1.7	13.5
2015	4	0.6	6.8	0.1	1.7
Total	621		5662.5		9.1

Source: [13]

3.3 Correlation of the forest fire risk indices with the forest fire database

The daily values of the Canadian Forest Fire Weather Index (FWI) and the modified Angstrom index for the period 2005-2015 were correlated to the actual forest fires that hit the area of southern Serbia at the time. The values of these indices are shown in fig. 1 and 2.

3.4 Principal Component Analysis (PCA)

PCA was applied to determine the variability of data between and within the analyzed fire indices in order to select the best variable for discrimination. The results of these analyses are presented both numerically and graphically.

The principal component analysis (PCA) of the data related to meteorological stations for the observation period from 2005 to 2015 distinguishes three components (fig. 3). The numeric results of this analysis are shown in tab. 4. According to the obtained eigenvalue and percentage values, the first three components (coordinates) are sufficient to explain 84.686% of the total variability of the data. The value that each variable (climatic factor) contributes to the overall variability of data (according to the first, second and third axis) are shown in tab. 5.

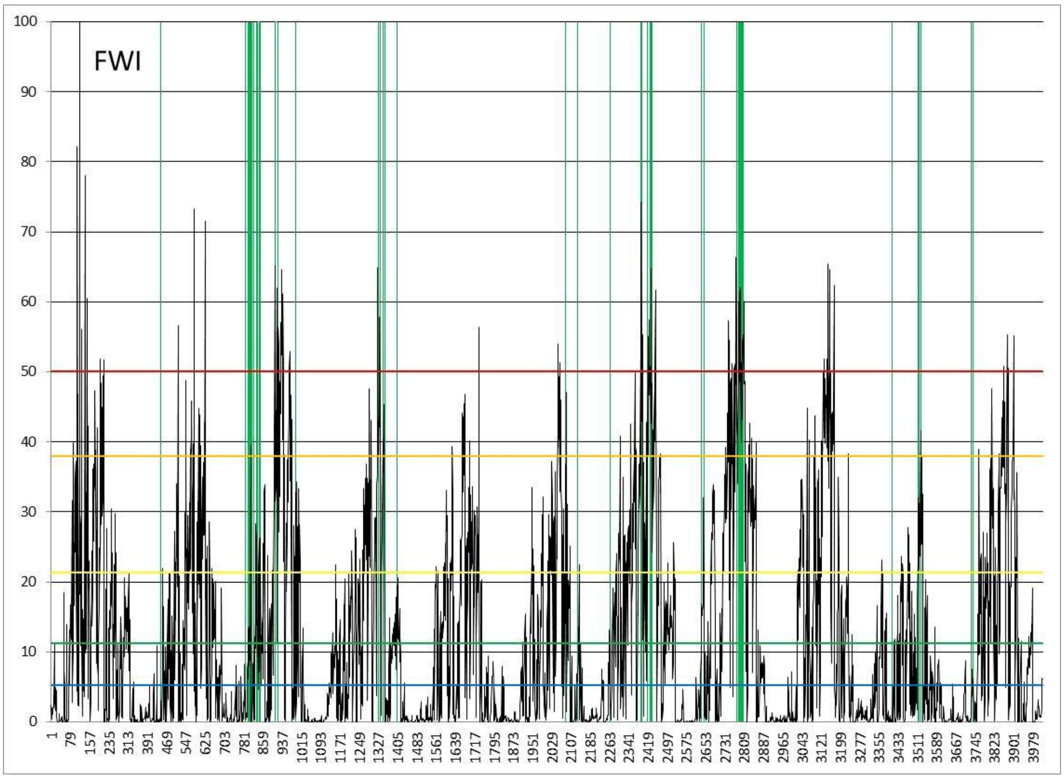

Figure 1. FWI for the research area

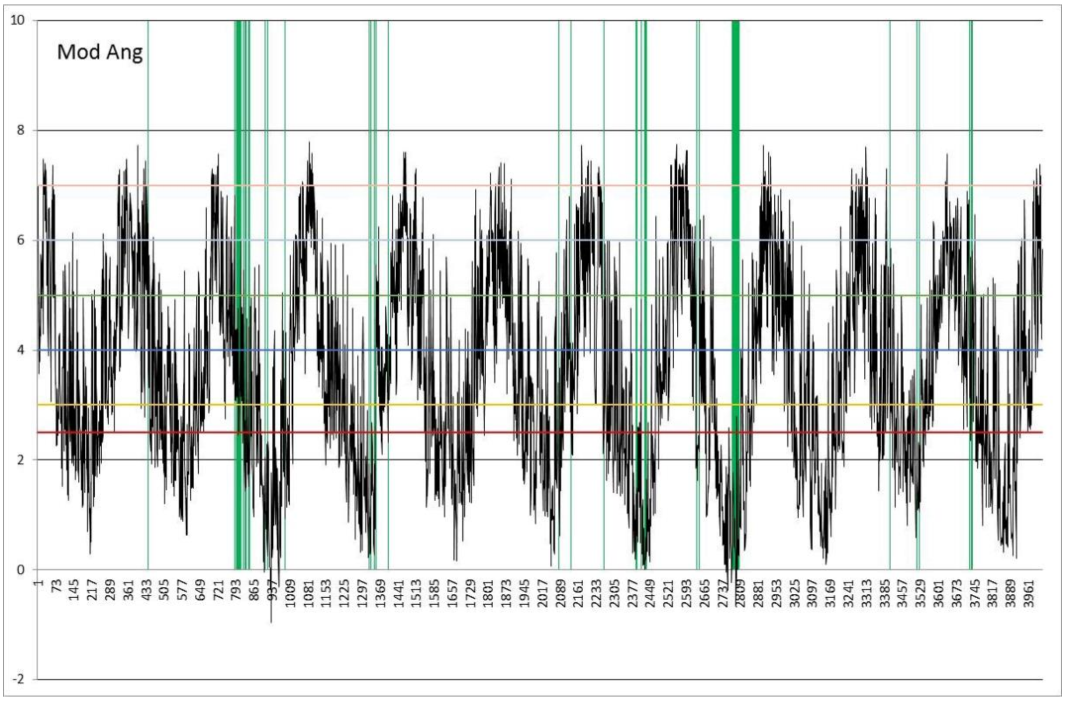

Figure 2. Mod Ang for the research area

Table 4. Eigenvalues and percentage values each coordinate contributes to the overall variability of the investigated fire burned areas and the data obtained

Component number	MS Vranje		
	Eigenvalue	Variance percentage	Cummulative percentage
1	3.87681	48.460	48.460
2	1.64824	20.603	69.063
3	1.24982	15.623	84.686
4	0.826939	10.337	95.023
5	0.259255	3.241	98.263
6	0.0842699	1.053	99.317
7	0.043637	0.545	99.862
8	0.0110306	0.138	100.000

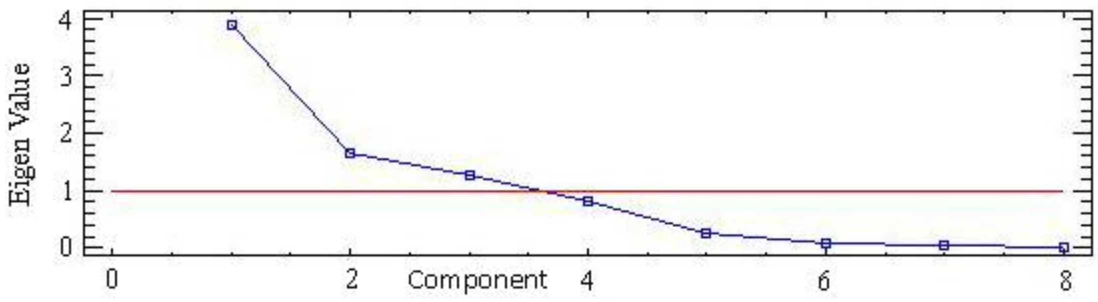

Figure 3. The number of derived components and their eigenvalues

Table 5. Values to which each variable (climatic characteristics) participates in describing the total variability of the tested fire samples and the data obtained

Factor	MS Vranje		
	Components		
	1	**2**	**3**
T Max	0.4722	0.2469	0.0086
T Min	0.3977	0.4282	0.1120
T Mean	0.4566	0.3138	0.0334
MIN Humid	-0.3942	0.3379	0.2729
Mean Humid	-0.3692	0.3755	0.2887
Wind	0.0471	-0.3154	0.7726
Insolation	0.3393	-0.3805	0.3687
Precipitation	-0.0362	0.3973	0.3091

The graph of scattering points (fig. 4) shows the geometric distance between the observed climatic parameters as well as the variability that can be noticed between them.

According to the first component, the investigated fields are divided into two groups. One group is composed of the mean, the minimum and the maximum air temperatures. It also includes precipitation. The second group consists of the minimum and the maximum relative humidity, while the third group includes the wind and the insolation.

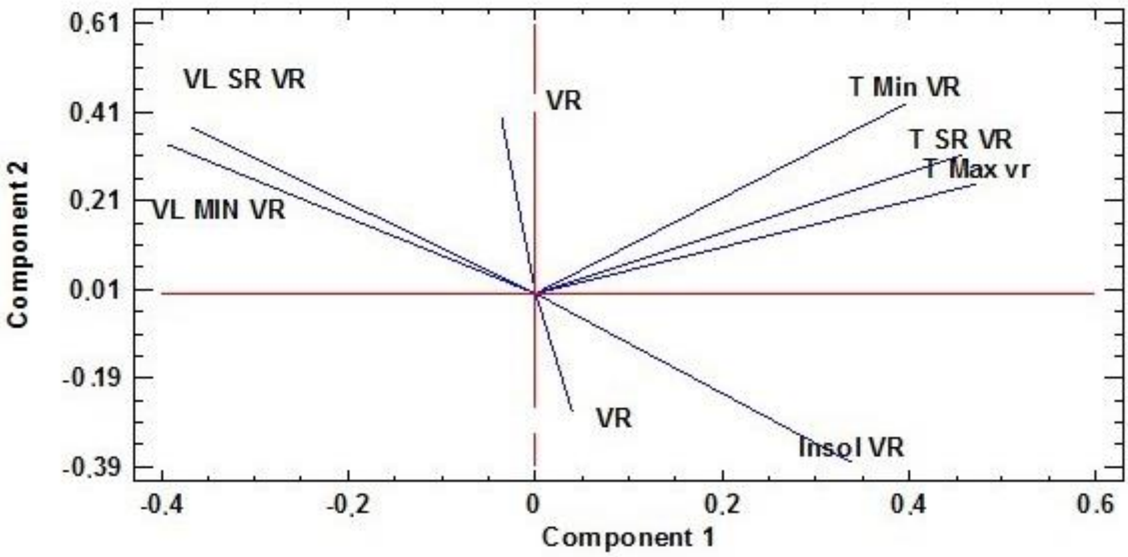

Figure 4. Two-dimensional presentation of data distribution (scattering points)

3.5 *The correlation between the Canadian Forest Fire Weather Index (FWI) and the Modified Angstrom Index (Mod Ang)*

The correlation was established between the Canadian Forest Fire Weather Index (FWI) and the Modified Angstrom Index of the potential danger of forest fire outbreaks. The results of this analysis are shown in tab. 6 and in fig. 5.

The F-test value indicates a level of significance of 95% and amounts to 5417.47. The coefficient of determination shows that the variability of the variables is explained with 57.42%. The standard estimation error is 9.54. The Durbin-Watson test indicates that there is a possibility of serial correlation between the analyzed indexes.

Table 6. Correlation between the FWI and the Modified Angstrom Index (original data)

Correlation equation	Regression parameters	Values
FWI = 33.3826 – 5.93719 ModAng	Standard regression error	9.53671
	Coefficient of correlation	0.7577
	Coefficient of determination	0.5742
	F-test	5417.47
	Durbin-Watson test	0.833663

Correlation coefficients point to a strong correlation between the Canadian Forest Fire Weather Index (FWI) and the Modified Angstrom Index of the potential danger of forest fire outbreaks.

The correlation between the Canadian Forest Fire Weather Index (FWI) and the Modified Angstrom Index of potential dangers of forest fire outbreaks (categories) is shown in tab. 7 and in fig. 6.

F-test value is 5667.56. The coefficient of determination shows that the variability of the variables is explained with 58.52%. The standard error of estimation is 0.92. The Durbin-Watson test indicates that there is a possibility of a serial correlation between the analyzed indices and it amounts to 0.93.

Regarding the number of days in the study period from 2005 to 2015 (a total of 4017 days), according to the Canadian index there are 83 days of extreme fire risk1 (2.07% of the total), 238 (5.92%) of very high risk, 614 (15.29%) of high risk, 625 (15.56%) of moderate risk, 505 (12.57%) of low risk and 1952 (48.59%) of very low risk.

Table 7. Correlation between the Canadian Forest Fire Weather Index (FWI) and the Modified Angstrom Index (Mod Ang) (categories)

Correlation equation	Regression parameters	Values
	Standard regression error	0.924727
	Coefficient of correlation	0.7649
FWI cat = 2.79954 + 0.512418 ModArn cat	Coefficient of determination	0.5852
	F-test	5667.56
	Durbin-Watson test	0.925497

If we compare Canadian index data with the forest fire database for the study period, only 416 fires occurred (66.88% of the total) at the time of extreme fire risk, while 121 fires (19.45%) were registered in the very high and 25 (4.02%) in the high-risk category. There were 20 fires (3.22%) in the category of low fire risk and 16 fires (2.57%) in the category of very low risk. The number of fires classified according to the forest fire risk based on the Canadian Weather Index is shown in tab. 8.

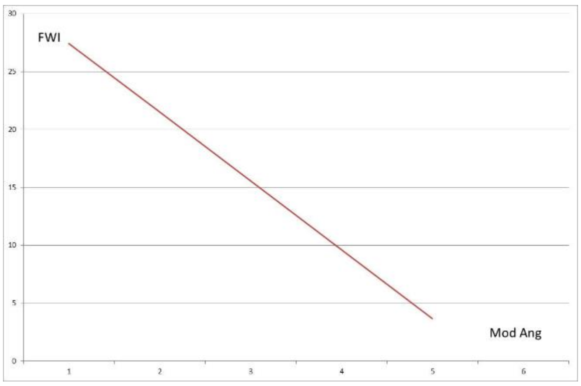

Figure 5. The correlation between the Canadian Forest Fire Weather Index (FWI) and the Modified Angstrom Index

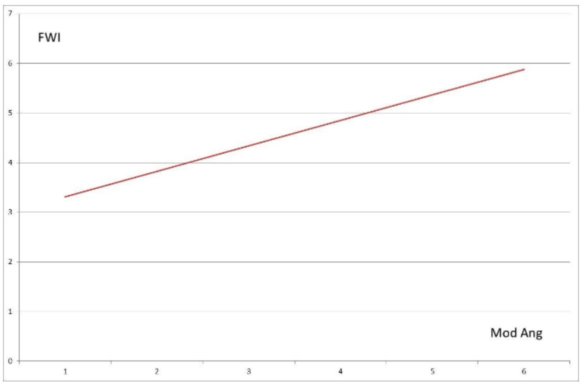

Figure 6. Correlation between the degree of the Canadian Forest Fire Weather Index (FWI) and the degree of the Modified Angstrom Index

According to the Modified Angstrom Forest Fire Risk, extreme conditions for the occurrence of forest fires 1 were recorded in 959 days (23.9% of the total), extreme conditions for the occurrence of forest fires 2 were registered in 367 days (9.1% of the total number), while very high risk 1 was observed in 365 days (9.1%), and very high risk 2 in 686 days (17.1%). High risk was recorded in 592 days (14.7%). The low risk of forest fires was recorded in 412 days (10.2%) and very low in 105 days (2.6%).

The comparison of the modified Angstrom Index with the forest fire database shows that 548 fires (88.1% of the total) were registered at the time of extreme fire risk 1, 14 fires (2.3% of the total) were registered in the extreme fire risk 2. The category of very high risk 1 registered 24 fires (4.3%), while the category of very high risk 2 registered 18 fires (2.9%). In the category of high risk, there were 6 fires (0.9%). Only 1 fire (0.2%) was registered in the category of low risk of forest fires of the Modified Angstrom index, while no fire was recorded in the very low-risk category.

The number of fires and the number of days according to the forest fire risk based on the Modified Angstrom is shown in tab. 9.

Table 8. The number of days and the number of fires according to the forest fire risk based on the Canadian Fire Weather Index (FWI)

Fire risk	Number of days		Number of fires	
	N	%	N	%
ER	83	2.07	416	66.88
VH	238	5.92	121	19.45
HR	614	15.29	25	4.02
MR	625	15.56	24	3.86
LR	505	12.57	20	3.22
VLR	1952	48.59	16	2.57

Table 9. The number of days and the number of fires according to the forest fire risk based on the Modified Angstrom index (Mod Ang).

Fire risk	Number of days		Number of fires	
	N	%	N	%
EC1	959	23,9	548	88.1
EC2	367	9.1	14	2.3
VH1	365	9.1	27	4.3
VH2	686	17.1	18	2.9
HR	592	14.7	6	0.9
MR	531	13.2	8	1.3
LR	412	10.2	1	0.2
VLR	105	2.6		

4. Conclusion

This study shows that the analysis of forest fires in the period from 2005 to 2015 provided a more efficient way of predicting forest fires in southern Serbia. The Modified Angstrom Index has a significantly greater correlation with the actual events of forest fires. Therefore it can be recommended for its further application.

The Modified Angstrom Index can be used in the creation of climate change scenarios when data on the amount of fuel for combustion and microclimate conditions that can cause a forest fire are not available, which is the case in most underdeveloped countries, including Serbia.

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