IFSCOM2019 6th International IFS and Contemporary Mathematics Conference, 07-10 June, 2019 Mersin TURKEY

FOREST FIRE ANALYSIS BASED ON INTERCRITERIA ANALYSIS

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ABSTRACT

Forest fires annually affect large areas all over the world. They are one of the reasons for changes in the forest ecosystems, which lead to unpredictable consequences in long term. The present research builds up an analysis of the forest fires risk assessment in Bulgaria over the last 20 years.

Two methodologies, different in their essence, are used in the study: a common approach (Lubenov's methodology) and InterCriteria Analysis (ICrA). Lubenov's methodology classifies the different regions of Bulgaria in groups according to the risk of forest fires. ICrA, which seeks to find relations between some predefined criteria, is used as an additional approach to refine this classification. The research is based on the number of the forest fires occurred in different regions of Bulgaria and the size of the burned areas over the past 20 years.

FOREST FIRES DATA

The territory of Bulgaria is divided into sixteen Regional Forest Directorates (RFD):

Berkovitsa, Blagoevgrad, Burgas, Kardzhali, Kyustendil, Lovech, Pazardzhik, Plovdiv, Ruse, Sofia, Shumen, Sliven, Smolyan, Stara Zagora, Varna and Veliko Tarnovo.

Each year in its Annual Reports, the Bulgarian Executive Forest Agency provides statistics for the fires occurred on the RFD territories. The data include the number of the forest fires, size of the burned territories, type of the fires, type of woods affected by the fires, reasons for the fires and others.

The present research uses data on the number of the forest fires and the size of the burned territories in each RFD for the past 20 years, from 1999 to 2018. These data are illustrated in Fig. 1 and Fig. 2.

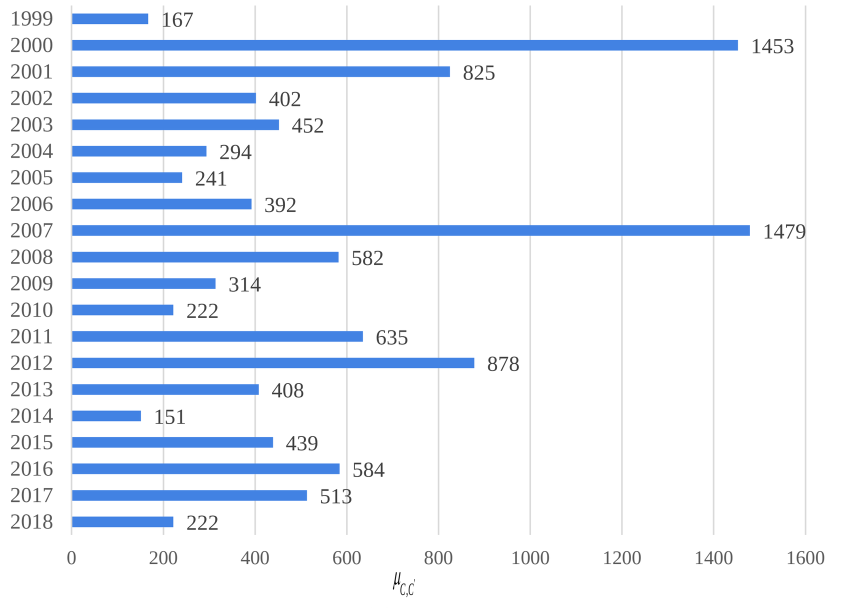

Figure 1. Number of fires in Bulgaria (1999 – 2018)

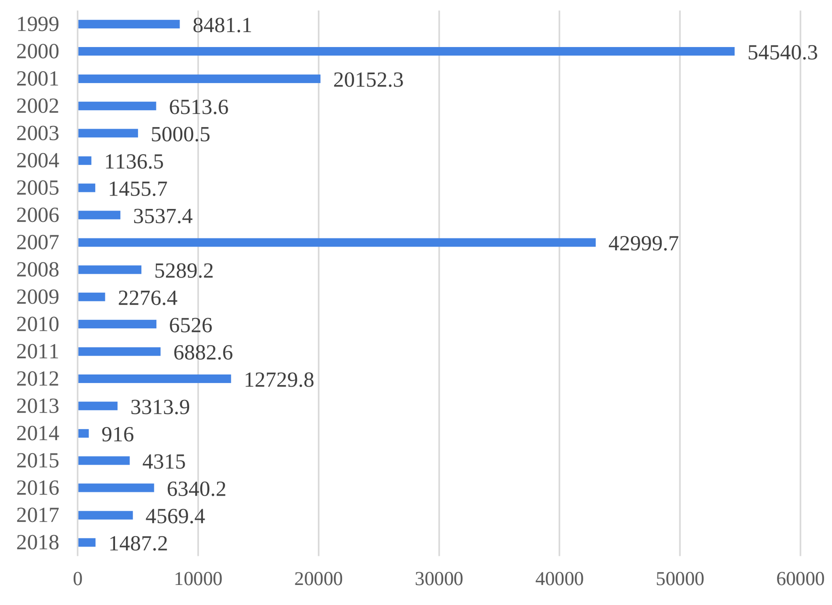

Figure 2. Burned territories in Bulgarian (1999 – 2018)

THEORETICAL BACKGROUND

Methodology of Lubenov

The risk of occurring of forest fires in a certain region R_{ffo} is defined as:

$$R_{ffo} = R_{dens} \times R_{rba}, \qquad R_{dens} = \frac{1000 \sum_{i=1}^{n} N_i}{n \times F_{reg.ter.}}, \qquad R_{rba} = \frac{1000 \sum_{i=1}^{n} F_{ba}}{n \times F_{reg.ter.}}$$

where R_{dens} is the average annual numerical value of the fire density on the given region, defined as the average annual number of fires (N_i) occurred over a given period of time (n) on an area of 1000 ha (10 km^2) of the total area of the region ($F_{reg.ter.}$) and R_{rba} is the real burned area is defined as the average annual burned area (F_{ba}) in hectares (ha) over a given period of time (n) on 1000 ha (10 km^2) of the total area of the region ($F_{reg.ter.}$).

InterCriteria Analysis

Let $O = \{O_1, O_2, \dots, O_n\}$ denotes the set of objects being evaluated, and $C(O) = \{C(O_1), C(O_2), \dots, C(O_n)\}$ be the set of objects evaluations by a given criterion C. Then for a fixed criterion C a vector with $\frac{n(n-1)}{2}$ elements is constructed as:

$$V(C) = \{\langle C(O_1), C(O_2)\rangle, \langle C(O_1), C(O_3)\rangle \dots, \langle C(O_1), C(O_n)\rangle, \dots, C(O_{n-1}), C(O_n))\}.$$

The elements of the vector $V(C)$ are then replaced by
1 if $C(O_i) > C(O_j)$, –1 if $C(O_i) < C(O_j)$ and 0 if $C(O_i) = C(O_j)$, $\forall i \in [1; n-1], \forall j \in [i+1; n]$.

The degree of "agreement" and "disagreement" between two criteria *C* and *C'* are denoted as $\mu_{C,C'}$ and $\nu_{C,C'}$, respectively.

Depending on the specific ICrA algorithm, $\mu_{C,C'}$ ($\mu_{C,C'} = \mu_{C',C}$) and $\nu_{C,C'}$ ($\nu_{C,C'} = \nu_{C',C}$) are calculated. For example, in case of μ-biased algorithm, the degree of "agreement" $\mu_{C,C'}$ is defined as the number of matching components of the respective vectors, normalized by the length of the vector. Respectively, the degree of "disagreement" $\nu_{C,C'}$ is the number of components of opposing signs in the two vectors, again normalized by the length of the vector.

As a result, $\langle \mu_{C,C'}, \nu_{C,C'} \rangle$ is an IFP. For most of the cases the sum $\mu_{C,C'}, + \nu_{C,C'}$ is equal to 1. However, there might be some pairs, for which this sum is less than 1. The difference $\pi_{C,C'} = \mu_{C,C'}, + \nu_{C,C'}$ is considered as a degree of "uncertainty".

RESULTS

Table 4. RFD classification according Lubenov's methodology (2009 – 2018)

RFD	Degree of forest fires risk
Blagoevgrad, Sofia, Shumen, Ruse, Veliko Tarnovo, Smolyan, Pazardzhik, Plovdiv	Low
Berkovitsa, Burgas, Kardzhali, Kyustendil, Sliven, Varna	Average
Lovech	High
Stara Zagora	Very high

Table 5. RFD classification according to Lubenov's methodology (1999 - 2018)

RFD	Degree of forest fires risk
Blagoevgrad, Sofia, Shumen, Ruse, Veliko Tarnovo	Low
Burgas, Kyustendil, Pazardzhik, Plovdiv, Smolyan, Varna	Average
Sliven	High
Berkovitsa, Kardzhali, Lovech, Stara Zagora	Very high

RESULTS

Table 7. ICrA results for the period 1999 – 2018

$\mu_{C,C'}$	Berkovitsa	Blagoevgrad	Burgas	Varna	Veliko Tarnovo	Kardzhali	Kyustendil	Lovech	Pazardzhik	Plovdiv	Ruse	Sliven	Smolyan	Sofia	Stara Zagora	Shumen
Berkovitsa	1.00	0.70	0.63	0.54	0.68	0.53	0.67	0.76	0.57	0.74	0.61	0.61	0.54	0.65	0.62	0.70
Blagoevgrad	0.70	1.00	0.69	0.57	0.62	0.56	0.78	0.57	0.67	0.69	0.54	0.64	0.57	0.68	0.57	0.73
Burgas	0.63	0.69	1.00	0.58	0.57	0.71	0.74	0.60	0.63	0.74	0.59	0.80	0.74	0.58	0.69	0.64
Varna	0.54	0.57	0.58	1.00	0.65	0.64	0.62	0.53	0.70	0.63	0.74	0.62	0.46	0.62	0.62	0.64
Veliko Tarnovo	0.68	0.62	0.57	0.65	1.00	0.46	0.64	0.67	0.61	0.64	0.67	0.49	0.44	0.62	0.68	0.67
Kardzhali	0.53	0.56	0.71	0.64	0.46	1.00	0.58	0.52	0.64	0.65	0.57	0.85	0.68	0.62	0.57	0.58
Kyustendil	0.67	0.78	0.74	0.62	0.64	0.58	1.00	0.62	0.69	0.73	0.55	0.65	0.62	0.68	0.64	0.71
Lovech	0.76	0.57	0.60	0.53	0.67	0.52	0.62	1.00	0.56	0.72	0.58	0.55	0.55	0.52	0.74	0.59
Pazardzhik	0.57	0.67	0.63	0.70	0.61	0.64	0.69	0.56	1.00	0.58	0.65	0.66	0.53	0.71	0.61	0.77
Plovdiv	0.74	0.69	0.74	0.63	0.64	0.65	0.73	0.72	0.58	1.00	0.59	0.68	0.59	0.65	0.68	0.66
Ruse	0.61	0.54	0.59	0.74	0.67	0.57	0.55	0.58	0.65	0.59	1.00	0.59	0.46	0.53	0.69	0.61
Sliven	0.61	0.64	0.80	0.62	0.49	0.85	0.65	0.55	0.66	0.68	0.59	1.00	0.73	0.64	0.59	0.60
Smolyan	0.54	0.57	0.74	0.46	0.44	0.68	0.62	0.55	0.53	0.59	0.46	0.73	1.00	0.46	0.52	0.45
Sofia	0.65	0.68	0.58	0.62	0.62	0.62	0.68	0.52	0.71	0.65	0.53	0.64	0.46	1.00	0.52	0.75
Stara Zagora	0.62	0.57	0.69	0.62	0.68	0.57	0.64	0.74	0.61	0.68	0.69	0.59	0.52	0.52	1.00	0.63
Shumen	0.70	0.73	0.64	0.64	0.67	0.58	0.71	0.59	0.77	0.66	0.61	0.60	0.45	0.75	0.63	1.00

Table 9. Results for fire risk according to the ICrA (2009 – 2018)

RFD	Degree of forest fires risk
Sofia, Ruse, Veliko Tarnovo, Smolyan, Blagoevgrad	Low
Pazardzhik, Plovdiv, Shumen, Varna	Low/ Average
Kyustendil, Kardzhali, Berkovitsa, Burgas, Sliven	Average
Lovech	High
Stara Zagora	Very high

The Lubenov's methodology for the whole 20-year period has shown differences for five regions:

- Smolyan has been classified in the group of average risk of occurring of forest fires when data of the period 1999 – 2018 are analyzed, in comparison to low risk group over the shorter period of time (Table 4).
- Sliven has moved to the high risk group instead of the average one.
- Berkovitsa is in the group of very high risk, while for the 10-year period it has been classified in the average risk group (Table 4).
- Kardzhali has moved from the average to the very high risk group.
- The degree of risk for Lovech has been increased to very high when data on the forest fires over the period of 20 years have been considered (Table 5).

These result could be explained with the much higher number of fires occurred in these regions in the first 10 years (1999 – 2009) of the 20-years period (Fig. 1). The reasons for these fires are not simply the meteorological conditions, but also some unpredictable and uncontrollable human factors.

Pazardzhik and Plovdiv, classified in the group of low risk of occurring of forest fires by the Lubenov's methodology for the 10-year period (Table 4), rather should have been classified in the average risk group (Table 9). This inference has been confirmed by the results of Lubenov's methodology applied to the data for 20-year period (Table 5).

Shumen has been confirmed to be part of the low risk group (Table 5) as in the case of data on the 10-year period (Table 4). There has been uncertainty about Varna being classified in the low risk group rather than the average in the case of 10-year period data (Table 9). Now, when all 20 years are taken in consideration, Varna is classified again in the average risk group (Table 5).

Sliven is in weak positive consonance with Kardzhali. The reasoning behind this could be explained by the fact that the two RFD has been classified in the same group, the group of average risk of occurring of forest fires, when the 10-year period (2009 – 2018) is analyzed (Table 9). The bigger number of forest fires and the larger area of burned territories in the previous ten years (1999 – 2008) (Fig. 1 and Fig. 2) imply that these regions will be classified in groups with higher risk. According to the Lubenov's methodology for the whole 20-year period (Table 5), Sliven is in the group of high risk, while Kardzhali moves to the group of very high risk.

Sliven and Burgas are in weak positive consonance too, with a degree of "agreement" right in the middle of the interval according to Table 8. The reason is similar to the above.

The weak positive consonance found between Shumen and Pazardzhik leads to the conclusion that Shumen should be considered as a region with average risk of fires rather than low. Here, when the whole 20-year period is considered, a hesitation about the belonging of Shumen in the group of low risk arises again, similarly to the results of the 10-year period (Table 9).

ICrA has shown weak positive consonance also for Blagoevgrad and Kyustendil. There is a clear tendency of increasing the relation between those two regions in comparison to the results of the 10-year period, weak dissonance is found there [12]. However, there are still insufficient data to consider Blagoevgrad as a region with average risk of occurring of forest fires.

The classification of the RFD, refined and confirmed by the results of the ICrA, is presented in Table 10. The RFD Blagoevgrad and Shumen should be examined with caution. The measures which are usually taken to prevent fire occurring should be applied to these regions as well as the regions in the group of average risk of forest fires.

Table 10. Results for fire risk according to the ICrA (1999 – 2018)

RFD	Degree of forest fires risk
Sofia, Ruse, Blagoevgrad, Veliko Tarnovo	Low
Shumen	Low/ Average
Burgas, Kyustendil, Pazardzhik, Plovdiv, Smolyan, Varna	Average
Sliven	High
Berkovitsa, Kardzhali, Lovech, Stara Zagora	Very high

CONCLUSION

The present research uses data on the number of forest fires occurred in Bulgaria, as well as the size of the burned territories. The research period are the past 20 years, 1999 – 2018. The regions in Bulgaria are classified in a predefined groups of forest fires risk, consequently using two essentially different methodologies for the analysis – Lubenov's methodology and InterCriteria Analysis.

ICrA is used as a complementary approach to the Lubenov's methodology in order to refine and improve the classification of the regions in Bulgaria into forest fires risk groups. ICrA is able to identify regions which are classified in a particular risk group with ambiguity. Thus, certain areas identified as out of risk will not be overlooked.

ACKNOWLEDGEMENT

The paper is partially funded by the Project DN16/6/2017 "Integrated Approach for Modeling of the Forest Fires Spread" funded by the National Science Fund of Bulgaria.