InterCriteria Analysis of Forest Fire Risk

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Introduction

According to the last European report the impact of forest fires in the EU in the 2000-2017 period could be summarized as:

- *Environmental losses*:
  8.5 million ha burned, approximately 480 000 ha/year.
- *Human losses*:
  611 firefighters and civilians killed, nearly 34 people/year.
- *Economic losses*:
  over EUR 54 billion, approximately EUR 3 billion/year.

In view of this it is important to determine the forest regions with high risk of fires, in order to provide the required preventive measures.

Lubenov's methodology for determining the risk of forest fires

The ***risk of forest fires occurring*** is defined as:

$$R_{ffo} = R_{dens} \times R_{rba}$$

where:

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

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

- R_{dens} - average annual numerical value of the fire density on a given region;
- N_i - annual number of fires occurred on the territory of the region;
- n - number of years in the considered period (10 years in this particular case);
- $F_{reg.\ ter.}$ - total area of the region, ha;
- R_{rba} - average annual numerical value of the real burned area of the region;
- F_{ba} - annually burned area of the region.

Lubenov's methodology for determining the risk of forest fires

Table 1. Scale for the degree of the forest fires risk

Values of the integrated indicator R_{ffo}	**Degree of the forest fires risk**
$R_{ffo} \leq 0.1$	low
$R_{ffo} > 0.1$ and $R_{ffo} \leq 0.3$	average
$R_{ffo} > 0.3$ and $R_{ffo} \leq 0.6$	high
$R_{ffo} > 0.6$	very high

Originally, the scale includes three degrees of forest fires risk:

low, *average* and *high*, above 0.3.

Here, we propose the *high* degree of forest fires risk to be divided into two categories:

high and *very high*.

InterCriteria Analysis – proposed in 2014 by Atanassov et al.

Let the initial index matrix M is presented in the form:

$$M = \begin{array}{c|ccccccc} & O_1 & \dots & O_k & \dots & O_l & \dots & O_n \\ \hline C_1 & a_{C_1,O_1} & \dots & a_{C_1,O_k} & \dots & a_{C_1,O_l} & \dots & a_{C_1,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_i & a_{C_i,O_1} & \dots & a_{C_i,O_k} & \dots & a_{C_i,O_l} & \dots & a_{C_i,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_j & a_{C_j,O_1} & \dots & a_{C_j,O_k} & \dots & a_{C_j,O_l} & \dots & a_{C_j,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_m & a_{C_m,O_1} & \dots & a_{C_m,O_j} & \dots & a_{C_m,O_l} & \dots & a_{C_m,O_n} \end{array},$$

where for every i, k ($1 \leq i \leq m, 1 \leq k \leq n$):

- C_i – a criterion that takes part in the evaluation;
- O_k – an object to be evaluated;
- a_{C_i,O_k} – a real number, the value assigned by the i-th criterion to the k-th object.

InterCriteria Analysis

$$M = \begin{array}{c|cccccccc} & O_1 & \dots & O_k & \dots & O_l & \dots & O_n \\ \hline C_1 & a_{C_1,O_1} & \dots & a_{C_1,O_k} & \dots & a_{C_1,O_l} & \dots & a_{C_1,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_i & a_{C_i,O_1} & \dots & a_{C_i,O_k} & \dots & a_{C_i,O_l} & \dots & a_{C_i,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_j & a_{C_j,O_1} & \dots & a_{C_j,O_k} & \dots & a_{C_j,O_l} & \dots & a_{C_j,O_n} \\ \vdots & \vdots & \ddots & \vdots & \ddots & \vdots & \ddots & \vdots \\ C_m & a_{C_m,O_1} & \dots & a_{C_m,O_j} & \dots & a_{C_m,O_l} & \dots & a_{C_m,O_n} \end{array},$$

For every k, l, such that $1 \le k \le l \le m$, and for $n \ge 2$, the two intuitionistic fuzzy numbers are defined – μ_{C_k,C_l} and ν_{C_k,C_l} (degree of "agreement" and degree of "disagreement").

$$M^* = \begin{array}{c|ccc} & C_1 & \dots & C_m \\ \hline C_1 & \langle \mu_{C_1,C_1}, \nu_{C_1,C_1} \rangle & \dots & \langle \mu_{C_1,C_m}, \nu_{C_1,C_m} \rangle \\ \vdots & \vdots & \ddots & \vdots \\ C_m & \langle \mu_{C_m,C_1}, \nu_{C_1,C_m} \rangle & \dots & \langle \mu_{C_m,C_m}, \nu_{C_m,C_m} \rangle \end{array}.$$

Data of forest fires in Bulgaria

The data is based on the Annual Reports of the Bulgarian Executive Forest Agency for the period 2009 to 2018.

The purpose of this research is to establish the risk of forest fires for each of sixteen Regional Forest Directorates (RFD) in Bulgaria.

Table 2. Burned area by Regional Forest Directorates

RFD	Burned area									
	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009
Varna	26.4	31.5	154.5	44.1	21.7	114.5	474.2	98.2	7.4	57.1
Sofia	1.2	9.2	6.2	55.2	2.6	10.4	42.2	22.9	0.1	4.5
Kyustendil	27.8	113.1	40	98	23.5	230.1	717	749.4	76.2	18.8
Burgas	19.6	538.2	497.5	259.6	12.3	304.9	2304.9	804.7	41.8	133.1
Shumen	7	11.2	4.9	11	6.5	1.5	239.4	28.3	2.6	4.4
Sliven	58.3	272.2	414.7	207.7	2.7	417.5	1965.9	250.9	15	260.3
Kardzhali	10.7	194.1	3494.9	268.7	12	796.3	372.4	303.4	26.3	753.1
Lovech	667.3	179.1	402.9	1471.5	337.7	181.1	942.3	1214.8	3000.6	420.5
Ruse	29.4	40.4	29.8	8.8	32.3	1.9	179.1	56.5	27.8	15.3
Veliko Tarnovo	6.6	93	15.5	138.2	2.4	6.3	268.6	157.5	123.5	118.2
Smolyan	14.6	249.9	695.5	13.9	3.2	513.8	337.4	67.5	20.8	8.2
Berkovitsa	419.1	612.3	147.8	530	28.3	79.3	2731.5	1026.6	576	118.4
Pazardzhik	8.2	127.6	146.3	26.4	35.7	92.6	802.8	225.9	13.8	146.9
Plovdiv	60.4	116.9	77.2	139.5	3.7	176	185	380.7	66.1	32.3
Stara Zagora	29.4	286.6	154.4	872.3	371.3	307.5	623.8	980.8	2507	171.5
Blagoevgrad	101.2	1694.1	58.1	170.1	20.1	80.2	543.3	514.5	21	13.8

Data of forest fires in Bulgaria

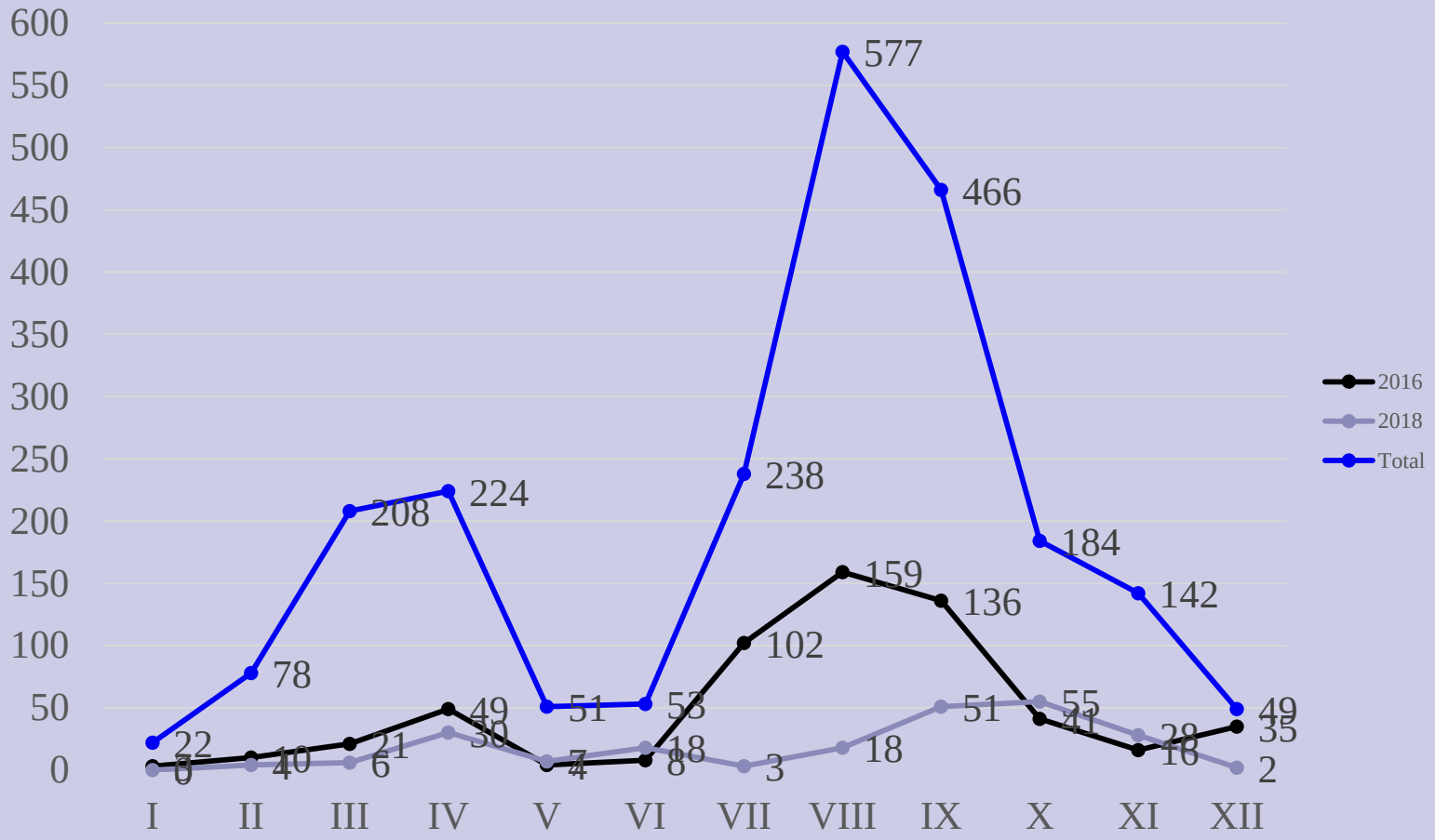

Figure 1. Number of fires in Bulgaria – years 2016 and 2018 versus total number of fires for 10 years period

Results: Application of the Lubenov's methodology

Table 3. Results for fire risk according to the Lubenov's methodology

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

Results: Application of the Lubenov's methodology

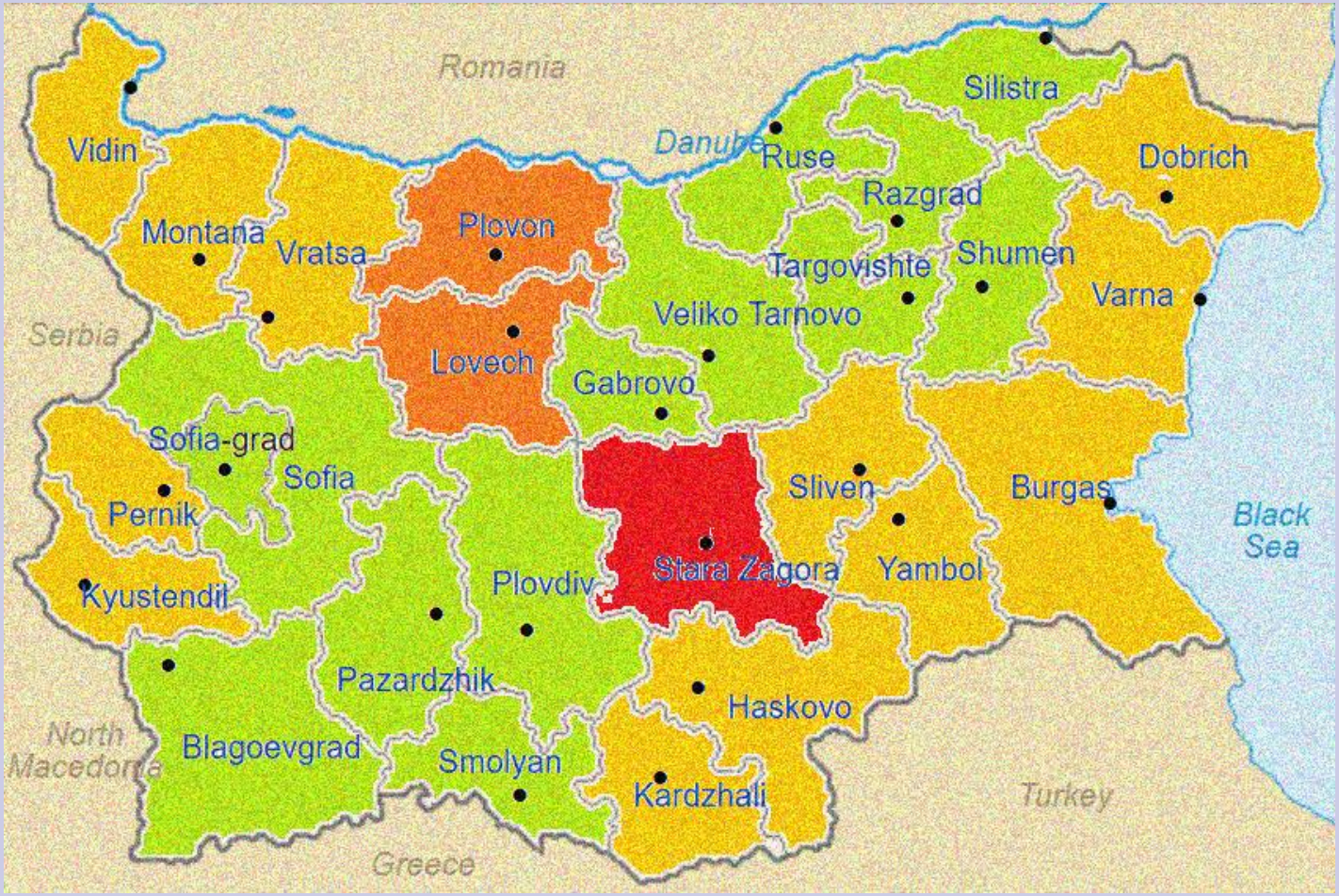

Figure 2. Fire risk map:
red – very high, orange – high, yellow – average, green - low

Results: Application of the InterCriteria Analysis

Table 4. Input IM for the ICrA

RFD	Burned Area/Number of fires									
	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009
Varna	1.26	0.95	3.22	2.59	3.68	2.66	4.65	2.89	1.48	1.68
Sofia	0.30	0.54	0.23	2.12	7.89	0.58	0.84	0.79	0.10	0.45
Kyustendil	1.26	2.41	1.11	2.80	8.91	7.93	13.28	11.53	4.76	1.57
Burgas	2.45	16.82	11.06	7.02	64.90	13.86	38.42	16.42	13.93	4.29
Shumen	1.00	1.12	0.82	1.22	2.75	0.25	8.87	1.42	1.30	0.88
Sliven	8.33	13.61	12.57	10.39	103.85	29.82	31.71	9.29	1.88	11.83
Kardzhali	0.47	4.41	38.41	5.60	33.59	13.73	6.31	8.43	2.02	23.53
Lovech	33.37	4.84	13.43	40.88	50.74	10.06	27.71	32.83	47.63	15.57
Ruse	2.94	2.53	2.13	1.76	0.63	0.38	6.40	2.97	3.48	5.10
Veliko Tarnovo	1.65	8.45	1.72	13.82	46.07	0.79	9.95	8.29	20.58	6.22
Smolyan	1.83	9.26	20.46	0.87	3.48	28.54	9.92	3.75	2.97	1.03
Berkovitsa	34.93	15.31	5.10	27.89	106.00	6.10	35.02	22.81	24.00	7.89
Pazardzhik	1.03	4.56	5.23	1.55	6.60	2.65	10.85	3.83	1.25	4.32
Plovdiv	4.31	4.33	1.80	4.65	23.25	5.50	3.36	12.28	5.51	1.24
Stara Zagora	1.63	5.31	2.57	10.64	33.55	5.39	10.06	12.57	92.85	7.15
Blagoevgrad	2.81	24.20	1.14	5.32	14.18	2.51	7.55	7.46	1.31	1.15

Results: Application of the InterCriteria Analysis

Table 5. Results from InterCriteria Analysis

	Varna	Sofia	Kyustendil	Burgas	Shumen	Sliven	Kardzhali	Lovech	Ruse	Veliko Tarnovo	Smolyan	Berkovitsa	Pazarzhik	Plovdiv	Stara Zagora	Blagoevgrad
Varna	1.00	0.69	0.73	0.69	0.64	0.71	0.73	0.56	0.49	0.56	0.60	0.53	0.80	0.58	0.60	0.53
Sofia	0.69	1.00	0.78	0.69	0.69	0.76	0.56	0.60	0.40	0.69	0.47	0.71	0.62	0.67	0.69	0.76
Kyustendil	0.73	0.78	1.00	0.78	0.82	0.62	0.51	0.60	0.53	0.69	0.60	0.67	0.62	0.76	0.73	0.71
Burgas	0.69	0.69	0.78	1.00	0.73	0.76	0.56	0.51	0.49	0.73	0.64	0.62	0.76	0.71	0.69	0.76
Shumen	0.64	0.69	0.82	0.73	1.00	0.49	0.47	0.73	0.62	0.82	0.47	0.80	0.62	0.71	0.73	0.76
Sliven	0.71	0.76	0.62	0.76	0.49	1.00	0.71	0.36	0.38	0.53	0.67	0.51	0.82	0.51	0.49	0.64
Kardzhali	0.73	0.56	0.51	0.56	0.47	0.71	1.00	0.42	0.40	0.42	0.64	0.36	0.76	0.49	0.51	0.40
Lovech	0.56	0.60	0.60	0.51	0.73	0.36	0.42	1.00	0.49	0.78	0.29	0.76	0.40	0.71	0.78	0.53
Ruse	0.49	0.40	0.53	0.49	0.62	0.38	0.40	0.49	1.00	0.53	0.40	0.56	0.51	0.33	0.53	0.47
Veliko Tarnovo	0.56	0.69	0.69	0.73	0.82	0.53	0.42	0.78	0.53	1.00	0.38	0.76	0.58	0.67	0.82	0.67
Smolyan	0.60	0.47	0.60	0.64	0.47	0.67	0.64	0.29	0.40	0.38	1.00	0.36	0.67	0.49	0.38	0.53
Berkovitsa	0.53	0.71	0.67	0.62	0.80	0.51	0.36	0.76	0.56	0.76	0.36	1.00	0.47	0.60	0.67	0.73
Pazardzhik	0.80	0.62	0.62	0.76	0.62	0.82	0.76	0.40	0.51	0.58	0.67	0.47	1.00	0.47	0.49	0.60
Plovdiv	0.58	0.67	0.76	0.71	0.71	0.51	0.49	0.71	0.33	0.67	0.49	0.60	0.47	1.00	0.76	0.64
Stara Zagora	0.60	0.69	0.73	0.69	0.73	0.49	0.51	0.78	0.53	0.82	0.38	0.67	0.49	0.76	1.00	0.58
Blagoevgrad	0.53	0.76	0.71	0.76	0.76	0.64	0.40	0.53	0.47	0.67	0.53	0.73	0.60	0.64	0.58	1.00

Results: Application of the InterCriteria Analysis

Table 6. Results for fire risk according to the InterCriteria Analysis

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

Conclusions

- Based on the Lubenov's methodology the Bulgarian Regional Forest Directorates are classified according to the risk of forest fires and a fire risk map of Bulgaria is proposed.
- The obtained results show that the ICrA could be used as an additional approach in order to refine the classification of the regions in the specific risk groups.
- The result of ICrA can prevent the neglect of certain areas identified as out-of-risk, which might be actually in risk.

As further research, data for a period of 20 years will be considered. It is expected that when applied to data for a longer period of time, even the Lubenov's methodology will approve the ICrA results.

Thank you for your attention!

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