InterCriteria analysis of forest fires in the Mediterranean area in 1990–2017

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Abstract: In the present paper, the novel decision support method of InterCriteria Analysis, based on the concept of intuitionistic fuzzy sets, has been applied to a dataset of the forest fires in the Mediterranean Area in the period between 1990 and 2017 year. The available data from the European Forest Fire Information System (EFFIS) concern the number of fires and the burned area per year in the seven investigated countries Portugal, Spain, France, Italy, Greece, Turkey, with the addition of Bulgaria. The method aims at detecting patterns of correlation, here specifically termed InterCriteria consonance, between the criteria in the dataset. With the application of the proposed method, the coefficients of intuitionistic fuzzy positive consonance are being calculated between the countries' fire regime indicators, and commented accordingly. The results can be informative for the yearly and countrywise trends in the wildfire activity in the Mediterranean Area in support of prediction and prevention, as well as contribute to the research on InterCriteria Analysis.
Keywords: Forest fires, Wildfires, InterCriteria Analysis, Intuitionistic fuzzy sets.
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1   Introduction

Forest fires are a serious environmental hazard in southern Europe. Most of the total burned area in Europe occurs in Mediterranean regions, causing severe economic and environmental damage, including the loss of ecosystem services such as carbon sequestration and provisioning of raw materials, the loss of lives and an average of about 4500 km^2 burned every year.

Understanding fire regimes is very important for the assessment of the ecological effects of forest fires and for the analysis of trends and shifts in fire occurrence during the recent history and in the inter-annual variability of the fire activity. Such trends likely result from the combined effect of extreme fire weather events, changes in policies and management practices, law enforcements and reporting systems, [13].

2   Presentation of the input data

The input data that has been collected for investigation is extracted from the European Forest Fire Information System (EFFIS) and covers the Southern European Mediterranean countries Portugal, Spain, France, Italy and Greece, with the addition of Turkey and the authors' homeland Bulgaria, whose fire regime in the last years is familiar with that of the Mediterranean countries. For each of these seven countries the data about the burned area (in hectares) and number of fires for the period 1990 – 2017. The input data are as listed below in Table 1 and Table 2, [7].

Year	Portugal	Spain	France	Italy	Greece	Bulgaria	Turkey
1990	137252	203032	72625	195319	38594	315	13742
1991	182486	260318	10130	99860	13046	511	8081
1992	57011	105277	16593	105692	71410	5243	12232
1993	49963	89267	16698	203749	54049	18164	15393
1994	77323	437635	24995	136334	57908	18100	38128
1995	169612	143484	18137	48884	27202	550	7676
1996	88867	59814	11400	57988	25310	906	14922
1997	30535	98503	21581	111230	52373	595	6316
1998	158369	133643	19282	155553	92901	6967	6764
1999	70613	82217	15906	71117	8289	8291	5804
2000	159605	188586	24078	114648	145033	57406	26353
2001	111850	93297	20642	76427	18221	20152	7394
2002	124411	107464	30160	40791	6013	6513	8514
2003	425726	148172	73278	91805	3517	5000	6644
2004	129539	134193	13711	60176	10267	1137	4876
2005	338262	188697	22135	47575	6437	1456	2821
2006	75510	155345	7844	39946	12661	3540	7762
2007	31450	86122	8570	227729	225734	42999	11664
2008	17244	50322	6001	66329	29152	5289	29749
2009	87416	120094	17000	73355	35342	2271	4679
2010	133090	54770	10300	46537	8967	6526	3317
2011	73813	102161	9400	72004	29144	6883	3612
2012	110231	226125	8600	130814	59924	12730	10455
2013	152756	58985	3608	29076	46676	3314	11456
2014	19929	46721	7493	36125	25846	916	3117
2015	64443	103200	11160	41511	7096	4313	3219
2016	161522	65817	16093	47926	26540	6340	9156
2017	540630	178234	26378	161987	13393	4569	11993

Table 1. Overview of the burned area reported by the investigated seven countries

Year	Portugal	Spain	France	Italy	Greece	Bulgaria	Turkey
1990	10745	12913	5881	14477	1322	76	1750
1991	14327	13531	3888	11965	858	73	1481
1992	14954	15955	4002	14641	2582	602	2117
1993	16101	14254	4769	14412	2406	1196	2545
1994	19983	19263	4618	11588	1763	667	3239
1995	34116	25827	6563	7378	1438	114	1770
1996	28626	16771	6401	9093	1508	246	1645
1997	23497	22320	8005	11612	2273	200	1339
1998	34676	22446	6289	9540	1842	578	1932
1999	25477	18237	4960	6932	1486	320	2075
2000	34109	24118	4603	8595	2581	1710	2353
2001	26533	19547	4309	7134	2535	825	2631
2002	26488	19929	4097	4601	1141	402	1471
2003	26195	18616	7023	9697	1452	452	2177
2004	21870	21396	3775	6428	1748	294	1762
2005	35697	25492	4698	7951	1544	241	1530
2006	19929	16354	4608	5634	1417	393	2227
2007	18722	10936	3364	10639	1983	1479	2829
2008	13832	11655	2781	6486	1481	582	2135
2009	26119	15643	4800	5422	1063	314	1793
2010	22026	11721	3900	4884	1052	222	1861
2011	25221	16414	4500	8181	1653	635	1954
2012	21176	17503	4105	8252	1559	876	2450
2013	19291	10626	2223	2936	862	408	3755
2014	7067	9771	2778	3257	552	151	2149
2015	15851	11928	4440	5442	510	429	2150
2016	13261	8817	4285	4793	777	584	3188
2017	21002	13793	4403	7855	1083	513	2411

Table 2. Overview of the number of fires reported by the investigated seven countries

3 Application of the intercriteria analysis

Here we are interested in detecting patterns and trends between the investigated countries' fire regimes, specifically the criteria Number of Fires and Burned Area. We are mainly interested in results in the following three directions: dependencies between the burned areas in the different countries, between the number of fires that have occurred in the different countries, as well as between the pairs of criteria Burned Area and Number of Fires per investigated country. The method of InterCriteria Analysis (ICA) is based on intuitionistic fuzzy sets, thus rendering account of the effects of uncertainty. Originally, ICA was been proposed in [2], and various aspects of its theoretical investigation are given in papers [1, 3–6, 12, 15].

For this aim, we use the developed software for InterCriteria Analysis [8–11] (freely available online at: http://intercriteria.net/software) and feed it with the combined data for the

whole period. The complete resultant table with InterCriteria intuitionistic fuzzy pairs, as divided in membership and non-membership parts, is given on Table 3 (a) and (b).

(a)

	Portugal-BA	Spain-BA	France-BA	Italy-BA	Greece-BA	Bulgaria-BA	Turkey-BA	Portugal-NF	Spain-NF	France-NF	Italy-NF	Greece-NF	Bulgaria-NF	Turkey-NF
Portugal-BA	1.000	0.683	0.659	0.495	0.407	0.426	0.487	0.648	0.624	0.561	0.487	0.389	0.384	0.437
Spain-BA	0.683	1.000	0.696	0.638	0.508	0.460	0.556	0.571	0.672	0.593	0.667	0.519	0.447	0.429
France-BA	0.659	0.696	1.000	0.653	0.455	0.505	0.540	0.653	0.683	0.704	0.630	0.556	0.452	0.399
Italy-BA	0.495	0.638	0.653	1.000	0.712	0.616	0.675	0.487	0.537	0.587	0.807	0.693	0.606	0.534
Greece-BA	0.407	0.508	0.455	0.712	1.000	0.590	0.693	0.442	0.481	0.474	0.646	0.648	0.619	0.579
Bulgaria-BA	0.426	0.460	0.505	0.616	0.590	1.000	0.593	0.542	0.521	0.434	0.521	0.664	0.831	0.683
Turkey-BA	0.487	0.556	0.540	0.675	0.693	0.593	1.000	0.418	0.474	0.471	0.646	0.585	0.624	0.590
Portugal-NF	0.648	0.571	0.653	0.487	0.442	0.542	0.418	1.000	0.810	0.664	0.492	0.579	0.439	0.368
Spain-NF	0.624	0.672	0.683	0.537	0.481	0.521	0.474	0.810	1.000	0.693	0.585	0.664	0.444	0.344
France-NF	0.561	0.593	0.704	0.587	0.474	0.434	0.471	0.664	0.693	1.000	0.646	0.542	0.376	0.349
Italy-NF	0.487	0.667	0.630	0.807	0.646	0.521	0.646	0.492	0.585	0.646	1.000	0.714	0.516	0.442
Greece-NF	0.389	0.519	0.556	0.693	0.648	0.664	0.585	0.579	0.664	0.542	0.714	1.000	0.627	0.487
Bulgaria-NF	0.384	0.447	0.452	0.606	0.619	0.831	0.624	0.439	0.444	0.376	0.516	0.627	1.000	0.696
Turkey-NF	0.437	0.429	0.399	0.534	0.579	0.683	0.590	0.368	0.344	0.349	0.442	0.487	0.696	1.000

(b)

	Portugal-BA	Spain-BA	France-BA	Italy-BA	Greece-BA	Bulgaria-BA	Turkey-BA	Portugal-NF	Spain-NF	France-NF	Italy-NF	Greece-NF	Bulgaria-NF	Turkey-NF
Portugal-BA	0.000	0.317	0.339	0.505	0.593	0.566	0.513	0.347	0.370	0.415	0.508	0.556	0.529	0.505
Spain-BA	0.317	0.000	0.302	0.362	0.492	0.532	0.444	0.423	0.323	0.384	0.328	0.426	0.466	0.513
France-BA	0.339	0.302	0.000	0.344	0.542	0.484	0.458	0.339	0.310	0.270	0.362	0.386	0.458	0.540
Italy-BA	0.505	0.362	0.344	0.000	0.288	0.376	0.325	0.508	0.458	0.389	0.188	0.251	0.307	0.407
Greece-BA	0.593	0.492	0.542	0.288	0.000	0.402	0.307	0.553	0.513	0.503	0.349	0.296	0.294	0.362
Bulgaria-BA	0.566	0.532	0.484	0.376	0.402	0.000	0.399	0.444	0.466	0.534	0.466	0.278	0.079	0.251
Turkey-BA	0.513	0.444	0.458	0.325	0.307	0.399	0.000	0.577	0.521	0.505	0.349	0.360	0.288	0.352
Portugal-NF	0.347	0.423	0.339	0.508	0.553	0.444	0.577	0.000	0.180	0.307	0.497	0.360	0.468	0.569
Spain-NF	0.370	0.323	0.310	0.458	0.513	0.466	0.521	0.180	0.000	0.278	0.405	0.275	0.463	0.593
France-NF	0.415	0.384	0.270	0.389	0.503	0.534	0.505	0.307	0.278	0.000	0.325	0.378	0.513	0.574
Italy-NF	0.508	0.328	0.362	0.188	0.349	0.466	0.349	0.497	0.405	0.325	0.000	0.225	0.392	0.495
Greece-NF	0.556	0.426	0.386	0.251	0.296	0.278	0.360	0.360	0.275	0.378	0.225	0.000	0.235	0.405
Bulgaria-NF	0.529	0.466	0.458	0.307	0.294	0.079	0.288	0.468	0.463	0.513	0.392	0.235	0.000	0.180
Turkey-NF	0.505	0.513	0.540	0.407	0.362	0.251	0.352	0.569	0.593	0.574	0.495	0.405	0.180	0.000

Table 3. Results of the application of the InterCriteria Analysis on the aggregated data from Tables 1 and 2. (a) membership parts, (b) non-membership parts of the IF pairs

From the upper left quadrants of Table 3 (a, b) we obtain information about the countrywise relations discovered between the burned areas among all pairs of investigated countries, see Table 4.

Criterion *i*	Criterion *j*	μ	ν	Distance to Truth
Italy-BA	Greece-BA	0.712	0.288	0.408
Spain-BA	France-BA	0.698	0.302	0.427
Greece-BA	Turkey-BA	0.693	0.307	0.434
Portugal-BA	Spain-BA	0.683	0.317	0.449
Italy-BA	Turkey-BA	0.675	0.325	0.460
Portugal-BA	France-BA	0.661	0.339	0.479
France-BA	Italy-BA	0.653	0.347	0.490
Spain-BA	Italy-BA	0.638	0.362	0.513
Italy-BA	Bulgaria-BA	0.622	0.378	0.535
Greece-BA	Bulgaria-BA	0.598	0.402	0.569
Bulgaria-BA	Turkey-BA	0.593	0.407	0.576
Spain-BA	Turkey-BA	0.556	0.444	0.629
France-BA	Turkey-BA	0.540	0.460	0.651
Spain-BA	Greece-BA	0.508	0.492	0.696
France-BA	Bulgaria-BA	0.508	0.492	0.696
Portugal-BA	Italy-BA	0.495	0.505	0.715
Portugal-BA	Turkey-BA	0.487	0.513	0.726
Spain-BA	Bulgaria-BA	0.460	0.540	0.763
France-BA	Greece-BA	0.455	0.545	0.771
Portugal-BA	Bulgaria-BA	0.429	0.571	0.808
Portugal-BA	Greece-BA	0.407	0.593	0.838

Table 4. InterCriteria pairs between the burned areas per countries, sorted by their distance to the intuitionistic fuzzy truth $\langle 1, 0 \rangle$

While not strictly strong positive consonances per [1], we see that the strongest available ones, i.e. those with smallest distance from the intuitionistic fuzzy truth $\langle 1, 0 \rangle$, are those detected between the neighbouring countries, with the top ranking pairs being Italy–Greece $\langle 0.712, 0.288 \rangle$, Spain–France $\langle 0.698, 0.302 \rangle$, Greece–Turkey $\langle 0.693, 0.307 \rangle$, Portugal–Spain $\langle 0.683, 0.317 \rangle$. The pairs formed between distantly located countries tend to belong to the dissonance and the negative consonance spectrum, as well as the pairs involving Bulgaria.

Second, from the lower right quadrants of Table 3 (a, b) we obtain information about the countrywise relations discovered between the numbers of fires registered in between all pairs of investigated countries, see Table 5.

The strongest available InterCriteria pairs again are those detected between the neighbouring countries, with the top ranking pairs being Spain–Portugal $\langle 0.810, 0.180 \rangle$, Turkey–Bulgaria $\langle 0.696, 0.180 \rangle$, Greece–Italy $\langle 0.714, 0.225 \rangle$, France–Spain $\langle 0.693, 0.278 \rangle$. The pairs formed between distantly located countries tend to belong to the dissonance and the negative consonance spectrum, as well as the pairs involving Turkey and Bulgaria.

Criterion i	Criterion j	μ	N	Distance to Truth
Spain-NF	Portugal-NF	0.810	0.180	0.262
Turkey-NF	Bulgaria-NF	0.696	0.180	0.353
Greece-NF	Italy-NF	0.714	0.225	0.364
France-NF	Spain-NF	0.693	0.278	0.414
Greece-NF	Spain-NF	0.664	0.275	0.434
Bulgaria-NF	Greece-NF	0.627	0.235	0.441
France-NF	Portugal-NF	0.664	0.307	0.455
Italy-NF	France-NF	0.646	0.325	0.481
Greece-NF	Portugal-NF	0.579	0.360	0.554
Italy-NF	Spain-NF	0.585	0.405	0.580
Greece-NF	France-NF	0.542	0.378	0.594
Bulgaria-NF	Italy-NF	0.516	0.392	0.623
Turkey-NF	Greece-NF	0.487	0.405	0.654
Italy-NF	Portugal-NF	0.492	0.497	0.711
Bulgaria-NF	Spain-NF	0.444	0.463	0.724
Bulgaria-NF	Portugal-NF	0.439	0.468	0.731
Turkey-NF	Italy-NF	0.442	0.495	0.746
Bulgaria-NF	France-NF	0.376	0.513	0.808
Turkey-NF	Portugal-NF	0.368	0.569	0.850
Turkey-NF	France-NF	0.349	0.574	0.868
Turkey-NF	Spain-NF	0.344	0.593	0.884

Table 5. InterCriteria pairs between the numbers of fires per countries, sorted by their distance to the intuitionistic fuzzy truth $\langle 1, 0 \rangle$

Finally, in Table 6 and graphically in Figure 1, are presented the results of the application of ICA on the data for the countries' burned areas and numbers of fires, and we are interested in the InterCriteria correlations between each country's number of fires and burned area. From the lower left quadrant, we only collect the results in the seven cells along the main diagonal, as in the other cells while there are computed degrees they are logically inconsistent. The results show that positive InterCriteria consonances are only detected in Bulgaria and Italy, respectively $\langle 0.831, 0.079 \rangle$ and $\langle 0.807, 0.188 \rangle$, while France, Greece, Spain, Portugal and Turkey score intuitionistic fuzzy dissonant values.

Area burned	Number of fires	μ	N	Distance to Truth
Bulgaria	Bulgaria	0.831	0.079	0.187
Italy	Italy	0.807	0.188	0.269
France	France	0.704	0.270	0.401
Greece	Greece	0.648	0.296	0.460
Spain	Spain	0.672	0.323	0.460
Portugal	Portugal	0.648	0.347	0.494
Turkey	Turkey	0.590	0.352	0.540

Table 6. InterCriteria pairs between the numbers of fires and burned areas in the investigated countries, sorted by their distance to the intuitionistic fuzzy truth $\langle 1, 0 \rangle$
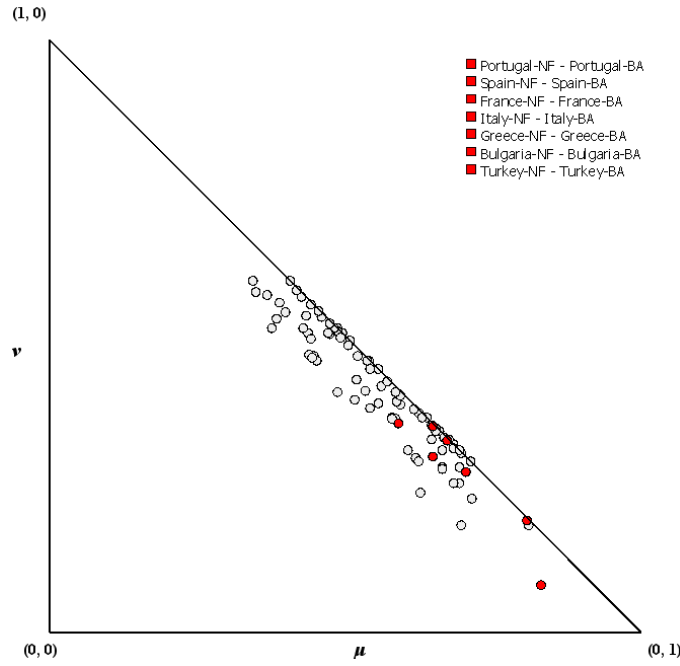
Figure 1. InterCriteria pairs between the numbers of fires and burned areas in the investigated countries (Table 6), as plotted as points (red) on the intuitionistic fuzzy interpretational triangle.

4   Conclusions and ideas for future work

The conducted investigation using the intuitionistic fuzzy sets-based novel approach of InterCriteria Analysis on data of the forest fires in the Mediterranean Area in 1990–2017 detects the strongest positive countrywise consonances in the two basic indicators – burned area and number of fires – only between pairs of neighbouring of the investigated countries. Concerning burned area, the strongest consonances are detected in the pairs Italy–Greece $\langle 0.712, 0.288 \rangle$, Spain–France $\langle 0.698, 0.302 \rangle$, Greece–Turkey $\langle 0.693, 0.307 \rangle$, Portugal–Spain $\langle 0.683, 0.317 \rangle$, while concerning the number of fires the strongest consonance are detected in the pairs Spain–Portugal $\langle 0.810, 0.180 \rangle$, Turkey–Bulgaria $\langle 0.696, 0.180 \rangle$, Greece–Italy $\langle 0.714, 0.225 \rangle$, France–Spain $\langle 0.693, 0.278 \rangle$. On the other hand, when these two indicators are considered in pair, the countries that exhibit highest positive consonances are Bulgaria and Italy. This research can be especially relevant in the context of the new paradigm for pan-European collaboration in the efforts for fire science research and collaborative prevention of wildfires. A similar, more focused research on the level of regional forest directorates of Bulgaria only, has been already conducted for the period 2009–2018 (see [16]) and 1999–2018 (see [14]).

Upon available data, the conducted investigation can be performed for the respective countries in Northern Africa, as well as onto all the Mediterranean countries. Another direction of research is feeding the ICA method with same set of data, yet transposed, and to pursue patterns of correlation across the years in the researched period. Furthermore, collecting a variety of other data, reflecting the fire ecology, meteorology, economic losses and damages, etc. – of these countries, can be further informative for the yearly and countrywise trends in the wildfire activity in the Mediterranean Area in support of prediction, prevention, decision making and international cooperation.

Acknowledgements

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