EVALUATING FUZZY MULTI-FEATURE SCENARIOS FOR FOREST FIRE RISK ESTIMATION

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Abstract

This paper presents the development and the application of a fuzzy inference intelligent system that performs and evaluates scenarios towards the estimation of a characteristic overall forest fire risk index. The system was built in the integrated environment of the MATLAB platform. It employees fuzzy triangular membership functions to estimate the partial degrees of risk. It also makes use of various fuzzy conjunction operators called T-Norms which are embedded in a fuzzy inference system together with a specially designed *Mamdani* Ruleset. The main concern was to overcome the problem of combinatorial explosion. The final target was the production of distinct scenarios based on the importance of each involved feature and the determination of the corresponding integrated degrees of risk. Through the execution phase the system assigned even or uneven weights in the involved features giving emphasis either in morphological plus meteorological data or in forest fire history records. Thus the problem was faced under different perspectives. Through its pilot application the system proved its ability to estimate efficiently the partial and the overall risk indices and the results were encouraging.

Keywords: Forest fire risk, Fuzzy sets, Fuzzy Relations, Fuzzy Inference, Fuzzy weighted scenarios

1. Introduction

1.1. The wild fire problem in Europe

The development and the protection of forest and natural environment can contribute significantly towards a better quality of life which is one of the major questions of modern societies. Subsequently the forest and natural environment must be effectively protected and preserved. Forest fires constitute a direct and major threat on the maintenance and the productivity of forests. No other enemy can cause such big scale and rapid destruction. Around the Mediterranean basin, approximately 50,000 forest fire incidents are recorded annually whereas the corresponding total burned area varies from 700,000 to 1,000,000 hectares. Obviously, this causes a huge financial and ecological destruction. It has been estimated that more or less, the average burned are per forest fire in Greece is 93.4 hectares, whereas the respective number in Spain is 28.4, in Italy 19.74 and in Portugal 15.29 which is due to the climate differences between the easten and the western parts of the Mediterranean basin (Dimitrakopoulos A., 1994).

During the time period 2001-2006 the average annual burned area in Greece was approximately equal to 100,000 str which constituted a significant improvement. Unfortunately 2007 was of the worst years ever for Greece. Nearly 2000,000 str were burned down only in one year and 67 human lives were lost during the great forest fires of Peloponnesus and Evia.

1.2. Aim of this research

This research effort aims in the development of a fuzzy inference system (FIS) that estimates innovative multi-feature forest fire risk indices for the region of Eastern Macedonia and Thrace in north eastern Greece. The indices are estimated on an annual basis. This is achieved by performing scenarios of varying feature importance.

Fuzzy relations were employed assigning weights of importance to the features of the input vectors. Based on this weighting system, various scenarios were performed and the overall risk indices (ORI) were estimated for each case. The obtained results assign risk characterizations to the areas under examination for each distinct scenario, based on proper fuzzy linguistics.

1.3. Area of interest

The research area (colored blue in the following map 1) is the Eastern Macedonia and Thrace region of Greece with is located in the north-eastern part of the country. It comprises of the forest departments that belong to the prefectures of “*Kavala*”, “*Xanthi*”, “*Rodopi*” and “*Evros*”.

Map 1. Area of Research

2. Materials and methods

2.1. Fuzzy Sets and Operators

Fuzzy logic is an intelligent control technique which was firstly introduced by Lotfi A. Zadeh in 1968 that enables the user to develop models that embody the experts experience and the available measurements through a set of easy to follow rules (Zadeh, 1968), (Cox, 2005). Fuzzy logic is a human Knowledge embodying tool through operational algorithms Several intelligent Systems have been developed globally to estimate forest fire risk on an annual basis (Lin, 2002), (Iliadis, 2005), (Iliadis, 2007) and also for the estimation of risk due to natural hazards (Iliadis et al., 2005).
Every element of the universe of discourse belongs to a fuzzy set but with a different degree of membership which is a real number in the interval [0,1] and it is determined by the employment of proper fuzzy membership functions (FMF), like the triangular, the trapezoid and the Gaussian ones (Iliadis, 2007). The following function 1 and 2, present a triangular and a trapezoid FMF respectively. (Cox, 2005), (Kecman, 2001), (Leondes, 1998), (Kandel,1992).

$$\mu_s(x) = \begin{cases} 0 \text{ if } X < a \\ (X\text{-}a) / (c\text{-}a) \text{ if } X \in [a,c] \\ (b\text{-}X) / (b\text{-}c) \text{ if } X \in [c,b] \\ 0 \text{ if } X \geq b \end{cases} \quad (1)$$

$$\mu_s(X) = \begin{cases} 0, \text{ if } X \leq a \\ (X\text{-}a) / (m\text{-}a), \text{ if } X \in (a,m) \\ 1, \text{ if } X \in [m,n] \\ (b\text{-}X) / (b\text{-}n), \text{ if } X \in (n,b) \\ 0, \text{ if } X \geq b \end{cases} \quad (2)$$

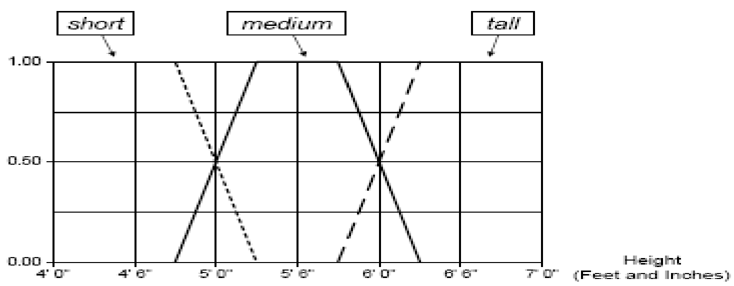


Figure 1. FMF and linguistics for the determination of the height of a human

Fuzzy Algebra utilizes several types of norms that perform the disjunction and the conjunction operations between fuzzy sets. In this case the T-Norm functions calculate the conjunction of the

partial risk indices whereas the S-Norm relations produce the pessimistic version of risk evaluation, since they perform the fuzzy "OR" operation between the partial risk indices.
Functions 3,4,5,6 represent the *Minimum*, the *Algebraic Product*, the *Einstein Product* and the *Hamacher Product* T-Norms respectively.

$$\tilde{A} \cap \tilde{B} = \left\{ \left(x, \mu_{\tilde{A} \cap \tilde{B}}(x) \right) \mid \mu_{\tilde{A} \cap \tilde{B}}(x) = \mu_{\tilde{A}}(x) \wedge \mu_{\tilde{B}}(x) = \min\left(\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(x) \right) \right\} \quad (3)$$

$$\tilde{A} \cap \tilde{B} = \mu \tilde{A}(X) * \mu \tilde{B}(X) \quad (4) \qquad \tilde{A} \cap \tilde{B} = \frac{\mu_{\tilde{A}}(x)\mu_{\tilde{B}}(x)}{2 - [\mu_{\tilde{A}}(x) + \mu_{\tilde{B}}(x) - \mu_{\tilde{A}}(x)\mu_{\tilde{B}}(x)]} \quad (5)$$

$$\tilde{A} \cap \tilde{B} = \frac{\mu_{\tilde{A}}(x)\mu_{\tilde{B}}(x)}{[\mu_{\tilde{A}}(x) + \mu_{\tilde{B}}(x) - \mu_{\tilde{A}}(x)\mu_{\tilde{B}}(x)]} \quad (6)$$

It should be explained that $\tilde{A} \cap \tilde{B}$ stands for the fuzzy conjunction (fuzzy "AND") operation between two fuzzy sets $\tilde{A}, \tilde{B}$ Also $\mu \tilde{A}(X)$ symbolizes the degree of membership of the element of the universe of discourse X to the fuzzy set $\tilde{A}$. Finally the notation $\mu_{\tilde{A} \cap \tilde{B}}$ is used for the degree of membership of the element of the universe of discourse X to the final fuzzy set $\tilde{A}$ AND $\tilde{B}$. For example (only to make the concepts more easy to follow) lets suppose that $\tilde{A}$ and $\tilde{B}$ are the fuzzy sets corresponding to the linguistics "area with high vulnerability to forest fires due to its meteorological conditions" AND "area with high vulnerability to forest fires due to its morphological characteristics" respectively.
Then the fuzzy conjunction will produce the fuzzy set "area with high vulnerability to forest fires due to its meteorological conditions AND due to its morphological characteristics".
A very interesting approach that is applied when the features have an uneven contribution expressed by proper weights is proposed by the following function 7

$$\mu_{\tilde{S}}(x_i) = Agg\left(f\left(\mu_{\tilde{A}}(x_i), w_1 \right), f\left(\mu_{\tilde{A}}(x_i), w_2 \right), ..., f\left(\mu_{\tilde{A}}(x_i), w_n \right) \right) \quad (7) \text{ where } f(\mu, w) = \mu^{\frac{1}{W}}$$

(Iliadis, 2007), (Calvo et al., 2002), (Yager, Kacprzyk, 1997).
In the case of function 7, the *Agg* stands for the Aggregation operator which is one of the T-Norm operators and $w_i \in [0,1]$ stands for the weight assigned to each feature.
By applying function 7 and uneven weights, several scenarios can be performed towards the overall risk estimation (Iliadis, 2005).
The assignment of the weights is done according to the scenario that the user intends to execute. For example if the user wishes to find the areas that are more vulnerable mainly due to morphological plus meteorological conditions, then the corresponding features of interest will be assigned higher weight values than the others (usually above 0.5). The choice of the specific values of the weights is done in a rather heuristic manner as it is always the case in the execution of scenarios. The choice of the proper weights can be based also in a trial and error approach according to (Iliadis, 2007).

2.2. Discussion on data

Totally six distinct risk parameters were considered, namely the *annual number* of *forest fire incidents* and the *total annual burned area per forest department* (historic data) the *average altitude* (morphological data), the *average temperature, average humidity* and *average wind intensity* (meteorological data). The data vectors used for the estimation of risk indices are related to the period 1983-2004. The area under study as it has already been mentioned covers the Eastern Macedonia-Thrace region. It should be specified that the measurements of the morphological-meteorological (MORMET) features are related only to the days and to the specific altitude where wild fire incidents occurred. The following figure 2 presents clearly not only the six features that were considered but also the structure of the risk model.

The actual data vectors come from the general forest secretariat of the Greek ministry of agricultural development.
Of course this is a pilot effort aiming in presenting an innovative approach and in demonstrating its potential good application in natural hazards' risk estimation.
The model can be expanded to accept larger input vectors with more parameters and moreover it can be adjusted (with a minor effort) to be used in cases of other natural hazards and for any part of the world.

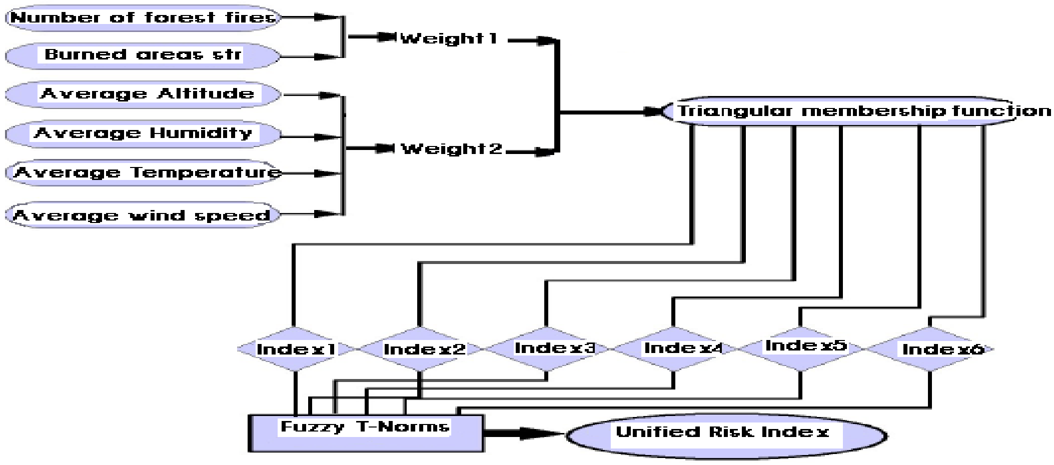
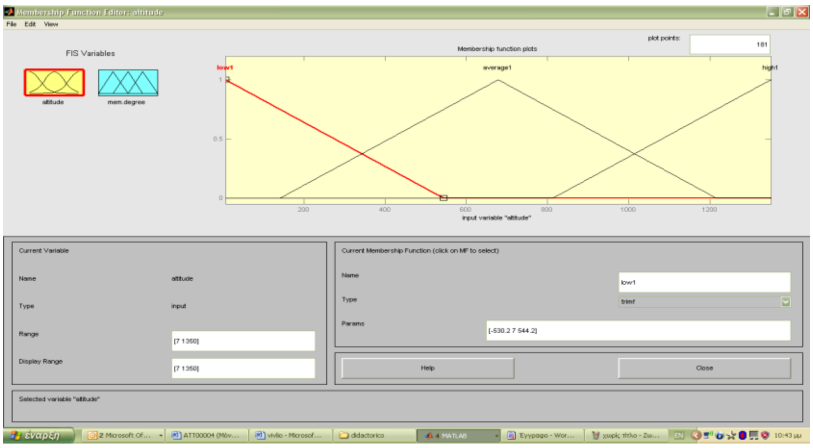


Figure 2. Overall structure of the risk index estimation model

3. Performing Scenarios

A Fuzzy rule based Inference System (FIS) of Mamdani type was developed in MATLAB, using triangular membership functions. The system was saved as a *forets_risk.fis* file and it runs from the command prompt of MATLAB, using data tables imported from MS-Excel. The following screenshot 1 presents the development environment of the FIS. Of course the Mamdani type ruleset was designed using proper heuristics in order to avoid the problem of combinatorial explosion.



Screenshot 1. Development of three fuzzy linguistics for the altitude feature

A Mamdani type FIS uses IF-THEN fuzzy rules. The number of rules p_{FIS} is given by the following function $p_{FIS} = k^m$ (8) where k is the number of membership functions used and m is the number of input variables (Olej and Hajek, 2009) (Hajek, Olej, 2007). This means that the developed system should have to use 729 rules in total if each one of the input parameters was examined separately.
A crucial task is the reduction of the number of IF-THEN rules by designing Mamdani FIS with a hierarchical structure (HFIS). In this way the FIS is designed in several consequent layers. The number of rules is reduced significantly and it is obtained by the following formula 9

$p_{HFIS} = \left(\dfrac{m-t}{t-1}+1\right) * k^{t}$ *(9)* where t equals the number if layers employed and the result obtained by function 9 is always integer by rounding the value of $\left(\dfrac{m-t}{t-1}\right)$ (Olej and Hajek, 2009) (Pedrycz, 1993).

In this research effort the number of input parameters used was 6 and the number of layers was equal to 3 whereas the membership functions were also 3. Thus, the total number of rules of the FIS was reduced to 54.

Decision trees were used to produce a rational, small and effective rule set. An example of rules used by the system is the following:

FIS_RULE$_1$: IF altitude is high$^{\mu1}$ AND average_moisture is high$^{\mu2}$ THEN overall_risk is low$^{\mu3}$

*FIS_RULE$_2$**:** IF average_burned_area is high$^{\mu1}$ THEN overall_risk is high $^{\mu2}$*

FIS_RULE$_3$: IF average_burned_area is medium$^{\mu1}$ AND average_moisture is low AND wind_speed is high$^{\mu2}$ THEN overall_risk is medium$^{\mu3}$

In the case of rule 2 if the vulnerability due to historical reasons (burned area) is high (meaning that the area is burned significantly during the last 15 years) then we do not have to consider the linguistic value of the other features.

The degrees of membership μ1, μ2 are used to determine the overall degree of membership μ3.

Three distinct scenarios were performed using different weights for each involved feature. For the first scenario, even weights were employed for all of the parameters assigning them equal importance for the period 1983-2004. Due to limitation of space in this paper, only results related to the last ten years (1995-2004) are shown in the following table 1.

In the following tables 1,2,3 the third and the fourth columns contain the overall vulnerability index due to forest fire history and due to the MORMET features respectively when the minimum T-Norm was employed (offering the most optimistic approach). The fifth column is related to the overall risk index (due to both historical and MORMET features) when the fuzzy conjunction is performed by the use of the minimum T-Norm. On the other hand columns 6,7,8 contain the overall vulnerability index due to forest fire history and due to the meteorological features respectively when the Algebraic Product T-Norm was employed. The last column contains the overall wild fire risk index for the case of the Algebraic Product.

It should be clarified that Tables 1,2,3 and 4 contain only the five most risky forest departments, which were identified after the execution of the FIS.

Table 1. Overall risk indices for the case of equal weights

Year	**Forest Department**	**Unified[1] Min T-Norm Fire history**	**Unified[2] Min T-Norm MORMET data**	**Overall risk Min**	**Unified[1] Algebraic product Fire History**	**Unified[2] Algebraic product MORMET data**	**Overall risk Algebraic**
1995	KAVALA	0.448	0.133	0.133	0.389	0.038	0.007
	THASSOS	0.437	0.133	0.133	0.206	0.053	0.004
	XANTHI	0.130	0.133	0.130	0.062	0.035	0.001
	STAVROUPOLI	0.130	0.135	0.130	0.018	0.039	0.000
	RODOPI	0.131	0.133	0.131	0.053	0.040	0.001
1996	KAVALA	0.434			0.378		
	THASSOS	0.436			0.199		
	XANTHI	0.131			0.062		
	STAVROUPOLI	0.130			0.018		
	RODOPI	0.131			0.054		
1997	KAVALA	0.201	0.244	0.201	0.087	0.061	0.002
	THASSOS	0.131	0.237	0.131	0.060	0.062	0.001
	XANTHI	0.131	0.238	0.131	0.017	0.059	0.000

	STAVROUPOLI	0.130	0.274	0.130	0.017	0.075	0.001
	RODOPI	0.131	0.232	0.131	0.017	0.058	0.000
1998	KAVALA	0.201	0.244	0.201	0.087	0.061	0.002
	THASSOS	0.131	0.237	0.131	0.060	0.062	0.001
	XANTHI	0.131	0.238	0.131	0.017	0.059	0.000
	STAVROUPOLI	0.130	0.274	0.130	0.017	0.075	0.001
	RODOPI	0.131	0.232	0.131	0.017	0.058	0.000
1999	KAVALA	0.199	0.337	0.199	0.173	0.084	0.007
	THASSOS	0.131	0.132	0.131	0.037	0.035	0.000
	XANTHI	0.133	0.238	0.133	0.070	0.059	0.002
	STAVROUPOLI	0.130	0.321	0.130	0.017	0.086	0.001
	RODOPI	0.133	0.136	0.133	0.083	0.037	0.001
2000	KAVALA	0.257	0.249	0.249	0.210	0.063	0.007
	THASSOS	0.150	0.246	0.150	0.053	0.087	0.002
	XANTHI	0.136	0.239	0.136	0.118	0.059	0.003
	STAVROUPOLI	0.130	0.284	0.130	0.017	0.078	0.001
	RODOPI	0.136	0.149	0.136	0.118	0.039	0.002
2001	KAVALA	0.257	0.150	0.150	0.210	0.039	0.004
	THASSOS	0.150	0.246	0.150	0.053	0.087	0.002
	XANTHI	0.132	0.239	0.132	0.066	0.060	0.002
	STAVROUPOLI	0.130	0.263	0.130	0.017	0.069	0.001
	RODOPI	0.350	0.146	0.146	0.175	0.063	0.003
2002	KAVALA	0.257	0.135	0.135	0.210	0.057	0.005
	THASSOS	0.150	0.246	0.150	0.053	0.087	0.002
	XANTHI	0.132	0.239	0.132	0.066	0.060	0.002
	STAVROUPOLI	0.130	0.251	0.130	0.017	0.063	0.001
	RODOPI	0.350	0.133	0.133	0.175	0.055	0.003
2003	KAVALA	0.257	0.132	0.132	0.210	0.057	0.005
	THASSOS	0.150	0.246	0.150	0.053	0.087	0.002
	XANTHI	0.131	0.239	0.131	0.065	0.060	0.001
	STAVROUPOLI	0.130	0.245	0.130	0.017	0.061	0.001
	RODOPI	0.142	0.134	0.134	0.071	0.042	0.001
2004	KAVALA	0.257	0.136	0.136	0.210	0.035	0.003
	THASSOS	0.150	0.246	0.150	0.053	0.087	0.002
	XANTHI	0.130	0.239	0.130	0.065	0.060	0.001
	STAVROUPOLI	0.130	0.230	0.130	0.017	0.100	0.001
	RODOPI	0.133	0.135	0.133	0.073	0.037	0.001

The following figure 3, presents in a rather comprehensive manner the overall risk indices (period 1995-2004) for the five most risky forest departments when all features are considered as having equal importance. It is obvious from the following figure 3 that “*Thasos*” and “*Xanthi*” have the highest degree of overall risk when all of the features are considered as of equal importance.

It is remarkable though that “*Xanthi*” and especially “*Stavroupol*i” areas appear a stable overall risk index during a period of ten years.

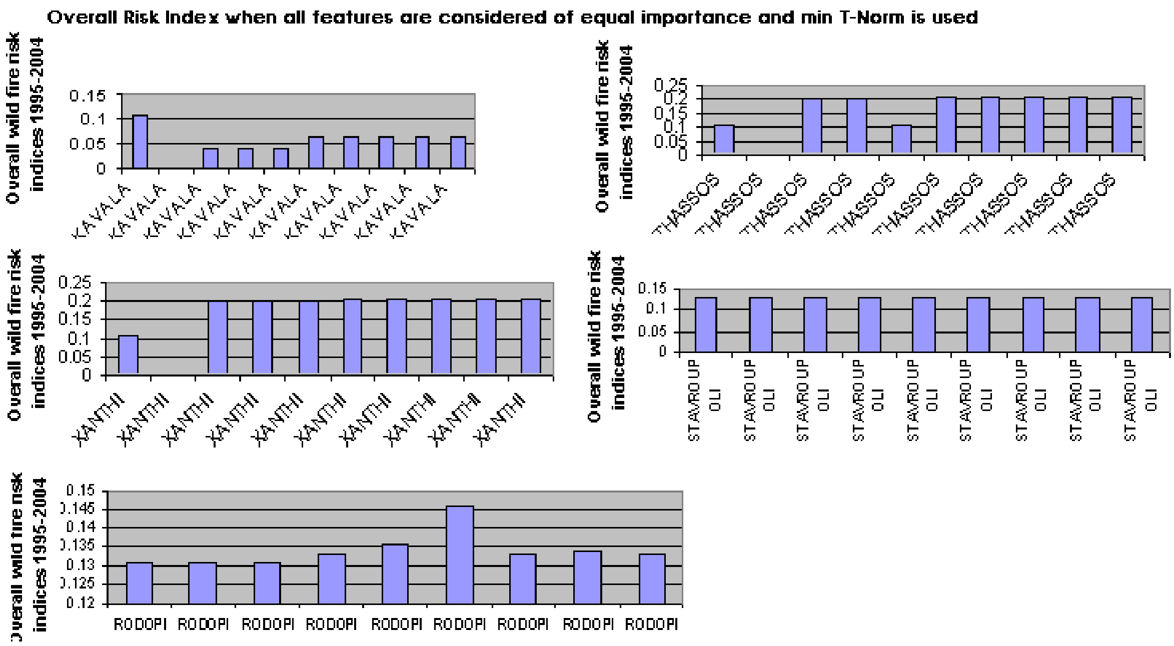


Figure 3. Overall Risk Index with min T-Norm when equal weights were used

For the second scenario, the MORMET factors were considered as having higher importance towards the estimated final forest fire risk. More specifically the following weights were applied: for the number of forest fires w_{ff}=0.5 for the burned area w_{ba}=0.5 for the average altitude w_{aa}=0.4 for the average humidity w_{ah}=0.8 for the average temperature w_{at}=0.9 for the average wind intensity w_{awi}=0.9. This means that this scenario considers the MORMET features as the most important ones. Again the application of the system was done for the period 1983-2004. However due to limitation of space only results related to the last ten years 1995-2004 and to the five most risky areas are presented in the following table 2.

Table 2. Overall risk indices when high weights are used for MORMET features

YEAR	Forest Department	Unified [1] Min T-Norm Fire history	Unified[2] Min T-Norm MORMET data	Overall risk Min	Unified [1] Algebraic product Fire History	Unified[2] Algebraic product MORMET data	Overall Algebraic risk *1000
1995	KAVALA	0.200	0.107	0.107	0.152	0.024	0.501
	THASSOS	0.191	0.106	0.095	0.042	0.037	0.148
	XANTHI	0.017	0.106	0.017	0.004	0.022	0.013
	STAVROUPOLI	0.017	0.108	0.017	0.000	0.026	0.001
	RODOPI	0.017	0.106	0.017	0.003	0.025	0.007
1996	KAVALA	0.189	0.000	0.000	0.143	0.000	0.000
	THASSOS	0.190	0.000	0.000	0.040	0.000	0.000
	XANTHI	0.017	0.000	0.000	0.004	0.000	0.000
	STAVROUPOLI	0.017	0.000	0.000	0.000	0.000	0.000
	RODOPI	0.017	0.000	0.000	0.003	0.000	0.000
1997	KAVALA	0.041	0.209	0.041	0.008	0.041	0.041
	THASSOS	0.017	0.202	0.017	0.004	0.041	0.015
	XANTHI	0.017	0.203	0.017	0.000	0.039	0.002
	STAVROUPOLI	0.017	0.237	0.017	0.000	0.052	0.002

	RODOPI	0.017	0.197	0.017	0.000	0.039	0.001
1998	KAVALA	0.041	0.209	0.041	0.008	0.041	0.041
	THASSOS	0.017	0.202	0.017	0.004	0.041	0.015
	XANTHI	0.017	0.203	0.017	0.000	0.039	0.002
	STAVROU POLI	0.017	0.237	0.017	0.000	0.052	0.002
	RODOPI	0.017	0.197	0.017	0.000	0.039	0.001
1999	KAVALA	0.040	0.298	0.040	0.030	0.058	0.251
	THASSOS	0.017	0.106	0.017	0.001	0.022	0.002
	XANTHI	0.018	0.203	0.018	0.005	0.039	0.023
	STAVROU POLI	0.017	0.283	0.017	0.000	0.060	0.003
	RODOPI	0.018	0.109	0.017	0.007	0.024	0.003
2000	KAVALA	0.066	0.213	0.066	0.044	0.042	0.315
	THASSOS	0.023	0.210	0.023	0.003	0.060	0.013
	XANTHI	0.018	0.204	0.018	0.014	0.039	0.067
	STAVROU POLI	0.017	0.247	0.017	0.000	0.053	0.003
	RODOPI	0.019	0.120	0.019	0.014	0.025	0.027
2001	KAVALA	0.066	0.122	0.066	0.044	0.025	0.141
	THASSOS	0.023	0.210	0.023	0.003	0.060	0.013
	XANTHI	0.017	0.204	0.017	0.004	0.040	0.016
	STAVROU POLI	0.017	0.226	0.017	0.000	0.046	0.002
	RODOPI	0.123	0.118	0.034	0.031	0.046	0.047
2002	KAVALA	0.066	0.108	0.066	0.044	0.040	0.221
	THASSOS	0.023	0.210	0.023	0.003	0.060	0.013
	XANTHI	0.017	0.204	0.017	0.004	0.040	0.016
	STAVROU POLI	0.017	0.216	0.017	0.000	0.042	0.002
	RODOPI	0.123	0.106	0.041	0.031	0.039	0.049
2003	KAVALA	0.066	0.105	0.066	0.044	0.041	0.170
	THASSOS	0.023	0.210	0.023	0.003	0.060	0.013
	XANTHI	0.017	0.204	0.017	0.004	0.040	0.015
	STAVROU POLI	0.017	0.210	0.017	0.000	0.041	0.002
	RODOPI	0.020	0.108	0.020	0.005	0.028	0.010
2004	KAVALA	0.066	0.109	0.066	0.044	0.022	0.115
	THASSOS	0.023	0.210	0.023	0.003	0.060	0.013
	XANTHI	0.017	0.204	0.017	0.004	0.040	0.015
	STAVROU POLI	0.017	0.195	0.017	0.000	0.076	0.004
	RODOPI	0.018	0.108	0.018	0.005	0.024	0.007

The main conclusion drawn from the following figure 4 is that both “*Kavala*” and “*Thasos*” are more vulnerable due to the average meteorological conditions and altitude for forest fire breakouts whereas “*Rodopi*” and “*Kavala*” have a quite unstable behavior in terms of risk.

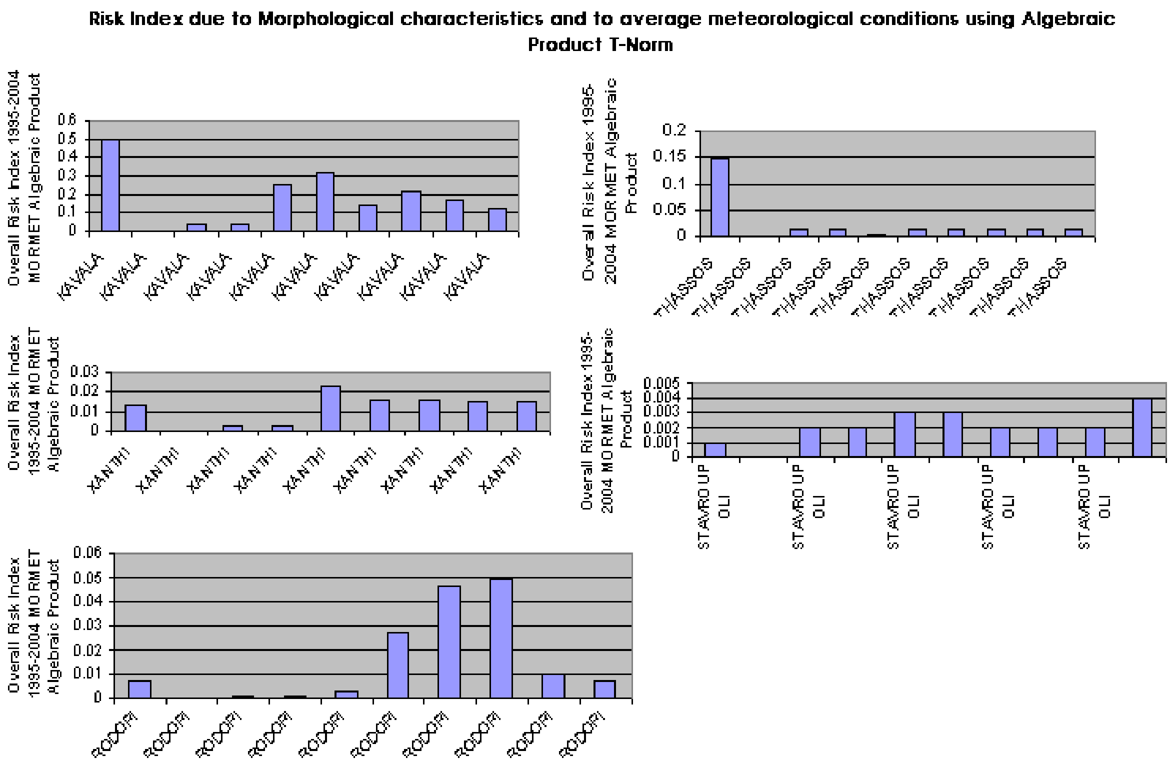


Figure 4. Risk Index based mainly on MORMET features with Algebraic Product T-Norm

For the third scenario the MORMET features were considered as having less impact on the estimated final forest fire risk and more emphasis was given to the historical data. More specifically the following weights were applied: for the number of forest fires w_{ff}=0.7 for the burned area w_{ba}=0.7 for the average altitude w_{aa}=0.4 for the average humidity w_{ah}=0.5 for the average temperature w_{at}=0.5 for the average wind intensity w_{awi}=0.5. This means that this scenario considers the forest fire history features as the most important ones. Again the application was done with data from 1983-2004 and for the whole region. Due to the large volume of data produced and due to the lack of space, the following table 3 presents the results for the third scenario with data from 1995 till 2004 and only for the five most risky areas.

Table 3. Overall risk indices for the case of high weights for the historical factors

YEAR	Forest Department	Unified[1] Min T-Norm Fire history	Unified[2] Min T-Norm MORMET data	Overall risk Min	Unified[1] Algebraic product Fire History	Unified[2] Algebraic product MORMET data	Algebraic risk *1000
1995	KAVALA	0.317	0.018	0.0178	0.260	0.001	0.077
	THASSOS	0.307	0.018	0.0177	0.105	0.003	0.045
	XANTHI	0.055	0.018	0.0177	0.019	0.001	0.005
	STAVROUPOLI	0.054	0.018	0.0182	0.003	0.001	0.001
	RODOPI	0.055	0.018	0.0177	0.015	0.002	0.004
1996	KAVALA	0.304	0.000	0.0000	0.249	0.000	0.000
	THASSOS	0.306	0.000	0.0000	0.100	0.000	0.000
	XANTHI	0.055	0.000	0.0000	0.019	0.000	0.000
	STAVROUPOLI	0.054	0.000	0.0000	0.003	0.000	0.000
	RODOPI	0.055	0.000	0.0000	0.016	0.000	0.000
1997	KAVALA	0.101	0.060	0.0596	0.031	0.004	0.023

	THASSOS	0.055	0.056	0.0549	0.018	0.004	0.011
	XANTHI	0.055	0.056	0.0545	0.003	0.004	0.002
	STAVROUPOLI	0.054	0.075	0.0543	0.003	0.006	0.004
	RODOPI	0.055	0.054	0.0538	0.003	0.003	0.002
1998	KAVALA	0.101	0.060	0.0596	0.031	0.004	0.023
	THASSOS	0.055	0.056	0.0549	0.018	0.004	0.011
	XANTHI	0.055	0.056	0.0545	0.003	0.004	0.002
	STAVROUPOLI	0.054	0.075	0.0543	0.003	0.006	0.004
	RODOPI	0.055	0.054	0.0538	0.003	0.003	0.002
1999	KAVALA	0.100	0.113	0.0997	0.081	0.007	0.123
	THASSOS	0.055	0.017	0.0175	0.009	0.001	0.001
	XANTHI	0.056	0.057	0.0558	0.023	0.003	0.014
	STAVROUPOLI	0.054	0.103	0.0543	0.003	0.007	0.005
	RODOPI	0.056	0.019	0.0186	0.029	0.001	0.002
2000	KAVALA	0.143	0.062	0.0620	0.108	0.004	0.103
	THASSOS	0.067	0.060	0.0603	0.015	0.007	0.014
	XANTHI	0.058	0.057	0.0570	0.047	0.004	0.031
	STAVROUPOLI	0.054	0.081	0.0543	0.003	0.006	0.004
	RODOPI	0.058	0.022	0.0221	0.047	0.002	0.009
2001	KAVALA	0.143	0.023	0.0226	0.108	0.002	0.032
	THASSOS	0.067	0.060	0.0603	0.015	0.007	0.014
	XANTHI	0.055	0.057	0.0554	0.021	0.004	0.011
	STAVROUPOLI	0.054	0.069	0.0543	0.003	0.005	0.003
	RODOPI	0.223	0.021	0.0213	0.083	0.004	0.022
2002	KAVALA	0.143	0.018	0.0182	0.108	0.003	0.066
	THASSOS	0.067	0.060	0.0603	0.015	0.007	0.014
	XANTHI	0.055	0.057	0.0554	0.021	0.004	0.011
	STAVROUPOLI	0.054	0.063	0.0543	0.003	0.004	0.003
	RODOPI	0.223	0.018	0.0177	0.083	0.003	0.019
2003	KAVALA	0.143	0.017	0.0173	0.108	0.003	0.053
	THASSOS	0.067	0.060	0.0603	0.015	0.007	0.014
	XANTHI	0.055	0.057	0.0547	0.020	0.004	0.011
	STAVROUPOLI	0.054	0.060	0.0543	0.003	0.004	0.003
	RODOPI	0.062	0.018	0.0181	0.023	0.002	0.005
2004	KAVALA	0.143	0.018	0.0184	0.108	0.001	0.024
	THASSOS	0.067	0.060	0.0603	0.015	0.007	0.014
	XANTHI	0.055	0.057	0.0545	0.014	0.004	0.007
	STAVROUPOLI	0.054	0.053	0.0529	0.003	0.010	0.007
	RODOPI	0.056	0.018	0.0181	0.024	0.001	0.003

From the following figure 5, it can be concluded that "*Kavala*" and "*Stavroupoli*" have the highest vulnerability based on historical data, whereas the island of "*Thasos*" has one peak with a very high degree of risk for 1995 and then a stable behavior for the following years. A closer look to the results shows that "*Thasos*" has also a risk index maximum due to meteorological features in 1995.

The main difference between "*Kavala*" and "*Stavroupoli*" is that "*Stavroupoli*" has a continuous risky behavior whereas "*Kavala*" does not.

The area of "*Xanthi*" has a similar behavior with "Thasos" but the peak of risk is estimated for 1999.

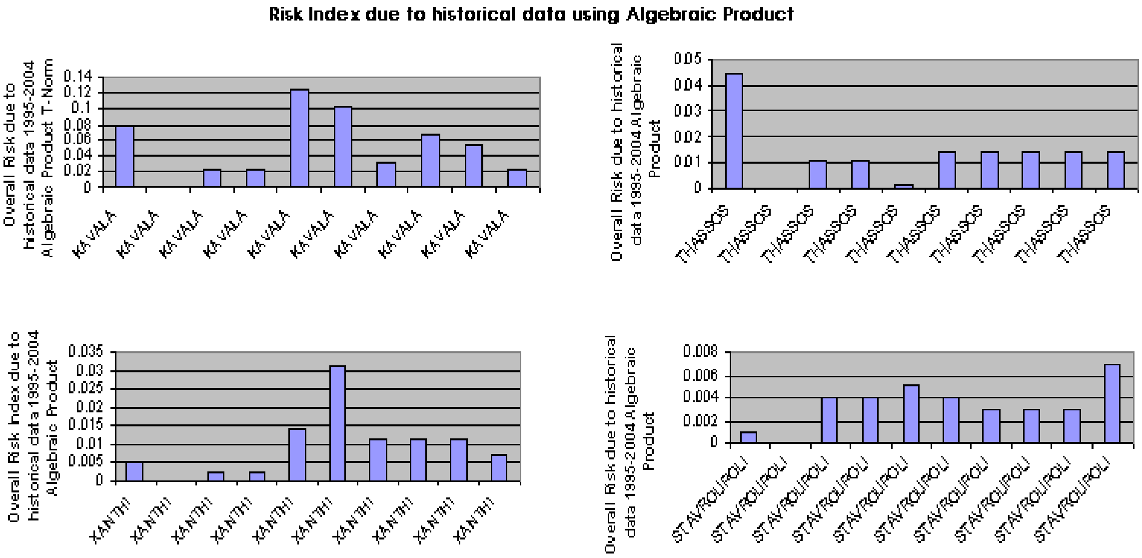


Figure 5. Risk Index based mainly on historical features with Algebraic Product T-Norm

4. Discussion - Conclusions

All of the performed calculations produced by the FIS were summed up in the following table 4 which shows the percentage of success for the system and the percentage of successful forest fire forecasting for the years 1983-2004.

Table 4. Evaluation of the FIS

YEAR	F. DEPARTMENTS WITH THE MOST BURNED AREAS (Ha)	MOST RISKY F. DEPARTMENTS ACCORDING TO THE FIS	Percentage of System's Success	Successful Forecast Percentage
1983	DRAMA ALEXANDROUPOLI NEVROKOPI SOYFLI DIDIMOTIHO	XANTHI RODOPI THASSOS ALEXANDROUPOLI DIDIMOTIXO	2/5 = 40%	NO AVAILABLE DATA
1984	THASSOS DRAMA KAVALA RODOPI DIDIMOTIXO	RODOPI DRAMA THASSOS KAVALA DIDIMOTIXO	5/5 = 100%	3/5 = 60%
1985	KAVALA THASSOS DRAMA ALEXANDROUPOLI DIDIMOTIXO	KAVALA THASSOS DRAMA ALEXANDROUPOLI RODOPI	4/5 = 80%	4/5 = 80%
1986	RODOPI DIDIMOTIXO DRAMA THASSOS STAVROUPOLI	THASSOS KAVALA RODOPI DRAMA ALEXANDROUPOLI	3/5 = 60%	3/5 = 60%
1987	ALEXANDROUP	KAVALA	4/5 = 80%	3/5 = 60%

	OLI NEVROKOPI DRAMA STAVROUPOLI KAVALA	THASSOS DRAMA ALEXANDROUPO LI STAVROUPOLI		
1988	DRAMA, ALEXANDROUP OLI KAVALA XANTHI NEVROKOPI	KAVALA THASSOS DRAMA STAVROUPOLI NEVROKOPI	3/5 = 60%	3/5 = 60%
1989	THASSOS DRAMA STAVROUPOLI XANTHI NEVROKOPI	KAVALA THASSOS DRAMA RODOPI STAVROUPOLI	3/5 = 60%	4/5 = 80%
1990	KAVALA DRAMA DIDIMOTIHO NEVROKOPI RODOPI	KAVALA THASSOS DRAMA RODOPI ALEXANDROUPO LI	3/5 = 60%	3/5 = 60%
1991	DIDIMOTIHO ALEXANDROUP OLI DRAMA KAVALA XANTHI	KAVALA THASSOS DRAMA NEVROKOPI DIDIMOTIHO	3/5 = 60%	3/5 = 60%
1992	KAVALA DRAMA DIDIMOTIHO NEVROKOPI XANTHI	KAVALA THASSOS DRAMA DIDIMOTIHO NEVROKOPI	4/5 = 80%	4/5 = 80%
1993	DRAMA THASSOS KAVALA NEVROKOPI DIDIMOTIHO	KAVALA THASSOS DRAMA ALEXANDROUPO LI NEVROKOPI	4/5 = 80%	5/5 = 100%
1994	DRAMA ALEXANDROUP OLI KAVALA RODOPI SOUFLI	KAVALA THASSOS DRAMA ALEXANDROUPO LI RODOPI	4/5 = 80%	3/5 = 60%
1995	XANTHI DRAMA KAVALA ALEXANDROUP OLI RODOPI	KAVALA THASSOS DRAMA ALEXANDROUPO LI NEVROKOPI	3/5 = 60%	4/5 = 80%
1996	RODOPI KAVALA XANTHI NEVROKOPI DIDIMOTIHO	KAVALA DRAMA DIDIMOTIHO XANTHI RODOPI	4/5 = 80%	2/5 = 40% INSUFFI CIE-NT DATA)
1997	RODOPI ALEXANDROUP OLI DRAMA	KAVALA DRAMA THASSOS XANTHI	3/5 = 60%	3/5 = 60%

	NEVROKOPI KAVALA	NEVROKOPI		
1998	KAVALA XANTHI RODOPI ALEXANDROUP OLI DRAMA	KAVALA DRAMA XANTHI RODOPI ALEXANDROUPO LI	5/5 = 100%	3/5 = 60%
1999	KAVALA RODOPI XANTHI ALEXANDROUP OLI DIDIMOTIHO	KAVALA XANTHI RODOPI DRAMA DIDIMOTIHO	4/5 = 80%	4/5 = 80%
2000	DIDIMOTIHO RODOPI XANTHI DRAMA KAVALA	KAVALA DRAMA THASSOS XANTHI DIDIMOTIHO	4/5 = 80%	5/5 = 100%

The evaluation of the system was performed based on two tests. Test *A* checked how many of the five most severely burned areas for each year were also characterized by the system as areas of highest risk. Thus, the forest departments with the highest burned area for each year were compared to the output of the FIS for the same year. The average percentage of successful characterizations ranged from 60 to 80%. However for the first year it dropped to 40%, whereas for 1984, 1998 and 2000 the percentage was 100%. The output of test A can be found in the fourth column of Table 4.

Test B was based on the ability of the FIS to forecast the degree of forest fire risk for the following year. This means that on an annual basis each area was assigned a corresponding *Linguistic* showing its vulnerability to wild fires. This overall vulnerability characterization of each forest department for year Y_n was compared to the actual status (in terms of burned area) for the following year Y_{n+1}.

Thus, in test B a comparison was performed between the five forest departments with the highest extend of burned area (as they were recorded by the forest administration of the region of Eastern Macedonia and Thrace) to the five most risky forest departments of the previous year as they were characterized by the system. The percentage of successful forecasting ranged from 60% to 80%. The system produced a perfect forecast for the years 1993 and 2000. The results of test B are presented in the fifth column of Table 4.

This is a pilot research effort that introduces an innovative approach for estimating the wild fire vulnerability of an area due to several categories of features and at the same time it outputs the overall risk indices.

In this study the final results have given merit to this approach. A more detailed research should be done with more features involved regardless the place or the time if more resources are available. The software is available after request to Dr Lazaros S Iliadis Associate Professor in the Democritus University of Thrace, Greece.

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