Fire hazard modelling using remote sensing and GIS. A case study of the Eparchy of Pylias (Messinia, Greece)

B.M. De Vliegher[1], P.S. Basigos[2]

1. Department of Geography, Universiteit Gent, Krijgslaan 281 (S8-A1), B-9000 Gent (Belgium). Tel. +32.9.264 47 09, Fax +32.9.264 49 85
2. Dieythisi Dason Messinias, Nomarchia Messinias, GR-24100 Kalamata (Greece). Tel. +30.721.20820, Fax +30.721.93723

ABSTRACT

A hazard model for fire spreading is set up for the Eparchy of Pylias (Messinia, Greece) based upon a combination of remote sensing and GIS. A multi source data set is used, comprising cartographic documents, satellite imagery and statistical information about the fire history of the region (1978-1993).

A thematic study is performed for each of the influencing factors (vegetation, topography, accessibility, influence of tourism, proximity to waste dumps). This information, together with the fire location map is stored in the GIS.

The relation between the occurrence of wild fires (1978-1992) and the influencing factors is searched for. Based upon the share of burnt land within each thematic class, a thematic hazard function is determined. The hazard map for fire occurrence is obtained by multiplying the thematic hazard maps. Six classes are differentiated.

The final stage of the research consists in the checking of the model reliability. Two periods are considered: 1978-1992 referring to the fire information used for the set up of the model, and 1992-1993 including the completed fire data for 1992 and information for the period January-August 1993. The checking shows that most of the observed fires occurred in areas with fire hazard > 2.

The resulting map can be of great benefit for the understanding of the fire problem and will offer a more effective control of the fires.

1. INTRODUCTION

1.1. Problem of wild fires

Wild fires are one of the major concerns of foresters in the Mediterranean regions. They affect about 5,000 km^2 every year (Kailidis D.S., 1992). Le Houérou H.N. (1981) has estimated that each plot of forest will burn once every 25 year. In Greece, about 900 fires are counted on average each year, covering an area of nearly 32,000 ha, corresponding to 35.13 ha per fire.

The susceptibility to wild fires is mainly due to climate (dry and hot summers; wind activity), and vegetation characteristics. Plants often are adapted to the dryness; most shrubs of Mediterranean plant communities are spiny and have a high content of resin and oils. Also topography and human influence acting since Antiquity play an important role in the occurrence of wild fires.

A strong increase in number of fires and in area is noted in the last two decades. In 1972, 385 fires are registered in Greece covering an area of 8,500 ha; in 1990 1,322 fires were counted over an area of 38,593 ha. An analogue trend is found in other countries of the Mediterranean (Italy, Portugal) (Kailidis D.S., 1992).

This increase in devastated area since the 60^s is mainly caused by the important growth of amount in fuels. Due to the rural exodus, agricultural land is abandoned and reforestation takes place.

1.2. Objectives

The aim of the study is to model the wild fire behaviour in the Eparchy of Pylias (SW-Peloponnese, Greece). This paper emphasises the spatial aspect of the fire problem, namely the spreading of the fire. The expansion hazard is investigated based upon the relationship between the fire history and the physical and human characteristics of the study region : vegetation, topography (altitude, slope, aspect), accessibility of the area, influence of tourism, proximity to waste dumps.

The study of wild fire hazard is very relevant to the rural management and the set up of a hazard model is required. This model will offer a more effective control of wild fires, in particular as it concerns (1) the opening of new fire roads, (2) special management planning of multi burnt areas (change of species or land use), (3) proposal for new policy and legislation in multi burnt areas, (4) the supply of useful technical equipment, (5) the rearrangement of the fire fighter's locations, (6) information towards the public, and (7) a better construction of development and management plans for the natural ecosystems in relation to wild fire behaviour.

1.3. Literature review

Remote sensing techniques are used for different purposes, concerning the study of wild fires.

1. Mapping of loss by wild fires. Tanaka S. *et al.* (1983) have used Landsat Multi Spectral Scanner (MSS) data for the classification, mapping and area estimation of devastated land in Japan. The classification is obtained by multivariate analysis and is superimposed on a topographical map to form a Landsat Map System. Karteris M.A. and Kritikos G. (1992) applied non-supervised and supervised classifications for assessing forest fire damages on the Holy Mount Athos (Greece).

The automatic classification of burnt land using satellite imagery can, however, cause some difficulties because of the spectral overlap between burnt/not-burnt land especially in areas where the vegetation is very sparse (Chuvieco E. and Congalton R.G., 1988; De Vliegher B.M., 1991).

A method for regional and global fire detection using NOAA-AVHRR images is proposed by Matson M. *et al.* (1987). Channel 3 of NOAA-AVHRR (middle infrared, 3.55-3.93 mm) seemed to be most useful for detecting active fires (Brustet J.M. *et al.*, 1991; Pereira M.C. and Setzer A.W., 1993). Malingreau J.P. (1984) and Malingreau J.P. *et al.* (1985) used the vegetation index (AVHRR data band 1 and band 2) for evaluating the extension and damage of fires. The potential for using multi temporal normalised difference vegetation index data, produced from NOAA-AVHRR, to locate and map the area of wild fires in boreal forests of Alaska is demonstrated by Kasischke E.S. *et al.* (1993).

2. Mapping of fire fuels. The gathering of information on fire fuels is very important since the availability and characteristics of fuels influence fire behaviour a great deal. Benson A. *et al.* (1983) used classified Landsat data in order to determine the distribution and quantities of vegetation and fuels in the Big Basin Redwoods State Park (California). A comparison between the results of visually interpreted Landsat data and of digitally processed NOAA-AVHRR data showed comparable accuracy (Werth L.F. *et al.*, 1985). McKinley R.A. *et al.* (1985) set up an operational technique using NOAA-AVHRR data in order to obtain broad scale fire fuel classes over large areas.

3. Monitoring of regeneration capability. This is done by calculation of leaf area index (Diamantopoulos J. and Paraskevopoulos S., 1986) or normalised difference vegetation index using a multi temporal data set (Lopez Soria S. *et al.*, 1988; Dagorne A. *et al.*, 1990).

Geographical information systems (GIS) offer a great help in the monitoring and mapping of fire risk.

In the past, fire risk models have been set up based upon the fire history of the region. The fire risk comprises three different components: (1) the basic risk, referring to the fire frequency, (2) the cause index, indicating the typology of the causes and (3) the vegetation index, showing the influence of plant associations (Anon., 1987).

Kailidis D.S. and Pantelis D. (1988) determined the relationship between fires and the climatic conditions using statistical fire data. Out of this, a fire danger rating system is set up for possible fire spreading. The relation between meteorological variables and the occurrence of wild fires is also studied by Vázquez A. and Moreno J.M. (1993). They have found a strong variation in space and in function of ignition source. In order to be operational, the model based upon the meteorological conditions must be incorporated in a broader model including other factors.

A GIS is an optimal technique in the forest fire research because of the relation between fire occurrence and the spatial characteristics of the numerous influencing factors. Chuvieco C. and Congalton R.G. (1989) combined GIS and remote sensing to obtain a fire hazard map with three hazard classes. Antoninetti M. *et al.* (1993) integrated topographical and satellite data for the identification of fire hazard areas. The research is based upon the use of fuzzy production rules representing the logical combination of all factors involved and the causal relationship between risk factors and final hazard judgements.

The combination of a spatial data base (elevation, slope, aspect, precipitation, plant community types, fuel models) with remote sensing appeared to be a working tool for management in North Cascades National Park (USA) with the necessity of training the park staff in the use of the system and timely access to processing (Root R.R. *et al.*, 1985).

1.4. Geography of the study area

1.4.1. Environmental settings

The study is applied upon the district ("Eparchy") of Pylias, located in the south-western part of the Peloponnese (Greece) **(Figure 1)**.

The Eparchy of Pylias is divided by the NNW-SSE oriented Kyparissia mountain range into the Gavrovon-Pylos zone to the west and the Olonos-Pindos zone to the east. The Kyparissia mountain range is built up of Jurassic limestone and Jurassic-Cretaceous radiolarite. The Gavrovon-Pylos zone forms a weak inclined plane, with altitude slowly decreasing towards the Ionian Sea. It consists of flysch (Eocene to Oligocene), marl-sandstone-conglomerate (Pliocene). A N-S oriented limestone ridge of Cretaceous to Eocene-Palaeocene age forms the western border of this plane. The Olonos-Pindos zone to the east is mainly composed of Pliocene marl deposits.

The southern part of the study area and the region along the Messinian Gulf belong to the Oleo-Ceratonia association. To the north, the vegetation is of the Quercion ilices type. Some of the important species are *Quercus* spp., *Pistacia lentiscus, Arbutus unedo. Pinus* spp. is found in the forested area. The density of the vegetation cover can vary extremely between "no vegetation present" to very dense vegetation.

The region has known a strong depopulation since 1940: 46084 inhabitants ('40) to 27626 ('81). The result is a lowering of the mean altitude of population settlements about 4.5 m every 10 years (Daels L. *et al.*, 1989). Consequently, the descent of the population results in the abandonment of the higher located agricultural lands involving an increase of fuel wood.

1.4.2. Fire history

Statistical data for the Eparchy of Pylias are available for the period 1978-1993*. Records of 118 fires are included, covering 4454 ha of forested land and 7015 ha in total, including agricultural land **(Figure 1)**. According to the statistics, 1988, 1992 and 1993 have been the most disastrous years **(Table 1)**.

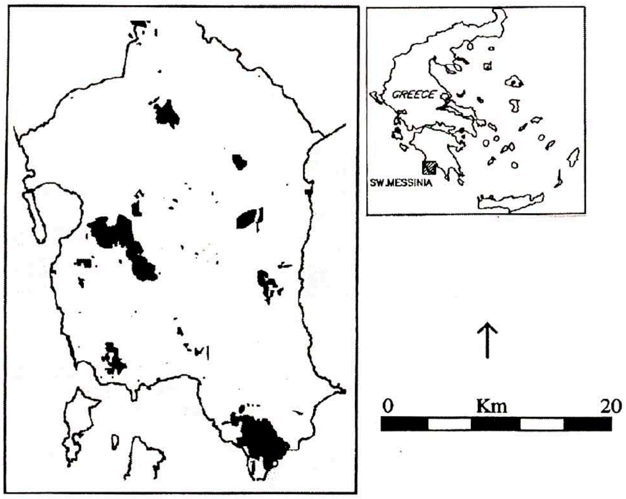


Figure 1 - Location of wild fires (1978-1993) in the Eparchy of Pylias (SW-Peloponnese, Greece)*

Table 1 - Information about wild fires for the years 1988, 1992 and 1993

Year	Number of fires	Area of forested land	Total Area	Area of forested land per fire	Total per fire
1988	11	1216 ha	1917 ha	110.5 ha	173.4 ha
1992	19	1003 ha	1478 ha	52.8 ha	77.8 ha
1993*	10	936 ha	1144 ha	93.6 ha	114.4 ha

* Information for the period January-August

2. DOCUMENTS AND METHODOLOGY

2.1. Documents used

The available data set consisted of:

- Topographical maps at a scale 1:50,000 (Hellenic Army Geographical Service, Athens). Additional information about the location of wild fires and waste dumps is given by the topographical map.

- Fire statistics for the period 1978-1993 which are made available through the Forestry directorate of the Nomos of Messinia (Kalamata, Greece). The statistical data include information about 1) the locality of the wild fires, 2) date and hour of start and end of the fire, 3) the area of the fire (forested land, agricultural land), 4) the vegetation type with density and species, 5) the type of fire, 6) the average altitude, slope and aspect of the area, 7) the lithology of the area, 8) the cause of the fire, 9) the climatic data at the time of the fire (temperature, relative humidity, wind speed and wind direction), 10) general description of the fire seat.

The statistical data are accompanied by a sketch of the affected area and a precise location on the 1:50,000 topographical maps.

• Satellite images. A multi spectral SPOT image (scene 088-278), dated August 12 1986, was to our disposal covering the southern part of the Nomos of Messinia. Furthermore, a SPOT-derived digital elevation model was available. This DEM was modified because of 1) an offset of the altitude of about 40 m, 2) the presence of some clouds in the northern part of the scene, and 3) the exclusion of the islands of Sapientza and of Schiza.

2.2. Methodology

The set up of the hazard model is based upon a combination of field survey, remote sensing techniques and GIS. The ILWIS-software (Integrated Land and Watershed Information System), developed at the ITC (Enschede, The Netherlands) is used with PC-configuration.

2.2.1. Study of the influencing factors

Based upon multi temporal field survey the influencing factors are determined. A thematic study of each factor is performed, either using remote sensing techniques (as it is the case for the vegetation information) or storing the statistical data and the cartographic information in the GIS.

2.2.1.1. Remote sensing

Because of their synoptic, temporal and spectral characteristics, the use of satellite images is of great benefit for the detection and the mapping of vegetation.

The thematic layer of vegetation is obtained by calculating the Normalised Difference Vegetation Index (NDVI) using the available multi spectral SPOT-image. The vegetation index is calculated with the formula:

$$\text{NDI:} = \left(\frac{(\text{SPOT3} - \text{SPOT2})}{(\text{SPOT3} + \text{SPOT2})} \text{ x } 100 \right) + 100$$

where: SPOT 2: red band, and SPOT 3: infrared band. The values of the resulting image vary between 0 and 200. The higher the NDVI value, the higher will be the density of the photosynthetic active material.

2.2.1.2. Geographical information system

The different data of the multiple influencing factors are stored in the GIS in order to investigate the relationship with the wild fires.

Cartographic information is digitised. This is done for the location of wild fires, the road network, the waste dumps and the influence of tourism.

Other information is derived from existing data layers, such as aspect and slope using the SPOT-DEM, and calculating distances (roads, waste dumps, coast).

2.2.2. Hazard modelling

Two steps can be distinguished in the hazard modelling: determination of the thematic hazard and calculation of hazard for fire spreading.

2.2.2.1. Determination of the thematic hazard

The procedure for determining the thematic hazard is shown in **Figure 2**.

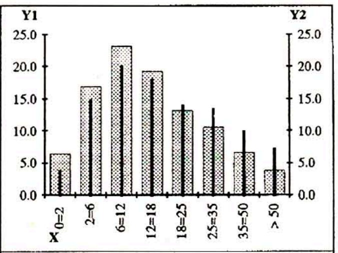
a. Each influencing factor is divided into thematic classes, e.g. slope 0-2 %. The frequency is determined for each thematic class and expressed in %.
The fire location map (period: 1978-1992) is combined with the thematic map.
The area affected by wild fires within each thematic class is determined and expressed in %.

b. The obtained results are represented in bar-line histograms. The X-axis refers to the thematic class, the proportional frequency is plotted along the Y-axis. Bars refer to the proportional frequency of the thematic class (Y1), lines indicate the proportional frequency of burnt land (Y2). In the case of an equal distribution, fire occurrence is not affected by the assumed "influencing" factor. Each line is then of equal length with the corresponding bar.
A line smaller than the bar indicates that fires occur less than expected (if equally distributed). The influence of a certain thematic class on fire occurrence is greater when the line exceeds the bar.

a.

SLOPE (%)	Frequency (%) Y1	Fire (%) Y2
0=2	6.5	3.6
2=6	16.9	14.7
6=12	23.1	19.9
12=18	19.3	17.8
18=25	13.1	13.9
25=35	10.6	13.2
35=50	6.6	9.8
> 50	3.8	7.0

b.



c.

SLOPE (%)	Ratio
0=2	0.6
2=6	0.9
6=12	0.9
12=18	0.9
18=25	1.1
25=35	1.2
35=50	1.5
> 50	1.8

d.

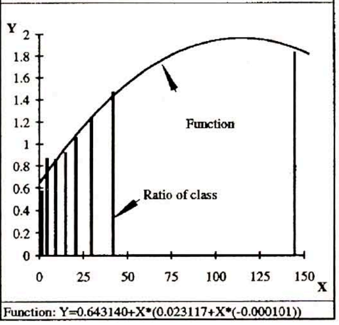


Figure 2 - Procedure for determination of the thematic hazard

c. The ratio "Burnt area per thematic class (%)/Frequency thematic class (%)" is calculated. Values higher than 1 indicate that the corresponding thematic class is more susceptible to fire occurrence.

d. A thematic hazard map can be obtained by converting the thematic values (NDVI, altitude (m), slope (%), distance to.. (m),...) into their corresponding ratio. Using the individual ratios for each class, it is assumed that fire hazard is discontinuous and each thematic class is represented by one single ratio.

Susceptibility to fire occurrence may, however, be considered as a continuous phenomenon and a hazard function is determined. Out of the calculated ratios and using X (thematic information) as independent and Y (ratio) as dependent variable, the best fitting curve is calculated.

The application of this hazard function converts the themaptic maps into thematic hazard maps.

2.2.2.2. Calculation of the fire hazard

A first step is taken by which thematic hazard values smaller than 1 are not taken into account; they all are set equal to 1. This is done in order not to neutralise the fire hazard caused by other factors.

The hazard for fire spreading is obtained by multiplying the different thematic hazard maps.

HAZARD: = V * A * S * O * R * C * D

where

V is the thematic hazard for	vegetation
A	altitude
S	slope
O	orientation (aspect)
R	distance to roads
C	distance to the coast
D	distance to waste dumps.

3. RESULTS AND DISCUSSION

3.1. Relation between influencing factors and occurrence of wild fires

3.1.1. Vegetation

An NDVI-value of 130 forms a distinct limit for fire occurrence. The proportional frequency of burnt land per vegetation index class exceeds the proportional frequency of the NDVI class if NDVI > 130. Fire hazard increases thus with increasing density of photosynthetic active material; scanty vegetation has a much lower risk.

The ratio "Burnt area per NDVI class (%)/Frequency NDVI class (%)" is equal to 1.74 (class 150-160) and 5.35 (class 160-170); the classes 110-120 and 120-130 have a ratio of 0.88 and 0.82 respectively.

3.1.2. Topography

Nearly 50 % of the burnt land is located within an altitude range of 118-229 m, covering 30 % of the entire area. The corresponding ratio "Burnt area per altitude class (%)/Frequency altitude class (%)" varies between 1.31 and 1.75.

Regions at lower altitude and altitudes between 229-419 m show a lower ratio (0.25 for the class 0-27 m to 0.88 for the class 72-118 m). The highest ratio (1.98) is noted for the class 419-927 m; nearly 20 % of the burnt land is located within this range.

Considering the general trend that temperature decreases and humidity increases with altitude, this fire behaviour is odd. It is expected that the area of fires should be the biggest at lower altitudes, at places with highest temperature and with lowest precipitation. The findings reveal that other factors, besides climate, are influencing the fire occurrence in a more explicit way, such as the accessibility of the area.

As shown in **Figure 2**, the most sensitive zones for fire spreading are steep to very steep with slopes of more than 18 %. This is because fuels growing uphill on steep slopes are brought into closer contact with the upward moving flames through which fire catch occurs faster.

Out of the statistical analysis, it appears that fire occurrence is relatively independent of the orientation of the region. The ratio "Burnt area per aspect class (%)/Frequency aspect class (%)" varies between 0.71 (SW) and 1.33 (E). East and northeast orientated areas are the most susceptible to fire occurrence.

3.1.3. Accessibility of the area

The accessibility of the area or the proximity to the roads is of great importance in the fire fighting programme. The largest areas which are affected by burnings are situated at a distance of more than 500 m.

The ratio "Burnt area per distance to roads class (%)/Frequency distance to roads class (%)" reaches a maximum for distances 1000-1750 m (varying between 2.56 and 3.23); the same ratio is 0.74 for distances 0-500 m.

3.1.4. Distance to the coast

The influence of tourism can be expressed in terms of distance to the coast. The closer to the coast, the higher will be the possible touristic pressure and the related building mania of the tourist project managers.

The highest ratios "Burnt area per distance to coast class (%)/Frequency distance to coast class (%)" are obtained for the classes 1-2 km (1.77) and 2-3 km (1.92).

3.1.5. Distance to waste dumps

The most susceptible areas to fire occurrence in function of distance to waste dumps are located within a distance of 500 m. The ratio "Burnt area per distance to waste dump class (%)/Frequency distance to waste dump class (%)" for the class 0-500 m is equal to 3.41. Regions at remote distance have a lower risk and the ratio drops below 1 (class 2.5-3 km with a ratio of 0.51).

3.2. Hazard model for occurrence of wild fires

Following the procedure described in 2.2.2.1, the thematic hazard functions are determined. The type of function for each influencing factor is given in **Table 2**.

The hazard model for fire occurrence is shown in **Figure 3**. A value of 2 means that the considered region is twice as susceptible to fire spreading as in the case of an equal distribution.

The hazard classes "2" and "3-5" are predominant and occupy nearly 75 % of the total area. These classes are mainly influenced by altitude and distance to coast, and additionally for the class "3-5" accessibility.

The hazard class "6-10" covers nearly 8 % of the region. The fire behaviour in these regions is influenced by accessibility; other factors are of second importance.

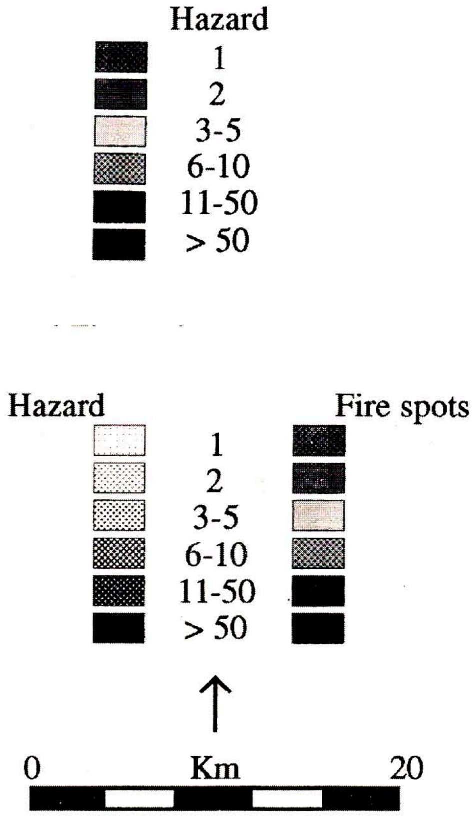
The classes of highest hazard (11-50 and > 50) are limited in area. The class "11-50" is mainly influenced by the accessibility, the other factors to a lesser extent. The most severe hazards are due to altitude, vegetation, accessibility and slope.

Table 2 - Description of thematic hazard functions

Influencing factor	Type of function	a0	a1	a2	a3
Vegetation	Exponential	0.052456	0.024041		
Altitude	Polynomial 3rd -0.000090	-0.274930 9.174E-08	0.022540		
Slope	Polynomial 2nd	0.643140	0.023117	-0.000101	
Orientation	Polynomial 3rd	0.879010	0.007218	-0.000050	8.230E-08
Distance to roads	Polynomial 3rd	-0.354499	0.004907	-0.000002	1.407E-10
Distance to coast	Polynomial 2nd	1.297378	0.002827	-0.000063	
Distance to dumps	Exponential	4.832991	-0.001200		

Exponential: Y=a0*exp(a1*X) Polynomial: Y=a0+a1*X+a2*X^2...

Figure 3 - Fire hazard map



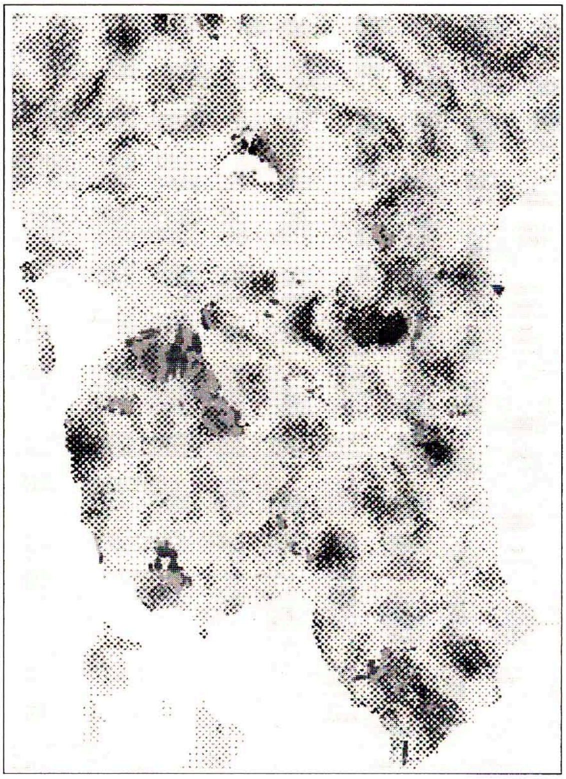


Figure 4a - Location of fires (1978-1992) in function of hazard

Figure 4b - Location of fires (1992-1993) in function of hazard

3.3. Checking of model reliability

The hazard model for fire occurrence is combined with the location of the observed wild fires. Two periods are distinguished: (1) 1978-1992 for which the data were available when the model was set up and (2) 1992-1993 with the completed fire data for 1992 and information for the months January-August 1993.

The combination of the fire location map and the hazard map for both periods is shown in **Figure 4 (a and b)**. The proportional distribution is given in **Table 3**.

Table 3 - Distribution of fire localisation in function of fire hazard (%)

Period	Hazard 1	Hazard 2	Hazard 3-5	Hazard 6-10	Hazard 11-50	Hazard >50
1978-1992	1.04	20.57	47.07	23.96	7.29	0.07
1992-1993	0.52	8.36	39.25	49.74	2.12	0.00

Both Figure 4 and Table 3 illustrate the accuracy and the reliability of the hazard model for fire occurrence. Most of the burnt land is found in regions with a hazard higher than 2. Only a small part of the land is burnt which is labelled as hazard 1.

4. CONCLUSIONS

This paper showed a first hazard model for fire spreading in the Eparchy of Pylias (SW-Peloponnese, Greece). It can be said that the methodology used, based upon a combination of remote sensing and GIS is an excellent tool for the assessment of fire hazard. The availability of highly detailed fire statistics as well as a good terrain knowledge are, however, of great importance for the success of the model. The determination of the influencing factors vary according to the study region and field survey is obligatory.

At present, a hazard model is being created for ignition, based upon the same principle. Other factors, such as meteorological conditions at the time of the fire, must also be taken into account. Therefore, the modelling of fire behaviour will also be focused upon the seasonality. A model will be set up for each season, for fire frequency as well as for fire expansion.

ACKNOWLEDGEMENT

This research forms part of the Belgian impulse programme "Global Change", project "Environmental degradation in past, present and future in the Mediterranean" (Belgian State Prime Minister's Services for Science Policy).

REFERENCES

Anon, 1987, *Course on wild fires and fire ecology in Mediterranean forest ecosystems*. Chania (Greece), Jan. 15-21 1987.

Antoninetti M., Binaghi E., Rampini A. & D'Angelo M., 1993, The integrated use of satellite and topographic data for forest fire hazard mapping. In: Winkler P. (ed.), *Proceedings of 12th EARSeL Symposium "Remote sensing for monitoring the changing environment of Europe"*, Eger (Hungary), Sept. 8-11 1992. Rotterdam: A.A.Balkema: 179-184.

Benson A., Greenlee J. & Langenheim J., 1983, Assessment of wildland fuel hazards in Big Basin Redwoods State Park, California. In: *International Society for Photogrammetry and Remote Sensing Commission IV – Proceedings 5th international symposium*, Crystal City (Virginia, USA), Aug. 22-28 1982: 55-63.

Brustet J.M., Vickos J.B., Fontan J., Manissadjan K., Podaire A. & Lavenu F., 1991, Remote sensing of biomass burning in West Africa with NOAA-AVHRR. In: Levine J.S. (ed.) *Global biomass burning. Atmospheric, climatic and biospheric implications*. Cambridge: the MIT press: 47-52.

Chuvieco E. & Congalton R.G., 1988, Mapping and inventory of forest fires from digital processing of TM data. *Geocarto International*, **4**: 41-53.

Chuvieco E. & Congalton R.G., 1989, Application of remote sensing and geographic information system to forest fire hazard mapping. *Remote Sensing of Environment*, **29**: 147-159.

Daels L., Antrop M., De Dapper M., Goossens R., Louis A., De Vliegher B.M., De Caluwe M., Brackman P., De Boeck M. & Van der Kerken L., 1989, *Analysis of landscape structures and dynamics in relation to soil, land use and settlement in Messinia using SPOT data*. Report Less Favoured Area Programme "Messinia", part 1. Gent (Belgium), Universiteit Gent, Laboratorium voor Regionale Geografie en Landschapskunde: 105 p.

Dagorne A., Dauphiné A., Escleyne G., Gueron L., Baudouin L. & Lenco M., 1990, L'utilisation de la télédétection aérospatiale en mode multi-satellites, multi-capteurs et multi-dates pour l'étude de la reprise de la végétation après incendie. L'exemple du massif de Tanneron (Var-Alpes Maritimes). *Photo-interprétation*, **1990-5**: 45-51.

De Vliegher B.M., 1991, *Studie van de actuele landdegradatie in Zuidelijk Euboia (Griekenland), gesteund op teledetectie en GIS*. 2 volumes. Gent (Belgium), Universiteit Gent: Non-published Ph.D.-Thesis, 459 p.

Diamantopoulos J. & Paraskevopoulos S., 1986, The use of remote sensing techniques in the study of vegetation recovery after fire in Mediterranean countries. A preliminary study. *Proceedings ISLSCP conference*, Rome (Italy), Nov. 2-6 1985, **ESA SP-248**: 537-538.

Kailidis D.S., 1992, *Forest fires in Greece-Italy-France-Spain-Portugal-USA and Canada. Thessaloniki (Greece).* Aristotelian University of Thessaloniki, Dept. Forestry Natural Environment, Laboratory Forest Protection, **1/1992**, 17 p.

Kailidis D.S., Theodoropoulou-Pierrakou D. & Papazoglou G., 1977, *Fire risk of plant zones and forest and grazing land fires in Greece (Data of the years 1973, 1974, 1975).* Thessaloniki (Greece), Aristotelian University of Thessaloniki, Dept. Forestry Natural Environment, Laboratory Forest Protection, **83/1988**, 36 p.

Kailidis D.S. & Pantelis D., 1988, *Sizes of forest-shrub and grazing land fires and relationship with meteorological conditions during the year and the day.* Thessaloniki (Greece), Aristotelian University of Thessaloniki, Dept. Forestry Natural Environment, Laboratory Forest Protection, **3/1988**, 26 p.

Karteris M.A. & Kritikos G., 1992, Assessment of forest fire damages in Holy Mount Athos Using Remote Sensing Techniques. In: Folving S. *et al.* (eds.) *European collaborative programme workshop on Remote Sensing for Forestry Applications.* Copenhagen (Denmark), Nov. 13-15 1992: 197-210.

Kasischke E.S., French N.H.F., Harrell P., Christensen Jr. N.L., Ustin S.L. & Barry D., 1993, Monitoring of wildfires in boreal forests using large area AVHRR NDVI composite image data. *Remote sensing of Environment,* **45**: 61-71.

Le Houérou H.N., 1981, Impact of man and his animals on Mediterranean vegetation. In: di Castri F. *et al.* (eds.) *Ecosystems of the world 11. Mediterranean-type shrublands.* Amsterdam, Elsevier: 479-521.

Lopez Soria S., Gonzalez Alonso F., Llop Pomares R. & Cuevas Gozalo J., 1988, An evaluation of the utility of NOAA-AVHRR images for monitoring forest fires in Spain. In: *Proceedings of the 8th EARSeL Symposium – Alpine and Mediterranean Areas: A Challenge for Remote Sensing.* Capri (Italy), May 17-20 1988: 246-254.

McKinley R.A., Chine E.P. & Werth L.F., 1985, Operational fire fuels mapping with NOAA-AVHRR data. In: *Pecora10 Proceedings.* Fort Collins (Colorado, USA), Aug. 20-22 1985: 295-304.

Malingreau J.P., 1984, Remote sensing and disaster monitoring: a review of application in Indonesia. *Proceedings E.R.I.M., International symposium on remote sensing of environment,* Paris (France), **1**: 283-297.

Malingreau J.P. Stephens G. & Fellows L., 1985, Remote sensing of forest fires: Kalimantan and North Borneo in 1982-83. *Ambio,* **14**: 314-321.

Matson M. & Stephens G., 1987, Fire detection using data from the NOAA-N satellites. *International Journal of Remote Sensing,* **8(7)**: 961-970.

Pereira M.C. & Setzer A.W., 1993, Spectral characteristics of deforestation in NOAA/AVHRR images.*International Journal Remote Sensing,***14(3)**:583-597.

Root R.R., Stitt S.C.F., Nyquist M.O., Waggoner G.S. & Agee J.K., 1985, Vegetation and fire fuel models mapping of North Cascades National Park. In: *Pecora10 Proceedings.* Fort Collins (Colorado, USA), Aug. 20-22 1985: 287-294.

Tanaka S., Kimura H. & Suga Y., 1983, Preparation of a 1:25,000 Landsat map for assessment of burnt area on Etajima island. *International Journal of Remote Sensing,* **4(1)**: 17-31.

Vázquez A. & Moreno J.M., 1993, Sensitivity of fire occurrence to meteorological variables in Mediterranean and Atlantic areas of Spain. *Landscape and Urban Planning,* **24**: 129-142.

Werth L.F., McKinley R.A. & Chine E.P., 1985, The use of wildland fire fuel maps produced with NOAA-AVHRR scanner data. In: *Pecora10 Proceedings.* Fort Collins (Colorado, USA), Aug. 20-22 1985: 326-331.