Assessment of forest fire damages in attiki using remote sensing and GIS techniques

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ABSTRACT

In September 1992 a fire lasting for one week destroyed a large forested area in Attiki north of Athens, Greece.

Within the bilateral cooperation between Germany and Greece, the DLR Institute of Optoelectronics and the Aristotelian University of Thessaloniki in a joint effort tried to estimate the acreage of the burnt area and the scorched vegetation using remote sensing and GIS techniques. For this purpose maps, aerial photographs and LANDSAT-TM satellite images taken before and after the fire disaster, as well as the image analysis system XDIBIAS and the GIS GRASS 4.0 were used.

A multispectral-multitemporal set of images for the area of interest was produced after registration of the LANDSAT-TM bands 2,3,4,5 & 7 from both dates, before and after the fire.

Training areas for two supervised classifications were selected. The Maximum Likelihood algorithm was applied to produce a land cover/use map of 8 categories with an overall accuracy of 87,2 %, as well as to extract the acreage of the burnt area.

Topographical data like contour lines, roads etc. were digitized from fourteen very detailed 1:5000 scale topographic diagrams. Using the GIS a digital terrain model (DTM) was calculated. The classified images, before and after the fire, were superimposed on the DTM to calculate the true acreage of the burnt area. The combination of the DTM and the classified image content can be presented as perspective viewing on the scene from various directions and altitudes. A number of statistical results like aspect, elevation and slope distribution of the burnt area have been derived by using the DTM and the classified TM images.

1. INTRODUCTION

On Saturday 5 September 1992 at 13:30', with a strong wind blowing (7 BF) and high air temperature (31°C), a forest fire broke out in an area close to the national road from Athens to Thessaloniki, which is used as a burning place for rubbish. The fire moved fastly eastwards. The arrival of two alerted trucks from the Forest Fire Brigade at the place of the fire within 30 minutes, had nearly no effect. The fire was completely extinguished a week later. It burned dense and open forests, brushlands, grasslands, pastures and agricultural land. Also four houses and a few hundred animals (sheeps, goats, etc.) were burnt. **Figures 1 and 2** give a little impression of the catastrophy showing two small burnt areas.

The goal of this study was to demonstrate the assessment of the actual burnt areas and vegetation species using satellite data and GIS techniques. For this purpose TM data, topographic and forestry maps as well as aerial photographs were used.

2. DESCRIPTION OF THE AREA

Attiki (Greece) **(Figure 3)**, is covered mostly by Pine Forests *(Pinus halepensis)* with an understory of evergreen shrubs which consist of species like *Pistacia lentiscus, Quercus coccifera, Arbutus spp.*, etc.

Figure 1 - A ground photograph showing the contrast between burnt and healthy forest area in the background

Figure 2 - A ground photograph showing the hilly burnt area

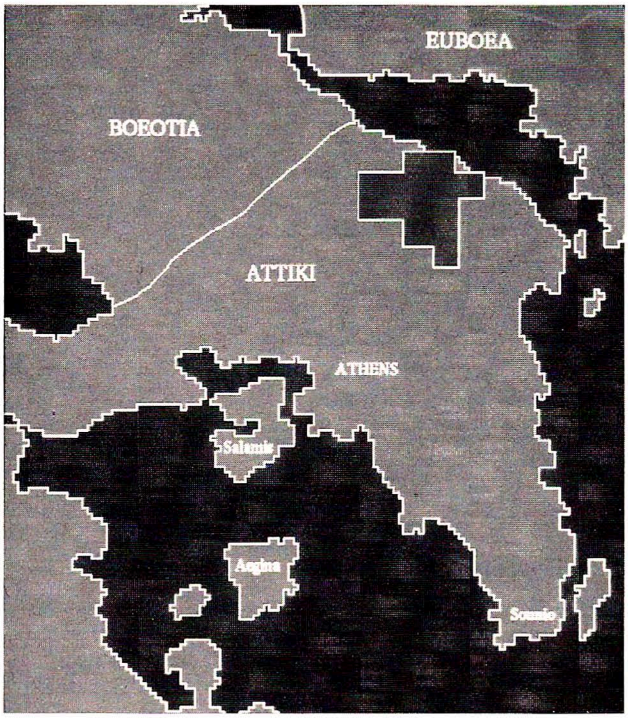

Figure 3 - A map of Attiki, Greece, indicating the fire site north-east of Athens

This kind of vegetation coverage is more or less typical of the lowlands of many Mediterranean countries and grows especially close to and along the coasts.

The burnt area occupies the northern part of Kapandriti Forest Region, which covers a total area of 68.000 ha. Most of this area is covered by dense or sparse forest stands (38.000 ha), while the rest is brushlands, agricultural lands, grasslands and pastures, olive tree plantations and residential areas.

The road network is dense and is used to connect several villages. Many of these roads have been constructed by the Forest Service. They cross the forested area from different directions and they are mainly used for forest management and protection.

In general, the area consists of a so called mosaic of landuse, which means that many different landuse/landcover classes appear as a mixture all over the area. This kind of landuse pattern, in conjunction with hot, dry summer, strong winds and various socioeconomic aspects, is considered by the wildfire managers and other forestry specialists in Greece, as one of the main reasons for having so many and difficult to control forest fires in Greece.

3. METHODOLOGY

A series of 1:5.000 detailed topographic diagrams were used together with several 1:50.000 and 1:100.000 topographic maps and also a series of 1:50.000 landuse/landcover maps, which cover the entire region and the surroundings of the area of interest.

Two successive high quality, cloud free LANDSAT TM images, the first taken before (26 Aug. 1992) and the second after the fire (11 Sep. 1992) were also acquired.

The first step was to prepare the LANDSAT imagery for classification analysis. For this purpose, two multispectral windows of LANDSAT TM images were extracted from the 100 x 100 km frames, containing the area of interest, from both dates before and after the fire disaster respectively (**Figures 4 and 5**). The two individual frames were registered in order to produce a multispectral-multitemporal image set, including ten TM bands, the same five from both dates (TM 2, 3, 4, 5 & 7). Two channel ratios, which represent the vegetation-index, were also derived and included in the set of image data, and were used in the classification process.

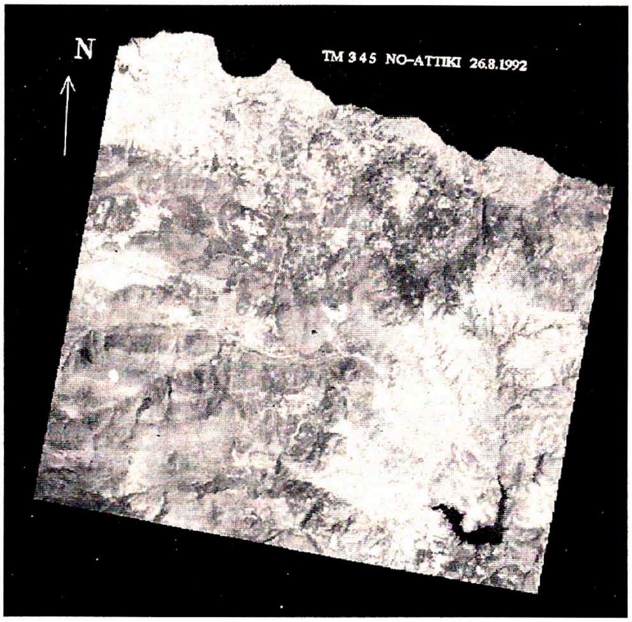

Figure 4 - TM multispectral image bands 3, 4 and 5 acquired on 26.8.92 over north of Attiki, Greece

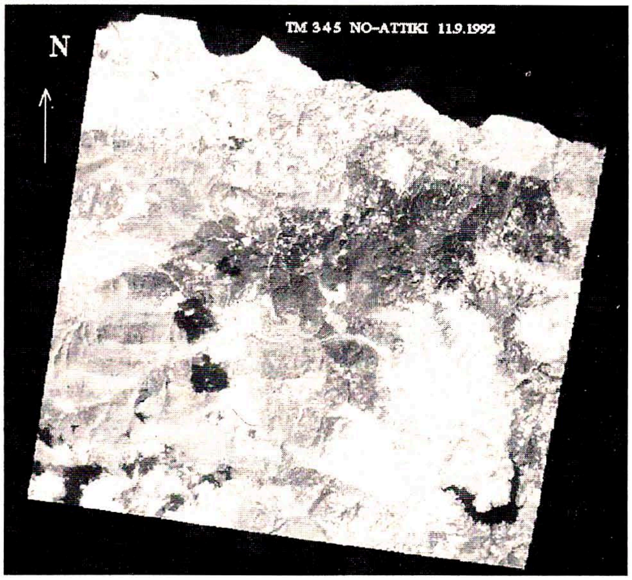

Figure 5 - This TM multispectral image shows exactly the same area as Figure 4, but acquired after the fire on 11.9.92

Several image enhancements, like contrast stretching, high-pass filterings, etc. were applied to the above images and also a number of different truecolor composites were produced to select different land cover categories as reliable training areas for the subsequent classification process.

The land cover/use classification system was then defined. Eight land cover/use informational categories which are abundant in the area were chosen. They were: Dense conifers (Pinus halepensis), Mixed conifers and shrubs (dense), Mixed conifers and shrubs (open), Fields (agricultural land, pastures and grasslands), previously Burnt area, Bare soil (with little or no vegetation), Sea and Lake. It should be pointed out that the categories agricultural land, pastures and grassland were combined in one, because in all these areas many herbaceous species were grown, resulting in spectral characteristics similar to those of grassland. Due to this situation, the creation of separate classification categories would result in many omission and commission errors, which in turn would reduce considerably not only the classification accuracy of each one of them, but also the overall classification performance.

The selection of the training sites is a crucial matter because of its influence on the classification performance. Having this in mind, several training sites, representative of the whole variability of each category, were carefully located and selected. The data collected from the sites data were used to calculate the training statistics (mean vectors and covariance matrices) associated with each classification category. The established training statistics were used to classify the entire study area. The procedure involved the maximum likelihood decision rule. The classification results are shown in **Table 1**. In **Table 2** is shown the distribution of the unburnt vegetation within the fire perimeter.

A quantitative assessment of the classification performance (i.e. the category specific and overall classification accuracy) was also performed. To accomplish this step the classification results were compared with available forest maps and aerial photographs. Also on site visits were conducted in order to collect field observations and answer to certain questions related to classification. The comparison was made by conducting a stratified random sampling of point locations, having in mind that the measure of accuracy is binomially distributed (a set of pixels is either correctly or incorrectly classified). The total number of points were calculated using the equation

$$N = \frac{P(100 - P)}{e^2} * t^2$$

where : N = the sample size of all categories
P = the expected level of accuracy in percent
t = Student's t factor
e = acceptable sampling error in percent.

The above equation gave a sample size of 196 points using P=90, e=3 and t=1,96 (for 95 % significance level).

The classification accuracy results are presented in a performance matrix **(Table 3)**, where omission and commission errors, as well as the producer's classification accuracy for each category are easily readable.

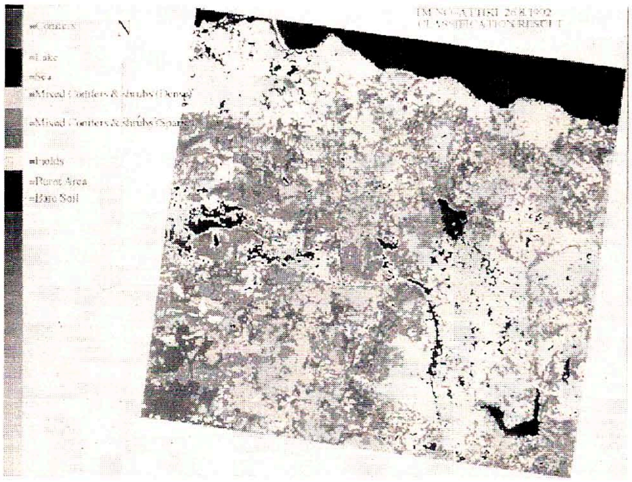

Figure 6 - Results of the classification of Figure 4. It shows the separated 8 categories in different colours

Table 1 - Classification results within the projected burnt area

Category	Cover hectares	%
No data – unclassified	2,65	0,05
Dense conifers	1790,37	30,98
Mixed conifers & shrubs (dense)	642,79	11,12
Mixed conifers & shrubs (open)	1991,64	34,47
Fields	1073,85	18,58
Burnt area	133,50	2,31
Bare soil	143,23	2,48
Lake	0,26	0,00
Sea	0,26	0,00
Total	5778,55	100,00

Table 2 - Classification results for the unburnt vegetation and other categories within the fire perimeter

Category	Cover hectares	%
No data – unclassified	5,81	0,38
Dense conifers	287,81	18,67
Mixed conifers & shrubs (dense)	91,19	5,92
Mixed conifers & shrubs (open)	357,84	23,21
Fields	637,03	41,32
Burnt area	21,95	1,42
Bare soil	140,00	9,08
Total	1541,63	100,00

The next step was the transformation of other additional data from analogue to digital form.

Topographic data such as contour lines, roads, railways, residential areas, etc. were digitized from fourteen very detailed 1:5.000 scale topographic diagrams. From this digitization process topographic and other vector maps showing the transportation network and other features of the study area were derived.

The topographic maps were mosaicked together and after an interpolation process, an evaluation datafile and a Digital Terrain Model (DTM) were calculated having a fifteen metre grid and one metre height resolution. A few other maps were also produced, like an aspect map containing nine aspect categories, a slope map and an elevation zone map containing six and eight categories respectively. All this information was also stored as individual map layers in the database for subsequent analyses and statistic evaluations.

The third step was the geometric correction and rectification of the classification results on the same coordinate system as the topographic maps. More than thirty control points were used to rectify the images. The classification results, before and after the fire, were overlayed on the 3D model of the area **(Figures 7 and 8)**.

Furthermore, a number of statistics were generated in tabular form for various features of land use and topography which can be used for further analysis of interdependences. These statistics include the burnt area distribution in dependence of the elevation zones, the slopes and the aspects **(Table 4)**. They are useful for a further analysis of fire risk in Mediterranean regions. Finally the acreage of the burnt area taking into account the DTM in comparison to the area obtained without the DTM was calculated **(Table 4)**.

3. RESULTS AND DISCUSSION

The classification results indicated that the burnt area was easily distinguished from the unburnt one. Its total acreage was estimated to be about 5778 hectares **(Table 1)**. Comparing the two scenes (before and after the fire) it was found that Dense conifers and Mixed conifers with shrubs (open) were the most predominant burnt categories. In other words these were the predominant vegetation categories in the area. The third most important category were the Fields (agricultural land, pasture, grassland). The above categories cover about 82 % of the total burnt area.

The matrix of classification performance **(Table 3)** showed that except the category Mixed conifers and shrubs (dense) which was misclassified considerably with Dense conifers and Mixed conifers with shrubs (open), all the other categories were classified with a very high accuracy which exceeded 85 %. This percentage is acceptable for forestry purposes.

The satellite data and the methodology followed are useful in determining the spatial distribution and the acreage of land cover/use categories unburnt within the fire perimeter. Actually in this study it was found that 1541 hectares were unburnt **(Table 2)**. Of them the most predominant unburnt category (41 % of the total unburnt area-637 hectares) was the so-called Fields, which consisted of agricultural land, pasture and grassland. This high figure, which was about 59 % of the total burnt area classified as Fields **(Table 1)**, is conceivable as the spread of the fire is more difficult in such ecosystems (stone fences, less biomass for burning, etc.). Twenty three percent (358 hectares) of Mixed conifers with shrubs (open) (which is about 18 % of the total burnt area classified in this category) were classified as unburnt. The high percentage is probably due to the obstacles in fire spreading encountered in this "open" ecosystem.

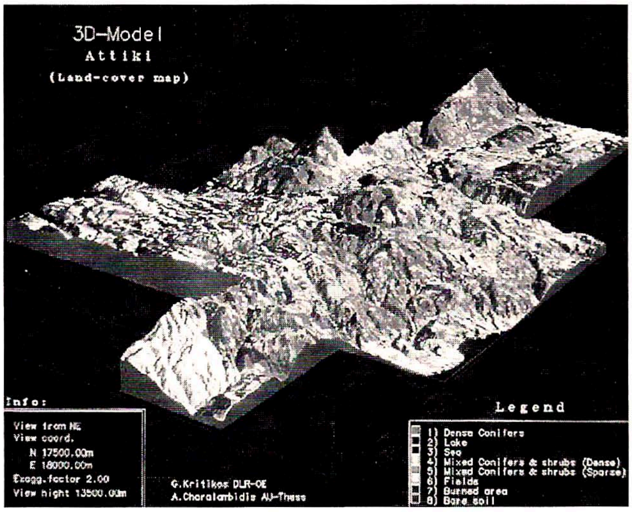

Figure 7 - Same as figure 6 but superimposed over the DTM (Digital Terrain Model) of this region

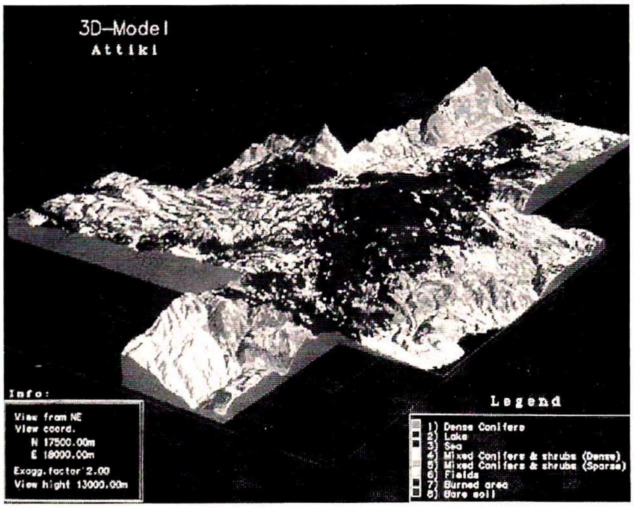

Figure 8 - Classification results after the fire with the DTM information

Table 3 - Matrix of classification performance

Category	Dense conifers	Lake – Sea	Mixed conifers & shrubs (dense)	Mixed conifers & shrubs (open)	Fields	Burnt area	Bare soil	Total	Omission errors	Accuracy
Dense conifers	49		2	3				54	5	90,7
Lake – Sea		4						4		100
Mixed conifers & shrubs (dense)	3		11	2				16		68,8
Mixed conifers & shrubs (open)	2		2	42	3			49	7	85,7
Fields	1		1	2	59		2	65	6	90,8
Burnt area						1		1		100
Bare soil					1		6	7	1	85,7
Total	55	4	16	49	63	1	8	196		
Commission errors	6		5	7	4		2		25	

Overall classification accuracy 87,2 %

Table 4 - The distribution of the projected burnt area by elevation zones, slopes and aspects.

Elevation zones			Slopes			Aspects		
Category	Cover		Category	Cover		Category	Cover	
	hectares	%		hectares	%		hectares	%
No data	197,33	3,41	No data	199,15	3,45	No data	199,15	3,45
1-100 m	22,98	0,40	1 – 10 %	643,67	11,14	East facing	594,65	10,29
101-200 m	308,28	5,33	11– 30 %	2896,23	50,12	Northeast	771,47	13,35
201-300 m	1360,30	23,54	31– 50 %	1595,75	27,62	North facing	771,49	13,35
301-400 m	1551,30	26,85	51– 70 %	366,89	6,35	Northwest	881,43	15,25
401-500 m	1789,73	30,97	71-100 %	62,30	1,08	West facing	806,74	13,96
501-600 m	522,16	9,04	> 100 %	14,56	0,25	Southwest	690,39	11,95
601-700 m	26,12	0,45				South facing	476,09	8,24
> 701 m	0,35	0,01				Southeast	570,01	9,86
						No aspect	17,13	0,30
Total	5778,55	100,00	Total	5778,55	100,00	Total	5778,55	100,00

The total acreage of the sloped burnt area is 6158,23 ha.
Difference with projected burnt area : 379,68

Regarding the topographic characteristics of the burnt area it was found that the sloped area was 6158 hectares and the projected 5778 hectares, that is a difference of about 379 hectares (**Table 4**). In addition, other characteristics are the following:

– the area is hilly (87 % of it has less than 500 m altitude). The predominant elevation zones are between 200 m and 500 m

– the predominant (50,1 % of the total area) slope category is 11-30 %. However, over 77 % of the area ranges between 11 and 50 % slope

– there is no specific trend in aspect distribution.

The above results have shown that with multitemporal satellite image data combined with DTM, a detailed mapping of the burnt area and the analysis of forest fire damages can be performed. This information is useful for a number of planning tasks:

– information on slopes, aspects and elevation zones can be used for reforestation measures

– updating the GIS-database with information from upcoming satellite images can serve the monitoring of natural or artificial reforestation

– the use of additional meteorological, geological, socioeconomic data etc. would strengthen information supplied by studies on risk, prevention and spreading of forest fires.

5. CONCLUSIONS

This study attempted to evaluate the usefulness of multitemporal LANDSAT TM digital data in classifying and mapping a burnt area and the corresponding burnt and unburnt land cover/use categories within the fire perimeter. The findings of the analysis indicated that the relevance of satellite data in such fire mapping related programmes is very high. It is considered that the use of ancillary data, mainly topographic data, improves considerably the classification effectiveness and the value of the data. Generally, satellite data and GIS techniques contribute substantially to the extraction of information required for the proper estimation of forest fire damages and the development of management planning, decisions and measures for the restoration of the damaged ecosystems.

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