# MONITORING FIRE - AFFECTED WILDLANDS IN THE MEDITERRANEAN REGION BY APPLYING A REMOTE SENSING AND GIS APPROACH

**Heinz Gallaun and Cliff Banninger**
Institute for Digital Image Processing, JOANNEUM RESEARCH
Wastiangasse 6, A-8010 Graz, AUSTRIA
Tel.: +43-316-876-757; Fax: +43-316-876-720
Email: gallaun@pdib40.joanneum.ac.at

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## 1. ABSTRACT:

Wildfires are one of the major factors that initiate land degradation processes in a semi-arid environment. Landsat Thematic Mapper imagery acquired in the dry period are used to derive vegetation cover maps. From these vegetation cover maps for different acquisition dates, vegetation cover change maps are produced, which allow the assessment of vegetation regeneration processes.

The prediction of the risk of desertification is based on estimates of the potential for natural regeneration and risk of soil erosion. By combining remote sensing, geology, and topographic information within a GIS a relative ranking of the desertification risk is achieved.

The results show the usefulness of the approach for resource management at the regional and national level and for many needs at the local level.

## 1. INTRODUCTION

Desertification is a process with a significant detrimental socio-economic impact on the environment, affecting the planet as a whole, but giving also an immediate cause for concern in the Mediterranean region. There are many factors that contribute to or aid in desertification, ranging from physical, through biological, to social processes. As one such factor forest wild fires may initiate a desertification process, depending on the extent and severity of damage in the burnt areas, climatic conditions, geology, and the state of the soil.

Land permanently degraded to desert-like conditions, according to UNEP documents, continues to grow at an annual rate of 6,000,000 hectares. In Greece and Spain alone 420,000 ha of forests were destroyed by wild fires in the year 1991.

This paper describes parts of the work performed by the Institute for Digital Image Processing (DIB) at Joanneum Research within the EEC project entitled *A GIS Decision Support System for the Prevention of Desertification Resulting from Forest Fires* within the Environment Research Programme of the EEC, Climatology and Natural Hazards. The project was undertaken in collaboration with the Department of Electronic and Electrical Engineering at the University of Surrey (UoS), the Laboratory of Remote Sensing at the National Technical University of Athens (NTUA), and the Institute of Mediterranean Forest Ecosystems at the National Agricultural Research Foundation (NARF).

The project objectives were to design and develop a GIS decision support system for monitoring and predicting the recovery of burnt forest areas after a fire and provide information on their potential for natural regeneration, risk of soil erosion, and risk of desertification. The definition of the system's requirements was provided by NARF, in consultation with the other consortium partners, based upon the needs of resource managers in the Mediterranean region.

## 2. STUDY AREA / GROUND TRUTH

Four previously burnt areas in Greece, situated in the hilly to mountainous Pateras, Lavrio, Pendeli, and Varnavas regions of Attica surrounding Athens, were selected as test areas. Extensive forest fires have occurred in these areas, some areas burnt twice within a decade *(comp. Fig. 1)*. The main vegetation types within the study areas are closed stands of Aleppo Pine (Pinus Halepensis), phrygana, and phrygana/maquis.

Within the four test areas, 39 reference sites ranging between 1 ha and 4 ha and representative of different stages of regeneration after a forest fire, were selected by NARF for detailed measurement of plant, soil, geology, and physiographical features, for use in establishing relationships between remote sensing data and ground features.

## 3. VEGETATION MONITORING

Monitoring the vegetation cover and the regeneration rate at burned sites is of major importance for land resource management. In this study an approach is suggested that uses multitemporal TM imagery. In a first step, vegetation cover is determined from the near - infrared and red spectral region of the imagery by applying a vegetation index. The vegetation cover estimates for different dates are used in a second step to determine regeneration rate.

### 3.1. Vegetation Cover

A dense vegetation cover at a burnt site has normally re-established itself within two to five years of a fire. However, the process of regeneration can be impeded by many factors, such as animal grazing, a paucity of precipitation, or soil erosion.

Aerial photographs are commonly used to obtain an estimate of a region's vegetation cover, but there also exists a strong correlation between vegetation cover and satellite-based vegetation indices that can provide this information over much larger areas. One such index is the Modified Soil Adjusted Vegetation Index (MSAVI) of Qi et al. (1994), which is given by

$$MSAVI = \frac{2*\rho_{NIR} + 1 - \sqrt{(2\rho_{NIR}+1)^2 - 8(\rho_{NIR} - \rho_{RED})}}{2}$$

where $\rho_{NIR}$ = *Reflectance in the NIR spectral region*

$\rho_{RED}$ = *Reflectance in the red spectral region*

For quantitative estimates of vegetation cover, field sites without any vegetation cover and forested sites with "full" cover were used in the analysis. The selection of appropriate sites is critical for the accuracy of the estimates. For non-vegetated areas, sites with bare soil and rocks were selected. No burnt sites were included. Aleppo pine forests were used as a reference for "full" vegetated sites. A comparison of the MSAVI values with ground-acquired vegetation cover data for the 39 reference sites shows a linear relationship. Therefore, the MSAVI values were linearly stretched between the mean values for the non-vegetated and the forested sites.

As an independent quality control, 14 validation sites in addition to the 39 reference sites were used. A comparison between ground cover estimates for this 14 validation sites and their corresponding MSAVI-obtained estimates is given in *Table 1*.

*Table 1: Vegetation Cover for the Validation Sites*

| Test Area | Site | Ground truth (%) | Estimate (%) | Residual (%) |
|---|---|---|---|---|
| Lavrio | 1 | 85 | 82 | 3 |
| | 2 | 90 | 75 | 15 |
| Pateras | 1 | 75 | 74 | 1 |
| | 2 | 85 | 81 | 4 |
| | 3 | 70 | 86 | 16 |
| | 4 | 90 | 72 | 17 |
| | 5 | 30 | 43 | 13 |
| | 6 | 30 | 38 | 8 |
| Pendeli-1 | 1 | 65 | 74 | 9 |
| | 2 | 70 | 92 | 22 |
| | 3 | 40 | 58 | 18 |
| Pendeli-2 | 1 | 95 | 80 | 15 |
| Varnavas | 1 | 95 | 95 | 0 |
| | 2 | 100 | 91 | 9 |

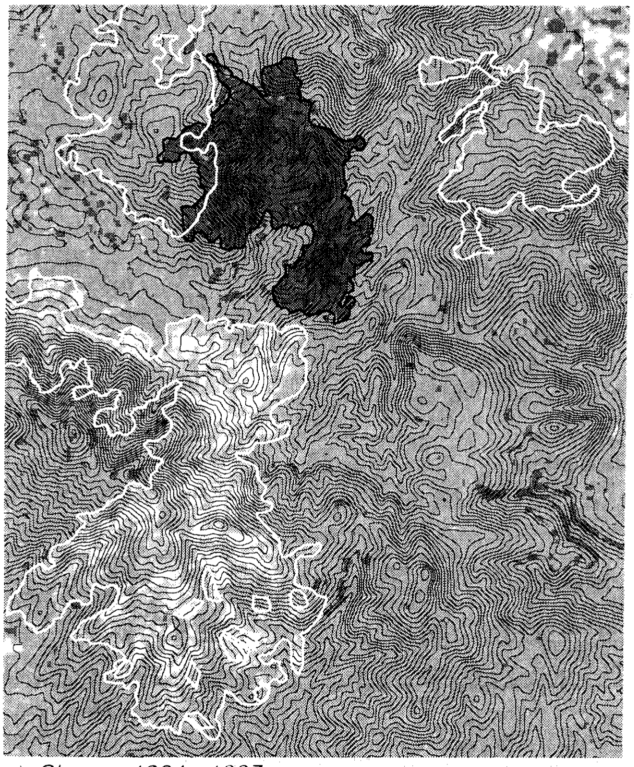
The results give an overall RMS-Error of ±13 %.

### 3.2. Monitoring regeneration rates

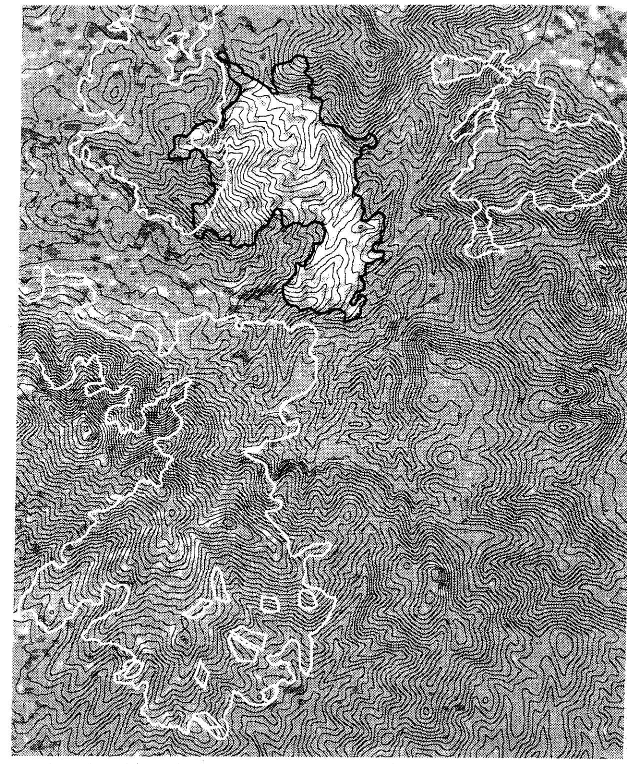
For quantitative and qualitative evaluation of the degree and extent of regeneration, the difference in vegetation cover between two image acquisition dates is used.

A prerequisite for this approach is a high precision overlay of the image data sets. At a minimum, the different image data sets have to be registered to one "reference" image. If coordinate information for further analysis or mapping is required, georeferencing of the images is necessary. *Almer et al. (1991)* give an estimate of the geometric location accuracy as a function of terrain height and imaging geometry for affine and parametric geocoding. In this study parametric geocoding was performed for the image data sets, incorporating a digital elevation model. By using the RSG (Remote Sensing Software Package Graz) developed at our institute, we achieved absolute geometric accuracies better than ± 1 pixel for all image data sets. However, for many monitoring applications, an affine transformation without a digital elevation model can be sufficient and very cost effective, especially for monitoring large regions.

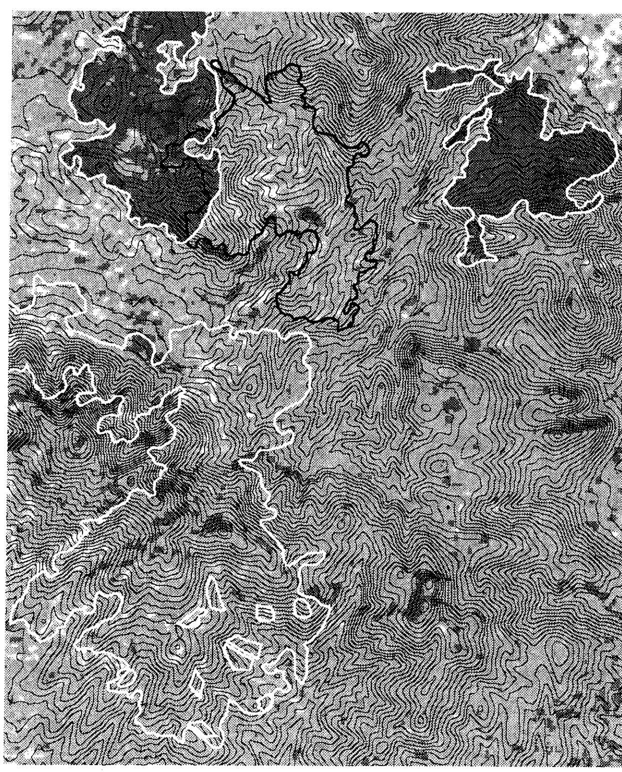
By incorporating imagery from several acquisition dates throughout the monitoring period, the dynamics of the vegetation development can be studied in detail. In this study TM imagery acquired in 1984, 1987, 1990 and 1993 were incorporated. Figure 1 shows the dramatic developments in a part of the Pendeli test area, north-east of Athens.



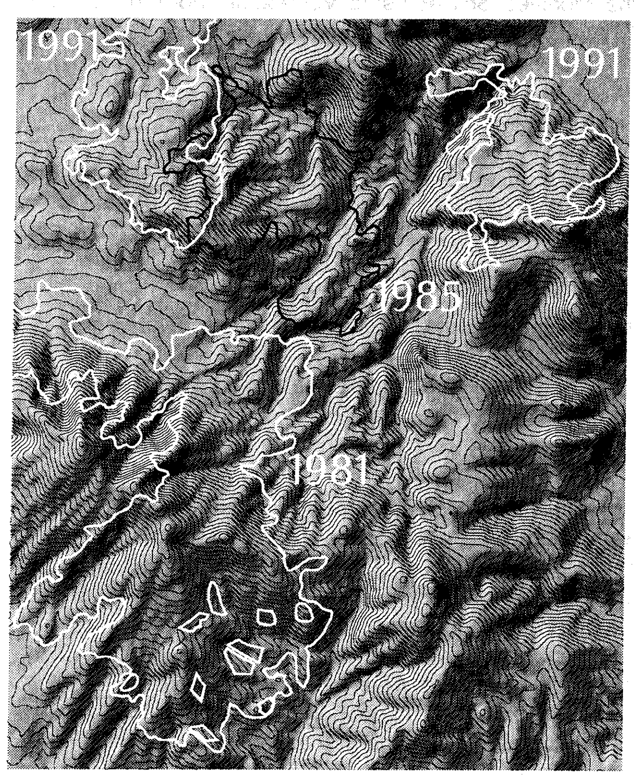
a) Change 1984 - 1987



b) Change 1987 - 1990



c) Change 1990 - 1993




d) Hillshading, fire boundaries / dates

*Figure 8: Dynamics of fires and regeneration in a part of the Pendeli test area, north-east of Athens. Grey indicates no change, black indicates fires, light grey indicates moderate regeneration and white good regeneration. The polygons overlain show the fire boundaries and some of the reference areas used. The thin black lines are the 20 m isolines. The flat areas in the north-east and north-west are agricultural areas. Fig. 8a) shows good regeneration in the 1981 fire affected areas and a large fire in 1985. Fig. 8b) shows good regeneration in the 1985 fire area and no to moderate regeneration in the 1981 fire area. Fig. 8c) shows large new fires, parts of which affect the 1985 fire areas (compare topography at this twice affected areas), the 1981 and 1985 fire areas show no significant regeneration.*

## 4. DESERTIFICATION RISK ASSESSMENT

The risk of desertification at a site increases the longer it remains without a protective vegetation cover after a fire and the higher its susceptibility to soil erosion. Therefore, desertification risk is assessed by combining the estimates for potential for natural regeneration (PNR) and risk of soil erosion (ROE).

### *4.1. Potential for Natural Regeneration*

The main restrictive factor for natural regeneration after a fire is the availability of water for plant regrowth in the dry period. In addition to the amount of rainfall, this depends on the water storage capacity of the soil and the topographic aspect for a given site. Deep soils generally store more water and carry denser vegetation than shallow soils, and south-facing slopes receive higher amounts of solar radiation than north-facing slopes and are therefore drier.

Based on decision rules provided by NARF, the following decision table was used to estimate the potential for natural regeneration.

*Table 2: Potential for Natural Regeneration Decision Rules.*

| Water Storage Capacity | Aspect Class | PNR | |
|---|---|---|---|
| | | Class | Characterisation |
| moderate to high | North | 1 | no limitation |
| | South | 2 | slight limitation |
| low | North | 2 | slight limitation |
| | South | 3 | moderate limitation |
| very low | North | 4 | strong limitation |
| | South | 5 | severe limitation |

<u>The problem of obtaining water storage capacity data:</u>

The water storage capacity of a soil depends on its type and depth. As no detailed soil maps are available for most wildlands / forests in the Mediterranean region, other information sources had to be considered. An approach, using ERS-1 data was not successful, due mainly to the complex signal response, which depends on soil grain size, distribution of dead branches after a fire, and rocks-stones-bare soil distribution *(Banninger et al., 1994)*. As the water storage capacity is a main factor for Potential of Natural Regeneration and Risk of Soil Erosion assessment, a rough estimate, using TM imagery acquired in the dry period, was applied. In arid and semiarid regions, the amount of green biomass in the dry period is mainly dependent on the quantity of water available to the plants. Since there is a high correlation between MSAVI and green biomass or vegetation cover, MSAVI-derived values from imagery acquired in the dry period can be used to estimate the water storage capacity of an area. However, this estimate is based on the assumption that the maximum possible biomass for a given soil is present, which is only the case when a forest / wildland has not been affected by fires for a long period of time. For the test areas in Attica, the maximum cover estimate was based on the maximum vegetation cover derived from TM scenes from 1984, 1987, 1990, and 1993, which were acquired in the dry season of the year. The algorithm was specifically developed to estimate the water storage capacity in wildlands / forests growing in arid and semiarid regions, and gives no useful estimate for agricultural or urban areas.

The accuracy was assessed by comparing the obtained PNR estimates for 14 validation sites with field-based estimates of NARF. For 13 of the 14 validation sites, the estimates correspond within ± 1 category, and one site giving a discrepancy of 2 categories (for category characterisation see *table 2*).

### *4.2. Risk of Soil Erosion*

After a wildfire, the vegetation cover that protects the underlying soil substrate is removed, thus exposing the soil to the forces of wind and rain and, thereby markedly increasing its ability to be denuded. The following main factors govern the risk of soil erosion in a burnt forest / wildland:

- Permeability
- Water storage capacity
- Topography

<u>Permeability:</u>

Permeability is mainly determined by surface geology and was grouped into permeable rocks (hard limestones, calcareous Tertiary deposits, siliceous Tertiary deposits, and colluvium), and impermeable rocks ( mica schists and other metamorphic rocks).

<u>Water Storage Capacity:</u>

The approach used to obtain this parameter is described in section 4.1 (Potential for Natural Regeneration).

<u>Topography:</u>

For the derivation of this parameter, the topographic factor (LS-factor), as defined by the Universal Soil Loss Equation (USLE) and modified by Hensel (1991), was used.

$$LS = (H/22)^m * (65.41 * \sin^2 N + 4.56 * \sin N + 0.065)$$

| | | | |
|---|---|---|---|
| where | LS | = | Topographic factor |
| | H | = | Slope length |
| | m | = | Slope length exponent |
| | N | = | Slope |

The slope length exponent (m) depends on the mean slope within the watershed area *(Hensel, 1991)*.

$m = 0.2$ for slope $< 1°$
$m = 0.3$ for $1° \leq$ slope $< 3°$
$m = 0.4$ for $3° \leq$ slope $< 5°$
$m = 0.5$ for slope $\geq 5°$

For an assessment of the risk of erosion, the above derived parameters were combined, according to decision rules provided by NARF *(Table 3)*.

Instead of using soil depth for the measure of water storage capacity, as was proposed by NARF, the maximum green vegetation cover for the dry period between 1984 and 1993 was used to estimate this factor (see section 4.1). Similarly, the slope parameter proposed by NARF was replaced by the more comprehensive topographic factor (LS), as described above.

As for the estimate of the PNR, 13 of the 14 validation sites correspond with the field based estimates within ± 1 category for the estimate of the Risk of Soil Erosion.

### *4.3. Risk of Desertification*

According to NARF, the additive combination of the two factors for the PNR and the ROE gives the relative risk of desertification, which, for the four test areas, has been divided into five classes, with values ranging from a minimum of 2 (without any risk) for class 1, to a maximum of 10 (very high risk) for class 5.

*Table 4: Class Definitions for Risk of Desertification*

| Class | Values | Desertification Risk |
|---|---|---|
| 1 | 2 | Sites without any risk |
| 2 | 3,4 | Sites with a low risk |
| 3 | 5,6 | Sites with a moderate risk |
| 4 | 7,8 | Sites with a high risk |
| 5 | 9,10 | Sites with a very high risk |

The accuracy assessment gave a correspondence of ±1 category for all 14 validation sites compared with the field based estimates.

*Table 3: Risk of Soil Erosion Decision Rules.*

| Permeability | Water Storage Capacity | Topographic Factor LS | Risk of Erosion | |
|---|---|---|---|---|
| | | | Category | Characterisation |
| permeable | bare rocks | -- | 1 | no to slight risk |
| | low | < 1.5 | 2 | slight risk |
| | | > 1.5 | 3 | moderate risk |
| | high | < 1.5 | 1 | no to slight risk |
| | | > 1.5 | 2 | slight risk |
| impermeable | bare rocks | -- | 1 | no to slight risk |
| | low | < 1.5 | 4 | high risk |
| | | > 1.5 | 5 | very high risk |
| | high | < 1.5 | 2 | slight risk |
| | | 1.5 to 3 | 3 | moderate risk |
| | | > 3 | 4 | high risk |

## 5. SUMMARY

Classification accuracy's attained for validation sites within the Attica, Greece, test areas were greater than 90% (for ± one map category) in comparison with field-derived results, which meet the requirements for resource management decisions at the regional and national level and which are also adequate for many needs even at the local level.

The results of the project demonstrated the practicality and value of using satellite remote sensing data for monitoring and mapping land cover and related changes over large geographical areas, which is achieved at substantially lower costs than traditional ground-based or aerial photography surveys.

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