INTEGRATING REMOTE SENSING PROCESSING AND GIS TO FIRE RISK ZONE MAPPING: A CASE STUDY FOR THE SEIH-SOU FOREST OF THESSALONIKI

Sofia SIACHALOU, Georgia DOXANI and Maria TSAKIRI-STRATI
Aristotle University of Thessaloniki
University Campus, Box 439
GRE - 541 24 Thessaloniki, Greece
ssiacha@auth.gr, gdoxani@topo.auth.gr, martsaki@topo.auth.gr

Abstract

During the last years the forest management community has acknowledged the need of monitoring the vegetated and forest areas as well as mapping burned areas. The hazard of a forest fire is encountered in the Mediterranean territory quite often, mainly due to its climate. Notwithstanding the catastrophic effects to the entire ecosystem, for decades these countries have not taken proper precautionary measures. Remote sensing faces this challenge and emerges a necessity, for the accurate detection and control of the areas with a high fire risk.

In order to map a fire risk zone and prevent future possible fires, an attempt is made to set up a risk model. The model deals with remote sensing data in a GIS environment. The model parameters that trigger the fire spreading are estimated by satellite imagery and topographical data. The vegetation type, the relief and the location of man-made features, such as tanks for reserving water, roads and fire belts are some of the model input data.

In this study the image analysis of low and high resolution satellite imagery results to an effective study of the area. Image processing methods such as band ratios and vegetation indices offer the potential of exploring vegetated and non-vegetated areas, by creating new bands where the burned and un burned territory is highlighted. These bands in combination with the initial multispectral bands are inserted in an object based classification scheme designed to estimate the fire extent.

The study area covers the suburban forest of Seih Sou situated around the city of Thessaloniki, Greece. Taking into account that only the 0.9% of the city is vegetated, this forest is considered the main source of oxygen for the city which greatly affects the microclimate of the territory. A significant part of the forest was destroyed by a fire in July 1997 causing severe ecosystem damage.

Introduction

The Mediterranean is acknowledged as one of the most important ecosystems globally considering its outstanding plant diversity. Unfortunately the forests in the area are gradually diminishing by destructive forest fires; every year more than 50,000 fires burn and up to 1.3 – 1.7 % of the total Mediterranean forests are stricken (WWF, 2007). In Greece extreme weather events, such as periods of high temperatures, air dryness and very strong winds, are becoming frequent and increase the probability of fire in the area. Thus, effective regulations at a national level are needed to protect forests and prevent ecological disaster caused by fires.

A fire management system should be integrated in land use planning in the case of forests prone to fires. The basic principles of this system are prediction, prevention, response and restoration. Estimation of the vulnerability of an area to fire is essential to the "prediction" of future possible fire outbreaks and "prevention" is accomplished by taking proper action in high risk areas. Satellite remote sensing can contribute to the "prediction" of fires and the protection of forests by offering up to date information about the Earth's surface. It provides constant monitoring of the land covers including the vegetation type, the temperature, the humidity of the soil, the existence of water sources and other parameters which affect the spreading of the fire that would otherwise require intensive time-consuming research.

Geographical Information Systems offer the capability of constructing models which simulate the effect of factors to a phenomenon. The great advantage of GIS is the possibility to incorporate different types of data and make qualitative and quantity analyses which are essential for a decision system structure. The selection of the appropriate model criteria is imperative for the estimation of fire hazard probability and the creation of a fire risk map.

Another significant issue in forest management is mapping the extent of the fire stricken territory. Remote sensing is able to provide post-fire data immediately after a fire, covering wide areas, in various scales. Nowadays the implementation of innovative methodologies on the available high resolution satellite data has made possible the accurate classification even of the types of burned vegetation (Mitri et al., 2006).

The present study aimed to combine remote sensing image processing and GIS technology so as to construct a fire risk model. The model parameters were selected according to the characteristics of the study area and they were estimated by the analysis of satellite and topographical data. The identification of burned areas was an additional objective of this study. An object-based classification scheme was implemented on the imagery data for the accurate determination of the burn extent.

Study area and data

The area of the study is the suburban hilly forest of Seih Sou which is located in the boundaries of the city of Thessaloniki. It was considered Thessaloniki's largest source of oxygen when a fire in July 1997 burnt down the two thirds of the forest. It is estimated that the 75% of the total forest is covered by pine trees, 18% by oak trees, 5% by cypress trees and the rest by bushes. The anaglyph of the area is generally smooth with an elevation of 50m to 450m. The climate displays characteristics of continental as well as Mediterranean climate. Annual rainfall has averaged 451 mm and it is infrequent during summer with temperature rising often above 30°C. The winter is relatively dry with snow occurring almost annually but not persisted and temperature dropping as low as -10°C.

The imagery data consist of multispectral orthorectified Landsat TM images acquired in July, 1996 (pre-fire image) and in November, 1997 (post-fire image), with spatial resolution of 30 m. The images depict the Seih Sou region with a size of 203x274 pixels. The elevation data consist of a DTM with a 25-m grid size.

Methodology

1. Definition of the fire risk model

Many researchers have focused on the definition of reliable fire risk indices. Risk indices are calculated by mathematical models setting as input data the parameters that influence fires and different weights (Garcia-Montero et al, 2003, Jaiswal et al, 2001). The parameters as well as the weights assigned in the model vary according to the characteristics of the study area.

The parameters selected in this study were the moisture of the vegetation, the slope and aspect of the anaglyph, the distance from roads and settlements (Jaiswal et al, 2001, Erten et al, 2004). The structure of the fire risk model is presented in figure 1.

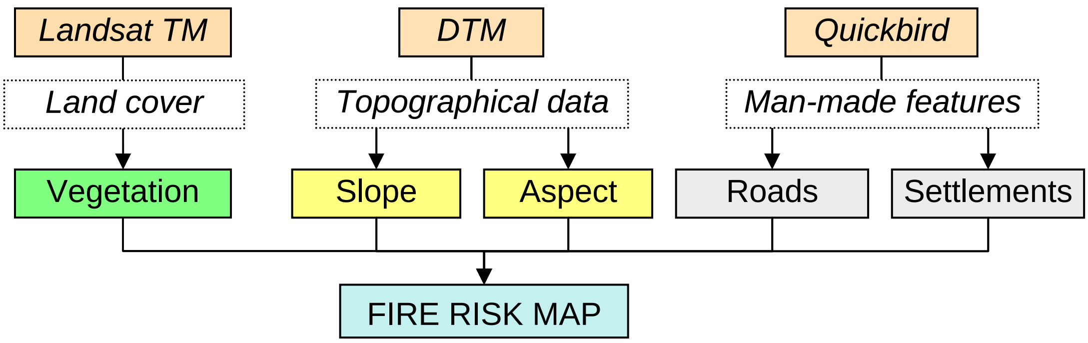

Figure 1. The factors and the structure of the fire risk model.

The vegetation type was classified according to the moisture that influences the spreading of the fire. Dryness is one of the most critical parameter in fire risk because it increases the flammability of the land. In order to assess the moisture of the vegetation the Normalized Difference Moisture Index (NDMI) is commonly used (Wilson et al, 2002, Hemmleb et al, 2006, Sader et al, 2003, Jin et al, 2005). The NDMI index highlights areas of healthy green vegetation with high moisture content by exploiting the strong absorption of SWIR radiation by thin layers of canopy and soil water, and the high reflectance of NIR radiation by healthy green vegetation; it is described by the following equation.

$$NDMI = (NIR-SWIR)/ (NIR+SWIR) \quad (1)$$

Several studies indicate that slope is a critical component in fire spread (Weise, 1993, Viegas, 2005, Butler et al, 2007). It is pointed out that as the slope increases so does the rate of the fire spread. Another important component is the aspect; south facing slopes have greater sun exposure in the North hemisphere, resulting in drier soil that is more receptive to ignition (Noon, 2003).

Man-made features such as roads and settlements are directly linked to forest fires. Studies demonstrate that the risk of fire is higher in areas where many people and vehicles daily move. The impact of human activities in starting a fire can be expressed mathematically in the form of proximity of roads and settlements to a forest (Rogan and Miller, 2006).

In order to form the risk model all the above parameters were quantified according to their influence in provoking a fire. For this reason the parameters are separated in classes; first classes represent high fire risk and last classes, minor fire risk (Table 1).

PARAMETERS	CLASSES	FACTORS	RISK
VEGETATION MOISTURE	Very dry	5	Very High
	Dry	4	High
	Moist	3	Medium
	Fresh-like	2	Low
	Fresh	1	Very Low
SLOPE OF THE TERRAIN	>35%	5	Very High
	35-25%	4	High
	25-10%	3	Medium
	10-5%	2	Low
	<5%	1	Very Low
ASPECT OF THE TERRAIN	South	5	Very High
	West	4	High
	East	3	Medium
	North	2	Low
DISTANCE FROM ROADS	<100 m	5	Very High
	100-200 m	4	High
	200-300 m	3	Medium
	300-400 m	2	Low
	>400 m	1	Very Low
DISTANCE FROM SETTLEMENTS	<500	5	Very High
	1000-1500 m	4	High
	1500-2000 m	3	Medium
	>2000 m	2	Low

Table 1. The classification of the parameters that influence fire.

The model used is this study is described in Equation 2 (Erten et al, 2004).

$$\text{FIRE RISK INDEX}=7\text{VEGETATION}+5(\text{SLOPE} + \text{ASPECT})+3(\text{DISTANCE}_{\text{ROADS}}+ \text{DISTANCE}_{\text{SETTLEMENTS}}) \quad (2)$$

The final step of the procedure is the analysis of the results of the fire risk model in GIS and the creation of a fire risk zone map.

2. Classification of burned area

In the present study a knowledge-based classification scheme was formed so as to identify the extent of the burned area. The object-oriented classification approach was selected since it is considered to be a powerful tool for image analysis. Object-oriented classification methodology consists of two steps, segmentation and fuzzy classification of image objects. The segmentation of the multispectral image aims to divide the image into different meaningful regions; this means that the objects should approach objects of the real world so as to provide optimal information for further processing. The classification of the image is based on fuzzy logic by either using the Nearest Neighbor method or the combinations of fuzzy sets on object features, defined by Membership Functions (Baatz et al., 2003).

In particular the classification process was applied on images acquired on dates before and after the fire in the study area. The Normalized Difference Moisture Index (NDMI) was implemented on each image for the identification of vegetated areas on two dates. A certain image object level was then formed for each image and the appropriate rule set was generated by using a combination of object features of the two different levels.

Results

The NDMI index is calculated by the spectral values of the near infrared and shortwave infrared bands; in this case the Landsat TM image was selected. This parameter is dynamic which means that it changes with time because it depends on weather conditions. In this study the NDMI index was assessed for the date the image was acquired (July 1996). The ‘Very High Risk’ areas are indicated by red color and the ‘Very Low Risk’ areas by green (Figure 2). Moisture is a parameter that affects ignition as well as fire spreading.

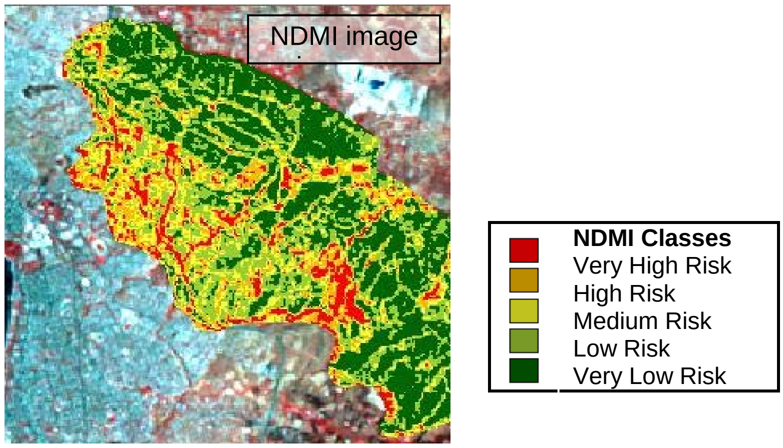

Figure 2. The classification of the NDMI Landsat image in five risk classes. The image is draped over the DTM

The 'Slope' and 'Aspect' parameters were calculated by the elevation values of the available DTM. Both parameters are related to the anaglyph and for this reason are not time-depended. The resulting images were classified in 5 and 4 risk classes respectively and are presented in Figure 3. In the area of Seih Sou slopes are relatively steep and the majority is facing south and west (High Risk Areas).

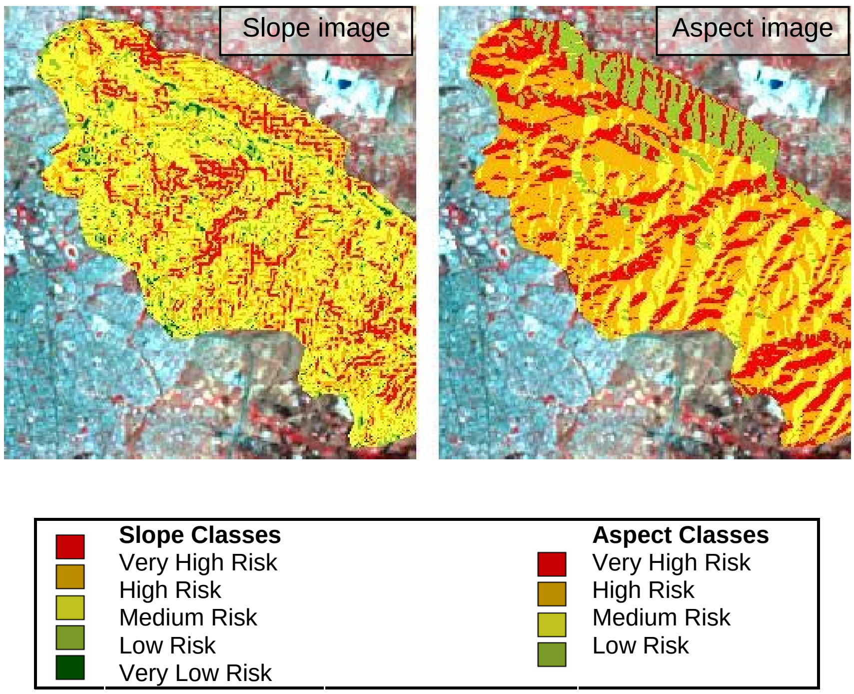

Figure 3. The classification of the "Slope" and "Aspect" image.

The proximity of roads and settlements to a forest is a significant parameter in provoking a fire. For this reason the roads and the boundaries of the settlements were digitized in a Quickbird image and the distances were calculated for each pixel in GIS. Finally two buffer maps were produced (Figure 4). Areas of 'Very High Risk' are situated near roads and settlements.

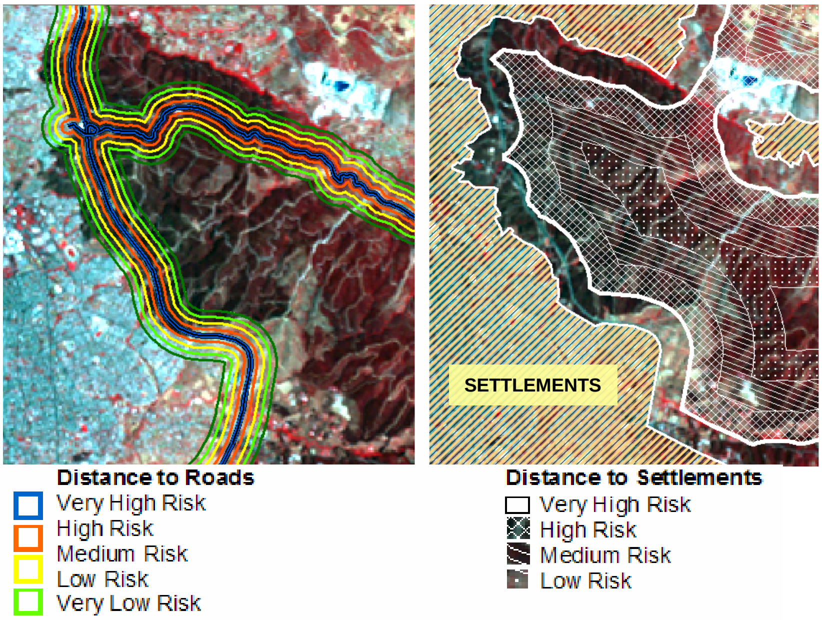

Figure 4. Roads and Settlement buffer maps.

The classification of the area after the fire with Landsat (November, 1997) has led in distinguishing the burned area from the forest (Figure 5). It was estimated that almost 1100 ha of forest in the study area were burned. It is interesting to compare this image with the results of the fire risk model. Fire Risk Index values were calculated and separated in three categories: High, Medium and Low Risk (Figure 6). The correlation of the fire risk values to the areas that were actually burned in 1997, led to some observations regarding the model's reliability (Chuveico et al, 1989). The results are presented in the diagram that follows (Figure 7). In areas classified as 'low risk' 43.9% of the area were burned, in 'medium risk', 57.6% were burned and in 'high risk' areas, 78.3%. The fact that in low risk areas the percentage of the burned territory is not very low does not mean that our model failed. Fire risk values were calculated based on data from July, 1996 while the fire took place a year after. Slopes, aspect of the anaglyph, distance from roads and settlements have not altered but the moisture of the vegetation may have been different in the day of the fire. It should be noted that especially within the 'high risk' areas, only the 21.7% was not burned by the fire. Therefore, despite the fact that the input data of the model were taken one year before the fire the model succeeded in predicting which areas are more likely be affected by fire. The model can be further improved by using daily measurements of meteorological data such as the speed and the direction of the wind, the atmosphere's dryness, rainfall etc.

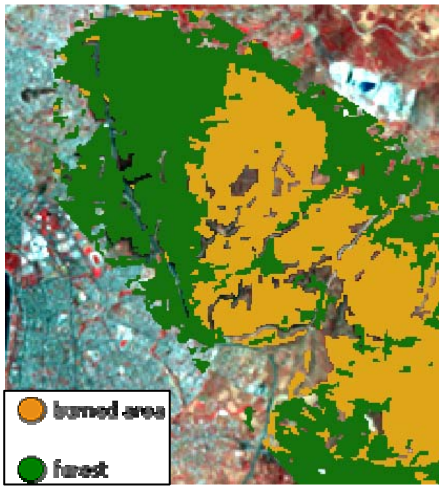

Figure 5. The result of the object-oriented classification. The burned area is highlighted with orange color.

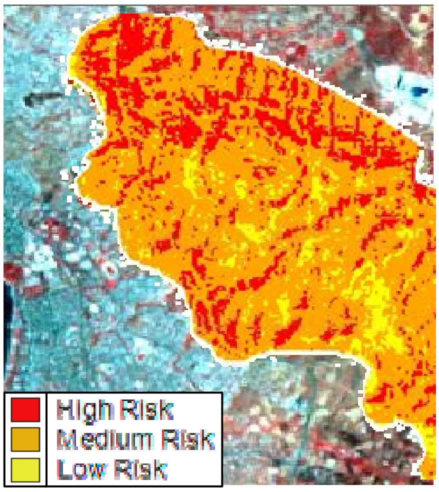

Figure 6. The fire risk zone map divided in three classes: High, Medium and Low Risk areas.

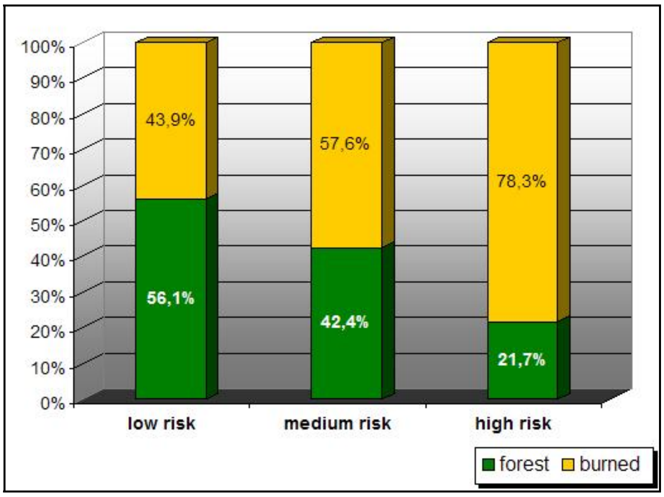

Figure 7. Diagram presenting the percentage of burned and forest areas that corresponds to low, medium and high risk areas.

Conclusions

The objective of this project was to build a fire risk model for Seih Sou, the suburban forest of Thessaloniki. The model parameters were a set of vegetation type, slope, aspect and distance from roads and settlements. Appropriate weight factors were selected for each parameter in an attempt to adjust the model to the characteristics of the study area. The model implementation resulted in the classification of the area in fire risk zones. The fire risk map indicated that the larger part of the forest belongs to high risk zone because the slope values range from 25-35% and they are mainly south and west facing. Moreover an object oriented classification was applied in order to map the extent of the fire in 1997. Overlaying the fire risk zone map to the classified image provided an assessment of the reliability of our approach.

The present study was an attempt to integrate remote sensing image processing and GIS theory to investigate the factors which make a forest region vulnerable to fire. Fire risk models are a powerful tool in order to take precautionary measures for the environmental protection of the forests.

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