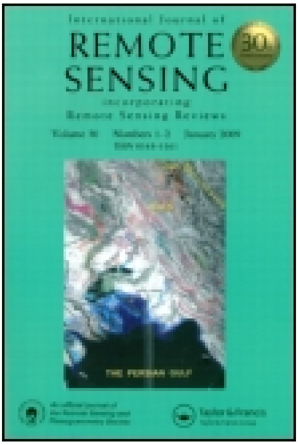

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Forest fire analysis with remote sensing data

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Abstract. Forest fires cause major damage to the environment, human health and property, and endanger life. Fires can be monitored and analysed over large areas in a timely and cost-effective manner by using satellite sensor imagery in combination with spatial analysis as provided by Geographical Information Systems (GIS). In this study, the forest area damage caused by a large fire which occurred in the Marmaris, province of Muğla in July 1996 was analysed using satellite sensor images. Digital image processing methods, such as spectral profile analysis, vegetation indices and multispectral classification, were applied to the satellite sensor images acquired before and after the forest fire. Besides the conventional maximum likelihood classification algorithm, a multilayer feed-forward neural network architecture was also used for comparison and evaluation of its effectiveness. A GIS database was constructed from the raster (satellite sensor data), vector (the forest type and topographical maps) and ancillary data (meteorological data). The GIS is being used to develop an information and decision support system to monitor and predict forest fire activity, and to enhance fire management efficiency. This study highlights the deficiencies in the current approach to fire management and emphasizes the need for an improved method along the lines outlined.

1. Introduction

Forest fires, whether natural or initiated by man, have an important influence on the environment, human health (often leading to fatalities) and property. In terms of annual damage, Turkey is one of the most susceptible countries in the Mediterranean region (figure 1). According to the National Forest Service records (State Forest Directorate 1998), the causes of fires are various but are mainly, more than 97% of the time, due to human activity while the rest, less than 3%, are caused by natural phenomena, such as lightning. Human related fires are mainly grouped as intentional and unintentional fires. The unintentional fires are mostly due to carelessness caused by hunters or picnickers, whereas the intentional fires are mostly related to forest or shrub elimination, for transformation of the land for agricultural purposes, or generation of pastures.

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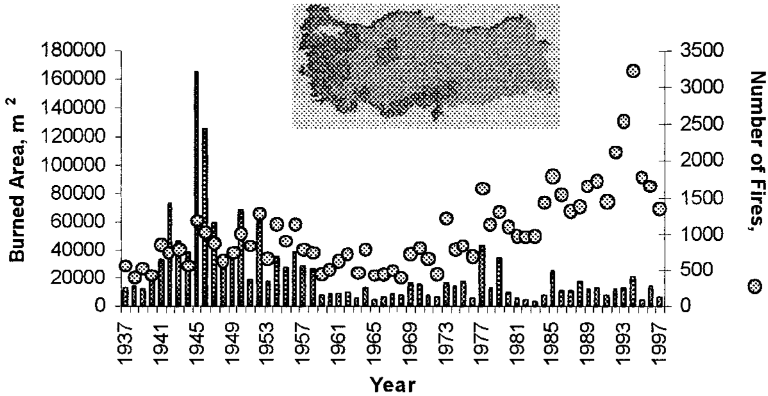


Figure 1. Forest fires and the most susceptible regions in Turkey (Forest Fire Statistics 1998).

The information needed for fire management includes fire risk mapping, fire detection and monitoring, damage assessment and planning post-fire recovery. Effective management requires the use of new techniques using remote sensing and Geographical Information Systems (GIS); these must, however, produce results in a timely and cost-effective manner (Fox and Stuart 1994). In fire damage assessment, satellite sensor imagery in conjunction with ground observations is the main source of information from which pre-fire vegetation condition can be determined. Pre-fire condition is important both in order to assess potential fire risk and to make rational judgements on the precautionary measures required to avoid potential soil erosion which topographic and meteorological conditions may promote on newly burnt land (Chuvieco and Martin 1994).

One of the largest forest fires in Turkey in recent years occurred in the Marmaris, province of Muğla in July 1996. The effect of this fire was analysed using satellite sensor images acquired before and after the forest fire. A GIS was established to monitor and predict the extent of the damage, and to enhance fire management efficiency.

2. Study area

The fire occurred in the area bounded by the Muğla Forestry Chief Directorate, the Marmaris Forestry Chief Directorate, and the Çetibeli Forestry Chief Directorate Office (42°W 35°N–40°W 33°N), located on the southern coast of Turkey (figure 2). The fire started in the northern part of the area on 27 July 1996, spreading to the forests of the Hisarönü and Marmaris Forestry Chief Directorate, and continued burning for 4 days.

The topography of the area is broken and steep commonly having slopes steeper than 5–12%. Elevations range from 50 m to the ridge tops at 600 m. The average August temperature is 42°C and the annual average precipitation is 1257 mm. The study area is covered with forest dominated by Red Pine (*Pinus brutia*).

3. Data collection

Effective decision-support systems are needed to monitor, and predict fire activity and enhance sustainable fire management. To develop and use such a system requires a computerized forest fire information system supported by remotely sensed information. In this study, inputs to the system were obtained from the following sources:

(i) Raster data: one Landsat TM (Thematic Mapper) image acquired before the

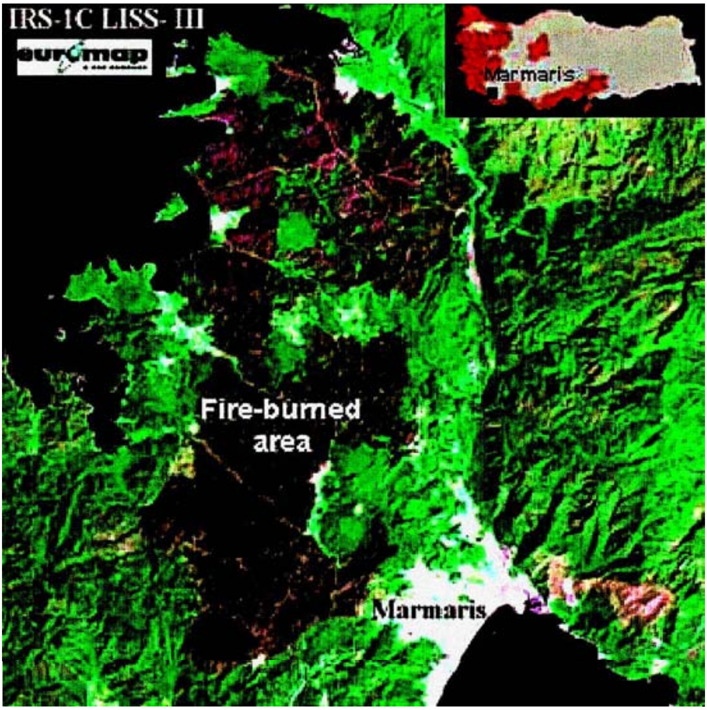


Figure 2. The study area.

fire (24 July 1996), and two images, IRS-1C LISS (Linear Imaging Self-Scanner) and SPOT HRV (High Resolution Visible) Panchromatic, acquired after the fire (22 August 1996 and 15 November 1996, respectively) were used in the analysis. Pre-fire condition was assessed from the Landsat TM imagery, whereas post-fire condition and the areal extent of the burned area were assessed from the IRS-1C data. SPOT panchromatic data was only used for visual analysis due to its broad spectral resolution.

(ii) Vector data consists of map data. The three national topographic maps (1:25 000 scale) which covered the area were digitized at 50 m contour intervals. Thematic forestry maps (1:25 000 scale), prepared by the Muğla Forestry Directorate Office, which showed previously burned areas, were digitized. On these forest maps the burnt areas were classed as productive, disturbed and afforested.

(iii) Ancillary data: meteorological data (mean and maximum wind velocity, wind direction, mean relative humidity (%), mean air temperature (dry thermometer °C) and total precipitation (mm)) were obtained from the meteorological station located in the study area. The data were selected with respect to the acquisition dates of the satellite sensor data, i.e. between July and November 1996.

4. Application

There are several different ways to detect fire damaged forested areas using digital image processing: spectral profile analysis, vegetation indices and classification.

4.1. *Spectral profile analysis*

All surface features have spectral response patterns. If these patterns, or spectra, are unique then the features can clearly be identified from spectral information using remotely sensed data. Although it may not be feasible to define unique signatures for features with similar spectral characteristics (such as between some vegetation types), distinctive spectral patterns for vegetated versus non-vegetated areas, and also the existence of diseased or stressed vegetation, can often be recognized. With this in mind, four identifiable points on the images were selected arbitrarily and their spectral reflectance profiles were extracted from the pre- and post-fire imagery (figure 3). These points were then evaluated with, and compared to, the reference information contained in the forestry maps.

4.2. *Vegetation indices*

These are quantitative measures, based on vegetation spectral properties, that attempt to measure biomass or vegetative vigour. The simplest form of vegetation index is simply a ratio between two digital values from independent spectral bands. High values of the vegetation index identify pixels covered by substantial proportions of healthy vegetation (Campbell 1987). Vegetation indices can be classified into two broad categories: the ratio indices and orthogonal indices. The first category, used in this study, are based on ratios of the digital values in the red (R) and near-infrared (NIR) spectral bands, chosen because of the inverse relationship between the reflectance of vegetation in these regions. In this study, the Normalized Difference Vegetation Index ($NDVI = NIR - R/NIR + R$), the most commonly used ratio transformation for vegetation studies, was applied. The normalization of the NDVI reduces the effects of variations caused by topography.

The two satellite sensor images, taken before and after the fire, were co-registered with a normal registration procedure and ratioed (IRS NIR/Landsat NIR and IRS NDVI/Landsat NDVI) to assess the changes occurring between the two dates.

4.3. *Classification*

In this study, two different classification methods were applied to classify fire damaged forest areas: conventional classification and neural network classification.

4.3.1. *Conventional classification*

The classification process is described as the identification of the pattern associated with each pixel position in an image in terms of characteristics of the objects or materials at the corresponding point on the Earth's surface (Mather 1987). The problem of allocating pixels to their most likely class can be approached in one of two ways. The first one, unsupervised classification, can be defined as the identification of natural groups, or structures, within multispectral data whereas the latter, supervised classification, can be defined informally as the process of using samples of known identity (Campbell 1987).

In this study, the classification method was based on an interactive Iterative Self-Organizing DATA (ISODATA) algorithm and was used to determine the initial classes. The resulting classes were examined both spectrally and spatially with ground information and merged, split or discarded and reclassified as appropriate. The statistics from these classes were than used as input to a maximum likelihood classification which basically allocates pixels to the class to which they have the highest probability of belonging. This approach assumes that the real classes to discriminate are represented in the image data as normal distributions around class mean values. The form of each normal distribution is determined by mean and variance/covariance of the class. Allocation of pixels to classes involves using class distribution statistics as a probability density function for the class which indicates the likelihood of a particular pixel value belonging to the class (Swain and Davis 1978, Harrison and Jupp 1990).

4.3.2. *Neural network classification*

A neural network, applied to a number of image classification problems recently, is a directed graph consisting of neurons or nodes arranged in layers with interconnecting links (Haykin 1994). These structures represent a system composed of many simple processing elements operating in parallel whose function is determined by network structure, connection, weights and node function (Hara *et al.* 1994). The main characteristics of neural networks are (i) they have an intrinsic ability to generalize, (ii) they make weaker *a priori* assumptions about the statistical distribution of the classes in the dataset than a parametric Bayes classifier, and (iii) they are capable of forming highly nonlinear decision boundaries in the feature space (Bock 1996).

Various neural network architectures and algorithms have been developed and used extensively, e.g. in classification, forecasting and modelling. There exist two primary types of neural network architectures: supervised and unsupervised. The supervised method, used in this study, is a process achieved by the presentation of the input data to the neural network and then performing a comparison of the actual known output together with the predicted output. The unsupervised method is a process when the network is able to discover statistical regularities in its input space and automatically develops different modes of behaviour to represent different classes of inputs (Özkan and Sunar 1999, Berberoğlu and Curran 1998).

5. Results

Since fire-affected green areas are stressed and nutritionally deficient environments for plant growth, the spectral properties of these areas, measured through time from remotely sensed data, will permit the burnt vegetation canopy to be identified and assessed (Sunar and Taberner 1998). As may be seen in figure 3(*a*), a characteristic canopy reflectance curve for selected four points in the Landsat TM image shows relatively low values in the red and blue regions in the visible spectrum with a peak in the green spectral band due to absorption of blue and red light by chlorophyll and other pigments, whereas there is high reflection in the infrared region due to internal leaf structure (Lillesand and Kiefer 1994). However, the curve has different characteristics in the IRS-1C image due to forest fire burning (figure 3(*b*)). The differences observed in these two graphs made it possible to analyse the vegetation cover destruction due to forest fire and to interpret the classification results more accurately.

Since fire removes variable amounts of green biomass from a plant canopy, and the amount removed depends upon the severity of the fire, there is a good correlation between the vegetation indices and fire severity. In this study, the NDVI was applied to Landsat TM (pre-fire, figure 4(*a*)) and IRS-1C (post-fire, figure 4(*b*)) images and scaled from 0 to 255 for image display. As may be seen in figure 4(*a*), vegetated areas generally yield high values because of their relatively high near-infrared reflectance and low visible reflectance, whereas the heavily burned areas (black) were easily distinguished from unburned areas (white) in figure 4(*b*). The degree of change that has taken place between the two dates in the study area can be readily delineated in the IRS NIR/Landsat NIR ratio image (figure 4(*c*)).

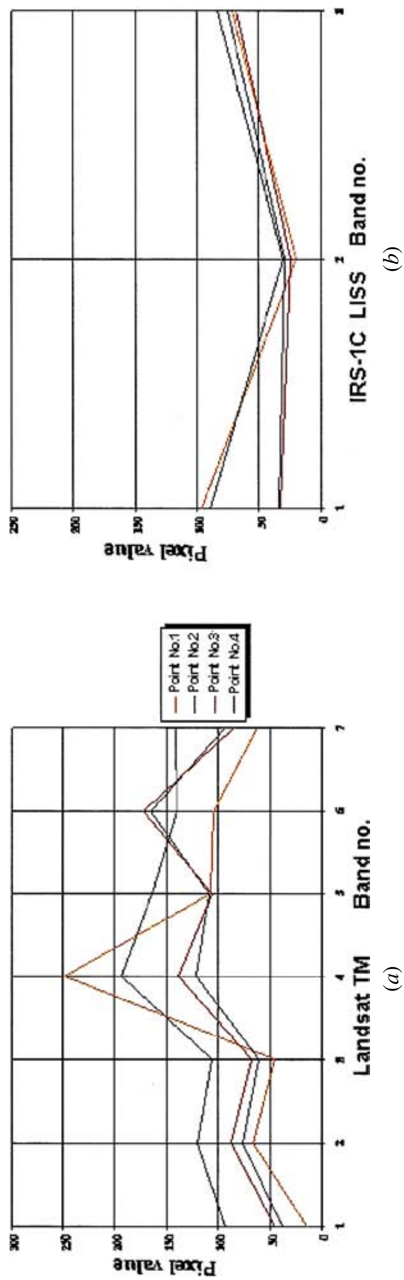


Figure 3. Spectral profiles of the selected four points from (*a*) The Landsat TM (pre-fire) image and (*b*) The IRS-1C (post-fire) image.

The classes obtained from the classification procedures corresponding to the burned forest areas were identified by examining them both spectrally and spatially (figure 5(*a*)). The major ground cover types isolated in the study area were (i) burned forest area; (ii) forest area; (iii) urban areas; (iv) bare soil; (v) rocky area, and (vi) sea. The classified image agreed with the thematic map prepared by the regional Forestry Chief Directorate in general, but it was found that there were some differences in the forest structures in the southern and northern parts (figure 5(*a*), (*b*)). This was especially notable in the southern parts—the vigorous forest structure (shown in pink in the thematic map (figure 5(*b*)) had been affected, depicted by a decrease in vegetation cover with time (Özkan 1998).

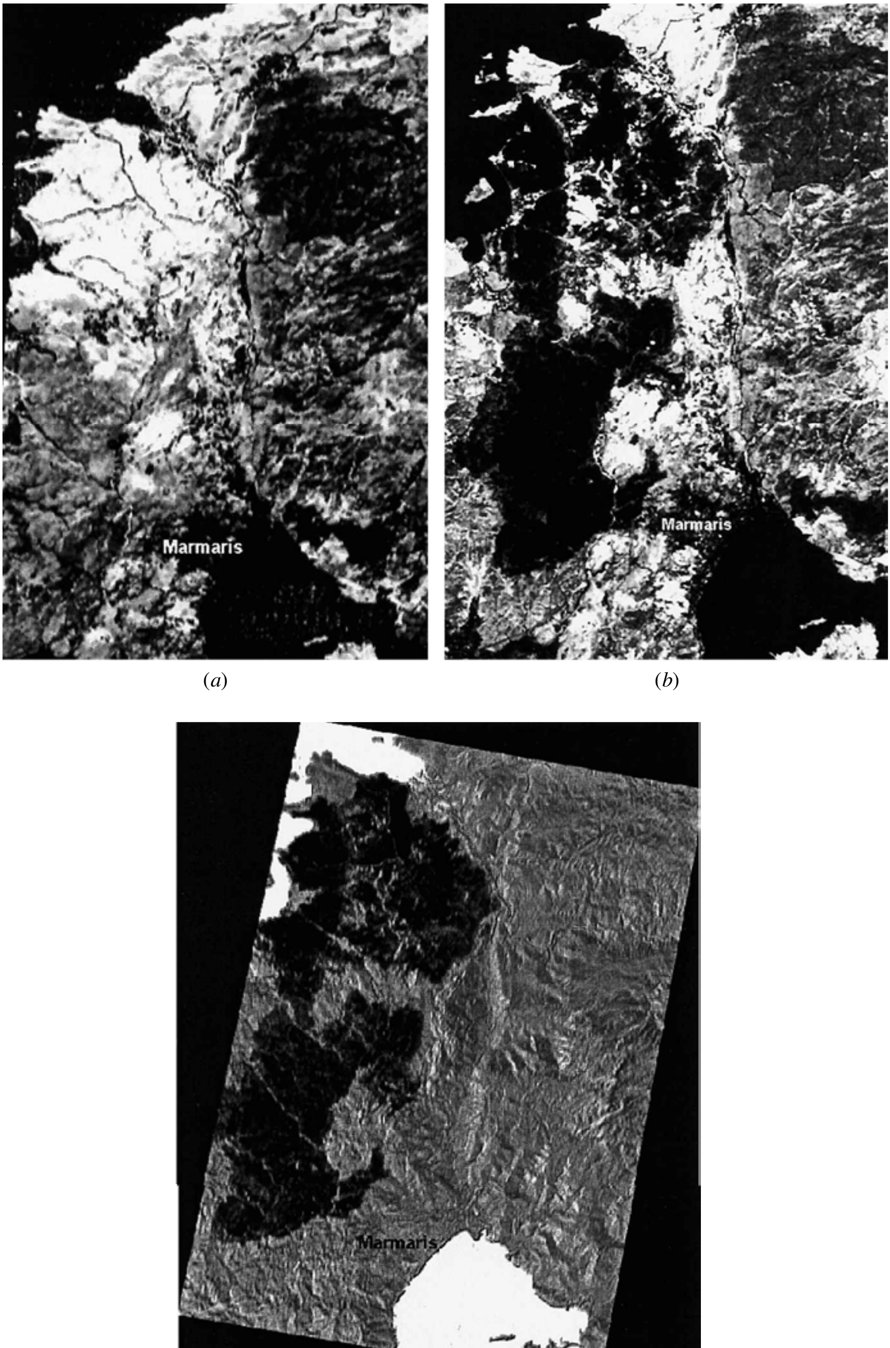
A multilayer feed-forward perceptron model, which consists of an input layer, two hidden layers of processing nodes and an output layer, was applied to IRS-1C image data. The network was trained with a back-propagation learning algorithm comprising a forward and a backward phase through the neural-network structure and a 0.4 learning momentum. The network architecture consists of two input units (IRS-1C near-infrared and red bands, respectively), five first hidden units, 15 second hidden units, and six output units representing land cover classes. The training dataset used comprised 864 pixels with different number of pixels per land cover class (259, 217, 57, 219, 50 and 67 pixels for burned forest area, forest area, urban areas, bare soil, rocky area and sea, respectively) and the network was trained cycles of 2000 with a learning rate of 0.3. The transfer function used in this study was sigmoid. The neural network classification result of IRS-1C image was given in figure 6.

The classified IRS-1C images obtained each classification methods were registered to the national Universal Transverse Mercator (UTM) map projection system to quantify and delineate the burned areas. According to the records of the regional Forestry Chief Directorate, the area burned was 7094 ha, this is much higher than that calculated from both conventional methods (6290 ha) and artificial neural network algorithm (6294 ha). There are three main reasons for this discrepancy:

(1) The thematic map prepared by the regional Forestry Chief Directorate delineated the burned areas using conventional methods: the boundaries of the burnt forest areas were approximately delineated on the forestry plans by inspecting the damage from helicopter or by field checking. The areal extent was calculated using planimetric methods.
(2) Some of the afforested regions, shown with red circles in the classified image (figure 5(*c*)), were not classified as burnt though they were marked as burnt on the thematic map. It is thought that this is a result of the generalization of the thematic map prepared after the fire.
(3) Remote sensing enables more objective, definitive and unbiased decisions to be made from a synoptic viewpoint with capabilities to detect and monitor vegetation biomass in more detail than approximate ground estimates.

6. Forest fire management system

Assessments of the impact of human activities on the environment requires qualitative and quantitative information on the spatial distribution and dynamics of natural resources. Fire, the most important disruptive factor in forestry in the Mediterranean, often leads to rapid loss of soil fertility, to erosion, to desertification, and ultimately to poorer human habitability and survival. GIS integration with



(*a*) (*b*)

(*c*)

Figure 4. NDVI image of the (*a*) Landsat TM image and (*b*) IRS-1C LISS image. (*c*) The ratio image of IRS NIR/Landsat NIR.

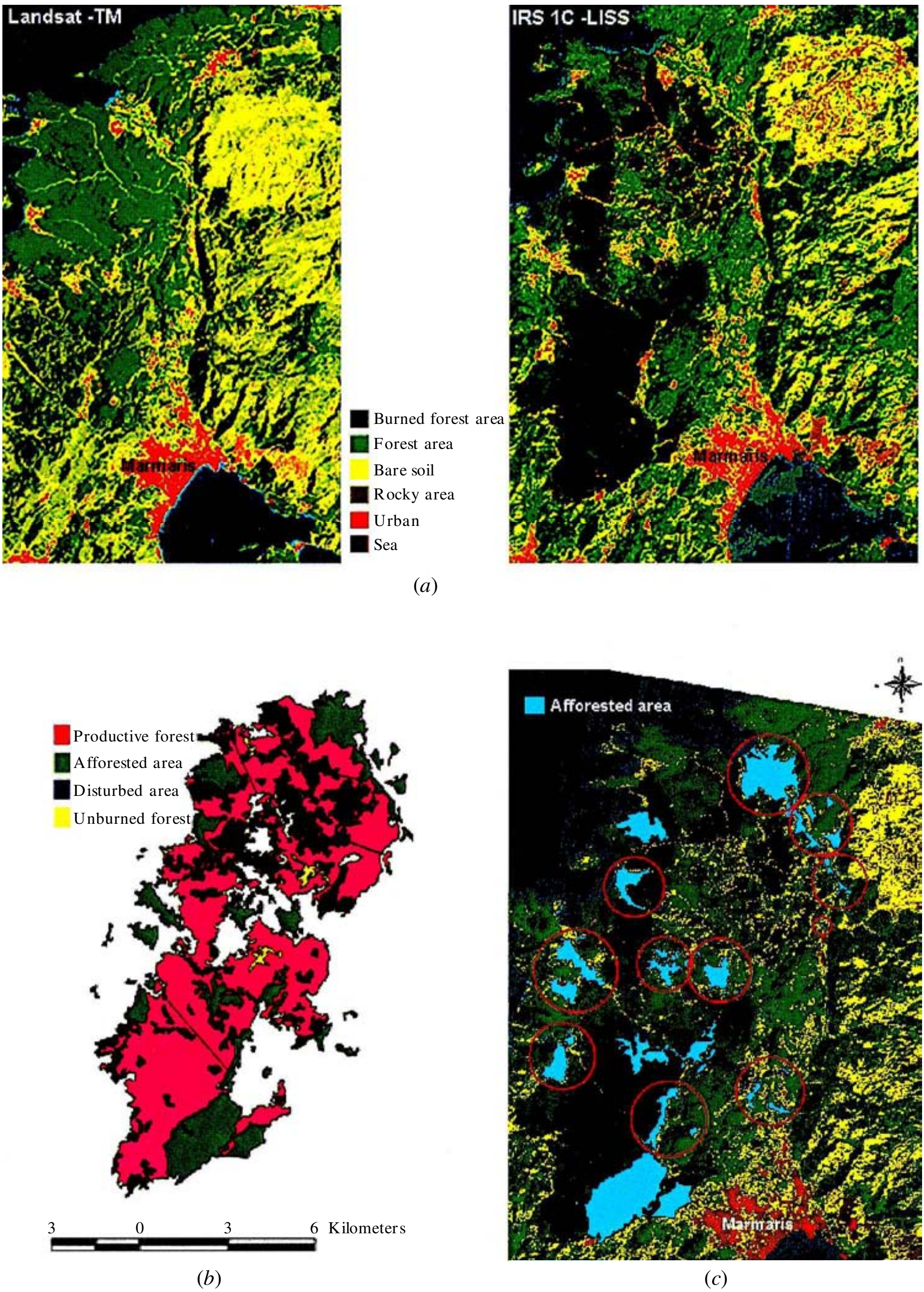


Figure 5. (*a*) Classified image of the Landsat TM (left) and the IRS-1C (right). (*b*) Thematic map of the burned area prepared by the Forestry Chief Directorate. (*c*) Conflicts between the classified IRS-1C image and the thematic map. Red circles demonstrate unburned afforested areas.

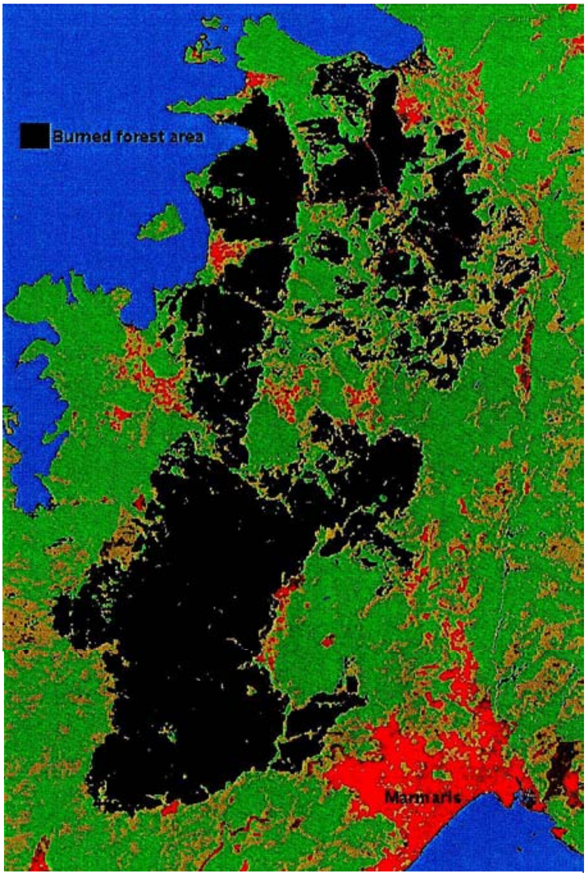


Figure 6. Neural network supervised classification result of IRS-1C image.

multitemporal remotely sensed data is necessary, and achievable, to protect and manage forests before, during, and after fires (Chuvieco and Congalton 1989, Klaver *et al.* 1997).

The reasons why a computerized forest fire information system used in conjunction with remotely sensed imagery is required can be outlined as follows:

1. To identify the forest fire risk areas by taking into account the actual and predicted meteorological conditions and the vegetation condition before the fire to enable the necessary control and precautionary measures to be instigated.
2. To supply other types of crucial information, such as the location of human settlements, water resources, road networks, etc., for sustaining fire management and controlling fire-fighting during the fire.
3. To retrieve information on the vegetation condition after the fire in order to assess forest fire damage and to evaluate the post-fire situation with and, in particular, in relation to soil and topography in order to minimize erosion and control recovery.

In this study, the Forest Fire Information system was established with ArcView V.3.0. The thematic map derived from the Forestry Chief Directorate

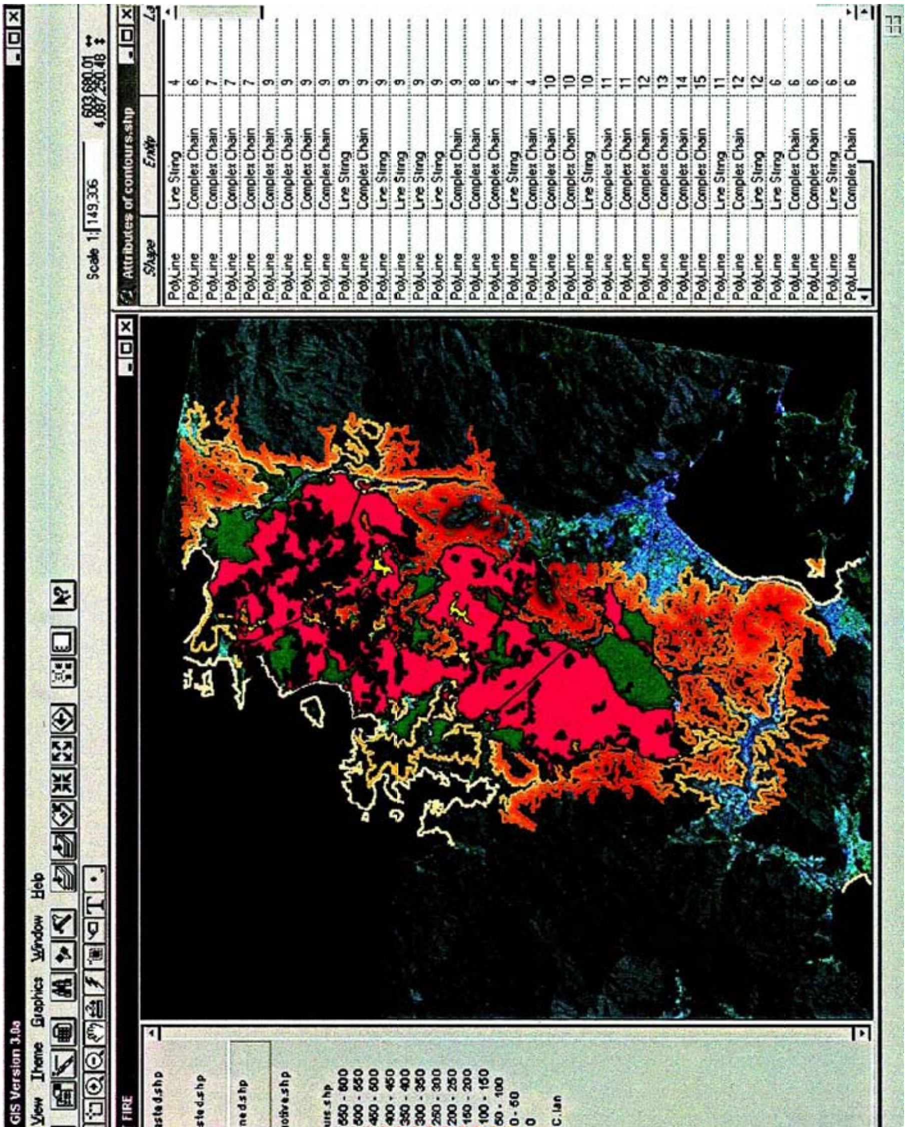


Figure 7. An example view of the Forest Fire Information System established.

was overlayed on the pre- and post-fire satellite sensor images to determine and compare the inter-relationships between fire effects, the types of vegetation affected, and the areal extents (figure 7). Meteorological data was only used as an input to this system, but will be intended to use for preparation of the forest fire risk map in conjunction with the weather forecast and the vegetation condition in future. All entries in the dataset relating to the study area were registered and referenced to a national UTM projection system. For the raster datasets, the geometric registration process was carried out using standard techniques with 75 ground control points, a first-degree polynomial equation, and resampling using cubic convolution with a ± 0.5 pixel registration accuracy.

Future improvements will include the use of any additional information such as short-term risk prediction, i.e. distance to roads, distance to human settlements and to land-use interfaces together with digital terrain model.

7. Conclusions

In recent years, GIS has emerged as a powerful tool in conjunction with multitemporal remote sensing data for studying and monitoring the impact of many environmental factors. Many government agencies now use a wide range of computer-based information systems to handle geographic aspects of their business, particularly mapping, by integrating spatial data collected from different sources, and in different formats, into GISs. In this way, it is possible to address the critical questions of how economic, meteorological, hydrological and other processes interact with geographically disposed natural resources like forests.

With its rich biological diversity, the Turkish forests (covering 26% of the country) are very important, and forest fires are the most important of the factors threatening them. Today, the concept of sustainable management of forest has changed considerably, and advanced forest management systems play an important role in organizing, maintaining, accessing and reporting on all aspects of forest information required to support management planning functions such as control, scheduling and monitoring resources for the future. Forestry in Turkey has to change quickly to adapt to this new concept, however, there is still a significant gap between what is possible, in terms of knowledge and management from the new techniques such as remote sensing, and traditional forestry techniques. Reducing this gap is only possible if it can be shown that digital remote sensing techniques are at least as accurate and economically viable as current operational tools, and that GIS can play a decisive role in the measurement and assessment stages of a forest management strategy. An integrated management system could have an important role in the planning, review and improvement of current methods, primarily through better modelling.

Over recent years, technologies using GIS and remote sensing have gained momentum in Turkey. Many of these GIS/remote sensing applications, however, are not fully integrated with organizational business processes nor are they being used to their greatest potential in resource analysis. Success will also require a government initiative in data management and in the integration of data flows within and between agencies. As shown in this paper, the analysis of the fire effects using satellite sensor images and GIS uncovered significant inadequacies in the results of areal extent and type of forest destruction achieved by the Forestry Chief Directorate using conventional and neural network classification algorithms. It was also seen that the result from the neural network classification is quite harmonious with that calculated using conventional remote sensing methods. The results presented here suggest that a co-operative forest management programme that monitors, assesses and reports on the long-term status, changes and trends in forest ecosystem health, based on the new technologies, should be initiated, developed and incorporated within the regional forest services/public sector.

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References

BERBEROĞLU, S., and CURRAN, P. J., 1998, Optimising the remote sensing of Mediterranean land cover, *Proceedings of the 24th Annual Conference and Exhibition of the RSS, The University of Greenwich, 9–11 September, UK* (Nottingham: Remote Sensing Society), pp. 105–106.

BOCK, S., 1996, A region-based approach to land-use classification of remotely-sensed image data using artificial neural networks. *International Archives of Photogrammetry and Remote Sensing*, Vol. XXXI, Part B7, Vienna.

CAMPBELL, J. B., 1987, *Introduction to Remote Sensing*, 2nd edn (New York: The Guildford Press).

CHUVIECO, E., and CONGALTON R. G., 1989, Application of remote sensing and geographic information systems to forest fire hazard mapping. *Remote Sensing of Environment*, **29**, 147–159.

CHUVIECO, E., and MARTIN, M. P., 1994, A simple method for fire growth mapping using AVHRR channel 3 data. *International Journal of Remote Sensing*, **15**, 3141–3146.

FOX, L. III, and STUART, J. D., 1994, Detecting changes in forest condition following wildfire, using image processing and GIS. *ASPRS Technical Papers: 1994 ASPRS-ACSM Annual Convention, American Society of Photogrammetry and Remote Sensing, Reno, Nevada, April 1994* (Maryland: American Society for Photogrammetry and Remote Sensing), pp. 197–206.

HARA, Y., ATKINS, R., YUEH, S., SHIN, R., and KING, J., 1994, application of neural networks to radar image classification. *IEEE Transactions on Geoscience and Remote Sensing*, **32**, 100–109.

HARRISON, B. A., and JUPP, D. L. B., 1990, Introduction to image processing. CSIRO, Australia.

HAYKIN, S., 1994, *Neural Networks* (New York: Macmillan).

KLAVER, J. M., KLAVER, R. W., and BURGAN, R. E., 1997, Using GIS to assess forest fire hazard in the Mediterranean region of the United States, 1997 ESRI Users Conference, San Diego, CA, 8–11 July, http://www.esri.com/base/common/userconf/proc97/HOME. HTM.

MATHER, P. M., 1987, *Computer Processing of Remotely-Sensed Images, An Introduction* (Chichester: Wiley).

ÖZKAN, C., 1998, Forest fire analysis with remote sensing data. MSc Thesis, ITU, Istanbul, Turkey {in Turkish}.

ÖZKAN, C., and SUNAR, F., 1999, The use and effectiveness of artificial neural networks in forest fire classification. *Proceedings of the RSS 99 Earth Observation, From Data to Information, University of Wales, 8–10 September, UK* (Nottingham: Remote Sensing Society), pp. 767–772.

STATE FOREST DIRECTORATE, 1998, Forest fire statistics, Turkey, HYPERLINK http://www.ogm.gov.tr ://www.ogm.gov.tr

SUNAR, F., and TABERNER, M., 1998, An evaluation of forest burning in the Kapidağ Peninsula, Turkey, using multitemporal satellite data. *Proceedings of the 27th International Symposium on Remote Sensing of Environment—Information for Sustainability, 8–12 June, Tromso, Norway* (Baltimore, MD: International Center for Remote Sensing of Environment), pp. 648–651.

SWAIN, P. H., and DAVIS, M. S., 1978, *Remote Sensing: The Quantitative Approach* (New York: McGraw Hill).