Evaluating performances of spectral indices for burned area mapping using object-based image analysis

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Abstract

Determining post-fire information is crucial for post-fire management activities and rehabilitation treatments. The use of robust and advanced approaches is needed to determine fire severity and thoroughly analyze post-fire rehabilitation period. Object-based image analysis (OBIA) is a powerful approach that has been successfully applied in many research problems in remote sensing arena. However, its use in forest fire and related studies including fire severity and burned area estimation is quite limited. This study was carried out in Antalya's Taşağıl district (Turkey) where according to Directorate of Forestry reports one of the largest wildfires in the Turkey occurred in 2008. The objectives of the present work are (i) to investigate the performance of object based analysis for burned area mapping; (ii) to compare the performances of widely-used burned area related spectral indices in identifying burned, slightly burned, water and non-burned areas from each other, and (iii) to delineate the boundaries of burned area. In this context, spectral indices of Normalized Burn Ratio (NBR), Normalized Vegetation Index (NDVI), Burned Area Index (BAI) derived from the satellite image were employed in analyses. Multiresolution segmentation and fuzzy membership function classifier were applied to the combinations of the selected indices (NDVI, BAI-NBR, NDVI-NBR) to discriminate burned, slightly-burned and non-burned areas from each other. Results showed that all combinations constructed in this study produced satisfactory results in terms of classification accuracy. However, the highest accuracy (98.37%) was achieved by NDVI-NBR index combination whilst the lowest accuracy (94.59%) was achieved when only the NDVI index was employed in OBIA process. It is hoped that with this work a contribution will be made for the government agencies to delineate fire perimeter and determine risk of wildfire for post-fire damage management.

Key words: Forest fire, Wildfire, NBR, NDVI, BAI, Object-Based Image Analysis

I Introduction

Wildfires are one of the most important natural disasters with respect to catastrophic consequences which cause serious social, economic and environmental problems. Particularly, the Mediterranean ecosystem of Turkey is suffered from increasing number of forest fires and severities due to human-induced activities or natural conditions. According to Turkish General of Directorate of Forestry report, 142,409 hectares of forest was burned between the years 2002 and 2014, most of which are located in the Aegean and Mediterranean regions of Turkey (OGM, 2014). In this context, burned area mapping is of crucial importance for fire management and post-fire damage estimation to determine fire behavior.

Several studies have investigated the use of remote sensing in burned area mapping on Mediterranean region (Mitri and Gitas, 2004; Kavzoglu et al., 2014; Pleniou and Koutsias, 2013). In addition; various spectral indices (e.g. NBR, NDVI, BAI) have been widely utilized to monitor fire-induced vegetation changes, including burn severity and regeneration (Chen et al., 2011; Chuvieco et al., 2002; Veraverbeke et al., 2011).

OBIA considers spectral, textural and hierarchical information of objects, a group of neighboring pixels with similar characteristics. In contrast to pixel-based image analysis, it constructs segments from the objects and show high performances by producing more accurate thematic maps. OBIA, which deals with spectrally homogenous image objects instead of single pixels, may be more effective for burned area mapping (Mitri and Gitas, 2004). Mitri and Gitas (2002) states that "the combination of the object-oriented approach and the multispectral resolution data of Landsat TM showed very promising results in burned area mapping and in discriminating between burned and the other classes of confusion."

The aim of this study was to examine the efficiency of OBIA together with various spectral indices for the Antalya-Taşağıl wildfire in Turkey by using Landsat ETM+ images. Main objectives of this study are twofold; i) to distinguish burned and non-burned areas precisely, (ii) to assess the effectiveness of object-based image classification for burned area mapping.

II Study Area and Dataset

This study focuses on a large fire that occurred on 31th July 2008, in the Antalya-Taşağıl region (the central coordinates: 37° 03'N, 31° 10'E) of Turkey (Figure 1). The fire was human-induced and worsened by the prevailing winds. Pinus brutia is the dominant tree species at the region and other types of Mediterranean vegetation, (e.g. maquis) exist in the study area. The region is characterized by the Mediterranean climate, mean annual temperatures ranging between 10° and 18.5° C and with dry and hot summers. The mean annual precipitation ranges between ~450 and ~1020 mm.

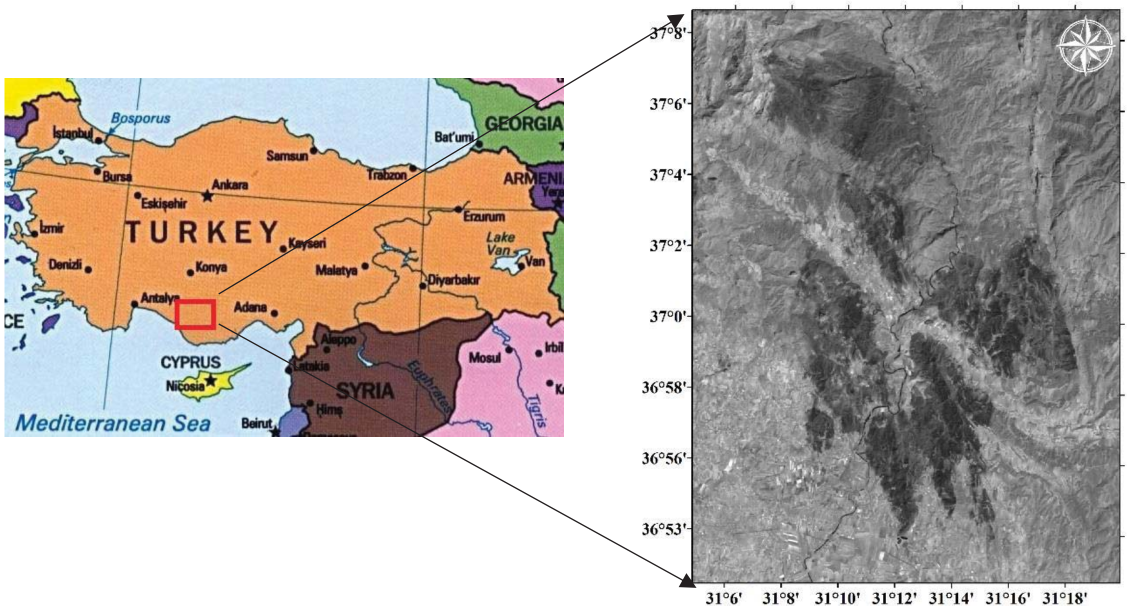

Figure 1: Location of the study area.

A cloud-free Landsat ETM+ image with an acquisition date of 12 September 2008 was obtained at no cost from the United States Geological Survey (USGS) archive (http://earthexplorer.usgs.gov/). The preprocessed (radiometrically corrected and geometrically registered) image was registered to UTM projection with WGS84 datum. A widely-used object based image processing software, eCognition Developer (v9.1), was used for segmentation and classification experiments in this study.

III Methodology

Spectral Indices

In this study, three spectral indices (NDVI, NBR and BAI) were calculated using the following equations (Table 1) to distinguish between burned and unburned surfaces for Landsat ETM+ image. The indices were calculated using the bands wavelengths: NIR (0,75 to 0.90 μm), R (0.63 to 0.69 μm), and SWIR (1.55 to 1.75 μm) for each spectral region.

Spectral Index	Abbreviation	Formula
Normalized Difference Vegetation Index	NDVI	$NDVI = \frac{NIR-R}{NIR+R}$
Normalized Burn Ratio	NBR	$NBR = \frac{NIR-SWIR}{NIR+SWIR}$
Burned Area Index	BAI	$BAI = \frac{1}{(0.1-R)^2+(0.06-NIR)^2}$

Table 1. Spectral indices used in this study (NIR: Near Infrared, R: Red, SWIR: Short Wave Infrared).

Veraverbeke et al. (2011) state that enhancing the NBR with Landsat's thermal band provides better seperability between burned and unburned lands. The latter index, the BAI, has a high discrimination ability for burned areas in the R-NIR spectral domain (Chuvieco et al., 2002). Furthermore, the NDVI has been widely used in monitoring fire affected areas (García-Haro et al., 2001; van Leeuwen et al., 2010).

Image Segmentation and Classification

Segmentation, the first step in the OBIA, splits an image into random object primitives to build up homogenous (segments or image objects) regions. Multiresolution segmentation algorithm (Baatz and Schäpe, 2000), which is a bottom-up region merging technique was utilized in this paper. The segmentation of Landsat ETM+ image was constructed by adjusting the scale, band weights and color-shape parameters.

The scale parameter is an unitless abstract which asses the maximum allowed heterogeneity of image objects. Optionally, user can define the scale parameter according to required level of detail in image. Higher scale parameter values construct larger objects; smaller scale parameter values generate smaller objects. Some studies emphasized the relation between scale parameter and number of objects (Addink et al., 2007). Moreover, several studies have underlined the variation in classification accuracy due to the user-defined scale setting (Kim et al., 2009; Kavzoglu and Yildiz, 2014).

In this study, bottom-up approach was performed to define land use/land cover objects. Based on a "trial and error" procedure, scale parameter was set to 50 and 15 respectively for level 1 and 2 in segmentation process. Membership function classifier was implemented in the commercial software eCognition (Developer v. 9.1). Membership functions allow users to define the relationship between feature values and the degree of membership to a class using fuzzy logic. Minimum and maximum value set the upper and lower limits of the membership function (Trimble, 2011). The fuzzy sets were defined by membership functions to identify feature attributes according to spectral and contextual information. Classifications were performed on two segmentation levels: "water" class at Level 1 (i.e., scale 50); 'burned area', 'slightly-burned area' and 'non-burned' class at Level 2 (i.e., scale 15).

IV Results and Discussion

Multiresolution segmentation and fuzzy membership function classifier were applied by using three different combinations of the selected indices (NDVI, BAI-NBR, NDVI-NBR) to discriminate water, burned, slightly-burned and non-burned areas from each other. In iterative steps, a two-level network of image objects was advanced. Membership functions were utilized by the thresholds of objects regarding to their spectral characteristics.

The Level 1 objects were initially categorized. SWIR band and NDVI values were utilized on membership functions of spectral information to distinguish water class, which was delineated similarly on the combinations. Level 2, main level of classification, was created smaller image objects. Three classes representing 'burned area', 'slightly-burned area' and 'non-burned area' were generated at this level.

In the first combination which is based on only NDVI, classification results were not sufficient to detect burn scars. It was observed that rocky land, vegetation and urban areas were mixed with burned area (Figure 2a). Mean brightness and NDVI values were used to define membership functions for burned area and slightly-burned area. NDVI based threshold values were selected as "0.089 / 0.20", "0.20 / 0.34" and "-0.52 / 0.85" for burned, slightly burned and non-burned class, respectively. At the end of the first step, the overall accuracy of the classification was estimated as 94.59%. Secondly, BAI-NBR combination was implemented to delineate the burned areas (Figure 2b). Image segments were classified as burned area class using NBR based threshold values "-0.8 / 0.1" and excluding the BAI based threshold values "-1.0 / 1.8". Similarly, slightly-burned area was determined using NBR based threshold values "-0.03 / 0.41" and excluding the BAI-based threshold values "-0.8 / 2.33". The related BAI-based threshold values excluded to eliminate confusion between burned and non-burned pixels. In non-burned area class determination, NBR based threshold values were selected as "-0.39 / 0.99". Although this approach produced good results for burned area discrimination, it was observed that several pixels were misclassified in coastal regions. In BAI-NBR combination, overall classification accuracy was estimated 97.23%. In third approach, NDVI-NBR combination was applied to distinguish burned areas from non-burned areas (Figure 2c). NBR index was utilized to differentiate burned areas. NBR based threshold value was selected as "-0.38 / -0.08" for burned area class. Slightly-burned area was determined by using NDVI and NBR indices together. Thresholds of NBR and NDVI for slightly burned area class selected as "-0.06 / 0.42" and "0.19 / 0.42", respectively. In non-burned area discrimination, NBR based threshold value was chosen as "-0.3 / 0.79". Finally, overall classification accuracy was calculated 98.37% for NDVI-NBR combination.

Since there is no information about post-fire perimeter map estimated by the Turkish Directorate of Forestry, the accuracy assessment was evaluated by using authors' previous research (Kaya et al., 2014). The related study was investigated to predict burn severity with using the differenced Normalized Burn Ratio (dNBR) algorithm in same region. Training and test datasets were collected according to mentioned above study's results. The overall classification accuracies of three combinations for burned area mapping were presented in Table 2.

Results presented in Table 2 showed that the NDVI-NBR approach increased the overall accuracy by about 4% compared to NDVI, while this increment was approximately 3% for the burned area class. It was also observed that producer's accuracy calculated for each class was higher for BAI-NBR combination than NDVI-NBR combination.

Combination		Producer's Class Accuracy (%)				Overall Accuracy(%)
		Burned	Slightly Burned	Non-Burned	Water	
1	NDVI	94.06	92.42	94.64	100	94.59
2	BAI-NBR	98.03	94.62	94.56	100	97.23
3	NDVI-NBR	96,66	97.48	98.31	100	98.37

Table 2. Accuracy assessment results for NDVI, BAI-NBR and NDVI-NBR analysis.

It is apparent from Figure 2 that the classified objects of burned area (especially in NDVI-NBR and BAI-NBR combinations) could strongly be distinguished from other classes. Additionally, users and fire agencies can extract burned area borders by using burned area mask for the purpose of fire perimeter definition.

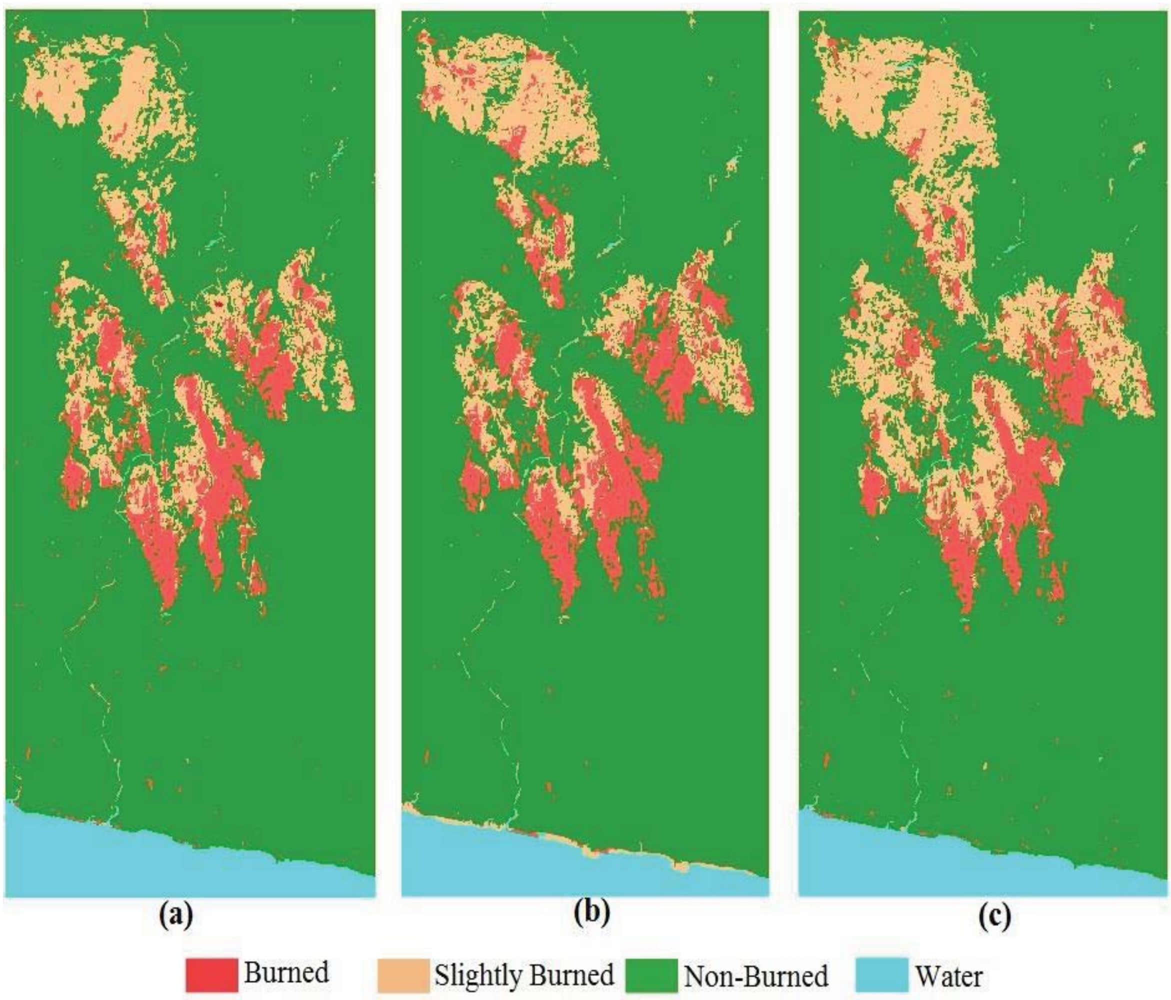

Figure 2: Classification results of three different combinations: (a) NDVI, (b) BAI-NBR, (c) NDVI-NBR.

V Conclusion

In this study, effectiveness of object-based classification was assessed in the determination of burned area mapping of Antalya-Taşağıl forest fire in Turkey. For this purpose, spectral indices of NDVI, NBR and BAI derived from Landsat ETM+ image were computed in analyses. Multiresolution segmentation and fuzzy membership function classifier were implemented to determine burned area.

The findings from this study make several contributions to the current literature. The combination of different spectral indices with OBIA approach showed very promising results. Furthermore, the use of membership functions contributed to reduction of misclassified pixels. The highest accuracy (98.37%) was obtained from NDVI-NBR combination in OBIA process. The following conclusions can be drawn from the present study, object-based classification can be used as a tool for rapid operational burned area mapping of Mediterranean forest fires. Unfortunately, no information about post-fire perimeter map was estimated by the Turkish Directorate of Forestry. The results obtained from these findings could provide valuable information for government agencies, planners and decision makers to construct management of forest fire strategies.

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