Detecting Forest Fire Damage Using Remote Sensing

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Abstract

Forest fires have become a huge and global problem in recent years. Although the large fires seen in almost every continent and country have started due to natural causes or human activities, the general management policies of forests are being questioned in many ways in the context of fires. The direct and indirect effects of reasons such as changes in climatic temperature and precipitation regimes, the decrease in rural population due to migration, the reduction of wild animals and livestock in natural environments and forests, and the accumulation of excessive amounts of flammable organic matter on forest floors are being discussed in wide circles from academic circles to the public. Climatic changes resulting from human activities over time, the rapid increase in the world population, and incorrect application in forests indicate that forest fires will continue to be a serious problem for humanity in the coming years. The important point of forest fires is the amount of burned area. Geographic Information Systems and Remote Sensing are the most preferred methods for determining the amount of burned area with satellite images. The study aims to determine the calculation of the fire in Izmir in the summer of 2024. Satellite images were obtained before and after the fire in the study. Normalized Burn Ratio and Normalized Difference Vegetation Index analyses were applied to the obtained satellite images, and the amount of burned area was calculated with both methods. Finally, it was determined that remote sensing and geographic information systems can be used to calculate the amount of burned area, and the resolution of the satellite image used is important. It was also determined that the difference between the determined amount and the data of the Regional Forestry Directorate is small.

Keywords: Forest, Forest Fire, Remote Sensing, Environmental Management, İzmir

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INTRODUCTION

In addition to having significant impacts on the ecosystem and climate, forests are among the most vital renewable natural resources that contribute to the nation's economy in some sectors, including industry, tourism, health, and the economy. Forest fire is defined as an anthropogenic and natural disturbing phenomenon that has an impact on the ecosystem, biodiversity, and human health and has increased significantly in the world (Bar et al., 2020). Forest fires are frequently seen, especially in the Mediterranean and Aegean regions greatly affected by fires due to the effect of the climate in Turkey. Forests that burn cause great economic and ecological damage in the region every year (Karabulut et al., 2016).

Turkey is located in the Mediterranean climate zone, a large part of the forests under the threat of fire, and 60% of the total forest area consists of first and second-degree fire-sensitive areas. For this reason, forest fires are among the priority issues of our country's forestry (OGM, 2021). In the last 20 years, 45,681 forest fires have occurred in Turkey and a total of 183,756.2 hectares of forest area have been burned (OGM, 2019). Forest fires can be caused by natural events and various reasons such as the involvement of human factors (Beşli and Tenekeci, 2020). Forest fires show different behaviors depending on topography, flammable material, and the factors affecting it (wind, climate, elevation, slope, type and amount of the flammable material, etc.) (Küçük et al., 2005). While there is no control over meteorological and topographic factors, flammable materials can change and be controlled in time and space. This important feature gives flammable materials critical importance in the planning and activities carried out for forest fires (Yılmaz et al., 2021).

The greatest power of today's world is accessing information. Accessing the right data on time, organizing data, and managing data on the way to accessing information depends on information technologies. Remote Sensing comes first among these information technologies. Remote sensing is a method of obtaining information from a certain distance with satellite sensors without physical contact with objects (Figure 1) (Çağlak and Özelkan, 2019).

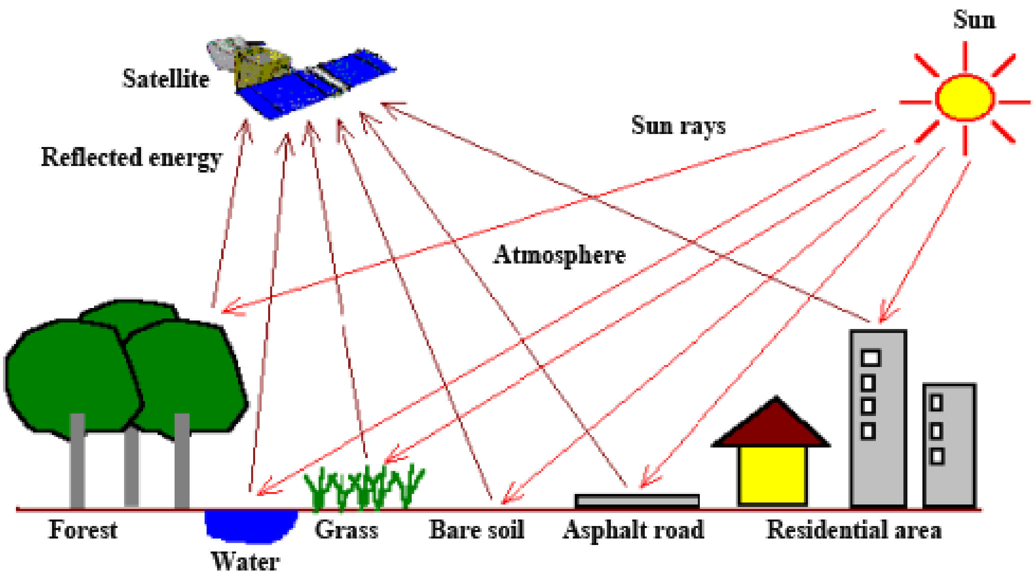

Figure 1. Optical remote sensing (Gövdetaşan, 2022)

Remote sensing techniques, models and indices are designed to convert spectral information into a form that can be easily interpreted.

The applicability of remote sensing measurements should be realized in solving environmental problems (Bannari et al., 1995). The development of remote sensing devices has provided the opportunity to evaluate the recovery of vegetation after forest fires (Riano et al., 2002). It is possible to examine the changes in the study area with remote sensing and satellite data after the fire (Aksoy and Çabuk, 2018).

Remote sensing technology has provided successful studies in recent years thanks to significant developments in the technology. These studies increase the importance of indices that are used especially for short-term and rapid changes such as forest fires and provide both time and financial benefits (Sabuncu and Özener, 2019). Remote sensing technology can be used in different stages of fire management (estimation, detection, and evaluation). Remotely sensed data provides information about the characteristics and structures of plants spectrally (Algancı et al., 2011). It is possible to evaluate and monitor the direction and intensity of the fire in places where access is not provided during the fire with remote sensing techniques (Sarp et al., 2018). In addition, comparing and analyzing satellite data with ground data increases the importance of remote sensing (Özelkan, 2019). In other words, the reason for the effective use of remote sensing is that the data obtained through satellite technology provides different spatial and spectral analyses (Özdemir et al., 2010).

This study aims to determine the destroyed area with Landsat 8 OLI satellite images after the forest fire that occurred on August 15 2024 in the Karşıyaka, İzmir and caused the destruction of approximately 1600 (ha) (16.00 km²) area. In the study, the performances of the NBR and NDVI remote sensing indices were calculated with pre- and post-fire images, and the indices used in the study and the remote sensing data used were evaluated.

MATERIAL and METHOD

In this study, various analyses were conducted to evaluate the performances of different remote sensing indices and different sensors using pre-fire and post-fire Landsat-8 OLI images to determine the burned forest area (Figure 2). The fire, which broke out on Yamanlar Mountain in Karşıyaka district at around 21:00 on August 15, 2024, spread to a wide area due to the wind. Residential areas were also affected by the fire. 17 houses were burned in the fire, 105 houses were evacuated. 44 workplaces were also evacuated. Therefore, the entire district borders were included in the study.

A single sensor was used in this study. Landsat-8 OLI includes 11 spectral bands with 30 m spatial resolution (100 m - thermal, 15 m panchromatic). Landsat-8 OLI; It has Coastal/Aerosol (0.433-0.455 µm), Blue (0.450-0.510 µm), Green (0.530-0.590 µm), Red (0.640-0.670 µm), Near Infrared (0.850-0.880 µm), Short Wave Infrared (1.570-1.650 µm), Short Wave Infrared (2.100-2.290 µm) and Cirrus (1.360-1.380 µm) bands with 30 m spatial resolution. It is an important data source especially for monitoring long-term changes (Mert et al. 2016; Yılmaz et al., 2022). Landsat-8 OLI, two pairs of images were studied on July 20, 2023 and September 1, 2024. NIR stands for near-infrared, SWIR stands for shortwave infrared.

Detection of burnt areas after forest fire is carried out quickly and with high accuracy with remote sensing technology. In this study, burnt forest area was determined with different remote sensing indices using Landsat-8 OLI images which are freely available, and the obtained results were compared. Landsat-8 OLI images were first acquired before and after the forest fire to identify burned regions using photographs from those times. After applying the cutting process to these images, they were processed with various indices selected according to the results of the literature research. Then, the differences between the index images calculated before and after the fire were determined.

Separate accuracy assessment analyses of these difference indices were made with error matrices for both sensors and finally, the conclusion was reached by making comparisons and evaluations.

Figure 2. Study area

Spectral index-based methods are widely used to determine burned areas (Liu et al. 2020). In this study, Normalized Difference Vegetation Index (NDVI), Normalized Burning Intensity (NBR), Difference Normalized Burning Intensity (dNBR) were selected to determine the burned area using Landsat-8 OLI satellite images.

These difference indices were used to determine the pre- and post-fire changes. In this study, Normalized Difference Vegetation Index (NDVI) (Eq. 1), Normalized Burning Intensity (NBR) (Eq. 2), and Difference Normalized Burning Intensity (dNBR) (Eq. 3) were selected to determine the burned area using Landsat-8 OLI satellite images. These difference indices were used to determine the pre- and post-fire changes.

$$NDVI = \frac{NIR\ (Band\ 5) - Red\ (Band\ 4)}{NIR\ (Band\ 5) + Red\ (Band\ 4)} \quad (1)$$

$$NBR = \frac{NIR\ (Band\ 5) - SWIR\ (Band\ 7)}{NIR\ (Band\ 5) + SWIR\ (Band\ 8)} \quad (2)$$

$$\Delta NBR = NBR_{Before\ Fire} - NBR_{After\ Fire} \quad (3)$$

If the NDVI value approaches -1, it means that the vegetation has decreased, and if it approaches 1, it means that the vegetation has increased. A high NBR value means healthy vegetation (Keeley, 2009). The NBR value range is -1 to 1. NDVI is one of the most well-known and widely used indices that exploit the strong absorption of visible red light by green vegetation, in contrast to the high reflectance of near-infrared light in areas covered with healthy vegetation. When vegetation is damaged by fire, NDVI values decrease significantly. Therefore, it is an effective method to obtain accurate results for burned areas (Fornacca et al. 2018). In theory, when the Difference Normalized Burning Intensity index was analyzed, the results obtained ranged from -2.00 to +2.00. The values for burnt areas vary from 0.10 to 1.35, whereas those for unburned regions range from -0.10 to +0.10. Furthermore, values ranging from -0.50 to -0.10 were reported for plants that demonstrated advanced re-growth following the fire (Key and Benson, 2006; Sabuncu and Özener, 2019; Soydan, 2022) (Table 1).

Table 1. Burn severity categories (Sabuncu and Özener, 2019)

dNBR	Burning Intensity
< - 0.25	High Post-Fire Greenery
-0,25/ -0.1	Low Post-Fire Greenery
-0.1/0.1	Unburnt
0.1/0.27	Low Burning Intensity
0.27/0.44	Medium/Low Burning Intensity
0.44/0.66	Medium/High Burning Intensity
>0.66	High Burning Intensity

After all the operations, it is important to perform an accuracy assessment analysis to determine the thematic accuracy of the results. Accuracy assessment evaluates how accurately pixels are assigned to the correct land cover and land use classes (Rwanga and Ndambuki, 2017). In this study, the error matrix method was used to determine the thematic accuracy of the calculated indices. The error matrix is a square matrix containing rows and columns expressing the number of pixels corresponding to that category according to the reference data (Vanwambeke et al., 2007). User Accuracy (UA), Producer Accuracy (GCA), Overall Accuracy (GA), and Kappa Statistics are calculated using the generated error matrix (Yılmaz et al., 2021).

RESULTS and DISCUSSION

Using Landsat-8 OLI satellites, the area destroyed after the İzmir/Karşıyaka forest fire was detected and the performances of different methods and different data were compared with the accuracy assessment results. Figure 3 shows the NDVI analysis for Landsat-8 OLI before and after the fire. To detect fire damaged areas, NDVI and NBR indices were calculated, respectively. The value range for the before and after NDVI index was obtained between approximately -1 and 1. The reason why the NDVI value became negative after the fire is that the vegetation was damaged due to the fire because if the NDVI value approaches -1, the vegetation has decreased, and if it approaches +1, the vegetation has increased.

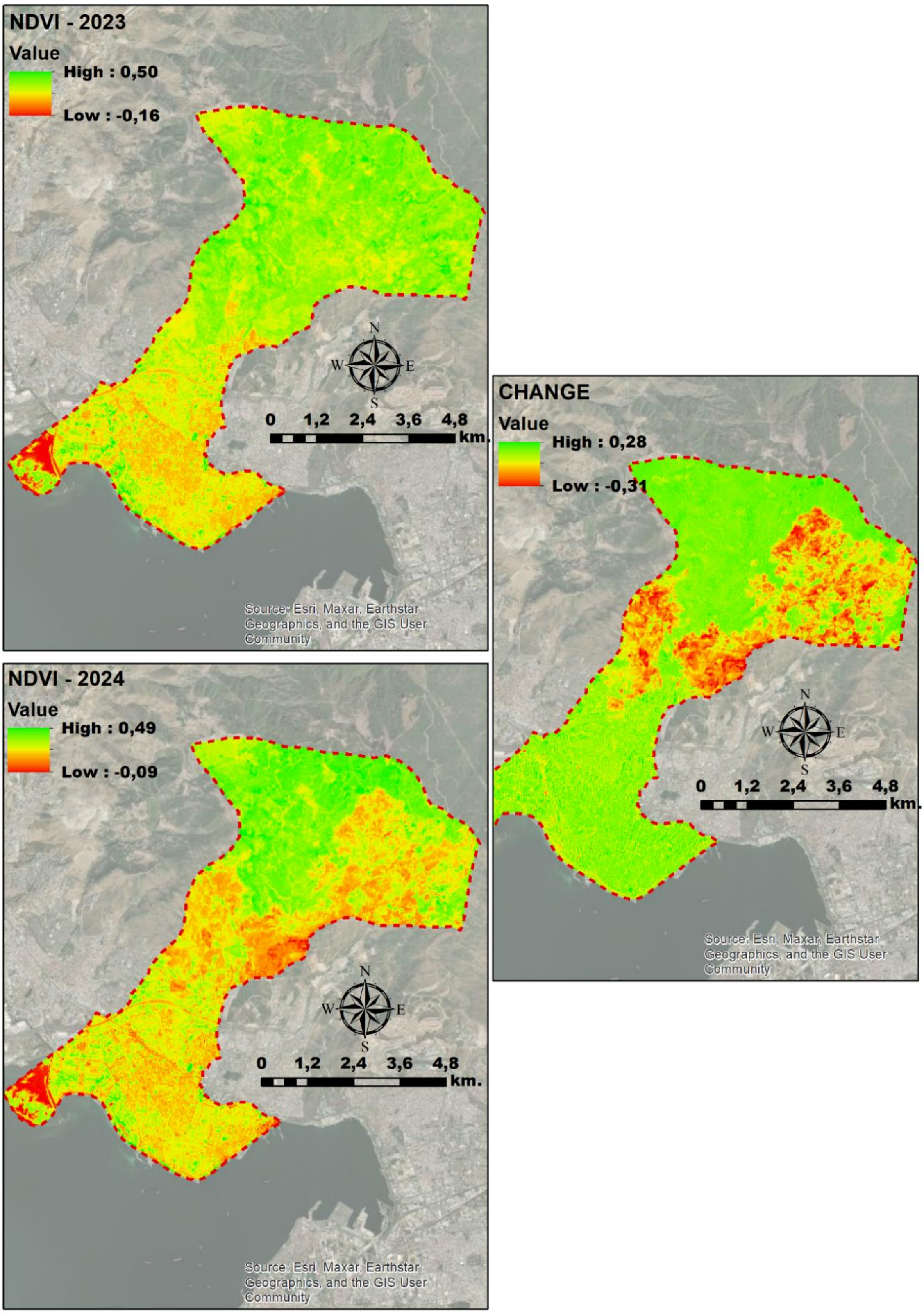

Figure 3. NDVI analysis

An NBR analysis was conducted for the research region. After creating two distinct maps for the pre-fire and pro-fire phases, NBR analysis was used to identify the burned areas. (Figure 4).

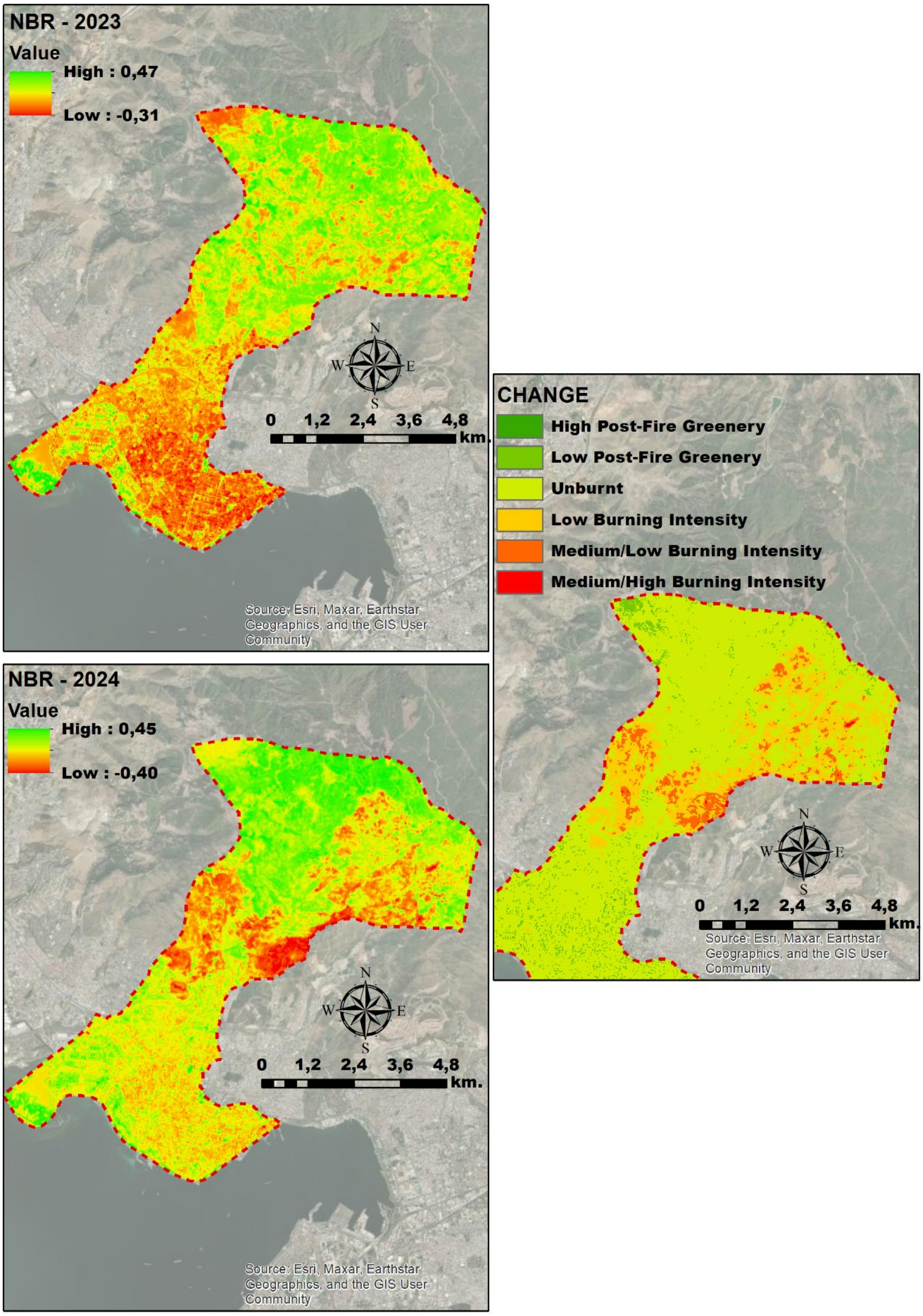

Figure 4. NDVI analysis

This study uses Landsat 8 satellite images and two remote sensing analytic methods to map the area burned by a forest fire in Karşıyaka, İzmir, on August 15, 2024.

The approaches are NBR-dNBR and NDVI-NDVI, respectively. The forest areas burned by fire were identified as 20,65 ha using NBR-dNBR and 18,85ha using NDVI-NDVI change detection analysis. According to the General Directorate of Forestry's damage assessment studies in the area after the fire, some 16,000 hectares of forest land had burnt, which was in line with the findings of the remote sensing studies. The accuracy assessment of the obtained difference images was performed using the error matrix. For the accuracy assessment, a total of 100 test points were selected to represent the randomly distributed region and the two categories we wanted to detect homogeneously, 50 for burned areas and 50 for unburned areas, and error matrices were created for all calculated difference indices and two different sensors.

According to the accuracy assessment results obtained, dNDVI was determined as the index with the highest overall accuracy and Kappa statistic value for Landsat-8 OLI. According to the results, the highest accuracy value for Landsat-8 OLI was calculated as 0.87 and the Kappa value as 0.91. The lowest overall accuracy value was found as 0.82 with dNBR for Landsat-8 OLI. Kappa statistic values were calculated as 0.81 dNBR (Landsat-8 OLI). The highest user accuracy was calculated as 0.97 with dNDVI for Landsat-8 OLI for burned areas. The highest producer accuracy for Landsat-8 OLI was calculated as 0.94 with dNDVI for burned areas. As a result, among the selected indices, dNDVI was determined to be the index that determined the burned forest area with the highest accuracy for the selected region. After the accuracy assessment process, the burned area boundary obtained by digitizing the high spatial resolution data obtained by Maxar Technology via Google Earth was compared with the burned area values obtained from Landsat-8 OLI images with different indices. The burned area boundary obtained with the reference data was calculated as 16 km^2. The closest area value to the reference was obtained with both Landsat-8 OLI dNDVI index. It was determined that the areas calculated with the difference of the indices were lower than the area value produced from the reference data for both images.

CONCLUSION

In recent years, forest fires have increased worldwide and this situation causes deforestation. Turkey, located in the Mediterranean basin, is under high threat from forest fires increased by global climate change. Therefore, detection of forest fires and determination of their damage is one of the necessary elements for sustainable forest management. For all these reasons, the study was carried out in Izmir province, located in the Aegean Region in the west of Turkey. The aim of the study was to determine the amount of burned area after the forest fire in Karşıyaka district of İzmir province with NDVI and NBR indexes. According to the analysis results, it was determined that the NBR index gave the closest value to the reference value. NBR is the index used to detect burned areas. Near infrared (NIR) and short wave infrared (SWIR) wavelengths are used when calculating NBR. The land ecosystem shows different reflections before and after the fire. While burned areas have low reflection values in NIR, they have high reflection values in SWIR. Information about the burning status is obtained by taking the difference between NIR and SWIR with the NBR index. NBR is an index created directly depending on the burned areas. However, NDVI may differ according to the type of land surface. It can also give results on the region affected by the fire and the ecosystem in its immediate surroundings. For this reason, it is said that NDVI analysis gives more accurate results than the NBR test. Due to the high spatial resolution of Landsat satellite images, some problems have been encountered: (i) overestimation of burned areas, (ii) classification of pixels outside the burned area as burned areas. These problems arise from the large pixel size of Landsat satellite images, which classifies a pixel as burned when it is not completely burned.

However, considering the size of the study area, Landsat satellite images can be easily obtained and used in such studies, as they are free of charge. In addition, with comprehensive data and sufficient computer hardware systems, the boundaries of the study can be expanded regionally, nationally, continentally or globally. The main purpose of these operations is to manage forests and forest fires under sustainable land management. Ultimately, to establish a sustainable forest management system. Thus, forests can be protected, managed in the best way, transferred to future generations, and forest fires can be reduced and prevented. It is envisaged that this study will serve the sustainable forest management system in İzmir and Turkey.

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