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Burned Forest Area Detection in the Manavgat Forest Fire Using NBR and dNBR Indices

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Abstract

Rapid identification of damaged areas following forest fires is a crucial initial response phase after such events. Under current conditions, these assessments are conducted using remote sensing techniques, allowing for quick and cost-effective data acquisition. This study analyzes the significant fire that began on July 28, 2021, and ravaged a large area within the boundaries of Manavgat District in Antalya Province for approximately 28 days, using remote sensing techniques. Pre-fire and post-fire satellite data for the study area were analyzed using the Normalized Burn Ratio (NBR) index and differenced Normalized Burn Ratio (dNBR) index. Additionally, the results were compared with data obtained from official institutions regarding the burned area. The analysis revealed that the burned areas were estimated at 61,502.76 hectares using NBR-dNBR. The destroyed area announced by official institutions is 59,985 hectares. The NBR-dNBR index, which is frequently preferred in burned forest area detection, coincides with the official results by approximately 97.5%.

Keywords: *Burned area detection, Remote sensing, NBR index, dNBR index, Manavgat forest fire, Landsat 8.*

Manavgat Orman Yangınında NBR ve dNBR İndeksleri Kullanılarak Yanmış Orman Alanlarının Tespiti

Öz

Orman yangınları sonrası hasarlı alanların hızlıca tespit edilmesi, yangın sonrası ilk ve en önemli müdahale aşamasıdır. Günümüz koşullarında bu işlemler uzaktan algılama araçlarıyla hem kısa sürede hem de maliyeti düşük olarak elde edilmektedir. Bu çalışmada Antalya İli, Manavgat İlçesi sınırları içerisinde 28 Temmuz 2021 yılında başlayan ve yaklaşık 28 gün süren oldukça büyük bir alanı tahrip eden yangın, uzaktan algılama teknikleri ile analiz edilmiştir. Çalışma alanına ait yangın öncesi ve yangın sonrası uydu verilerine, Normalize Edilmiş Yanma Oranı (NBR) indeksi ve Fark Normalize Edilmiş Yanma Oranı (dNBR) indeksi uygulanmıştır. Ayrıca elde edilen sonuçlar, resmî kurumlar tarafından yanan bölgeye ait veriler ile karşılaştırılmıştır. Sonuç olarak, yanarak tahrip olmuş olan alanlar NBR-dNBR ile 61.502,76 ha bulunmuştur. Resmi kurumlar tarafından açıklanan tahrip edilen alan ise 59.985 hektardır. Bu çalışma özelinde, yanmış orman alanı tespitinde sıklıkla tercih edilen NBR indeksi sonuçlarının, resmi sonuçlarla ile %97,5 oranında örtüştüğü ortaya konulmuştur.

Anahtar kelimeler: *Yanmış alan tespiti, Uzaktan algılama, NBR indeksi, dNBR indeksi, Manavgat orman yangını, Landsat 8.*

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1. Introduction

Forests that persist on earth are among the most critical components of ecosystems (Landuyt et al., 2019). Forests can be defined as ecosystems that host interactions among plant, animal, and organism habitats, play significant roles in mitigating the effects of climate change, and are key elements of ecological cycles (Mackey, Kormos, Keith, Moomaw, Houghton, Mittermeier & Hugh 2020; Gezer & Gül, 2009). In addition to the impacts of global climate change, fires caused by anthropogenic factors devastate forest ecosystems and disrupt the ecological cycles of forests, inflicting substantial damage on wildlife (Badia, Sauri, Cerdan & Llurdés, 2002; Tuğuler & Çakır, 2021;) as well as on air, soil, and water (Sannigrahi, 2020). According to recent statistics from the "Global Forest Resources Assessment 2020" report prepared by the Food and Agriculture Organization (FAO) under the United Nations, an analysis covering local, national, and global levels across 236 countries and regions indicates that 178 million hectares of forest area have been lost since 1990 (FAO, 2020). When considered on a global scale, forest fires have adverse effects not only on climate change but also on soil fertility and structure (Vieira, Barnes & Mitchell, 2011) Ashes from accumulated plant material on the soil after a fire damage soil permeability and prevent rainwater from infiltrating (Pereira, Pereira, Francos, Brevik, Ubeda & Bogunovic, 2018). This leads to erosion. Similarly, the increase in ground temperature during a fire causes the death of organic matter in the soil (Sobrino, Llorens, Fernández, Fernández-Alonso, & Vega 2019). The extreme temperature rise during a fire results in the burning of the above-ground portions of plants, causing the soil to be exposed to sunlight to a greater extent (Bowd, Banks, Strong & Lindenmayer, 2019). Consequently, forest fires significantly damage the soil, disrupting ecological cycles (Neary, Klopatek, Debano & Folliott, 1999). Forest fires also have significant direct and indirect effects on water quality. The quality and quantity of water are primarily dependent on the diversity and amount of vegetation cover. The loss of vegetation cover leads to a decrease in soil moisture, infiltration rates, and rainwater permeability, exacerbating soil erosion and increasing flood risks (Venkatesh, Preethi & Ramesh, 2020). Additionally, air quality deteriorates as a result of forest fires (Jaffe, O'Neill, Larkin, Holder, Peterson, Halofsky & Rappold, 2020). Therefore, forest fires not only impair habitat health but also have significant negative impacts on air, water, and soil quality (Mallongi, Indra, Arief, & Satrianegara, 2020)

Türkiye is relatively rich in forest cover, exhibiting significant bioclimatic and geomorphological diversity, and supporting a wide variety of vegetation types and landscape connectivity (Parolly, 2004; Selim & Demir, 2018; Noroozi, Zare, Sherafati, Mahmoodi, Moser, Asgarpour & Schneeweiss, 2019). It is located at the intersection of three biogeographic regions: the Mediterranean, Euro-Siberian, and Iran-Turan regions (Davis, 1971; Kirca, Kreutz & Çolak, 2020). In Turkey, forested areas are estimated to cover approximately 22.3 million hectares, constituting 28.6% of the country's total area (OGM, 2015). It is estimated that over 12,000 vascular plant species inhabit these forests, with approximately 32% classified as endemic (Özhatay & Kültür, 2006; Özhatay, Kültür & Aslan, 2009; Özhatay, Kültür & Gürdal, 2011). This makes Türkiye's forests valuable and significant in terms of biodiversity. However, similar to many European countries, particularly in the Mediterranean region, these forests are constantly threatened due to the high risk of fire spread (Paveglio, Carroll & Jakes, 2010).

The ecosystem of the Mediterranean region in southern Türkiye is one that has adapted to years of exposure to forest fires. In recent years, the incidence of forest fires in the region has significantly increased. It has been observed that the burned areas due to forest fires in the Mediterranean region can reach up to 600,000 hectares annually (Rulli & Rosso, 2007). Statistical studies concerning forest areas indicate that Türkiye has approximately 22.3 million hectares of forest, with 35% classified as first-degree fire-sensitive areas, 23% as second-degree, 22% as third-degree, 15% as fourth-degree, and 5% as fifth-degree fire-sensitive regions (Küçük & Ünal, 2005). Approximately 57% of Türkiye's forests are located in regions with the highest fire risk, particularly within the Mediterranean and Aegean basins. Between 1937 and 2016, a total of 1,661,506 hectares of forest were reported to have been damaged due to forest fires in Türkiye (Sabuncu & Özener, 2019).

Critical intervention time and post-forest fire rehabilitation efforts form the foundation of forest fire management (Sakellariou, Samara, Tampekis, Sfougaris & Christopoulou, 2020). This study focuses on

rapid detection and prioritization for post-forest fire rehabilitation. Recently, various reasons such as the high costs associated with post-fire land survey, difficulties in accessing burned areas, and the inability to accurately determine lost forest cover with high precision have led to the adoption of remote sensing technologies instead of traditional land surveys (Di Biase & Lanave, 2018; Gao, Skutsch, Paneque-Gálvez & Ghilardi, 2020). Alongside advancements in sensor technologies, the use of different band combinations in satellite imagery allows for the identification of burned forest areas with high accuracy, low cost, and in a short timeframe (Youn & Jeong, 2019; Bar, Parida & Pandey, 2020). Various indices are utilized for the detection of burned areas and fire, including the Normalized Burned Ratio (NBR), the Normalized Difference SWIR (NDSWIR), the Burning Area Index (BAI), the Mid-Infrared Bi-Spectral Index (MIRBI), the Normalized Burned Ratio SWIR (NBRSWIR), the Normalized Difference Vegetation Index (NDVI), the Fire Detection Index (FDI), the Forest Fire Detection Index (FFDI), the Normalized Multi-Band Drought Index (NMDI), the Normalized Difference Water Index (NDWI), and the Composite Burn Index (CBI) etc. (Wang, Qu & Hao, 2008; Cruz, Eckert, Meneses & Martínez, 2016; Jang, Kang, Im, Lee, Yoon & Kim, 2019; Liu, Zheng, Dalponte & Tong, 2020; De Luca, Silva, & Modica, 2021; Lee, Park, Kim, Liu,Reba, Oh & Han, 2022; Kurbanov, Vorobev, Lezhnin, Sha, Wang, Li & Wang, 2022; Aydın-Kandemir & Demir, 2023). Among these indices, NBR is a commonly used index designed to highlight burned areas in large fire regions (UN, 2024)

In this context, Landsat satellite imagery is frequently utilized for detecting burned areas (Pacheco, Junior, Ruiz-Armenteros & Henriques, 2021). One of the freely accessible satellites, Landsat is effective for larger areas due to its resolution; however, newer generation sensors that operate with different satellites provide clearer spatial details (Zhang, Long, He Wei, Tang, Wang & Zhang, 2020). Nevertheless, the presence of near-infrared and shortwave infrared bands, their radiometric correction, and their long-standing use in research have made Landsat satellite imagery a preferred choice for analyzing post-fire land cover changes (Liu et al., 2020).

The aim of this study is to determine the extent of areas damaged by the forest fire that occurred in Antalya Province, one of Turkey's most significant tourism destinations, in 2021, which lasted approximately one month, and to evaluate its accuracy by comparing it with data reported by official institutions. In this context, the Normalized Burn Ratio (NBR) and differences Normalized Burn Ratio (dNBR) indices were employed. The data obtained and the maps generated provide information on the precise size of the area affected by the fire and offer prioritization for rehabilitation efforts to both central and local authorities.

2. Material and Method

2.1. Study area

The research was carried out in Manavgat, the second-largest district of Turkey's Antalya province, which is located between 31° 01' 30.19" and 31° 45' 51.28" E longitude and 36° 39' 45.19" – 37° 26' 15.26" N latitude (Fig.1). The Manavgat district has a land area of 2349.47 km² and is characterized by a variety of geological features. The elevation profile of the research region ranges from 0 to 2499.27 meters above sea level. According to 2021 data, the population of Manavgat is 245,740 (Dogan et al., 2024). Manavgat district has a total of 49,064 hectares of forest, 38,469.1 hectares of which are normally closed and 10,594.4 hectares of which are interspersed (OGM, 2024a).

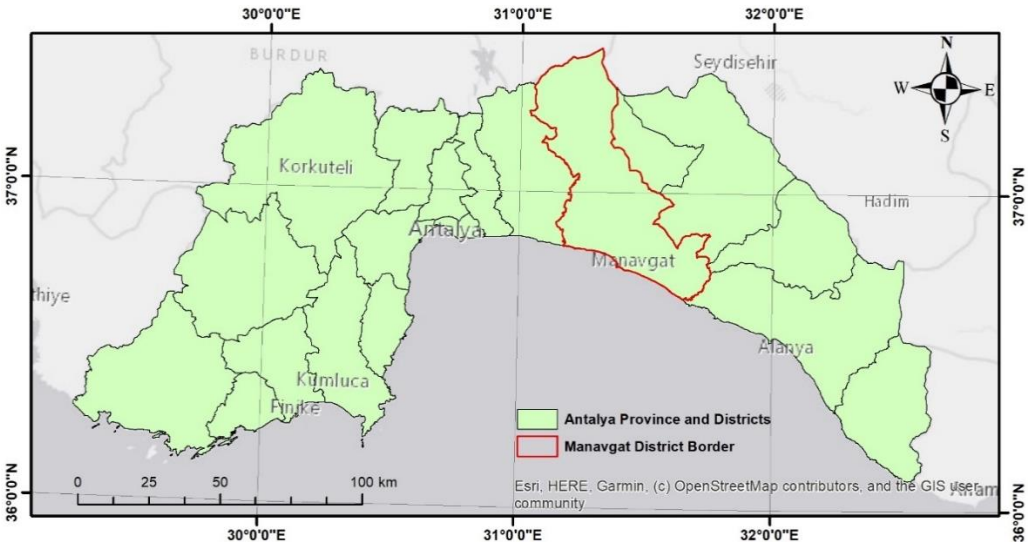


Figure 1. Location of the study area

The area extending from the coastline to the Taurus Mountains is mostly agricultural, and tourist facilities are concentrated in the coastal areas. As you rise above sea level, maquis and forest areas begin. The dominant vegetation types in the forests are *Pinus brutia*, *Pinus nigra*, *Picea sp., Cedrus sp.,* and *Cupressus sp.* Manavgat's climate is Mediterranean. Summers are hot and dry, winters are mild and rainy (Akıncı & Akıncı, 2023). Within the boundaries of the Manavgat Forest Management Directorate, 141 fires occurred in the last three years. An analysis of the causes of these fires reveals that 0.52% were due to lightning, 6.74% to negligence and carelessness, 40.12% to intentional actions, 13.82% to energy transmission lines, and 38.80% were caused by unknown factors (OGM, 2024b).

2.2. Data sets

Landsat 8 satellite images with a resolution of 30 meters were used to examine the forest fire that started on July 28, 2021 in Manavgat District and was extinguished on August 20, 2021. Satellite images were obtained free of charge from the United States Geological Survey (USGS) web page (https://earthexplorer.usgs.gov/). Landsat satellite data is one of the important datasets for detecting the effects of forest fires. Landsat 8, which has eleven (11) spectral bands, features an 8th band with a resolution of 15 meters, and the 10th and 11th thermal bands with a resolution of 100 meters, while the remaining bands have a resolution of 30 meters. Due to these characteristics, Landsat 8 data is frequently utilized in the literature for the detection of forest fires. Additionally, the 20-day temporal resolution before and after the fire provides a significant time frame for detecting burned areas before they regenerate. For fire detection and intensity assessment, Landsat 8 satellite images from July 15, 2021, to September 17, 2021, were used. Furthermore, Table 1 provides the bands, wavelength, and resolution characteristics of the satellite images used.

Table 1. Specifications of spectral bands of Landsat 8 OLI (Landsat, 2024)

	Landsat 8 Bands	Wavelength (µm)	Resolution (m)
Band 1	Coastal aerosol	0.43 – 0.45	30
Band 2	Blue	0.45 – 0.51	30
Band 3	Green	0.53 – 0.59	30
Band 4	Red	0.64 – 0.67	30
Band 5	Near Infrared (NIR)	0.85 – 0.88	30
Band 6	SWIR 1	1.57 – 1.65	30

Band 7	SWIR 2	2.11 – 2.29	30
Band 8	Panchromatic	0.50 – 0.68	15
Band 9	Cirrus	1.36 – 1.38	30
Band 10	Thermal Infrared 1 (TIRS) 1	10.60 – 11.19	100
Band 11	Thermal Infrared 2 (TIRS) 2	11.50 – 12.51	100

Due to its high accuracy and ease of use, the spectral index-based approach for burned area recognition has gained popularity. Spectral features are more intuitive and effective in distinguishing various land-cover objects. In order to identify burned regions, the most commonly used short wave infrared (SWIR) bands are 1.57–1.65 µm and 2.11–2.29 µm, while the near-infrared (NIR) band (0.85–0.88 µm) is also available on the most recent Landsat-8 OLI sensor.

2.3. Methods

The methodology of the study consists of four stages: obtaining satellite data for free, applying preprocessing to this data, implementing indices for the detection of burned areas, and comparing the obtained results with those produced by official institutions (Fig. 2).

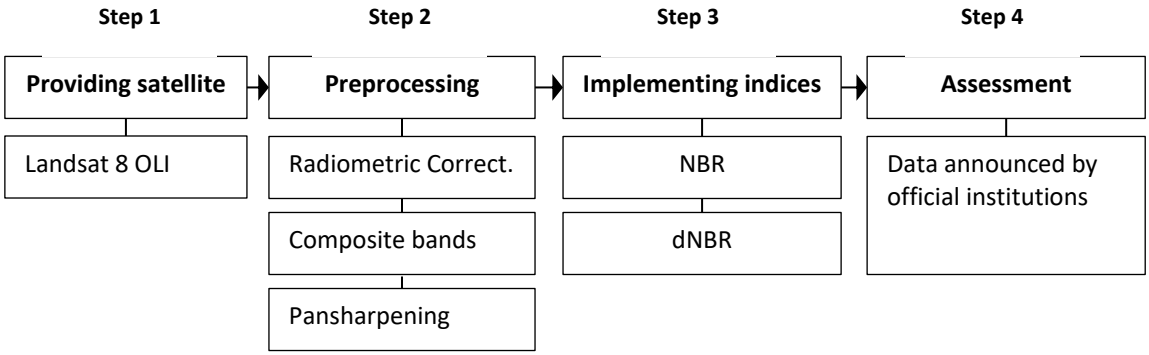


Figure 2. Method flow chart

Radiometric correction of the satellite images was conducted using QGIS, an open-access software. In ArcGIS Pro, the bands of the satellite images were merged, and pansharpening was performed using the 8th band with a resolution of 15 meters. Subsequently, algorithms for the NBR and d(NBR) indices were employed to identify the burned areas.

The NBR index used to determine burned areas is calculated with the equation (1) and takes values between -1 and +1. The formula below illustrates how NBR employs the ratio between NIR and SWIR bands to take advantage of the magnitude of spectral difference. Healthy vegetation is indicated by a high NBR value, whereas recently burned areas and bare land are indicated by a low value. Values near "0" are typically assigned to non-burned areas (Arisanty, Adyatma, Muhaimin & Nursaputra, 2019).

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

The difference in NBR indices applied to pre-fire and post-fire imagery is used to calculate dNBR. Additionally, dNBR is utilized to predict burn severity. A higher dNBR value indicates more severe damage, while areas with negative dNBR values may reflect post-fire regrowth (Miller & Thode, 2007; Keeley, 2009). The equation used to calculate dNBR is shown below in equation (2)

$$d(NBR) = (\text{Prefire } NBR - \text{Postfire } NBR) \quad (2)$$

dNBR values can differ from case to case, so in order to get the best results, interpretation in particular cases should also be done by field evaluation, if at all possible (Keeley, 2009). But as you can see in Table 2 below, the United States Geological Survey (USGS) suggested a classification table to assess

the burn severity. In this study, low severity, moderate-low severity and moderate-high severity were focused on for the detection of burned forest areas.

Table 2. Burn severity level calculated by dNBR and recommended by USGS (UN, 2024)

Severity Level	dNBR Range (scaled by 10^3)	dNBR Range (not scaled)
Enhanced Regrowth, high (post-fire)	-500 to -251	-0.500 to -0.251
Enhanced Regrowth, low (post-fire)	-250 to -101	-0.250 to -0.101
Unburned	-100 to +99	-0.100 to +0.99
Low Severity	+100 to +269	+0.100 to +0.269
Moderate-low Severity	+270 to +439	+0.270 to +0.439
Miderate-high Severity	+440 to +659	+0.440 to +0.659
High Severity	+660 to +1300	+0.660 to +1.300

In the final stage of the methodology, the burned areas identified using dNBR were compared in size with the damaged areas determined by the damage assessment studies conducted by the Forest Regional Directorate and the Ministry of Environment, Urbanization, and Climate Change in the post-fire region. The official data announced in this context is 59,985 ha (OGM, 2024c).

3. Findings and Discussion

This study focused on the identification and mapping of burned areas resulting from the forest fire that occurred on July 28, 2021, in the Manavgat district of Antalya Province. Landsat 8 satellite imagery was utilized, and NBR and dNBR indices were applied. Additionally, the study aimed to determine the extent and severity of the burned areas using the most commonly employed indices quickly and practically, and to compare the obtained results with official data. The results indicate that the area affected by the fire, as assessed through the NBR and dNBR indices, is approximately 61,502.76 hectares (Fig. 3).

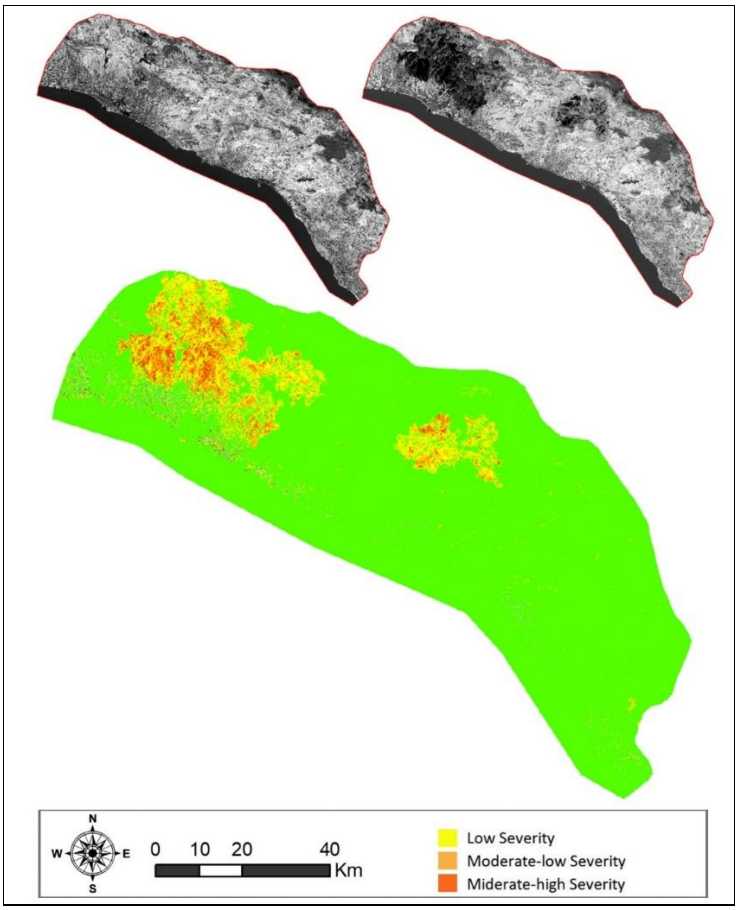


Figure 3. pre-fire NBR (top-left), after-fire NBR (top-right), and dNBR results (below)

According to the results obtained, the northwestern part of the study area experienced significant forest damage due to the fire, with a notably high level of severity in this region. It is believed that factors such as land slope, forest density, and wind speed influenced the extent and intensity of the fire. Conversely, the fire-affected area partially located in the northwest developed over a smaller area and exhibited lower severity. According to the Republic of Turkey General Directorate of Forestry, Antalya Regional Directorate of Forestry (OGM, 2024c), approximately 59,985 hectares were reported as damaged by the fire. In this study, the area affected by the fire is estimated to be 61,502.76 hectares, which overlaps with the official data by approximately 97.5%.

Numerous academic studies have been conducted regarding the 2021 Manavgat forest fire, employing various methods to identify the burned areas. Akıncı & Akıncı (2023) reported that, according to WWF data, approximately 60,154.13 hectares were affected by the fire. Although the method used by WWF to detect the burned areas was not specified in their study, the results align with those of our study by approximately 97.8%. Atalay, Dervisoglu & Sunar (2024) indicated that using the Fire Weather Index (FWI), an extensive burn area of about 60,000 hectares was identified in the same region. The results of this study also overlap with our findings by 99.9%. Soydan (2022) reported that the NDVI-NDVI change detection analysis indicated damage to 56,865 hectares in the same fire, demonstrating a 92.4% match between the NDVI-NDVI change detection analysis used in that study and the NBR-dNBR analysis employed in our work. Tuygun et al. (2023) stated that the European Forest Fire Information System (EFFIS) indicated that 52,856 hectares were burned in the Manavgat fire. Additionally, Bilgili et al. (2021) reported that 55,000 hectares were affected by the fire. The results of these two studies overlap with our findings by approximately 86% and 89%, respectively

The results of this study indicate that, following the 2021 Manavgat fire—one of the largest fires in Turkey that significantly damaged forest cover—the findings are consistent with the meticulously conducted assessments of burned areas by official institutions. The overlap rate is 97.5%, demonstrating that the NBR-dNBR indices perform well in this specific area.

Healthy vegetation exhibits high reflectance in the NIR band and low reflectance in the SWIR band, while the opposite is true for areas that have been damaged by fire. Recently burned areas show low reflectance in the NIR band and high reflectance in the SWIR band, meaning that the spectral responses between healthy vegetation and burned areas peak in the NIR and SWIR regions (UN, 2024). Due to these characteristics, the NBR index provides highly accurate data for detecting burned areas. The high degree of overlap between the results of this study and those of other studies employing different methods further demonstrates that the NBR index, derived from freely accessible Landsat 8 imagery, can produce data with high accuracy.

4. Conclusion and Suggestions

Remote sensing technologies encompass various research topics across different disciplines, particularly due to significant advancements in satellite technology in recent years. These remote sensing technologies provide substantial contributions to rehabilitation efforts following forest fires in terms of cost, time, and labor. This study demonstrates that both satellite imagery and field surveys allowed for the rapid and practical identification of burned areas, as detected by relevant official institutions, using NBR and dNBR indices during the 2021 Manavgat forest fire, without the need for land survey. The indices employed in this study, derived from Landsat 8 satellite data, produced effective results in identifying burned forest areas following a fire of this scale. Burn severity data and maps can assist in the development of emergency rehabilitation and restoration plans post-fire. These tools can be used not only to assess forest fire severity but also to estimate other burned land use/land cover (LULC).

The fire that occurred in Manavgat in 2021 was a large-scale incident. Consequently, the identification of burned areas was achieved using the NBR-dNBR indices derived from Landsat 8 imagery. However, it is recommended that higher-resolution satellite data be utilized for the precise detection of smaller-scale fires. This approach would enable more accurate assessments of LULC changes in burned areas and enhance the accuracy of fire severity detection in these regions.

Acknowledgments and Information Note

The article complies with national and international research and publication ethics. Ethics committee approval was not required for the study.

Author Contribution and Conflict of Interest Disclosure Information

All authors contributed equally to the article. There is no conflict of interest.

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