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# DETECTION OF WILDFIRES WITH SATELLITE IMAGES AND EVALUATION OF THEIR EFFECTS: THE EXAMPLE OF MARMARİS

*Ahmet Emrah SİYAVUŞ*[*]

***Abstract***

*With the increase in temperature throughout the world, wildfires have become common in certain regions, such as the Mediterranean basin. The study discussed wildfires after 2000 in Marmaris, located in the southwest of Turkey, and their effects. Thanks to the analyses made with the help of satellite images, wildfires were detected, and then the situation before the fire area and the damages that occurred after it was determined. The study aims to reveal the damage caused by fires and their interrelationships with the physical and human environment.* This study applied a document analysis research design, and a secondary data analysis method was followed. *Damage determinations were made with NBR, dNBR, NDVI, NDMI, NMDI, and LST analyses on Landsat satellite images. Immediately after the fires, vegetation disappeared, water stress increased, and the level of drought increased. In the following years, it was determined that the plant density increased again, and water stress and deficit decreased. In addition, the effects of the fire on residential areas, tourism activities, and agricultural areas were analyzed. It has been understood that the fires have seriously damaged residential areas and tourism activities, and farming areas have become uncultivated for a while. However, it has been understood that humans cause a significant part of the fires. In this context, it is thought that human activities should be carried out far from forest areas.*

***Keywords:*** *Marmaris, Wildfires, Landsat, Effects of fires.*

## Orman Yangınlarının Uydu Görüntüleri ile Tespiti ve Etkilerinin Değerlendirilmesi: Marmaris Örneği

***Öz***

*Dünya genelinde meydana gelen sıcaklık artışlarıyla birlikte Akdeniz havzası gibi belirli bölgelerde orman yangınları sık yaşanır olmuştur. Çalışmada Türkiye'nin güneybatısında yer alan Marmaris ilçesinde 2000 yılından sonra meydana gelen orman yangınları ve bunların etkileri ele alınmıştır. Uydu görüntüleri yardımıyla yapılan analizler sayesinde yaşanan orman yangınları ve bunların öncesi ile sonrasında ortaya çıkan hasarlar tespit edilmiştir. Çalışmanın amacı yangınlar sonrasında ortaya çıkan hasarı ile bunların fiziki ve beşerî ortam üzerindeki karşılıklı ilişkisini ortaya koymaktır. Doküman inceleme yöntemiyle toplanan veriler, ikincil veri analizi yöntemiyle analiz edilmiştir. Landsat uydu görüntüleri üzerinden NBR, dNBR, NDVI, NDMI, NMDI, LST analizleri ile hasar tespitleri yapılmıştır. Yapılan analizler sonucunda bitkilerin olası yangın durumunda yanma eğilimlerinin çok fazla olduğu anlaşılmıştır. Yangınların hemen sonrasında bitki örtüsü yok olmuş, su stresi artmış, kuraklık seviyesi yükselmiştir. İlerleyen yıllarda ise bitki yoğunluğunun tekrardan artış gösterdiği, su stresinin ve kuraklığın azalmakta olduğu tespit edilmiştir. Ayrıca yangının yerleşim alanları, turizm faaliyetleri ve tarım alanları üzerine olan etkileri analiz edilmiştir. Yaşanan yangınlarda yerleşim alanlarının ve turizm faaliyetlerinin ciddi zararlar gördüğü, tarım alanlarının bir süre ekilemez hale geldiği anlaşılmıştır. Bununla birlikte yangınların önemli bir kısmının insan kaynaklı olduğu anlaşılmıştır. Bu bağlamda beşerî faaliyetlerin orman alanlarından uzaklarda gerçekleştirilmesi gerektiği düşünülmekte, ormanların uydu görüntüleri ile takip edilip yanma eğiliminin olduğu alanlarda gerekli çalışmaların yapılması gerekmektedir.*

***Anahtar Kelimeler:*** *Marmaris, Orman yangınları, Landsat, Yangınların etkileri.*

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## 1. Introduction

Forests, life insurance for living things, consist of trees and shrubs that grow naturally or with labor and the areas where they are found (Forest Law, 1956). Forests organize life in and around the area where they are located and prevent many disasters. Especially after the industrial revolution, the forest area is decreasing with population growth, human activities, and various disasters. Agriculture and gaining grazing land, settlements in and around the forest, and fires are the main factors that destroy forests (Doğanay, 1988). While approximately 60% of the world was covered with forests 10 thousand years ago, this rate decreased to 35% for these reasons (Ritchie & Roser, 2018).

Wildfires in various parts of the world have played an essential role in forest loss in recent years. So much so that over 80 million forests have been lost due to fires in the last ten years (Global Forest Watch, 2023). Wildfires, one of the leading disasters, can occur spontaneously and due to human activities. In addition to natural events such as lightning strikes, friction of dry branches, and excessive increase in surface temperatures, there are human-induced wildfires due to broken glass, mistakes, terrorism, and economic concerns (Şahin & Sipahioğlu, 2002).

The geographical place where fires occur most frequently is the Mediterranean basin, where our country is located. Characteristic vegetation adapting to the fire in the region, long summer drought, temperatures above 30 °C, and winds with low humidity are effective in the fire outbreak and increase in severity (Food and Agriculture Organization of the United Nations, [FAO], 2007; Duran, 2014). For example, two-thirds of the forest cover within the borders of Thessaloniki was destroyed by burning in July 1997 (Siachalou et al., 2009). Again in Italy, between 1978-1988, 147 thousand hectares of forest were burned (Calabri, 1990). In Turkey, located in the Mediterranean Basin, forests are at risk of fire, as in the countries in the said basin. 41% of the fires in our country took place in the Aegean Region, 24% in the Mediterranean Region, and 22% in the Marmara Region. (Doğanay & Doğanay, 2004). 1,851,476 ha of forest area was damaged in 117,734 fires in Turkey from 1937 to 2021; 8 of the 20 big fires were in Muğla, 7 in Antalya, 2 in İçel (Mersin) and Çanakkale, and 1 in İzmir (Atmiş, et al., 2023).

After wildfires, the ecosystem is seriously damaged, and human activities are adversely affected. So much so that wildfires are a disaster that damages the natural environment and infrastructure and affects wildlife and human health (Sullivan et al., 2022). Surface temperatures increase, air movements change, relative humidity and soil moisture decrease, living things living in forest ecosystems are directly damaged, and water and air quality deteriorate. In addition, the ecological functioning of many ecosystems is adversely affected by processes such as soil erosion, flooding, and the recovery of vegetation change as a result of fires (Verma & Jayakumar, 2012).

Wildfires not only affect natural systems but also negatively affect human activities. The settlement areas where people carry out their sheltering activities are damaged, especially the settlements in the forest and on the edge of the woods in rural areas can be affected by wildfires. Wildfires in the USA, Australia, Canada, and Mediterranean countries mainly affect the settlements in these areas, and people are evacuated from the region (Ertuğrul, 2010). For example, the devastating Maui wildfires in the US state of Hawaii damaged 3,088 homes and caused a loss of 1.3 billion dollars (CNN, 2023). Tourism areas on the edge of the forest can also be affected by fires, and loss of life and property may occur, so much so that 32 tourists lost their lives in the fires in Sardinia, Italy, in 1989, which damaged tourism (Calabri, 1990). In the last years, sites, holiday villages, and hotels established on the edge of the forest away from the city center in Turkey may encounter similar problems (Ertuğrul, 2010). This situation negatively affects tourism activities in these areas. Especially tourists coming to the Mediterranean and Aegean prefer the bays and coasts where the sea meets the forest, and they can witness the fires in the region. In addition, damage to buildings, roads, atmosphere, and other resources

can create a negative perception of tourists. However, agricultural activities, another human activity, can be damaged by the burning of farmlands and the deterioration of the forest ecosystem.

In the last years, remote sensing and Geographical Information Systems (GIS) have been used to monitor wildfires, which leave deep traces on natural and human life on a temporal and spatial scale. Satellite images can monitor fires, allowing intervention during and after (Bahadır, 2010). In addition, it provides effective management of studies such as determining the damage caused by fires in terms of area and forest type and the afforestation of the region with appropriate species (Yavaşlı et al., 2013). In this regard, of the last years, various studies have been carried out on detecting and evaluating wildfire areas with satellite images. Ertuğrul (2010), Yavaşlı et al, (2013), Duran (2014), Butsic et al., (2015), Barbati et al, (2015), Adıgüzel et al., (2016), Braun (2017), Last and Topuz (2021), Ascoli et al., (2021), Parente et al, (2023) are the main academic studies in this field.

Various methods are applied for the detection and recovery of wildfires in Turkey and the destruction caused by them. In this context, this study discusses the detection and effects of wildfires, which have come to the fore with wildfires of the last years and occurred in Marmaris, located in the southwest of the Aegean Region, with satellite images. 11 fires occurred in the study area only in 2021, and more than 9 thousand hectares were affected (Worker, 2022). It is aimed to contribute to academic studies and field studies on this subject by revealing the size of the fires in Marmaris and the situation before and after the fire areas. In this context, the fires that occurred in the last 23 years in Marmaris were determined from satellite images, and the surface temperature, vegetation density, drought, and humidity conditions were examined before and after the fire in the areas where the most significant fires occurred. In addition, the distribution of fires according to years and their effects on human activities such as settlement, tourism, and agriculture in the region is emphasized. In this context, while discussing fire areas, their causes, and their effects on the human and physical environment, the study distinguishes it from others.

## 2. Method

### 2.1. Model of The Study

In this research, the document analysis method examined the existing records and documents in which documentary scans were made (Sak et al., 2021). The study examined and evaluated materials with internet access (Bowen, 2009). A framework has been created on the research subject, and documents suitable for the study have been obtained in this direction (Fitzgerald, 2012; Forster, 1994).

### 2.2. Research Area

In this study, forest fires that have become more frequent in recent years and the effects of these fires are analyzed through the Marmaris sample. Located in the southwest of the Aegean Region, there are Köyceğiz districts in the east of Marmaris and Ula in the northeast. The Aegean Sea is north of the district, and the Mediterranean Sea is south, located on the border between the two seas (Figure 1).

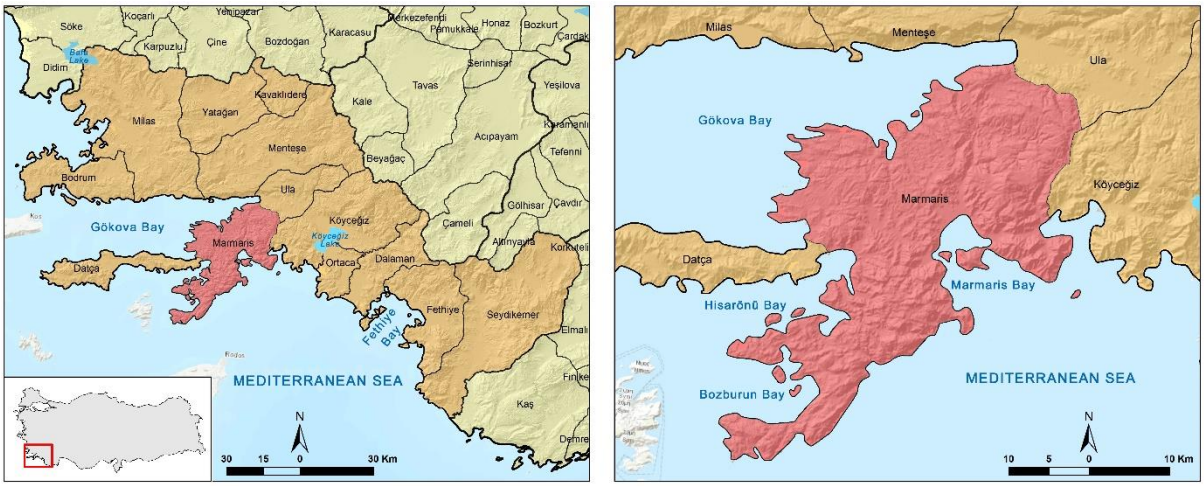


***Figure 1.*** *Location of the study area*

Surrounded by sea on three sides, an isthmus connects the district to the Datça peninsula. There is a rugged topography throughout the district, and rivers split valleys. There are masses such as Balaban Mountain (999 m), Eren Mountain (843 m), Kırzeytin Mountain (705 m), and Bonito Mountain (880 m) behind the indented coast formed as a result of tectonic activities. In addition, the narrow coastal plains in the district were used for settlement purposes, and the city of Marmaris was located in the widest one. In addition, the bays located at some points where the valleys reach the sea have been evaluated for settlement and tourism activities. One of them is İçmeler, located in the southwest of Marmaris.

The bays and gulfs on the shores of the Marmaris district and suitable climatic conditions have enabled the development of sea tourism. In the district, where the characteristic Mediterranean climate prevails, the temperature above 30 °C in summer months and the fact that a significant part of the annual precipitation of 1200 mm falls in the winter months has allowed the formation of a suitable environment for coastal tourism.

The vegetation belonging to the flora of the Mediterranean Region located behind the coast includes red pines, as well as species such as larch, stone pine, melengic, sandalwood, arbutus, kermes oak, maple, laurel, carob, and sweetgum tree. The total forest area is 116 thousand hectares under the Marmaris Forestry Management Directorate. Wildfires, especially in the summer, damage forest property.

### 2.3. Data Collection

The data sources of the research are Landsat satellite images obtained from the United States Geological Survey (USGS) website. Landsat 5 in 2002 and 2003; Landsat 8 data was used in 2021 and 2022. In addition, printed and electronic resources such as the Ministry of Agriculture and Forestry fire reports, General Directorate of Forestry, Muğla Forestry Regional Directorate, and Marmaris Status Report Update were used. In addition to these, Google Earth Pro's open-access application was used.

### 2.4. Analysis of Data

In the study area analysis, the data available on the USGS website were evaluated with the secondary data analysis technique (Punch, 2005). By obtaining information about the impact of forest fires on land and human activities, a descriptive table was presented, and the data were visualized (Leech and Onwuegbuzie, 2007; Yıldırım and Şimşek, 2003; Miles and Huberman, 1984). To obtain information about wildfires in the study, Landsat 5 in 2002 and 2003; Landsat 8 data was used in 2021 and 2022. The Landsat images' cloudiness rates were considered to get more precise information about

the study area. Then, normalized difference vegetation index (NDVI), normalized differential moisture index (NDMI), normalized multi-band drought index (NMDI), normalized burn rate (NBR), delta normalized burn rate (dNBR) and land surface temperature (LST) analyses were determined using map algebra in ArcMap 10.5 program, over Landsat 5 and 8 images. Pre-fire, post-fire, and 2023 images chose the fire areas and the current change. The formula used to determine the burning rate (NBR) in the plant is given in Equation 1.

The formulas used to determine the combustion cells (NBR) in the plant are given in Equation 1.

Equation 1

$$\mathbf{NBR} = \frac{(\mathbf{NIR}^{Landsat8:BAND5}_{Landsat5:BAND4} - \mathbf{SWIR2}^{BAND7})}{(\mathbf{NIR}^{Landsat8:BAND5}_{Landsat5:BAND4} + \mathbf{SWIR2}^{BAND7})}$$

The difference between the NBR values before and after the fire, the delta normalized combustion rate (dNBR), was formulated in Equation 2.

Equation 2

$$\mathbf{dNBR} = \left(\mathbf{NBR}^{pre-fire} - \mathbf{NBR}^{post-fire}\right)$$

The formula in Equation 3 was used to calculate the normalized difference in vegetation index and the density of healthy vegetation.

Equation 3

$$\mathbf{NDVI} = \frac{(\mathbf{NIR}^{Landsat8=BAND5}_{Landsat5=BAND4} - \mathbf{RED}^{Landsat8=BAND4}_{Landsat5=BAND3})}{(\mathbf{NIR}^{Landsat8=BAND5}_{Landsat5=BAND4} + \mathbf{RED}^{Landsat8=BAND4}_{Landsat5=BAND3})}$$

The formula used to measure the normalized difference moisture index moisture level in vegetation is as in Equation 4.

Equation 4

$$\mathbf{NDMI} = \frac{(\mathbf{NIR}^{Landsat8=BAND5}_{Landsat5=BAND4} - \mathbf{SWIR1}^{Landsat8=BAND6}_{Landsat5=BAND5})}{(\mathbf{NIR}^{Landsat8=BAND5}_{Landsat5=BAND4} + \mathbf{SWIR1}^{Landsat8=BAND6}_{Landsat5=BAND5})}$$

The Normalized Multiband Drought Index (NMDI) was used to measure the degree of drought of the soil (Equation 5).

Equation 5

$$\mathbf{NMDI_{vejetasyon}} = \frac{\mathbf{NIR}^{Landsat8=BAND5}_{Landsat5=BAND4} - (\mathbf{SWIR1}^{Landsat8=BAND6}_{Landsat5=BAND5} - \mathbf{SWIR2}^{BAND7})}{\mathbf{NIR}^{Landsat8=BAND5}_{Landsat5=BAND4} + (\mathbf{SWIR1}^{Landsat8=BAND6}_{Landsat5=BAND5} - \mathbf{SWIR2}^{BAND7})}$$

In the last stage of the algorithm, Land Surface Temperature (LST) values were determined (Equation 6).

Equation 6

$$\mathbf{LST} = \frac{\mathrm{BT}}{\left(1 + \left(\frac{\mathrm{w.BT}}{\rho}\right) * \ln(\varepsilon)\right)}$$

In addition, the temporal and spatial distribution of the fires that occurred in the last 23 years was made using satellite images. In addition, the effects of wildfires on residential areas, tourism activities, and agricultural areas were determined.

### 2.5. Research Ethics

This work is original; I have acted by scientific, ethical principles and rules from all stages of the study, including preparation, data collection, analysis, and presentation of information; I have cited all data and information not obtained within the scope of this study and that I have included these sources in the bibliography; I declare that I have not made any changes in the data used and that I abide by the ethical duties and responsibilities by accepting all the terms and conditions of the Committee on Publication Ethics (COPE).

## 3. Findings

### 3.1 Spatial and Temporal Distribution of Fires in Marmaris Between 2000-2023

Wildfires in and around Marmaris have been increasing in recent years. In Figure 2, the fires in the last 23 years in the Marmaris district and the affected areas are shown in color according to 5-year periods. Fire areas over 1 ha are included on the map. In addition, in Marmaris, neighborhoods outside the city and areas with old village settlements connected to the settings are marked. When the distribution of fires according to years is examined, 2,127.2 ha area was burned between 2000 and 2005, and a fire occurred in a wide area of 446.5 ha in 2003 near Orhaniye District. Between 2006 and 2010, less forest was burned, with 194.1 hectares compared to other years. In 2007, it was determined that an area of 108.9 ha was burned in the Bördübet locality, where tourism facilities are located. In 2011-2015, there were almost no wildfires throughout the district, and 17.7 ha of the area was burned. During the five years between 2016-2020, wildfires occurred on 163.2 hectares of land at different points. In the three years from 2021 to the present, the severity and intensity of wildfires increased and spread over a wide area. In the said period, a total of 15,757,5 ha area was burned, 11,003.9 ha of them were burned in 2021, 4,749,6 ha in 2022, and 3.9 ha in 2023. Considering the district's general situation, 18,259.6 ha of the area has been burned since 2000.

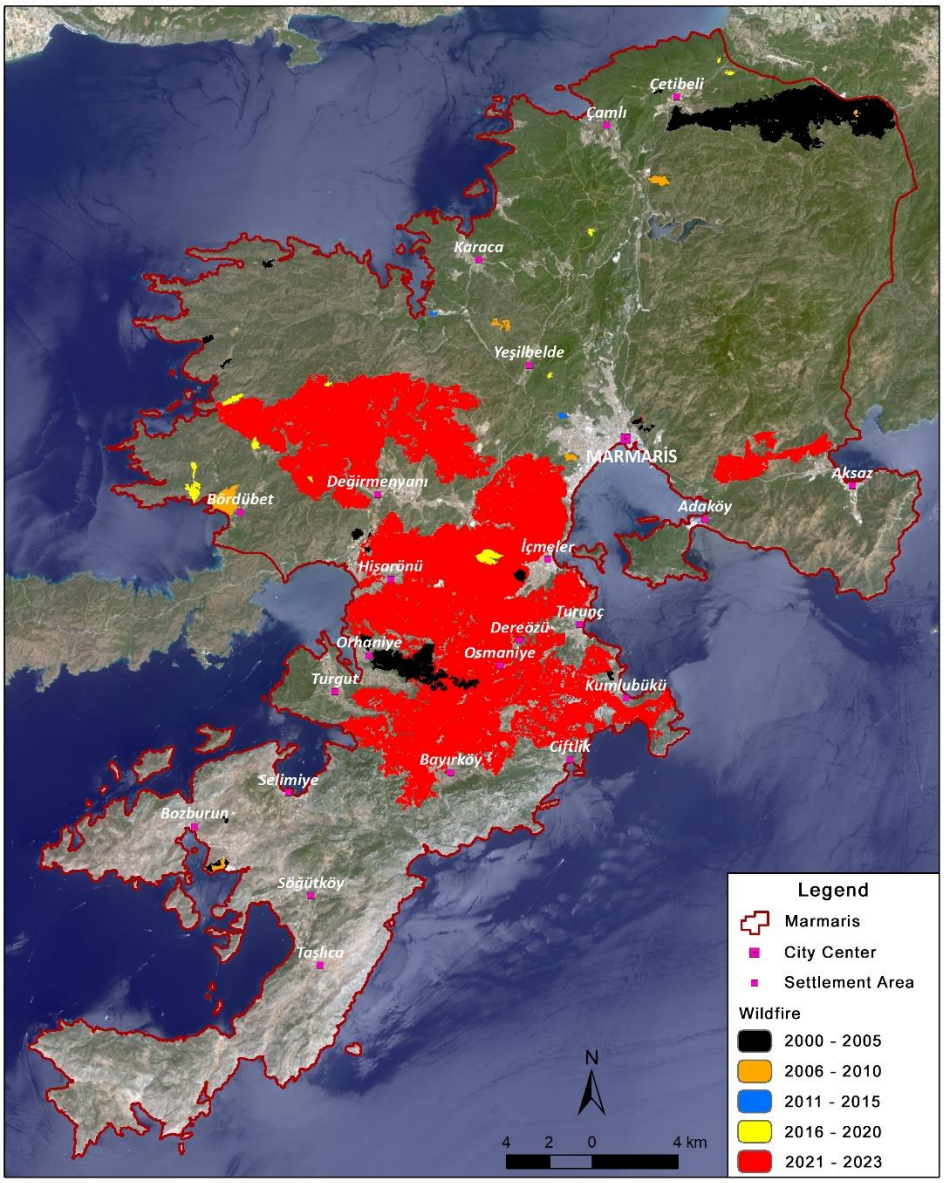


**Figure 2**. *Distribution of wildfires between 2000-2023 in Marmaris district according to 5-year time intervals*

It is seen that the fires that occurred in Marmaris between the years 2000-2023 are more common in forest areas near residential areas and tourist facilities. The increase in population, construction and tourism facilities, intention, unconsciousness, and severe temperatures of the last years have triggered wildfires.

According to the study conducted by the Ministry of Agriculture and Forestry, General Directorate of Forestry, Muğla Regional Directorate of Forestry (2022), 16% of the fires occurred in recent years, Neglect and Carelessness, 9% malicious, 33% Lightening, 42% part has been released for unknown reasons. In this respect, approximately 70% of wildfires in the region may be caused by human activities.

It is understood that the fires in Marmaris between 2000-2023 were primarily seen in forest areas close to settlements and tourist facilities.The increase in population, construction and tourism facilities, intention, unconsciousness, and severe temperatures of the last years have triggered wildfires.

As a matter of fact, according to the study conducted by the Ministry of Agriculture and Forestry, General Directorate of Forestry, Muğla Regional Directorate of Forestry (2022), 16% of the fires occurred in recent years, Neglect and Carelessness, 9% malicious, 33% Lightening, 42% part has been released for unknown reasons. In this respect, approximately 70% of wildfires in the region may be caused by human activities.

### 3.2 Monitoring of Fires Between 2000-2023 with Satellite Data

Satellite images taken just before and immediately after the fire are crucial to determining the burned areas and their severity. In the study, with the help of Landsat satellite data between the years 2000-2023, NBR and dNBR analyses were performed to reveal the amount of burned area and fire severity, NDVI for vegetation detection, NDMI for moisture detection, NMDI for drought situation, and LST analyzes to detect surface temperature change. In addition, pre-fire, post-fire, and current satellite images were used to analyze the damage caused by the fire and the situation in the following years.

The fires in Marmaris between 2000-2023 were examined, and the five most extensive fires were analyzed (Table 1, Figure 3). An area of 1507.8 ha was damaged in the 17 August 2002 wildfire, which is one of the three biggest fires in this process. NBR and dNBR analyses revealed the amount of burned area and fire severity. Burned areas are primarily in the medium/low and medium/high burning intensity categories. These areas are areas with dense green vegetation. In addition, NDVI, NDMI, NMDI, and LST analyses were carried out to determine the damage immediately after the fire and the change in the land in the process until today. The values obtained as a result of the NDVI analysis are in the range of -1.0 to 1.0, and the height of these values represents healthy and dense vegetation. According to this, the average plant density on the land before the fire in 2002 was 0.34. This indicates that moderately healthy vegetation was concentrated on the ground before the fire occurred. When the post-fire NDVI values are examined, it decreases to an average of 0.1, which indicates that the vegetation cover is almost destroyed throughout the land. When the NDVI values of the burned area are examined in 2023, it is seen that the average has increased to 0.25. This result indicates that the burned areas have started to green again, but the healthy plant density has not yet reached the thickness before the fire.

***Table 1.*** *NDVI, NDMI, NMDI and LST analysis statistics of fires in Marmaris in 2002 and 2003.*

| **Time** | **Values** | **2002 Wildfire** | | | | **2003 Wildfire** | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **Indexes** | | | | **Indexes** | | | |
| | | *NDVI* | *NDMI* | *NMDI* | *LST* | *NDVI* | *NDMI* | *NMDI* | *LST* |
| **Pre-fire** | *Min* | 0 | -0.33 | 0.03 | 30.4 | 0.1 | -0.33 | 0.11 | 26.7 |
| | *Maks* | 0.6 | 0.32 | 0.6 | 39.9 | 0.62 | 0.36 | 0.63 | 37.2 |
| | *Avg* | 0.34 | -0.01 | 0.25 | 33.9 | 0.42 | 0.1 | 0.34 | 30.3 |
| **Post-fire** | *Min* | 0 | -0.41 | 0.46 | 31.7 | 0 | -0.47 | 0.53 | 19.7 |
| | *Maks* | 0.56 | 0.24 | 0.79 | 47 | 0.5 | 0.2 | 0.77 | 38.8 |
| | *Avg* | 0.1 | -0.28 | 0.71 | 41.4 | 0.13 | -0.18 | 0.71 | 25.7 |
| **2023 Year** | *Min* | 0.05 | -0.09 | 0.57 | 34.6 | 0.1 | -0.09 | 0.59 | 32.4 |
| | *Maks* | 0.41 | 0.29 | 0.77 | 43.6 | 0.39 | 0.31 | 0.78 | 43.4 |
| | *Avg* | 0.25 | 0.09 | 0.67 | 39.3 | 0.22 | 0.06 | 0.68 | 36.7 |

As NDMI increases, water stress decreases, and very high values represent flooding. The average NDMI value before the fire in 2002 was -0.01, indicating that the vegetation is under high water stress. NMDI values indicate the degree of drought. While the area above was in the wet category with an average drought value of 0.25 before the fire, it increased to 0.71 after the fire and entered the dry

type. By 2023, the land has been classified as medium humidity with an average of 0.67, and forest recovery has been realized (Figure 3).

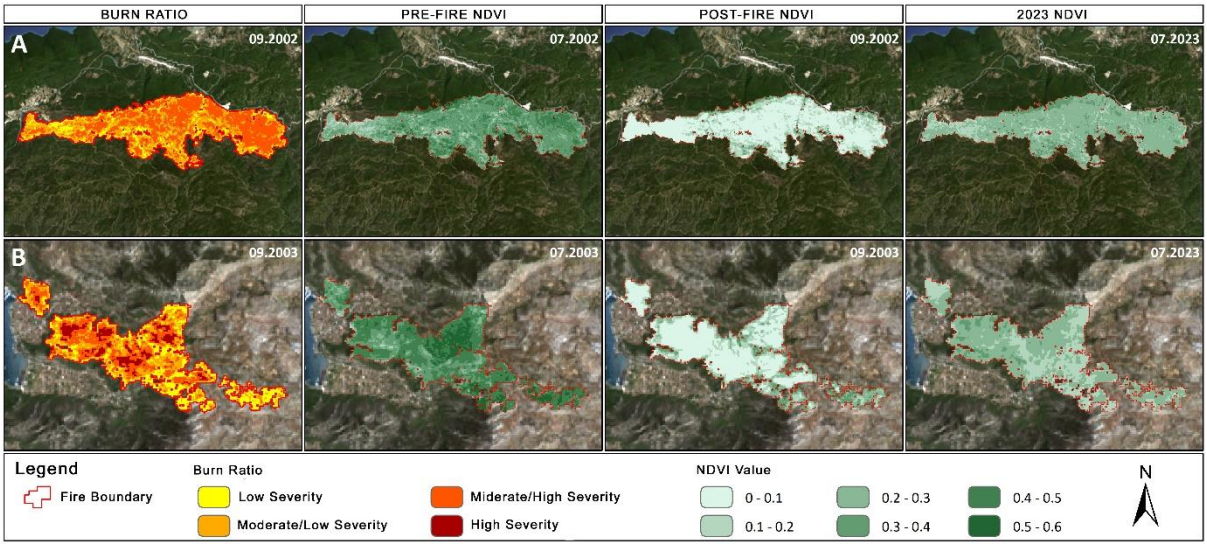


**Figure 3.** *Burning Intensity (dNBR) analysis of the fires in Marmaris in 2002 and 2003 on Landsat satellite images and the change of NDVI values over time.*

The most significant fires in Marmaris after 2000, which started in Armutalan on July 29, 2021, spread over 11,003.9 hectares. The NDVI average before the fire was 0.33, which indicates that the moderately healthy vegetation decreases to 0.1 after the fire and disappears, and after two years, it increases to 0.18 depending on the development of the vegetation, albeit a little. The NDMI average is 0.19 before the fire, -0.02 after the fire, and 0.01 after two years. This indicates that the high water stress before the fire increased with the fire and started to change positively in the two years. NMDI average values were 0.71 dry before the fire, and 0.79 after the fire, which was very dry, and after two years, it decreased to 0.66 and rose to medium humidity (Table 2, Figure 4).

**Table 2.** *NDVI, NDMI, NMDI, LST analysis statistics of fires in Marmaris in 2021 and 2022.*

| **Time** | **Value** | **2021 Wildfire** | | | | **2022 1. Wildfire** | | | | **2022 2. Wildfire** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Indexes** | | | | **Indexes** | | | | **Indexes** | | | |
| | | *NDVI* | *NDMI* | *NMDI* | *LST* | *NDVI* | *NDMI* | *NMDI* | *LST* | *NDVI* | *NDMI* | *NMDI* | *LST* |
| **Pre-fire** | *Min* | 0.01 | -0.11 | 0.49 | 17.6 | 0.11 | -0.08 | 0.49 | 26.1 | 0.08 | -0.08 | 0.53 | 28.6 |
| | *Mak* | 0.55 | 0.4 | 1.29 | 32.6 | 0.45 | 0.31 | 0.79 | 39.5 | 0.41 | 0.29 | 0.75 | 35.9 |
| | *Avg* | 0.33 | 0.19 | 0.71 | 23 | 0.26 | 0.1 | 0.65 | 32.4 | 0.25 | 0.08 | 0.64 | 32.2 |
| **Post-fire** | *Min* | 0 | -0.19 | 0.49 | 22.4 | 0.01 | -0.17 | 0.53 | 28.9 | 0 | -0.18 | 0.58 | 24.3 |
| | *Mak* | 0.38 | 0.23 | 1.27 | 42.2 | 0.36 | 0.25 | 1.23 | 46.8 | 0.33 | 0.24 | 1.24 | 44.6 |
| | *Avg* | 0.1 | -0.02 | 0.79 | 30.2 | 0.07 | -0.07 | 0.87 | 39.5 | 0.07 | -0.07 | 0.93 | 35.5 |
| **2023 Year** | *Min* | 0 | -0.15 | 0.49 | 31.3 | 0.03 | -0.15 | 0.53 | 34.2 | 0.06 | -0.13 | 0.58 | 36 |
| | *Mak* | 0.4 | 0.25 | 1.05 | 48.7 | 0.32 | 0.2 | 0.91 | 51.7 | 0.33 | 0.22 | 0.86 | 49.7 |
| | *Avg* | 0.18 | 0.01 | 0.66 | 39.7 | 0.13 | -0.05 | 0.69 | 45.4 | 0.03 | -0.06 | 0.71 | 3.3 |

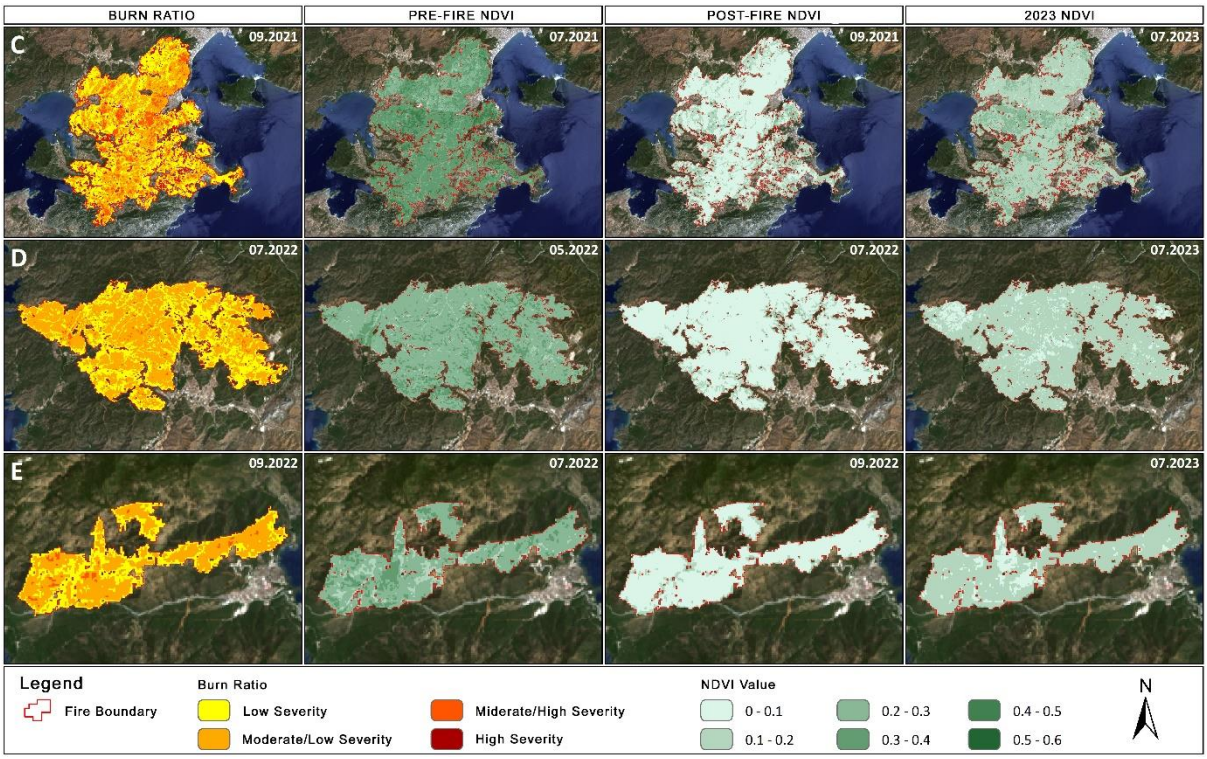


**Figure 4.** *Burning Intensity (dNBR) analysis of the fires in Marmaris in 2021 and 2022 on Landsat satellite images and the change of NDVI values over time.*

### 3.3 The Effects of Wildfires in Marmaris District on Human Activities

While fires threaten human-dominated lands, fire risk itself has become a driver of land change, affecting lands through land use regulations and fire management (Butsic et al., 2015). In this respect, there is a reciprocal relationship between wildfires and human activities such as settlement, agriculture, and tourism. The desire of people to move away from urban areas and settle in areas intertwined with nature causes the suppression of forests and possible wildfires to damage residential areas (Ertuğrul, 2010).

Residential areas are affected by fires in the work area, and many people are evacuated to other areas. The wildfire that started in the Armutalan of Marmaris district on July 28, 2021, spread to the villages of İçmeler, Turunç, Osmaniye, Bayır, Turgut, Çiftlik, Orhaniye, and Hisarönü and reached the city of Marmaris (Batu, 2021) (Figure 5, Photo 1). Approximately 75% of the residential areas in the said region have been evacuated (Coşandal & Partigöç, 2022).

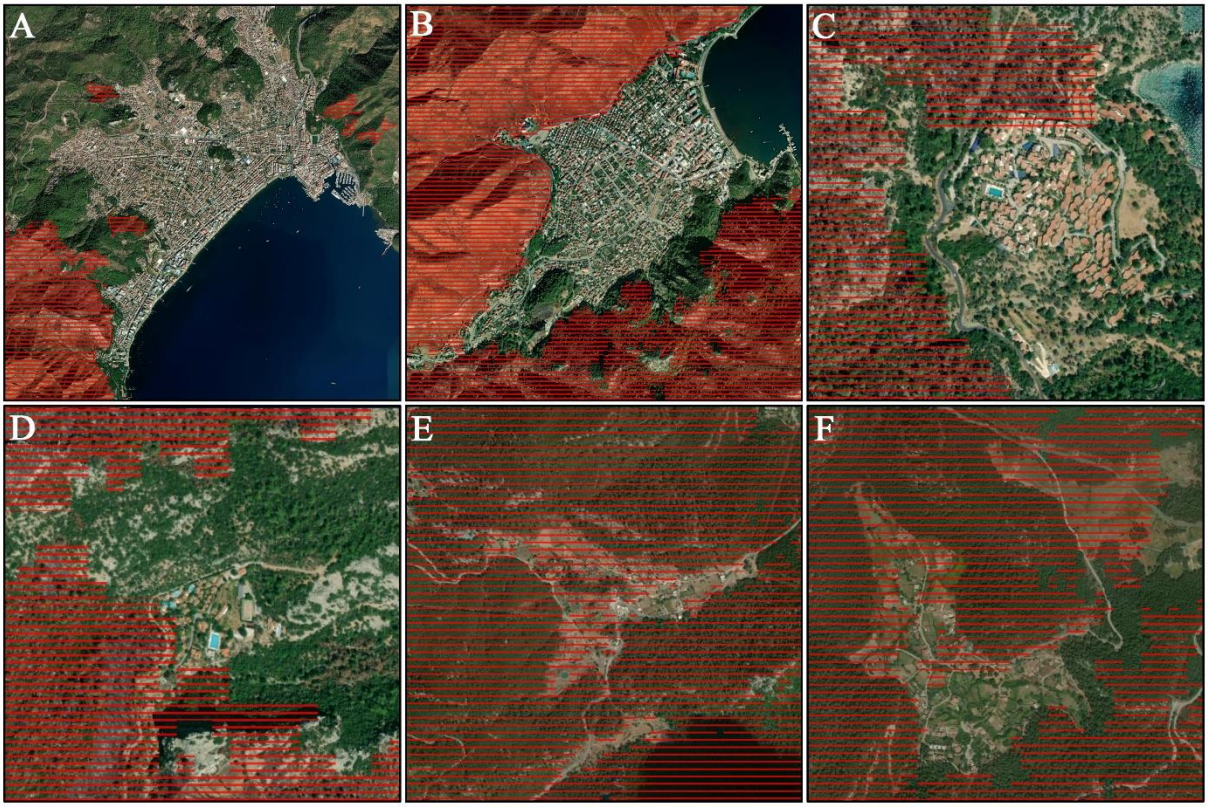


**Figure 5.** *A- Marmaris city, B- İçmeler, C- Kumlubükü touristic facilities, D- Kumlubükü sites and holiday villages, E- Osmaniye rural settlement and burned agricultural areas F- Dereözü rural settlement and burned agricultural areas.*

***Photo 1.*** *The fire that occurred in Marmaris on July 28, 2021 (DW, 2021)*

Another human activity affected by wildfires is agriculture. While people have opened up agricultural areas by burning forests for centuries, fires threaten rural areas today. The narrow agricultural lands in the Marmaris district were affected by the fires in 2000, 2003, 2005, and 2021 (Figure 5). Socio-economic activities based on collecting forest products such as thyme, sage, laurel, and pine mushrooms have been damaged in mountain villages (Oktik, 2001). Apart from these, the areas where olive, peanut, almond, and citrus are cultivated were adversely affected by the fire. However, beekeeping activities in the region have also suffered greatly.

Forests attract visitors, adding attractiveness to the region and supporting local economies and communities, providing income for their long-term persistence (Boustras & Boukas, 2021). The burning of forests affects the tourists in the region psychologically and physically and harms tourism activities. So much so that the balance sheet that emerged in the fire in Marmaris in 2021 adversely affected tourism activities (Figure 5). As a result of the fire in 2021, the facilities closed the tourism season with a loss of approximately 70%, the tourism season, which lasted for 5-6 months, decreased to 2 months, 80% of the facilities had to downsize, and some of their staff had to be dismissed (Coşandal & Partigöç, 2022).

## 4. Conclusions, Discussion and Recommendations

Marmaris district, located in the southwest of the Aegean Region, has a forest area of 116 thousand hectares. Located in the Mediterranean basin, where fires are the highest in the world, vegetation is more sensitive to fire, such as red pine and maquis species belonging to the Mediterranean Region flora, in the immediate vicinity of the district. In recent years, the fires in the Marmaris district and its surroundings have increased the number of studies on the region. In this context, the fires in the last 23 years in the Marmaris district and their temporal-spatial distribution were examined. In addition, damage assessments were made by making NBR, dNBR, NDVI, NDMI, NMDI, and LST analyzes on Landsat satellite images of the before and after conditions of the areas where the fire occurred. In addition, the effect of wildfires on human activities such as settlement, tourism, and agriculture has been examined.

After 2000, fire areas over 1 ha were determined in the Marmaris district, and their distribution by year was examined. During the period, more than 18 thousand hectares of forests were burned, of which 11 thousand took place in 2021. The increasing population of the last years, suppression of forest areas by settlements and tourism facilities, growing temperatures, unconscious use, and malicious and economic reasons have increased fires. A significant part of the fires took place in the areas where there are residential areas and tourist facilities located in the southwest of Marmaris City, such as Değirmenyanı, Hisarönü, Orhaniye, Bayırköy, Çiftlik, Kumlubükü, Osmaniye, Dereözü, Turunç, İçmeler, Bördübet. This situation shows that the causes of fires are human sources rather than natural events. In addition, residential areas, tourist facilities, and agricultural areas were adversely affected in the areas close to the fire areas. In the fire on 28.07.2021, 70% of the settlements were evacuated, significant agricultural land was damaged, and severe economic losses were experienced in the tourism sector.

Five significant fires after 2000 were analyzed with NBR, dNBR, NDVI, NDMI, NMDI, and LST methods to determine the situation before and after the fires in the study area. According to the analyses made just before the fire, vegetation density is moderately healthy, water stress is high, and drought level is high. When these features are evaluated together, it is seen that the plants have an increased tendency to burn in case of a possible fire, and when we examine the burning intensity analysis, these areas burn at medium/low and medium/high intensity. Immediately after the fires, vegetation disappeared, water stress increased, and the level of drought increased. In today's satellite data of the said areas, it is seen that the plant density has risen again, the water stress has decreased compared to the situation after the fire, and it has been included in the medium humidity category by getting closer to the state before the fire in the drought category. However, these improvements progress slowly in fires in 2021 and beyond.

Approximately 70% of the fires in Marmaris district and its surroundings are likely human-induced. Especially in the forest and on the edges of the settlement and tourism facilities, camping areas cause an increase in fires. In this regard, buffer zones should be established between the regions and

forests. To prevent economic and deliberate fires, the gaps in the laws should be eliminated, and Forest Law No. 6831 should be revised. Areas at risk of fire should be identified with satellite images, necessary measures should be taken in the relevant areas, and the number of fire towers and roamers should be increased. Volunteer firefighting should be developed, mainly by training those living in areas close to forests, and coordination with firefighting teams should be improved. Aircraft, vital in extinguishing fires in fire-sensitive forest areas and their immediate surroundings, should be increased. However, touristic activities in and near the forest should be limited to reduce the fires in the summer period. In addition, forests should be followed with satellite images. Physical conditions such as temperature, drought, and humidity should be determined, and necessary studies should be carried out for areas with a tendency to burn.

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