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DETERMINING BURNED AREAS USING DIFFERENT THRESHOLD VALUES OF NDVI WITH SENTINEL-2 SATELLITE IMAGES ON GEE PLATFORM: A CASE STUDY OF MUĞLA PROVINCE

Sinan DEMİR*[1], İbrahim DURSUN[2]

[1]Isparta Uygulamalı Bilimler Üniversitesi, Ziraat Fakültesi, Toprak Bilimi ve Bitki Besleme Bölümü, Isparta
[2]Isparta Uygulamalı Bilimler Üniversitesi, Orman Fakültesi, Orman Mühendisliği Bölümü, Isparta

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ABSTRACT

Remote sensing technologies play a critical role in detecting land cover change and burned areas. Therefore, it is aimed to utilize satellite imagery and the Google Earth Engine (GEE) platform for the identification of burned areas and assessment of land cover changes (LULC). This study used the code block in the GEE platform to detect burned areas using high-resolution Sentinel-2 satellite imagery. The study focused on the province of Muğla, and the Normalized Difference Vegetation Index (NDVI) was calculated from Sentinel-2A satellite images for September 2020 and September 2021. Different threshold values (0.2, 0.3, 0.4, 0.5, 0.6) were applied to the different layers created from the dNDVI (Differenced Normalized Difference Vegetation Index) layers, and it was masked in the Global Water Surface dataset, to determine land cover changes and burned areas. The study results were compared with the Moderate Resolution Imaging Spectroradiometer (MODIS) burned area data. As a result, a threshold value of 0.3 was determined for the high-resolution satellite imagery, which can be used to identify land cover changes and burned areas without the interference of mixed pixels. The determined threshold value covered 82.77% (46966.44 hectares) of the area identified by the MODIS satellite. The used code block, utilizing Sentinel-2 satellite imagery within the GEE platform, not only successfully detected changes in burned areas but also holds promise as an effective tool for monitoring and tracking such changes.

Keywords; GIS, forest fire, remote sensing, spatial analysis

GEE PLATFORMUNDA SENTİNEL-2 UYDU GÖRÜNTÜLERİ İLE NDVI FARKLI EŞİK DEĞERLERİ KULLANILARAK YANMIŞ ALANLARIN BELİRLENMESİ: MUĞLA İLİ ÖRNEĞİ

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ÖZET

Uzaktan algılama teknolojileri, arazi örtüsü değişimi ve yanan alanların belirlenmesinde kritik bir rol oynamaktadır. Bu nedenle yanan alanların tespiti ve arazi örtüsü değişikliklerinin değerlendirilmesi (LULC) amacıyla uydu görüntülerinden ve Google Earth Engine (GEE) platformundan faydalanılması amaçlanmaktadır. Bu çalışmada, yüksek çözünürlüklü Sentinel-2 uydu görüntüleri kullanılarak yanmış alanların tespiti için GEE platformundaki kod bloğu kullanılmıştır. Çalışmada Muğla ili odaklı olup Eylül 2020 ve Eylül 2021 tarihlerine ait Sentinel-2A uydu görüntülerinden Normalleştirilmiş Fark Bitki Örtüsü İndeksi (NDVI) hesaplanmıştır. Farklı Normalleştirilmiş Fark Bitki Örtüsü İndeksi (dNDVI) katmanlarından oluşturulan farklı katmanlar, arazi örtüsü değişikliklerini ve yanmış alanları belirlemek için küresel su yüzeyi veri setinde maskelendi. Çalışma sonuçları, Orta Çözünürlüklü Görüntüleme Spektroradiometresi (MODIS) yanmış alan verileriyle karşılaştırıldı. Sonuç olarak, karışık piksellerin müdahalesi olmadan arazi örtüsü değişikliklerinin ve yanan alanların tespitinde kullanılabilecek yüksek çözünürlüklü uydu görüntüleri için 0.3 eşik değeri belirlendi. Belirlenen eşik değer, MODIS uydusu tarafından belirlenen alanın %82.77'sini (46966.44 hektar) kapsamaktadır. GEE platformunda Sentinel-2 uydu görüntülerinden yararlanılarak kullanılan kod bloğu, yalnızca yanan alanlardaki değişiklikleri başarıyla tespit etmekle kalmıyor, aynı zamanda bu değişikliklerin izlenmesi ve takibi için etkili bir araç olarak da umut vaat etmektedir.

Anahtar Kelimeler; CBS, orman yangını, uzaktan algılama, mekansal analiz

1. Introduction

The importance of wildfires to the natural processes that affect the Earth's ecosystems is undeniable (Bowman et al., 2009). One of the main reasons for changes in land use and land cover is the occurrence of fire-prone areas. Land use, as a global change factor, influences several terrestrial processes, including fires (Foley et al., 2005). Since ancient times, Mediterranean forests have been significantly affected by the strong influence of human factors associated with changes in land use (Viedma et al., 2017).

Forest fires are among the most significant factors threatening forest lands in Türkiye, as in many other countries around the world. It is an inevitable reality that every terrestrial ecosystem with vegetation is affected by natural wildfires. The occurrence of these fires in ecosystems can vary, sometimes happening frequently and other times occurring sporadically. As a result of these fires, some ecosystems can sustain their existence, while others can transform into different types of vegetation. Each terrestrial ecosystem has its fire regime, meaning that terrestrial ecosystems, especially forests, have undergone changes and transformations over time due to fires (Kavgacı et al., 2023).

Forest fires, with their highly complex nature, are one of the most devastating disasters that can impact forest ecosystems. Apart from causing significant damage to various flora regions and forested areas globally each year, they result in billions of dollars spent on firefighting efforts and lead to loss of life, property, and recreational opportunities (Türkeş and Altan, 2012). In addition, forest fires are responsible for soil degradation, carbon dioxide emissions, desertification, and deforestation (Bo et al., 2020; Moayedi et al., 2020).

Global fire statistics vary due to different definitions of forests and forest fires. The total affected area by fires is estimated to be around 400 million hectares annually. Among the countries with a coastline along the Mediterranean, Türkiye has the smallest average annual burned forest area (Atmiş et al., 2023). In Türkiye, official records of forest fires date back to 1937 until the present day. From that year until 2021, a total of 117.734 fires resulted in damage to 1.851.476 hectares of forest land. On average, each fire during this period burned 15.73 hectares of forest (Atmiş et al., 2023). The year 2021 in Türkiye witnessed several mega-fires, with 11 out of the top 20 largest fires occurring within the last 50 years. In total, 2.793 fires affected and damaged 139.503 hectares of forest area in 2021 (Atmiş et al., 2023; Tolunay, 2021). Climate change intensifies the severity and extent of forest fires. Additionally, forest fires contribute to adverse impacts on climate change. Global climate change, with increased temperatures and reduced rainfall, renders high mountain ecosystems, which would have had a lower fire risk, more vulnerable. Consequently, likely, the number of fires and burned areas will likely increase in these mountain ecosystems. Pine forests, consisting of resinous and dry vegetation, possess a high fire potential. This situation highlights the susceptibility of the forests in Muğla province to fire and the likelihood of damage. Moreover, due to the influence of both north and south winds, Muğla forests are one of the most vulnerable regions in Türkiye concerning fire (Altan et al., 2011). For instance, in the research area located in Muğla province, pine forests at an elevation of 1800 m have been affected by fires. Taking into account these natural effects of climate change during decision-making and planning processes would greatly facilitate firefighting efforts. Furthermore, preserving the ecological balance in high mountain ecosystems, where endemic species are predominant, can be achieved (Türkeş and Tolunay, 2023).

Remote sensing emerges as a frequently used tool for monitoring and managing disasters such as fires, utilizing high-resolution data (Akyürek, 2023). Various remote sensing data can provide information before and after forest fires. Parameters that are crucial for forest fire, such as vegetation types and cover, wind, temperature, humidity, precipitation, topography, and Land Use/Land Cover (LULC) interactions with the forest, can be determined at different scales. Nowadays, change analysis can be conducted using satellite imagery (Çoban and Koç, 2008; Çoban et al., 2010; Musaoğlu et al., 2021). Multispectral satellites play an important role in supporting ground-based data acquisition concerning fire severity. Furthermore, they facilitate the efficient and rapid generation of risk maps in fire-affected areas (Tonbul, 2015).

In the study conducted by Gürbüz (2022) in the Menderes district of İzmir province firstly, the Normalized Burning Index (NBR), differentiated Normalized Burning Index (dNBR), Normalized Difference Vegetation Index (NVDI), and differentiated Normalized Difference Vegetation Index (dNDVI) were applied to Landsat 8 images obtained using the GEE (Google Earth Engine) platform to identify the burned areas in the region, and then the vegetation change of the fire-damaged area between 2012 and 2022 was monitored.

When the global literature is examined, it is reported that successful results were obtained by using Sentinel-2 data for the detection and analysis of fires in studies conducted for forest fires in Türkiye, Amazon, California, and Australia (Brovelli et al., 2020; Seydi et al., 2021). These examples show that the automatic detection of burning areas with Sentinel satellite imagery using GEE is an important tool for successfully identifying and controlling fires.

Indices such as NDVI, EVI (Enhanced Vegetation Index), VFC (Vegetation Fractional Cover), DI (Disturbance Index), and NDMI (Normalized Difference Moisture Index) calculated using Sentinel satellite imagery are used to obtain information about vegetation. These indices use parameters that determine the growth rate, health, and stress levels of vegetation to differentiate between vegetation density, plant growth, and the presence of green areas and settlements. In particular, the NDVI is frequently used to determine vegetation cover and plant density (Chuvieco et al., 2002; Lacouture et al., 2020; Lasaponara et al., 2022).

Natural hazards, especially forest fires, can cause large areas of damage and environmental loss. Remote sensing technology and Sentinel-2 satellite imagery are effective tools for identifying areas where fires occur and monitor the post-fire recovery process (Xulu et al., 2021). These studies can provide valuable information to decision-makers and other interested parties on issues such as firefighting and forest management.

Forest fires occur frequently in Muğla province and its surrounding provinces and natural resources are damaged by this situation (Sarı, 2022) This study was conducted to determine 296 fires and approximately 50602.92 hectares of burned area (OGM, 2023) in 2021 using Sentinel-2 satellite imagery in the GEE platform. For this purpose, Sentinel-2 satellite images from September 2020 and 2021 were used. The source code developed by Demir (2023) was used to determine the spatial variation of land cover changes at different threshold values of dNDVI. Spatial analysis was validated with MODIS burning area data. This study has produced a model that can be utilized in creating thematic maps, which can aid in protecting the region's natural resources and mitigating future occurrences of similar natural disasters. As a result of the study using the GEE platform and Sentinel-2 satellite imagery, it was determined that it can be used to provide data that can help decision-makers in issues such as determining the damage caused by fires, fire control, and forest management.

2.Material and Methods

2.1. Material

2.1.1. Study Area

Muğla province, which was selected as the research site, is located in southwestern Türkiye between 27° 13′- 29° 46′ E east and 36° 17′-37° 33′ N north UTM Zone 35N coordinates. The province is bordered by Aydın to the north, Denizli and Burdur to the northeast, and Antalya to the southeast. It is surrounded by the Aegean Sea to the west and the Mediterranean Sea to the south (Figure 1).

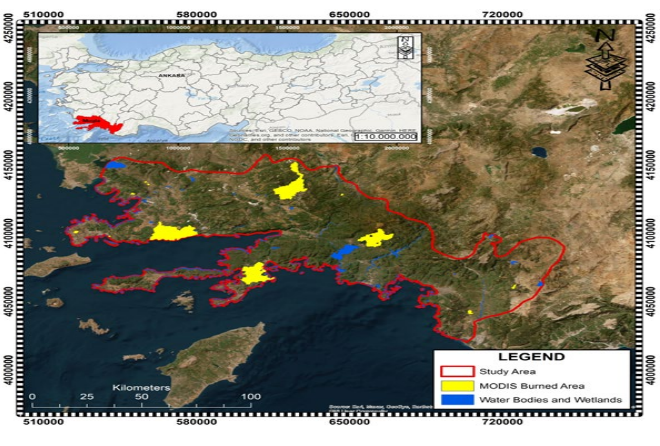

Figure 1. Geographical location of the study area

Muğla Regional Directorate of Forestry has a forested area of 1.158.925 hectares. Approximately 65% of these forests consist of productive forests, while the remaining portion is composed of degraded forests (OGM, 2023). The vegetation includes Turkish red pine (*Pinus brutia* Ten.), Anatolian black pine (*Pinus nigra* Arnold), Taurus cedar (*Cedrus libani* A. Rich.), stone pine (*Pinus pinea* L.), oak (*Quercus* spp.), Turkish sweetgum (*Liquidambar orientalis* Mill.), eucalyptus (*Eucalyptus camaldulensis* Dehn.), and shrubs (Sevinç et al., 2020).

Muğla province ranks among the regions in Türkiye most affected by the adverse effects of forest fires. Its location within the Mediterranean climate zone exposes it to high temperatures and severe summer droughts. As a natural consequence, large-scale forest fires that can affect extensive areas and cause damage to forested areas are likely to occur during the summer season (Altan et al., 2011). The research area has been chosen due to the experts' indication of high climate variability and the potential for more severe natural disasters in the future. Considering all these factors, the selection of this research area, which is both sensitive and of high importance, has been justified (Türkeş and Altan, 2012).

The general soil types in the province can be classified into fourteen groups, including brown forest soils, alluvial soils, red Mediterranean soils, colluvial soils, hydromorphic soils, regosols, rendzinas, podzolic soils, and sandy soils (Gül, 2018; Tuncer, 2022).

The CORINE (Coordination of Information on the Environment) land cover classification was used to determine LULC. According to CORINE, land cover classes were encoded. In this context, artificial areas (1), agricultural areas (2), forests and semi-natural areas (3), wetlands (4), and water bodies (5) were encoded (Table 1) (CORINE, 2023).

Table 1. CORINE LULC 2018 of Muğla province

Land Cover Class	Hectare	%
1) Artificial Surfaces	31175.50	2.46
2) Agricultural Areas	229.835	22.55
3) Forest and Seminatural Areas	928450.01	73.39
4) Wetlands	4138.92	0.33
5) Water Bodies	16063.61	1.27
Total	1265092.47	100.00

2.1.2. Climate

The climate is defined as the average of meteorological events observed over a long period in a region. The climate also determines the character of a region in terms of weather events and vegetation cover (Dursun and Babalık, 2021).

Long-term precipitation and temperature data (1928-2022) for Muğla province are presented in Figure 2. The annual average temperature is 15.2 °C, and the annual total precipitation is 1207.4 mm (MGM, 2023). Additionally, when examining the diagram, it includes the months with the highest temperatures and the lowest precipitation during the fire season.

According to the climate diagram drawn using the Walter method (Walter, 1958), a dry season prevails in the region from mid-March to the end of October (Figure 2).

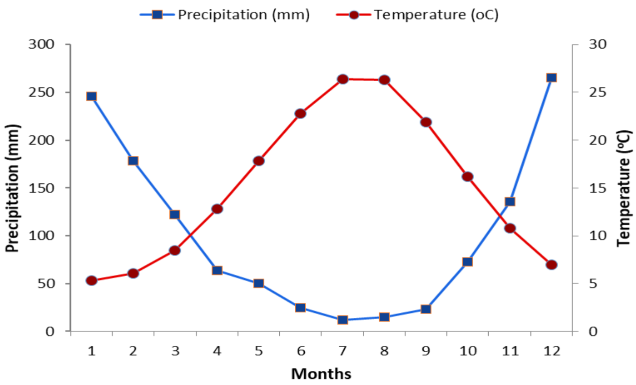

Figure 2. Muğla province Walter diagram

As shown in Figure 3, the data of the study area is the average max and min temperature between the years 1928-2022. According to the diagram, it can be concluded that the highest temperature data belongs to July and the lowest temperature data belongs to January.

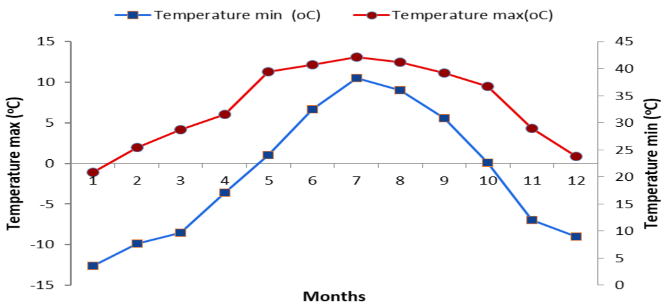

Figure 3. The diagram of Muğla province the average max and min. temperatures (1928-2022)

The prevailing climate is the Mediterranean climate. In the region, the Mediterranean climate can be divided into two zones: the "Genuine Mediterranean Climate" in areas up to 800 m altitude, and the "Mediterranean Mountain Climate" in higher areas. In this zone, winters are short and mild, while summers are hot, and the average temperatures during the summer months are relatively high (Gayır and Arslan, 2018; Çetin et al., 2023).

2.1.3. Database

The data sets related to the study area in the GEE (Google, 2021) platform are specified in Table 2. The 'FAO/GAUL/2015/level1' data set was used for the study area in Muğla province. The 'JRC/GSW1_0/GlobalSurfaceWater' data set was utilized for masking operations within the study area. The 'COPERNICUS/S2_SR' data set was used for the multispectral Sentinel-2 imagery. For the burned area data in the year 2021, the 'MODIS/006/MCD64A1' data set was employed. The 'BurnDate' band from the 'MODIS/006/MCD64A1' database is a MODIS satellite data band used for the detection and monitoring of fire activities. This band relies on thermal data collected by the MODIS sensors. Fires can be distinctly observed in the thermal bands due to higher surface temperatures in burned areas. MODIS satellite data is utilized for fire detection in these thermal bands and helps determine the location, size, and intensity of fires (Boschetti et al., 2009; Demir, 2023).

Table 2. Databases used to determine burned areas

Database Code	Database Description
'FAO/GAUL/ 2015/level1'	This database is based on the FAO (Food and Agriculture Organization of the United Nations) global administrative unit classification (GAUL). This database includes the boundaries and subdivisions of countries around the world and some important socioeconomic data (FAO, 2015).
'JRC/GSW1_ 0/GlobalSurfa ceWater'	This database is managed by Global Surface Water Monitoring (GSW), a project to monitor the water resources of the Earth's surface. This database uses high-resolution satellite imagery to monitor water resources around the world, including surface waters such as water lakes, rivers, and reservoirs (JRC, 2016).
'COPERNIC US/S2_SR'	These images provide color images of the earth's surface and are used to monitor landform characteristics such as vegetation, water, and soil (Roca et al., 2022).
'MODIS/006/ MCD64A1'	This database contains fire detection data used for global fire monitoring. The data are collected using high-resolution satellite imagery and are used to determine the location, size, and intensity of fires (Xu et al., 2022).

2.2. Method

A comparative analysis was performed on the spatial analysis results of burned area data obtained from NDVI calculations using different threshold values in the GEE platform based on Sentinel-2 satellite imagery (Zhang et al., 2018; Demir, 2023) and the MODIS burned area data. The layers obtained in the GEE platform were exported in GeoTIFF file format, and the workflow is presented in Figure 4.

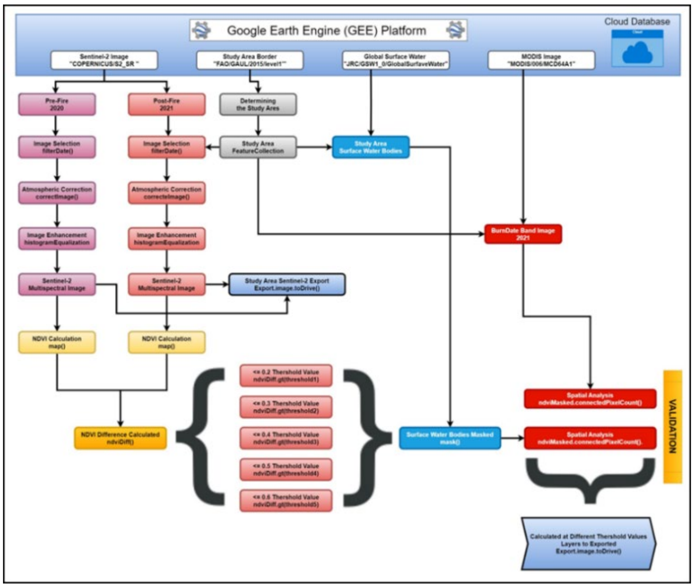

Figure 4. Flowchart of the method

In conclusion, this code block demonstrates the calculation and export of NDVI using Sentinel-2 satellite imagery in the GEE platform. The threshold values used for determining the burned areas in the NDVI difference image were determined through visual inspection, histogram analysis (Chen et al., 2016), and MODIS burned area data (Boschetti et al., 2009). Additionally, the threshold value to be used in the determination of burned land change and burned area was identified. The difference between the two NDVI thematic layers is taken. The difference NDVI thematic layer creates burned area layers according to specific threshold values. Then, the water bodies within the different layers are masked, and area calculations are performed. The burned area values calculated for the study area were validated using MODIS data. An appropriate method was determined for identifying the burned areas in the study area in different years. The developed code block, which has been calibrated at the national and international levels, will be shared as open-source code in the GEE platform.

3. Result and Discussions

This study focuses on forest fires within the provincial boundary of Muğla and was conducted to determine the damage caused by fires. High-resolution (10 m) Sentinel-2 satellite image maps of the study area from September 2020 and 2021, which were image enhanced with atmospheric correction and histogram equalization in the GEE platform, and NDVI maps created by masking water bodies are given in Figure 5.

NDVI mapping and identification of burned areas using the Sentinel-2 satellite is extremely important for the prevention or mitigation of natural disasters, especially forest fires. The first objective of Sentinel-2 is to provide high-resolution satellite data for land cover/land use monitoring, climate change, and disaster monitoring. Many researchers are working on land cover and land use classification using Sentinel-2 imagery. Sentinel-2 has a positive impact on LULC monitoring, especially for forests, urban areas, and water resources monitoring (Phiri et al., 2020).

The Sentinel-2 satellite has a multispectral band sensor capable of high spatial-resolution imaging (Mandanici and Bitelli, 2016). Therefore, it can be used to create NDVI maps and detect burning areas. Studies show that NDVI maps using Sentinel-2 satellites are an important tool for monitoring and controlling natural disasters such as forest fires (Lasaponara et al., 2022; Yılmaz et al., 2023; Demir, 2023).

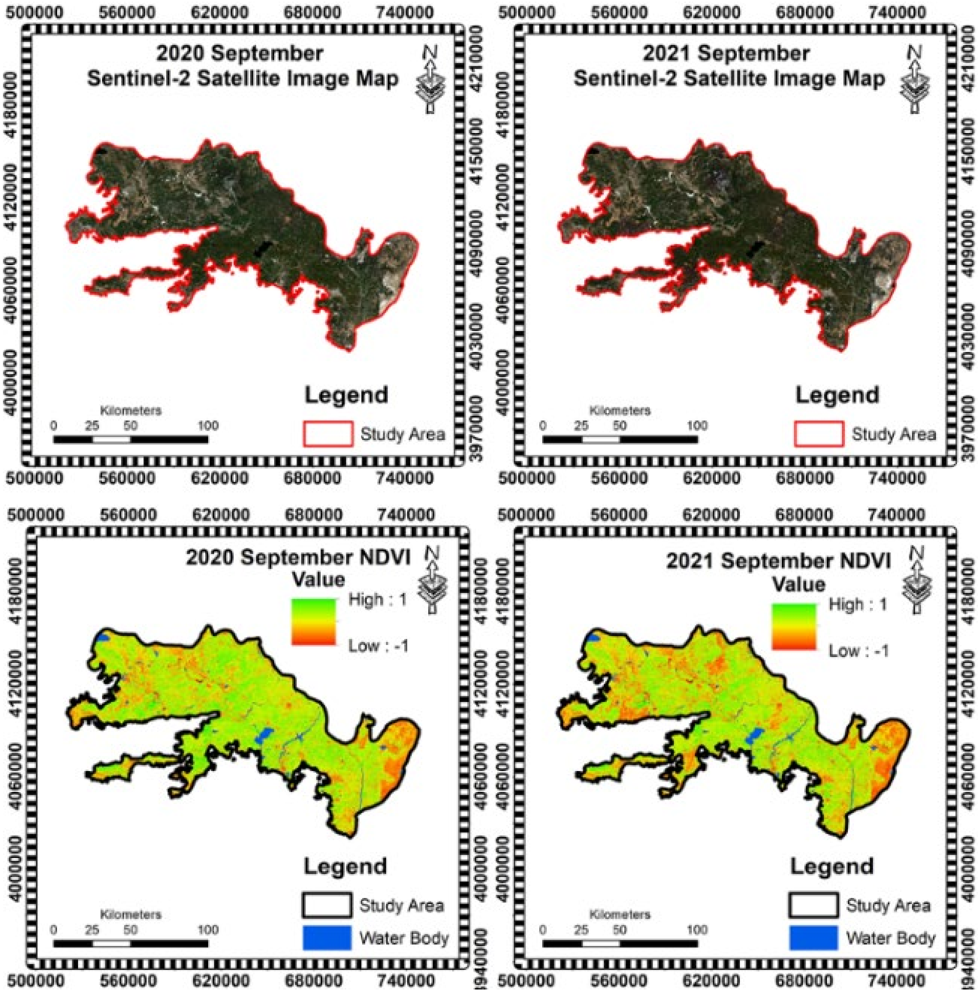

Figure 5. Sentinel-2 satellite image of the study area and NDVI layers

NDVI is an index of plant structure related to the leaf of a tree, which helps us understand the difference in spectral reflectance between pigment and leaf structure. Pigment, chlorophyll, and leaf structure reflect more than half of the radiation in the near-infrared band, while strongly absorbing radiation in the red band. In the use of NDVI, whether an area is devoid of vegetation or has sparse herbaceous taxa, it is the most suitable method to determine the contrast between the trees in the area and the surrounding soil (Catalão et al., 2022). NDVI is also a vegetation index sensitive to the red and near-infrared regions of the electromagnetic spectrum.

NDVI, which represents vegetation cover, corresponds to a value between 0 and 1, with pixel values closer to 1 indicating the density of vegetation (Tucker, 1979). In this context, fire indices and

NDVI are used to identify areas at risk of fire and vegetation destroyed by fire (Atun et al., 2020).

The areas identified using different threshold values in the NDVI image of the study area in September 2020 and 2021 are given in Figure 6. The results of the low spatial resolution MODIS burning area data were compared with the results of the high-resolution identified areas in the study area (Table 3).

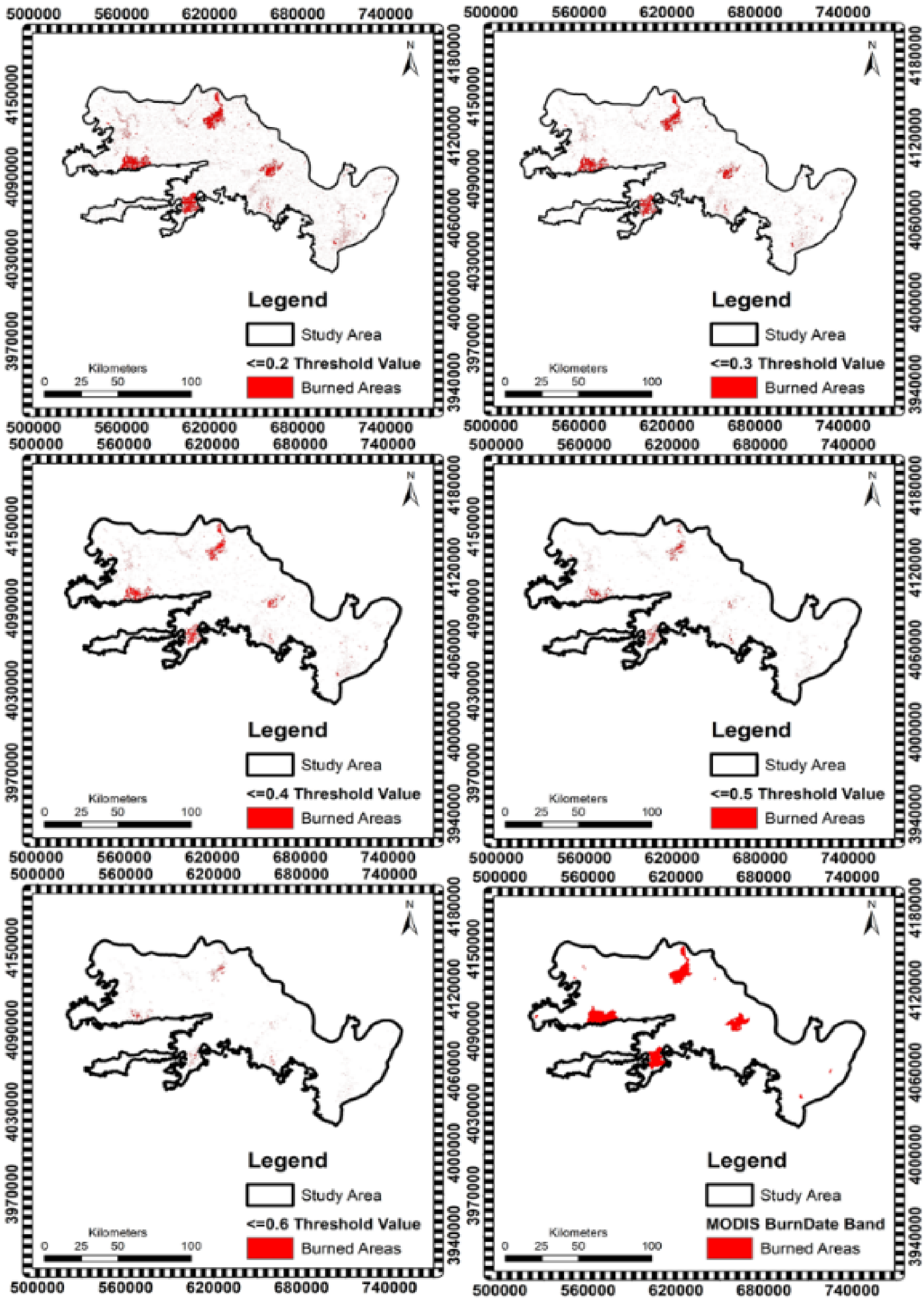

Figure 6. Study area burning area layers calculated at different threshold values

Table 3. Spatial analysis of burning areas calculated at different thresholds

Sentinel 2 Different NDVI Threshold	Burned Area and Land Change (hectare)	Change (%) MODIS (%)	OGM (%)	MODIS Burned Area (hectare)	OGM Burned Area Data for 2021 (hectare)
≤0.2	68092.56	119.99	134.6	56746.37	50602.92
≤0.3	46966.44	82.77	92.8	56746.37	50602.92
≤0.4	31050.3	54.72	61.4	56746.37	50602.92
≤0.5	17020,2	29.99	33.6	56746.37	50602.92
≤0.6	7086.14	12.49	14.0	56746.37	50602.92

Threshold determination methods are preferred because they have few parameters and a complex structure. It is used in vegetation and land use change. It is also effectively used to identify tree species and burnt areas (Agrillo et al., 2021; Ngadze et al., 2020).

According to the results of the threshold values and areal size determined in the GEE platform, the threshold value of 0.2 shows that it is more than the areas calculated with the low-resolution MODIS satellite. When the threshold value is 0.2, it is determined that the area determined with high-resolution data is higher, the land cover and burning areas are calculated at a higher rate, and the changes in agricultural and forest areas are mixed and give positive values. It is also expected that at high resolution, gaps in land cover are identified and the change is expected to be at a lower level. The area of 46966.44 hectares determined when the threshold value is 0.3 corresponds to 82.77% of the burned area data determined with MODIS data. The area of 46966.44 hectares determined when the threshold value is 0.3 corresponds to 92.8% of the area data determined according to OGM (2023) ground data. It was determined that the MODIS burned area data used as verification data is spatially larger than the OGM (2023) data due to resolution and confusion. It was determined that the majority of the identified burned areas and land change class represent the burned areas (Table 3).

The code block developed in the GEE platform shows that the NDVI can be used to identify burned areas at a threshold value of 0.3 with an acceptable level of accuracy. These results show that it can be used to determine land cover changes and the amount of burned area in September using high-resolution satellite imagery (Table 3). When the threshold value was 0.3, it was determined that the success of high-resolution data increased in determining land cover change and gaps in burnt areas. At other threshold values, the rates gradually decreased and the success decreased in the forested areas in the areas determined with MODIS data (Table 3).

In land cover change analyses using different threshold values, it is stated that it becomes more sensitive with increasing threshold values. However, the use of high threshold values has been reported to give useful results in the detection of forest fires and false positive results in agricultural areas (Sertel et al., 2018; Topaloğlu et al., 2022; Demir, 2023). The potential and reliability of the combined use of GEE and Sentinel-2 NDVI time series have been underlined (Lasaponara et al., 2022).

Similarly, in another study using different threshold values, Sentinel-2 NDVI images were used to detect burned areas after forest fires in Türkiye in 2020. The results of the study suggested combining different methods to determine the most appropriate threshold values (Abdikan et al., 2022). According to the results obtained for the study area, it was determined that the more sensitive threshold value for determining land change and burning areas was 0.3 according to the histogram analysis. It was determined that the results of the study were similar to the studies conducted.

Forest fire risk classes were determined using Sentinel-2 images after the forest fire in the Belen district of Hatay by Yilmaz et al. (2023) and after the forest areas burned in Syria by Al-hasn and Almuhammad (2022). NDVI was used to identify and determine how many forests were destroyed. According to NDVI, it was determined that the NDVI value of the areas with high vegetation decreased after the fire.

Using Sentinel-2 satellite image in the GEE platform, land change and burning area were determined using NDVI maps of September 2020 and 2021 and different threshold values. As a result of the study, it was determined that in the areas determined at different threshold values, there were interferences in areas where there were single pixels due to the salt-pepper effect and shadow effect in the image. It was determined that these single pixels can enter into the burning area in a very small amount due to the distortions and shadow effects that occur during the different processes. This is considered to be at an acceptable level in a study on the determination of burning areas for an area of approximately 12761.8 km^2. In addition, it is possible to reduce distorted pixels by merging pixels.

However, due to the coarse resolution of the MODIS satellite, high-resolution results were used.

In the NDVI maps of Atun et al. (2020) obtained after the fire, pixel values for the fire-damaged area vary between 0.1 and 0.3. In another study, an NDVI threshold of 0.3 was chosen in consultation with staff who were very familiar with the burned area in the years immediately after the fire. This threshold is also consistent with values previously used to define 'vegetation cover' (Vanderhoof et al., 2018).

The study by Chuvieco et al. (2002), which identified burned areas using different spectral indices, reported similar confounding for the NDVI index. It was observed that the rates of land change also changed when different threshold values were used. Higher thresholds resulted in lower rates of land change, while lower thresholds resulted in higher rates of land change.

In the study by Long et al. (2019), in which annual burning areas with a resolution of 30 m in Landsat image were determined via GEE, NDVI threshold change rates were obtained with threshold values of 0.2 and 0.3.

In recent years, climate changes in the world, increasing temperatures, melting glaciers, storms, and changes in natural vegetation have led many countries to act together in the international arena, and such situations that threaten the environment have been recognized as global problems rather than international problems (Dursun et al., 2018). In this context, Türkiye is a country that has to fight against climate change, forest fires, and other environmental threats.

As the impact of climate change increases further, the climate of the southern half of Türkiye will be transformed into a more arid climate, while central and northern regions may face a milder climate structure, and in this case, it will be inevitable that the risk of drought will increase further in all regions. Especially in Central Anatolia, Southeastern Anatolia, Aegean, and Mediterranean regions of Türkiye, which have semi-arid and semi-humid characteristics under the threat of desertification, more negative consequences will be seen in terms of agriculture, forestry, and water resources. It is known that mass tree drying, pest outbreaks, and fires have increased in Türkiye's forests in recent years, while crop losses have increased in agricultural areas due to agricultural drought. Undoubtedly, the increased risk of drought due to climate change will further accelerate these events (Babalık et al., 2018).

In the results of the study conducted by Demir (2023), it was observed that the detection rate for the burning area class was highest at threshold values of 0.2 and 0.3. Notably, as the threshold values increased, a decrease in detection within the burning area class was observed, aligning with similar results in previous studies. The successful masking of water bodies was found to be an effective solution to address this issue.

The majority of the identified burned areas predominantly comprised forests and shrublands. Furthermore, it was determined that the primary cause of these wildfires was anthropogenic activities, emphasizing the critical role of human intervention in these destructive events. These results underscore the critical importance of detecting and rehabilitating burned areas due to their significant impact on ecosystems and biological diversity. Remote sensing technologies, specifically the use of satellite imagery and the Google Earth Engine (GEE), played a pivotal role in this study's methodology aimed at detecting burned areas with high-resolution Sentinel-2 satellite imagery.

To broaden the scope and applicability of the methodology developed by Demir (2023), it is recommended to conduct further testing and validation in various geographic regions. By doing so, it is anticipated that this methodology, coupled with the results of the study, could serve as a valuable tool for national-scale forest fire detection efforts. This approach holds promise in supporting broader strategies for mitigating the ecological and environmental impacts of wildfires.

4. Conclusion

This study showed that using Sentinel-2 satellite images in the GEE platform, the NDVI vegetation index can be used to determine terrain change and burning areas through threshold values. When different threshold values are used, it has been observed that they have effects on land change rates and burnt area classification.

The results of the study show that the threshold value of 0.3 gives more sensitive and accurate results. This threshold value is not only suitable for the detection of burned areas but also provides successful results in land change analysis. However, it was also stated that different threshold values were preferred in different studies.

The results of the study showed that high-resolution satellite data is more effective in determining terrain change and burning area. It was determined that low-resolution MODIS data caused confusion and a salt-pepper effect in the determined areas.
It has been determined that the burned areas were mostly forests and bushland. In addition, it has been determined that the transition zones between agricultural areas, forested areas, and wetlands play an important role in land use.

In conclusion, this study showed that land change and burning areas can be determined with high-resolution data using Sentinel-2 satellite images and NDVI vegetation index in the GEE platform. The code block used in this study will be made available to other researchers as an open-source code to determine the burned areas of agricultural and forest areas after different validation processes in the future. The results of the study can help decision-makers and experts in matters such as risk analysis, land management, and environmental protection related to forest fires. However, it is recommended to further increase the reliability and generalizability of this method developed with further research and validation studies.

5. Appendices

The code was implemented following the processing steps suggested by Demir (2023):
• A FeatureCollection object named "Mugla" is created. This object is filtered from the data obtained from the FAO/GAUL/2015/level1 dataset.
• A FeatureCollection object is created using the function "studyArea."
•The ImageCollection dataset "COPERNICUS/S2_SR," which contains Sentinel-2 surface reflectance data, is loaded, and the images within the study area boundaries are filtered using the "filterBounds()" function.
• The data is limited to Sentinel-2 satellite images from September 1, 2020, to September 30, 2020, and from September 1, 2021, to September 30, 2021, using the "filterDate()" function. As a result of this process, images with less than 10% cloud cover taken within a 5-day revisit frequency during the filtering dates are selected. A total of 151 Sentinel-2 satellite images covering the study area were chosen. The composite image is created using the median mosaic method (Roteta et al., 2021).
• The function "correctImage()" passes each image through atmospheric correction processes and resizes the result. The function "histogramEqualization()" is used for histogram equalization in each image, enriching the image. The atmospheric correction process is developed to perform pixel normalization and 8-bit data transformation in the used image. The histogram equalization process is carried out by calculating the histogram of pixels belonging to the bands used in the true color composition and obtaining the frequency distribution of pixels. The normalized pixel values are rescaled to the original image's 0-255 range. Atmospheric correction is applied again on the Sentinel-2 images in the GEE platform to convert the images specific to the study area. This code is developed to be applied to the bands used in the study.
• The NDVI of the atmospherically corrected and image-enhanced images is calculated and added to the ImageCollection using the "map()" method.
• A color palette is defined to display the NDVI layers on the map. NDVI layers at different threshold values (0.2, 0.3, 0.4, 0.5, and 0.6) are created using the function "ndviThreshold." The threshold values used in the study are based on the threshold values determined by Chen et al. (2016). Additionally, burned areas in the satellite image are determined using the MODIS BurnDate band, and threshold values showing high compatibility through histogram analysis are identified.
• The NDVI layers created at different threshold values are masked using the "mask()" function to prevent the mixing of burned areas with water bodies in spatial analysis. The spatial extents of the layers created at different threshold values are calculated using the "ndviMasked.connectedPixelCount()" function.
• The "BurnDate" layer for September 2020-2021, obtained using MODIS satellite data in the GEE platform, is filtered. Then, cropping is performed based on the study area boundaries. After the cropping process, a color palette is defined, and the burned areas are shown in red.
• The layers created are added to the GEE platform using the "Map.addLayer()" function.
• The function "Export.image.toDrive()" is used to export the NDVI, Sentinel-2 images, and MODIS burned area layer to Google Drive in GeoTIFF format.

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