https://doi.org/10.1051/bioconf/20248501041

Determination of fire intensity after forest fire by remote sensing: marmaris case study

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Abstract. Forest fires in Turkiye are a frequently encountered natural disaster, especially in recent years. After a fire, identifying the plant species to be used in the area and determining the intensity of the fire in the region are important for assessing the area's capacity for natural regeneration. In this process, geographic information systems and remote sensing methods and techniques are commonly used tools for assessing burned areas and fire intensities following forest fires. In this study, one of Turkiye's devastating fires, the Marmaris fire, which began on June 21, 2022, is examined. Landsat satellite images, geometrically and radiometrically corrected, were utilized to determine the intensity of the Marmaris fire. As part of the method, the NBR (Normalized Burn Ratio), dNBR (Difference Normalized Burn Ratio), NDVI (Normalized Difference Vegetation Index), and dNDVI (Difference Normalized Difference Vegetation Index) indices were used for burned area detection. As a result of the study, information about the burned areas, fire intensities, and the regenerative capabilities of post-fire vegetation growth has been obtained. Furthermore, suitable pioneer plant species, considering the fire intensity, have been suggested for the restoration of burned landscape areas after the fire. This study is expected to serve as a guide for relevant public institutions and organizations, particularly the General Directorates of Forestry, enabling them to respond most effectively after fires and implement reforestation efforts considering the usage areas and growth capabilities of needle-leaved and broad-leaved plants.

1 Introduction

Fires are an example of environmental disruptions that cause partial or complete vegetation loss. Forest fires have become a significant and global issue in recent years. Large fires occurring on nearly every continent and in various countries, whether initiated by natural causes or human activities, have led to a multifaceted questioning of overall forest management policies in the context of wildfires [1,2]. In these disturbed or damaged ecosystems, the pioneering plant species that emerge first and contribute to the restoration of these areas are known as pioneer plants. The gradual development of forests starting with pioneer species, building upon the opportunities provided by the previous formation, and advancing beyond it, while also paving the way for subsequent compositions, is referred to as forest succession [3,4]. The presence of pioneer plants is crucial not only for organizing the physical characteristics of the altered environment but also for the successful initial development of vegetation. In the stages of succession, some species withdraw from the environment in later stages once their pioneer roles are fulfilled, while other species can persist in the forest composition even after the completion of their pioneering roles [5,3]. Forest fires occur due to human activities or natural factors. After a fire, the vegetation on the soil surface is partially or entirely eradicated. Fires lead to harm to the natural environment or buildings, changes in landscapes, disruption of vanished vegetation, ecological imbalance, and damage to human or animal lives and ecosystems. Besides causing damage to numerous forests and tree species, fires also result in the demise of beneficial soil bacteria and the disappearance of seeds within the vegetation.

One of the most significant damages caused by fire to vegetation, especially trees, is the reduction in the resistance of fire-damaged trees against various insects. This is because trees affected by fire, whether due to the burning of the canopy or the overheating of the cambium layer near the base of the trunk, result in their death or weakening. Trees damaged in this way provide the best environments for the development of secondary harmful species and various insects [6].

After a while, when vegetation slowly begins to recover on the bare soil, various plants known as pioneer species start to emerge [7]. Pioneer plants are dominant and evolving species that appear in the aftermath of a disaster in the previously devastated area. The recovery of vegetation begins with the presence of plants that adapt to soils lacking in organic matter and soil nutrients [8,9]. Over time during the course of vegetation, a plant species composition begins to form. During this process, plant

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 https://doi.org/10.1051/bioconf/20248501041

communities with compositions of different species that succeed one another are formed. Post-fire pioneer plants are the first to grow in disrupted ecosystems, providing a foundation for the growth of other species. Taking certain precautions is necessary to prevent the creation of unfavorable conditions after fires. In forested areas, the presence of both coniferous resinous species and broadleaf plants slows down the rapid burning of vegetation during a fire. Clearing the lower branches of resinous plants will reduce the intensity of the fire.

Following a fire, along with the severity of damage in vanished or affected forests, geographic information systems and remote sensing methods and techniques have become frequently used tools in recent years for detecting burned areas. These tools provide rapid access to information. Numerous studies on this subject exist in national and international literature. However, no study has been conducted to determine the fire severity for the forest fire that occurred in Marmaris on June 21, 2022, where approximately 4,500 hectares were lost. In this study, using satellite imagery before and after the Marmaris fire, remote sensing techniques were employed to detect the severity of burning and burned areas. Additionally, species that would slow down the fire were proposed for the pre-fire period, alongside recommendations for post-fire landscape restoration efforts.

Extensive research conducted on 'sustainable forest management in Turkiye' highlights the multifaceted management complexity over forests, analyzing various pressures including social, economic, and ecological issues. It is stated that differences encountered in expert education levels and assessment criteria criteria challenge the process [10]. The aim of this study is to serve as a guide for activities to be conducted by public institutions and organizations both before and after fires.

2 Material and method

2.1 Study area

The main material of the research consists of the forest areas located within the boundaries of Marmaris, a district of Muğla, a province in Turkiye. Marmaris is surrounded by the Datça Peninsula and the Gulf of Kerme to the west, Ula to the north, Balan Mountain, Karadağ, and Günlük Hills to the east, and the Mediterranean Sea to the south. According to the data from the General Directorate of Forestry (OGM) in 2023, there is a total of 116,371 hectares of forest land within the borders of Marmaris [11]. Of this forest land, 56.3% (65,495.4 ha) is covered by dense forests, and 43.7% (50,875.2 ha) consists of open forests with gaps.

On June 21, 2022, a fire began in Marmaris, which was one of the highly damaging fires in Turkiye. This fire lasted for four days and resulted in the destruction of approximately 4,500 hectares of forest land. This accounts for about 3.86% of the forest area in Marmaris. Fig.1 in the document shows the geographical location map of Marmaris. The Marmaris forest fire that occurred on June 21, 2021, can be observed in Fig. 2 and Fig. 3.

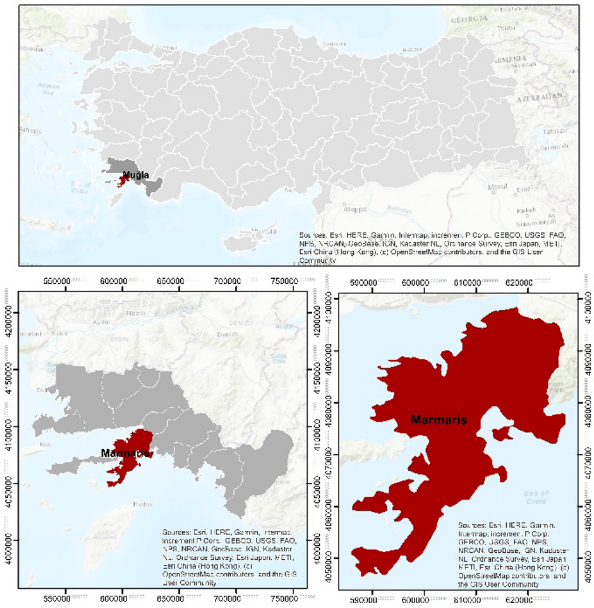

Fig. 1. Geographical location map of Marmaris.

Fig. 2. The Marmaris forest fire [12].

Fig. 3. The Marmaris forest fire [12].

2.2 Data sets

Table 1 presents the datasets used in this study, their source and intended use. The projection system of the data sets used in Geographic Information Systems and Remote Sensing analyses is organized as "WGS_1984_UTM_Zone_35N".

Table 1. Data sets and details

Data Set	Detail
Geometrically and radiometrically corrected satellite image [13]	**Data Type:** Raster Satellite Image **Satellite Type:** Landsat 8 OLI-TIRS **Resolution:** 30m x 30m **Image Date:** 05.06.2022 **Image Date:** 07.07.2022 **Intended Use:** NBR (pre&post), dNBR, NDVI (pre&post), dNDVI
Provincial and district administrative boundaries [14]	**Data Type:** Vector **Data Type:** Polygon **Intended Use:** Geographical Location

2.3 Method

Within the scope of the method, NBR (Normalized Burn Ratio) index was utilized for the determination of pre- and post-fire burn ratio and intensity, and NDVI (Normalized Difference Vegetation Index) indices were used for the assessment of vegetation cover change in Marmaris. The method of the research is given in Fig. 4. Geometrically and radiometrically corrected Landsat 8 satellite images were used in the analyzes performed in ArcGIS 10.5.

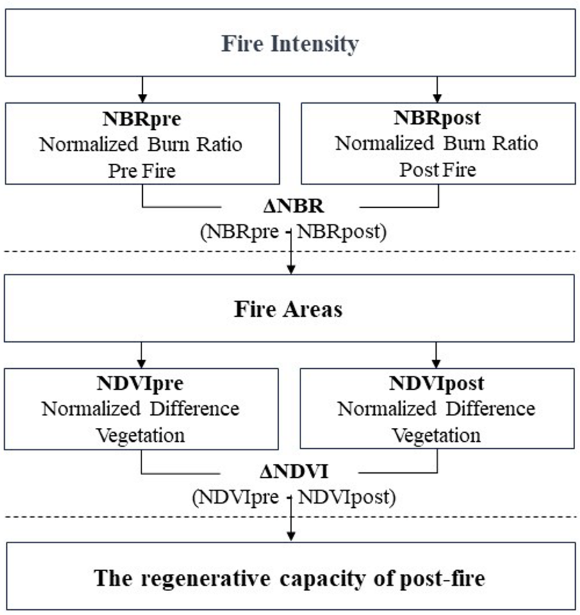

Fig. 4. Schematic of the methodology.

NBR is used to identify burned areas and provide a measure of burn intensity. It is calculated as a ratio between the NIR (Bant 5) and SWIR2 (Bant 7) values in traditional fashion. The NBR index used to determine pre-fire and post-fire burn ratios is presented in Equation 1. Equation 2 was used to determine the burning intensity [15].

$$NBR = (NIR - SWIR2)/(NIR + SWIR2) \quad (1)$$

$$\Delta NBR = (NBRpre - NBRpost) \quad (2)$$

The normalized difference vegetation index (NDVI) is a standardized index allowing you to generate an image displaying greenness, also known as relative biomass. This index takes advantage of the contrast of characteristics between two bands from a multispectral raster dataset—the chlorophyll pigment absorption in the red band (Band 4) and the high reflectivity of plant material in the near-infrared (NIR) band (Band 5) [16]. In this study, the NDVI index applied for the determination of pre- and post-fire vegetation cover in Marmaris is as shown in Equation 3. The change in post-fire vegetation cover, on the other hand, is depicted in Equation 4.

$$NDVI = (NIR - RED)/(NIR + RED) \quad (3)$$

$$NDVI = NDVIpre - NDVIpost \quad (4)$$

3 Results

Within the scope of the research, NBR and NDVI analyses were conducted using Landsat 8 satellite images taken before the fire (June 6, 2022) and after the fire (July 7, 2022).

The NBR analysis conducted for the pre-fire period reveals that settlement areas, highways, water surfaces, and clearings within the forest have reflection values ranging from -0.36 to 0.12. After the fire, it was determined that the reflection values for the mentioned land cover ranged from -0.3 to 0.08. The difference in the obtained burn rates for the pre-fire and post-fire periods indicates the severity of the fire in the region. The normalized burning intensity maps (pre-fire, post-fire, and change) are presented in Fig. 5.

The NDVI analysis conducted for the pre-fire period resulted in reflection values ranging from -0.11 to 0.19. In contrast, the NDVI analysis carried out for the post-fire period shows that these values range from -0.13 to 0.17. The normalized difference vegetation index maps (pre-fire, post-fire, and change) are shown in Fig. 6.

https://doi.org/10.1051/bioconf/20248501041

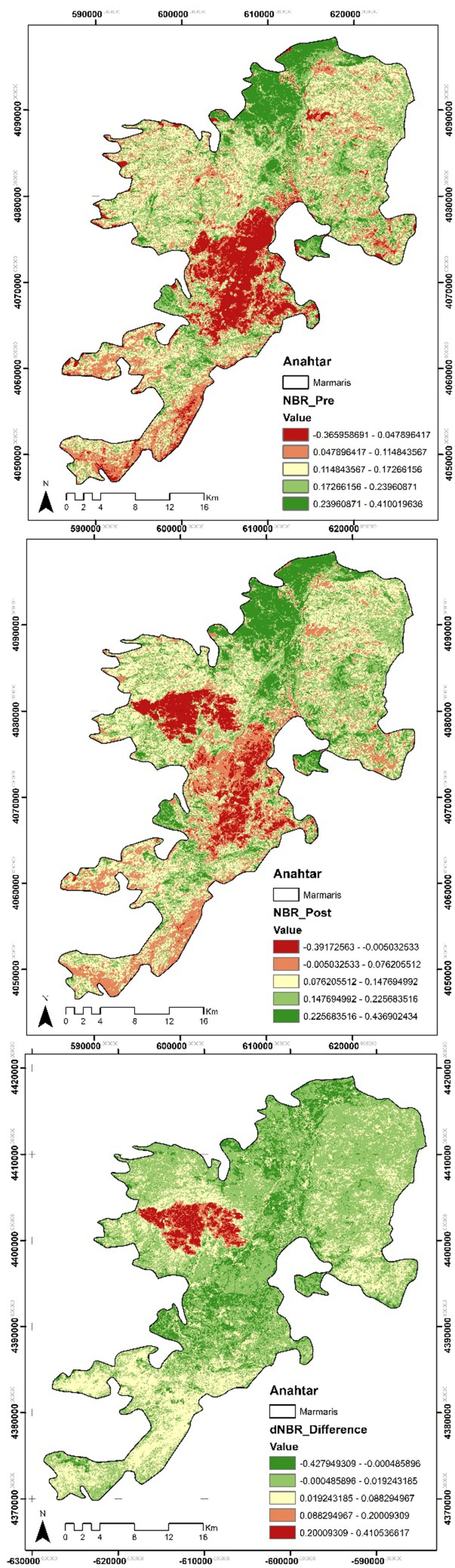

Fig. 5. Normalized burning intensity maps (pre-fire, post-fire and change).

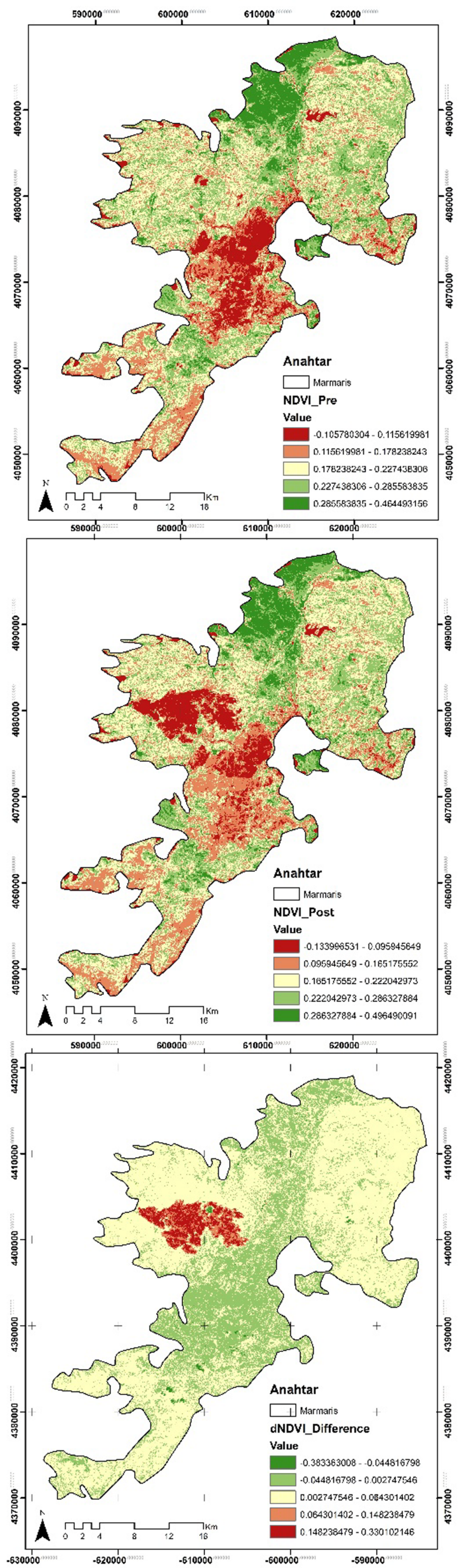

Fig. 6. Normalized difference vegetation index maps (pre-fire, post-fire and change).

4 Discussion and conclusion

Marmaris and its surroundings are sensitive areas in Turkiye when it comes to wildfires. The damages caused by this forest fire, which covers approximately 5% of Marmaris, should be rapidly repaired. The size of the areas to be restored due to the fire necessitates the essential planning to make them more resilient against future fires.

NBR and NDVI change maps are presented in Fig. 7. According to the NBR analysis, it has been determined that a total of 4.80% of Marmaris's area burned at high and very high intensities (Table 2). When compared with the results of the NDVI analysis, it is observed that areas burned at the mentioned intensities transformed into open spaces or bare areas within the forest after the fire. In other words, these values indicate the extent of the destruction of existing vegetation in the area [17]. Upon examining the NDVI calculations, it can be seen that the burned healthy forest tissue reaches reflectance values of unhealthy plants and areas without plant tissue after the fire. Therefore, it can be stated that the forested area covered by trees has decreased by 4.80% (Table 3).

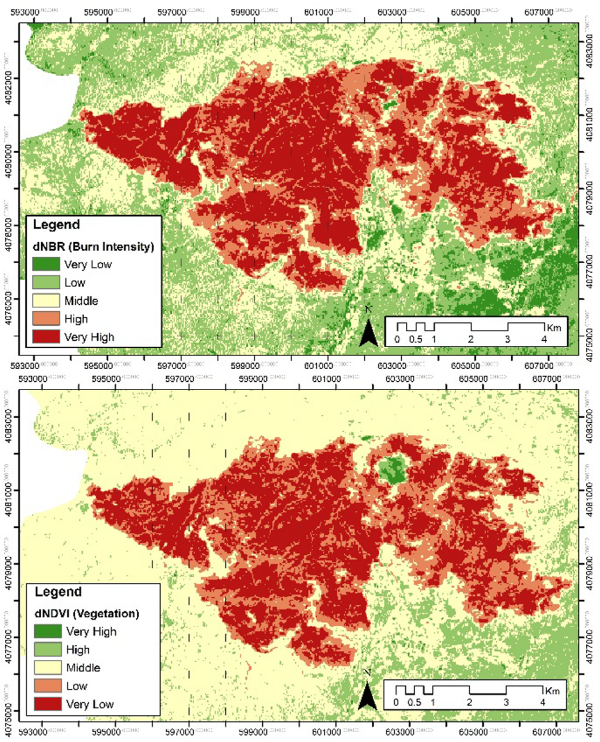

Fig. 7. dNBR and dNDVI maps (Reclassified).

Table 2. Burn intensity and field sizes

Burn Intensity	dNBR Value	Count of Cells	Percentage
Very Low	-0.43 - 0.00	137771	13.71
Low	0.00 – 0.02	539937	53.74
Middle	0.02 – 0.09	278882	27.75
High	0.09 – 0.20	19741	1.96
Very High	0.20 – 0.41	28470	2.83
Total		1004801	100

Table 3. Vegetation areas and field sizes.

Vegetation	dNDVI Value	Count of Cells	Percentage
Very High	-0.38 - -0.05	3532	0.351512
High	-0.05 - 0.00	310282	30.87995
Middle	0.00 - 0.06	643244	64.01705
Low	0.06 - 0.15	20605	2.050655
Very Low	0.15 - 0.33	27138	2.700833
	Total	1004801	100

One of the most crucial factors threatening forests is undoubtedly wildfires. Approximately 98.8% of forest fires worldwide are caused by human activities, with only 1.2% resulting from natural causes [18]. Unfortunately, our country is also one of the countries most severely affected by forest fires in the world. As it is known, our country is situated within the Mediterranean basin, and a significant portion of our forests is under the constant threat of wildfires. Specifically, the section of the 1,700 km-long coastal strip extending from Kahramanmaraş through the Mediterranean and Aegean to Marmara, reaching a depth of 160 km, is recognized as an extremely sensitive area concerning forest fires [19].

In the restoration efforts, the burned areas should first be divided into compartments of 3-5 hectares in size. Around the boundaries of these compartments, a clear fire safety strip of 5-6 meters in width should be established, and on both sides of this strip, a green belt of fire-resistant species such as cedar, oleander, mastic, myrtle, and wild pear, spanning 60-120 meters in width, should be created. As is the case with all afforestation efforts, both within and outside the forest, the vegetation along streams and rivers must be conserved and any disturbed parts should be restored considering their original structure. Furthermore, intermittent mixtures of needle-leaved species should be incorporated with broad-leaved species. Especially in areas highly sensitive to fires, the natural plant composition must be identified, and these species should be conserved in ex-situ gene conservation areas [20].

This study is important in terms of determining the intensity of burning in the repair works to be carried out after the forest fires, the number of which has increased in recent years. Also, this study is expected to serve as a guide for relevant public institutions and organizations, particularly the General Directorates of Forestry, enabling them to respond most effectively after fires and implement reforestation efforts considering the usage areas and growth capabilities of needle-leaved and broad-leaved plants.

4.1 Fire resisting plants

Plants with high water content, soft leaves, and low dead parts, as well as species with low flammable content like volatile oils, paraffin, and resin, are resistant to burning. These include *Acer sp., Alnus sp., Betula sp., Celtis sp., Daphne sp., Fagus sp., Ficus sp., Fraxinus sp., Juglans sp., Magnolia sp., Malus sp., Morus sp., Populus sp., Quercus sp., Salix sp., Tilis sp., Ulmus sp., Berberis sp., Camelis sp., Cornus sp., Cotoneaster sp., Crataegus sp.,* *Euonymus sp., Lavandula sp., Ligustrum sp., Lonicera sp., Philadelphus sp., Rhamnus sp., Hedera sp., and Festuca sp*. species would be suitable for use.

In areas dominated by fire-resistant species, the average fire severity is lower compared to forests where other species prevail.

The utilization of fire-resistant species ensures the preservation of species. Fires generally lead to a decrease in biodiversity in areas where local species are present. Species diversity and richness vary with the fire regime. Vegetation and species diversity decrease after a fire.

Severe fires can diminish the ability of plant species to establish colonies, thereby affecting their survival. Additionally, moderate-intensity fires can result in the dominance of new species [21].

Selecting and employing plant species that are fire-resistant and suitable for the region's climate and soil conditions will reduce the severity of the fire.

Preserving post-fire vegetation development and using plant species that enhance vegetative growth will create an environment for new plants.

References

1. R. F. Noss, J. F. Franklin, W. L. Baker, T. Schoennagel, P. B. Moyle. Front Ecol Env. **4**, 9 (2006)
2. Ç. Elmas ve Y. Sönmez, Politeknik Der., **11**, 2. (2008)
3. J.W. Dalling. Pioneer Species. In Encyclopedia of Ecology, Five-Volume Set. (Elsevier Inc., 2008)
4. N. Kemer. E.J.Sci.Tech. **33** (2022)
5. B. Finegan. Nature. **312**, 8 (1984)
6. E. Bilgili. Web Sitesi: https://www.ktu.edu.tr /dosyalar/ormankoruma_213b0.pdf. (2018)
7. D.M. Nuryanti, L. Witno, A.S. Soma, Asrianny, A.S., Ayu, I.M. Awalia. Biodiversitas, **24**, 3 (2023)
8. L.C. Cline, D.R. Zak. Ecology **96**, 12 (2016)
9. J. Wang, G. Liu, C. Zhang, G. Wang, L. Fang, Y. Cui. Soil Till. Res. **194**, 104305 (2019)
10. A. Akyol, A. Tolunay. S. D. Ü., Fen Bil. Ens. Der., **10**, 2 (2006)
11. OGM. Orman Varlığı. Web Sitesi: https://www.ogm.gov.tr/muglaobm/ormanlarimiz/orman-varligi. (2023)
12. BIA. Web Sitesi: https://l24.im/pCbTREK. (2022)
13. USGS. Web Sitesi: https://earthexplorer. usgs.gov/. (2023)
14. HGM. Türkiye Mülki İdari Sınırları. Web Sitesi: https://www.harita.gov.tr/urun/turkiye-mul ki-idare-sinirlari/232 (2023)
15. S. Veraverbeke, S. Lhermitte, W.W. Verstraeten, R. Goossens. Rem. Sens.of Env., 114, 11 (2010)
16. ESRI. Indices gallery. Web Site: https://pro.arcgis.com/en/pro-app/latest/help/data/imagery/indices-gal lery.htm (2021)
17. T. Aksoy, A. Çabuk, *Orman Yangını Sonrası Uzaktan Algılama Yöntemleri ile Yangın Şiddetinin Tespiti İzmir Menderes Orman Yangını Örneklemi*, Uluslararası Marmara Fen ve Sosyal Bilimler Kongresi Bildiriler Kitabı, 23-25 Kasım 2018, Kocaeli (2018)
18. C. Şahin, Ş. Sipahioğlu. Doğal Afetler ve Türkiye. (Gündüz Eğitim ve Yayıncılık, 2002)
19. H. Doğanay, S. Doğanay. D. Coğ. D. **9**, 11 (2004)
20. M. Ertekin, H.B. Özel, G. Baygın. Bar. O.F.D, **13**, 20 (2011)
21. V.A. Buramuge, N.S. Ribeiro, L. Olsson, R.R. Bandeira, S.N. Lisboa. Fire, **6**, 26 (2023)