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Analysis of the burned area in Grebaštica using Sentinel-2 satellite imagery and vegetation indices

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Abstract: This study analyzed the area of Grebaštica, located in the Šibenik-Knin County, before and after a major fire that occurred on 13 July 2023, with the aim of calculating the extent of the burned area using Sentinel-2 satellite imagery and QGIS software. Three vegetation indices were used for the analysis: the Normalized Difference Vegetation Index (NDVI), the Enhanced Vegetation Index (EVI), and the Normalized Burn Ratio (NBR). Low values of these indices indicate significant damage to vegetation and soil. The analysis revealed that the NBR index was the most effective for detecting burned areas due to the high reflectance of vegetation in the near-infrared and shortwave infrared regions of the electromagnetic spectrum, while the NDVI index proved to be the least effective. To calculate the area affected by the fire, the delta Normalized Burn Ratio (dNBR or ΔNBR) was also computed. Using the ΔNBR index, different levels of vegetation damage and fire hazard were identified. These indices enabled clear differentiation between damaged and undamaged areas, based on the specific reflectance characteristics of materials affected by fire.

Key words: burned area, Grebaštica, vegetation indices, NBR, satellite imagery

Analiza opožarenog područja u Grebaštici uz korištenje Sentinel-2 satelitskih snimki i vegetacijskih indeksa

Sažetak: U ovom radu analizirano je područje Grebaštice, smještene u Šibensko-kninskoj županiji, prije i poslije velikog požara koji se dogodio 13. srpnja 2023. godine, s ciljem izračuna obuhvata opožarenog područja korištenjem Sentinel-2 satelitskih snimki i QGIS softvera. Za analizu opožarenog područja korištena su tri spektralna indeksa: Normalizirani indeks razlike vegetacije (NDVI), Poboljšani vegetacijski indeks (EVI) i Normalizirani indeks sagorijevanja (NBR). Niske vrijednosti ovih indeksa ukazuju na značajna oštećenja vegetacije i tla. Analiza je pokazala da je NBR indeks najučinkovitiji za detekciju opožarenog područja zbog visoke refleksivnosti vegetacije u bliskom infracrvenom i kratkovalnom infracrvenom području elektromagnetskog spektra, dok se NDVI indeks pokazao najmanje učinkovitim. Za izračun površine opožarenog područja, dodatno je izračunat delta normalizirani indeks sagorijevanja (dNBR ili ΔNBR). Korištenjem ΔNBR indeksa, također su identificirane različite razine oštećenja i opasnosti od požara. Ovi indeksi omogućili su jasnu diferencijaciju između oštećenih i neoštećenih područja, temeljem specifičnih refleksijskih karakteristika materijala pogođenih požarom.

Ključne riječi: opožareno područje, Grebaštica, spektralni indeksi, NBR, satelitske snimke

1. INTRODUCTION

In recent years, we have witnessed increasingly severe climate change, manifested in the Mediterranean part of the Republic of Croatia through an increased frequency of fires in open areas [4, 27]. Fires in open areas are usually vegetation fires. According to Stipaničev [1], a vegetation fire is any uncontrolled burning of vegetation in open areas. Fires in open areas have very negative consequences on the quality of water, soil, and landscape. Kisić et al. [4] state that in addition to the consequences directly related to fires, such as changes in vegetation and physical, chemical, and microbiological properties of soil, there are also indirect consequences related to erosion caused by wind and water, and landslides. Croatia is one of the countries with a high risk of fire in the open air, especially in the Mediterranean part of the country [1]. The high risk of fire is the result of dry and very hot summers, as well as strong winds. Also, natural features contribute to the rapid flammability and spread of fires. The lack of freshwater resources for firefighting contributes to the accelerated decline in soil quality.

In the period from 1996 to 2021, 115,000 fires in open areas were registered in the Mediterranean. The annual average of fires in the Republic of Croatia between 1980 and 1989 was 667 open-air fires [4]. In the period from 2006 to 2021, the average number of fires per year is 2,541. In 2021, there were 8,146 fires in open areas, while in 2022 this number increased to 10,110, i.e. the number of fires increased by 24.11% [12].

The cause of fires in the open air is usually human negligence and uncontrolled use of open flames, such as using barbecues, burning dry grass, throwing cigarette butts, etc. In order to reduce the frequency of fires caused by human factors, there is a ban on lighting fires in the open air in the Republic of Croatia from 1 June to 31 October.

In their work, Balen et al. [5] emphasize that each year fire causes a significant number of fatalities, as well as significant material losses. They also refer to the importance of fire prevention and early detection in order to minimize the harmful effects of fires.

Grebaštica, a settlement located in the Šibenik-Knin County, was hit by a large fire on 13 July 2023. The fire spread very quickly, affecting low vegetation, pine forests, maquis, grass, and eventually nearby houses and cars. Firefighters from several fire departments, as well as firefighting aircraft, were involved in firefighting. After five days, on 18 July 2023, the fire was extinguished with great efforts of firefighters.

This paper covers an analysis of the area in Grebaštica engulfed by fire on 13 July 2023 using remote sensing. Images from the Sentinel-2 satellite of the European Space Agency's Copernicus program were used for fire analysis. Satellite images required for fire analysis were freely downloaded from the Copernicus Data Space Ecosystem website. The high resolution of satellite images from the Sentinel-2 mission allows for precise analysis thanks to the spatial and spectral resolution, which includes parts of the electromagnetic spectrum relevant for calculating vegetation indices such as NDVI, EVI and NBR. The inclusion of visible and infrared wavelengths, from blue to short-wave infrared regions, allows for detailed monitoring of changes on the ground, so pre- and post-fire images were downloaded to analyze the impacts on vegetation and the environment. Vegetation indices are used to assess damage and provide insight into the burned area, and this paper compares three vegetation indices. The most popular open source software, QGIS, was used to process satellite images and calculate vegetation indices. It provides advanced fire processing and analysis.

The objective of this paper is to analyze the fire in Grebaštica in detail using Sentinel-2 satellite images before and after the fire. Processing in QGIS enabled the calculation of vegetation indices (NDVI, EVI and NBR). The fire severity and burned area were explored using vegetation indices. The most effective index for fire detection and analysis was selected by comparing three different vegetation indices.

2. AREA OF ANALYSIS

Grebaštica is a settlement located in the Šibenik-Knin County. It is divided into Gornja Grebaštica and Donja Grebaštica, and is part of the city of Šibenik. It is situated about 14 kilometers south of the city of Šibenik, at 43°38' latitude and 15°59' longitude. It is surrounded by the Vela Oštrica peninsula to the north and the islet of Tmara to the south. It extends over an area of 18 km2. Grebaštica is rich in Mediterranean vegetation, pine forests and pebble beaches. It attracts visitors by its purity and numerous coves and beaches. The geographical position of Grebaštica is shown in Figure 1.

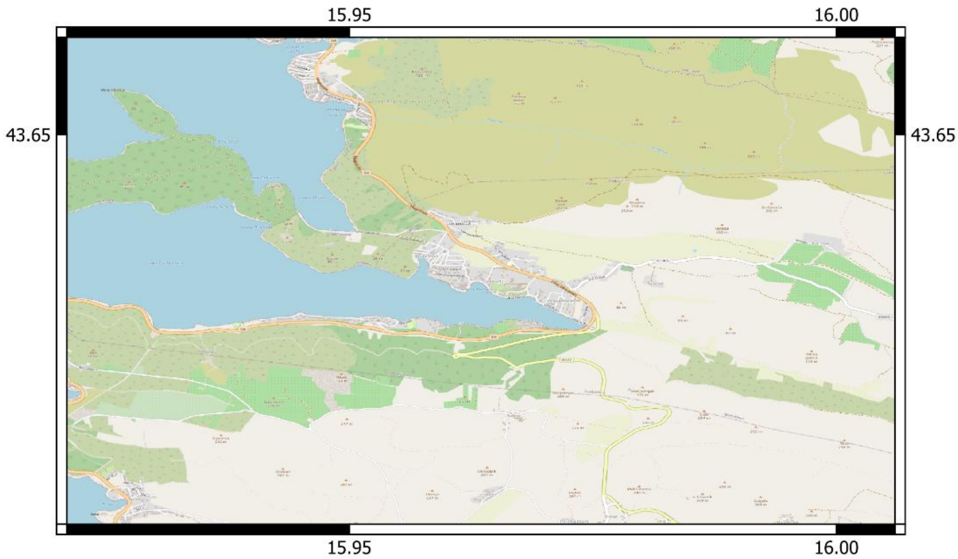


Figure 1. Geographical position of the study area: Grebaštica

According to the latest census, Grebaštica has a population of approximately 900. The economy of this area is based on the production of olive oil, known for its high quality, while fishing is also an important branch, with an annual catch of about 5 tons of fish, most often tuna and Atlantic bonito. Grebaštica is also a popular tourist destination, especially among visitors looking for a quiet vacation.

The fire in Grebaštica was reported to the Šibenik County Fire Operations Center on 13 July 2023 at around 11:00. Thirty-three firefighters and 12 fire engines were deployed to the scene. Due to the rapid spread of the fire, three water bombers were quickly deployed. The fire came close to homes, resulting in the evacuation of two families and three firefighters being injured. One hundred and fifty firefighters with 55 vehicles remained on duty. According to the official report of the Croatian Firefighting Association, the burned area is about 600 hectares, and the fire engulfed low vegetation, grass, pine forest, maquis, houses and vehicles. The Canadair CL-415, Air Tractor and AT 802 FireBoss firefighting aircraft were deployed to extinguish the fire, while firefighters from a number of units were involved in the field, including IVP and JVP Šibenik, IVP Split, IVP Zadar, JVP Knin, JVP Vodice and numerous companies. The fire was finally declared extinguished on 18 July 2023 at around 21:00.

3. METHODOLOGY

3.1 Sentinel-2 satellite imagery

Sentinel-2 is a mission of the Copernicus program of the European Space Agency (ESA) in collaboration with the European Commission. “ESA is Europe’s gateway to space" and "an international organisation with 22 Member States” [17]. The Sentinel-2 mission is conceived and designed to provide wide-swath, high-resolution, multispectral imagery of the Earth. The Sentinel-2 satellite system was developed by an industrial consortium led by Astrium GmbH of Germany, while Astrium SAS of France developed the Multispectral Instrument (MSI) [29]. The data collected by the Sentinel-2 satellites are freely available and can be widely used in the exploration and analysis of the Earth’s surface.

The Sentinel-2 mission consists of 2 satellites, Sentinel-2A and Sentinel-2B. The satellites fly in the same orbit with a phase difference of 180°. The satellites were launched in 2015 (Sentinel-2A) and in 2017 (Sentinel-2B) in Kourou (French Guiana) using the European VEGA launch station. Each of the satellites has a mass of approximately 1.2 tons. The lifetime of the satellites is about 7 years, while the batteries and motor fuel are provided for 12 years of operation. The satellites are in sun-synchronous orbit at a mean altitude of 786 km [29], and the orbit is maintained by the propulsion system. The orbit has an inclination of 98.62°, and this is exactly what provides good coverage of the Earth's surface. The Sentinel-2 mission covers all land surfaces between 56° south latitude and 82.8° north latitude [29] and all coastal waters up to 20 km from the coast. The satellites are located above the same area on Earth every 5 days. An illustration of one Sentinel-2 satellite is shown in Figure 2.

Figure 2. Schematic view of the Sentinel-2 satellite [28]

This mission performs high-resolution multispectral imaging. The satellites are equipped with a Multispectral Instrument (MSI). The MSI is an optical telescope that uses the concept of push-broom, which is actually a sensor that collects image data. MSI is a passive sensor that uses sunlight reflected from the Earth. The reflected light is collected, or redirected via three mirrors (M1, M2 and M3) to the sensor. The field of view of the MSI telescope is 290 km wide [29]. The sensor collects data in 13 spectral bands with spatial resolutions of 60, 20 and 10 meters. Table 1 shows a detailed description of each band of the Sentinel-2 mission.

Table 1. Overview of spectral bands.

Bands	Resolution [m]	Wavelength [nm]	Bandwidth [nm]	Description
B1	60	443	20	Ultra blue band, aerosol detection
B2	10	490	65	Blue band, soil and vegetation discrimination
B3	10	560	35	Green band, gives contrast between clear and turbid (muddy) water, helps in highlighting oil on water surfaces
B4	10	665	30	Red band, detects dry vegetation, useful in identifying vegetation
B5	20	705	15	Red edge, for classifying vegetation
B6	20	740	15	Near infrared band (NIR), for classifying vegetation
B7	20	783	20	Near infrared band (NIR), for classifying vegetation
B8	10	842	115	Near infrared band (NIR), good for mapping shorelines and analyzing vegetation.
B8A	20	845	20	Near infrared band (NIR), for classifying vegetation
B9	60	940	20	Short Wave Infrared (SWIR) band, good for detecting water vapor
B10	60	1375	30	Shortwave infrared band (SWIR), for cirrus cloud detection
B11	20	1610	90	Shortwave infrared band (SWIR), measuring moisture content in soil and vegetation, differentiating between snow and clouds
B12	20	2190	180	Shortwave infrared band (SWIR), measuring moisture content in soil and vegetation, differentiating between snow and clouds

The Sentinel-2 mission, with its wide coverage area and wide field of view of both satellites, provides the possibility of monitoring fires. The high resolution of the Sentinel-2 MSI sensor allows accurate detection of even small fires, which is exceptionally important in order to respond in time. According to Qi Zhang et al.[11], the B4, B11 and B12 bands of the Sentinel-2 satellite are especially important in the process of fire detection because it has been shown that large active fires exhibit higher top of atmosphere reflectances in SWIR bands. SWIR reflectance is impacted by water absorption, which makes the SWIR spectral bands positively sensitive to the presence of water within vegetation. The reflectance of burnt vegetation in the SWIR bands is therefore significantly higher, in contrast to the very low reflectance in the NIR bands. The development of fire hazard maps, which show areas with an increased probability of fire outbreaks, is of key importance in the context of fire prevention. Such maps provide vital information that makes it possible to make informed decisions within preventive measures to reduce environmental risks. The map should also include vegetation data, providing a view of different degrees of hazard. Using remote sensing techniques and data from the Sentinel-2 MSI sensor, it is possible to apply multispectral imagery to map vegetation and assess burned areas. According to Georgios Zagalikis [2], fires on areas up to 30 ha can be detected with the resolution of Sentinel-2 satellite images of 20 m. The spatial resolution of Sentinel images of

10 m enables the identification of smaller burned areas with high accuracy, often reaching an accuracy of 85–90%, while the 20 m resolution reduces this accuracy to 70–80% due to mixing pixels and limited ability to detect smaller or fragmented fires. Post-fire data from Sentinel-2 play a key role in damage assessment and recovery planning of the affected area. A map of the burned area can be generated using multispectral data and applying vegetation indices, which significantly improves the detection of fire-affected areas.

3.2 Satellite data download

Multispectral satellite images from the Sentinel-2 satellite, which are freely available through the Copernicus Data Space Ecosystem [26] platform, were used for fire analysis. Access to data requires user registration and allows searching according to the selected area of interest. For the analysis of the images, the Sentinel-2 mission was selected with the time range from 10 to 31 July 2023, with the maximum cloud coverage set to 30% for the Grebaštica area. Low cloud coverage is crucial for the accuracy of burned area analysis, as it ensures better visibility of the scene and facilitates further data processing. The downloaded images were taken on 11 July 2023 (before the fire) and 16 July 2023 (after the fire).

3.3 Image preprocessing and processing

Data were analyzed and processed using QGIS software (version 3.36.2-Maidenhead). It is a free software used to present, edit, analyze, manage, and visualize geospatial data. Satellite imagery data were processed using the Semi-Automatic Classification Plugin. Initially, pre-fire images were corrected for atmospheric effects using the option of removal of atmospheric reflectance which occurs when light is scattered by various air molecules in the atmosphere. Applying atmospheric correction improves the image quality.

3.4 Calculation of vegetation indices

Vegetation indices, dimensionless quantities based on reflected or absorbed light, are used to present the affected area and inspect the damage caused [10]. Vegetation indices find wide application in agriculture, forestry and environmental change monitoring, including flood detection and vegetation vigor monitoring. Healthy plants are characterized by high reflectance in the NIR region of the electromagnetic spectrum and low reflectance of red light due to chlorophyll absorption, while in dry plants this ratio changes, with red light reflectance increasing and NIR decreasing. Vegetation indices are based on a mathematical combination of at least two spectral bands, and since different indices are adapted to different parameters, three vegetation indices adapted to fire detection were selected for fire detection in this paper. The analysis was performed on images before and after the fire, where it is important to note that the vegetation indices were calculated only with images on which atmospheric correction was performed.

NDVI, or the Normalized Difference Vegetation Index is adapted to monitoring the health of plants and is most widely used in forestry. NDVI is calculated as the ratio of the difference and sum of reflectances in the red and near-infrared parts of the spectrum, which is shown by the following expression:

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (1)$$

EVI, or the Enhanced Vegetation Index, is a vegetation index similar to NDVI. Unlike NDVI, EVI also uses the blue band to improve the sensitivity of vegetation reflectance. EVI also corrects the background signal of the soil and reduces atmospheric effects. The EVI index is calculated according to the following formula:

$$EVI = G \times \frac{NIR - RED}{NIR + C1 \times RED - C2 \times BLUE + L} \tag{2}$$

NIR, RED and BLUE indicate spectral bands, or their reflectances in the near infrared, red and blue parts of the electromagnetic radiation spectrum. C1 and C2 are coefficients related to aerosol corrections and are usually C1 = 6 and C2 = 7.5. G is the gain factor and is 2.5, while L is the canopy adjustment factor and is 1 [30].
NBR, or the Normalized Burn Ratio, is a vegetation index specifically adapted for the detection and analysis of vegetation damage caused by fires. The formula for calculating the NBR index is similar to the formula for calculating the NDVI index. The difference is that the formula for the NBR index uses near-infrared and short-wave infrared spectral bands. The formula for calculating the NBR index is shown by the following expression:

$$NBR = \frac{NIR - SWIR}{NIR + SWIR} \tag{3}$$

3.5 Analysis of the burned area

The post-processing of the data included several key steps. After calculating the vegetation indices with spectral bands of the pre- and post-fire satellite images, the ΔNBR index, also known as the Delta Normalized Burn Ratio, was calculated. This vegetation index is used to assess vegetation damage, burn severity, and to calculate the burned area. The ΔNBR index is based on a comparison of the reflectance in different spectral bands, where areas with greater fire damage have positive index values, while areas with less or no damage have negative values or values close to zero.

In this research, the ΔNBR index was used to estimate the burned area and for a more detailed visualization of the extent of the fire, which will be further elaborated in the following parts of the paper. To precisely calculate the burned area, it is necessary to identify the area of interest, and for this purpose, data on the administrative boundaries of the Republic of Croatia, downloaded from Geoportal of the National Spatial Data Infrastructure (*NIPP*), were used. The area of analysis included the wider area around Grebaštica, as shown in Figure 3.

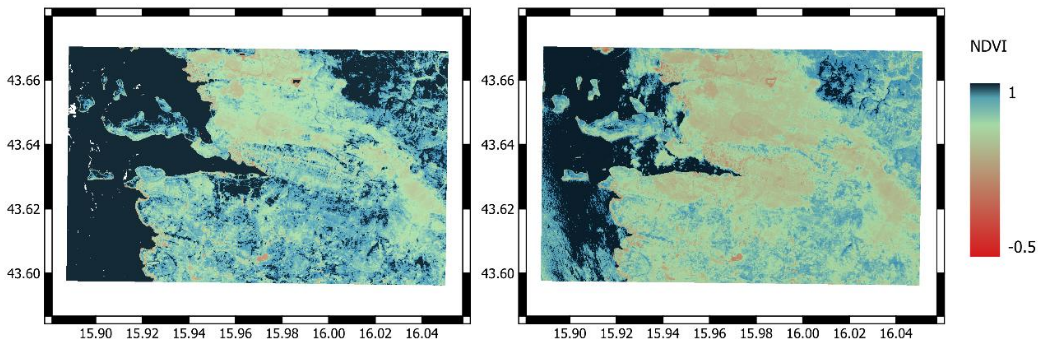
Figure 3. Selected administrative research area

The administrative area of Grebaštica was identified within the dNBR index using the method of selecting the target layer and mask, which made it possible to precisely identify the relevant area. Before calculating the area, the dNBR index was reclassified according to the USGS standard. The final calculation of the area was performed on the reclassified layer, thus generating a report on the size of the fire-affected area.

4. RESULTS

Vegetation indices (NDVI, EVI, NBR, and ΔNBR), which make it possible to clearly present the impact of fire on vegetation, were used for fire detection and monitoring. They were made for the area of Grebaštica before and after the fire and are shown as maps at a scale of 1:60,000. The results are presented in Figure 4 in the official coordinate system of the Republic of Croatia, HTRS96 (epoch 1995.55).

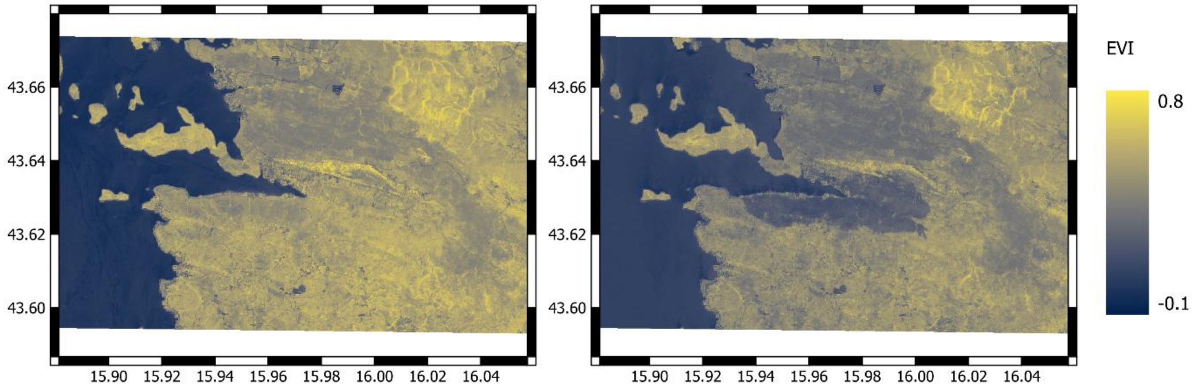
In Figure 4a, which shows the pre-fire NDVI, the values range from -1 to 1, where brown indicates areas without vegetation (-1) and green indicates healthy vegetation (1). The dominance of yellow and green shades indicates the presence of healthy vegetation, with smaller areas of dry vegetation or areas without vegetation. Figure 4b shows the post-fire NDVI values, where a wider area colored in yellow is visible, indicating damage to the vegetation caused by the fire.



a) b)

Figure 4. View of the NDVI index a) before the fire on 11 July 2023, and b) after the fire on 16 July 2023.

The EVI values are shown in shades of red and black in Figure 5. Black indicates water surfaces, while different shades of red show land. In Figure 5a, which shows the EVI before the fire, the red color dominates, indicating soil without visible damage. Figure 5b illustrates the area affected by the fire, where a darker shade indicating damage is clearly visible. The burned area is better visible with the EVI index than with the NDVI values, which indicates a higher sensitivity of the EVI index in the detection of fire damage.

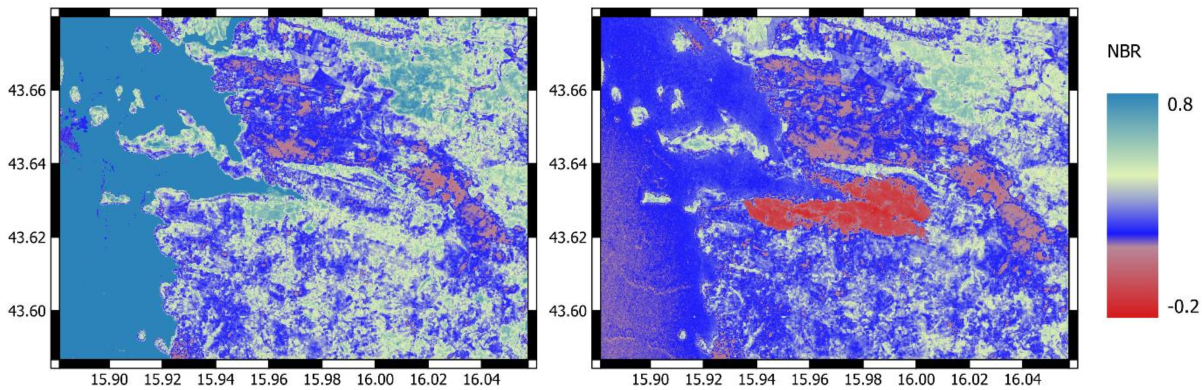


a) b)

Figure 5. View of the EVI index a) before the fire on 11 July 2023, and b) after the fire on 16 July 2023.

Figure 6a shows the NBR index before the fire, with index values ranging from -1 to 0.5. This index is represented by a color scale that ranges from red, corresponding to a value of -1, to green, corresponding to a value of 0.5. The transition colors, orange and yellow, are indicative of intermediate values between completely damaged vegetation and healthy vegetation. Red indicates areas with a high level of vegetation damage, while green suggests the presence of healthy vegetation and water surfaces, like the sea. The image shows the dominance of healthy to partially damaged vegetation, indicating relatively independent and unchanged ecosystems before the fire broke out.

The NBR index for the Grebaštica area after the fire (Figure 6b) uses the same color scale and values, which allows a comparison between the state of vegetation before and after the fire. The image clearly shows an increase in the area marked in yellow and orange, indicating significant damage caused by the fire. The clarity and identification of affected areas in the image approaches that achieved using EVI, while NDVI was less effective in accurately detecting affected areas. This analysis indicates a high sensitivity of the NBR index in distinguishing the degree of vegetation damage, confirming its usefulness in assessing the ecological and spatial consequences of the fire.



a) b)

Figure 6. View of the NBR index a) before the fire on 11 July 2023, and b) after the fire on 16 July 2023

The intensity of burning and danger and a slightly different visualization of the fire are shown in Figure 7. The ΔNBR vegetation index represents the difference between the NBR indices of the pre- and post-fire images. This index makes it possible to more accurately assess the damage to vegetation and soil caused by the fire. According to ΔNBR, green color indicates areas where vegetation is burned, implying the absence of fire danger. Yellow color indicates areas with mild damage to vegetation, indicating a low fire danger. Orange color indicates areas that have suffered moderate damage and represent a medium danger, while red color shows more severe damage to vegetation and soil, indicating a high danger. Very severe damage is indicated by purple color, indicating extreme fire danger. This color system provides a clear visualization and interpretation of the danger in the post-fire environment.

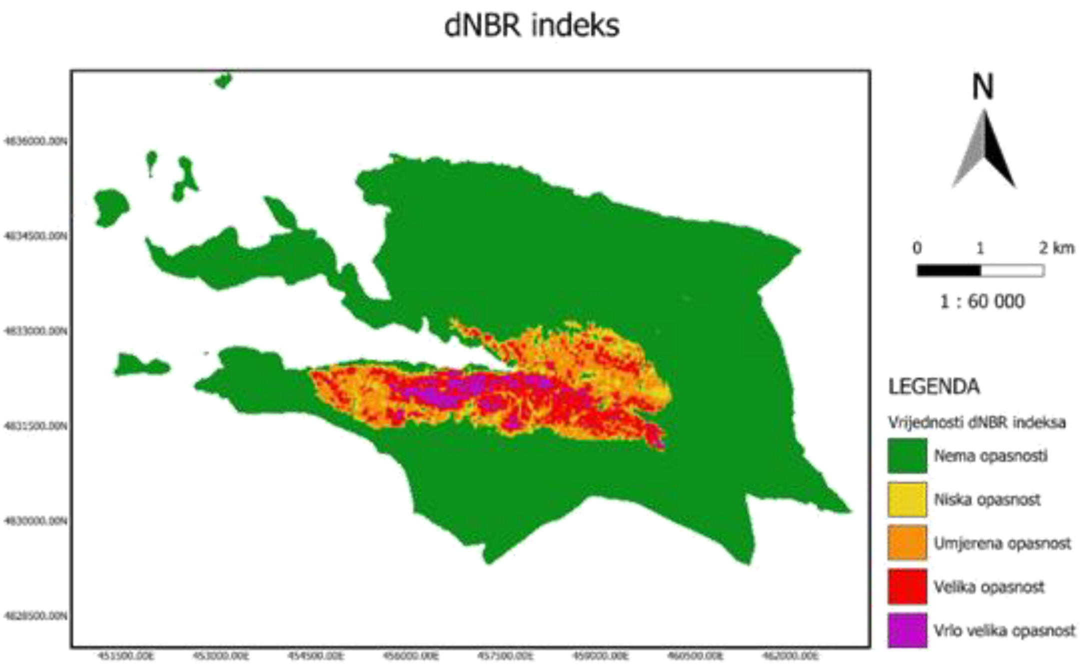


Figure 7. View of the NBR index

For an accurate calculation of the burned area, the ΔNBR index was subjected to reclassification according to USGS standards, which ensures uniform rules for the interpretation of changes in vegetation caused by fire. The reclassified presentation of the ΔNBR index makes it possible to precisely quantify the affected burned areas and to better analyze dangers in the post-fire landscape. The reclassified ΔNBR index is visualized according to a similar principle as the standard ΔNBR index, but with additional categories that provide a more accurate analysis of the vegetation condition. In this expanded classification, two new categories indicate areas with very healthy vegetation, which implies exceptionally dense vegetation, and areas with healthy vegetation, which are recognized as non-fire areas and areas not warning of fire danger.

The reclassified ΔNBR index provides a better and more detailed interpretation of the state of fire-affected areas, with an emphasis on the differences between healthy and damaged vegetation. This index has proven to be exceptionally useful for accurately presenting fire-affected areas, because it provides a clear identification of the severity and spread of damage, thus improving the understanding of the danger and the need for recovery of the affected areas. In accordance with the reclassified ΔNBR, an automatic calculation of burned areas from satellite data was conducted, and the results are shown in Figure 8.

```
+-----------------------------------------------------------------------------+
|                        RASTER MAP CATEGORY REPORT                            |
|LOCATION: temp_location                              Tue Jun 25 00:35:04 2024|
|-----------------------------------------------------------------------------|
|          north: 4900020    east: 609780                                     |
|REGION    south: 4790220    west: 499980                                     |
|          res:        10    res:       10                                    |
|-----------------------------------------------------------------------------|
|MASK: none                                                                   |
|-----------------------------------------------------------------------------|
|MAP: (untitled) (rast_6679f49542ad96 in PERMANENT)                           |
|-----------------------------------------------------------------------------|
|                     Category Information                        |          |
| #|description                                                    |  hectares|
|-----------------------------------------------------------------------------|
|-2|# Enhanced Regrowth, high (post-fire). . . . . . . . . . . . . |         0|
| 0|# Unburned . . . . . . . . . . . . . . . . . . . . . . . . . . |        64|
| 4|# High Severity. . . . . . . . . . . . . . . . . . . . . . . . |        65|
| 1|# Low Severity . . . . . . . . . . . . . . . . . . . . . . . . |       116|
| 3|# Moderate-high Severity . . . . . . . . . . . . . . . . . . . |       213|
| 2|# Moderate-low Severity. . . . . . . . . . . . . . . . . . . . |       248|
|-1|# Enhanced Regrowth, low (post-fire) . . . . . . . . . . . . . |      3170|
| *|no data. . . . . . . . . . . . . . . . . . . . . . . . . . . . | 1,201,728|
|-----------------------------------------------------------------------------|
|TOTAL                                                             | 1,205,604|
+-----------------------------------------------------------------------------+
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Figure 8. View of the burned area calculation report

The report shows the calculation of the burned area of the extracted part of the raster, as well as individual areas at risk of fire. It is also visible that the areas are expressed in hectares. The total burned area is 642 ha.

5. CONCLUSION

This paper includes an analysis of the burned area caused by the fire that engulfed the area of Grebaštica, Croatia, on 13 July 2023. The analysis was conducted using multiband data from the European Space Agency's optical satellite mission Sentinel-2. All data used were downloaded without restrictions through the open and publicly available platforms of the Copernicus program, which provides free access to high-quality satellite images and products.

The analysis of vegetation indices (NDVI, EVI and NBR) calculated from pre- and post-fire satellite images determined that the fire caused significant damage to vegetation and soil, which was clearly reflected in a significant decrease in the value of the indices. Based on the conducted analysis, it was concluded that the NBR vegetation index is the most suitable for quantifying and visualizing the effects of fire, thanks to its sensitivity to changes in vegetation reflectance, especially in the near-infrared (NIR) and short-wave infrared (SWIR) spectra. While EVI also presented a good insight into the burned areas, NDVI did not provide sufficiently accurate information on the severity of the damage.

By calculating the dNBR value, based on the difference between the pre- and post-fire NBR, it is possible to assess the danger and degree of damage caused by the fire. Using dNBR in combination with administrative boundaries, the burned area was calculated to be 642 ha, which is larger than the estimated area of 600 ha according to official data from the Croatian Firefighting Association.

The research confirms the high efficiency of using satellite images and vegetation indices in the analysis and assessment of catastrophic events such as fires. Using satellite images and vegetation indices, it is possible to quickly, accurately and quantitatively determine the extent of the burned area.

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REFERENCES

1. Stipaničev, D.: Centar za istraživanje požara otvorenog prostora Split, Godišnjak Akademije tehničkih znanosti Hrvatske, 2021, pp. 322-325.
2. Zagalikis, G.: Remote Sensing and GIS Applications in Wildfires, Climate Change and Fires, 2023, pp. 5-15.
3. Farhadi, H., Ebadi, H., Kiani, A.: BADI: A novel burned area detection index for Sentinel-2 imagery using Google Earth Engine platform, ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences GeoSpatial Conference, Teheran, 2022, pp. 179-183.
4. Kisić, I., Bogunović, I., Delač, D., Barčić, D.: Open space fires in the Republic of Croatia occurrence, frequency and suppression (in Croatian), Hrvatske vode, 2023, pp. 117-128.
5. Balen, J., Damjanović, D., Marić, P., Vdovjak, K., Arlović, M., Martinović, G.: FireBot – An Autonomous Surveillance Robot for Fire Prevention, Early Detection and Extinguishing, International Conference on Computer and Automation Engineering, 2023.
6. Lapaine, M., Frančula, N.: Kartografija i daljinska istraživanja, Bilten Znanstvenog vijeća za daljinska istraživanja i fotointerpretaciju, 2021, pp. 1-2.
7. Mahmood, M. R., Jumaah, H. J.: NBR Index-Based Fire Detection Using Sentinel-2 Images and GIS: A Case Study in Mosul Park, International Journal of Geoinformatics, Iraq, 2023.
8. Sivakumar, M. V. K, Roy, P. S., Harmsen, K., Saha, S. K.: Satellite Remote Sensing and GIS Applications in Agricultural Meteorology, Proceedings of the Training Workshop, Dehra Dun, India, 2003, pp. 28-37.
9. Kulo, N.: Multisensor remote sensing data integration (in Bosnian), Geodetski glasnik, 2019, pp. 71-74.
10. Bugarin, N.: Remote sensing and computer vision in the analysis of orchard images collected by a drone (in Croatian), Qualification exam, Faculty of Electrical Engineering, Mechanical Engineering and Naval Architecture, Split, 2022.
11. Zhang, Q., Ge, L., Zhang, R., Metternicht, G. I., Liu, C., Du, Z.: Towards a Deep-Learning-Based Framework of Sentinel-2 Imagery for Automated Active Fire Detection, MDPI, 2021, pp. 1-5.
12. URL1:https://hvz.gov.hr/vijesti/13-vise-pozara-u-2022/3421 (available on 1.7.2024).
13. URL2:https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used (available on 22.6.2024).
14. URL3:https://www.earthdata.nasa.gov/sensors (available on 22.6.2024).
15. URL4:https://eos.com/blog/types-of-satellites/ (available on 22.6.2024).
16. URL5:https://dataspace.copernicus.eu/explore-data/data-collections/sentinel-data/sentinel-2 (available on 22.6.2024).
17. URL6:https://www.esa.int/About_Us/Corporate_news/ESA_facts (available on 22.6.2024).
18. URL7:https://sentiwiki.copernicus.eu/web/s2-mission (available on 22.6.2024).
19. URL8:https://custom-scripts.sentinel-hub.com/custom-scripts/sentinel-2/bands/ (available on 22.6.2024).
20. URL9:https://climate.esa.int/es/proyectos/fire/#_about-tab (available on 22.6.2024).
21. URL10:https://www.rezerviraj.hr/social/zapis-40708-o-mjestima-grebastica-i-sparadici.html (available on 15.6.2024).

22. URL11:https://pomorska.lzmk.hr/Natuknica?id=2584 (available on 15.6.2024).
23. URL12:https://hvz.gov.hr/vijesti/pozar-otvorenog-prostora-kod-grebastice/3884 (available on 15.6.2024).
24. URL13:https://www.agroklub.com/poljoprivredne-vijesti/sto-su-vegetacijski-indeksi-koji-su-i-cemu-sluze/76027/ (available on 20.6.2024).
25. URL14:https://www.un-spider.org/advisory-support/recommended-practices/recommended-practice-burn-severity/in-detail/normalized-burn-ratio (available on 22.6.2024).
26. URL15:https://dataspace.copernicus.eu/ (available on 8.7.2024).
27. Strategija prilagodbe klimatskim promjenama u republici hrvatskoj za razdoblje do 2040. godine s pogledom na 2070. Godinu, Narodne novine (online), 2020, https://narodne-novine.nn.hr/clanci/sluzbeni/2020_04_46_921.html (accessed on 28.11.2024).
28. Nakar, D.: Sentinel-1: Multispectral Instrument (MSI) design and system performance, 2019, DOI:10.13140/RG.2.2.27242.67529.
29. ESA: Sentinel-2: ESA's Optical High-Resolution Mission for GMES Operational Services, 2012, https://sentinel.esa.int/documents/247904/349490/S2_SP-1322_2.pdf (accessed on 28.11.2024)
30. University of Arizona: MODIS Collection 6.1 Vegetation Index Product User Guide, product guide, 2019. https://lpdaac.usgs.gov/documents/621/MOD13_User_Guide_V61.pdf (accessed on 28.11.2024)