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GEOSPATIAL ASSESSMENT OF VEGETATION CONDITION PRE-WILDFIRE AND POST-WILDFIRE ON LUŠTICA (MONTENEGRO) USING DIFFERENCED NORMALIZED BURN RATIO (DNBR) INDEX

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ABSTRACT

Wildfire is one of the most dangerous environmental stressors in most vegetation zones worldwide. Determining and monitoring this stressor is important because of the disturbances that occur during the burning of biomass in ecosystems, as well as because of the damage or suffering of organisms. In the last decade, a greater number of wildfires and burnt areas were recorded in Southern Europe and Montenegro. Therefore, it is important to develop optimal methodology and models to help in better management of forest protection against wildfire. The spatial component in firefighting plays a significant role in management. In this context, Remote Sensing and Geographic Information Systems (GIS) come to the fore, which analyze spatial data and turn it into useful information - models applied in practice. The study aims to geospatial assess condition of vegetation pre-wildfire and post-wildfire in study area of the Luštica peninsula in Montenegro during the summer of 2017. Open and publicly available Sentinel 2 satellite was used. The scaled index differenced Normalized Burn Ratio (dNBR) of burned vegetation was applied as an indicator for assessing the state of vegetation after a wildfire in the open source software Quantum GIS (QGIS). The results of the damage assessment of the burned area based on the applied scaled index reveal that the category of low severity occupies an area of 335.86 ha (7%), moderately-low severity 250.13 ha (5%), moderately-high severity 406.22 ha (8%), high severity 238.03 ha (5%). The unburned areas occupy an area of 3624.95 ha (75%). This study contributes to assessing vegetation conditions and other accompanying activities pre-wildfire and post-wildfire using modern open-source geospatial tools.

Keywords: Wildfire, GIS, Remote sensing, Burned vegetation, Montenegro.

INTRODUCTION

Wildfire (Pavelek et al., 2017) or wildland fire (Eskandari, 2017) burns without control in a natural environment where the main and primary fuel is vegetation (Marić et al., 2021).

Wildfire is the one of most hazardous natural disasters (Bonazountas et al., 2005). It is also one of the most dangerous environmental stressors today. It is a significant disorder where a large part of the biomass is combusted and burned, and due to intensive exposure to heat and toxicity, organisms can be killed or damaged (Freedman, 2015; Potić et al., 2017).

Their impact on the physical and biological environment is hard to underestimate; they affect land use and land cover, ecosystems, biodiversity, natural disasters and contemporary climate change. As such, they influence and somewhat determine the socio-economic system of the areas in which they appear (Lukić et al., 2017; Adaktylou et al., 2020).

During the last decade, a large number of forest fires affected the area of southern Europe, as well as Montenegro. The previous wildfire protection system in Montenegro, especially in the coastal region of Montenegro, was inadequate. Given that it does not produce results, one could safely conclude that it is dysfunctional (Ministry of the Interior of Montenegro, 2021).

Therefore, it is important to develop optimal methodology and models to help in better management of forest protection against wildfire. The spatial component in firefighting plays a significant role in management. In this context, Remote Sensing and Geographic Information Systems (GIS) come to the fore, which analyze spatial data and turn it into useful information - models applied in practice (Valjarević & Živković, 2016; Jovanović et al., 2018; Potić & Šimunić, 2019; Milanović et al., 2009, 2016, 2019, 2020; Šiljeg et al., 2017, 2021 Artan & Spalević, 2020; Durlević et al., 2021; Ćurić et al., 2022).

Remote sensing enables the use of various tools, which with the help of recordings from several periods ensure users the identification of changes and the quantification of losses after wildfire. Due to their high spatial (10 m) and temporal (5 days) resolutions, the time series of images of the Copernicus satellite SAR Sentinel 1 (S-1) and the optical Sentinel 2 (S-2) provide a great opportunity to monitor vegetation areas. Unlike most SAR data (e.g. RADARSAT-2 or TerraSAR-X) and optical satellite platforms (e.g. SPOT, Planet, WorldView 2,3) this data is free and available for use without restrictions (Jovanović et al., 2021).

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The application of Normalized Burn Ratio (NBR) and differenced Normalized Burn Ratio (dNBR) indices using satellite images has been the subject of many studies in various wildfire-affected landscape areas and is considered to be effective for identifying damage to burned areas (Roy et al., 2006; Miller & Thode, 2007; Keeley, 2009; Veraverbeke et al., 2010; Parker et al., 2015; Potić et al., 2016, 2017, 2019; Jovanović & Župan 2017; Santos et al., 2020; Alcaras et al., 2022; Ponomarev et al., 2022).

This study aims to geospatial assess condition of vegetation pre-wildfire and post-wildfire in study area of the Luštica peninsula in Montenegro during the summer of 2017. Open and publicly available Sentinel 2 satellite data were used. The scaled index dNBR of burned vegetation was applied as an indicator for assessing the state of vegetation after a wildfire in GIS open-source software Quantum GIS (QGIS).

MATERIALS AND METHODS

Study area

This study was conducted for the area of the Luštica peninsula (Figure 1), which is located in the coastal area of Montenegro at the entrance to the Bay of Kotor (42°21′42″ - 42°25′55″ N, 18°32′50″ - 18°42′36″ E). It covers an area of 48 km^2. The territory of the peninsula belongs to the municipalities of Tivat and Herceg Novi. The most widespread is the karst type of relief formed by banked and layered limestones, and less often dolomite, in the central part it has the character of an undulating plain with several scarps, sinkholes and coves. The coast is characterized by numerous bays, cliffs, capes and coves with several beaches. The climate has all the characteristics of the Mediterranean.

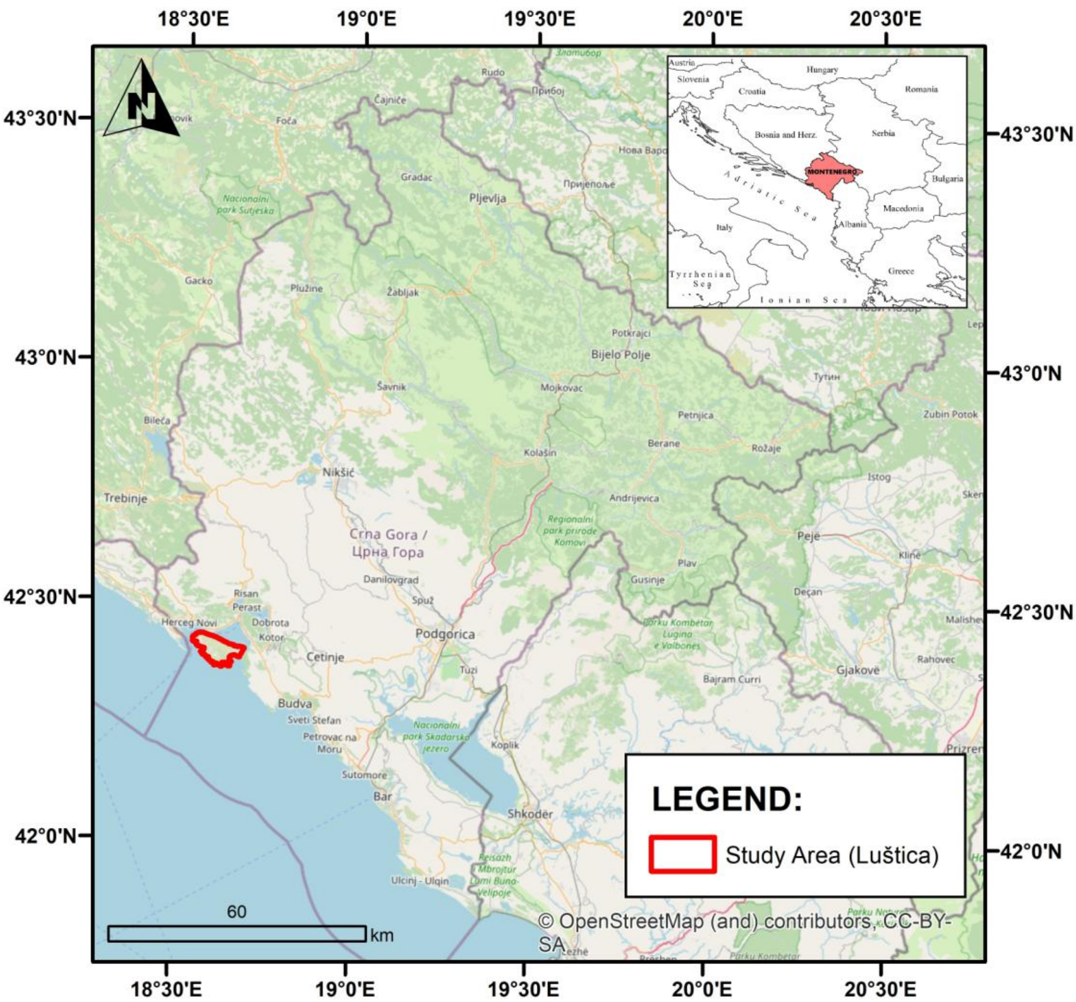

Figure 1. Location map of Luštica.

Typical Mediterranean vegetation has developed on Luštica. Maquis is the dominant type of vegetation. A set of specific and varied natural and cultural landscapes (Figure 2) characterizes the entire geospace making a unique and harmonious whole of natural, semi-natural, cultural and recognizable remains of olive cultivated area (Čurović et al., 2019).

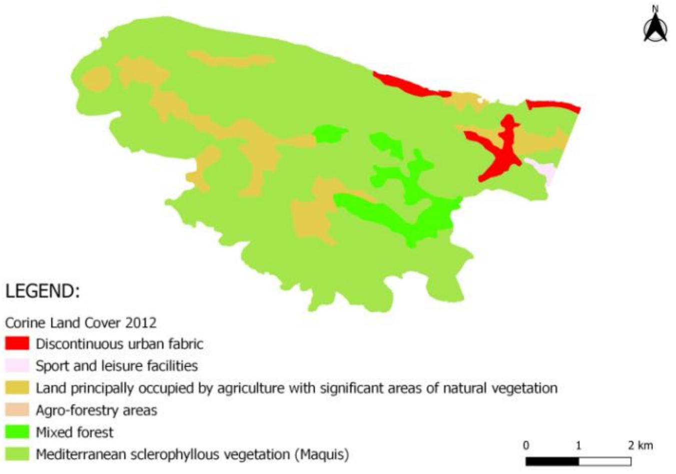

Figure 2. Landscape map according to CLC 2012.

Input data

Open-source and free-of-charge Sentinel-2 satellite images are provided by ESA (European Space Agency) through the constellation of Sentinel-2A and Sentinel-2B satellites. For this study, images from the Sentinel-2A satellite are used. Band characteristics with resolution and central wavelengths are found in Table 1. The Copernicus program continuously monitors the Earth through Sentinel satellites. These satellite images from the geospatial database are the main data acquisition channel for risk and recovery mapping (ESA, 2015).

For the purposes of this study, two Sentinel-2A data sets were used: the first data set refers to July 14, 2017, and represents the pre-wildfire scenario. While the second one was acquired on August 23, 2017, and represented the scenario post-wildfire.

Methodology

Geospatial modeling process of selected Sentinel-2A images for geospatial assessment of vegetation condition pre-wildfire and post-wildfire implemented in open-source GIS software Quantum GIS (QGIS) 3.18.2.

Both images were resampled using the cubic convolution method, so they are oriented towards the north and georeferenced projection coordinate system of the universal transverse Mercator projection (UTM 34N) on the WGS84 rotation ellipsoid (EPSG:32634) and stored in raster GeoTIFF format. The images are cropped within the boundaries of the Luštica peninsula for easier further processing using tool Extract by Mask.

The Normalized Burn Ratio (NBR) was developed to help identify areas affected by wildfire and assess the damage to those areas (Equation 1) (García & Caselles, 1991). The Differenced NBR (dNBR) is a scaled index of the magnitude of changes caused by wildfire in a certain area and is used as a descriptive measure of environmental change (Equation 2) (Key & Benson, 1999, 2004; Twele, 2004). Finally, the NBR and dNBR were calculated in Raster Calculator using expressions:

$$NBR = \frac{(NIR - SWIR)}{(NIR + SWIR)} \quad (1)$$

$$dNBR = NBR_{pre} - NBR_{post} \quad (2)$$

Obtained raster values after implementation expressions were reclassified according to the standardized dNBR categories from Table 2 for easier quantitative and visual interpretation of the results using Reclassify by Table tool. After that, the reclassified raster values were converted to a vector using Raster to Polygon tool for calculation of the area for the categories. In the end, the areas were calculated for all categories in Attribute Table in Field Calculator.

Table 1. Features of Sentinel-2A images.

Sentinel-2A		
Band	Central Wavelength (μm)	Resolution (m)
B1-Coastal Aerosol	0.443	60
B2-Blue	0.490	10
B3-Green	0.560	10
B4-Red	0.665	10
B5-Red Edge1	0.705	20
B6-Red Edge2	0.740	20
B7-Red Edge3	0.783	20
B8-NIR	0.842	10
B8A-Narrow NIR	0.865	20
B9- Water Vapor	0.945	60
B10-SWIR Cirrus	1.375	60
B11-SWIR1	1.610	20
B12-SWIR2	2.190	20

*Source: ESA, 2015

Table 2. Value range of the dNBR to classify fire severity.

dNBR value range	Wildfire severity
<0.099	Unburned
0.100 - 0.269	Low severity
0.270 - 0.439	Moderate-low severity
0.440 - 0.659	Moderate-high severity
>0.660	High severity

*Source: ESantos et al., 2020; Ponomarev et al., 2022

RESULTS

The results of geospatial assessment reveal (Table 3) that the dNBR category of low severity occupies an area of 335.86 ha (7%), moderately-low severity 250.13 ha (5%), moderately-high severity 406.22 ha (8%), high severity 238.03 ha (5%). The dNBR category of unburned areas occupy an area of 3624.95 ha (75%). In order to simplify the spatial layout and scope, an overview map was created (Figure 3).

The maximum value of dNBR for burned areas was 1.07, the minimum value was 0.100, the mean value was 0.467, and the standard deviation was 0.208. Figure 4 shows the dependence (distribution) of dNBR value of each image pixel and frequency. The most frequent value was 0.617.

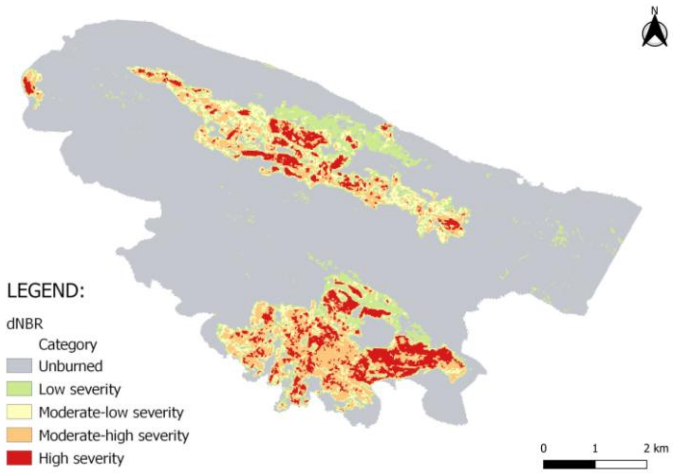

Figure 3. Overview map according to dNBR categories.

Table 3. Results according to dNBR categories.

Wildfire severity	ha	%
Unburned	3624.95	75
Low severity	335.86	7
Moderate-low severity	250.13	5
Moderate-high severity	406.22	8
High severity	238.03	5

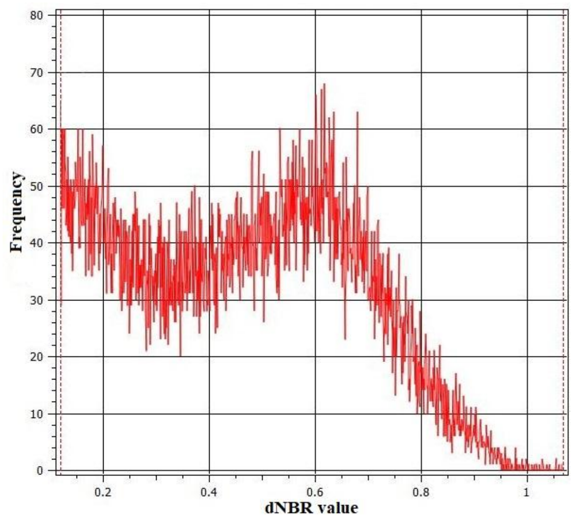

Figure 4. Graph of frequency.

DISCUSSION AND CONCLUSION

From geospatial assessment results, one can gain an insight into the harmful effects of wildfire activities on the vegetation cover. Information on vegetation condition post-wildfire in the study area can be significant for continuous monitoring of the environment and assessment of vegetation succession (Brovkina et al., 2020; Pešić et al., 2020).

This kind of geospatial assessment using the dNBR index has been validated many times in different geographical conditions, and its high efficiency has been widely discussed in previous studies (Jovanović & Župan 2017; Potić et al., 2017; Llorens et al., 2021; Alcaras et al., 2022; Ponomarev et al., 2022). This study shows the possibility of assessing vegetation's condition pre-wildfire and post-wildfire based on Sentinel-2a satellite images in a QGIS environment using the dNBR index.

There are numerous advantages of this assessment: the possibility of using it in different geographical conditions, fast research for a large area, continuous monitoring of the environment, using open-source geospatial data and software without restrictions, easy possibilities of obtaining the results of the assessment with cartographic presentation in a GIS. In addition, this approach represents an alternative to the European Forest Fire Information System (EFFIS), which uses MODIS satellite images to assess burned areas (Llorens et al., 2021). However, it is essential to say that the assessment in this study uses Sentinel-2a images that have satisfactory resolution and quality for certain applications (Jovanović et al., 2021).

Therefore, in future studies, it would be good to use satellite images of better resolution or quality in order to obtain more relevant assessment results.

This approach contributes significantly in the case of scarce geospatial tools and can be decisive for the need for sustainable and ecological management of the vegetation cover of southern Europe, which is under constant wildfire hazard in the summer.

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