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ASSESSING WILDFIRE IMPACT ON VEGETATION IN PROTECTED AREAS USING THE DNBR INDEX: INSIGHTS FROM THE DESIGNATED LOCATION IN SERBIA

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Abstract: Wildfires represent one of the most dangerous hazards to vegetation. Although they can result from natural factors, the majority of wildfires are caused by human activity. In Serbia, most fires originate from agricultural burning and subsequently spread to forests and protected areas. This study focuses on a wildfire that occurred near the Special Nature Reserve (SNR) "Carska Bara" in October 2018. SNR "Carska Bara" is located in Vojvodina, northern Serbia. Based on Sentinel-2A satellite imagery and reflectance in the NIR and SWIR2 bands, the differenced normalized burn ratio (dNBR) index was calculated in GIS environment. The dNBR values were reclassified into five categories, where lower pixel values represent areas with lower burn severity, while higher values indicate higher intensity of wildfire. The high-severity category covers 0.09% of the SNR territory, moderate-high severity 4.91%, and moderate-low severity 7.49% of the territory. The category of low severity covers 39.13% of the territory, while unburned areas account for nearly half of SNR "Carska Bara" (48.38%). The study results highlight the significance of GIS and remote sensing in wildfire detection and damage assessment in protected areas. Effective wildfire risk reduction requires prohibition of illegal agricultural burning and implementation of early warning systems that provide timely fire alerts.

Keywords: wildfires, remote sensing, dNBR, GIS, protected areas

1. Introduction

Wildfires represent one of the most significant and hazardous environmental stressors in most vegetation zones across the world (Kurbanov et al., 2022; Potić et al., 2017; Vujović & Nikolić, 2022). The environment and geodiversity, the natural diversity of geological, geomorphological, soil, and hydrological features, are also subjected to fire-induced changes during wildfire occurrence (Hoyland et al., 2024).

Protected areas represent areas of the highest importance for the ecosystems, especially in maintaining biodiversity and ecological processes (Dos Santos et al., 2018). As a result, protected areas are particularly vulnerable to hazardous events, including wildfires. Several papers investigate forest fire susceptibility in national parks (Chicas et al., 2022; Nikolić, 2024), nature parks (Novkovic et al., 2021), or geoheritage sites (Gonçalves et al., 2024).

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Satellite imagery represents a widely used data source for wildfire damage assessment (Henry & Maingi, 2024; Jovanović & Župan, 2017; Vujović & Nikolić, 2022). The destruction of chlorophyll, exposure of the bare soil, root charring, and changes in soil moisture content result in changes in the spectral characteristics of vegetation. The loss of chlorophyll leads to an increase in reflectance within the visible region of electromagnetic spectrum, while simultaneously causing a reduction in near-infrared reflectance. Additionally, the decrease in tree canopy cover and soil moisture results in an increased reflectance in the mid-infrared region after a fire event (Escuin et al., 2007; Pausas & Vallejo, 1999).

Various band combinations and mathematical formulas derived from satellite imagery produce numerous indices, which serve as valuable tools for assessing wildfire damage through different analytical approaches. According to the literature review conducted by Kurbanov et al. (2022), the most common index for calculating pre- and post-fire vegetation damages was Normalized Difference Vegetation Index (NDVI) in the period from 2000 to 2020. Following NDVI, the differenced Normalized Burn Ratio (dNBR) and NBR were among the most frequently utilized indices. NBR represents the index developed for identifying and assessing wildfire damages (García & Caselles, 1991), while dNBR is the index of the magnitude of changes caused by wildfire in a certain area (Key & Benson, 2006). Since their development, NBR and dNBR indices have demonstrated high effectiveness across various regions and countries all over the world, such as Serbia (Jakovljević & Đurđić, 2024; Potić et al., 2017), Montenegro (Vujović & Nikolić, 2022), Croatia (Jovanović & Župan, 2017), Brazil (Santos et al., 2020), Turkey (Aksoy & Selim, 2024; Masshadi & Alganci, 2021), Russia (Ponomarev et al., 2022), Kenya (Henry & Mangi, 2024), etc.

The focus of this research is the wildfire that occurred on October 15, 2018 next to Carska Bara Lake in Special Nature Reserve (SNR) and Ramsar area “Carska Bara” in Vojvodina, northern Serbia. Throughout its one-day duration, the wildfire covered over 800 ha (Živić, 2018). To the author's knowledge, no scientific data are available regarding the wildfire progression or the specific plant species affected. The aim of this research is to calculate NBR and dNBR indices in order to assess the damage caused by the wildfire. The purpose of this analysis is to call attention to the damages wildfires can cause to protected areas, expand the knowledge base, and encourage future research on this topic, thus supporting future decision-making processes in wildfire events.

2. Data and methods

2.1. Study area

SNR “Carska Bara” is located within the territory of the City of Zrenjanin, 17 km from Zrenjanin settlement, covering an area of 4,726 ha (Figure 1). This area was first designated as a protected site in 1955. In 1986, the protected area was expanded and renamed the Regional Nature Park “Stari Begej”. Ten years later, it became internationally recognized wetland of great importance for biodiversity and was included in the Ramsar site network. It was granted the status of a SNR in 2008, while its current name and extent were established in 2011 (Uredba o proglašenju Specijalnog rezervata prirode “Carska bara”, 2011, 2021).

The protected area is located in the alluvial plain of the Begej and Tisa rivers. It comprises the old Begej riverbed, lakes Carska Bara, Mala Bara, Zegmjenica, Perleska Bara, and the surrounding floodplain (Mrkša & Milanović, 2007). The area was put under protection in order to preserve the diverse flora and fauna. In “Carska Bara”, there are 32 communities of aquatic, saline, steppe, and forest vegetation, 500 taxa of higher plants, around 150 insect species, 20 fish species, 10 amphibian species, seven reptile species, as well as 239 bird species, and 31 mammal species. Many of those species are under strict protection, while 15 bird species are globally endangered (Uredba o proglašenju Specijalnog rezervata prirode "Carska bara", 2011, 2021).

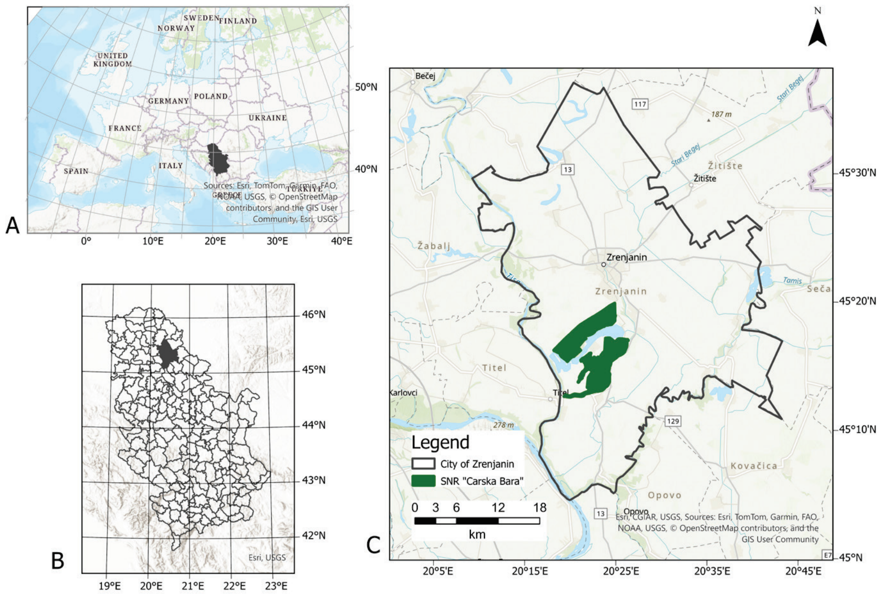

Figure 1. Study area: Serbia in Europe (A); The City of Zrenjanin in Serbia (B); and SNR "Carska Bara" (C).

The protection of "Carska Bara" contributes to the improvement of natural habitats, biological and landscape values of the area. Some of SNR's most distinctive traits are authenticity, representativeness, landscape integrity and attractiveness (JP Zavod za urbanizam Vojvodine, 2023). SNR area enables the use of the area in the interest of science, education, culture, recreation, sustainable tourism, agriculture, and fishing (Uredba o proglašenju Specijalnog rezervata prirode "Carska bara", 2011, 2021).

2.2. Data

For the analysis conducted in this research, open-source and free-of-charge Sentinel-2A data were used (Copernicus Programme, n.d.). Sentinel-2 delivers multi-spectral optical imagery essential for land monitoring, vegetation analysis, and disaster assessment, and serves as a valuable tool for wildfire mapping. It enables precise delineation of wildfire extent, including smaller and remote areas that are otherwise difficult to access. Additionally, satellite imagery can be used for post-fire damage assessment and monitoring vegetation recovery over time (Jovanović & Župan, 2017). Sentinel-2 data found their use in numerous scientific papers assessing post-fire damage through calculating dNBR index (Henry & Maingi, 2024; Jovanović & Župan, 2017; Vujović & Nikolić, 2022).

The Sentinel-2A images for pre- and post-fire dates were downloaded from the Copernicus Browser. The images were chosen based on the date that was the closest to the date of the fire, with cloud cover < 5%. The wildfire occurred on October 15, 2018, and the downloaded images were from October 14 and October 29. Choosing the images that are the closest to the fire allows comparison in vegetation, since the phenological changes in the vegetation are minimal in shorter periods. The borders of SNR "Carska Bara" were downloaded from the Protected Planet website (UN Environment Programme World Conservation Monitoring Center & International Union for Conservation of Nature, 2025). One of the advantages of using satellite imagery in analyses is their compatibility with different geographic information systems (GIS). In this paper, software QGIS (Version 3.28.12) was used for the analysis, and ArcGIS Pro (Version 3.2.0) was used for the visualization of the results.

2.3. Methodology

The images were recorded in Universal Transversal Mercator, zone 34N, with the WGS84 (World Geodetic System 1984) datum. All images were clipped using area of interest—SNR "Carska Bara" vector, for easier further processing.

As previously mentioned, the indices used for wildfire damage assessment in this paper were NBR and dNBR. The NBR (Equation 1) is calculated based on the reflectance data for Sentinel-2A Band 8 (NIR) and Band 12 (SWIR2) (García, & Caselles, 1991). Due to the difference in spatial resolution, the data were resampled to the resolution of 20 m for the final calculations. The dNBR index is calculated according to Equation 2 (Key & Benson, 2006).

$$NBR = \frac{(NIR - SWIR2)}{(NIR + SWIR2)} \tag{1}$$

$$dNBR = NBRpre\text{-}fire - NBRpost\text{-}fire \tag{2}$$

The theoretical range of the NBR varies between –1 and +1. Positive values represent productive vegetation, with high NIR reflection and low SWIR2 reflection. Values close to 0 indicate clouds, grasses, bare soil, and rocks, which do not have clear contrast between NIR and SWIR2 reflection. Negative values imply water stress on plants or wildfire damage. Due to the damages of the vegetation during the fire, SWIR2 reflection is increased, and NIR reflection is decreased, resulting in negative NBR values. The theoretical range of the dNBR varies between –2 and +2 (Escuin et al., 2007; Key & Benson, 2006; Santos et al., 2020).

After calculating the dNBR index, the results were reclassified according to the standardized dNBR categories, used in several research papers (Jovanović & Župan, 2017; Ponomarev et al., 2022; Santos et al., 2020; Vujović & Nikolić, 2022). Pixels with values lower than 0.099 were categorized as unburned, while those with values higher than 0.660 represent high wildfire severity. Three intermediate categories were distinguished between the two extreme categories: *low severity* (0.100–0.269), *moderate-low severity* (0.270–0.439), and *moderate-high severity* (0.440–0.659).

3. Results and discussion

The results of calculations show that the values of dNBR vary from –0.291 to 0.768. Most pixels have values from 0.05 to 0.12, and the mean value is 0.13915. Visual representation of NBR pre- and post-fire is given in Figure 2.

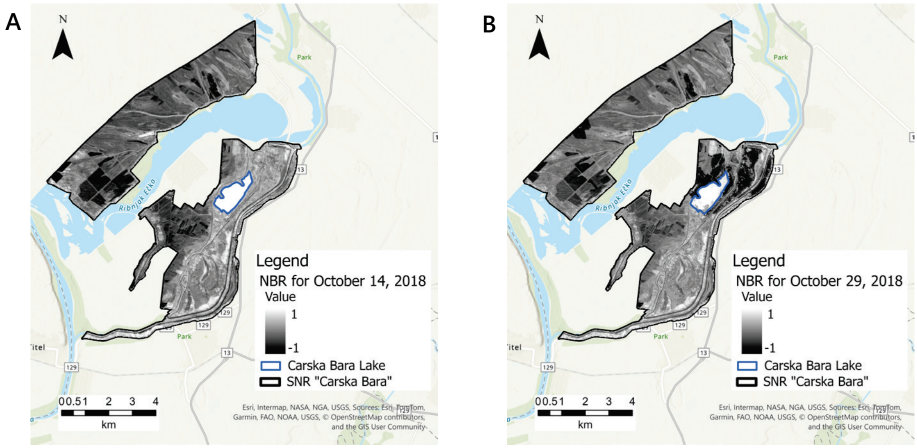

Figure 2. NBR values: Pre-fire (A); Post-fire (B).

The dNBR category of unburned areas covers nearly half of the SNR "Carska Bara" territory (48.38%). The category of *low severity* covers 39.13% of the territory. The areas of *moderate-low severity* occupy 7.49% of the territory, *moderate-high severity* 4.91%, and *high severity* 0.09% of the territory. The visualization of the final results is shown in Figure 3.

The highest values of dNBR were recorded around Carska Bara Lake in the northern part of the SNR's southern section, confirming the location of the wildfire. Although water surfaces typically do not show high NBR or dNBR values, in this case, high NBR values indicate dense wetland vegetation, as well as the presence of algae. Previous research point to the vegetation disturbance (Yu & Ginoux, 2022) and changes in hydrological systems, such as creating a low conductive ash layer through soil pore sealing (Lewis et al., 2021), due to post-fire dust and ash emissions. Therefore, high dNBR values on Carska Bara Lake can be the result of both vegetation and algae damages, as well as the dust and ash accumulation. The areas that show *low severity* values do not necessarily represent the burned areas, but the areas where the phenological changes of vegetation occurred during the two weeks between the satellite images. During October, agricultural activity declines, and vegetation naturally transitions due to seasonal changes.

In Serbia, a significant number of wildfires originate on the agricultural land, as a part of traditional land preparation practices (Novkovic et al., 2021). Studies of spatial and temporal patterns of wildfires in Serbia were conducted for the periods 2000–2013 (Gajović & Todorović, 2013) and 2013–2023 (Vranić & Mišić, 2024). In the period 2000–2013, the highest peak of wildfire frequency was recorded in October, due to the illegal burning of the remaining crops on agricultural land (Gajović & Todorović, 2013). In the light of this, it is not surprising that the highest number of wildfires in Serbia occurs in the agricultural land of Vojvodina—60% of all wildfires in Serbia for both periods (Gajović & Todorović, 2013; Vranić & Mišić, 2024). For the period 2013–2023, the City of Zrenjanin was the third municipality by the number of wildfires in Serbia, with the total of 2,471 wildfires. In the year 2018, the City was ranked the second, with 740 wildfires that occurred in that year (Vranić & Mišić, 2024). With four protected areas on its territory, the City of Zrenjanin should work on reducing wildfire risk in order to decrease the risk of wildlife destruction.

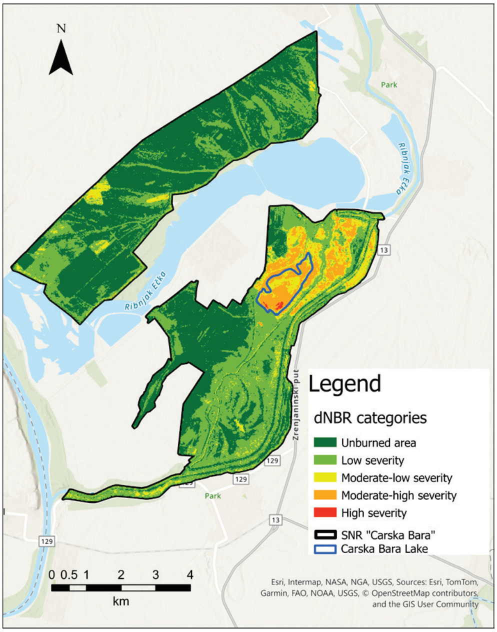

Figure 3. dNBR categories map.

To minimize wildfire risk, it is essential to prohibit illegal agricultural burning and implement early warning systems, integrated with satellite imagery and GIS. In addition to that, Internet of Things (IOT)-based sensor networks may also be integrated in wildfire prevention by continuously providing local environmental data, enabling real-time fire risk assessment (Novkovic et al., 2021).

4. Conclusion

The burning of agricultural land, negligence, and inadequate response to wildfire spreading often lead to disturbances in the ecosystems, especially in the protected areas. Located in the agricultural region, SNR "Carska Bara" is highly vulnerable to wildfires originating from agricultural land. In October 2018, one such wildfire extended into parts of this protected area. The results indicate that 13.3% of the territory was affected by the wildfire, falling into the *moderate-low*, *moderate-high*, and *high severity* categories. The highest dNBR values were recorded over Carska Bara Lake itself, primarily due to the damage of wetland vegetation, algae, and the accumulation of ash resulting from the fire.

This research emphasizes the significance of utilizing geoinformation technologies in processing wildfire data, determining the most damaged territories and the influence of wildfire on the environment. Some of the main constraints of satellite imagery are relatively low spatio-temporal resolution, high cloud coverage, etc. Considering that the research area is relatively small, and that the wildfire lasted for one day, the aforementioned constraints did not affect the results. Further research may include post-fire vegetation recovery tracking, monitoring wildfires around this SNR, as well as studying the damages wildfires caused in other protected areas in the country, and therefore influence decision-making related to (spatial) planning, managing, and response strategies in the wildfire occurrence.

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