Assessing Forest Fire Severity Using Remote Sensing: A Case Study in Western Rajaji National Park, Uttarakhand, India

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Abstract

Forest fires produces notable global threat and it can damage various ecosystems, human lives and infrastructure. This article take a look at the uses of remote sensing satellite data and techniques. In this paper the Normalized Burn Ratio (NBR) and Differenced Normalized Burn Ratio (dNBR) indices is used to estimate and visualise the burn intensity of forest fires. The Western Rajaji National Park (RNP) in Uttarakhand, India is selected as study area for this paper. Landsat satellie imagery and SNPP-VIIRS data used in this method to calculate NBR and dNBR. The research highlights the significance of appropriate satellite imagery collection and precisely prepare pre-and post-fire images. The obtained pre- and post-fire are used to create burn severity (intensity) images, produce significant observations into the impact of the forest fire ecosystems. The findings shows the efficiency of NBR and dNBR in mapping and visualizing the severity of the fire incident, helping in forest fire prevention, monitoring and evaluation. The paper contributes to the comprehensive understanding of geospatial applications for assessing various impacts and aiding decision-making actions for controlling and reduce the effects of forest fires.

Keywords: *Remote Sensing, Forest Fires, Normalized Burn Ratio (NBR), Severity and Delta Normalized Burn Ratio (NBR)*

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1. Introduction

Over the past 2 decades, there has been an annual growth in forest fires of 5.4 percent, with over 120 lakh hectares destroyed in year 2023 (MacCarthy et al., 2024). Thus, it is important to develop useful methods for estimating and monitoring the burn intensity of forest fires.

Remote sensing and satellite imagery are now un-avoidable techniques and dataset to proceed in this type of work. Remote-sensed satellite data provide a valuable resource for mapping burned area and estimating burn intensity (Prabowo et al., 2022).

To support forest fire prevention, monitoring and evaluation, and at the global to local levels, optical remote sensing methods have shown to be effective in developing models for precisely estimating fire-affected areas and burn intensity (Novo et al.,2022). Three recognizable temporal fire-related stages have been addressed by these methods: pre-fire situation, burn intensity, and post-fire vegetation growth. NBR and dNBR are are widely used indices in forest fire assessment. These quantitative indices prepared from satellite imageries that provide significant information on the intensity of burn patches (De Santis & Chuvieco, 2007).

These indices are based on the spectral reflectance values of satellite imagery's Near-Infrared and Shortwave Infrared bands. NBR and dNBR are commonly used remote sensing indices to estimate and monitor the intensity of wildfires or post-fire vegetation conditions. NBR and dNBR fomulas are as following:

$$NBR=(NIR-SWIR)/(NIR+SWIR)$$

Where,

NIR= Near Infrared image and SWIR= Shortwave Infrared image

$$dNBR=NBR\ post\text{-}fire-NBR\ pre\text{-}fire$$

Where,

NBR pre-fire is Normalized Burn Ratio of pre-fire event and NBR post-fire is vice versa.

They are derived by using of satellite images, usually from Landsat or Sentinel programs. NBR is quantify by dividing the result by the sum of the satellite's near-infrared and mid-infrared images, then multiplying the result by 1000. Subtracting post-fire NBR data from pre-fire NBR values yields continuous values between -2 and 2, which are then used to construct differenced NBR (dNBR) products. Increases in soil exposure and vegetation degradation are correlated with higher dNBR values (Key & Benson, 2006).

2. Study Area

Rajaji National Park (RNP) is a renowned national park located in the northern state of Uttarakhand, India. Established in 1983, it covers an extensive area and is named after C. Rajagopalachari, a prominent freedom fighter and the last Governor-General of India. The Park is situated in the Shivalik range of the Himalayas and is known for its rich biodiversity, stunning landscapes, and varied wildlife. Rajaji National Park covers an area of approximately 820 square kilometers. It extends across three districts of Uttarakhand: Haridwar, Dehradun, and Pauri Garhwal.

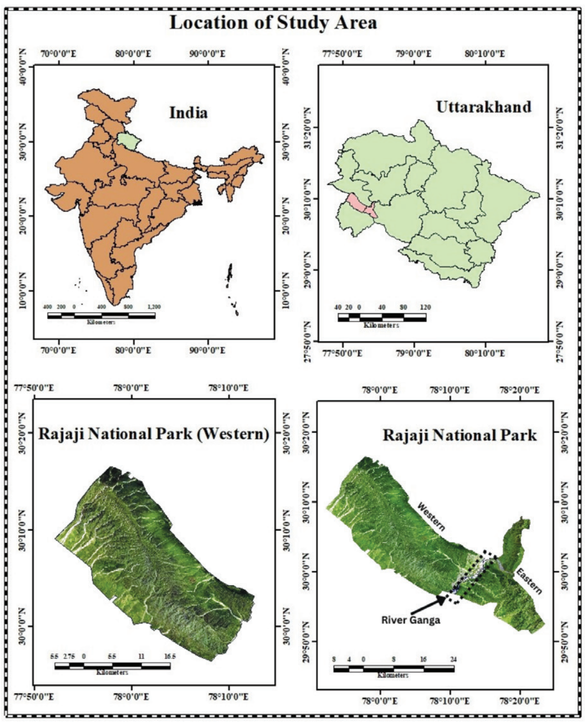

Figure 1: Map of Study Area in Rajaji National Park

The Shivalik hills, river valleys, and dense forests characterize the Park. Rajaji National Park [29°15' North to 30° 31' North Latitude, 77° 52' East to 78° 22' East Longitude] is spread over an area of 820.42 Km^2. As shown in the study area map River Ganga flows between RNP near Haridwar. The forest fire event happened between the 13^{th} to 16^{th} of May on the western side of RNP. Thus, I choose Western Rajaji National Park as the study area for better analysis. Western RNP is spread over 564.32 km^2 or 56432 hectares.

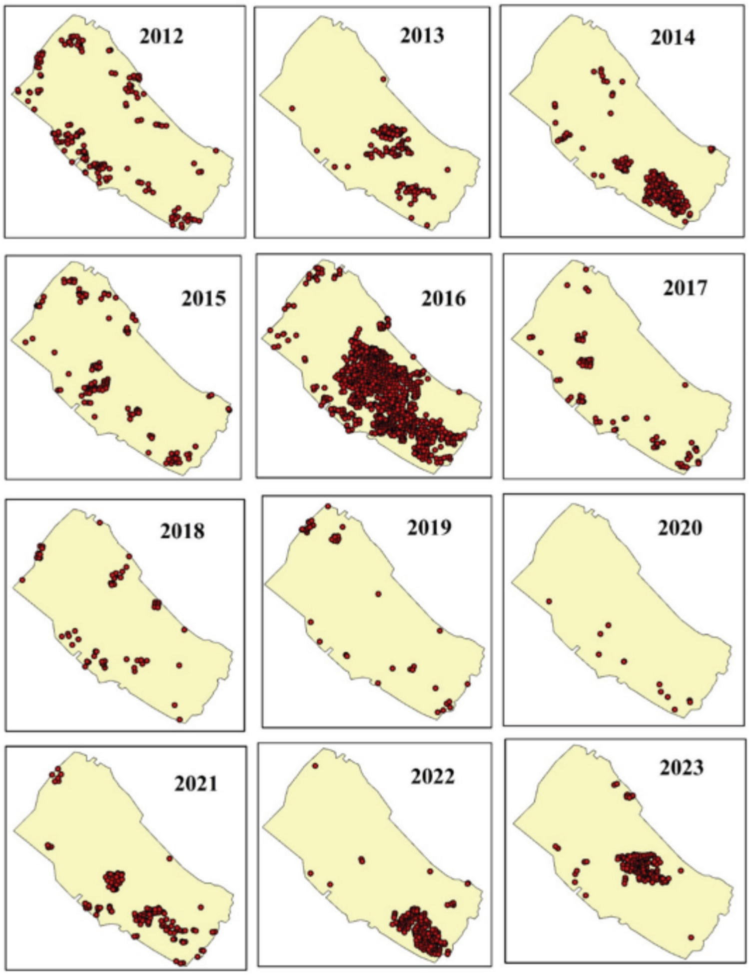

Figure 2: Historic locations of forest fires from 2012 to 2023 in Western Rajaji National Park

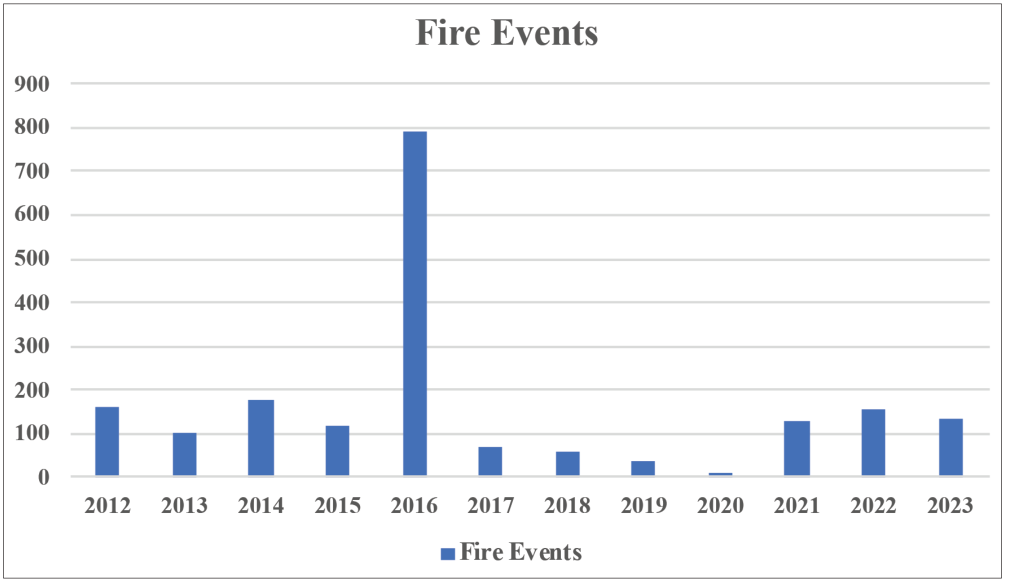

Figure 3: Historic pattern of forest fires from 2012 to 2023 in Western Rajaji National Park

The above figure 2 and 3 shows the historic pattern of forest fires from 2012 to 2023 in Western Rajaji Nation Park. One thing is important that forest fire event occurs in different places in successive years due to lack of fuel wood after forest fire event. In 2016 a massive fire erupted in this region and the number of forest fires declined in subsequent years. In 2020 number of forest fire events is lowest due to lockdown, where human activities were restricted, temperature declines and rainfall is equally distributed in the season.

3. Materials and Methodology for Calculating NBR and dNBR

The information on fire events is collected from the forest fire alert system of Forest survey of India. The bunch of polygon shown fire regions in following figure 4 are collected by SNPP-VIIRS (Visible Infrared Imaging Radiometer Suite) sensor which hast resolution of 375m. India Landsat imagery is commonly used due to its availability and spectral bands. Landsat imagery is collected from USGS Earth Explorer. Infrared (NIR) and Short-Wave Infrared (SWIR) bands were collected from the above data source. Atmospheric correction and Geometric correction of the spectral band were carried out on QGIS software. NBR is collected by using raster calculator in QGIS. To attain severity of forest fire delta NBR is calculated by measuring of difference between Pre-NBR and Post-NBR.

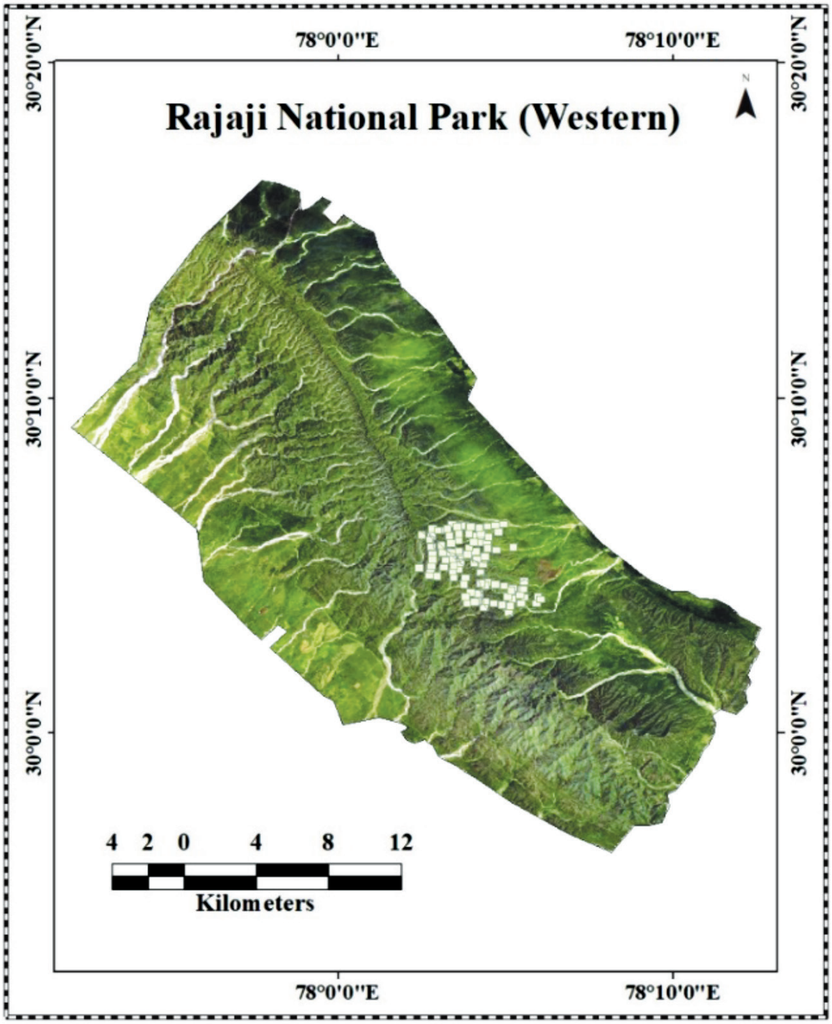

Figure 4: Showing fire region in Rajaji National Park

Data Processing: For calculating NBR satellite data of pre-fire event and post fire events are important. Condition of just before fire and just after fire is crucial for to assess severity of the fire event. If satellite data is taken much before fire event the actual condition of vegetation of the respective area is uncertain. Vegetation condition or health may be increase or decrease at the time of fire and after the fire. After some time vegetation regrowth may be start on the surface. All above condition affects the result of calculation of NBR. So satellite image collected as possible as close to the pre-fire event and post-fire event. Table 1 shows fire event date and satellite imagery acquisition date. Here satellite image of before fire event is four day older whereas satellite image is collected next day of Post-fire event.

NBR is calculated using the formula: NBR = (NIR - SWIR2) / (NIR + SWIR2)

NIR = Reflectance in the Near Infrared band

SWIR2 = Reflectance in the Short-Wave Infrared 2 band

Table 1: Pre-fire and post-fire events satellite imageries

Satellite Imagery (Acquisition Date)	Fire Event Date
09/05/2023 (Pre-Fire)	13/05/2023
17/05/2023 (Post-Fire)	16/05/2023

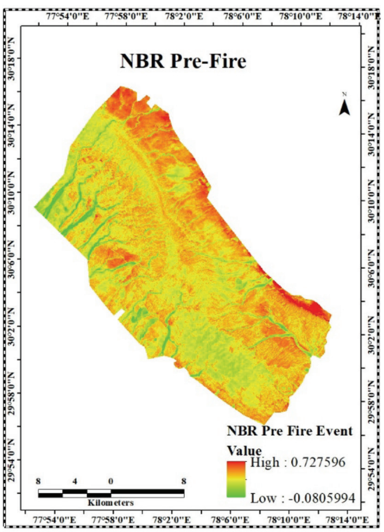

Figure 5: NBR pre-fire event

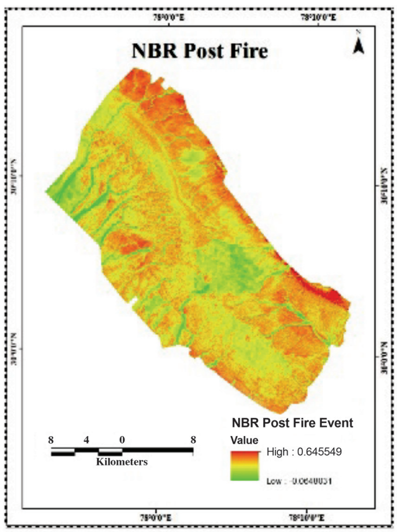

Figure 6: NBR post-fire event

Calculation of dNBR or ΔNBR: A fire's magnitude is determined by how much of an immediate impact it has on soils and vegetation due to the loss or degradation of organic matter (Keeley, 2009). The difference between the NBR composites before and after the fire is then used to calculate the Delta NBR (dNBR). The difference between the pre-fire and post-fire NBRs is known as the dNBR:

$$dNBR = NBRpost – NBRpre$$

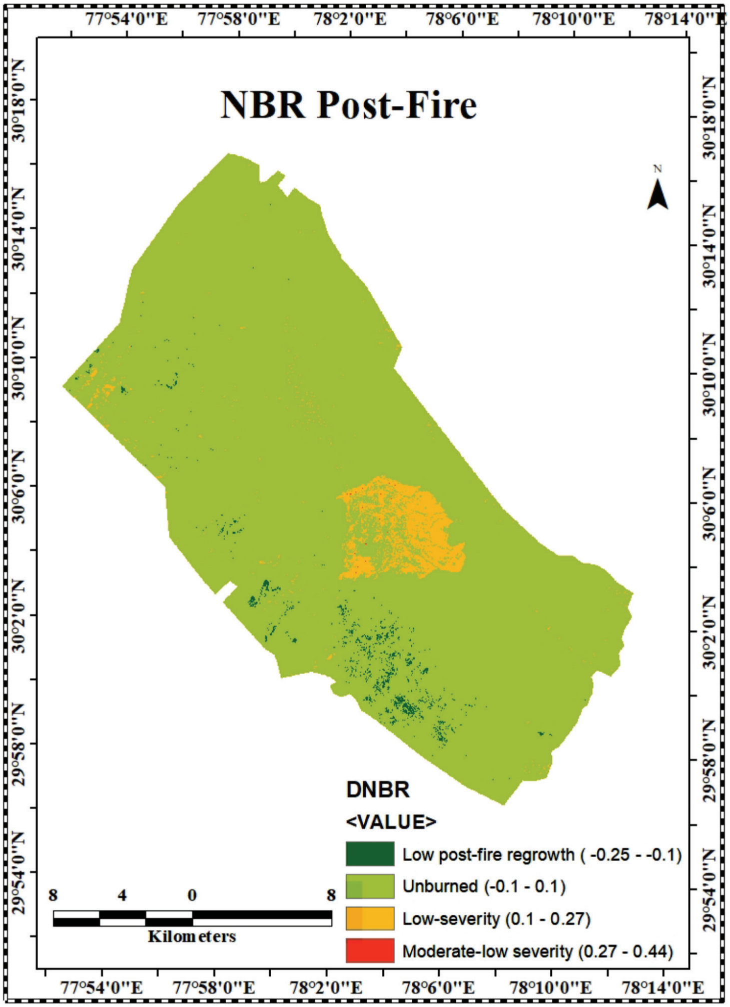

Figure 7: Showing dNBR value of post-fire

4. Results

Using formulas, NBR is calculated for the study area by using respective bands. In Figure 4 some polygons which represent fire spot by the SNPP-VIIRS sensor are shown. When we compare pre-fire and post-fire NBR data, a change recognizable change in both images are spotted in the same place as the fire spot pixel given by FSI. In post-fire events that specific place reflects less radiance as compared to other areas in both images.

The NBR indices work on reflectance values of vegetation in near-infrared and short-wave infrared. As shown in the above figure reflectance of healthy vegetation is highest in near infrared and lowest in short-wave infrared. Thus, the computation of differences between these highlight burned areas and estimate fire scar.

Table 2: Fire severity with range of dNBR

Fire Severity	Range of dNBR	Area in km^2	Area in percent
Very low Burn or post-fire regrowth	-0.25 - -0.1	4.8402	0.858
Un-burned	-0.1 - 0.1	534.2949	94.679
Low-burn	0.1 - 0.27	25.1433	4.456
Moderate-Burn	(0.27 - 0.44)	0.045	0.008

dNBR is a measure of the change in vegetation and surface conditions caused by a fire. The above table shows four classes of dNBR that exist in the study area. Based on dNBR data, the fire severity study shows that 534.29 km^2 (94.68%) of the area is still unburned, indicating little to no fire impact in this substantial area of the region. Smaller but no less significant, 25.14 km^2 (4.46%) of the area is classified as having low-burn severity, meaning that the fire only slightly damaged or destroyed some vegetation. 4.84 km^2 (0.86%) of the land is categorized as having very low burn severity or exhibiting post-fire regrowth, meaning that it was either hardly affected by the fire or is now regenerating. A small portion of 0.45 Km^2 areas lies under moderate burn.

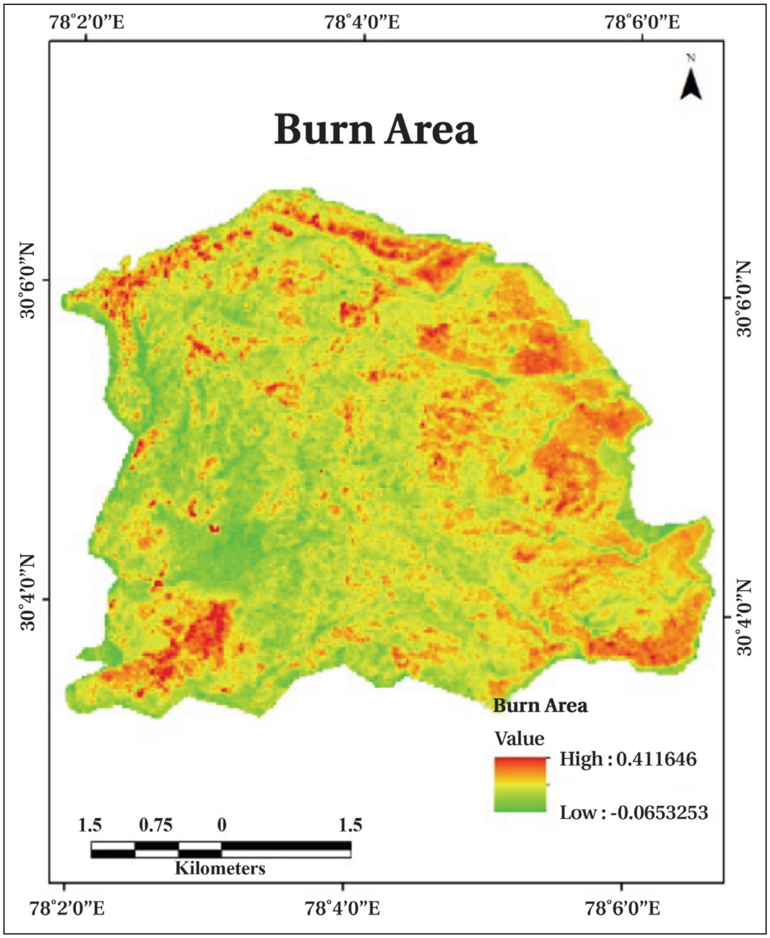

Figure 8: Showing burnt area

The above table shows the area which was impacted by fire from 13/05/2023 to16/05/2023. This area is extracted with the help of polygons downloaded from fsi.nic.in and dNBR map. During the respective period around 34 km^2 area is effected by forest fire in which some area faces moderate fire where some are facing very low or entered in the stage of plant regrowth. One the basis above image we can say polygons cannot show the exact figures of fire but they are important to locate the area where the event was happened.

5. Discussion

The study evaluated the intensity of a forest fire in the Western Rajaji National Park (RNP), Haridwar district, Uttarakhand, India, using the Normalized Burn Ratio (NBR) and differentiated NBR (dNBR). The findings show that 94.68% of the region was left unburned, indicating that the fire had little effect. Just 0.008% of the terrain was classed as having moderate burn severity, 4.46% as having low burn severity, and 0.86% as having extremely low burn or post-fire regrowth.

The capacity of dNBR to distinguish between these different levels of burn intensity was demonstrated by its successful use in remote sensing applications for assessing forest fires. But the study also raises questions about how accurate these indices are, particularly in heavily vegetated areas where it may be difficult for satellite images to properly catch surface fires because of thick canopies. Pre-fire imagery was acquired four days prior to the fire, and post-fire imagery was obtained the day following the fire's conclusion. The satellite imagery utilized in this study was meticulously selected to guarantee closeness to the fire event. To delineate the burn areas and accurately determine the intensity of the burns, earliest data collection was important.

Very low area of moderate burn intensity suggests that the fire's intensity was relatively low, and much of the area either escaped the fire or is now recovering. The ability of dNBR to detect post-fire regrowth is particularly useful in assessing vegetation recovery, providing views of how fast the forest is healing to its pre-fire state.

Beside the application of NBR and dNBR in mapping fire intensity, this paper highlights the requirement for further validation through ground-based observation or survey will improve accuracy, especially in regions with dense forest canopy. The combination of high-resolution satellite image could also improve the estimation of fire intensity assessments. Overall, this paper illustrates the application of remote sensing techniques in monitoring forest fire patches and recovery in RNP, providing significant information for forest management and conservation efforts.

When evaluating ecosystem recovery, the capacity of dNBR to identify post-fire regrowth is very helpful since it offers information on how quickly the forest is reverting to its pre-fire state.

This study emphasizes the necessity for additional validation through ground-based assessments to increase accuracy, especially in places with dense forest cover, not withstanding the usefulness of NBR and dNBR in mapping fire intensity. The accuracy of fire severity evaluations may potentially be improved by integrating igher-resolution satellite data. Several scholarly articles explore the complexities of NBR and dNBR, enhancing our comprehension of its advantages and disadvantages. Here are a few examples:

- “Explaining Sentinel 2-based dNBR and RdNBR variability with reference data from the bird's eye (UAS) perspective” examines how dNBR relates to actual burn severity on the ground, using high-resolution drone imagery for validation.

- **“Fire and burn severity assessment**: Calibration of Relative Differenced Normalized Burn Ratio (RdNBR) with field data” explores the use of RdNBR, anormalized version of dNBR, for more accurate mapping of burn severity indifferent vegetation types.

- **“Normalized Burn Ratio Plus (NBR+)**: A New Index for Sentinel-2 Imagery” proposes an NBR variation specifically tailored for Sentinel-2 satellite data, improving its sensitivity to burn scars in diverse landscapes.

The NBR and dNBR raises several interesting questions:

- **Accuracy and limitations**: What elements, such as the kind of vegetation and the severity of the fire, can influence their accuracy? Updates and improvements: How might these indices be modified and enhanced to suit other satellite data sets and particular use cases?

- **Beyond mapping**: Can the behavior of fires be predicted, the effects of fires on ecosystems modeled, or even fire management activities supported by NBR and dNBR??

5. Conclusion

NBR and dNBR are just the tip of the fiery iceberg in remote sensing of fire. By delving into their nuances and the rich tapestry of research surrounding them, we can better understand the dance of fire in our landscapes and use this knowledge to inform fire management and ecology, and perhaps even predict future flames. Let the discussion continue, fueled by research and data, as we unravel the secrets of fire from the dizzying heights of satellite imagery.

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