Identification of Forest Fire Affected Area and Burn Severity Analysis in Bankati Forest Block of Dudhwa National Park, Uttar Pradesh Using Geospatial Techniques

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ABSTRACT: In the present study analysis of forest fire location is based on MODIS/ VIIRS satellite data. Fire alert locations were downloaded from the forest fire portal http://fsi.nic.in/index.php of Forest Survey of India (FSI), Dehradun. Latest Sentinel satellite images pre and post fire was used for mapping extent area and burn severity analysis of forest fire affected because of its 5th day revisit period. Burn severity analysis has been done through NBR and dNBR indices supported by field survey. In Dudhwa National Park total 99 fire points were found and out of which 07 were large and 92 were small fire points was observed. In Bankati-1 forest block of Dudhwa National Park fire affected area was estimated as 134.17 ha. The forest type and forest density wise mapping was also done and found that 100.20 ha area is covered with grassland and 33.97 ha area is covered with Miscellaneous forest. In Bankati-1 forest block low severity, moderate-low severity and moderate-high severity was observed but in major part of forest block, Moderate-low severity is noticed, which covers about 70.13ha area besides that Moderate-high severity and Low severity also observed and covers 56.201 ha and 7.841 ha area respectively. The investigation demonstrated that remotely sensed data is an important source to map the fire affected areas in forest and assessment of burn severity.

Keywords: Sentinel, NBR, dNBR, Forest Type, Forest Fire

1. Introduction

Forest fires, alongside floods, droughts, and storms, pose a significant threat to our environment. They cause widespread damage, leading to the loss of valuable timber, rare plant species, property, and endanger wildlife. Furthermore, the aftereffects of forest fires, such as landslides, erosion, and desertification, have a detrimental impact on human life.

These fires disrupt the natural balance within forests, altering the composition, structure, and distribution of plant life. They reduce biomass and inflict significant damage on the ecological landscape. In Uttar Pradesh, human activity is a major culprit, with actions like poaching, carelessly discarded cigarettes and matchsticks by travelers and grazers, all contributing to the increasing number and severity of forest fires each year. The rising frequency of fires is linked to the decline of smaller trees, reduced overall tree density, and a proliferation of grassy undergrowth.

Accurate mapping of fire burn severity is essential to support fire management activities such as strategic planning, mitigation measures and vegetation monitoring (Garcia and Caselles, 1991; Michalek et al., 2000; Parks et al., 2014; Somashekar, 2009) whereas accurate mapping of burned areas is crucial for forest officials. This information allows them to plan mitigation measures and restoration activities after the fire season. Additionally, pinpointing the severity of fire damage is essential for effective fire management strategies, including strategic planning, mitigation efforts, and post-fire vegetation monitoring.

Forest fires inflict significant damage, disrupting the natural composition, structure, and distribution of plant life within affected areas. They reduce overall biomass and have a devastating impact on the ecological landscape. In Uttar Pradesh, human activity is a major cause of forest fires. Careless actions such as poaching, discarded cigarettes and matches by travelers and grazers contribute to the increasing frequency and severity of these fires. This rise in fire frequency is linked to the decline of smaller trees, reduced overall tree density, and a proliferation of grassy undergrowth.

Unfortunately, India lacks comprehensive and regularly updated data on the various aspects of forest fires. To address this issue and create a sustainable forest fire management strategy on a national level, several key areas require more attention. These include identifying fire-prone areas, assessing fire recurrence patterns, understanding the impacts on forest regeneration, ecological succession, biodiversity, wildlife, and conducting precise assessments of burned areas. Advancements of technology in high and moderate resolution satellite data offer valuable tools for addressing these needs (Joseph et al., 2009; Holdsworth and Uhl, 1997).

Combined with spatial analysis tools available through Geographical Information Systems (GIS), satellite remote sensing technology allows for timely and cost-effective monitoring and analysis of forest fires over vast areas. Remote sensing and GIS technology are already being used extensively in various aspects of forest fire management, including identifying fire zones, determining burn severity, and developing fire management strategies. Currently, a range of satellite-based sensors (AWiFS, LISS-III, MODIS, ETM+, SPOT, AATSR, AVHRR, and MODIS) provide data sets with potential applications in forest fire detection, inventory, mapping, and damage assessment (Joseph et al., 2009).

Image classification and fire index methods are frequently employed to analyze temporal changes in forest areas and assess burn severity. Two main spectral index methods are particularly popular for burned area detection due to their simplicity and accuracy: vegetation indices and fire indices. These indices, such as the Normalized Difference Vegetation Index (NDVI) (Tucker, 1979) and the Global Environmental Monitoring Index (GEMI) (Pinty & Verstraete, 1992), enable a more precise study of the differences between burned and unburned areas, particularly the loss of vegetation. Notably, the near-infrared (NIR) and mid-infrared (MIR) bands are preferred for forest fire analysis because they are most effective in revealing fire characteristics. Escuin et al., 2008 applied Normalized Burn Ratio (NBR) and NDVI indexes on Landsat satellite images to analyze three different fires that occurred in Cazorla, Nerva and Anzalcollar regions of Southern Spain in 1995 and 2001.

2. Study Area

Dudhwa National Park, nestled within the Lakhimpur-Kheri district of Uttar Pradesh, holds the distinction of being the state's sole National Park also known as Dudhwa Tiger Reserve Forest, this protected area sprawls between latitudes 28°41'34.948"N and 28°41'36.654"N, and longitudes 80°27'56.775"E to 80°55'27.284"E. The landscape is renowned for its rich tiger population.

Dudhwa experiences an extreme sub-tropical climate with dry winters. Summers are scorching, with temperatures reaching up to 40°C (104°F). Winters, from mid-October to mid-March, offer a respite with temperatures ranging between 20°C and 30°C (68°F and 86°F). Lush greenery dominates the park, with Sal, Teak, Asna, Shisham, Jamun, Gular, Sehore and Bahera trees forming the major part of the flora. Grasslands encompass around 19% of the park's area, adding a distinct character. The air is often filled with the fragrance of silvery Munj grass and dry red retwa petals, while vibrant hues are brought in by the golden blossoms of Narkul and cotton-like Kans near water bodies. This serves as a protected home to over 38 species of mammals, 16 species of reptiles, and countless avian species. Tigers, Rhinos, Swamp Deer, Elephants, Sambars, Hog Deer, Cheetals, Kakars, Wild Pigs, Rhesus Monkeys, Langurs, Sloth Bears, Blue Bulls, Porcupines, Otters, Turtles, Pythons, Monitor Lizards, Muggers, and Gharials are just a few of the fascinating creatures that call Dudhwa home. Remarkably, over 450 bird species, constituting nearly a third of all the birds found in the Indian subcontinent, can be spotted within the Dudhwa Tiger Reserve. Location map of study area is shown in Figure 1.

3. Materials And Methods

Forest fires in Uttar Pradesh typically occur during the dry season, concentrated between February and June. The peak fire period falls within March to May across various districts of the state. To analyze these fires effectively, Sentinel-2 satellite imagery has been chosen due to its frequent revisit time of just 5 days. Sentinel-2 carries a Multi-spectral Imaging Instrument (MSI) that captures high-resolution optical images specifically designed for land monitoring. These detailed images serve multiple purposes, including emergency response, security applications, as well as the core objective of mapping and monitoring land cover, vegetation health, burned areas, and changes occurring over time. This data from Sentinel-2 is particularly valuable for analyzing pre-fire and post-fire conditions, enabling a comprehensive assessment of forest fire events. The details given in Table1.

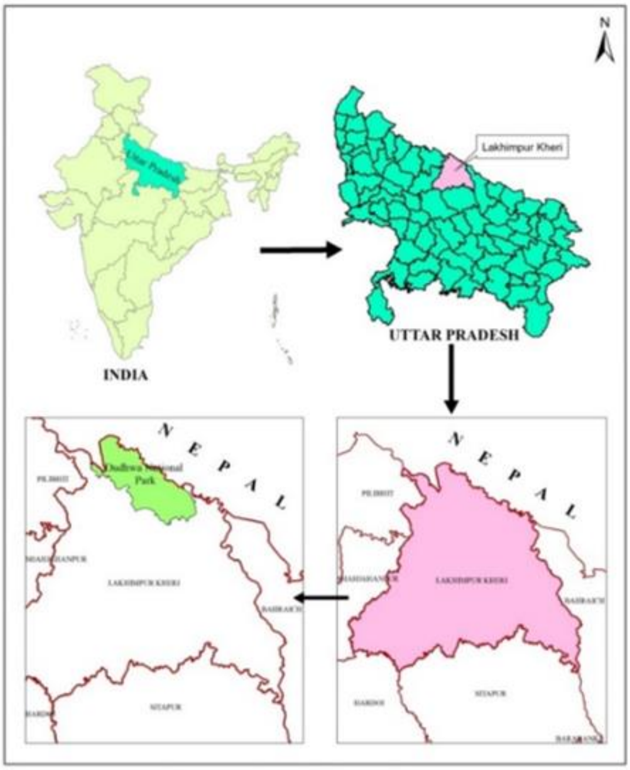

Figure 1. Location Map of the study area

Table 1. The details of satellite data

Sentinel-2 Bands	Central Wavelength (µm)	Resolution (m)
Band 1- Coastal Aerosol	0.443	60
Band 2- Blue	0.490	10
Band 3- Green	0.560	10
Band 4- Red	0.665	10
Band 5- Vegetation Red Edge	0.705	20
Band 6- Vegetation Red Edge	0.740	20
Band 7- Vegetation Red Edge	0.783	20
Band 8- NIR	0.842	10
Band 8A- Vegetation Red Edge	0.865	20
Band 9- Water Vapour	0.945	60
Band 10-SWIR-Cirrius	1.375	60
Band 11-SWIR	1.610	20
Band 12-SWIR	2.190	20

The analysis utilized geo-referenced digital satellite data downloaded from the USGS website. To create a clearer visualization of fire scars, a false-color composite (FCC) image was generated. This FCC combined data from the near-infrared (B8), red (B4), and green (B3) bands of the electromagnetic spectrum. Additionally, the near-infrared (NIR) and short-wave infrared (SWIR) bands (B12) were used to calculate indices essential for analyzing forest fire severity.

The geo-referenced data further aided in identifying and mapping the extent of the fire. Fire locations within Dudhwa National Park were obtained through the Forest Survey of India's fire portal (https://fsi.nic.in/forest-fire-activities). These locations were then converted into point data within the GIS environment. To verify the accuracy of fire locations, particularly for larger fires, a field survey was conducted. GPS coordinates were collected during this field survey to confirm burnt areas and classify forest type and density within the study area. Notably, this study employed two indices – Normalized Burn Ratio (NBR) and differenced NBR (dNBR) – calculated arithmetically from specific bands. These indices were used to estimate both the extent of the forest fire and the severity of the burn

3.1 Normalized Burn Ratio (NBR)

The Normalized Burn Ratio (NBR) index is one of the most actively used indexes in remote sensing studies for analyzing fire events. It leverages near-infrared (NIR) and shortwave infrared (SWIR) bands by calculating the ratio between their difference and their sum (Roy et al., 2005).

$$\mathbf{NBR} = \frac{\mathbf{NIR-SWIR}}{\mathbf{NIR+SWIR}}$$

NBR values range from -1 to +1. Healthy vegetation with high near-infrared reflectance typically results in high NBR values. Conversely, areas with reduced vegetation cover, such as recently burned areas or barren land, exhibit low NBR values. This essentially means that NBR allows researchers to identify fire scars based on the changes in reflected light across these specific spectral bands.

3.2 Differenced Normalized Burn Ratio (dNBR)

The Differenced Normalized Burn Ratio (dNBR) takes NBR calculations from pre-fire and post-fire satellite images to pinpoint burn scars (Mallinis and Vassilakis 2019). Because healthy areas have higher NBR values (represented as brighter gray values) compared to burned areas after a fire (represented as darker gray values), positive dNBR values indicate regions impacted by fire. Conversely, negative dNBR values suggest areas that haven't been affected by the fire. This approach essentially leverages the changes in NBR between pre and post fire imagery to identify and map fire scars. calculate the difference NBR, the post-fire NBR raster data is subtracted from the pre-fire NBR raster data.

$$\mathbf{dNBR\ or\ \Delta NBR = Pre\ fire\ NBR - Post\ fire\ NBR}$$

4. Results And Discussions

Using the website of Forest Survey of India, numbers of fire points were studied and it was found that in Dudhwa National Park, total fire points were 99 out of which 07 were large and 92 were small fire. In Bankati-1 forest block of Dudhwa National Park fire affected area was estimated as 134.17 ha. Ground Survey also has been done for verification. Forest fire sites with location is given in Table-2. Satellite images of post and pre fire with extent area are illustrated in Figure 2**.** The forest type and forest density wise mapping were also done and found that Bankati-1forest block mainly covered with grassland occupies100.20 ha area and 33.97 ha area is covered with Miscellaneous Forest.

Table 2. Forest fire sites with location in Bankati-1 Forest Block

Block Name	Month	Location	
		Latitude	Longitude
Bankati-1	April	28° 33' 14.179" N	80° 35' 16.315" E
		28° 33' 36.584" N	80° 34' 50.891" E
Total			

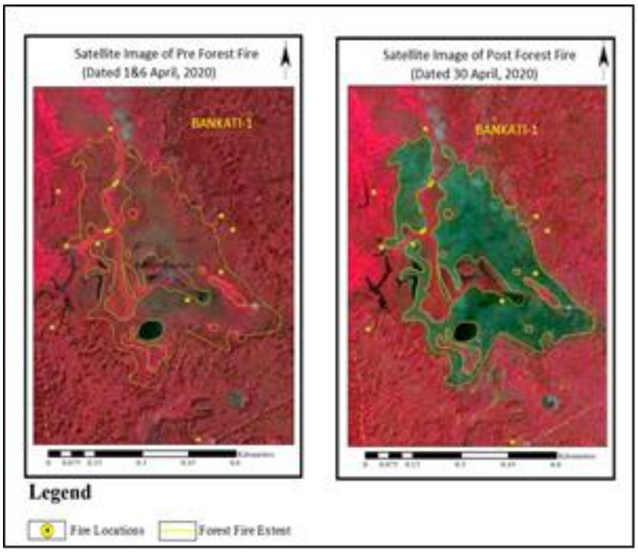

Figure 2. Pre and post Forest Fire Image

Forest, has been further classified into forest density classes. Bankati-1 forest block is having <10% and 10-40% density classes only. Only controlled fire has been reported by forest department but after observation, it was found that fire was also spread in adjacent area of forest block. Forest type and Forest density maps are represented in Figure 3. The area statistics of vegetation due to forest fire in Dudhwa National Park is given in Table 3.

Table 3. Area Statistics of Vegetation Affected due to Forest Fire

Block Name	Forest Type	Forest Density	Area (ha)
Bankati-1		< 10 %	23.49
	Miscellaneous	10-40 %	10.48
	Total		**33.97**
	Grassland	-	100.20
	Total		**100.20**
Total			**134.17**

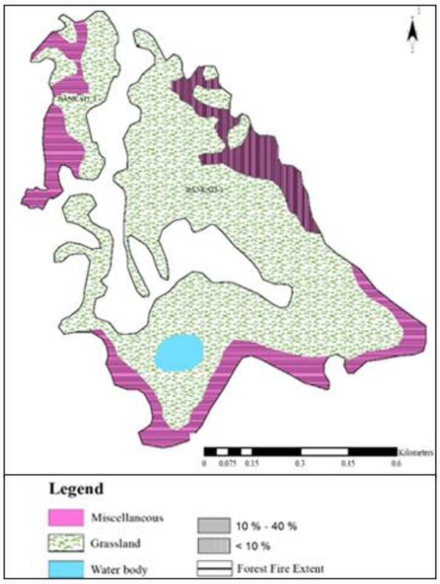

Figure 3. Forest Type and forest Density Maps of Bankati-1 Forest Block

The severity of forest fire can also be identified by using Normalized Burn Ratio (NBR). Normalized Burn Ratio is frequently used to estimate burn severity. Imagery collected before a fire will have very high near-infrared band values and very low mid-infrared band values and an Imagery collected over a forest after a fire will have very low near infrared band values and very high mid-infrared band values. Higher dNBR indicate more severe damage. Areas with negative dNBR values may indicate increased vegetation productivity, following a fire. Range of Differenced Normalized Burn Ratio of Burnt Severity is shown in Table 4.

Table 4. Range of Differenced Normalized Burn Ratio of Burnt Severity of Sentinel-2 .

Sl. No.	ΔNBR	Burn Severity
1.	< -0.25	High post-fire regrowth
2.	-0.25 to -0.1	Low post-fire regrowth
3.	-0.1 to +0.1	Unburned
4.	0.1 to 0.27	Low-severity burn
5.	0.27 to 0.44	Moderate-low severity burn
6.	0.44 to 0.66	Moderate-high severity burn
7.	> 0.66	High-severity burn

(*Source:United States Geological Survey (USGS) standard for Burn Severity assessment*)

In present study, selected site location was extracted from burned and unburned categories to analyze its spectral distribution. The unburned class contains every pixel that could not be classified as burned i.e. water, cloud or cloud shadow. Identification of forest fire through FCC of satellite data and indices in Dudhwa National Park are shown in Figure 4.

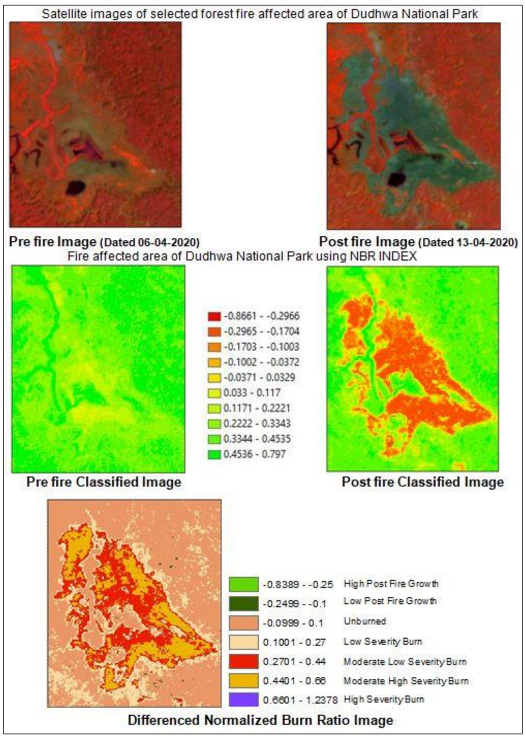

Figure 4. Pre & Post Forest Fire Satellite Images, NBR Classified Images and Differential NBR Showing Forest Fire in Bankati-1 Forest Block of Dudhwa National Park

The composition of FCC of pre and post fire images clearly shows difference in colour due to fire. In pre fire image no fire was shown, whereas in post fire image, fire severity was observed. Through analysis of image using NBR indices of pre and post fire images, it was found that range from 0.0330 to 0.7970 showing no fire, whereas range from -0.8661 to 0.0329 represents burnt area.

Through differenced normalized burnt ratio (dNBR) of post and pre fire of NBR images, it was observed that the values are ranging from -0.8389 to 1.2378. It was further classified as per the Table 4, it was found that ranges from -0.8389 to 0.1000 having unburned area, range from 0.1001 to 0.2700 shows low severity, range from 0.2701 to 0.4400 represents moderate low severity burn, range from 0.4401 to 0.6600 shows moderate high severity burn and range from 0.6601 to 1.2378 shows high severity burn areas.

In Bankati-1Forest Block low severity, moderate-low severity and moderate-high severity has been observed but in major part of forest block, moderate low severity is noticed, which covers about 70.130ha area. It was also observed that the selected site having no high severity burn. Consequently, miscellaneous forest was mainly affected by forest fire. Details are showing the in Table 5.

Table 5 Forest Type and Forest Density wise Burn Severity in Bankati-1 Forest Block

Block Name	Burn Severity	Fire Affected Forest		Area (ha)
		Forest Type	Forest Density	
Bankati-1	Low Severity Burn	Miscellaneous	<10 %	0.396
			10-40 %	0.187
		Total		**0.583**
		Grassland		7.258
		Total		**7.258**
	Total			**7.841**
	Moderate High Severity Burn	Miscellaneous	<10 %	12.668
			10-40 %	5.673
		Total		**18.341**
		Grassland		37.860
		Total		**37.860**
	Total			**56.201**
	Moderate Low Severity Burn	Miscellaneous	<10 %	10.425
			10-40 %	4.620
		Total		**15.045**
		Grassland		55.085
		Total		**55.085**
	Total			**70.130**
Grand Total				**134.172**

Conclusions

Uttar Pradesh faces a significant challenge due to the lack of reliable data on forest fire damage. This data gap hinders accurate assessment of fire-related losses. Accurate mapping of fire burn severity is essential.

Remote sensing technology offers a powerful solution, aiding in various fire management stages: strategic planning for vegetation monitoring, risk assessment, fire detection and damage evaluation.

This study highlights the importance of remotely sensed data for mapping fire-affected areas and assessing damage. Combining this data with ground-truth information provides valuable insights into the spatial distribution and extent of fire damage. Furthermore, multi-temporal satellite imagery allows for effortless monitoring of post-fire land cover changes. This information is crucial for understanding the ecological and biodiversity impacts of fires.

The findings of this study hold significant implications for improved forest fire management practices. It's not just about the loss of timber and property; forest fires also cause severe environmental pollution, making effective fire management even more critical.

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