Journal of Remote Sensing, Environmental Science & Geotechnical Engineering
Volume 3, Issue 1, January-April, 2018

Forest Fire Detection and Damage Assessment Using Satellite Imagery

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ABSTRACT

Forest fires represent a critical ecological disaster, resulting in significant environmental, economic, and social losses. The integration of satellite-based remote sensing technologies offers a rapid, large-scale, and efficient solution for detecting, monitoring, and assessing fire events. This paper presents an in-depth study on forest fire detection and damage assessment using multi-spectral and thermal satellite imagery, focusing on the application of advanced algorithms such as Normalized Burn Ratio (NBR) and thermal anomaly detection. The methodology employs data from sensors like MODIS, VIIRS, and Sentinel-2 to identify active fire locations, estimate burnt areas, and evaluate post-fire vegetation loss. A case study on the 2023 Uttarakhand forest fire event demonstrates the efficacy of the approach, highlighting the advantages of remote sensing over traditional ground-based monitoring. This study emphasizes the importance of integrating satellite imagery with GIS-based analytics to develop early warning systems, thus minimizing the ecological and socio-economic impact of forest fires.

Keywords: Forest fire detection, Remote sensing, Satellite imagery, Burn severity, Damage assessment, NBR index, Thermal anomaly detection

1. INTRODUCTION

Forest fires are among the most destructive natural hazards, impacting biodiversity, altering carbon cycles, and threatening human lives and property. Globally, climate change, prolonged droughts, and human activities have intensified the frequency and severity of wildfires. Traditional fire monitoring methods, such as ground patrols and lookout towers, are limited in spatial coverage and timeliness.

Satellite remote sensing, with its capability to capture real-time, wide-area observations, has emerged as a transformative tool for forest fire detection and damage assessment. Multi-temporal datasets from various satellite sensors enable tracking of fire spread, estimation of burnt areas, and evaluation of ecosystem recovery post-fire.

This paper outlines the methodology and case study for detecting and assessing forest fires using satellite imagery, emphasizing its potential for integration into early warning systems.

2. REMOTE SENSING FOR FOREST FIRE DETECTION

2.1 Principles of Satellite-Based Fire Detection

Satellite-based fire detection relies primarily on thermal infrared (TIR) and shortwave infrared (SWIR) bands, which can detect elevated surface temperatures caused by active fires. Multi-spectral analysis further enhances the ability to differentiate between fire-affected and unaffected regions.

2.2 Key Satellite Sensors

- **MODIS (Moderate Resolution Imaging Spectroradiometer)** – Provides twice-daily global coverage with thermal bands optimized for fire detection.
- **VIIRS (Visible Infrared Imaging Radiometer Suite)** – Offers improved spatial resolution for nighttime fire detection.
- **Sentinel-2** – High-resolution multi-spectral data suitable for burn severity mapping.

MANTECH Publications
Journal of Remote Sensing, Environmental Science & Geotechnical Engineering
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3. DAMAGE ASSESSMENT USING SATELLITE DATA

3.1 Normalized Burn Ratio (NBR)

The NBR index is widely used to assess burn severity by comparing pre- and post-fire imagery.
Formula:

NBR=(NIR−SWIR)(NIR+SWIR)NBR = \frac{(NIR - SWIR)}{(NIR + SWIR)}NBR=(NIR+SWIR)(NIR−SWIR)

Post-fire NBR values are subtracted from pre-fire values to compute the **dNBR**, which classifies burn severity.

3.2 Vegetation Indices for Recovery Monitoring

Indices such as NDVI (Normalized Difference Vegetation Index) help assess the regrowth of vegetation after a fire event.

4. CASE STUDY: 2023 UTTARAKHAND FOREST FIRE

A large-scale forest fire in Uttarakhand, India, in April 2023, was monitored using Sentinel-2 imagery. The methodology included:

1. Pre-fire image acquisition (March 2023).
2. Post-fire image acquisition (May 2023).
3. Calculation of NBR and dNBR to classify burn severity.
4. Estimation of total burnt area.

Table 1: Burn Severity Classification Using dNBR

dNBR Value Range	Burn Severity Class	Description
< 0.1	Unburned	No visible fire impact
0.1 – 0.27	Low severity	Minimal vegetation loss
0.27 – 0.44	Moderate-low severity	Partial vegetation damage
0.44 – 0.66	Moderate-high severity	Significant canopy and ground cover loss
> 0.66	High severity	Complete vegetation destruction

Table 2: Satellite Sensors Used for Forest Fire Assessment

Satellite/Sensor	Spatial Resolution	Revisit Time	Key Applications
MODIS	250m – 1km	Twice daily	Active fire detection, thermal anomaly
VIIRS	375m – 750m	Daily	Nighttime fire monitoring
Sentinel-2	10m – 60m	5 days	Burn severity mapping, vegetation loss

5. INTEGRATION WITH GIS AND EARLY WARNING SYSTEMS

Combining satellite-based fire detection with GIS platforms enables spatial analysis, integration of weather data, and dissemination of alerts to authorities. Automated algorithms can trigger warnings when thermal anomalies or high dNBR values are detected, allowing for quicker response.

6. ADVANTAGES AND LIMITATIONS

Advantages:

- Large-scale coverage and high temporal frequency.
- Ability to operate in remote, inaccessible areas.
- Objective and repeatable analysis.

Limitations:

- Cloud cover can obscure fire detection in optical imagery.
- Lower spatial resolution in some sensors limits small fire detection.
- Requires validation with ground truth data.

7. CONCLUSION

Satellite imagery plays an indispensable role in detecting, monitoring, and assessing forest fire impacts. By leveraging indices like NBR and integrating results into GIS-based early warning systems, decision-makers can improve response times and resource allocation. Although challenges such as cloud cover and sensor resolution remain, advancements in multi-sensor integration and machine learning offer promising avenues for more accurate and timely fire monitoring.

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