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A REVIEW ON METHODS FOR DETECTING STUBBLE RESIDUE BURNING USING SATELLITE REMOTE SENSING

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ABSTRACT
Stubble residue burning is a significant environmental issue, contributing to air pollution, greenhouse gas emissions, and public health hazards. Satellite remote sensing has emerged as a vital tool for detecting and monitoring stubble burning events over large areas. This paper reviews the various methods used for detecting stubble residue burning through satellite remote sensing. Various methods discussed include thermal anomaly detection, smoke plume identification, spectral analysis and the role of machine learning. A comparative analysis of these methods is provided, focusing on their accuracy, resolution, computational requirements and ability to capture the spatial and temporal dynamics of stubble burning. Sentinel-2 MSI and MODIS data is used to detect and visualize the fire for state of Punjab region.

KEYWORDS: Stubble Burning; Environment; GIS; Remote Sensing; Satellite.

INTRODUCTION
Stubble burning, especially after rice and wheat harvests, has become a significant environmental issue in many agricultural regions worldwide, particularly in India and Southeast Asia. Timely detection and monitoring of stubble burning are crucial for reducing its environmental and public health impacts. Satellite remote sensing has enabled continuous and large-scale monitoring, providing data crucial for policy formulation and enforcement 1.

(Mandal, Mittal, & Saxena, 2022). To address this challenge, accurate and timely detection of stubble burning events is crucial for enforcing regulations, raising public awareness, and informing mitigation strategies. Traditional ground-based monitoring methods are inadequate for covering the vast geographic areas where stubble burning occurs, particularly in remote or rural regions. As a result, satellite remote sensing has emerged as an essential tool for monitoring stubble burning at scale, providing near-real-time data across large spatial extents (Stroppiana, Grippa, & Castelli, 2022).

Satellite-based detection of stubble burning leverages different sensors and data products, which can detect thermal anomalies, map burned areas, and identify smoke plumes. The availability of satellites such as MODIS (Moderate Resolution Imaging Spectroradiometer), Sentinel-2 and Sentinel-3, and VIIRS (Visible Infrared Imaging Radiometer Suite) has revolutionized the ability to monitor and track stubble burning. These satellites provide high spatial and temporal resolution data that can detect both active fires and the extent of burned areas. The development of advanced machine learning and artificial intelligence (AI) algorithms further enhances the accuracy and speed of fire detection, allowing for more precise identification of stubble burning events (Wang et al., 2023).

RELATED WORK
This section gives a detailed review about the existing techniques and methods used for implementing Stubble Burning Detection:

A) Overview of Satellite Remote Sensing for Stubble Burning Detection

Remote sensing techniques for stubble burning detection typically focus on thermal emissions, smoke, and burned area identification using satellites equipped with thermal infrared, visible, and near-infrared sensors. Key platforms include MODIS, Sentinel-2, and VIIRS, each offering different spatial and temporal resolutions (Shukla et al., 2021).

1. MODIS (Moderate Resolution Imaging Spectroradiometer)

This method provides moderate spatial resolution (250 m - 1 km) and high temporal resolution (daily).

2. Sentinel-2

Sentinel 2 offers improved spatial resolution (~300 m) for vegetation and land monitoring(Stroppiana, Grippa, Verhegghen, &Castelli, 2022).

3. VIIRS (Visible Infrared Imaging Radiometer Suite):

VIIRS method ombines moderate spatial resolution (375 m) with high temporal coverage, making it suitable for real-time fire detection (Schroeder et al., 2022).

B) Methods for Stubble Burning Detection

1. Thermal Anomaly Detection

Thermal anomaly detection leverages the heat emitted by stubble burning fires, particularly in the thermal infrared (TIR) and mid-infrared (MIR) bands. The technique includes

• Fixed Threshold Algorithms: Use predefined temperature thresholds in thermal infrared bands to detect potential burn sites based on heat emission. While simple, this method can result in false positives due to solar reflections and other heat sources like industrial activities [5].

• Contextual Algorithms: These methods compare the temperature of suspected burning pixels with surrounding pixels, reducing false positives and improving detection accuracy. Contextual algorithms are more reliable than fixed-threshold techniques and are used in systems like MODIS's Active Fire Product (Houghton et al., 2022).

2. Smoke Detection

Smoke detection methods focus on identifying the distinct spectral and textural characteristics of smoke plumes which are

• Spectral Analysis: Smoke particles have unique optical properties. The ratio of visible (0.6 µm) to near-infrared (2.1 µm) reflectance can distinguish smoke from clouds and other aerosols (Giglio et al., 2023).

• Texture Analysis: Smoke plumes exhibit distinct textural features that can be identified through image analysis techniques like the Gray-Level Co-occurrence Matrix (GLCM), enabling better differentiation from similar features such as haze or cloud cover (Chen et al., 2023).

3. Burned Area Mapping

Mapping burned areas helps in assessing the spatial extent and environmental impact of stubble burning which uses

• Spectral Index Approaches: The Normalized Burn Ratio (NBR) and the Burned Area Index (BAI) are widely used to identify burned areas. NBR uses near-infrared and shortwave infrared bands to measure the extent and severity of burned regions (Zheng et al., 2022).

• Change Detection Methods: By comparing pre- and post-fire satellite images, change detection methods can identify burned areas with higher accuracy. This approach is used in high-resolution satellites like Sentinel-2 and Landsat(Roy et al., 2023).

4. Machine Learning and AI Approaches

Recent developments in machine learning (ML) and artificial intelligence (AI) have enabled more sophisticated approaches for stubble burning detection

• Supervised Learning: Algorithms like Random Forests (RF) and Support Vector Machines (SVM) have been employed to classify stubble burning events, using labeled datasets of known fire instances (Dasgupta, Banerjee, & Pal, 2022).

• Deep Learning: Convolutional Neural Networks (CNNs) have shown promise in learning complex features from satellite data for more accurate fire detection, including stubble burning (Wang et al., 2023).

C) Comparison of Methods

A comparison of the various methods for stubble burning detection is presented in Table 1, summarizing key characteristics such as spatial resolution, temporal resolution, accuracy, and computational complexity.

Table 1. Comparison of Stubble Burning Detection Methods

Method	Spatial Resolution	Temporal Resolution	Accuracy	Computational Complexity	Advantages	Limitations
Thermal Anomaly (Fixed)	Moderate (250m - 1km)	High (daily - hourly)	Moderate	Low	Simple, fast	High false positives, misses small fires
Thermal Anomaly (Contextual)	Moderate (250m - 1km)	High (daily - hourly)	High	Moderate	Reduced false positives	Background heat can affect accuracy
Smoke Detection (Spectral)	High (10m - 250m)	Moderate (daily)	Moderate	High	Detects early-stage fires	Affected by clouds and aerosols
Burned Area Mapping	High (10m - 30m)	Low (weekly - monthly)	Very High	Moderate	Accurate post-burn assessment	Not suitable for real-time detection
Machine Learning (RF, SVM)	Varies	Varies	Very High	Very High	Integrates multiple data sources	Requires large training datasets
Deep Learning (CNN)	Varies	Varies	Very High	Very High	Learns complex patterns, high accuracy	Computationally intensive, data-hungry

GENERAL METHODOLOGY

Detection of stubble burn

The study focuses on Punjab region. The data used in this study is sourced from various reliable and high resolution remote sensing platforms. These sources provide the necessary spatial and temporal resolution to accurately capture and analyze the occurrence of crop residue burning across study area. Sentinel-2 Multi Spectral instrument (MSI) Level 2-A data has been used. Sentinel-2 and MODIS fire data were fileted for the specific time of October 1, 2023 to November 30 2023. Figure 1 is flowchart shows that steps of process.

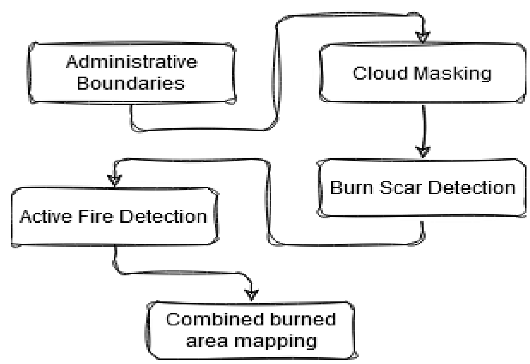

Fig. 1. Stubble burn detection

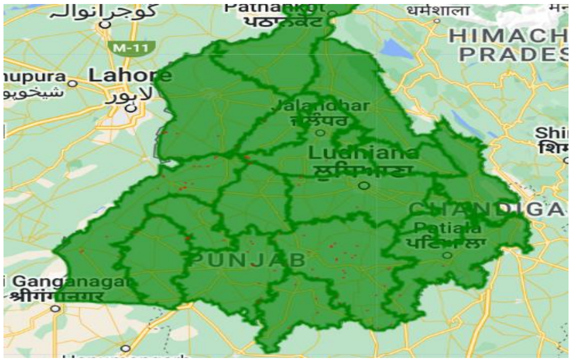

Figure 2. Punjab administrative boundary plotted

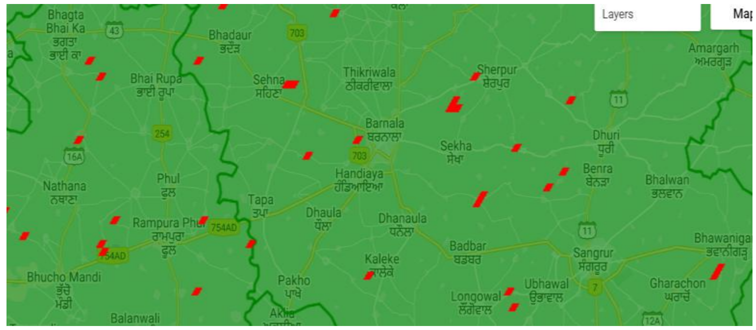

Figure 3. Burn scar detection

Figure 2 shows administrative boundry of punjab for stubble burning detection. Figure 3 shows burning scars on region.

The spatial distribution of burning is clearly visualized in Google Earth Engine (GEE) platform. This shows stubble residue burning in Punjab. The total burned area calculated is 222. 533 Km2.

CONCLUSION & FUTURE SCOPE

Satellite remote sensing has become an essential tool for detecting and monitoring stubble residue burning. However, current methods face limitations in terms of spatial resolution, false positives, and cloud cover. Advances in machine learning and deep learning offer significant potential for improving the accuracy and reliability of detection. By integrating multi-source data and improving real-time processing capabilities, satellite-based systems can help mitigate the environmental and public health impacts of stubble burning.

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