Multidisciplinary Research: Innovations in Science, Arts and Commerce
Published in October 2025 by Deep Science Publishing (USA | UK | India | Turkey)
ISBN: 978-93-7185-157-2 | E-ISBN: 978-93-7185-737-6 | DOI: https://doi.org/10.70593/978-93-7185-737-6

Automated Detection of Forest Encroachment: Emerging Techniques and Comparative Analysis

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Abstract

Forests are an important block in the ecological framework. Protecting and safeguarding the forests are very important for maintaining the ecological balance. However, forests are susceptible to encroachment due to increased human activity and rapid urbanization. Monitoring and managing forest encroachment is crucial for safeguarding ecosystem integrity and biodiversity. This study presents a brief review of the different approaches used to monitor forest cover and the different methodologies used to detect forest encroachment. The paper also presents a comparison of the different methodologies used for detecting forest encroachment and also presents a generalised framework to automatically detect forest encroachment.

Keywords*: Automated Detection, Forest Encroachment.*

1. Introduction

Forest encroachment poses a persistent threat to global biodiversity, ecosystem services, and sustainable resource management. Growing populations and land-use pressures have resulted in the gradual and often undetected expansion of settlements, agriculture, and infrastructure into forested areas. Early detection and accurate mapping of such encroachments are essential to mitigate forest degradation and to develop effective forest management policies.

Forests play a critical role in maintaining environmental balance by sequestering carbon, providing habitats for diverse flora and fauna, and regulating water cycles. Encroachment often leads to irreversible ecological loss, increased greenhouse gas emissions, and diminishment of ecosystem services. Monitoring these changes is vital for enforcing conservation measures, planning restoration efforts, and ensuring the sustainability of forest resources.

The advancements in geospatial technologies, particularly remote sensing and GIS, have revolutionized forest monitoring. Remote sensing enables data acquisition over large, inaccessible, and dynamic landscapes, providing periodic, high-resolution imagery for temporal analysis. The use of different sensors—including optical, radar, and LiDAR—

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enables detailed mapping of canopy structure, land cover types, and human-induced changes, supporting multi-faceted detection approaches

2. Literature Review:

There are several advanced methods for automated encroachment detection, drawing from geospatial, remote sensing, and AI technologies. Each has distinct technical strengths, and most modern solutions combine these approaches for accuracy and scalability. In this section, we attempt to investigate and analyse the different methodologies used for detecting forest encroachment.

Uddin et al. (2015) employed Geographic Object-Based Image Analysis (GEOBIA) techniques on QuickBird and IKONOS satellite images to detect, map, and assess changes in tree cover and forest condition, including deforestation due to encroachment, in a remote watershed in Nepal. The study applies region-growing and multiresolution segmentation methods for tree crown detection and land cover change analysis and demonstrates the effectiveness of object-based techniques for monitoring forest encroachment and degradation with fine spatial detail.

Weishampel et al. (2012) uses small-footprint airborne LiDAR to identify areas of canopy disturbance and illegal deforestation in the Caracol Archaeological Reserve along the Belize-Guatemala border. By comparing canopy height measures from LiDAR with deforestation patterns derived from Landsat images, the authors demonstrate that LiDAR reveals a significantly larger extent and depth of forest encroachment and canopy degradation than traditional optical sensors. The study highlights the added value of high-resolution LiDAR for locating and quantifying forest encroachment with greater accuracy.

Soorya Narayan Satheesh (2025) proposed a novel AI-based method leveraging very high-resolution satellite imagery to automatically identify and monitor forestland encroachments in India. The AI-driven approach aims to increase land available for afforestation, support real-time monitoring, and help India meet climate change commitments by improving CO2 sequestration prospects. The feasibility assessment concludes that current AI tools are practical and effective for automated encroachment detection, making proactive intervention possible.

Another notable publication is by Desclée et al. (2006), which proposes a statistical object-based change detection method to identify forest land cover changes using high spatial resolution satellite images. They proposed a robust approach effective in mapping various forms of forest encroachment and degradation. Multidate segmentation was used to delineate

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objects that are similar spatially, spectrally, and temporally across a sequence of satellite images. Each object is characterized by the statistical difference in reflectance values over time, with changed areas identified through a chi-square hypothesis test applied to these statistics. Objects showing abnormal (outlier) temporal changes are iteratively trimmed and labelled as changed using automated statistical procedures.

Kumar et al. (2014) applied high-resolution WorldView-II satellite data combined with cadastral vector data to digitize and update protected forest boundaries at the cadastral level. The research integrates cadastral data, GPS surveys, and satellite imagery using ArcGIS to produce highly accurate cadastral forest maps. These maps support transparency in forestland administration, precise boundary delineation, and monitoring of encroachments. A critical focus is on overlaying cadastral forest boundary vectors on ortho-rectified satellite images for spatial analysis and encroachment detection with sub-meter accuracy. The methodology offers a geospatial infrastructure for forest management and policy-making based on cadastral GIS layering techniques.

Purbahapsari et al. (2022) proposed an innovative GeoAI system that integrates satellite image data processed by machine learning to perform early detection and monitoring of forest and land fires. The GeoAI approach improves accuracy compared to traditional hotspot methods by using deep learning models trained on satellite image time series for burnt area recognition. The system overlays fire detection with forest area and concession boundaries, providing a comprehensive integrated platform that supports law enforcement, forest management, and public service effectiveness.

3. OBJECTIVES OF THE STUDY

Based on the literature review, the following objectives were formulated:

1. To address the benefits and limitations of the different methods used for automated forest encroachment detection.
2. To examine the general methodology used for automated forest encroachment detection.
3. To propose a generalized framework for automated forest encroachment detection.

4. COMPARATIVE ANALYSIS OF THE DIFFERENT METHODS USED IN AUTOMATED FOREST ENCROACHMENT DETECTION

Various methodologies have been used for detecting forest encroachment. Some of the most notable methods used for Automated Encroachment Detection are:

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- **High-Resolution Satellite Imagery & Object-Based Analysis:** Satellite images, sometimes combined with drone surveys, are processed using Object-Based Image Analysis (OBIA), allowing for the detection of land use changes and unauthorized constructions at fine spatial resolutions.
- **LiDAR Technology:** LiDAR provides detailed three-dimensional mapping of landscapes. When combined with GIS, even subtle elevation changes and new structures that might indicate encroachment can be detected, especially in complex terrain.
- **AI and Deep Learning Algorithms:** Machine learning classifiers, particularly convolutional neural networks (CNNs), support vector machines (SVMs), and random forest algorithms, are trained to identify patterns and anomalies in spatial and temporal data. These efficiently spot changes not easily visible to human analysts, and enable near-real-time monitoring.
- **Change Detection Analysis:** Automated comparison of historical and current geographic datasets (satellite or LiDAR) highlights new constructions or land use changes, flagging potential encroachment areas.
- **Cadastral Audits and GIS Data Layering:** Systematic review and comparison of digital cadastral records, zoning data, and property maps using GIS tools can expose boundary violations and unapproved land use when coupled with field surveys.
- **Geospatial AI Platforms:** Comprehensive solutions such as ArcGIS-powered GeoAI and LEDS (Land Encroachment Detection System) use multi-sensor data fusion, AI-powered change detection, and real-time alerting to support efficient land management at scale.

Table 1: Comparison of the different methods used in Automated Forest Encroachment Detection.

Method	**Strengths**	**Limitations**
Satellite & OBIA	Wide area coverage, fine detail	May miss changes under canopy/buildings
LiDAR	3D accuracy, detects elevation changes	Costly, less frequent data updates
AI/ML (CNN/SVM/RF)	High accuracy, adaptable to new patterns	Needs quality labeled data
Change Detection	Effective for temporal monitoring	Relies on time-series historical data
Cadastral & GIS	Legal/reporting integration, spatial	Requires up-to-date records

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	analysis	
GeoAI/Integrated Platforms	Scalable, real-time, multi-sensor fusion	Initial setup/integration complexity

5. METHODOLOGICAL FRAMEWORK

Based on the literature review and analysis of the different models, the standard workflow for forest encroachment detection includes:

• **Data Collection:** Acquisition of multi-temporal, high-resolution satellite imagery (e.g., Landsat, Sentinel) along with ancillary spatial data (e.g., DEMs, thematic maps).

• **Preprocessing:** Radiometric and geometric corrections, followed by image enhancement to improve feature discrimination.

• **Training Data Preparation:** Collection of field data and reference samples, classifying areas as forest, non-forest, and encroached zones for algorithm training.

• **Classification and Analysis:** Application of machine learning classifiers to segment imagery and detect encroachment. Knowledge-driven and data-driven approaches are employed, often validated using ground truth data and accuracy assessments.

• **Mapping and Monitoring:** Visualizing and quantifying spatial trends of encroachment, generating actionable outputs for stakeholders and policymakers.

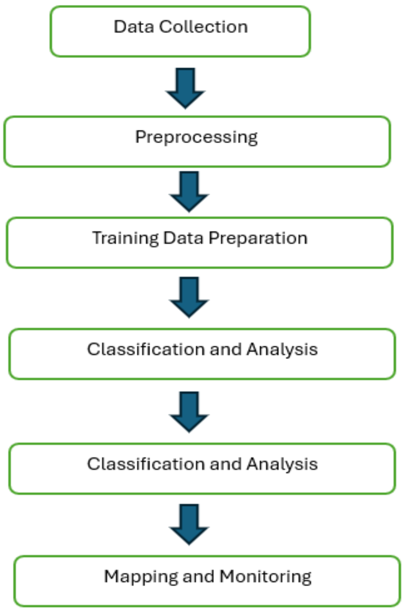

Figure 1: Overall Framework for Encroachment Detection.

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6. Conclusion

Automated encroachment detection is increasingly important for urban planning, forest conservation, infrastructure protection, and dispute resolution, driven by technological innovation and growing demand for effective land management. The convergence of remote sensing, machine learning, and geospatial analysis offers powerful tools for early detection, accurate mapping, and adaptive management of forest encroachment. As technology advances and more data become accessible, these integrated approaches will play an increasingly pivotal role in safeguarding forests and supporting evidence-based policy interventions.

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