

# Remote Sensing Tools for Monitoring Land Use Change and Forest Dynamics (2010–2025): A Comprehensive Review

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## Abstract

Monitoring land use change and forest dynamics is essential for understanding environmental transformations, biodiversity conservation, and sustainable resource management. Over the past decade, remote sensing technologies have significantly advanced, enabling researchers to monitor large-scale landscape changes with improved accuracy and temporal resolution. Satellite imagery, aerial sensors, and geospatial analysis tools have become critical components in assessing deforestation, forest degradation, urban expansion, and agricultural land conversion. Between 2010 and 2025, the integration of high-resolution satellite data, cloud-based computing platforms, and machine learning algorithms has revolutionized environmental monitoring and forest management. Remote sensing tools such as multispectral and hyperspectral imaging, LiDAR, and radar systems have provided detailed insights into vegetation structure, biomass estimation, and ecosystem health. Furthermore, the use of geographic information systems (GIS) has facilitated spatial analysis and mapping of land use changes over time. This review examines the major remote sensing tools and techniques used between 2010 and 2025 for monitoring land use change and forest dynamics. It also discusses recent technological developments, applications in forest conservation and management, and future prospects for integrating artificial intelligence and big data analytics in environmental monitoring.

**Keywords:** Remote sensing; land use change; forest dynamics; GIS; satellite imagery; LiDAR; environmental monitoring.

## 1. Introduction

Land use and land cover change has become one of the most critical environmental challenges facing the world today. Rapid population growth, industrial development, agricultural expansion, and urbanization have significantly altered natural landscapes over the past few decades. Among the various ecosystems affected by these transformations, forest ecosystems are particularly vulnerable to human activities and climate-related disturbances [1]. Forests play a vital role in maintaining ecological balance, regulating climate, conserving biodiversity, and supporting livelihoods for millions of people around the world. However, large-scale deforestation, forest degradation, and land conversion continue to threaten the sustainability of these ecosystems. Land use change refers to the transformation of natural landscapes into different types of land use such as agriculture, urban areas, or industrial zones [2]. These changes can lead to significant environmental consequences, including biodiversity loss, soil degradation, alteration of hydrological cycles, and increased greenhouse gas emissions. Forests act as major carbon sinks and play an essential role in mitigating climate change by absorbing atmospheric carbon dioxide.

When forests are cleared or degraded, large amounts of stored carbon are released into the atmosphere, contributing to global warming and climate instability. Accurate monitoring of land use change and forest dynamics is therefore essential for environmental conservation, sustainable land management, and climate change mitigation. Traditional ground-based monitoring methods, such as field surveys and forest inventories, provide valuable information but are often limited by time, cost, and spatial coverage. These conventional approaches are particularly challenging in remote or inaccessible areas where large-scale environmental monitoring is required. In recent decades, remote sensing technologies have emerged as powerful tools for monitoring environmental changes at local, regional, and global scales. Remote sensing involves the acquisition of information about the Earth's surface using sensors mounted on satellites, aircraft, or unmanned aerial vehicles [3]. These sensors capture electromagnetic radiation reflected or emitted from the Earth's surface, allowing researchers to analyze land cover patterns, vegetation health, and environmental changes over time.

Between 2010 and 2025, significant technological advancements have transformed the field of remote sensing.

Improvements in satellite sensor resolution, data processing capabilities, and computational power have greatly enhanced the ability of scientists to monitor land use change and forest dynamics with greater accuracy and efficiency. High-resolution satellite imagery, combined with advanced geospatial analysis tools and machine learning algorithms, now enables researchers to detect even subtle changes in vegetation cover and forest structure. The increasing availability of open-access satellite data from international space agencies has further expanded the use of remote sensing in environmental research [4]. Platforms such as satellite-based Earth observation systems provide continuous global coverage and long-term datasets that are essential for analyzing environmental trends over extended periods. These datasets allow researchers to track deforestation patterns, monitor forest regeneration, and assess the impacts of natural disturbances such as wildfires, storms, and pest outbreaks. Remote sensing technologies also play an important role in supporting international environmental initiatives aimed at reducing deforestation and promoting sustainable land management [5]. Programs focused on forest conservation and climate change mitigation rely heavily on accurate land cover data and forest monitoring systems. Remote sensing tools provide the spatial and temporal information necessary for evaluating policy effectiveness and guiding conservation strategies.

Recent advancements in drone technology and airborne sensors have enabled researchers to collect high-resolution data at local scales. These technologies allow detailed assessment of forest canopy structure, tree health, and vegetation stress, providing valuable information for forest management and ecological research [6]. Despite the many advantages of remote sensing technologies, several challenges remain in the effective monitoring of land use change and forest dynamics. Issues such as data processing complexity, sensor limitations, cloud cover interference, and the need for ground validation continue to influence the accuracy of remote sensing analyses. Nevertheless, ongoing advancements in artificial intelligence, machine learning, and cloud-based computing platforms are helping to overcome many of these challenges and improve the efficiency of remote sensing applications. This review aims to examine the major remote sensing tools and techniques used between 2010 and 2025 for monitoring land use change and forest dynamics [7]. The article discusses recent technological developments, the applications of remote sensing in forest ecosystem monitoring, and the integration of geospatial technologies for environmental analysis. By highlighting the capabilities and limitations of different remote sensing approaches, this review contributes to a better understanding of how modern technologies can support sustainable forest management and environmental conservation efforts in the future.

## 2. Overview of Remote Sensing Technologies



**Fig 1: Remote sensing and GIS technologies**

Remote sensing technologies have become essential tools for monitoring environmental changes, particularly land use change and forest dynamics. These technologies allow researchers to observe and analyze large geographic areas over extended time periods without direct physical contact. Remote sensing systems capture information about the Earth's surface by detecting reflected or emitted electromagnetic radiation using sensors mounted on satellites, aircraft, or ground-based platforms. Between 2010 and 2025, remote sensing technologies have undergone rapid advancements in spatial resolution, temporal frequency, data accessibility, and analytical capabilities. The increased availability of open-access satellite data, improvements in sensor technology, and the integration of cloud computing platforms have significantly enhanced the ability to monitor environmental changes in near real time [8]. Remote sensing platforms can generally be categorized into three major groups: satellite-based systems, aerial or drone-based systems, and ground-based monitoring technologies.

### 2.1 Satellite-Based Remote Sensing

Satellite-based remote sensing has been widely used for large-scale environmental monitoring due to its ability to provide continuous and consistent observations of the Earth's surface. Satellites orbit the Earth and collect imagery across multiple spectral bands, allowing scientists to analyze vegetation cover, forest structure, land use patterns, and environmental changes. Several satellite missions have played key roles in land use and forest monitoring during the past decade. The Landsat satellite program, for example, provides one of the longest continuous records of Earth observation data, with imagery available since the 1970s [9]. Landsat satellites offer moderate spatial resolution imagery that is widely used for mapping forest cover, detecting deforestation, and analyzing long-term land use changes.

Another important satellite system is the Sentinel series, which provides high-resolution optical and radar imagery for environmental monitoring. Sentinel satellites offer improved temporal resolution, enabling more frequent observations and more accurate detection of land cover changes.

Moderate Resolution Imaging Spectroradiometer (MODIS) sensors are also widely used for monitoring large-scale environmental processes such as vegetation dynamics, forest fires, and seasonal changes in plant productivity. Satellite remote sensing offers several advantages, including wide spatial coverage, long-term data archives, and the ability to monitor remote or inaccessible regions [10]. These capabilities make satellite imagery particularly valuable for global forest monitoring programs and climate change studies.

### 2.2 Aerial and Drone-Based Remote Sensing

Aerial remote sensing systems include sensors mounted on aircraft or unmanned aerial vehicles (UAVs), commonly referred to as drones. These systems have gained increasing importance in environmental monitoring due to their ability to capture high-resolution imagery with flexible flight scheduling [11]. Drone-based remote sensing has become particularly popular for studying forest ecosystems at local and regional scales. UAVs can capture images with centimeter-level spatial resolution, allowing researchers to observe fine-scale details such as individual tree crowns, canopy gaps, pest infestations, and forest health conditions. Modern UAV platforms are equipped with various sensors, including multispectral cameras, thermal sensors, and hyperspectral imaging systems. These sensors enable detailed analysis of vegetation stress, plant health, and ecosystem dynamics. Another advantage of UAV technology is its relatively low operational cost compared to traditional aircraft-based surveys. Researchers can deploy drones quickly in areas affected by natural disasters such as wildfires, storms, or disease outbreaks to assess damage and monitor ecosystem recovery. Despite their advantages, UAV systems have limitations such as limited flight duration, restricted coverage area, and regulatory constraints in some regions.

### 2.3 Ground-Based Remote Sensing

Ground-based remote sensing systems play a complementary role in environmental monitoring by providing detailed field measurements that can be used to validate satellite and aerial observations. These systems include portable sensors, weather stations, and terrestrial laser scanning technologies. Field measurements collected through ground-based monitoring include tree height, trunk diameter, canopy density, leaf area index, and soil characteristics. These data are often integrated with remote sensing imagery to improve the accuracy of forest biomass estimation and land cover classification [12]. Terrestrial LiDAR scanning is another important ground-based technology used to capture detailed three-dimensional representations of forest structures. This method allows researchers to measure tree architecture, canopy complexity, and forest structural diversity. Ground-based monitoring is essential for validating remote sensing data and ensuring the reliability of large-scale environmental assessments.

## 3. Remote Sensing Techniques for Forest Monitoring

Advances in sensor technology and data processing techniques have significantly improved the ability of remote sensing systems to monitor forest ecosystems. Several remote sensing techniques are commonly used to assess forest structure, vegetation health, and land cover changes.

### 3.1 Multispectral and Hyperspectral Imaging

Multispectral imaging systems capture data across several distinct spectral bands, typically including visible and near-infrared wavelengths. These spectral bands are useful for identifying vegetation characteristics, monitoring plant productivity, and detecting environmental stress.

One of the most widely used vegetation indices derived from multispectral imagery is the Normalized Difference Vegetation Index (NDVI). NDVI measures the difference between near-infrared and red light reflected by vegetation and is commonly used to estimate vegetation density and health. Other vegetation indices, such as the Enhanced Vegetation Index (EVI) and Soil Adjusted Vegetation Index (SAVI), provide additional insights into plant growth conditions and environmental changes. Hyperspectral imaging represents a more advanced remote sensing technique that captures hundreds of narrow spectral bands across the electromagnetic spectrum [13]. This high spectral resolution allows researchers to identify subtle differences in vegetation composition, plant species distribution, and biochemical properties. Hyperspectral data are particularly useful for detecting plant diseases, nutrient deficiencies, and environmental stress before visible symptoms appear.

### 3.2 LiDAR (Light Detection and Ranging)

LiDAR technology has revolutionized forest monitoring by providing highly detailed three-dimensional information about vegetation structure. LiDAR sensors emit laser pulses toward the Earth's surface and measure the time it takes for the reflected signals to return to the sensor. This information allows researchers to generate accurate three-dimensional models of forest canopies, tree heights, and terrain features. LiDAR is particularly useful for estimating forest biomass and carbon stocks, which are important for climate change research and carbon accounting programs [14]. The measuring canopy height and vegetation density, LiDAR data can be used to calculate forest structural attributes with high precision. Airborne LiDAR systems mounted on aircraft or drones have been widely used in forest inventory studies, habitat mapping, and ecosystem monitoring.

### 3.3 Radar Remote Sensing

Radar remote sensing systems operate by transmitting microwave signals and measuring the reflected signals from the Earth's surface. Unlike optical sensors, radar systems can penetrate clouds and operate under various weather conditions, making them highly useful for monitoring forest ecosystems in tropical regions where cloud cover is

common. Synthetic Aperture Radar (SAR) is one of the most widely used radar technologies in environmental monitoring. SAR systems provide detailed information about surface roughness, vegetation structure, and moisture content. Radar data are particularly useful for detecting deforestation, mapping forest degradation, and monitoring wetland ecosystems. Radar sensors can also be used to estimate forest biomass and detect structural changes in vegetation over time [15]. Recent advances in radar technology have improved spatial resolution and data processing capabilities, making radar remote sensing an increasingly important tool in forest monitoring.

#### 4. Applications of Remote Sensing in Monitoring Land Use Change

Remote sensing technologies have numerous applications in monitoring land use changes and forest ecosystem dynamics. These tools provide valuable insights into environmental transformations caused by human activities and natural processes.

##### 4.1 Deforestation Detection

Deforestation is one of the most critical environmental issues affecting global forest ecosystems. Remote sensing technologies allow researchers to monitor forest cover changes over large geographic areas and identify regions experiencing rapid deforestation. Satellite imagery enables the comparison of historical and current land cover data, allowing scientists to detect forest loss and quantify deforestation rates [16]. These observations are essential for supporting international environmental initiatives aimed at reducing deforestation and promoting sustainable forest management. Remote sensing data are also used to monitor illegal logging activities and evaluate the effectiveness of conservation policies.

##### 4.2 Forest Degradation Assessment

Forest degradation refers to the gradual deterioration of forest ecosystems due to human activities such as selective logging, fuelwood collection, overgrazing, and forest fires.

Unlike deforestation, which involves complete removal of forest cover, degradation often results in subtle structural changes that are more difficult to detect. Advanced remote sensing techniques such as LiDAR and radar imaging allow researchers to detect changes in canopy structure, tree density, and biomass distribution. These technologies provide important information about forest health and ecosystem resilience [4]. Monitoring forest degradation is essential for maintaining biodiversity, protecting wildlife habitats, and preserving ecosystem services.

##### 4.3 Urban Expansion Monitoring

Rapid urbanization has significantly altered land use patterns in many parts of the world. Urban expansion often leads to the conversion of forest land into residential, industrial, and commercial areas. Remote sensing technologies allow researchers to map urban growth patterns and analyze the spatial distribution of urban development. Satellite imagery can be used to identify newly developed areas and assess the environmental impact of urban expansion on surrounding ecosystems [12]. Understanding urban growth trends is essential for sustainable urban planning and environmental conservation.

##### 4.4 Agricultural Land Expansion

Agricultural expansion is one of the primary drivers of land use change worldwide. The conversion of forest land into agricultural fields contributes to biodiversity loss, soil degradation, and greenhouse gas emissions. Remote sensing data allow researchers to track changes in agricultural land use and analyze the relationship between agricultural development and deforestation [9]. Satellite imagery can also be used to monitor crop growth patterns, irrigation practices, and land management strategies. By providing accurate and timely information about agricultural expansion, remote sensing technologies support sustainable land management and food security planning.

**Table 1: Major Remote Sensing Tools Used for Monitoring Land Use and Forest Dynamics**

Remote Sensing Tool	Type of Data	Applications
Satellite Imagery	Multispectral	Land cover mapping, deforestation detection
UAV/Drones	High-resolution imagery	Forest health monitoring
LiDAR	3D structural data	Biomass estimation, canopy analysis
Radar (SAR)	Microwave signals	Forest cover monitoring under cloudy conditions

#### 5. Integration of GIS and Machine Learning

Geographic Information Systems (GIS) play a critical role in analyzing and visualizing remote sensing data. GIS platforms allow researchers to integrate multiple datasets, perform spatial analysis, and generate detailed land use maps. Machine learning algorithms have also been increasingly used to classify land cover types and detect changes in satellite imagery. Techniques such as random forest, support vector machines, and deep learning models can process large volumes of remote sensing data with high accuracy [12]. Cloud-based platforms such as Google Earth Engine have further simplified the analysis of large satellite datasets, making remote sensing more accessible to researchers and environmental managers.

**Table 2: Major Remote Sensing Technologies Used for Monitoring Land Use Change and Forest Dynamics (2010–2025)**

Remote Sensing Technology	Sensor Type	Data Characteristics	Key Applications in Forest Monitoring	Advantages
Multispectral Satellite Imagery	Optical sensors	Captures data in several spectral bands (visible, near-infrared)	Land cover classification, vegetation monitoring, deforestation detection	Wide coverage, long-term data availability, cost-effective
Hyperspectral Imaging	Advanced optical sensors	Hundreds of narrow spectral bands	Species identification, vegetation stress detection, plant health monitoring	High spectral resolution and detailed vegetation analysis
LiDAR (Light Detection and Ranging)	Laser-based active sensor	Provides 3D structural information	Forest canopy height measurement, biomass estimation, carbon stock assessment	Highly accurate structural data and terrain mapping
Synthetic Aperture Radar (SAR)	Microwave radar sensor	Active sensor capable of penetrating clouds	Forest cover mapping, deforestation detection, soil moisture analysis	Operates in all weather conditions and day/night imaging
UAV/Drone-Based Remote Sensing	Multispectral/thermal sensors	High-resolution aerial imagery	Forest health assessment, pest and disease monitoring, small-scale forest mapping	Very high spatial resolution and flexible deployment
MODIS Satellite Sensors	Moderate resolution optical sensor	High temporal frequency data	Large-scale vegetation monitoring, forest fire detection, seasonal vegetation analysis	Frequent data updates and global coverage

## 6. Challenges and Limitations

Despite its advantages, remote sensing faces several challenges. These include data processing complexity, high costs associated with certain technologies such as LiDAR, and the need for skilled personnel to analyze geospatial data. Cloud cover and atmospheric conditions can also affect the quality of optical satellite imagery [14]. In addition, integrating remote sensing data with field observations remains essential for improving the reliability of environmental assessments.

## 7. Future Perspectives

Future developments in remote sensing are expected to focus on improving spatial resolution, increasing data availability, and enhancing automated analysis techniques. The integration of artificial intelligence, big data analytics, and cloud computing will likely transform environmental monitoring systems. Emerging satellite missions and advanced sensor technologies will provide more detailed information about forest ecosystems and land use changes. These advancements will support more effective forest conservation strategies and sustainable land management practices.

## 8. Conclusion

Remote sensing has become an essential tool for monitoring land use change and forest dynamics. Technological advancements between 2010 and 2025 have significantly improved the ability of researchers and policymakers to assess environmental changes at multiple spatial and temporal scales. The integration of satellite imagery, UAVs, LiDAR, radar systems, and GIS technologies has enhanced the accuracy and efficiency of environmental monitoring. These tools play a vital role in supporting sustainable forest management, biodiversity conservation, and climate change mitigation efforts.

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