



Advancing Agroforestry Suitability Assessment through Remote Sensing

*Shivam Dinkar

Ph.D. Scholar, Department of Silviculture and Agroforestry, College of Agriculture, Raipur, IGKV, Chhattisgarh, Raipur, India

*Corresponding Author's email: shivamdinkar1997@gmail.com

Agroforestry, the integration of trees and shrubs with crops and livestock, offers a sustainable land-use approach that enhances productivity, biodiversity, and ecosystem services. Assessing the suitability of land for agroforestry has traditionally relied on ground-based surveys and empirical data, which are often time-consuming and spatially limited. Recent advances in remote sensing (RS), geographic information systems (GIS), and machine learning (ML) have revolutionized land suitability mapping by providing dynamic, multi-temporal, and large-scale datasets. This article explores the emerging role of remote sensing in agroforestry suitability assessment, focusing on its methods, data sources, modeling approaches, and practical implications for sustainable land-use planning.

Introduction

Agroforestry has been increasingly recognized as a climate-smart land management practice that contributes to soil conservation, carbon sequestration, microclimate regulation, and livelihood enhancement. Identifying suitable areas for agroforestry adoption is critical for maximizing ecological and socio-economic benefits. Traditional field-based suitability analyses are constrained by limited spatial coverage, high costs, and temporal inflexibility. Remote sensing technologies offer a solution by enabling continuous, synoptic monitoring of land attributes such as soil moisture, vegetation cover, topography, and land-use dynamics. Integration of RS-derived data with GIS-based multi-criteria evaluation (MCE) and machine learning algorithms has made it possible to conduct high-resolution and data-driven suitability assessments for agroforestry planning.

Remote Sensing Data Sources for Agroforestry Assessment

Optical Satellite Sensors: Optical data from sensors such as Landsat (30 m), Sentinel-2 (10 m), and MODIS (250 m) are widely used for vegetation mapping, land-use/land-cover (LULC) classification, and biomass estimation. Vegetation indices such as NDVI (Normalized Difference Vegetation Index) and EVI (Enhanced Vegetation Index) derived from optical imagery provide insights into vegetation health and productivity, essential for determining suitable zones for agroforestry establishment.

Radar and LiDAR Technologies: Active remote sensing systems such as Synthetic Aperture Radar (SAR) (e.g., Sentinel-1, ALOS PALSAR) and Light Detection and Ranging (LiDAR) provide critical structural information on canopy height, tree density, and surface roughness—parameters vital for agroforestry suitability modeling. Radar's ability to penetrate cloud cover ensures data availability even under tropical conditions where optical sensors face limitations.

Hyperspectral Imaging: Hyperspectral data offer detailed spectral information that aids in species identification, soil characterization, and stress detection. These datasets are particularly useful in diversified agroforestry systems involving multiple tree and crop species with unique spectral signatures.

Methodological Frameworks

GIS-Based Multi-Criteria Decision Analysis (MCDA): MCDA integrates various biophysical, climatic, and socio-economic factors to determine land suitability. Parameters such as slope, elevation, soil type, rainfall, land cover, and temperature are combined using weighted overlay analysis in a GIS environment. Remote sensing data serve as primary inputs for deriving these spatial layers with high accuracy.

Machine Learning and Artificial Intelligence Models: Recent advances in machine learning (ML) have enhanced the precision of agroforestry suitability mapping. Algorithms such as Random Forest (RF), Support Vector Machine (SVM), and Artificial Neural Networks (ANN) have been employed to predict suitable areas by learning from historical land-use patterns and environmental conditions. These models integrate satellite-derived variables (e.g., NDVI, soil organic carbon, temperature anomalies) with field-based training data to generate probabilistic suitability maps.

Time-Series Analysis and Change Detection: Temporal datasets from sensors like MODIS and Sentinel allow time-series analysis of vegetation dynamics and land degradation trends. Monitoring land-use transitions (e.g., agricultural expansion, deforestation) assists in identifying potential areas for agroforestry restoration and rehabilitation.

Applications in Agroforestry Planning

Species-Site Matching: Remote sensing aids in mapping microclimatic zones and edaphic conditions for matching tree species to site characteristics, ensuring optimal growth and productivity.

Carbon Sequestration Potential: RS-based models can estimate aboveground biomass and carbon storage capacity of different agroforestry systems, supporting climate change mitigation policies.

Land Degradation and Restoration: High-resolution imagery enables identification of degraded lands suitable for silvopastoral or agro-silvicultural systems, promoting land restoration and sustainable livelihoods.

Socio-Economic Integration: Combining RS data with socio-economic datasets (e.g., population density, proximity to markets) allows comprehensive evaluation of agroforestry's feasibility and adoption potential.

Challenges and Future Perspectives

Despite its advantages, RS-based agroforestry assessment faces several challenges:

- Data integration issues due to varying spatial and temporal resolutions across sensors.
- Limited ground truth data for model calibration and validation.
- High processing complexity of hyperspectral and radar datasets.
- Socio-economic parameters often remain underrepresented in biophysical models.

Future research should focus on developing standardized frameworks integrating multi-source remote sensing, Internet of Things (IoT), and AI-driven analytics to create dynamic, real-time suitability maps. The emergence of cloud computing platforms such as Google Earth Engine (GEE) enables scalable and accessible agroforestry assessment at regional and global levels.

Conclusion

Remote sensing has become an indispensable tool in advancing agroforestry suitability assessment, offering cost-effective, accurate, and spatially extensive solutions. By coupling satellite data with GIS and machine learning, researchers and policymakers can identify optimal zones for agroforestry interventions, monitor land-use dynamics, and support sustainable land management strategies. As technological advancements continue, the integration of high-resolution sensors, AI analytics, and participatory mapping approaches will further strengthen the role of remote sensing in building climate-resilient and sustainable agroforestry systems.