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Geospatial Assessment of Potential Agarwood (Aquilaria Malaccensis) Cultivable Areas in Assam, India: A Remote Sensing and GIS Approach for Sustainable Agroforestry

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Abstract

Agarwood (Aquilaria malaccensis), a critically endangered species prized for its resinous heartwood, represents one of the most valuable agroforestry commodities in Northeast India. Assam, with its favorable Agro-climatic conditions and centuries-old cultivation tradition, is a global production hub. However, the absence of systematic spatial data on existing plantations and potential cultivation zones constrains evidence-based planning. This study presents a comprehensive geospatial assessment using Resourcesat-2A LISS-IV satellite imagery (5.8 m), Support Vector Machine (SVM) classification, and mobile-based field validation (AXOM FIELD application). We mapped 30,963 hectares of existing plantations across fourteen (14) districts and identified approximately 1,99,602 ha of potential or additional cultivable area. Tinsukia (30,842 ha), Golaghat (28,394 ha) and Karimganj (23,293 ha) emerged as top potential districts. Three major development Corridors were delineated for the expansion of Agarwood cultivation in Assam, these are : (1) Upper Assam corridor, North Bank corridor and Barak Valley corridor. The study demonstrates the efficacy of integrating remote sensing, GIS and GPS based validation process for agroforestry resource assessment and provides a spatially explicit evidence base for sustainable agarwood expansion and conservation in Assam.

Keywords: Agarwood, Aquilaria malaccensis, Remote sensing, GIS, Land suitability, Agroforestry, Assam

1. Introduction

Agarwood, the resinous heartwood produced by Aquilaria species in response to fungal infection, ranks among the world's most valuable non-timber forest products (Barden et al., 2000). The resin, known as "Oud" in the Middle East and "Xasi" in Assam, is used in perfumery, incense and traditional medicine. Global trade is estimated at billions of dollars annually, with premium grades exceeding USD 100,000/kg (Lopez-Sampson & Page, 2018). Over-exploitation of wild populations has rendered Aquilaria malaccensis Critically Endangered (IUCN) and listed in CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) Appendix II. Sustainable cultivation is thus imperative.

Assam holds a unique position unlike other regions reliant on wild harvesting, its agarwood trade is based predominantly on cultivated trees within traditional agroforestry systems (Bhattacharya et al., 2012). Upper Assam districts—Golaghat, Jorhat and Sibsagar—have a centuries-old cultivation tradition of Agar trees. Despite this, systematic spatial data on plantation extent and suitable areas are lacking, hampering policy and investment planning.
Remote sensing and GIS have proven effective for agroforestry assessment (Dewan et al., 2019; Kumar et al., 2020). Studies using Sentinel-2, LISS-4 and Landsat with machine learning have achieved high accuracy in mapping tree cover (Varshitha et al., 2024). Specific to agarwood, Rahmawaty et al. (2019) mapped land suitability in North Sumatra, and Anuber et al. (2025) used multi-criteria analysis for habitat suitability in the Philippines. However, no such comprehensive assessment exists for Assam till date. So the present study is a kind of initiative to assess and highlight the existing status of Agarwood in the state and similarly to predict a focus in the potential expansion patches in the state.
This study aims to: (1) Map existing Agarwood plantations areas across the different districts of Assam. (2) Characterize plantation attributes; (3) Identify potential cultivable areas; (4) Delineate development corridors and (5) To Provide evidence for sustainable expansion.

2. Study Area

The study covered fourteen (14) districts of Assam, extending from 24°08′ to 28°02′ N latitude and 89°42′ to 96°02′ E longitude, spreading mainly in Tinsukia, Dibrugarh, Sivasagar, Jorhat, Golaghat, Charaideo, Dhemaji, Lakhimpur, Biswanath, Sonitpur, Hojai, Cachar, Karimganj and Hailakandi districts. These districts were selected based on their known agarwood cultivation history, presence of processing infrastructure and representation of different Agro-ecological zones.
Assam is characterized by a tropical monsoon climate with high rainfall (average 1,500-3,000 mm annually), warm temperatures (average 22-28°C), and high humidity conditions highly favorable for Aquilaria malaccensis cultivation

3. Materials and Methods

3.1 Data Sources

The study utilized Resourcesat-2A LISS-IV satellite imagery, comprising Green, Red and Near-Infrared (NIR) spectral bands at a spatial resolution of 5.85 m, acquired during the period from March 2022 to April 2023. Field-level information was collected using the "**AXOM FIELD" mobile application**, which facilitated the acquisition of geotagged data on Plantation location, Plantation age, Number of trees, Plantation area, Plantation condition and Intercropping practices. Ground Control points (GCP) were collected and used for image classification, training sets identification and validation. In addition to satellite and field datasets, several ancillary datasets were incorporated to support the spatial analysis, including the 30 m resolution **Copernicus** Open access Digital Elevation Model (DEM), Soil maps obtained from the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), existing land use/land cover (LULC) maps, and administrative boundary datasets. These datasets collectively provided the spectral, field-based, topographic, soil and administrative information required for the spatial assessment and mapping of agarwood plantation areas in the state.

3.2 Methods

3.2.1 Existing Plantation Mapping

The existing plantation mapping was carried out using a Supervised remote sensing classification approach. Initially, the satellite imagery underwent Radiometric and atmospheric corrections to minimize sensor and atmospheric-related distortions, followed by Geometric correction to ensure spatial accuracy, with a Root Mean Square (RMS) error maintained below 0.5 pixels. The corrected imagery was then classified using a Support Vector Machine (SVM) algorithm with a Radial Basis Function (RBF) kernel. The classification utilized the available spectral bands along with the Normalized Difference Vegetation Index (NDVI) to improve the discrimination of plantation areas from other land-cover classes. Following classification, a 3 × 3 majority filter was applied to reduce isolated pixels and classification noise. The preliminary plantation map was subsequently subjected to visual refinement and on-screen digitization using ancillary information and spatial interpretation to improve the delineation of plantation boundaries. Finally, the accuracy of the classified plantation map was evaluated using independent ground-truth points through a confusion matrix, from which the overall accuracy and Kappa coefficient were calculated to assess the reliability and consistency of the classification results.

3.2.2 Potential Area Identification:

The following procedures were applied to map the potential Agarwood expansion area in the state:

- Interpretation of satellite imagery to identify Tree Outside Forest (TOF) landscapes.
- Exclusion of unsuitable categories: Water bodies, Built-up, Dense forests, Ecologically sensitive zones, Slopes >30°, Elevation >1,000 m.
- GIS-based spatial analysis of remaining parcels for suitability (land use, soil, accessibility, agro-climatic factors).
- District and circle-level aggregation using zonal statistics.

Corridor Delineation: Three corridors delineated based on spatial clustering: Upper Assam Corridor (UAC), North Bank Corridor (NBC), and Barak Valley Corridor (BVC).

4. Results

4.1 Existing Plantations: Extent and Distribution

The assessment of agarwood cultivation indicates that the activity is geographically distributed across 14 districts of Assam**,** covering an estimated total area of 30,963.38 hectares. The distribution shows considerable spatial variation among the districts, with Golaghat recording the highest area under agarwood cultivation at 7,590.20 ha**,** followed by Jorhat (4,000.00 ha)**,** Dibrugarh (3,730.97 ha)**,** Cachar (3,072.20 ha) and Tinsukia district (2,521.15 ha). Other notable areas are observed in Hojai (2,286.78 ha), Sivasagar (2,190.29 ha), Hailakandi (1,669.59 ha), Karimganj (1,309.81 ha) and Dhemaji (977.60 ha)**.** Charaideo and Lakhimpur also show substantial cultivation areas, while relatively smaller areas are recorded in Biswanath and Sonitpur. The concentration of agarwood cultivation in several districts, particularly in Upper Assam and parts of the Barak Valley**,** demonstrates the strong existing cultivation base and significant potential for further development. This spatial distribution provides an important basis for identifying priority districts, planning targeted interventions, strengthening farmer support systems, and developing an integrated agarwood value chain covering cultivation, sustainable management, processing, marketing, and livelihood generation. Overall, the findings highlight the considerable potential of agarwood as an important agroforestry and rural economic resource for Assam.

4.2 Existing Plantation Characteristics:

- **Age:** 6 to 45+ years; plantations >30 years in Golaghat/Jorhat reflect tradition.
- **Size:** 100–3,500 trees; most farmers maintain 500–2,000 trees.
- **Condition:** 65% Good, 30% Medium, 5% Poor.
- **Intercropping**: Tea-agarwood (dominant), Arecanut-agarwood, Bamboo-agarwood, Mixed systems.

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Figure.1 Existing Agarwood Plantation area in Assam

Table 1: Area under Agarwood Cultivation by District

District	Area under Agarwood Cultivation (Ha.)
Golaghat	7,590.20
Jorhat	4,000.00
Biswanath	41.79
Cachar	3072.20
Charaideo	769.97
Dhemaji	977.60
Dibrugarh	3730.97
Hailakandi	1669.59
Hojai	2286.78
Karimganj	1309.81
Lakhimpur	777.85
Sibsagar	2190.29
Sonitpur	25.18
Tinsukia	2521.15
Total Area	**30,963.38**

4.3 Potential Cultivable Areas

The existing study was not only confined to the delineation of present Agarwood patches but an approach was undertaken to identify the potential areas for future Agarwood cultivation. After the final delineation of the analysis almost 1,99,602.22 Ha. Land was identified in 14 study districts of Assam.

Table 2: Potential Agarwood Cultivable Area by District

Sl.No	District	Potential Area (Ha)
1	Tinsukia	30,842.31
2	Golaghat	28,394.00
3	Karimganj	23,293.34
4	Sonitpur	21,770.33
5	Hailakandi	19,330.65
6	Lakhimpur	15,120.61
7	Biswanath	13,131.07
8	Jorhat	11,329.09
9	Cachar	10,002.77
10	Dhemaji	8,982.91
11	Dibrugarh	8,903.32
12	Sibsagar	4,269.89
13	Hojai	3,022.62
14	Charaideo	1,209.31
	Total	**1,99,602.22**

Source: (Resourcesat-2A, LISS-IV, March 2022- April,2023

The district-wise assessment of potential areas indicates that Assam possesses substantial spatial potential for the expansion of agarwood cultivation, with a total estimated potential area of **1,99,602.22 hectares** across 14 districts. The highest potential area is identified in Tinsukia (30,842.31 ha)**,** followed by Golaghat (28,394.00 ha) and Karimganj (23,293.34 ha)**.** Other districts with considerable potential include Sonitpur (21,770.33 ha), Hailakandi (19,330.65 ha), Lakhimpur (15,120.61 ha), Biswanath (13,131.07 ha), and Jorhat (11,329.09 ha)**.** Moderate potential is observed in Cachar (10,002.77 ha), Dhemaji (8,982.91 ha), Dibrugarh (8,903.32 ha), and Sibsagar (4,269.89 ha), while Hojai (3,022.62 ha) and Charaideo (1,209.31 ha) exhibit comparatively lower potential areas. The spatial pattern suggests that agarwood cultivation potential is not confined to a single geographical region but is distributed across both Upper Assam and the Barak Valley, as well as parts of the North Bank region**.**

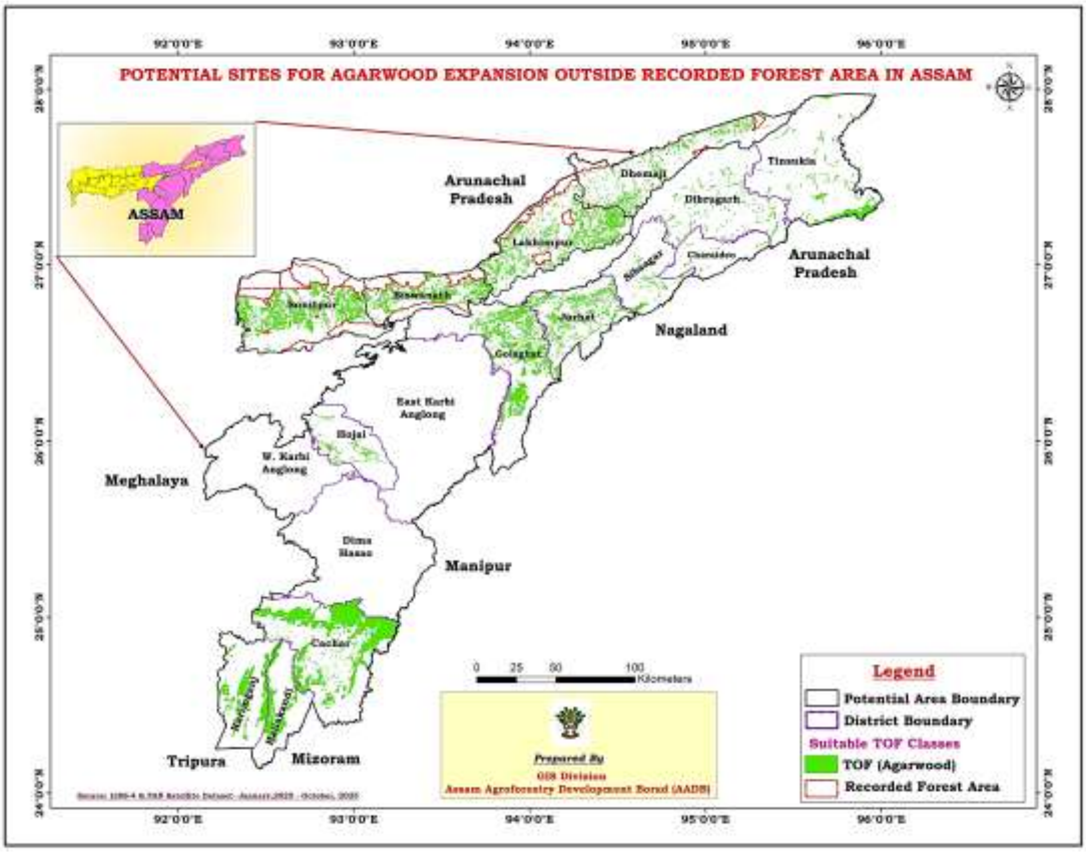

Fig.2 Map Showing the distribution pattern potential agarwood expansion area in Assam

5 Development Corridors

The Agarwood Development Corridors of Assam can be broadly categorized into three major zones. The Upper Assam Corridor (UAC)**,** comprising Tinsukia, Dibrugarh, Sivasagar, Jorhat, Golaghat and Charaideo, represents a strong agarwood production belt supported by existing infrastructure, tea-based intercropping practices and a substantial cultivation base, although the area remains vulnerable to recurrent flooding. The North Bank Corridor (NBC)**,** covering Sonitpur, Biswanath, Lakhimpur and Dhemaji, is characterized by large and relatively contiguous suitable areas with considerable scope for expansion, but comparatively limited processing and value-addition infrastructure. The Barak Valley Corridor (BVC)**,** comprising Cachar, Karimganj and Hailakandi, exhibits exceptional climatic suitability, high rainfall and a growing cultivation base, offering significant potential for future agarwood-based economic development.

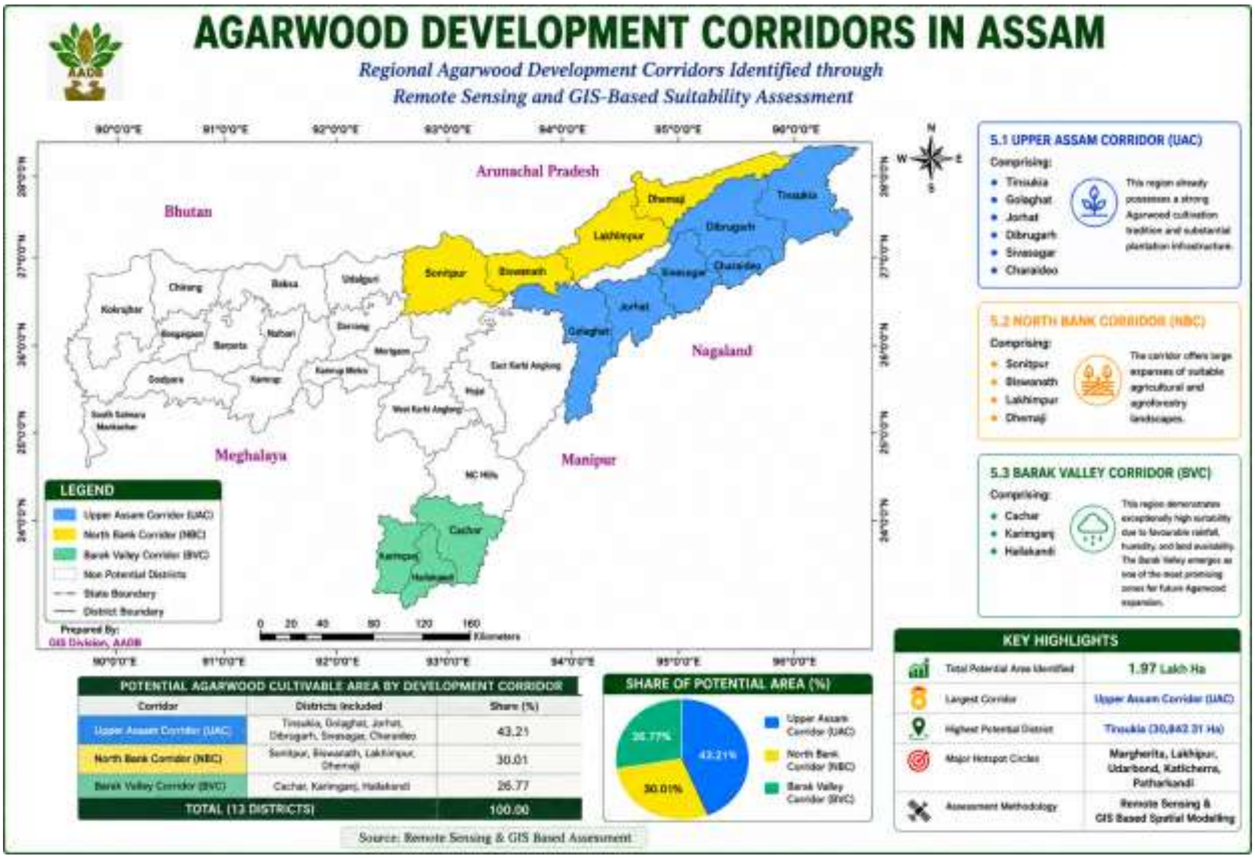

Fig.3 Showing the model for Agarwood Development Corridors in Assam

6. Discussion

6.1 Methodological Insights

The integration of Resourcesat-2A LISS-IV (5.8 m) with SVM classification and AXOM FIELD mobile validation achieved an overall accuracy of **87.3%** (kappa 0.84), comparable to other agroforestry mapping studies (Varshitha et al., 2024). The SVM approach effectively distinguished agarwood plantations in complex agricultural mosaics. The mobile-based field data collection enabled precise georeferencing and reduced survey costs. This framework is replicable for other high-value tree species.

6.2 Spatial Patterns and Expansion Potential

The identification of 1,99,602 ha potential area—six times the existing plantation extent—indicates substantial scope for sustainable expansion. Tinsukia and Golaghat lead in both current and potential area, confirming their strategic importance. The Barak Valley's high potential (Karimganj, Hailakandi, Cachar) aligns with its favorable rainfall and humidity, corroborating findings from Anuber et al. (2025) on precipitation as a key determinant. The three corridors provide a spatial framework for targeted interventions: UAC for intensification and modernization, NBC for greenfield expansion with infrastructure development, and BVC for climate-advantaged production.

6.3 Conservation and CITES Implications

As a Critically Endangered CITES Appendix II species, cultivation expansion must be undertaken with conservation safeguards. The exclusion of natural forests and sensitive zones from potential areas reflects a precautionary approach. Cultivation in agricultural and agroforestry landscapes can reduce pressure on wild populations, provided that genetic diversity is maintained and sustainable management practices are adopted (Nath et al., 2024). Certification and traceability systems are essential for compliance and market access.

6.4 Socio-Economic and Policy Relevance

The concentration of plantations in rural, smallholder-dominated landscapes underscores agarwood's role in livelihood enhancement. The identified potential areas offer opportunities for targeted farmer support, FPO formation, and value-chain development. The circle-level priority zones (e.g., Margherita, Sarupathar) enable fine-scale planning. Policymakers can use these data to allocate resources, design extension programs and incentivize sustainable cultivation. Climate change projections suggest increased flood risk in Upper Assam; diversification across corridors can reduce vulnerability.

6.5 Limitations

The study did not incorporate socio-economic constraints (land ownership, farmer willingness, market access) nor climate change scenarios. The 5.8 m resolution may miss scattered trees in highly fragmented systems. Ground validation was concentrated in Golaghat/Jorhat; more points in other districts would improve accuracy.

7. Conclusion

This geospatial assessment provides the first comprehensive baseline of agarwood cultivation in Assam: 30,963 ha existing and 1,99,602 ha potential area across fourteen districts. Three development corridors—Upper Assam, North Bank and Barak Valley offer a spatial framework for evidence-based planning. The methodological integration of remote sensing, SVM classification and mobile-based validation proved effective and replicable. The findings underscore Assam's immense potential for sustainable agarwood expansion, contributing to rural livelihoods, export earnings and conservation of a globally threatened species. Realizing this potential requires coordinated policy support, investment, and farmer engagement, guided by the spatial evidence presented herein.

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