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Land Cover Mapping Of Mandailing Natal

Surahman Putra[1]*, Bambang Tri Sasongko Adi[2], Ratna Kusuma Sari[3], Bonie Dewantara[4], Puspita Suryaningtyas[5]
PT Hatfield Indonesia[1,2], Universitas Brawijaya, Indonesia[3], CTSS (Center for Transdisciplinary and Sustainability Science) IPB University[4], Magister Manajemen Universitas Gadjah Mada, Indonesia[5]

Abstract: *This article explores land cover mapping conducted in the Mandailing Natal District, North Sumatra. Using PlanetScope 2022 data and Object-based Image Analysis (OBIA) methodology, it mapped land cover with a map scale of 1:25.000 within the district in 2022. Indonesia National Standard (SNI) 7645:2010 was used to determine the land cover class identified from OBIA. The land cover identified the distribution of forest cover, key commodities, plantations, and other land cover, which can be used for further study, such as HCV-HCS assessment and Targeted Scenario Analysis (TSA) of sustainable commodities.*
Keywords: *Land Cover Mapping, OBIA, Mandailing Natal.*

1. INTRODUCTION

Mandailing Natal District, located in North Sumatra Province, has undergone substantial land cover change in recent years, primarily due to the expansion of plantations and agricultural activities. Commodities such as oil palm, coffee, and rubber have played a central role in reshaping the landscape, with plantation areas now covering nearly half of the district's land area (Hatfield Indonesia, 2025). These land cover changes not only reflect evolving land use practices but also present important implications for environmental planning and sustainable development in the region.

To support evidence-based land management, a detailed land cover analysis was conducted in 2022 as part of the High Conservation Value (Area Bernilai Konservasi Tinggi, or ABKT) assessment under the FOLUR project. The study employed Object-Based Image Analysis (OBIA) techniques on PlanetScope satellite imagery with 3.7-meter spatial resolution to produce a land cover map at a scale of 1:25,000. The classification process followed the SNI 7645:2010 standard and involved three hierarchical levels of categorization, from basic forest/non-forest classes to more specific categories such as plantation type, forest density, and agricultural land (Hatfield Indonesia, 2025; Nasiri et al., 2023; Junior et al., 2023).

The findings show that oil palm plantations (23.75%), mixed plantations (17.17%), and rubber plantations (6.6%) dominate the landscape, while primary dryland forests, though still present, are increasingly fragmented (Hatfield Indonesia, 2025). These results underscore the dynamic nature of land cover development in the district and highlight the need for continuous monitoring to inform spatial planning, conservation strategies, and land governance.

This research paper focuses on analyzing the current condition and development of land cover in Mandailing Natal, drawing from high-resolution satellite data and verified field observations to map spatial patterns and identify key trends in land cover transformation.

This study aims to analyze the current state and recent development of land cover in Mandailing Natal District, North Sumatra, using high-resolution satellite imagery and object-based image analysis (OBIA) techniques. Specifically, the objectives of this research are to:

1. Map and classify the land cover types in Mandailing Natal District based on the most recent available satellite imagery using the SNI 7645:2010 land cover classification standard.
2. Quantify the extent and proportion of major land cover classes, such as forest, plantation, agricultural land, and settlement, as of 2022.
3. Identify spatial patterns and trends in land cover development, with particular attention to plantation expansion and forest area fragmentation.

4. Provide a spatial reference for stakeholders involved in land use planning, environmental monitoring, and sustainable resource management in Mandailing Natal.

Through these objectives, the study seeks to support informed decision-making in landscape governance and to contribute to a broader understanding of land use dynamics at the district level.

2. METHOD

The study was conducted in Mandailing Natal District, located in the southern region of North Sumatra Province (98°48'47" to 99°58'10" E and 1°20'09" to 0°13'24" N), Indonesia. Covering approximately 652,000 hectares, the district features a mix of lowland and upland landscapes, including extensive forested areas and rapidly expanding plantations. Administratively, the district is divided into 23 subdistricts, with varied land uses ranging from protected forests to production zones and agricultural areas. Given the district's ecological significance and increasing land use pressure from commodity crops such as oil palm, rubber, and coffee, Mandailing Natal was selected as a key focus area for land cover assessment under the FOLUR project.

The primary dataset used for land cover classification was high-resolution PlanetScope satellite imagery captured in 2022. PlanetScope provides multispectral data at a spatial resolution of approximately 3.7 meters, making it suitable for detailed land cover analysis at the subdistrict level (Planet Labs Inc., 2022). To ensure consistency with national guidelines, the classification process adhered to the Indonesian National Standard for Land Cover Classification (SNI 7645:2010; Badan Standardisasi Nasional [BSN], 2010). Ancillary data, such as official land use zoning maps and existing forest estate classifications, were also consulted during the classification and validation processes.

Image Pre-processing

Before classification, PlanetScope imagery underwent pre-processing steps including mosaicking and normalization to ensure consistent reflectance values across scenes. All imagery was projected to the geographical coordinate system using the WGS 84 datum to maintain spatial alignment with administrative and field data layers. Only cloud-free or minimally obstructed scenes were selected for analysis to maintain classification accuracy.

Accuracy Assessment

An initial accuracy assessment was conducted using field observation data and visual interpretation of high-resolution imagery. A confusion matrix was developed to compare classified land cover against reference data, although detailed accuracy metrics such as the overall accuracy or Kappa coefficient were reserved for a subsequent validation phase in the full ABKT assessment.

Data Analysis

The final land cover map was used to calculate class-wise area statistics and identify spatial patterns of land use in Mandailing Natal. Area summaries were produced at the district level and disaggregated by subdistrict where appropriate. Particular attention was given to mapping the extent of plantations, residual forest patches, and areas with mixed land use. This information provides a baseline for monitoring land cover change and supports district-level spatial planning and conservation decision-making.

3. FINDINGS AND DISCUSSIONS

In 2022, the landscape of Mandailing Natal District was primarily shaped by plantation and forest land cover, with plantations occupying a significant share of the area (Table 1 and Figure 1). Oil palm plantations were the most dominant, covering approximately 156,112.76 hectares (23.75%), followed by mixed plantations at 112,845.58 hectares (17.17%) and rubber plantations at 43,376.22 hectares (6.6%). Coffee plantations accounted for a smaller fraction of 4,865.93 hectares (0.74%), yet remain locally important for smallholder livelihoods. The extensive coverage of oil palm reflects broader trends observed across Sumatra, where commercial expansion often overlaps with forest zones and designated conservation areas (Gaveau et al., 2014). The overlap of plantation land within forest estate categories also indicates ongoing challenges in enforcing land use zoning and regulating informal expansion (PT Hatfield Indonesia, 2025).

Forests still represent a major land cover component, encompassing approximately 282,778 hectares or 43.33% of the district. The largest share is high-density primary dryland forest at 247,975.35 hectares (37.73%), followed by lower proportions of low-density primary dryland forest (20,664.96 ha or 3.14%), high-density secondary dryland forest (10,037.58 ha or 1.53%), and low-density secondary dryland forest (5,711.44 ha or 0.87%). Minor forest types such as low-density secondary mangrove forest (342.05 ha) and low-density secondary swamp forest (39.52 ha) are restricted to specific subdistricts—Muara Batang Gadis and Natal, respectively. The spatial concentration of these forest types aligns with earlier ecological surveys that identified Muara Batang Gadis as a biodiversity-rich area with high forest integrity (Wich et al., 2011). The remaining forests, although fragmented, still offer ecological functions and carbon storage potential, reinforcing their conservation value amid rising land use pressures.

The other land cover categories each contribute a smaller proportion to the overall landscape. Rice fields cover 17,231.46 hectares (2.62%), while shrubs and swamp shrubs account for 22,844.56 hectares (3.48%) and 870.43 hectares (0.13%) respectively. Open land (5,021.62 ha or 0.76%), settlements (4,849.31 ha or 0.74%), and water bodies (4,465.15 ha or 0.68%) are dispersed across the district, often concentrated along valley floors, rivers, and road networks. These patterns are consistent with broader settlement and infrastructure development trends in forest-agriculture frontiers in Indonesia (Dewi et al., 2013). Although their individual footprints are modest, these classes can be important indicators of human activity, future expansion, or land degradation. Taken together, the land cover distribution in Mandailing Natal underscores the importance of harmonizing agricultural productivity with spatial planning and conservation, particularly in districts where plantation growth intersects with critical forest ecosystems.

Table 1. Land cover distribution in Mandailing Natal

Land Cover Class	Area (ha)	Proportion (%)
High-density primary dryland forest	247,975.35	37.73
Oil palm plantation	156,112.76	23.75
Mixed plantation	112,845.58	17.17
Rubber plantation	43,376.22	6.60
Shrub	22,844.56	3.48
Low-density primary dryland forest	20,664.96	3.14
Rice field	17,231.46	2.62
High-density secondary dryland forest	10,037.58	1.53
Low-density secondary dryland forest	5,711.44	0.87
Open land	5,021.62	0.76
Coffee plantation	4,865.93	0.74
Settlement	4,849.31	0.74
Waterbody	4,465.15	0.68
Swamp shrub	870.43	0.13
Low-density secondary mangrove forest	342.05	0.05
Low-density secondary swamp forest	39.52	0.01
Totals	**652,386.77**	**100.00**

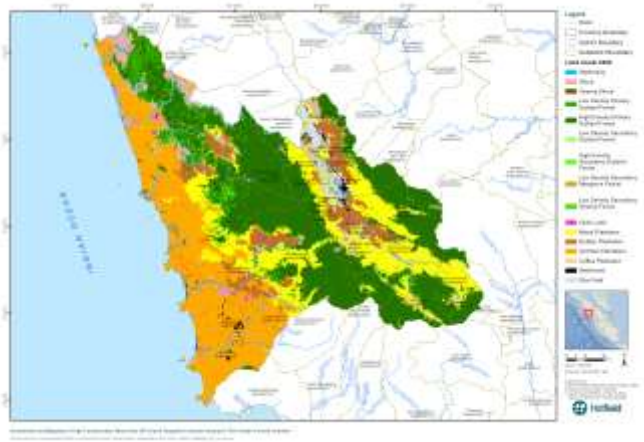

Figure 1. Land cover distribution map in Mandailing Natal

Forest Cover Distribution Forest cover remains a significant component of the land surface in Mandailing Natal District, occupying approximately 43.33% of the total area or about 282,778 hectares as of 2022 (PT Hatfield Indonesia, 2025). The largest share is attributed to high-density primary dryland forest, covering 247,975 hectares (37.73%), which is concentrated primarily in the Muara Batang Gadis, Panyabungan Timur, and Batang Natal subdistricts. These primary forest blocks are associated with steep terrain, limited access, and inclusion within conservation zones such as the Batang Gadis National Park and protection forest areas. The presence of extensive primary forest in upland regions is consistent with findings in other parts of Sumatra, where forest persistence is often linked to elevation and distance from roads (Margono et al., 2014). Secondary forest cover is notably less extensive and tends to be more fragmented. Low-density primary dryland forest accounts for 20,665 hectares (3.14%), while high- and low-density secondary dryland forests cover 10,038 hectares (1.53%) and 5,711 hectares (0.87%), respectively. These forests are typically found in transition zones between plantations and intact forest blocks and may represent areas recovering from previous logging or smallholder encroachment. Fragmentation of secondary forest is a critical concern, as it reduces ecological connectivity and increases edge effects, which can significantly alter species composition and ecosystem function (Haddad et al., 2015). Notably, Muara Batang Gadis alone holds the largest share of both high- and low-density secondary dryland forest in the district, reflecting its importance not only in terms of forest extent but also in the range of successional stages present.

Other forest types, while limited in area, reflect important ecological niches. Low-density secondary mangrove forest, totaling just 342 hectares (0.05%), is found exclusively in Muara Batang Gadis Subdistrict, likely associated with riverine and estuarine margins. Likewise, low-density secondary swamp forest is confined to Natal Subdistrict and occupies a mere 40 hectares (0.01%). Although small in extent, these forests offer critical ecosystem services such as flood regulation, sediment trapping, and habitat for specialized flora and fauna (Alongi, 2012). The highly localized nature of these ecosystems makes them particularly vulnerable to land use conversion and hydrological alteration. Taken together, the forest cover distribution in Mandailing Natal not only underscores the dominance of primary dryland forest but also highlights the need for spatially differentiated conservation strategies that consider both core forest areas and marginal, yet ecologically significant, forest types.

Plantation Cover Distribution

Plantation agriculture has become the most dominant land cover category in Mandailing Natal District, accounting for over 317,200 hectares or approximately 48.6% of the total land area (PT Hatfield Indonesia, 2025). Among the plantation types, oil palm dominates the landscape, covering 156,113 hectares (23.75%), followed by mixed plantations at 112,846 hectares (17.17%) and rubber plantations at 43,376 hectares (6.6%). Coffee plantations, although less extensive, still occupy 4,866 hectares (0.74%) and are concentrated in highland areas such as Ulu Pungkut and Kotanopan. This expansion of monoculture plantations, particularly oil palm, mirrors broader land use trends in Sumatra, where commodity-driven land transformation has contributed significantly to forest loss and landscape homogenization (Gaveau et al., 2016).

The spatial distribution of plantation cover reflects both agroecological suitability and accessibility. Oil palm plantations are primarily located in lowland areas with favorable terrain and road access, including parts of Ranto Baek, Siabu, and Lingga Bayu subdistricts. Mixed plantations, which often include combinations of oil palm, rubber, and other crops, tend to dominate transition zones between forested uplands and intensively cultivated lowlands. Rubber plantations are more dispersed but are notably present in the central and southern parts of the district. Coffee plantations, in contrast, are largely confined to the upland subdistricts, often situated along forest margins where microclimatic conditions are more suitable. Similar patterns have been observed in other parts of Indonesia, where smallholder coffee cultivation is frequently interspersed with remnant forest and traditional agroforestry systems (de Foresta et al., 2015).

A noteworthy aspect of Mandailing Natal's plantation distribution is the extent to which these land uses overlap with designated forest estate categories. According to the ABKT assessment, approximately 101,615 hectares of plantation cover—nearly one-third of all plantations—are located within zones legally designated as protection, production, or limited production forests (PT Hatfield Indonesia, 2025). This overlap highlights governance challenges in enforcing spatial planning regulations and underscores the risk of further deforestation within the forest estate. As documented in previous studies, unregulated or poorly monitored plantation expansion within forest zones can lead to significant carbon emissions, biodiversity loss, and disruption of ecosystem services (Carlson et al., 2013). Addressing these overlaps is critical for aligning land-based development with conservation and climate mitigation goals.

The land cover dynamics of Mandailing Natal District illustrate a landscape under increasing pressure from commodity-driven expansion, particularly from oil palm and mixed plantations. The 2022 land cover data reveals a near-equivalent proportion between plantation areas (48.6%) and forested land (43.3%) (PT Hatfield Indonesia, 2025). This near parity underscores a critical land use transition point: while natural forest still retains a substantial spatial presence, the rapid growth of plantation areas suggests a trajectory toward landscape simplification and functional homogenization. Similar patterns have been documented across Sumatra, where the growth of commercial plantations has emerged as a dominant driver of deforestation and forest fragmentation (Gaveau et al., 2016; Margono et al., 2014).

The distribution of forest types indicates that while large tracts of high-density primary dryland forest remain, especially in upland, inaccessible zones, the lower extent of secondary forest and the scarcity of wetland and mangrove forest types suggest a history of degradation and selective conversion. These changes are consistent with land-use intensification patterns observed in other parts of Indonesia, where forests near roads or settlements are more likely to be encroached upon or converted (Hansen et al., 2013). Additionally, the confinement of low-density mangrove and swamp forests to narrow geographic ranges highlights their ecological vulnerability. Given their disproportionate importance in carbon sequestration and hydrological regulation, the continued loss or degradation of these marginal forest types could carry long-term consequences for both biodiversity and ecosystem services (Alongi, 2012; Murdiyarso et al., 2015). Perhaps the most concerning finding is the spatial overlap between plantation cover and legally designated forest estate categories. The presence of over 100,000 hectares of plantations within protection and production forest zones in Mandailing Natal reflects governance gaps and weak enforcement of spatial planning regulations (PT

Hatfield Indonesia, 2025). This trend has been widely reported in Indonesia, where the disconnection between formal land use plans and on-the-ground agricultural development has fueled conflicts over tenure, undermined conservation targets, and contributed to greenhouse gas emissions (Austin et al., 2019; Carlson et al., 2013). These findings suggest that without stronger monitoring and corrective mechanisms, the forest estate in Mandailing Natal may continue to be eroded by creeping plantation expansion, particularly in frontier areas where regulation is weakest.

4. CONCLUSION

The analysis of land cover in the Mandailing Natal District reveals a landscape at a crossroads. While forest cover still plays a central role in shaping the district's ecological identity, the scale and spatial footprint of plantations—especially oil palm and mixed commodity systems—suggest a rapidly changing land use matrix. The observed pattern of plantation expansion into forest areas is not only a reflection of economic pressures but also indicative of planning and regulatory deficiencies. Left unchecked, these trends may lead to further loss of primary forest, reduced ecological resilience, and missed opportunities for sustainable land governance.

To address these challenges, local and provincial authorities should prioritize integrated spatial planning that reconciles agricultural development with ecological protection. This includes strengthening the enforcement of forest estate boundaries, conducting participatory mapping with local communities to clarify land tenure, and establishing incentive mechanisms for maintaining forest cover within and outside protected areas. In particular, areas with high-density primary forest and localized ecosystems such as mangroves and swamp forests should be designated as conservation priorities. Additionally, the expansion of plantations into sensitive or contested zones should be subject to stricter environmental assessments and compliance monitoring, consistent with national sustainability commitments and the FOLU Net Sink 2030 target (MoEF, 2021).

Moreover, land cover maps such as the one developed in this study should be institutionalized as decision-support tools for local development planning, licensing, and restoration programs. Reliable, high-resolution data is essential not only for identifying current land use patterns but also for anticipating future change and its potential impacts. By aligning spatial data with policy instruments and cross-sector collaboration, Mandailing Natal has the opportunity to chart a path toward landscape sustainability that integrates production, conservation, and community rights.

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