

ASSESSMENT OF FOREST CHANGES IN NGHE AN PROVINCE FOR RISK DETERMINATION UNDER THE EUROPEAN UNION DEFORESTATION REGULATION

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Abstract. Forest changes in Nghe An province were analyzed to support supply chain product traceability in compliance with the European Union Deforestation Regulation (EUDR) as well as to assess the risks and drivers of deforestation and forest degradation. Geographic Object-Based Image Analysis (GEOBIA) of remote sensing data, supported by documentary evidence and field surveys, was utilized to map forest cover status. Between 2020 and 2025, the natural forest area increased marginally, whereas the plantation forest area grew substantially, raising the overall forest cover rate from 58.5% to 59.16%. Deforestation, totaling nearly 800 hectares (0.19%), occurred mainly where poor forests and plantation forests were converted into agricultural land. Forest degradation affected 0.06% of natural forests, 4.16% of poor forests and 3.45% of plantation forests, driven by their conversion into plantation forests and shrubby grassland. Deforestation and forest degradation risks are driven and influenced by the following spatial factors: topography, cropland expansion, residential distribution, road networks, and forest tenure.

Keywords: deforestation, forest degradation, forest change, European Union Deforestation Regulation (EUDR), Nghe An.

1. Introduction

According to the European Union Deforestation Regulation (EUDR), deforestation is defined as the conversion of forest to agricultural use whether human-induced or not (Article 2(3)); forest degradation refers to structural changes to forest cover, taking the form of the conversion of (a) primary forests or naturally regenerating forests into

plantation forests or into other wooded land; or (b) primary forests into planted forests (Article 2(7)) [1]. EUDR-compliant products fed with or made using relevant commodities, namely cattle, cocoa, oil palm, rubber, soya and wood, shall not be placed or made available on the EU market or exported, unless they are deforestation-free, produced in accordance with the relevant legislation of the country of production, and covered by a due diligence statement (Article 3). The deforestation-free requirement in the EUDR stipulates that products must not be derived from land subject to deforestation or forest degradation after 31 December, 2020 (Article 2(13)).

In 2023, Vietnam's Ministry of Agriculture and Rural Development (MARD) - now the Ministry of Agriculture and Environment (MAE) - issued an Action Plan Framework (APF) in compliance with EUDR [2]. Following MARD's request, Nghe An province organized a workshop on 19-20 December, 2023, focused on implementing the EUDR and the APF. The workshop served as a platform to connect scientists, forest holders, and timber enterprises, driving the development of certified sustainable raw material areas that meet EUDR standards across Nghe An and adjacent provinces [3]. To support this transition, the province also launched several specific initiatives such as conducting communication campaigns, reviewing and planning timber plantations, establishing a tracking data system, and developing sustainable supply chains.

In this study, Sentinel-2 imagery from 2020 and 2025 was utilized alongside field survey data to delineate forest cover and assess its spatiotemporal changes over the 2020-2025 period. This provides a reliable scientific basis for determining product compliance in accordance with EUDR requirements, identifying deforestation and forest degradation, and assessing their underlying drivers and associated risks. This, in turn, will facilitate the development of more effective long-term forest management plans, strategies, and policy interventions.

2. Data and methodology

2.1. Data

Sentinel-2 imagery was acquired from the Copernicus Data Space Ecosystem [4]. Since 31 December 2020 serves as the regulatory cutoff date for determining deforestation-free status under the EUDR, satellite images from both 2020 and 2025 were required for change detection analysis. Taking into account cloud cover conditions and local vegetation phenology, images captured in March 2020, as well as January and March in 2025, were selected for this study (Table 1).

Table 1. Utilized Sentinel-2 images

#	Scene name	Date
1	S2A_MSIL1C_20200309T032551_N0500_R018_T48QWF_20230409T184059.SAFE	09 Mar. 2020
2	S2A_MSIL1C_20200309T032551_N0500_R018_T48QVG_20230409T184059.SAFE	09 Mar. 2020
3	S2A_MSIL2A_20250112T033111_N0511_R018_T48QWG_20250112T071550.SAFE	12 Jan. 2025
4	S2A_MSIL2A_20250325T033151_N0511_R018_T48QVG_20250325T111922.SAFE	25 Mar. 2025

2.2. Ancillary data and documentation

All available official records and data on forest status and annual dynamics, as well as information from mass media, were utilized as supplementary reference sources. In addition, local cadastral maps and land-use planning documents were incorporated for spatial reference and validation.

2.3. Remote sensing and GIS analysis

Based on satellite imagery, Land Use and Land Cover (LULC) was mapped using Geographic Object-Based Image Analysis (GEOBIA) [5]. Unlike traditional pixel-based methods, GEOBIA incorporates spatial features such as scale, shape, and compactness to segment images into meaningful image objects. By combining geospatial features and remote sensing data within a GIS environment, this approach enables precise land cover classification while minimizing classification errors caused by directly extracting objects from raw imagery [6]. The LULC types in Nghe An Province are classified into 10 categories: water bodies, terrestrial natural forests, karst terrestrial forests, poor forests, mangroves, shrubby grassland, plantation forests, aqua-cultural ponds, agricultural land, and residential areas.

Classification accuracy was validated against standard benchmarks for Overall Accuracy (OA) and the Kappa coefficient in satellite-based LULC mapping. A dataset of 220 GPS-referenced samples, labeled according to ground-truth classes during fieldwork, was used for accuracy assessment. The resulting OA reached 87.17% in 2020 and 88.23% in 2025, with corresponding Kappa coefficients of 0.85 and 0.86, fully satisfying the standard requirements ($OA \geq 85\%$ and $Kappa \geq 0.75$). To assess forest changes over time, LULC maps for 2020 and 2025 were overlaid using ArcGIS tools. This produced a forest change map of Nghe An Province for the 2020-2025 period and explicitly highlighted specific areas of change.

2.4. Field survey

Field surveys were conducted in May and June 2025 to verify the accuracy of satellite-derived deforestation and forest degradation data, as well as to identify the specific causes and risks underlying these adverse changes. The fieldwork involved ground-truthing geographic locations and current forest conditions against spatial data synthesized from satellite imagery, thematic maps, and documentation collected from relevant agencies. Additionally, the surveys cross-verified and verified historical natural forest footprints while interviewing forest owners, officials, and local officials, and residents regarding pre-conversion forest status, primary drivers of land-use change, and intended post-conversion land utilization. These efforts aimed to substantiate regional risk assessments regarding deforestation and forest degradation in accordance with EUDR due diligence requirements.

2.5. Deforestation assessment by influencing factors

Deforestation risk was evaluated based on five key impact factors: slope, elevation, distance to roads, distance to cropland, and residential areas. The Jenks natural breaks optimization method was used to classify each factor by minimizing within-class variance and maximizing between-class variance. Based on the distribution of the 2020 baseline forest area relative to these factors, five classes were determined for each factor as follows:

- Slope (°): < 13 , 13-25, 25-36, 36-50, and ≥ 50
- Elevation (m): < 295 , 295-634, 634-907, 907-1292, and ≥ 1292
- Distance to roads (m): < 794 , 794-2016, 2016-3788, 3788-6294, and ≥ 6294
- Distance to cropland (m): < 423 , 423-1171, 1171-2396, 2396-8314, and ≥ 8314
- Distance to residential areas (m): < 718 , 718-1548, 1548-2507, 2507-3976, and ≥ 3976

The deforestation risk of each class is quantified by the percentage of deforested area during the 2020-2025 period relative to the total 2020 baseline forest area within that class. This percentage serves as the basis for assessing the relative influence of each factor on deforestation.

3. Results and discussion

3.1. Current forest status in Nghe An province

Nghe An possesses one of Vietnam's largest provincial forest area, totaling 1,065,714 ha, which represents a forest cover rate of 59.16% across the province's total land area [7]. Most of this forest area is designated for production (46%) and protection (31%), while special-use forests account for 17% and the remaining 5% is allocated for other land uses. In terms of forest tenure and management, state entities - including special-use and protection forest management boards, alongside commune-level People's Committees - are the largest forest owners, managing 61% of the total forest area. Private households manage 23%, while the remainder is managed by economic organizations and local communities [8]. Forests in Nghe An Province are distributed across 108 out of 130 communes and wards following recent administrative reorganizations. Among them, commune-level forest areas range from 8.89 to 65,597.35 ha, and forest coverage varies widely from 0.3% to 93.63% (Figure 1). Statistically, 18 communes have a forest area exceeding 20,000 ha, and 29 communes have coverage rates above the provincial average of 59.16% [8].

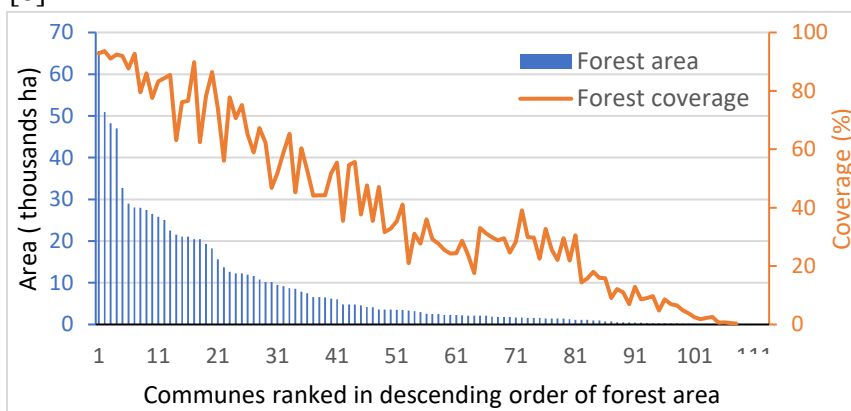


Figure 1. Forest area and coverage in 108 communes of Nghe An Province

Based on data from the People's Committee of Nghe An Province [8]

Natural forests occupy 790,439.60 ha, accounting for 81% of the province's total forest area [8]. The vast majority of these natural forests comprise secondary forests (97%), which serve various functional categories, including special-use (national parks, nature reserves, and landscape protection areas), protection (headwater protection, watershed protection, and coastal windbreak/sand stabilization), and production. In contrast, primary forests cover 23,509.27 ha (3%) of the total natural forest area and are strictly confined to Pu Mat National Park. Based on dominant species, natural forests are categorized into three types: (1) natural timber forests, (2) bamboo forests, and (3) mixed bamboo and broadleaved forests. Natural timber forests constitute the largest share (74%),

encompassing evergreen and semi-deciduous broadleaved forests covering 580,601.84 ha, alongside deciduous broadleaved forests covering a minor 12.98 ha [8]. Mixed bamboo and broadleaved forests cover 183,395.43 ha (23%), while bamboo forests occupy the remaining 3%.

Plantation forests in Nghe An province rank sixth nationwide in terms of total area [7]. Established plantation forests cover 184,906.72 ha, accounting for 19% of the province’s total forest area; additionally, there are 90,368.08 ha of non-established plantation forests [8]. Statistical data from 106 forest-planting communes in Nghe An Province show that total plantation forest areas range from 0.42 ha to 11,644.31 ha per commune. Specifically, established plantation forests vary from 0 to 5,965.49 ha, while non-established plantation forests range from 0 to 7,686.93 ha [8]. The plantation forests are classified by production purposes and tree species categories, including small-timber raw materials native trees, local specialty trees, and large-timber trees. In recent years, local authorities have gradually shifted toward developing large-timber plantation composed of native and high-value specialty tree species [9]. These plantations expanded rapidly in the districts of Con Cuong and Que Phong, with a total area exceeding 32,000 ha, accounting for nearly 20% of the province’s total plantation forest area [10]. Developing large-timber forestry not only demonstrates superior economic viability compared to small-timber alternatives, but also plays a crucial role in ecological preservation.

3.2. Forest changes in Nghe An province during the period 2020-2025

Official statistical data on forest land in Nghe An Province, as well as across other provinces and cities nationwide, typically distinguishes between total natural land area and forest land area. Among these, forest land encompasses natural forests and plantation forests; plantation forests, in turn, comprise established plantation areas and unestablished plantation areas. Data published by MARD and MAE indicate that the area in Nghe An Province increased marginally (by 0.5%) between 2020 and 2025; meanwhile, plantation forest area expanded significantly (by 14.66%), serving as the primary driver behind the increase in the overall forest cover rate from 58.5% to 59.16% [11]-[15]. These spatial forest dynamics were derived from Sentinel-2 satellite image classification across ten LULC categories, including terrestrial natural forests, karst natural forests, poor forests, shrubby grassland, mangrove forests, plantation forests, agricultural land, aquaculture ponds, residential land, and water bodies (Figure 2).

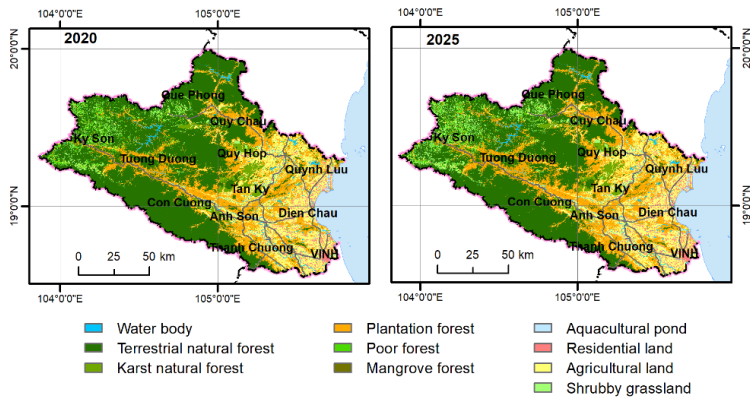


Figure 2. Nghe An’s LULC in 2020 (left) and 2025 (right)

The evaluated forest categories included natural forests (comprising both terrestrial and karst systems), poor forests, and plantation forests; notably, mangroves were excluded from this analysis. This remote-sensing based classification differs from official statistics, which may introduce discrepancies between datasets; nevertheless, it effectively captures spatiotemporal dynamics across forest classes and associated land cover types. Changes in forest area during the 2020 - 2025 period, presented by 82,318 detected hotspots of deforestation and forest degradation, were strongly coupled with expansions in agricultural land and shrubland/grassland forests (Figure 3, Table 2). Overall, 97.5% of the total forest area remained stable, particularly within national parks and nature reserves. Reductions in natural forests and poor forests were predominantly concentrated in protection and production zones, whereas the total surface area of plantation forests, shrubland/grassland, and agricultural land exhibited an upward trend (Table 2).

Table 2. Forest-related conversion in Nghe An from 2020 to 2025

		2020					Total
		NF	PoF	SG	PIF	AL	
2025	NF	608,870					608,870
	PoF		176,789				176,789
	SG	361	6,762	197,969	7,983	77	213,152
	PIF		924	8,030	222,559	552	232,065
	AL		196	32	602	337,674	338,504
Total		609,231	184,671	206,031	231,144	338,303	1,569,380

Note: NF-Natural Forest, PoF-Poor Forest, SG-Shrubby grassland, PIF-Plantation Forest, AL- Agricultural land. Unit: ha

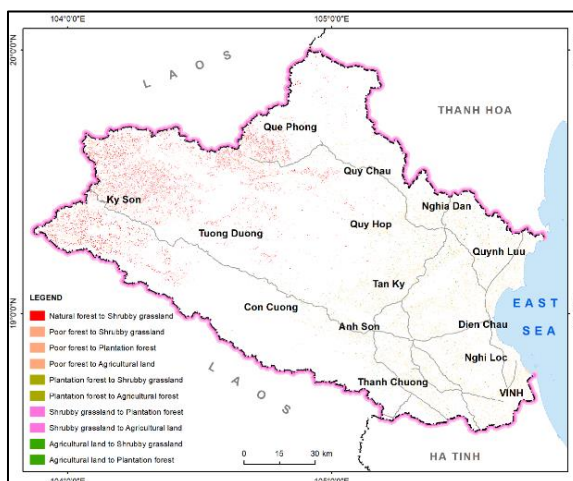


Figure 3. Forest changes in Nghe An province during the period 2020-2025

Deforestation primarily occurred when poor forests and plantation forests were converted into agricultural land. Remote sensing analysis revealed a net forest loss of nearly 800 ha (0.19%) across these categories, comprising 196 ha of poor forest and 602 ha of plantation forests (Table 2). In dense natural forests, deforestation was not detected in the satellite imagery, presumably due to effective forest protection policies or because

the affected areas fell below the spatial resolution detection threshold; however, forest degradation was observed within this category, with 361 hectares converting into shrubland/grassland. Field survey results and documentary evidence indicated that localized forest loss in these zones was primarily driven by illegal timber extraction and uncontrolled trade. Moreover, in the mountainous regions of Nghe An Province, local residents face a pressing need for arable land to alleviate poverty, stabilize livelihoods, and expand agricultural production. For instance, in 2023, a total of 196 ha was deforested in the Giang Man Mountain region within the former Thanh Ha commune of Thanh Chuong District. In this ecotone between natural and production forests, local inhabitants leveraged timber planting and harvesting operations on production land to encroach upon adjacent natural forests and expand agricultural plots [16]. Similarly, in 2022, upstream protection forests were cleared to accommodate road construction and power distribution infrastructure in the former Na Ngoi and Nam Can communes of former Ky Son District [17].

Forest degradation refers to structural changes in forest cover, taking the form of conversions from natural forests to shrubby grassland; poor forests to shrubland/grassland and plantation forests; and plantation forests to shrubby grassland. The proportion of degraded natural forest area was minor (0.06% of total natural forest area), whereas for poor forests and plantation forests, it was substantial, reaching 4.16% and 3.45%, respectively. The largest degraded land areas involved plantation forests converting into shrubland/grassland (7,983 ha) and poor forests converting into plantation forests (6,762 ha) (Table 2). These degradation events were mainly driven by clear-cutting or intercropping with commercial forestry species (e.g., *Acacia* spp., *Eucalyptus* spp., and *Pinus* spp.). Furthermore, the remaining natural forest patches managed by forest management entities are highly fragmented and interspersed with smallholder plots. Following clearing, local households tend to expand their newly established plantations into adjacent natural forests - a process directly identified as forest degradation. Additionally, mass media reports have documented several instances of encroachment: the destruction of natural protection forests in the former Nghia Binh Commune (former Tan Ky District) in March 2021 [18] the clearing of 9 ha of protection forest for *Acacia* and cinnamon cultivation in the former Bac Son Commune (former Quy Hop District) in June 2021 [19]; deforestation and degradation driven by *Acacia* planting in the former Thanh Chuong District in 2022 [20] and 23 recorded cases of forest clearing in the former Quy Chau District, alongside pine forest degradation in the former Hung Nguyen District [21].

Aware of the adverse impacts of forest loss, local authorities have not only prioritized the protection of existing forests but also focused on reforestation and afforestation initiatives. This contributed to a net expansion of 921 ha in plantation forests, driven by a gross gain of 9,506 ha through the conversion of poor forests, shrubland/grassland, and agricultural land, which was partially offset by a loss of 8,585 ha converted to shrubland/grassland and cropland (Table 2). Notably, 924 ha of this gain originated from the conversion of degraded poor forests. Official records from the Vietnam Administration of Forestry (VNFOREST) indicate that an area of 7,839.2 ha of natural forests - including primary, secondary, poor, and regenerating forests - was converted into plantation forests. Most of this area is under the management of private households (36%), Commune People's Committees (30%), and Protection Forest Management Boards (29%) [22]. This further confirms that the primary driver of natural forest

degradation and loss is land conversion for timber plantations. Under market pressures, the harvesting cycle of *Acacia* plantations has been abbreviated to 3-5 years, which exacerbates anthropogenic pressure on adjacent natural forest ecosystems. Combined with inadequate oversight and enforcement, many areas of natural forest remain vulnerable to gradual encroachment and conversion into production plantation forests.

3.3. Discussion of deforestation and forest degradation risk areas under the EUDR

Deforestation is governed by multiple biophysical and socioeconomic drivers, including topographic slope, elevation, spatial proximity to roads, settlements, and cropland, as well as forest tenure regimes [23]-[25]. Consequently, these spatially explicit variables were integrated to delineate and evaluate deforestation risk zones across the study area.

With respect to topographic features, the likelihood of deforestation is generally low in areas with gentle slopes and low elevations, primarily because stringent monitoring and law enforcement are more feasible despite high physical accessibility. Conversely, deforestation probability escalates along steeper slopes and higher elevations up to a critical threshold before declining markedly, as extreme terrain severely restricts human activity. In the study area, spatial analysis of historical deforestation hotspots relative to topography demonstrates that these risk thresholds occur at slopes between 36 and 50° and an elevation of approximately around 1,200 m above sea level.

Agricultural expansion represents the primary proximate driver of deforestation. Between 2020 and 2025, nearly 0.2% of poor natural forests and commercial plantations were cleared for agricultural land (Table 2). Spatially, deforestation risk exhibits a strong inverse relationship with distance to existing cropland. This risk is particularly pronounced within a proximity of less than 0.5 km [23] or 1 km [24]. Empirical analysis in the study area corroborates a high deforestation probability within a distance of less than 0.4 km, whereas the risk diminishes substantially beyond 1.2 km.

Consistent with agricultural proximity, the probability of deforestation decreases systematically as distance from human settlements and transport infrastructure increases. On average, local farming and resource extraction activities are concentrated within a 5 km buffer around villages, rendering forest areas within this radius highly susceptible to clearance. Indeed, spatial analysis of settlement and clear-cut events reveals that deforestation probability remains concentrated within 2.5 km. Similarly, road network expansion significantly amplifies deforestation risks. High deforestation probabilities have been documented within distances of less than 1 km [23], [24]. Our empirical findings indicate that deforestation risk peaks within 0.8 km of access roads and drops sharply beyond 2 km. A striking illustrative case occurred in 2022, when designated protection forests across two communes in the former Ky Son District were illegally cleared to construct a right-of-way for a power transmission line haul road [17]. This infrastructure not only induced immediate forest fragmentation but continues to serve as a long-term corridor accelerating future encroachment.

Forest tenure plays a pivotal role in forest management and conservation; empirical evidence indicates that the probability of deforestation is significantly lower in allocated forests compared to unallocated ones. This suggests that accelerating the formal allocation of forest land rights - clearly designating forest managers and legally binding

them to both resource utilization and protection responsibilities - is an effective mitigation strategy against deforestation. Forest and land management data from Nghe An Province indicate that by 2025, 914,052.78 ha of natural forest and plantation forest area had been allocated for management and tenure. However, 151,661.62 ha remained under the interim management of the Communal People's Committee [8]. In practice, these unallocated lands are actively cultivated by local households despite lacking formal Land-Use Right Certificates (LURCs). A critical EUDR compliance risk arises here: most plantation areas established through the historical conversion (deforestation) of natural forests will likely fail to qualify for LURCs under both past and present national legal frameworks, specifically the 2013 Land Law [26] and the 2024 Land Law [27].

Although forest management and protection efforts have received significant attention, several critical challenges remain to be addressed. Even within strictly protected areas such as national parks and nature reserves, deforestation still occurs—driven by administrative inefficiencies, weak enforcement, or natural disasters like wildfires. Empirical evidence shows that a large proportion of natural forests encroached upon and converted into plantations or agricultural land falls under the jurisdiction of non-corporate public entities rather than state forestry companies or specialized forest enterprises. These institutional managers often lack dedicated forestry officers and sufficient personnel for effective monitoring, patrolling, and enforcement. Such management gaps - frequently observed within protection forest management boards, prison management boards, military training units, and border guard stations—frequently exacerbate deforestation risks. In practice, these entities rely almost entirely on forest protection contracts with local households while lacking dedicated patrol forces across most of their assigned territories. Furthermore, due to complex socio-cultural dynamics in remote rural areas, residents rarely report illegal land clearing by neighboring households to authorities. Consequently, the absence of strategic forest checkpoint control, combined with a lack of rigorous annual inspections and quality control in forest governance, constitutes the primary driver of natural forest loss.

4. Conclusions

Nghe An is one of Vietnam's largest provinces in terms of forest area. The majority of these forests are designated for production, protection, and special-use purposes and managed predominantly by state authorities and local households.

Forest-related data extracted from remote sensing-derived land-use/land-cover (LULC) maps for 2020 and 2025 serve as the baseline for geospatial traceability - a key requirement for demonstrating compliance with EUDR regulations-while also enabling the analysis of forest changes, drivers of deforestation, and risk assessments for deforestation and forest degradation.

Between 2020 and 2025, the natural forest area increased insignificantly (by 0.5%), whereas the plantation forest area grew substantially (by 14.66%), elevating the overall forest cover rate from 58.5% to 59.16%. Deforestation, affecting nearly 800 ha (0.19%), occurred when poor forests and plantations were converted into agricultural land. Meanwhile, forest degradation affected 0.06% of natural forest, 4.16% of poor forests, and 3.45% of plantation forests. This degradation was driven by conversions from natural

forests to shrubby grassland; poor forests to shrubby grassland and plantation forests; and plantation forests to shrubby grassland.

The risk of deforestation and forest degradation is influenced and governed by several key biophysical and socioeconomic drivers: topographical slope and elevation, cropland expansion, residential distribution, road network accessibility, forest tenure regimes, and management effectiveness.

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