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Monitoring forest changes in lowland hilly terrain of the central highlands of Vietnam using landsat satellite imagery: A case study in Dak Nong province

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ABSTRACT

The Highland regions of Vietnam, known for their rich biodiversity and ecological importance, have undergone substantial land use changes over the past few decades. This article presents the results of applying remote sensing and GIS to assess forest cover changes in a district in the Highland of Vietnam over a 22-year period, from 2001 to 2023. The study applied remote sensing method and GIS for processing Landsat 5 TM and Landsat 8 OLI images to create forest cover maps and to analyze the change for the periods 2001, 2013, and 2023. The research results show that the forest cover in the district experienced significant changes during the 2001–2023 period. The total forest area in 2023 lost was over 38% (40166 ha) compared to 2001. The primary drivers identified for these changes include agricultural development, urban expansion, and the cultivation of cash crops such as coffee and rubber. The research results provide valuable reference materials for forest management and protection in a district in the Highland of Vietnam.

Keywords: landsat imagery, remote sensing, deforestation, land cover change, forest ecosystem.

INTRODUCTION

Forests are invaluable resources, playing a crucial role in water retention, soil stabilization, and regulating river flows for hydroelectric dams, as well as mitigating the effects of landslides, erosion, and flash floods (Brockerhoff et al., 2017; UN Environment Programme World Conservation Monitoring Centre, 2023). Forests are also essential to global sustainability and play a key role in achieving multiple sustainable development goals (SDGs). Dak Nong province, one of the five provinces in Vietnam's Central Highlands region bordering Cambodia, boasts one of the largest forested areas in Vietnam. However, illegal logging, intensified agricultural production, and mineral exploitation at the local level have significantly impacted the resources and environment (Bourgoin et al., 2020; Hong & Saizen, 2019; Pham Thu Thuy et al., 2012). Additionally, large areas of natural forest have been replaced by rubber and coffee plantations in the Central Highlands and Southeast region of Vietnam (Cochard et al., 2017). Currently, forests are primarily valued for their direct products such as timber, fuelwood, and food. Meanwhile, the environmental values and ecosystem services provided by forests are not fully understood. Despite contributing to various production sectors and human living environments, the role of forest ecosystems or forestry in Dak Nong province is generally undervalued. Therefore, researching and monitoring forest dynamics in Dak Nong province is essential and should be a top priority.

In natural resource management, remote sensing and geographic information systems (GIS) technologies have significantly aided database management, storage, modelling, especially in analyzing and linking attribute data with spatial data to select sustainable and effective resource management solutions. Land use and land cover (LULC) changes are commonly studied using remote sensing and GIS techniques. Previous studies have utilized land use auditing techniques and change detection methods to analyze deforestation trends and agricultural and urban expansion (Waiyasusri & Tananonchai, 2022; Waiyasusri & Wetchayont, 2020). The use of multi-temporal satellite imagery to monitor changes related to LULC, including forest cover, is highly efficient, cost-effective, and increasingly accurate (Decuyper et al., 2022; Pham-Duc et al., 2020; Zanchetta et al., 2020). Globally, numerous studies have applied remote sensing and GIS to monitor LULC dynamics and forest cover changes, yielding reliable results (Aung et al., 2020; Arahman et al., 2025; Ghouldan et al., 2024; Kiriwongwattana & Waiyasusri, 2024). In Vietnam, Landsat satellite imagery has been widely used to monitor LULC change (Nguyen et al., 2022a; Nguyen et al., 2022b) and forest cover change (Thien & Phuong, 2023; Tran et al., 2024), providing a solid scientific basis for land managers and planners. Therefore, Landsat imagery is considered an essential data source in monitoring and observing LULC as well as forest cover changes over time (Banskota et al., 2014).

This study aims to provide a basis database for land use policies and forest management and protection at the local level by using Landsat satellite imagery combined with GIS to map forest distribution and analyze forest cover changes over time in lowland hilly terrain of the Central Highlands of Vietnam – Tuy Duc district. The outcomes of this study directly contributes to SDG 13 (Climate Action) by assessing deforestation trends and SDG 15 (Life on Land) by analyzing forest cover loss and its ecological consequences. Sustainable forest management is crucial for biodiversity conservation, carbon sequestration, and mitigating land degradation. Understanding forest cover dynamics provides a scientific basis for improved land-use planning and conservation policies in Vietnam's Central Highlands.

DATA AND METHODOLOGY

Study area

The study focuses on Tuy Duc District, located in the western part of Dak Nong province – in the Central Highlands of Vietnam, with a natural area of 111,924 hectares, accounting for 17.2% of the province's area, and a population of over 52,000 people distributed across six communes (Fig. 1)

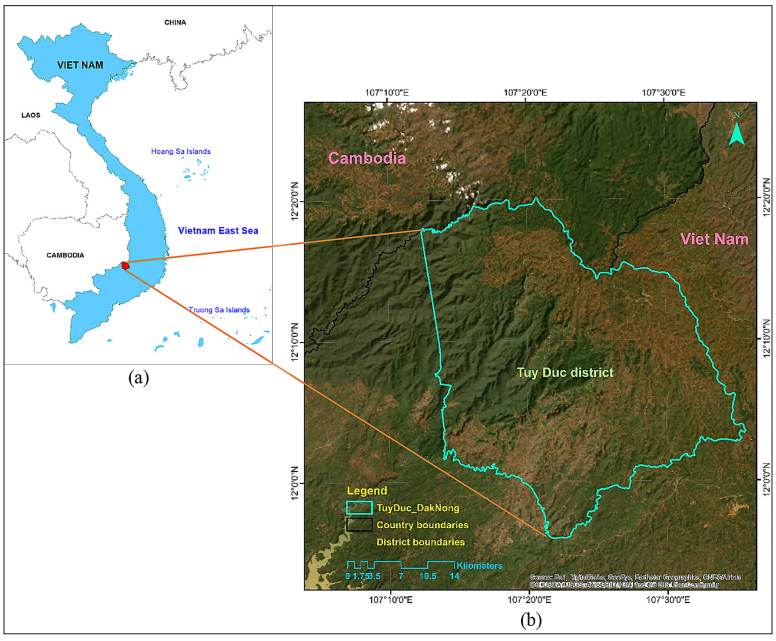

Figure 1. (a) Location of the study area in the central highlands of Vietnam, and (b) satellite images of the study area (Source: ESRI)

(GSO, 2022). The district borders Cambodia to the north, Dak R'Lap district to the southeast, Dak Song district to the northeast, and Binh Phuoc Province to the west and southwest. The terrain of Tuy Duc is generally complex, with an average elevation ranging from 800 to 1200 meters above sea level, gradually descending from northeast to southwest and divided into three main types of terrain: (i) Bazan plateau with elevations from 700 to 900 meters, where the plateau's top is relatively flat but its sides are very steep; (ii) low hills and mountains in the south and southwest with an average elevation from 400 to 700 meters; and (iii) alluvial valleys along the rivers and streams, primarily formed by sediment deposition (Tuy Duc District People's Committee, n.d.). The climate is influenced by the Southwest monsoon, characterized by a tropical highland climate with two distinct seasons: a rainy season from April to October, accounting for 90% of the annual rainfall, and a dry season from November to March (Tuy Duc District People's Committee, n.d.). The average temperature is 22°C, making the area suitable for a variety of tropical crops, particularly short- and long-term industrial plants and food crops. A portion of the district falls within the Bu Gia Map National Park, a rich conservation area for the genetic resources of the Central Highlands and Southeast Vietnam's flora and fauna. The national park encompasses 21,476 hectares, including various forest types and a buffer zone of 15,200 hectares shared between Binh Phuoc and Dak Nong provinces, mainly within Tuy Duc district.

Landsat imagery

This study utilized Landsat 5 TM and Landsat 8 OLI images from the USGS EarthExplorer (Table 1). Due to the equatorial region's high cloud cover, only scenes with less than 10% cloud cover were selected. The Landsat images were geometrically corrected to the WGS_1984_UTM_Zone_48N coordinate system and clipped to the administrative boundaries of Tuy Duc district. Official land use maps from local government (for the years 2000, 2010, 2020), existing forest status maps, and topographic maps of the study area were also used to assist the LULC classification process and forest cover layer. Details of the research procedure are shown in Figure 2.

Table 1. Specification of Landsat satellite images

Year	Satellite	Sensor	Path/Row	Resolution (m)	Acquisition date
2001	Landsat 5	TM	124/052	30	10/01/2001
2013	Landsat 8	OLI	124/052	30	29/12/2013
2023	Landsat 8	OLI	124/052	30	24/02/2023

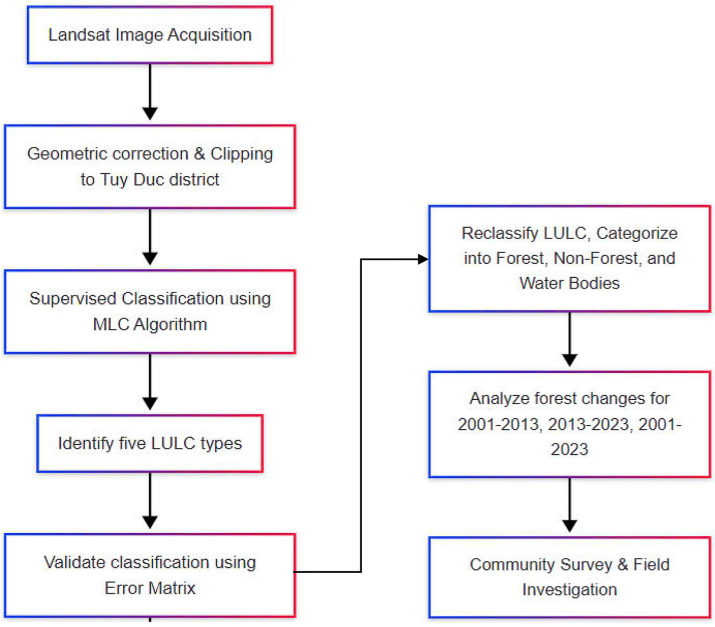

Figure 2. Flowchart of methodology

Land use/ land cover classification

A supervised classification approach was adopted for creating LULC maps, utilizing field survey data for training and validation. The maximum likelihood classifier (MLC) algorithm was utilized for the classification of Landsat images. This method has effectively been used for delineating both land use/land cover (LULC) and forest cover across regions with similar geographic characteristics (Duong & Son, 2024; Luong et al., 2017; Thien & Phuong, 2023). Based on image characteristics and related information like topographic maps and local land use maps, five LULC types were identified: built-up land, agricultural land, perennial crop land, forest, and water bodies. An error matrix was used to validate the classification results, displaying four different accuracy measures: overall accuracy (OA), producer's accuracy (PA), user's accuracy (UA), and the Kappa coefficient (Congalton & Green, 2019). The 2023 classification results were validated using field survey data, while the 2001 and 2013 results were validated using official land use maps for 2000 and 2015, respectively, combined with high-resolution Google Earth imagery.

Post-classification change analysis

The resulting LULC images were reclassified using ArcGIS 10.8 software to assess observed changes over the specified periods. To identify changes in forest area from the LULC maps, non-forest LULC types such as built-up land, agricultural land, and perennial crops were grouped into a single non-forest category. This resulted in three LULC maps for three different periods, each depicting forest, non-forest, and water bodies. These final classification results were overlaid to create matrices and maps illustrating the transition between forest and non-forest areas across the periods 2001–2013, 2013–2023, and 2001–2023.

Community survey and field investigation

Structured interviews using questionnaires were conducted with households in Tuy Duc district to understand the causes and trends in forest area changes. Interviews were carried out with families who had lived in the area for over 15 years and had a deep understanding of forest resources or livelihoods related to forestry around the study area.

RESULTS

LULC classification results

The LULC maps for the years 2001, 2013, and 2023 were derived from Landsat 5 and 8 imageries. The overall accuracy of these LULC maps was 86.5% (Kappa = 0.8), 92.2% (Kappa = 0.90), and 95.6% (Kappa = 0.92) for the respective years. The lower accuracy for 2001 can be attributed to the lack of reference data for surface cover during this period. Additionally, the lower image quality of Landsat 5 compared to Landsat 8 contributed to the decreased classification accuracy. Overall, the LULC maps' accuracy ranging from over 86% to 95% is excellent and suitable for analyzing forest cover changes in the study area.

Forest cover change from 2001 to 2023

The built-up, agricultural, and perennial crop lands from the LULC maps for 2001, 2013, and 2023 are now collectively classified under the non-forest category. This categorization has led to the creation of three distinct forest cover maps for Tuy Duc district for these periods, as depicted in Figure 3. Initially, the majority of Tuy Duc district was forested in the early 2000s, with early development focused on the east and northeast for residential and agricultural use (Fig. 3a). By 2013, non-forest areas expanded rapidly across the district, indicating a decline in forest area (Fig. 3b). By 2023, almost the entire central and northeastern areas saw forest replaced by non-forest land, with remaining forested areas primarily located in the western part of the district, within the Bu Gia Map National Park, a strictly protected area (Fig. 3c). Details of forest and non-forest cover areas for the years 2001, 2013, and 2023 are presented in Table 2.

Overlaying the forest cover maps from these periods shows a significant reduction in forest area from 104,777 hectares (93% of the district's area) in 2001 to 64,610 hectares (58% of the district's area) by 2023, nearly halving over two decades (Fig. 4).

Figure 5 clearly shows that the gain in non-forest areas almost directly correlates with the loss of forested areas, suggesting a conversion of forest land to non-forest land over the observed periods. The almost equal magnitude of increase in non-forest areas and decrease in forest areas

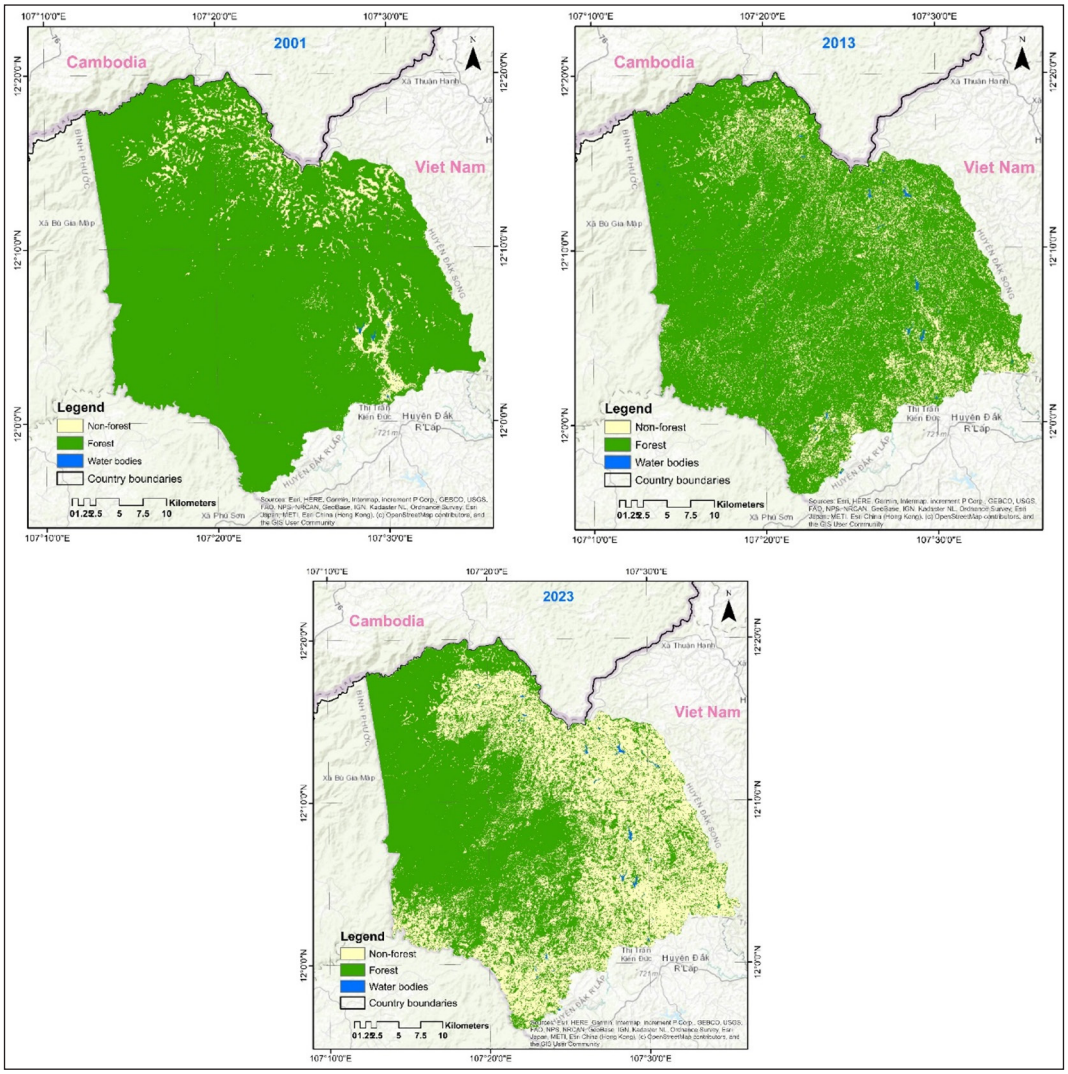

Figure 3. Forest distribution of Tuy Duc district over the years: (a) 2001, (b) 2013, and (c) 2023

Table 2. Forest and non-forest cover areas in Tuy Duc district from 2001 to 2023 (in hectares and in percentage)

Classification	2001		2013		2023	
	Area (ha)	Area (%)	Area (ha)	Area (%)	Area (ha)	Area (%)
Non-forest	7260	6.48	17582	15.68	47256	42.15
Forest	104776	93.46	94300	84.12	64610	57.64
Water	63	0.06	217	0.2	233	0.21

over the entire period from 2001 to 2023 (non-forest areas showed a net gain of 39,996 ha, compared to a net loss in forest areas of 40,166 ha) highlights a significant environmental concern, potentially impacting biodiversity, climate change, and ecosystem services. The spatial distribution of changed and unchanged forest/non-forest areas in Tuy Duc district for the three periods (2001–2013, 2013–2023, and 2001–2023) is shown in Figure 6.

DISCUSSION

The forest area in Tuy Duc district, part of the lowland hilly terrain of the Central Highlands of Vietnam, has been severely decreased from 2001 to 2023. The observed reduction in forest area aligns with findings from other research conducted in Vietnam (Hoang et al., 2020, Duong & Son, 2024) and the Central Highlands region of Vietnam (Luong et al., 2017; Thien & Phuong,

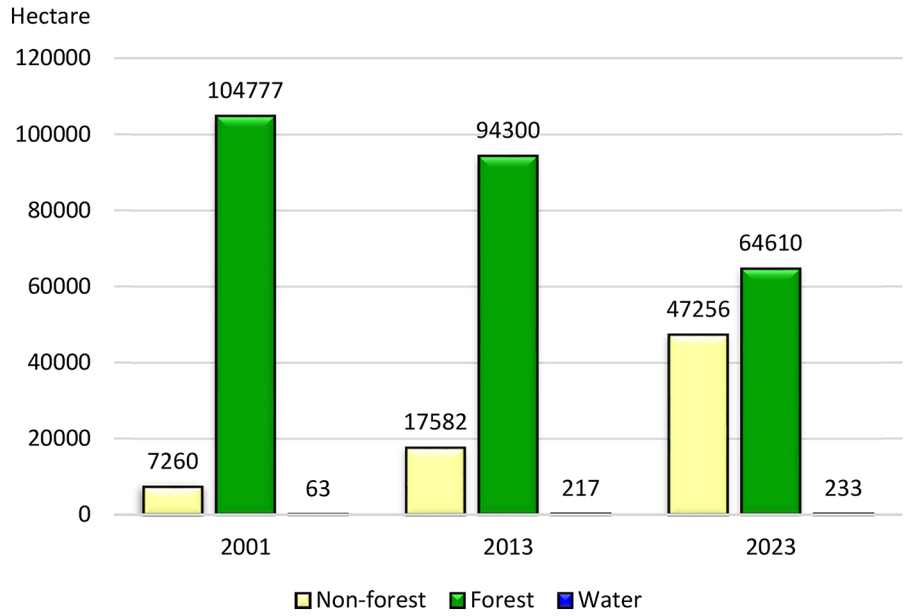

Figure 4. Changes in forest area of Tuy Duc district in the period 2001 – 2013 – 2023

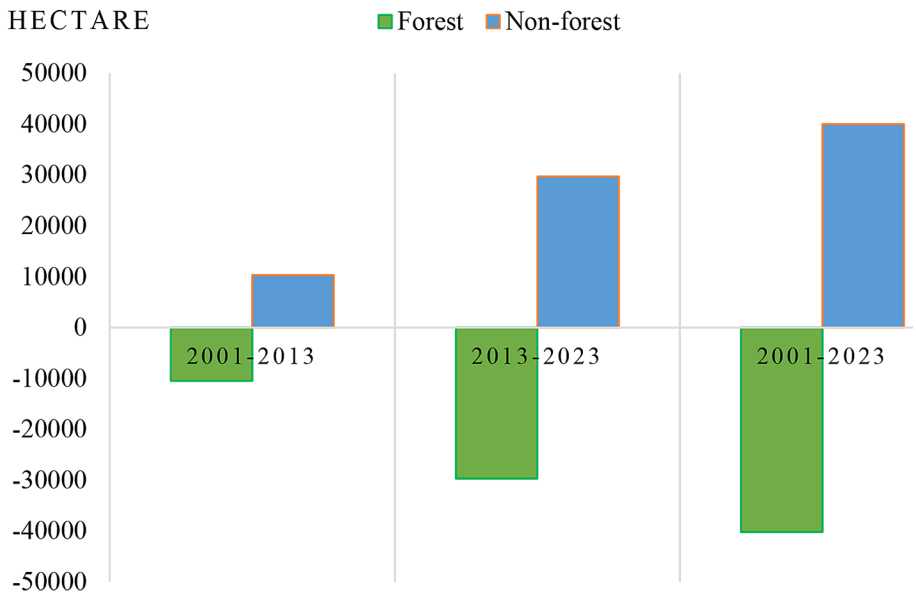

Figure 5. Comparison of the net forest [loss] and non-forest [gain] areas in Tuy Duc district

2023; Tran et al., 2024). The results of this study are consistent with the trend of forest loss observed in several regions of Southeast Asia (Surni et al., 2024; Waiyasusri & Tananonchai, 2022; Waiyasusri & Wetchayont, 2020), where forest cover has declined by approximately 15% from 1990 to 2019 (Turner & Snaddon, 2023). This drastic decline primarily occurred in natural forest areas located in hilly and mountainous terrains, as well as areas in the buffer zone of the national park, while non-forest areas expanded near residential zones and along riversides, facilitated by access to waterways and transportation infrastructure.

The trend of natural forest area reduction as shown in Figure 4 in favor of non-forest area expansion is a critical environmental issue, potentially implicating deforestation activities, land use changes for agriculture, urbanization, or other development projects. These changes have profound implications for carbon sequestration capacities, biodiversity, and the overall health of the ecosystem (Nguyen et al., 2019). Forests in the Central Highlands contribute to stabilizing river

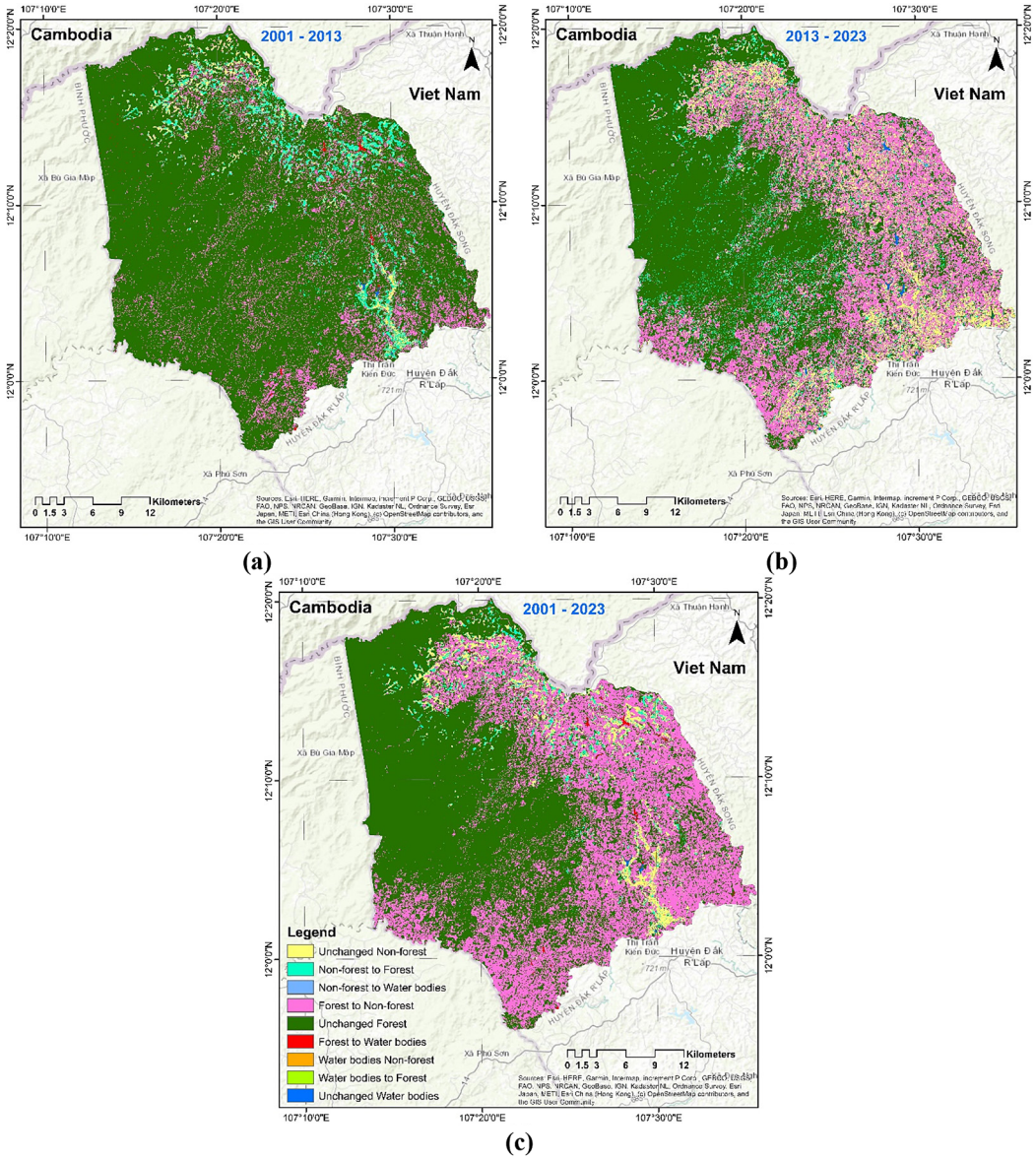

Figure 6. Spatial distribution of changed and unchanged forest/non-forest area at the Tuy Duc district in the period (a) 2001 – 2013, (b) 2013 – 2023, and (c) 2001 – 2023

flows, particularly crucial for hydroelectric power generation, which forms a significant part of Vietnam's energy infrastructure. The observed forest loss likely exacerbates soil erosion and increases the frequency of flash floods, particularly during the rainy season (Nguyễn et al., 2015). The forests of Tuy Duc district, particularly within the Bu Gia Map National Park, are home to numerous endemic and endangered species. Forest loss not only reduces available habitat but also fragments existing ecosystems, hindering species migration and genetic exchange.

The study conducted interviews with residents in areas of Tuy Duc district with large natural forest cover. These individuals represent families living in the district for over 15 years, witnessing changes in forest area. Initial analysis identified several causes for the decline in forest quality and area: slash-and-burn agriculture, over-exploitation, construction, and land use conversion. Notably, converting forest land to coffee, cashew, and rubber plantations emerged as a primary cause of deforestation. The causes of deforestation mentioned align with broader trends observed in the Central Highlands region and across Vietnam in recent decades (Bao et al., 2022; Cochard et al., 2017; Pham Thu Thuy et al., 2012). Local communities in Tuy Duc district depend heavily on forest resources for their livelihoods, including non-timber forest products

(NTFPs) such as medicinal plants, honey, and fuelwood. The diminishing forest area directly impacts these resources, forcing communities to seek alternatives that may not be sustainable. Furthermore, forests often hold cultural and spiritual significance for indigenous and local populations, making their loss an issue of socio-cultural concern (Nguyen et al., 2019).

Land use transformation is seen as inevitable in the district's socio-economic development. However, the rapid increase in residential and agricultural land, coupled with significant forest cover loss, poses sustainability challenges. While Vietnam has robust policies for forest conservation, including reforestation programs and protected areas, enforcement remains a challenge. Land management and planning need to consider strategies ensuring economic development while preserving environmental and landscape conservation. These include careful land use restructuring, strict protection of forest limits, especially in Bu Gia Map National Park, applying scientific agricultural practices to enhance productivity without expanding agricultural land, and providing employment for those affected by national park establishment to ensure stable income (Hong & Saizen, 2019; Nguyen et al., 2019).

Limitation

While the research highlights substantial forest area changes in Tuy Duc district, the drivers behind these changes are not fully elucidated. This limitation stems from the study's observation of forest changes at three time points, with a decade between each. Furthermore, the simple surveys conducted to understand deforestation causes lacked depth due to resource and time constraints. Future studies should aim for more frequent observations and deeper community engagement to better understand the socio-economic conditions, policies, and motivations behind forest cover dynamics. Additionally, using Landsat imagery with medium resolution (30 m) limited detailed analysis of small-scale land cover conditions (Phiri & Morgenroth, 2017). Additionally, the temporal resolution of the study (2001, 2013, and 2023) does not capture year-to-year variations in LULC/forest cover dynamics. Field validation was constrained by resource availability, which may have introduced uncertainties in classification accuracy. Despite field surveys to validate findings, higher resolution imagery could improve research reliability. Future studies should integrate high-resolution imagery (e.g., Sentinel-2, PlanetScope) and advanced classification techniques, such as machine learning algorithms, to improve accuracy (Pham-Duc et al., 2025).

CONCLUSIONS

The application of remote sensing and GIS in evaluating forest cover changes proves to be an effective method, widely adopted in many countries globally. This study successfully implemented a supervised classification approach with the Maximum Likelihood Classifier algorithm to classify forest cover in a district of the lowland hilly terrain in the Highlands of Vietnam. The classification accuracy is high and reliable, with an overall accuracy consistently around 90% and a Kappa coefficient ranging from 0.80 to 0.92. This method not only allows researchers to observe the current state of forest cover at specific times but also illustrates the dynamics of forest changes over different periods. The study highlights key points in the dynamics of forest cover in Tuy Duc District from 2001 to 2023, showing a gradual predominance of agricultural land and construction sites within the local land use structure. Consequently, nearly 50% of the forest area has been lost over more than 20 years. The study also preliminarily identifies the main causes of forest area reduction, including over-exploitation and land use conversion to agriculture, in addition to residential construction. The findings provide a valuable data reference for land managers and policymakers in land use planning and forest conservation at the local level.

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