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# Land cover change assessment in Thai Nguyen Province, Vietnam using GIS and remote sensing techniques

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**ABSTRACT**

The expansion of agricultural production and urbanization has led to the depletion of the global forest ecosystem, resulting in land cover changes (LCCs) that pose threats to the land environment. Therefore, it is imperative to identify these LCCs as an essential step toward resolution and mitigation. This study aims to evaluate temporal LCCs in Thai Nguyen province by utilizing GIS and remote sensing techniques (RST) to analyze high-resolution satellite imagery spanning from 2001 to 2023. LCCs were identified using semi-automatic classification plugin (SCP) techniques with Landsat-8 and Sentinel-2 images in ERVI software. The accuracy of the LCC maps was validated through post-classification comparisons, yielding high precision rates ranging from 87% to 96%. The results indicate a significant reduction in forest cover area, declining by 1018 ha from 226,18 ha in 2001 to 207,22 ha in 2023. This decline primarily occurred in urban areas, highlighting the intensification of urbanization processes. Cultivated and bare land experienced a minor decrease and a substantial decrease from 18,631 ha and 105,000 ha to 16,578 ha and 86,82 ha between 2001 and 2010, followed by a slight increase and a significant increase to 5,069 ha and 24,487 ha (1.4% and 6.9%) during the 2010-2023 period. These findings underscore the escalating risk of diminishing forest cover in the study area.

**Key words:** Cover changes, ERVI software, forest ecosystem, satellite imagery, urbanization

## INTRODUCTION

The assessment of land cover change (LCC) plays a critical role in understanding the dynamics of both human-influenced and natural environments (Abdullah *et al.,* 2018). Accurate information about LCCs is essential for effective land planning and management, as well as for predicting future changes and improving resource management practices (Khan *et al.*, 2020; Nguyen *et al.*, 2023). A variety of methods, including vegetation indices such as Normalized Difference Vegetation Index (NDVI), Atmospheric Resistant Vegetation Index (ARVI), Environmental Vulnerability Index (EVI), and Soil Adjusted Vegetation Index (SAVI), have been commonly applied to assess LCC (Thakkar *et al.,* 2016*;* Yulianto *et al.*, 2016). Remote sensing images have been widely employed since the launch of the first earth resources technology satellite in 1972, enabling real-time monitoring of LCCs (Liping *et al.,* 2018; Ismail *et al.*, 2021; Navin and Agilandeeswari, 2020). Reliable and up-to-date data on LCCs are necessary for various monitoring, planning, and management applications. Remote sensing techniques (RST) are highly valuable in identifying LCCs (Congedo, 2021) while GIS serves as a versatile tool for collecting, storing, analyzing, and providing crucial digital information for detecting LCCs (Liping *et al.,* 2018; MohanRajan *et al.,* 2020). The integration of GIS and RST has proven to be effective in studying LCCs, making the process easier, more accurate, and cost-effective (MohanRajan *et al.,* 2020; Nguyen *et al.*, 2023). This combination offers advantages such as time-saving (Duraisamy *et al.*, 2018), large area coverage (Rawat and Kumar, 2015; Li *et al.,* 2020), and facilitating long-term monitoring with faster implementation compared to ground-based methods (MohanRajan *et al.,* 2020).

In this study, the main objective is to assess the LCCs in Thai Nguyen province,

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Vietnam, utilizing the SCP techniques based on high-resolution satellite imagery collected from 2001 to 2023. By employing this approach, the study aims to provide comprehensive insights into the land cover dynamics of the region over the specified period. The integration of GIS and RST allows for precise and timely data acquisition, enabling a detailed analysis of LCCs across a wide area. The findings of this study will contribute to a better understanding of the land cover changes occurring in Thai Nguyen province and support informed decision-making regarding land planning and management in the region.

## MATERIALS AND METHODS

### Study Area

Thai Nguyen, located in the midland province of the Northeast region of Vietnam (Fig. 1), serves as a pivotal center for economic, political, and social activities in the northern midlands and mountains area (Phung *et al.*, 2019; Le and Nguyen, 2022). It occupies a strategic position within the northern economic region (Séférian *et al.*, 2019; Le and Nguyen, 2022). As of 2020, the natural land area of Thai Nguyen province measured 3,526.64 km$^2$, accommodating a population of 1,307,871 individuals, with approximately 68% residing in rural areas (Le and Nguyen, 2022). The province plays a crucial role in facilitating socio-economic exchanges between the mountainous midlands and the Northern Delta (Séférian *et al.*, 2019; Le and Nguyen, 2022). It shares borders with Lang Son and Bac Giang provinces to the east, Vinh Phuc and Tuyen Quang provinces to the west, while being adjacent to the capital city, Hanoi, in the south, and Bac Can province in the north (Phung *et al.*, 2019; Séférian *et al.*, 2019).

In terms of climate, Thai Nguyen falls within the humid subtropical climatic zone, which exhibits four distinct seasons *viz.*, spring, summer, autumn, and winter. Spring is observed from February to April, summer lasts from May to July, autumn arrives in August, September, and October, and winter sets in from November to January (Le and Nguyen, 2022). The average temperatures range from 21.5 to 23°C, with the highest recorded temperature reaching 41.5°C (Séférian *et al.*, 2019). The average annual rainfall in the region ranges from 2,000 to 2,500 mm (Séférian *et al.*, 2019; Phung *et al.*, 2019). Overall, Thai Nguyen province enjoys a climate that provides favorable conditions for the development of agriculture and forestry sectors (Séférian *et al.*, 2019; Le and Nguyen, 2022).

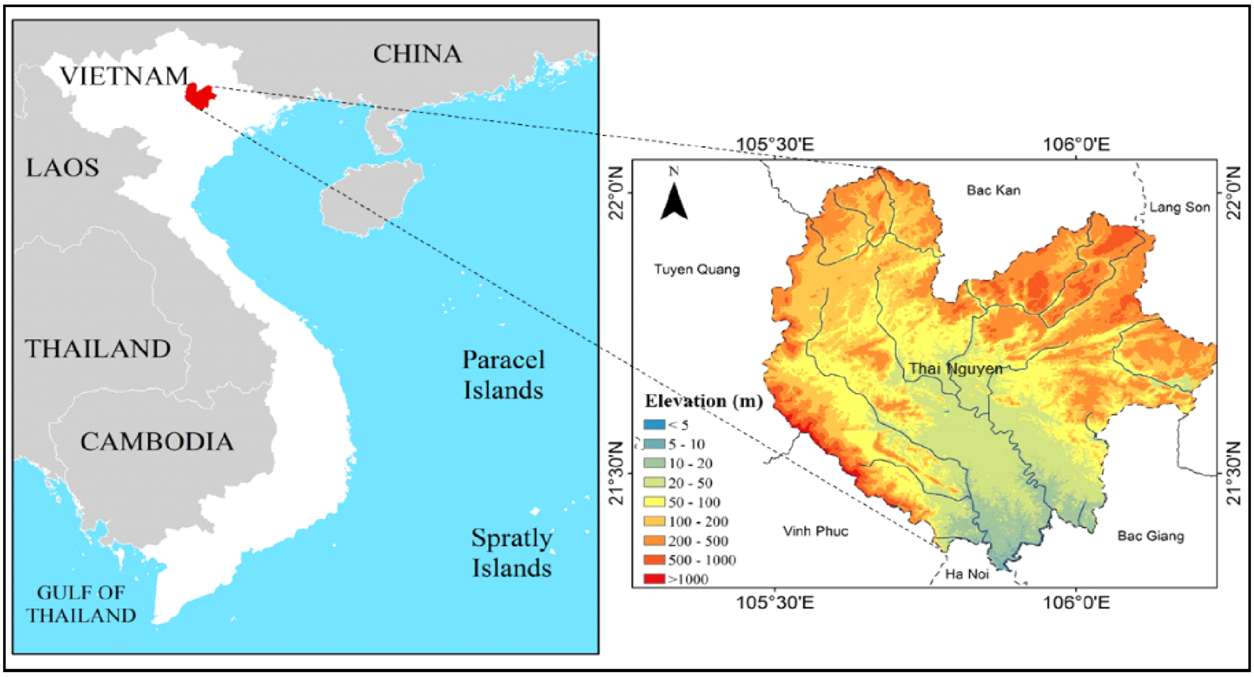


Fig. 1. Illustration of topographic map of the study area.

## Satellite Image Collecting for Assessing Land Cover Change

To assess LCCs over time, Landsat and Sentinel images were obtained from the websites (*e.g.*, https://earthexplorer.usgs.gov and https://scihub.copernicus.eu). The sets of images with 10-30 m resolutions were taken during the period 2001 - 2023 (Table 1). Before remote sensing image classification, the downloaded images were processed using ENVI software (Mas *et al.*, 2014). Aiming to achieve a high-precision image that covered the entire study area, atmospheric correction was performed to ensure the vegetation spectrum curve closely matched the actual vegetation spectrum (Zhang *et al.*, 2021). Various image processing procedures were conducted, including radiometric, atmospheric, geometric, and topographic corrections (Congedo, 2021). To meet quality requirements, preprocessing steps were implemented for the satellite images (Zhang *et al.*, 2021). These steps involved converting the digital number values of the image to top-of-atmosphere reflectance with atmospheric correction and resampling the resolution from 30 m to 10 m. For atmospheric correction of Sentinel-2A images, the semi-automatic classification plugin tool in QGIS software was used (Congedo, 2021).

## Semi-Automatic Classification Plugin Techniques

The semi-automatic classification plugin (SCP) is a valuable tool for supervised land cover classification through image processing techniques (Congedo, 2021). It achieves this by training an algorithm with spectral signature samples from different materials (Thakkar *et al.*, 2016; Zhang *et al.*, 2021). The SCP offers users the convenience of accessing and downloading seven satellite datasets, along with a comprehensive set of processing tools (Ojaghi *et al.*, 2016). These tools are beneficial for both the pre-processing and post-processing stages of image classification (Thakkar *et al.*, 2016). One notable advantage of SCP is that it empowers individuals without extensive remote sensing expertise to utilize advanced remote sensing techniques (Thakkar *et al.*, 2016; Congedo, 2021). It offers step-by-step procedures that can be applied in various fields such as urban planning, agriculture, and environmental monitoring (Zhang *et al.*, 2021). Additionally, SCP utilizes clustering and machine learning algorithms to encode context information, resulting in efficient computation (Zhang *et al.,* 2021).

# RESULTS AND DISCUSSION

## Results of Classification and Analysis

Fig. 2 depicts the LCCs observed in the classification results of processed images from 2001, 2010, and 2023. The forest area decreased from 226,182 ha in 2001 to 216,333 ha in 2010 and 207,226 ha in 2023. Conversely, urban land expanded significantly from 595 ha in 2001 to 9,037 ha in 2023, as shown in Table 2. Forested areas constituted the largest portion of the study area, accounting for 64.3% (226,183 ha) in 2001. This was followed by bare land (105,000 ha, 29.8%), cultivated land (18,631 ha, 5.3%), urban land (595 ha, 0.2%), and water (1,619 ha, 0.5%). Forest and bare land together represented approximately 90.5% of the total area (Table 2). In 2010, forested areas remained dominant, covering 216,333 ha (61.5%) of the study area. Bare land accounted for 86,823 ha (24.7%), urban land occupied 28,272 ha (8.0%), cultivated land encompassed 16,578 ha (4.7%), and water covered 4,022 ha (1.1%). During the period from 2001 to 2010, forest and bare land experienced declines of 2.8% and 5.1%, respectively, while water and urban land witnessed increases of 0.6% (2,403 ha) and 7.8% (27,677 ha). By 2023, forested areas remained the largest land cover category, covering 207,226 ha (58.9%) of the study area,

**Table 1.** Data of multispectral satellite sensors used for the purpose of the study

| Imagery data | Projection | Acquisition data | Spatial resolution | Data source |
|---|---|---|---|---|
| Landsat 5 TM | UTM-Zone-48N | 2001 | 30 m | https://earthexplorer.usgs.gov |
| Landsat 5 TM | UTM-Zone-48N | 2010 | 30 m | https://earthexplorer.usgs.gov |
| Sentinel 2A | UTM-Zone-48N | 2023 | 10 m | https://scihub.copernicus.eu |

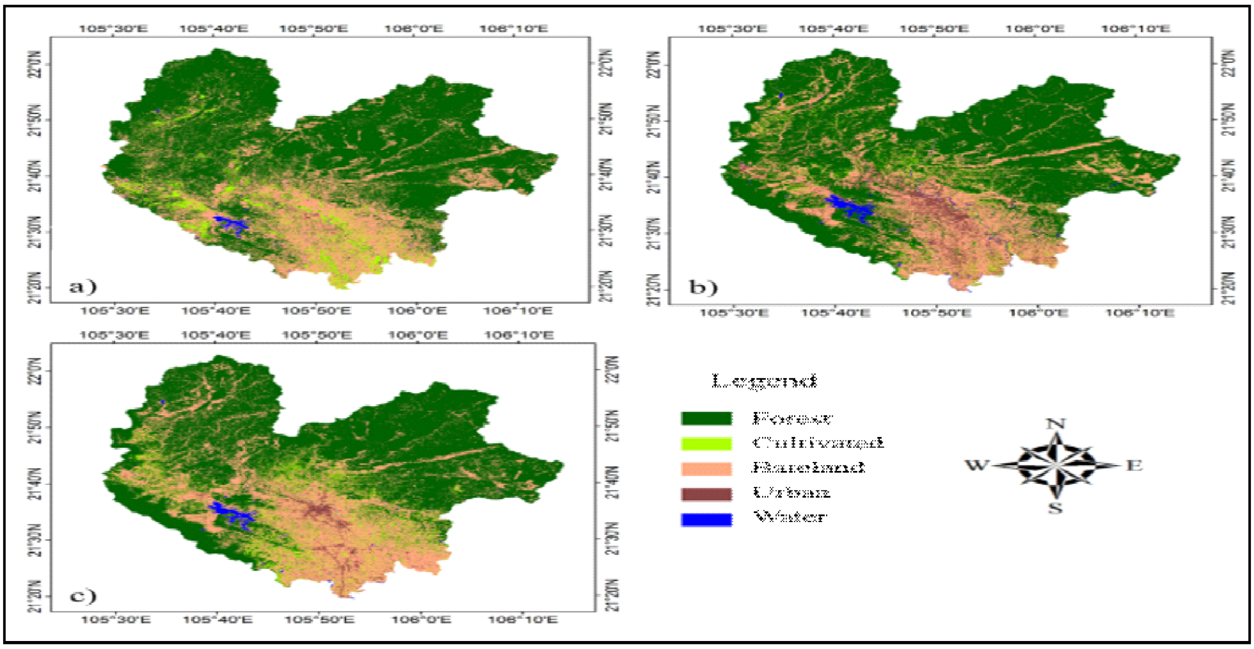


Fig. 2. The classification maps of land cover changes across the study area in the year 2001, 2010 and 2023.

followed by bare land (111,310 ha, 31.6%), cultivated land (21,647 ha, 6.1%), urban land (9,037 ha, 2.6%), and water (2,809 ha, 0.8%). The decline in forest and bare land continued, while water and urban land increased by 0.6% (2,403 ha) and 7.8% (27,677 ha), respectively.

**Land Cover Change Analysis**

During the 2001-2010 period, bare land experienced a significant decrease of approximately 5.1%, but it subsequently recorded a substantial increase of 6.9% (approximately 24,487 ha) from 2010 to 2023. The water area demonstrated an upward trend during 2001-2010, followed by a slight decrease in the 2010-2023 period. Urban land recorded a notable increase of 7.8% during 2001-2010, but then experienced a significant decrease of approximately 5.4% from 2010 to 2023 (Fig. 3). Urban land experienced significant growth throughout the 23-year study period, increasing from 595 ha in 2001 to 9,037 ha in 2023 (Table 2). Forest and bare land remained the dominant land cover types, comprising approximately 90.5% of the total area. This urbanization trend highlights the development of Thai Nguyen province. Cultivated land exhibited a slight decline of 0.6% during the 2001-2010 period, followed by a modest increase of 5,069 ha during 2010-2023.

The analysis of the study's images revealed a consistent decrease in forested areas throughout the entire study period from 2001 to 2023, while both cultivated and bare land experienced fluctuations with a decrease during 2001-2010 and an increase during 2010-2023. This continuous decline in forest

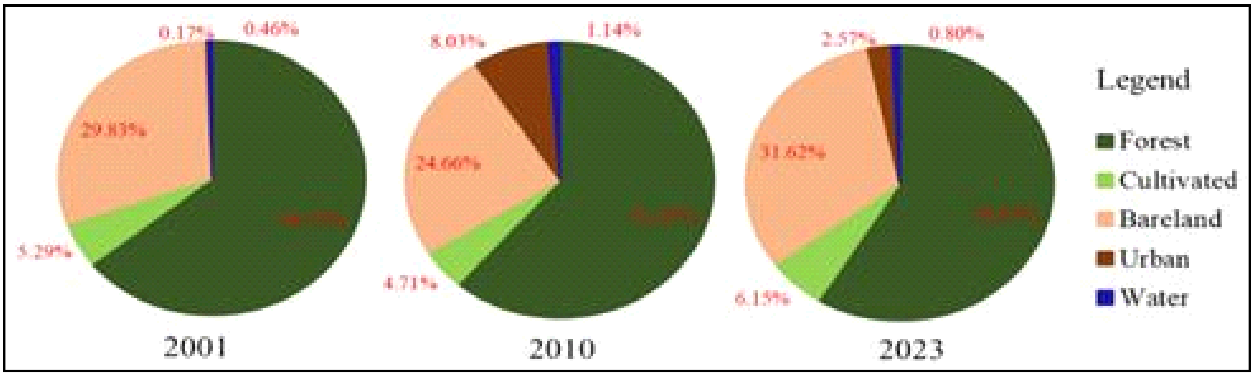


Fig. 3. Land cover categories statistical across the study area for 2001, 2010 and 2023.

cover raises concerns about potential ecological imbalances in the study area, attributed to urban expansion and deforestation activities such as wood cutting. Based on Fig. 4, it can be observed that significant land cover changes (LCCs) occurred during the periods of 2001-2023. In the 2001-2010 period, the LCCs in forest and bare land areas accounted for a substantial proportion, exceeding 90% of the total land area (TLA). Forest and bare land areas underwent conversions to other land cover types, with 9,850 ha (2.79%) and 18,177 ha (5.14%) being affected, respectively, in relation to the TLA.

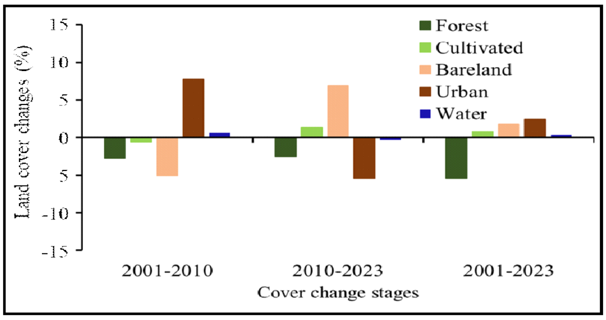


Fig. 4. Analysis of land cover distribution across the study area in the stages of 2001-2023.

The process of urbanization led to the conversion of forest and bare land into urban land. As indicated in Table 2, the urban land area experienced an increase of 27,677 ha, occupying 7.86% of the TLA. Conversely, the changes in cultivated land and water areas were relatively minor, with a decrease of 0.6% for cultivated areas and an increase of 0.6% for water areas. During the 2010-2023 period, the LCCs in forest and bare land areas continued to constitute a significant proportion, up to 90.5% of the TLA. Forest cover areas underwent conversions to other land cover types, amounting to 9,107 ha (2.6%), while bare land areas experienced conversions of 24,487 ha (6.9%) about the TLA. The urban land areas recorded a decrease of 19,235 ha, occupying 5.4% of the TLA. The changes in cultivated land and water areas were relatively minor, with an increase of 1.4% for cultivated areas and a decrease of 0.3% for water areas. The substantial increase in bare land areas during the 2010-2023 period can be attributed to forest maturity and economic development. Overall, the analysis indicates significant declines in forest areas from 2001 to 2023, while cultivated, bare, and urban land all experienced an increasing trend. This can be attributed to the expansion of agriculture and rapid urbanization processes.

## CONCLUSIONS

The study assessed the temporal changes in vegetation cover within Thai Nguyen province of Vietnam based on the analysis of high-resolution satellite imagery spanning from 2001 to 2023, using semi-automatic classification techniques in ERVI software. The precision of the vegetation cover change maps was confirmed through post-classification comparison, demonstrating high accuracy rates ranging from 87% to 96%. The findings revealed a concerning reduction in forest cover area up to 3,041 hectares. Notably, these reductions primarily occurred in urban areas, indicating a significant impact of urbanization on forest cover. Conversely, agricultural land experienced an increase from 10,508 hectares to 10,648 hectares between 2001 and 2023. These observations underscore the escalating risk of diminishing forest cover areas across the study area.

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**Table 2.** Land cover change categories across the study area for 2001, 2010 and 2023

| Cover types | 2001 | | 2010 | | 2023 | | Cover change trends | | |
|---|---|---|---|---|---|---|---|---|---|
| | Area (ha) | Ratio (%) | Area (ha) | Ratio (%) | Area (ha) | Ratio (%) | 2001-2010 | 2010-2023 | 2001-2023 |
| Forest | 226183 | 64.3 | 216333 | 61.5 | 207226 | 58.9 | -2.8% | -2.6% | -5.4% |
| Cultivated | 18631 | 5.3 | 16578 | 4.7 | 21647 | 6.1 | -0.6% | +1.4% | +0.8% |
| Bareland | 105000 | 29.8 | 86823 | 24.7 | 111310 | 31.6 | -5.1% | +6.9% | +1.8% |
| Urban | 595 | 0.2 | 28272 | 8.0 | 9037 | 2.6 | +7.8% | -5.4% | +2.4% |
| Water | 1619 | 0.5 | 4022 | 1.1 | 2809 | 0.8 | +0.6% | -0.3% | +0.3% |

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