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Pre-classification method for detecting vegetation cover changes in Dak Lak province (Vietnam)

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Abstract. In recent years, the process of socio-economic development and population growth have negatively affected the vegetation cover in the Central Highlands region of Vietnam, leading to a decline in forest cover area and quality. This article presents the results of monitoring and detecting the changes in vegetation cover in Dak Lak province (Vietnam) from Landsat image data for the period 2000–2020. Three Landsat image scenes, including Landsat TM images taken in March 2000, February 2010 and Landsat 8 OLI images taken in February 2020 were used to calculate the Normalized Difference Vegetation Index (NDVI); then, the NDVI value was classified into five ranges: NDVI ≤ 0.2, 0.2 < NDVI ≤ 0, 0 < NDVI ≤ 0.2, 0.2 < NDVI ≤ 0.4, 0.4 < NDVI ≤ 0.6 and NDVI > 0.6. The NDVI differencing and thresholding methods are used to evaluate spatio-temporal changes in vegetation cover quality in three categories (decreasing, increasing and no-change) during the research period. The results show that there is a significant change in the vegetation cover for the period 2000–2020. Among them, the majority vegetation cover with decreased quality is natural forest, while the vegetation areas with increased quality are mainly planted forests and industrial trees. The results received in the study provide objective and timely information, helping managers in monitoring and protecting forest resources.

Key words:
remote sensing,
vegetation cover change,
NDVI,
Landsat,
Dak Lak province,
Vietnam

Introduction

The Central Highlands is a region with a particularly important geographical position in Vietnam, bordering Laos and Cambodia, and is home to many ethnic minorities. Forests are an important natural resource of the Central Highlands region, playing a special role in the life and socio-economic development of the region (Muller and Zeller 2004; Do et al. 2017). According to the 2022 National Forest Status Announcement of the Forest Protection Department (Ministry of Agriculture and Rural Development MARD), the forest area in the Central Highlands reaches more than 2.5 million hectares, with a coverage density of 46.32%, which is higher than the national average of 42.02% (MARD 2023). However, the decline in forest area in the Central Highlands has been occurring at a high level. Exploitation, deforestation and encroachment of forest land for agricultural production occur regularly, causing serious consequences. Furthermore, the quality of forests is also being strongly reduced, especially of natural forests (MONRE 2014; Kissinger 2020). Detecting the changes in forest cover in the Central Highlands region, including Dak Lak province, is an urgent issue today.

Multi-temporal remote-sensing data have been used effectively in many different studies around the world to assess spatio-temporal changes in forest cover (Mohod et al. 2022; Vasquez et al. 2023; Pham et al. 2024). Methods for detecting changes in land cover can be divided into two groups: the pre-classification method and the post-classification method (Haque and Basak 2017). Traditional methods for detecting changes in land cover are based on the post-classification method, which uses the results of forest cover classification from remote-sensing images at different times, then compares and evaluates the changes in area and spatial distribution of forest objects (Purwanto et al. 2023; Tikuye et al. 2023). These studies have used many different classification methods such as pixel-based classification methods (Hagner and Reese 2007; Dinca et al. 2017; Norovsuren et al. 2019), object-oriented classification methods (Liu and Xia 2010; Oreti et al. 2021), and machine learning algorithms (Talukdar et al. 2020; Basheer et al. 2022; Aziz et al. 2024).

In addition, the pre-classification method analyzes the land cover change without classifying the image value, but uses spectral indices calculated from multi-temporal remote-sensing images (Haque and Basak 2017). Currently, hundreds of different vegetation indices calculated from multi-spectral images have been developed, in which the most common and widely used pre-classification method is the Normalized Difference Vegetation Index (NDVI) (Rhyma et al. 2019). The NDVI index proposed by Rouse et al. (1973) is a function of red and near-infrared (NIR) bands and has a value between –1 and +1, in which dense or healthy vegetation is represented by higher values. This is one of the most commonly used vegetation indices in research on global climate and environmental change (Lyon et al. 1998; Liu et al. 2018; Huang et al. 2021; Singh and Javeed 2021).

NDVI differencing (ΔNDVI) is an effective technique for detecting and monitoring changes in forest cover (Pu et al. 2008; Al-doski et al. 2013; Sahebjalal and Dashtekian 2013; Mancino et al. 2014; Hycza et al. 2018; Kenhinde et al. 2020; Trinh et al. 2020; Veeramani 2020; Singh and Javeed 2021; Dangulla et al. 2023). NDVI differencing is an effective method for enhancing the difference among spectral features and suppressing or reducing impacts of topographic effects and shade effects (Yacouba et al. 2010). In this method, the NDVI index is first calculated from multispectral images taken on two different dates, and then the second-date NDVI index is subtracted from the first-date NDVI index (Lu et al. 2004; Apraku et al. 2023; Gabrielle et al. 2023). If there is an increase in reflectance of vegetation cover, the ΔNDVI image appears light-toned. Conversely, the ΔNDVI image appears dark-toned if there is a decrease in reflectance of vegetation cover. If the ΔNDVI image is represented by gray color, the area has zero or minimal change in vegetation cover between two points in time. Thus, the NDVI differencing allows for assessment of changes in the quality of vegetation cover between two times by comparing their spectral reflectance without needing to classify land cover from satellite images. This allows time and effort to be saved in processing multi-temporal remote-sensing data compared to a “post-classification” method, which is based on land-cover classification results.

This paper focuses on the detection and monitoring the changes in forest cover in Dak Lak province (Central Highlands of Vietnam) during the period 2000–2020 from Landsat multi-temporal data using a “pre-classification method”. In this study, the NDVI index calculated from Landsat satellite images in 2000, 2010 and 2020 is divided into five ranges (NDVI ≤ –0.2, –0.2 < NDVI ≤ 0, 0 < NDVI ≤ 0.2, 0.2 < NDVI ≤ 0.4, 0.4 < NDVI ≤ 0.6 and NDVI > 0.6) to evaluate the vegetation cover change in the period 2000–2020. In addition, the NDVI differencing method was used to detect the changes in forest cover, based on classification into three classes: decrease, increase and no-change. The Google Earth Engine (GEE) cloud computing platform was used to process multi-temporal Landsat data and calculate the NDVI and ΔNDVI images, while forest cover maps were created using ArcGIS 10 software.

Materials and methods

Study area

Dak Lak is a province located in the center of the Central Highlands region (Vietnam), with the fourth largest area in the country. Dak Lak has a 73-km-long border, adjacent to Mondulkiri province (Cambodia) (DOI: https://daklak.gov.vn/). The geographical location of Dak Lak province is shown in Figure 1.

Forests are an important natural resource of Dak Lak province. According to statistics from the Ministry of Agriculture and Rural Development of Vietnam, as of December 31, 2022, the forest area in Dak Lak is 505,557 ha, including 413,845 ha natural forests and 91,711 ha planted forests. The forest coverage rate of province in 2023 reached 38.03% (0.32% lower than 2022), which is lower than the national forest coverage rate (42.02%) (MARD 2023). In recent years, forest cover in Dak Lak has changed dramatically due to the impacts of socio-economic development, population growth and the effects of climate change. The change in forest cover in Dak Lak province is reflected in the decrease in natural forest (evergreen forest, dipterocarp forest) and the increase in planted forest area and land for industrial crops (Nguyen et al. 2020; Nguyen et al. 2022). According to reports from the People's Committee of Dak Lak province, every year there are still many violations of forestry laws in the locality. Many areas of forest and forest land have been illegally destroyed, encroached upon and occupied, but they have not been recovered for forest restoration, leading to a decline in forest area and quality in Dak Lak province.

Materials

In this study, a total of three Landsat images acquired in the period 2000–2020 were used to assess forest cover changes in Dak Lak province, including Landsat TM images taken on January 17, 2000 and January 28, 2010 and Landsat 8 OLI image taken on January 16, 2020. The Landsat data were acquired at similar times of the year (dry season, January) to limit the effects of time differences on forest cover. Landsat images are collected at L2-level, which is radiometrically corrected and converted to surface reflectance values. The Landsat multispectral

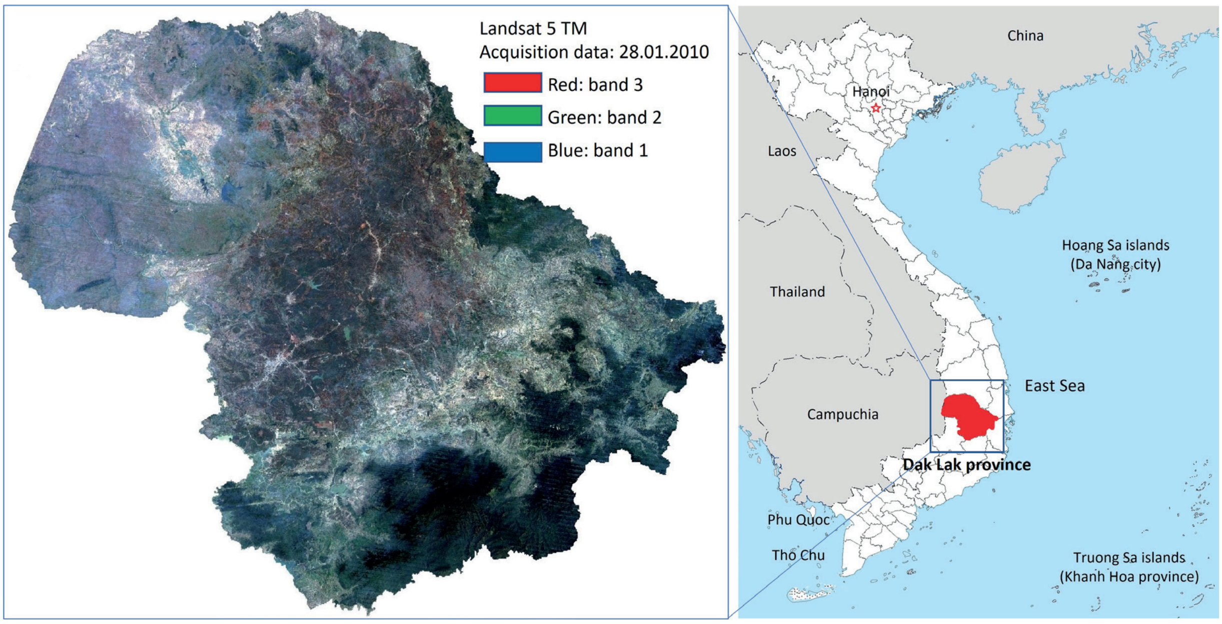

Fig. 1. Geographical location of Dak Lak province (Central Highlands of Vietnam)

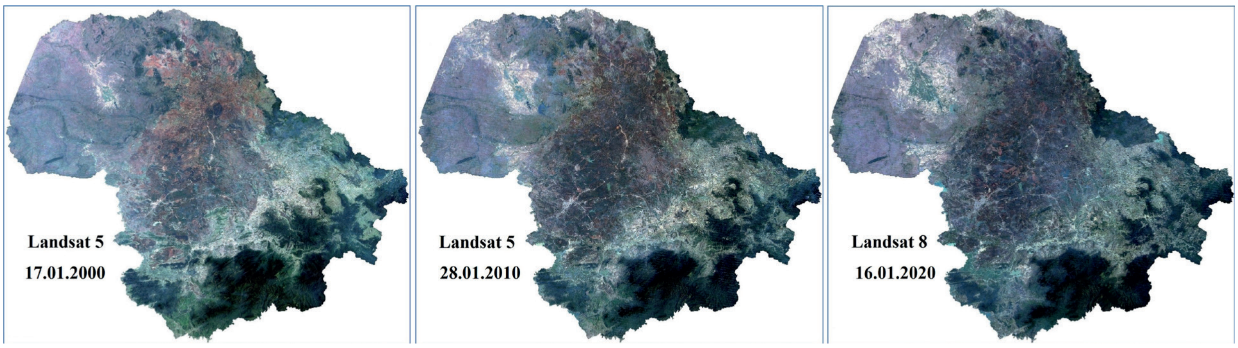

Fig. 2. Landsat images for the period 2000–2020 used in this study

images for the period 2000–2020 in natural color combination after cropping along the boundary of Dak Lak province are shown in Figure 2.

Methodology

To detect and monitor the changes in forest cover from multi-temporal Landsat images using the NDVI differencing method, first, the reflectance values of red and NIR bands were employed to calculate Normalized Difference Vegetation Index (NDVI) values using the following equation (Rouse et al. 1973):

$$NDVI = \frac{\rho_{NIR} - \rho_{RED}}{\rho_{NIR} + \rho_{RED}}$$

where: *ρRED* and *ρNIR* are reflectance values of red and near-infrared bands. For Landsat TM data, the red and NIR bands correspond to band 3 and band 4, while for Landsat 8 OLI_TIRS data, these bands correspond to band 4 and band 5.

In the next step, the NDVI differencing image (ΔNDVI) is calculated using the second-date NDVI index (*NDVI(post.)*) and the first-date NDVI index (*NDVI(pre.)*) following the equation:

$$\Delta NDVI = NDVI\,(post.) - NDVI\,(pre.)$$

Generally, the ΔNDVI image was then reclassified using a threshold value calculated as $\mu \pm n{\cdot}\sigma$; where μ represents the ΔNDVI pixels mean value, the n value is identified by the trial and test method, and σ is the standard deviation of the pixel values density function in the change image (Gabrielle et al. 2023). The threshold identifies three ranges in the normal distribution (Mancino et al. 2014):

(a) the left tail ($\Delta NDVI < \mu - n{\cdot}\sigma$);
(b) the right tail ($\Delta NDVI > \mu + n{\cdot}\sigma$);
(c) the central region of the normal distribution
($\mu - n{\cdot}\sigma < \Delta NDVI < \mu + n{\cdot}\sigma$).

Pixels within the two tails of the distribution are characterized by significant vegetation cover changes, while pixels in the central region represent no-change. The n factor defines the range of dispersion around the mean. The histogram of ΔNDVI image with changes and no-change in vegetation cover is shown in Figure 3 (Manzo et al. 2016).

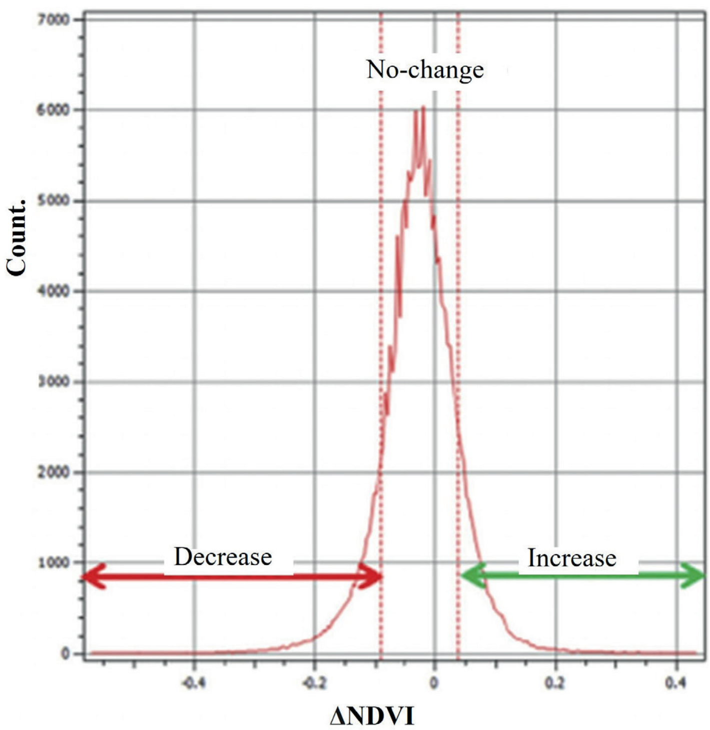

Fig. 3. Histogram of NDVI image with change and no-change in vegetation cover

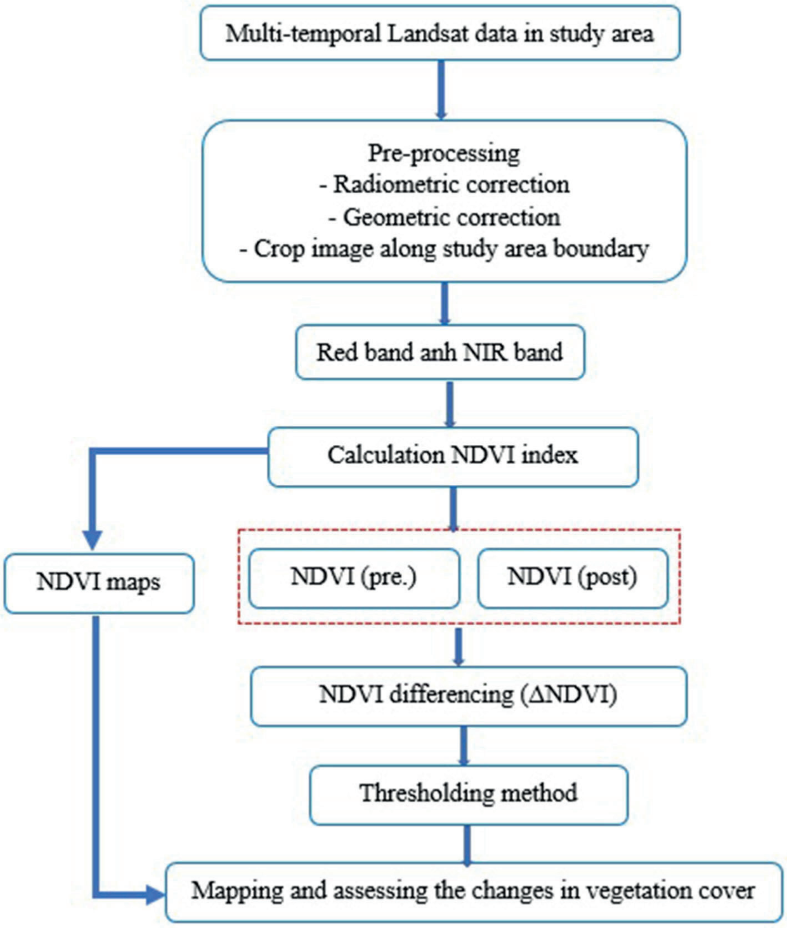

Fig. 4. Flowchart of NDVI differencing method for detecting changes in forest cover

A flowchart of the NDVI differencing method used in this study to detect the changes in forest cover based on Landsat multi-temporal data in the period 2000–2020 is shown in Figure 4.

In this study, multi-temporal Landsat satellite image data are processed directly on the Google Earth Engine (GEE) cloud computing platform using the Code Editor tool to calculate NDVI indices and ΔNDVI images. GEE archives remote-sensing data over the past 40 years, including data from the Landsat satellite systems. GEE also provides the necessary computational tools for online data analysis and users only need to download the data after processing. GEE is an effective tool in processing multi-temporal remote-sensing data, helping to overcome difficulties in remote-sensing storage infrastructure. The Java programming language is used in this study to process multi-temporal Landsat image data on the GEE platform.

Results and discussion

Figure 5 shows the NDVI indices calculated from Landsat images taken on January 17, 2000, January 28, 2010 and January 16, 2020, in which vegetation cover is represented by light-colored pixels, while the barren land and water body are represented by dark-colored pixels. The NDVI indices in 2000, 2010, 2020 have values ranging from –0.32 to 0.85 (January 17, 2000), –0.47 to 0.82 (January 28, 2010) and –0.45 to 0.83 (January 16, 2020). Analysis of Figure 5 shows that areas with high NDVI values are concentrated in

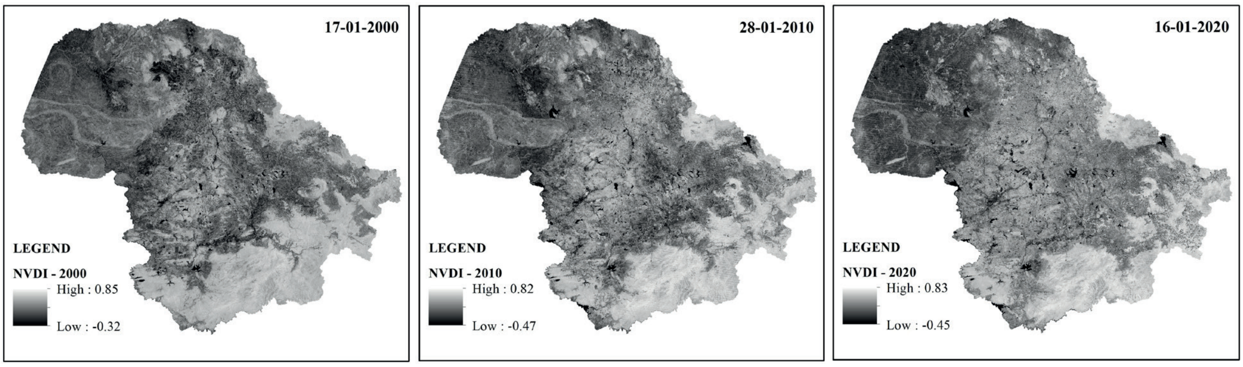

Fig. 5. NDVI indices, calculated from Landsat images 2000, 2010 and 2020

the south of Dak Lak province, where natural forest cover is distributed.

NDVI is used to measure the greenness of vegetation and helps determine vegetation density and detect changes in plant health (Viju et al. 2023). In this study, the NDVI index was classified into five classes: «water body» (NDVI ≤ –0.2), «wet soil» (–0.2 < NDVI ≤ 0.0), «low vegetation density» (0.0 < NDVI ≤ 0.2), «low-moderate vegetation density» (0.2 < NDVI ≤ 0.4), «moderate vegetation density» (0.4 < NDVI ≤ 0.6) and «high vegetation density» (NDVI > 0.6). The NDVI density maps calculated from the Landsat multi-temporal image for the period 2000–2020 in Dak Lak province are shown in Figure 6. The changes in vegetation cover for the period 2000–2020 in the study area are shown in Table 1.

Analyzing the results presented in Table 7 shows that the areas with NDVI values less than 0 (water body and wet soil) increased in the period 2000–2020, from 43.63 km^2 in 2000 to 71.44 km^2 in 2010 and 102.02 km^2 in 2020. This can be explained by the construction of a number of water reservoirs in Dak Lak province during this period, such as Ea Sup Thuong (2004) and Krong Buk Ha (2013). The areas at the «low vegetation density» level also increased in the period 2000–2020, from 0.59% of the province's total area in 2000 to 1.80% (in 2010) and 1.24% (in 2020). The increase in areas at «low vegetation density» level is due to the increase in residential and barren land areas in Dak Lak province.

The areas with NDVI values between 0.2 and 0.4 (low-moderate vegetation density) increased rapidly in the period 2000–2020, from 17.50% of the total area of Dak Lak province (2000) to 25.96% (2010) and 26.75% (2020). This is also similar to the decrease in areas at levels «moderate vegetation density» (0.4 ≤ NDVI < 0.6) and «high vegetation density» (NDVI > 0.6) in the study area during this period. In particular, areas with NDVI values between 0.4 and 0.6 decreased from 50.33% of the total study area (in 2000) to 43.73% (in 2010) and 42.12% (in 2020). Areas with NDVI values greater than 0.6 decreased from 31.25% (in 2000) to 27.98% (in 2010), then

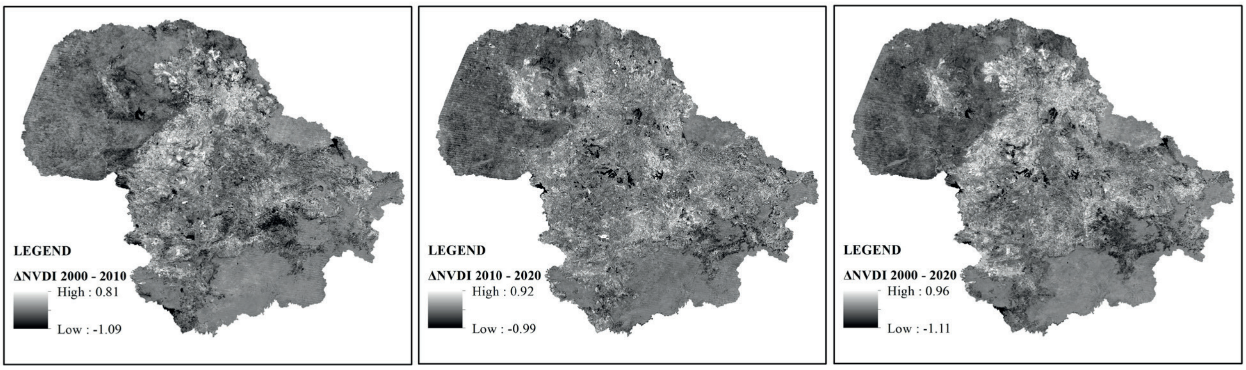

Fig. 6. NDVI density maps for the period 2000–2020

Table 1. NDVI density change for the period 2000–2020 using Landsat multi-temporal data

NDVI value	2000		2010		2020	
	Area (km²)	Area (%)	Area (km²)	Area (%)	Area (km²)	Area (%)
< -0.2	5.23	0.04	9.57	0.07	30.46	0.23
-0.2–0.0	38.40	0.29	61.87	0.46	71.56	0.53
0.0–0.2	79.62	0.59	241.72	1.80	166.95	1.24
0.2–0.4	2,352.15	17.50	3,488.61	25.96	3,594.69	26.75
0.4–0.6	6,764.23	50.33	5,876.68	43.73	5,660.59	42.12
> 0.6	4,199.31	31.25	3,760.49	27.98	3,914.69	29.13

increased to 29.13% (in 2020). Thus, the decline in area with NDVI value greater than 0.4 in the period 2000–2010 is higher than in the period 2010–2020. This result also reflects the effectiveness of forest protection and restoration policies in the study area in particular and Vietnam in general, in which the rate of forest cover has increased continuously in recent times.

Figure 7 presents the ΔNDVI images for the periods 2000–2010, 2010–2020 and 2000–2020, in which these indices are calculated as follows:

$$\Delta NDVI_{2000\text{-}2010} = NDVI\ (2010) - NDVI\ (2000)$$

$$\Delta NDVI_{2010\text{-}2020} = NDVI\ (2020) - NDVI\ (2010)$$

$$\Delta NDVI_{2000\text{-}2020} = NDVI\ (2020) - NDVI\ (2000)$$

The change in vegetation cover in Dak Lak province during the period 2000–2020 can be clearly recognized in Figure 7, where dark pixels represent areas of loss of vegetation cover (decrease) and light colored pixels represent areas with increased vegetation cover. Additionally, areas with little or no change in vegetation cover are shown as gray pixels.

The thresholding method is used to detect changes in vegetation cover from the ΔNDVI images. In this study, the final identification of the best-fitting n·σ threshold value was based on visual analysis on the ΔNDVI data for the period 2000–2020. In particular, a visual analysis based on four different threshold values (0.5σ, 1σ, 1.5σ and 2σ) was conducted using different thresholds over random points, in which the chosen threshold value used for the ΔNDVI image classification was 1.0σ. Thus, the vegetation cover in Dak Lak province is classified into four classes: (1) decrease; (2) increase; (3) no-change and (4) non-vegetation. In this case study, "non-vegetation" objects are considered pixels with the NDVI values less than 0.2 in both Landsat image acquisition times. The results of detecting the changes in vegetation cover in Dak Lak province from Landsat multi-temporal data for the period 2000–2020 are shown in Figures 8, 9 and 10.

Table 2 shows the results of assessing the changes in vegetation cover in Dak Lak province for the period 2000–2020 using the NDVI differencing method. It can be seen that the decreased vegetation area in both periods 2000–2010 and 2010–2020 is smaller than the increased vegetation area. For the period 2000–2010, the decreased vegetation area was 920.82 km² (6.85% of the study area), while the increased vegetation area was 1,526.82 km² (11.36%).

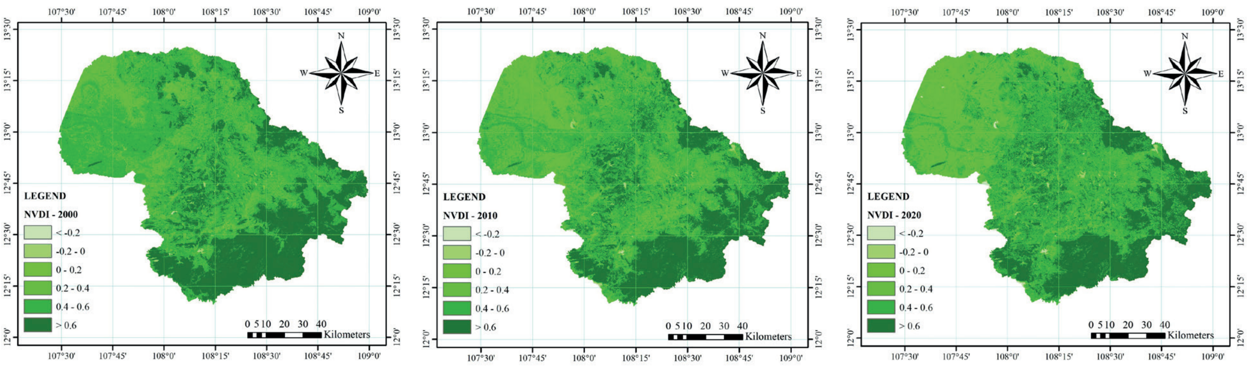

Fig. 7. NDVI images for the periods 2000–2010, 2010–2020 and 2000–2020

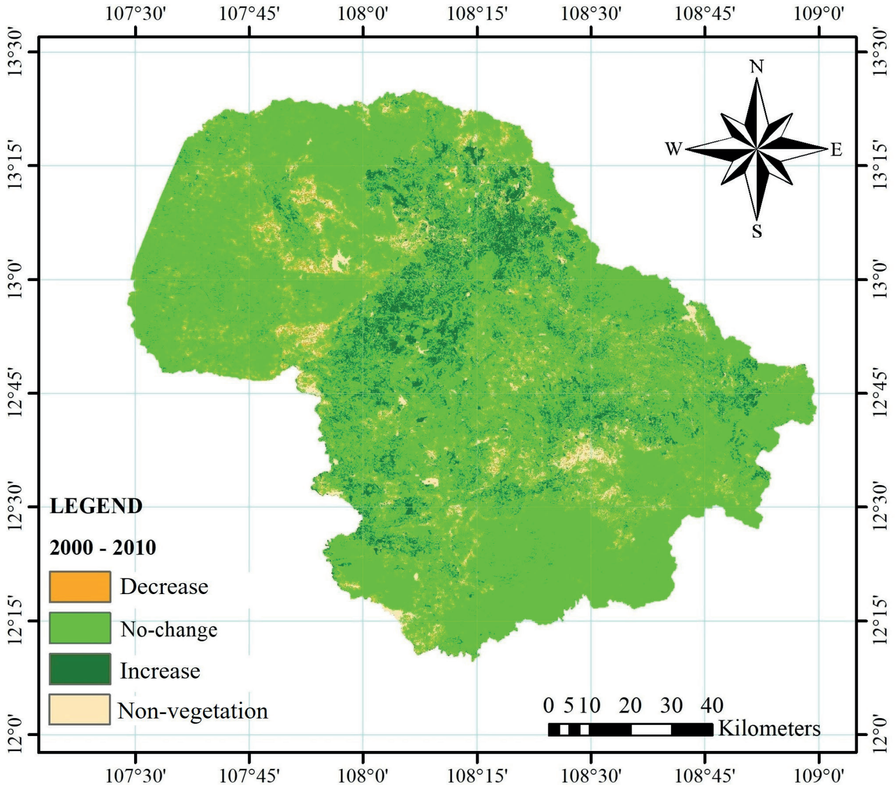

Fig. 8. Changes in vegetation cover in Dak Lak province for the period 2000–2010

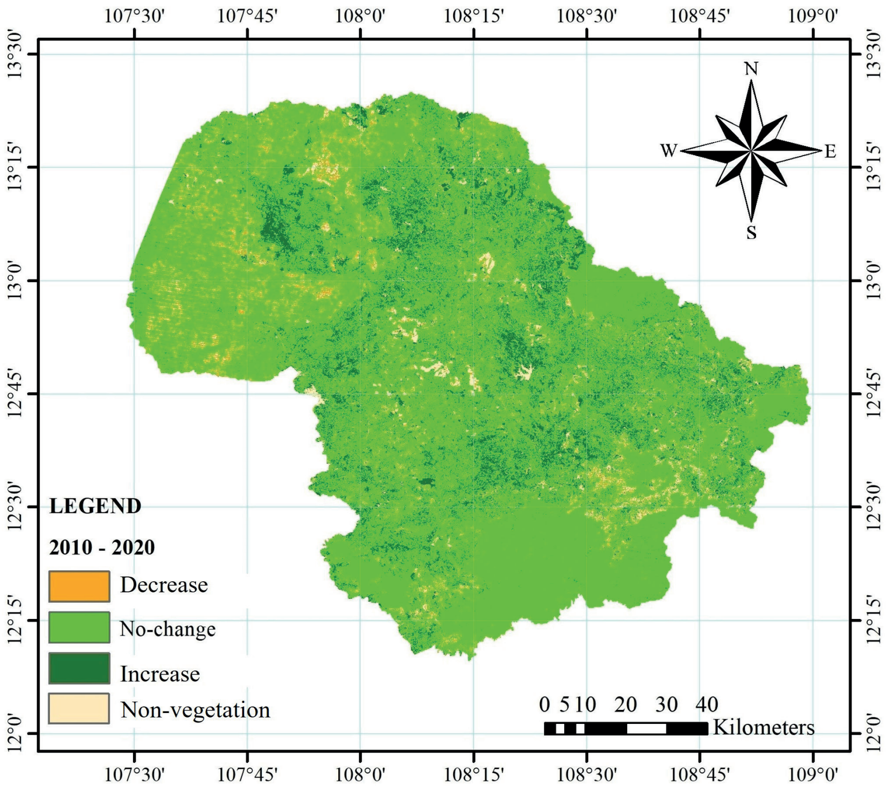

Fig. 9. Changes in vegetation cover in Dak Lak province for the period 2010–2020

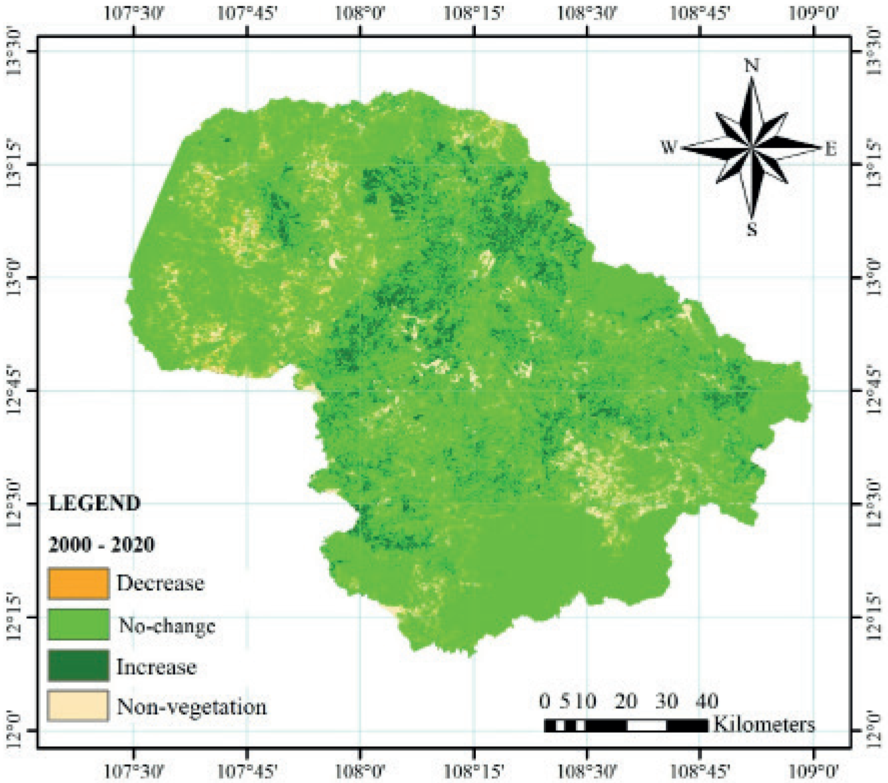

Fig. 10. Changes in vegetation cover in Dak Lak province for the period 2000–2020

For the period 2010–20, the decreased and increased vegetation area reached 1,147.17 km^2 (8.54%) and 1,736.90 km^2 (12.93%), respectively. Overall, during the period 2000–2020, the decreased vegetation area was 651.81 km^2, which is about one third of the increased vegetation area (1,787.26 km^2) (Table 2).

Although the decreased vegetation area during the period 2000–2020 is lower than the increased vegetation area, the majority of increased vegetation cover is located in the center of the study area, which is the agricultural and industrial cropland in Dak Lak province (shown by dark green in Figs 8–10). Meanwhile, the decreased vegetation cover areas are located mainly in the north-west and south of the province, where natural forests and dipterocarp forests are distributed. The results also show that a significant area of natural forest was reduced in the period 2000–2020, especially in the south-east of the study area.

Table 2. Changes in vegetation cover area in Dak Lak province for the period 2000–2020 using NDVI differencing method

Changes in vegetation cover	2000–2010		2010–2020		2000–2020	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Area (km^2)	Area (%)
Decrease	920.82	6.85	1,147.17	8.54	651.81	4.85
No-change	10,214.95	76.02	10,042.85	74.73	9,893.23	73.62
Increase	1,526.82	11.36	1,736.90	12.93	1,787.26	13.30

Conclusion

In this study, the pre-classification change assessment method using the NDVI differencing technique was used to detect the changes in vegetation cover in Dak Lak province for the period 2000–2020. A total of three Landsat satellite image scenes (i.e., Landsat TM images taken on January 17, 2000 and January 28, 2010 and Landsat 8 OLI images taken on January 16, 2020) are used to calculate NDVI index and NDVI difference images (ΔNDVI). In this study, the NDVI index is classified into five classes, corresponding to the density of vegetation cover – from low to high. The results showed that there was a significant increase in the low vegetation cover density area (NDVI value less than 0.4) and, at the same time, the high vegetation cover density area (NDVI value higher than 0.4) decreased sharply in the period 2000–2020.

In addition, the study also used a thresholding method to detect the changes in vegetation cover from ΔNDVI data, in which the vegetation cover change is evaluated at three levels: decrease, increase and no-change. Analysis of the results shows that, although the increased vegetation cover area is higher than the decreased vegetation cover area, the majority of increased vegetation area is agricultural and industrial crops. In contrast, the decreased vegetation area in Dak Lak province is mainly natural forests and dipterocarp forests. This shows a decline in forest cover quality in the study area during the period 2000–2020.

Disclosure statement

No potential conflict of interest was reported by the authors.

Author contributions

Study design: LHT; data collection: LHT, VPL, TTNN; statistical analysis: LHT, VPL; result interpretation: LHT, TTNN; manuscript preparation: LHT; literature review: LHT, VPL

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