Assessing forest cover changes in Dak Lak province (Central Highlands of Vietnam) from multi-temporal Landsat data and machine learning techniques

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Abstract. Dak Lak is a province in the Central Highlands region of Vietnam, with a large area of forests and forestry land. However, the forest cover has changed dramatically in recent times due to the influence of human activities and climate change. This article presents the results of assessing forest cover changes in Dak Lak province from Landsat satellite image data for the period 2000 – 2020. Three Landsat satellite image scenes, including Landsat 5 TM images taken in March 2000 and February 2010 and Landsat 8 OLI image taken in February 2020 are used to classify forest cover. Three common machine learning techniques, including Random Forest (RF), Support Vector Machine (SVM), Classification and Regression Tree (CART) and the traditional maximum likelihood classification algorithm are used to classify forest cover in the study area, thereby choosing the method with the highest accuracy. The results show that the RF algorithm has the highest accuracy in classifying forest cover from multi-temporal Landsat images by comparing the overall accuracy value and the Kappa coefficient. The obtained results are used to build forest cover change maps in the period 2000 - 2010, 2010 - 2020 and 2000 - 2020. The results received in the study provide information to help managers in monitoring and protecting forest resources.

Keywords: forest cover dynamic, remote sensing, machine learning, Landsat, Dak Lak province.

1. Introduction

Forests are an important natural resource of Vietnam, playing an important role in adapting to climate change through environmental functions such as preventing erosion and ensuring water circulation (CIFOR, 2014). In recent years, due to the impact of socio-economic development and population growth, Vietnam's forests have decreased drastically, especially the decline in forest quality. Although Vietnam's forest coverage rate increased from 30% to 42% in the period from 1990 to present (MARD, 2023), the increase in forest area does not mean improving forest quality. In fact, most of the increased forest area is planted forests, while the natural forest area is decreasing or severely degraded. Monitoring forest cover change is

therefore an urgent requirement in Vietnam, providing objective and timely information for managers in planning and developing forest resources.

Remote sensing technique is commonly used in studies around the world in assessing forest cover changes due to its outstanding advantages such as large coverage area and short update time (Rogan & Chen, 2004; Goparaju & Sinha, 2017). With multi-temporal data sets from the last decades of the 20th century, Landsat satellite data have been used effectively in monitoring and assessing forest cover changes at the regional scale. The provision of free data products since 2008 has promoted widespread use of Landsat time series data (Banskota et al., 2014). There are several methods to apply the extraction of information about forest cover objects such as unsupervised classification, supervised classification and object-oriented classification methods (Sun et al., 2005). This allows for quick extraction of information about the area and spatial distribution of forest cover to support forest change monitoring.

Recently, machine learning techniques have been effectively applied to improve the accuracy of land cover/land use classification (Talukdar et al., 2020). Machine learning algorithms are commonly used from multispectral satellite imagery from multispectral satellite imagery, including Random Forest - RF (Gislason et al., 2006; Kumar & Sinha, 2020), Support Vector Machine - SVM (Basheer et al., 2022; Huang & Song, 2016), Classification and Regression Tree - CART (Nguyen, 2020; Yang & Li, 2013), Artificial Neural Network - ANN (Alshari et al., 2023). The results obtained in these studies show that machine learning techniques help significantly improve the accuracy in forest cover classification compared to traditional classification methods. Oo et al. (2022) used machine learning algorithms, including RF, SVM, CART and maximum likelihood method in land cover classification of Kyaukpahto gold mine area, northern Myanmar from Landsat and Aster images. The overall accuracy value and Kappa index when classifying land cover using machine learning techniques are both higher than the maximum likelihood method, in which the RF algorithm achieving the highest accuracy (Oo et al., 2022). The effectiveness of the RF algorithm compared to other algorithms such as SVM, CART, ANN in classifying land cover/use from satellite images has also been proven in many studies in different regions of the world (Carrion & Southworth, 2018; Cheng & Wang, 2019; Volke & Abarca-Del-Rio, 2020; Mao et al., 2020; Yuh et al., 2023; Zhao et al., 2024).

Since the launch of Landsat-1 in 1972, the Landsat program represents the longest running terrestrial satellite record. In 2008, the United States Geological Survey (USGS) adopted a free and open Landsat data policy, which led to a substantial increase in the use of Landsat data that has been beneficial to many segments of society (Roy et al., 2014). With eight successful missions over 50 years, the Landsat image

database provides the continuous data of the Earth's continents from space. Therefore, the Landsat images data has been used very effectively for monitoring forest cover changes.

Tariq et al. (2024) used multi-temporal Landsat image data from 1990 to 2017 to monitor the spatio-temporal variation of forest cover density in Khyber Pakhtun Khwa, Pakistan. 3 machine learning techniques, including SVM, Naive Bayes Tree (NBT) and Kernel Logistic Regression (KLR) are used to classify forest objects from Landsat images, in which the SVM algorithm achieves the highest accuracy. According to the results, forest area decreased from 1990 to 2010, then increased from 2013 to 2017 (Tariq et al., 2023). Du et al. (2023) was developed the Landsat-based detection of trends in disturbance and recovery (LandTrendr) algorithm for mapping annual forest gain globally using Landsat time series and the Google Earth Engine platform (Du et al., 2023). In the Central European region, Senf et al. used 32-year Landsat time series to map forest disturbances in five sites across Austria, the Czech Republic, Germany, Poland, and Slovakia, in which disturbance maps achieved overall accuracies ranging from 81% to 93% (Senf et al., 2017).

In Vietnam, multi-temporal Landsat image data is also used in many studies to assess forest cover changes (Trinh et al., 2020; Vu & Bui, 2023; Vogelmann et al., 2017; Shimizu et al., 2023; Tran et al., 2023). The obtained results show that the forest cover changes are most marked along the relatively narrow interfaces between agricultural and forest areas. In addition, forest cover in national reserves has not changed much due to strict protection in these areas (Vogelmann et al., 2017). The LandTrendr model based on multi-temporal Landsat satellite images was also used in the study (Shimizu et al., 2022) to detect forest disturbances in the northern region of Vietnam. Meanwhile, the study (Tran et al., 2023) used a series of NDVI index images to evaluate the forest cover changes in Thua Thien Hue province (Central region of Vietnam) from Landsat images for the period 1991 - 2022. The NDVI time series calculated from Landsat images for the period 1990 - 2018 was also used in the study (Trinh et al., 2020) to evaluate the forest cover quality changes in Dak Nong province (Central Highlands region of Vietnam). In addition, some studies also use multi-temporal Landsat image data to monitor changes in forest cover density (Bui & Vu, 2023) and detect forest degradation (Vogelmann et al., 2017) in different areas in Vietnam. These studies have demonstrated the effectiveness of Landsat satellite data compared to other satellite data in monitoring and detecting forest cover changes at regional and national scales.

This article presents the results of mapping forest cover changes in Dak Lak province from Landsat multi-temporal data. 3 scenes of Landsat satellite images taken in 2000, 2010 and 2020 were used to classify land cover/land use, then evaluate forest cover changes in the study area. Four different classification algorithms are used to classify forest cover, including 3 machine learning algorithms (Random Forest,

Support Vector Machine (SVM), Classification and Regression Tree (CART)) and the maximum likelihood algorithm. The classification accuracy is evaluated through comparing the Mean Square Error (MSE) value and Kappa coefficient, from which the appropriate classification method is selected to create forest cover change maps for the period 2000 - 2020. Image processing is performed on the Google Earth Engine cloud computing platform and forest cover change maps are built using ArcMap 10.8 software. The obtanied results in this study provide objective and timely input data for local forest resource management models, especially in the context of Dak Lak province being seriously affected by climate change.

2. Materials and Methodology

2.1 Study area and Materials

Dak Lak is a province located in the center of the Central Highlands region (Vietnam), with the 4th largest area in the country. Dak Lak has a 73 km long border, adjacent to Mondulkiri province (Cambodia). (https://daklak.gov.vn/). The geographical location of Dak Lak province is shown in Figure 1.

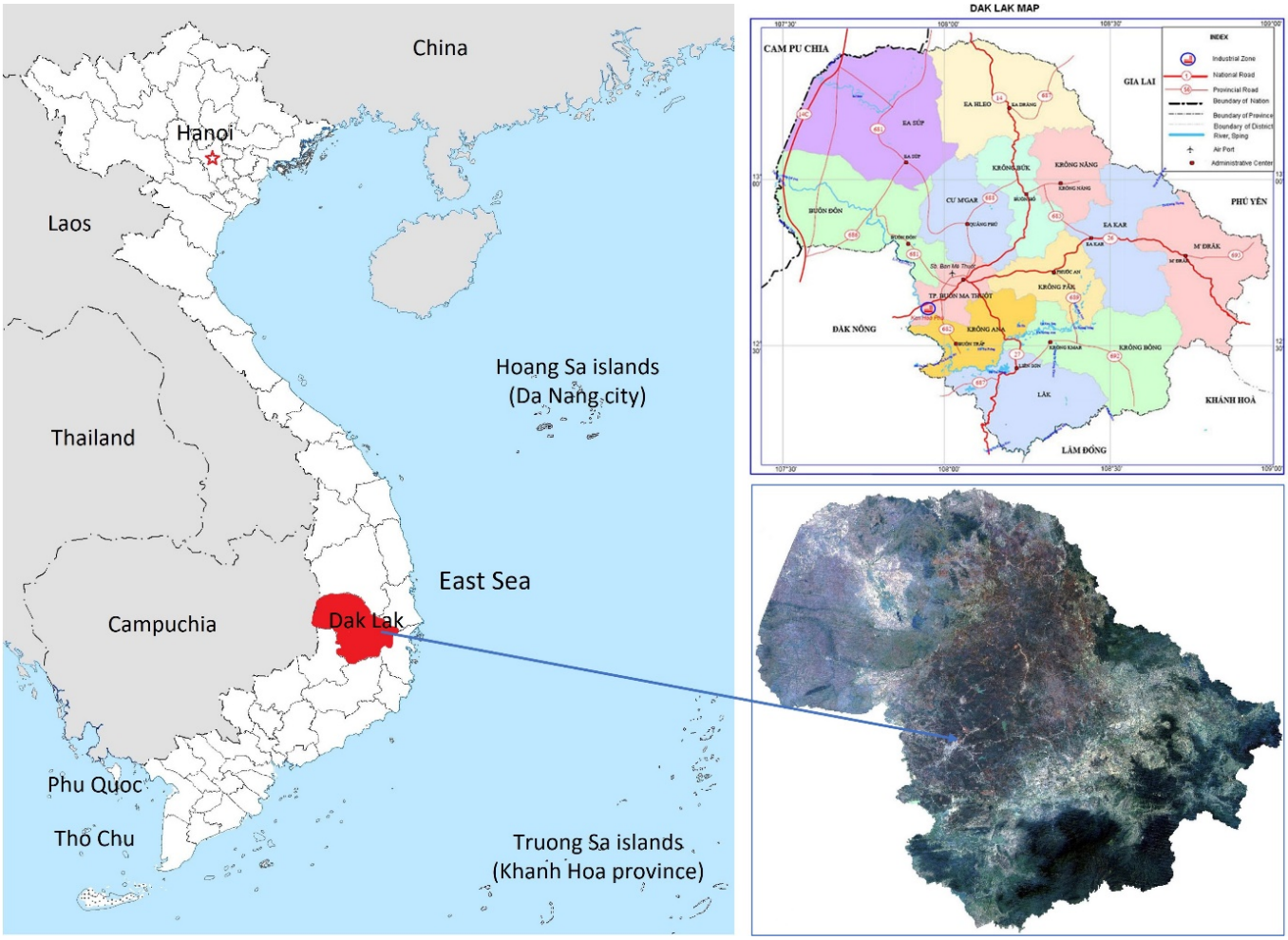

Figure 1. Geographical location of Dak Lak province

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 505557 ha, including 413845 ha natural forests and 91711 ha planted forests. The forest coverage rate of province reached 38.03%, which is average compared to other provinces in Vietnam and 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 influence of socio-economic development, population growth and the effects of climate change.

In this study, three Landsat images from the period 2000 - 2020 were used to assess forest cover changes in Dak Lak province, including: Landsat TM images taken in March 2000 and February 2010 and Landsat 8 OLI image taken in February 2020 (Fig. 2). The Landsat data was acquired at similar times of the year (dry season, February and March) to limit the effects of time differences on vegetation cover. The characteristics of Landsat TM and Landsat OLI_TIRS spectral bands is presented in Table 1 and 2. In addition, the study also used topographic map at a scale of 1:100 000 and forest inventory data of Dak Lak province in the period 2000 - 2020 to build a training dataset and evaluate the forest cover classification accuracy from Landsat satellite images.

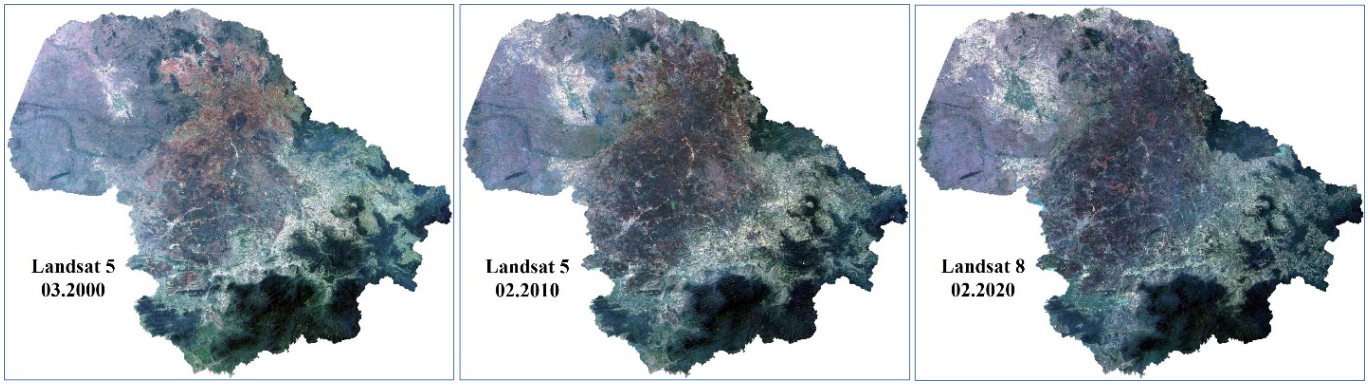

Figure 2. Landsat images for the period 2000 - 2020 used in this study

Table 1. Landsat 5 TM bands charateristics.

No.	Landsat 8 OLI_TIRS bands	Wavelength (µm)	Resolution (m)
1	Band 1 – Blue	0.45 – 0.52	30
2	Band 2 – Green	0.52 – 0.60	30
3	Band 3 – Red	0.63 – 0.69	30
4	Band 4 – Near Infrared (NIR)	0.76 – 0.90	30
5	Band 5 – Shortware Infrared ($SWIR_1$)	1.55 – 1.75	30

6	Band 6 – Thermal Infrared (TIR)	10.40 – 12.50	120
7	Band 7 – Shortware Infrared ($SWIR_2$)	2.08 – 2.35	30

Table 2. Landsat 8 OLI_TIRS bands charateristics.

No.	Landsat 8 OLI_TIRS bands	Wavelength (µm)	Resolution (m)
1	Band 1 – coastal/aerosol	0.433 – 0.453	30
2	Band 2 – Blue	0.450 – 0.515	30
3	Band 3 – Green	0.525 – 0.600	30
4	Band 4 – Red	0.630 – 0.680	30
5	Band 5 – Near Infrared (NIR)	0.845 – 0.885	30
6	Band 6 – Shortware Infrared ($SWIR_1$)	1.560 – 1.660	30
7	Band 7 – Shortware Infrared ($SWIR_2$)	2.100 – 2.300	30
8	Band 8 – Panchromatic (PAN)	0.500 – 0.680	15
9	Band 9 – Cirrus	1.360 – 1.390	30
10	Band 10 – Thermal Infrared (TIR)	10.30 – 11.30	100
11	Band 11 – Thermal Infrared (TIR)	11.50 – 12.50	100

2.2. Methodology

Landsat time series images are pre-processed to remove radiometric and geometric errors, then cropped according to the boundaries of the study area. Multispectral bands (visible, NIR and SWIR bands) with 30 m spatial resolution were used for land cover/land use classification.

Three machine learning algorithms, including RF (Random Forest), SVM (Support Vector Machine) and CART (Classification and Regression Tree) and maximum likelihood classification method are used to classify land cover/land use in Dak Lak province from Landsat satellite images for the period 2000 - 2020.

To build the sample dataset for object classification, we extract the training and validation image samples of different sizes match the land cover objects in experimental area. The sample dataset is divided into training set (70%) for building its specific machine learning classfication parameters and validation set (30%) for adjusting the model. The classification accuracy is evaluated based on the Kappa coefficient and overall accuracy value, thereby selecting the algorithm with the highest accuracy. Finally, the land cover/land use classification results are used to map the forest cover changes during the research period.

The flowchart methodology of this research is available in Figure 3.

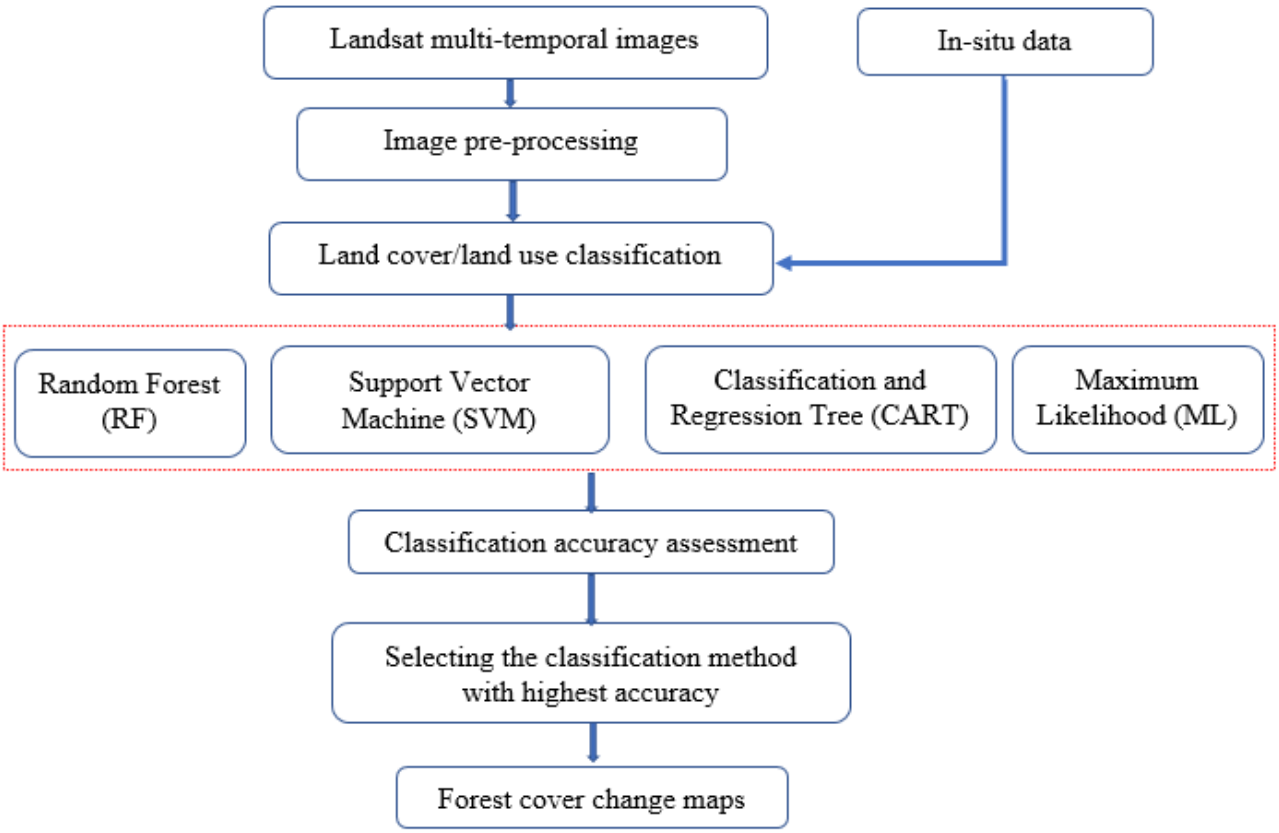

Figure 3. The flowchart of methodology for mapping forest cover changes from Landsat data

3. Results and Discusssion

As shown on Table 3, ten major land cover/land usse classes in Dak Lak province, among which there are 6 forest cover objects have been selected, including: (1) Evergreen forest, (2) Semi-evergreen forest, (3) Dipterocarpus forest, (4) Planted forest, (5) Rubber forest, (6) Coffee land, (7) Agricultural land, (8) Residential land, (9) Water body and (10) Bare land.

Table 3. Land cover/land use types in Dak Lak province

No.	Land cover/land use types	Legend
1	Evergreen forest	
2	Semi-evergreen forest	
3	Dipterocarpus forest	
4	Planted forest	
5	Rubber forest	
6	Coffee land	

7	Agricultural land	
8	Residential land	
9	Water body	
19	Bare land	

The sample dataset with 450 samples was used for land cover/land use classification and accuracy assessment. Samples are polygon shaped, have different size and are distributed over the entire region of interest.

Table 4 shows the results of comparing the overall accuracy value and Kappa coefficient in land cover/land use classification using 4 different algorithms (RF, SVM, CARRT and ML). From results obtained in Table 4 shows that the RF algorithm has the highest accuracy for land cover/land use classification in Dak Lak province from Landsat satellite images. The overall accuracy value and Kappa coefficient when using the RF algorithm reached 93.44% and 0.919, 93.54% and 0.921, 91.70% and 0.883 for Landsat images acquired in March 2000, February 2010, and February 2020, respectively. The CART algorithm has the second highest accuracy, after the RF algorithm and higher than the SVM and ML algorithms. The results also show that all three machine learning algorithms have higher land cover/land use classification accuracy from Landsat images than the traditional maximum likelihood method. This result is also consistent with many other studies around the world, which demonstrate that the RF algorithm achieves the highest efficiency in land cover classification from multi-temporal remote sensing data (Volke & Abarca-Del-Rio, 2020; Mao et al., 2020; Zhao et al., 2024).

Table 4. Comparison of forest cover classification accuracy using different algorithms.

Accuracy	**Landsat image, 03/2000**				**Landsat image, 02/2010**				**Landsat image, 02/2020**			
	SVM	RF	CART	ML	SVM	RF	CART	ML	SVM	RF	CART	ML
Overall accuracy (%)	86.90	**93.44**	90.77	85.98	88.72	**93.54**	89.81	87.29	85.12	**91.70**	83.53	80.14
Kappa	0.871	**0.919**	0.887	0.829	0.863	**0.921**	0.876	0.845	0.828	**0.883**	0.815	0.783

Figure 4 presents the results of land cover/land use classification in Dak Lak province from Landsat images in the period 2000 - 2020 using the RF algorithm. The changes in area of 6 forest cover types in 2000, 2010 and 2020 obtained when classifying land cover/use using the RF algorithm are presented in Table 5.

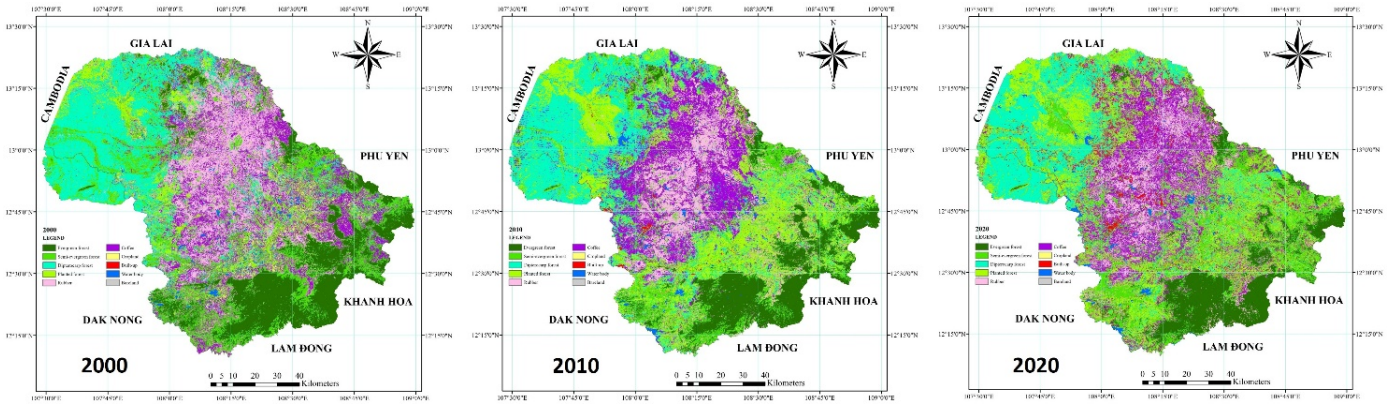

Figure 4. Results of forest cover classification in Dak Lak province using RF algorithm

Table 5. Change in area of forest cover types in Dak Lak province in the period 2000 – 2020.

Forest cover	Area (km^2)		
	2000	**2010**	**2020**
Evergreen forest	1719.28	1709.90	1126.31
Semi-evergreen forest	2205.16	2007.86	2068.97
Dipterocarp forest	2150.90	2036.82	2003.09
Planted forest	2084.48	2758.87	2687.97
Rubber	1379.15	1026.22	1030.70
Coffee	2099.35	2619.80	2429.94

The results in table 5 show that the area of evergreen forests remained almost unchanged in the period 2000 - 2010 (1719.28 km^2 in 2000 and 1709.90 km^2 in 2010), then decreased sharply in the period 2010 - 2020 (from 1709.90 km^2 to 1126.31 km^2, equivalent to 34.13%). The area of semi-evergreen forest decreased by about 8% in the period 2000 - 2010 (from 2205.16 km^2 to 2007.86 km^2), then increased slightly in the period 2010 - 2020 (to 2068.97 km^2).

Dipterocarp forest, an endemic forest type of Dak Lak province, decreased by about 5.3% in the period 2000 - 2010 (from 2150.90 km^2 to 2036.82 km^2), then was relatively stable in the period 2010 - 2020 (the area reached 2003.09 km^2 in 2020). This can be explained by the policy of preserving and developing dipterocarp forests, in addition most of dipterocarp forests area in Dak Lak province is distributed in Yok Don National Park.

The area of planted forests increased very strongly in the period 2000 - 2010, from 2084.48 km^2 to 2758.87 km^2, equivalent to 32.35%, then decreased slightly to 2687.97 km^2 in 2020.

The areas of rubber and coffee, two important industrial crops of Dak Lak province, have contrasting changes. While the rubber area decreased significantly in the period 2000 - 2020 (about 30%), the coffee area increased from 2099.35 km^2 in 2000 to 2619.80 km^2 in 2010, then decreased slightly to 2429.94 km^2 in 2020. This reflects the influence of the world market on the production of these industrial crops.

Overall assessment, the total forest land area (including rubber and coffee areas) of Dak Lak province increased in the period 2000 - 2010 (from 11638.32 km^2 to 12159.47 km^2), then decreased in the period 2010 - 2020 (to 11346.98 km^2 in 2020). The rate of decline in forest land area in the period 2010 - 2020 is higher than the rate of increase in the period 2000 - 2010, leading to a decreasing trend in forest cover rate in recent years. This is also consistent with the annual national forest status announcement report of the Ministry of Agriculture and Rural Development of Vietnam as well as statistical reports of the Forest Protection Department of Dak Lak province.

In this study, 4 land cover objects, including: Agricultural land, Residential land, Water body and Bare land were grouped into the "non-forest" class to build the forest cover change maps. The forest cover change maps in Dak Lak province built from Landsat satellite images for the periods 2000 - 2010, 2010 - 2020 and 2000 - 2020 is presented in Figures 5, 6 and 7, in which these maps represent the inter-change between 7 land cover types, including 6 forest cover objects (evergreen forest, semi-evergreen forest, dipterocarpus forest, planted forest, rubber forest, coffee land) and "non-forest" object.

Evergreen forest changes: analysis of the achieved results shows that, in the period 2000 - 2020, changes in evergreen forests mainly occurred due to conversion to semi-evergreen forests (297.04 km^2 in the period 2000 - 2010 and 237.92 km^2 in the period 2010 - 2020). The area of evergreen forests converted to other forest cover objects and "non-forests" is not much, the most significant is the evergreen forests converted to industrial crops land (rubber and coffee) (about a few dozen km^2 during the period). period 2000 - 2020).

Semi-evergreen forest changes: the main trend is conversion from semi-evergreen forests to planted forests (790.32 km^2 in the period 2000 - 2010 and 222.86 km^2 in the period 2010 - 2020) as well as land for industrial crops (529.97 km^2 in the period 2000 - 2010 and 300.27 km^2 in the period 2010 - 2020). In addition, a significant area of semi-evergreen forest is also converted to "non-forest" objects (residential land, agricultural land, bare land), 42.28 km^2 in the period 2000 - 2010 and 32.64 km^2 in the period 2010 - 2020.

Dipterocarpus forest changes: In the period 2000 - 2020, the transition between dipterocarp forests and planted forests is the main trend in dipterocarp forest changes (765.13 km^2). In addition, a significant area

of dipterocarp forest was also converted into land for industrial crops in the period 2000 - 2010 (over 200 km^2). During the period 2000 - 2020, the conversion about 100 km^2 of dipterocarp forest to semi-evergreen forest and over 142 km^2 to “non-forest” was also recorded.

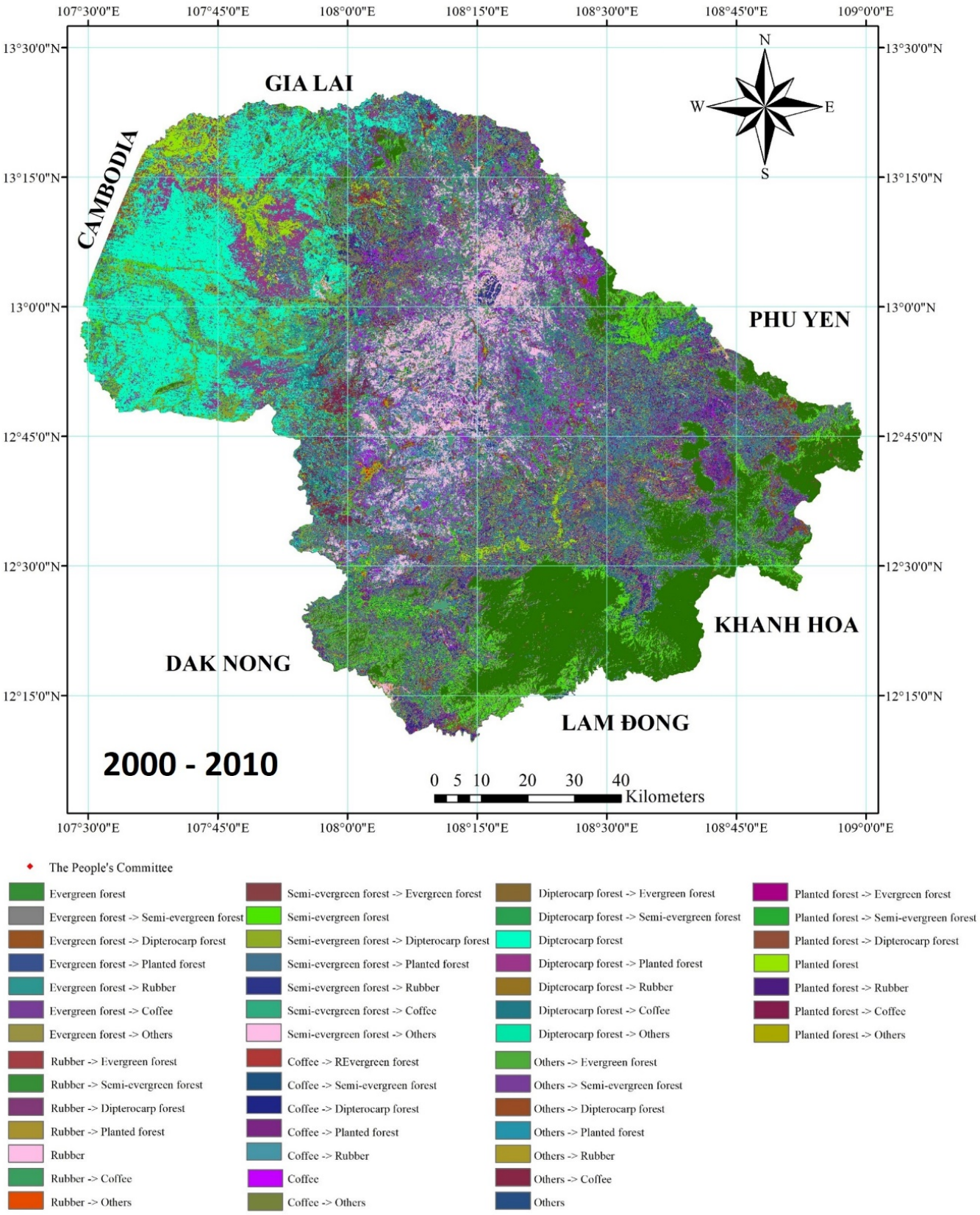

Figure 5. Forest cover change map for the period 2000 - 2010 in Dak Lak province

Planted forest changes: The planted forests area is mainly converted to industrial crops land (rubber, coffee) and semi-evergreen forests in the period 2000 - 2020. In addition, an area of about 180 km^2 of planted forests is also converted to dipterocarp forest during this period. More than 100 km^2 of planted forests were also converted into "non-forest" objects in the period 2000 - 2020, mainly converted to agricultural land.

Industrial crops land changes: The main change trend is the conversion from rubber growing land to coffee land (418.82 km^2 in period 2000 - 2020). In contrast, over 200 km^2 of coffee land were also converted into rubber land during this period. In the period 2000 - 2020, it also shows that a small area of "non-forest" objects (over 60 km^2) was converted into land for industrial crops.

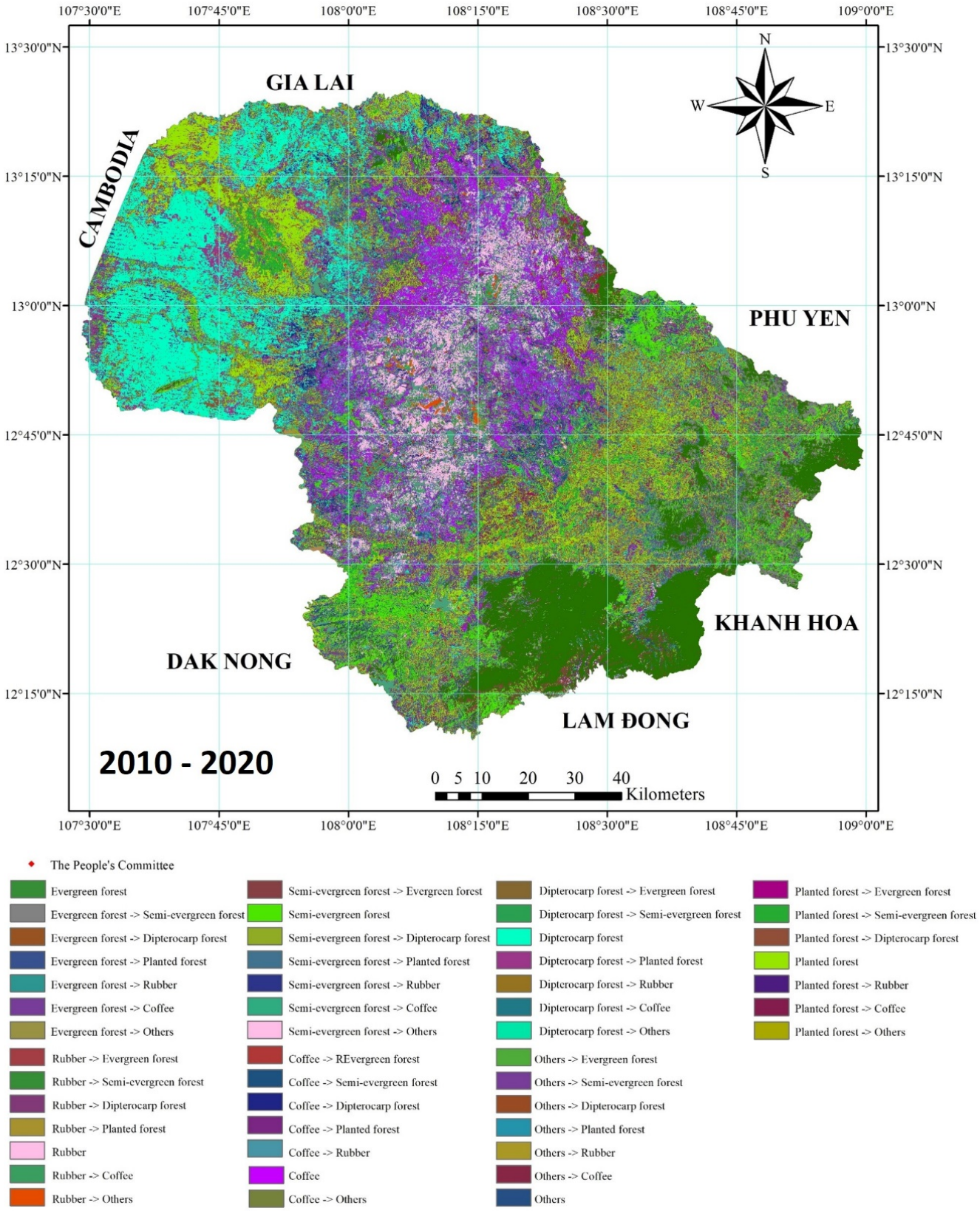

Figure 6. Forest cover change map for the period 2010 - 2020 in Dak Lak province

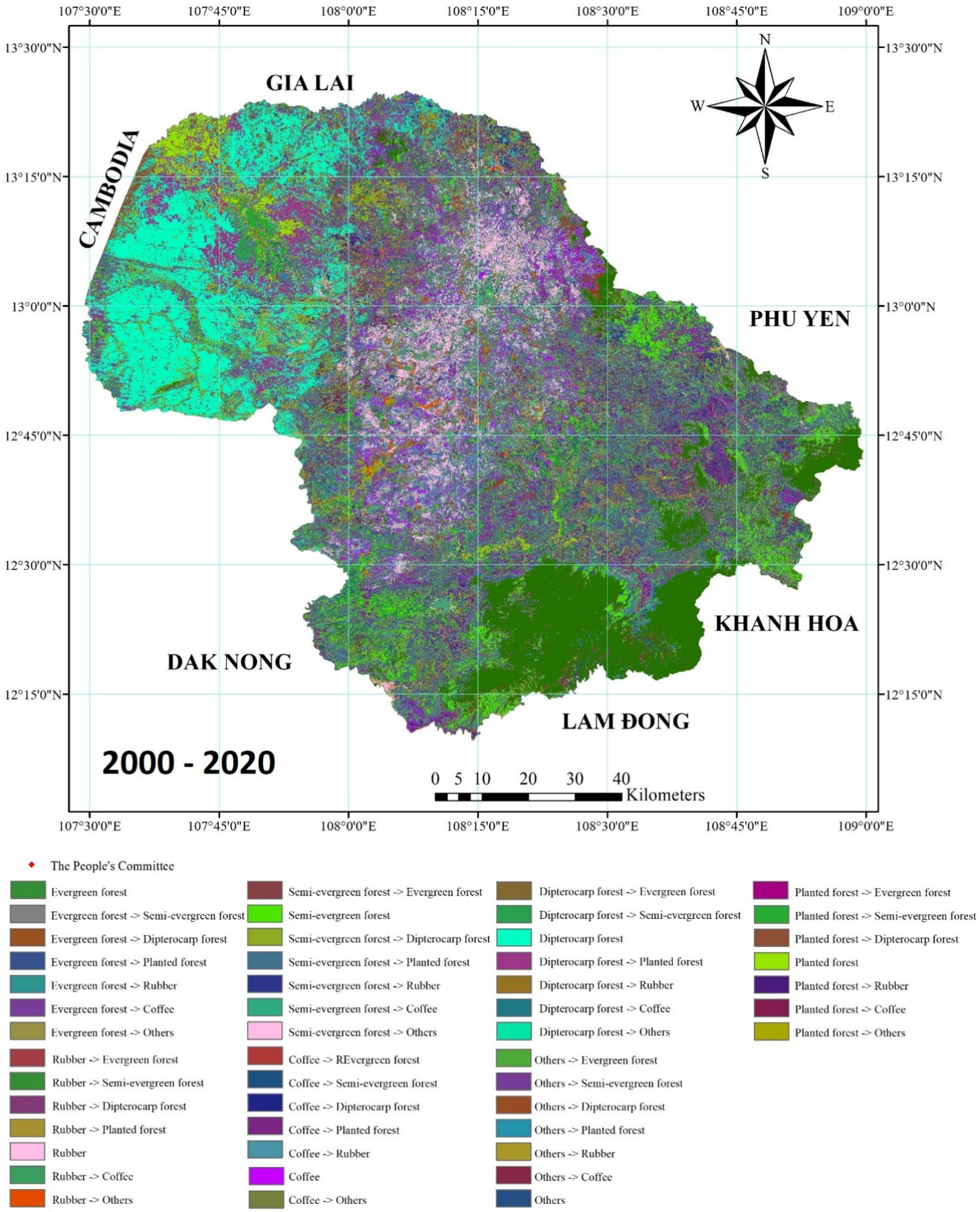

Figure 7. Forest cover change map for the period 2000 - 2020 in Dak Lak province

4. Conclusion

In this study, 03 Landsat multi-spectral images with 30m spatial resolution, acquired from March 2000, February 2010, and February 2020 in Dak Lak province (Central Highlands of Vietnam) were used to classify 10 land cover objects, including 06 types of forest cover (evergreen forest, semi-evergreen forest, dipterocarpus forest, planted forest, rubber forest and coffee land). 03 common machine learning techniques, including RF, SVM and CART and maximum likelihood classification method, were applied for land cover/land use classification. Analysis of the obtained results shows that the RF algorithm achieved the highest accuracy of land cover/land use classification, shown by comparing the overall accuracy value and Kappa coefficient in all 3 Landsat images in the period 2000 - 2020. From this result, the study built the forest cover change maps for the periods 2000 - 2010, 2010 - 2020 and 2000 - 2020.

The obtained results in this study show that natural forest types in Dak Lak province (evergreen forest, semi-evergreen forest, dipterocarp forest) have significantly decreased in 2020 compared to 2000. The planted forests and coffee land areas increased, while the area of rubber forests decreased in the period 2000 - 2020. The forest cover change maps established from Landsat multi-temporal data provide objective information that can help managers in monitoring and planning forest resources.

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