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ORIGINAL PAPER

Carbon emissions in the field of land use, land use change, and forestry in the Vietnam mainland

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Abstract The biennial report of Vietnam includes updated information on the greenhouse gas emissions for the base years which are specified by the United Nations Framework Convention on Climate Change for reporting on greenhouse gas emissions by member nations of the Intergovernmental Panel on Climate Change. The estimation of greenhouse gas emissions in general and carbon emissions in particular in the field of land use, land use change, and forestry using advanced technology to provide the input data was recommended. Remote sensing technology with transparency, multi-time characteristics, and wide coverage is useful in this area. An experiment on carbon emission estimation was carried out based on land cover change over ten years between 2002 and 2012. The results obtained by remote sensing data classification for the land cover categories achieved a reliability of 68% for the year 2002 and 67% for the year 2012. Data in relation to the land cover change, soil zoning, and ecological/climate zoning in the Vietnamese mainland, through the process of integrating, processing, and synthesizing data, and using the reported activity data and carbon emission coefficients, were input into the Agriculture and Land Use Greenhouse Gas Inventory Software for carbon emission estimations based on the quality control and quality assurance work.

Keywords Carbon · Land cover · Remote sensing · LULUCF · ALU software

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Introduction

The field of land use, land use change, and forestry (LULUCF) is one of the five main inventoried emission fields (energy, industrial processes, agriculture, LULUCF, and waste) that serve as national notifications for the United Nations Framework Convention on Climate Change (UNFCCC), which was expected to reduce emissions for Vietnam's Intended Nationally Determined Contributions/Nationally Determined Contributions (INDC/NDC) implementation. To implement a greenhouse gas (GHG) inventory, countries have had to follow the

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Intergovernmental Panel on Climate Change (IPCC) guidelines since 1996 (IPCC 1996). Depending on the availability of the input data, each country can choose to use different methods. The GHG inventory guidelines of the IPCC (IPCC 2003, 2006) showed these tiers, with the counting results ranging from the minimum level to the maximum level of the inventory uncertainty.

In Vietnam, for previous greenhouse gas inventories in the field of LULUCF, the activity data used for calculations were collected locally, and these data were not obtained continuously, completely, or systematically; therefore, the certainty of the GHG inventory results in the field of LULUCF in previous inventories was not high.

Lin et al. (2016) recommended the use of advanced technologies to build LULUCF data sets for GHG emission calculations. Remote sensing technology with transparency (Douglas 2006), multi-time, and multi-resolution characteristics (Cristina et al. 2016) provided the dataset to compare the carbon emission estimation years (IPCC 2003, 2006). Specifically, when using remote sensing data, the signals received from satellites will not be dominated by human agents, e.g., when conducting field surveys in remote and inaccessible areas or mountainous areas in Vietnam. Therefore, the obtained products from the remote sensing data processing will be highly transparent. As in the section, “input data”, the used data were at many different times, i.e., multi-time. Many types of optical remote sensing databases cover the study area with wide coverage; e.g., Landsat image coverage of the area is 180 km $\times$ 180 km, and SPOT image coverage of the area is 60 km $\times$ 60 km.

Remote sensing technology used to calculate vegetation biomass is typically used for aboveground biomass (AGB), whereas the belowground biomass (BGB) is calculated based on the inventory results of AGB via the correlation between AGB and BGB. Cairns et al. (1997) synthesized more than 160 biomass studies in tropical and temperate forests. The results showed that the ratio of AGB and BGB was 0.26, with fluctuations in the range of 0.18–0.30; this ratio did not change greatly between species, soil types, or latitudes. The research results also suggested that, in the case of lacking specific correlation equations for each location, species and forest types could be used in recognized general equations.

Presently, to use remote sensing technology to inventory the AGB of vegetation, there are two common methods: the remote sensing vegetation index and methods based on land cover changes observed by remote sensing.

The remote sensing vegetation index is useful for evaluating the carbon stock (Wang, 2018; Nam, 2016). The most commonly used indicators are the normalized difference vegetation index (NDVI), enhanced vegetation index (EVI), and leaf index (LAI), etc. These indicators can be used in combination with other methods such as field surveys, or alongside other environmental data to determine a carbon stock for the system of land cover types.

The vegetation spectrum indices extracted from the visible, near-infrared, infrared, and red bands (Gandhi, 2015) are intermediate parameters used to show the different characteristics of vegetation, such as the AGB, leaf area index, and photosynthesis ability of seasonal biomass products. The correlations among NDVI data are established via the carbon data acquired from field surveys using sample plots as the basis of biomass inventories in large areas. This method can inventory carbon emissions through remote sensing technology that requires a local emission coefficient (Lawson, 2015).

In our study, the emission coefficients used during the inventory process were the coefficients proposed by the IPCC and could be applied to many territories with the same climate zones. Countries often use national data sources for spatial data, default emission coefficients, and GHG emissions following the IPCC guidelines or the Food and Agriculture Organization of the United Nations (FAO) database (IPCC 2003). The coefficients of stock change and GHG emissions were applied to specific region data. We chose to use spatial and time data corresponding to the national coefficients with high resolutions and greater detail. These data were identified for each specific region and spatial land cover system (Table 1).

Land cover is an intrinsic element of most remote sensing analyses. An example is the use of remotely sensed imagery for straightforward land cover classification (Franklin and Wulder, 2002; Alvarez et al. 2003; Datta, 2018). The classification of remote sensing image types allows one to determine the land cover object changes. Richards (1993) and Jensen (2005) proposed three main groups of remote sensing image classifications, including pixel-wise

Table 1 The land use change matrix following IPCC guideline (2003, 2006)

Initial	F	G	C	W	S	O	Final sum
Final							
F	15	3	1				19
G	2	80					82
C			29				29
W							
S	1	1	1		5		8
O						2	2
Initial sum	18	14	31		5	2	140

Note: F = Forest island, G = Grassland, C = Cropland, W = Wetlands, S = settlements, O = other land

Numbers represent area units (Mha in this example.)

There is no Wetlands in this example. Blank entry indicates no land use change

classification, subpixel-wise classification, and object-based classification. Lu and Weng (2007) and Li et al. (2014) developed new methods for this purpose. Guidelines for the national greenhouse gas inventories (IPCC 2006) suggested a method of carbon emission estimation based on the land cover changes obtained from remote sensing data using two approaches: the post-classification change detection approach and the pre-classification change detection approach. The post-classification change detection approach detects changes at two or more different times based on the vegetation classification of remote sensing images and images from the field, and then overlaps the layers to determine the changes in the land cover system. The pre-classification change detection approach is used to detect the changes before classification that are related to more complex and physiological methods; however, this method is sensitive to image interpretation work and may show small changes in the land cover status that the post-classification method cannot test (Chen et al. 2017).

GHG emission calculation software for agriculture and land use, namely the Agriculture and Land Use Greenhouse Gas Inventory Software (ALU) (ALU, 2014), has been applied to Vietnam in recent years due to its usefulness (Second report, 2017). ALU software is specialized for calculating GHG emissions, not only in agriculture and industry but also in land use, land use change, and forestry. Currently, this software package is highly evaluated by the UNFCCC due to its usefulness in quality control (QC) and quality assurance (QA) (UNFCCC, 2012).

The uncertainty calculation of the inventory results is the process of importing data from a database based on the information extracted from the remote sensing data, the emission reduction analysis, the transparency of the calculation data by digitized data, and the calculation steps. The ALU software is always updated following new IPCC guidelines; however, the GHG emission estimation results in the field of LULUCF must be combined with the calculation results from agriculture and industry into general emissions for national reports (IPCC 2003).

The objectives of our study were (a) to demonstrate the proposed categories of land cover based on IPCC guidelines applied for the Vietnam mainland and (b) to illustrate the results of Vietnam's land cover and carbon emission calculations, which were estimated with ALU software using remote sensing data.

Study area and data

Study area

The study area was Vietnam's mainland area. Vietnam is located on the eastern margin of the Indochinese peninsula and occupies about 331,211 square kilometers at the coordinates of 14.0583° N, 108.2772° E. It borders the Gulf of Thailand, Gulf of Tonkin, and the Pacific Ocean, along with China, Laos, and Cambodia. The elongated roughly S-shaped country has a north-to-south distance of 1,650 km (1,030 mi) and is about 50 km (31 mi) wide at the narrowest point, with a coastline of 3,260 km (2,030 mi). Vietnam is divided into seven featured ecological regions (UN-REDD, 2011) as shown in Fig. 1.

Input data

Landsat remote sensing data for the years of 2002 and 2012 (USGS Landsat mission) in the Vietnamese mainland were collected. The land cover data layers follow the IPCC regulations for the country of Vietnam (forestland, grassland, cropland, wetland, residential land (residential and infrastructure land), and other land). The estimated Landsat remote sensing data for one year are the composite data of all Landsat

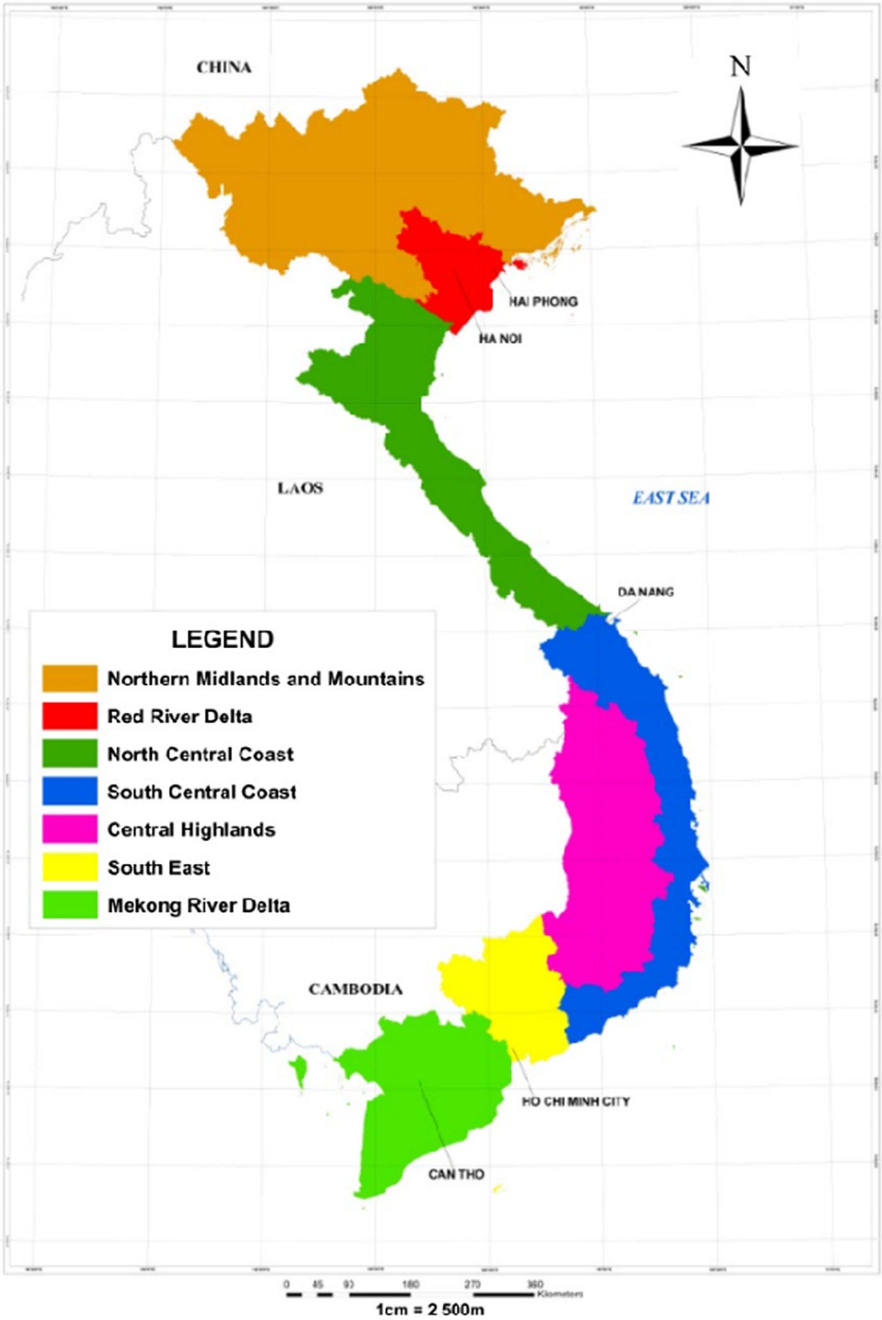

Fig. 1 Illustration of the ecological zoning of the Vietnamese mainland

images acquired for the whole year, e.g., the estimated Landsat data for the year 2002 are the composite data of all Landsat images from 1st January, 2002 to 31st December, 2002. The soil zoning and ecological/climate zoning data for the Vietnamese mainland were taken from one project from the Vietnam Institute of Agricultural Sciences.

Materials and methods

The process of carbon emission estimation using remote sensing data is shown in Fig. 2.

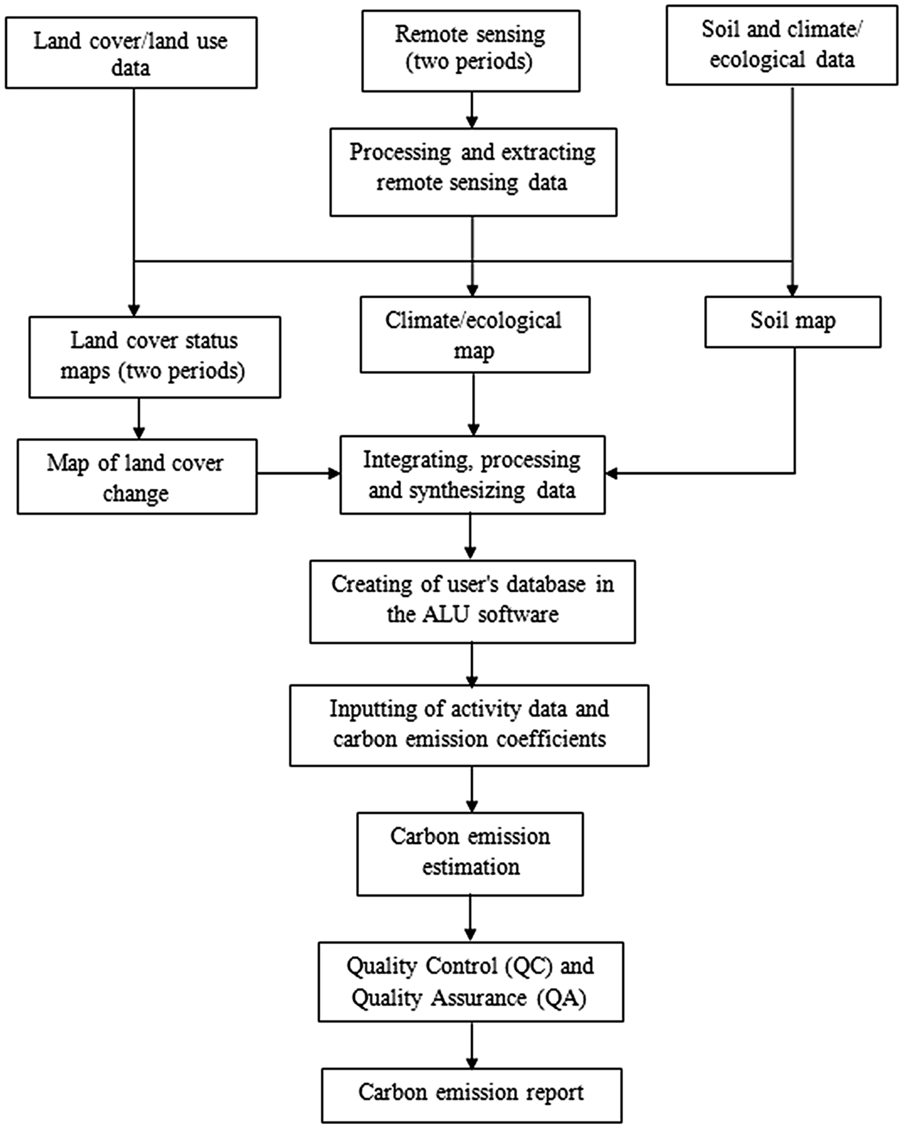

Fig. 2 The process of carbon emission estimation using remote sensing data

Land cover subject classification applied for the Vietnam mainland

In our study, the total area of different land use types was equal to the total area of the Vietnam mainland. Depending on the availability of the natural condition, each country should choose a particular approach. In Vietnam, a classification system of land cover objects was applied to the mainland as a land use status map classification system with seven ecological zonings. Land cover was established to serve specific purposes for the forest layer, the vegetation soil layer, etc. Currently, Vietnam uses the classification regulations following the land use purposes defined in Circular No. 27/2018/TT-BTNMT, dated December 14, 2018, of the Ministry of Natural Resources and Environment, which focuses on statistics, land inventory, and land use status mapping (MONRE, 2018).

Carbon emission estimation using remote sensing data

Remote sensing image data must be collected at two time intervals of 10 years and ensure unified and

Table 2 The six proposed categories of land cover applied for the Vietnam mainland

N°	IPCC guideline	Code IPCC _Vietnam	Vietnam mainland land cover classification system
1	Forestland	1.1	Evergreen broad-leaved forest land
		1.2	Deciduous forest land
		1.3	Planted forest land
		1.4	Mangrove land
		1.5	Other forest land
2	Cropland	2.1	Annual cropland
		2.2	Perennial cropland
		2.3	Rice land
3	Grassland	3	Grassland
4	Residential land	4	Residential and infrastructure land
5	Wetland	5	Wetland
6	Other land	6	Other land

homogeneous data. For the collection and processing of the soil, ecological, and climate zoning data, all collected data files (vector and raster) must be transferred to a unified coordinate system (VN2000) in Vietnam, with a six-degree zone and 105° axis meridian.

In our study, we first processed the remote sensing image data to create homogeneous images, eliminating the clouded effect on data quality and creating color composite images for the study area, while using a random classification method to classify the images (Li et al. 2014) with a classification key that offers a suitable classification sample set. Then, we evaluated the accuracy and reliability of the classification results. The data layers were classified by type with the categories following the IPCC guidelines and natural object classification regulations for Vietnam (MONRE, 2018).

After inputting the classification results, an overlay dataset was built for two points in the same location to assess the area accuracy and consolidation according to the required ratio. In the process of building a land cover object dataset, the technical requirements for those objects must comply with the current legal documents on the technical regulations for the production of optical sensing images with high and super high resolution, using the reference system and national coordinate system of Vietnam (MONRE, 2015), as well as the converted parameter system between the international coordinate system WGS-84 (VNPM, 2000) and the national coordinate system VN-2000 (MONRE, 2007). The next step was to import and overlay the data for the two periods and calculate and determine the specific changes.

We used the activity data file, the input standard for calculating carbon emissions by the ALU software, the comprised land cover change data, and the soil and climate/ biomass zoning data. This work consisted of transferring data into a data format for a database and adjusting the spatial correlations among the features. To estimate the carbon emissions, the first step is to establish the inventory year. First, we selected an inventory country and built the general country data. Then, we set the username to create a user database in the ALU software. We performed emission estimations in the ALU software to check the data accuracy in the input data table related to the data entry for errors that appeared after the estimation process. The next step was to run the software and export the emission results.

Accuracy evaluation of remote sensing imagery classification

We assessed the accuracy of the object classification using the Kappa Khat error matrix method (Congalton, 1991). The first step in the accreditation process was to identify high-resolution image areas on Google Earth for the years of 2002 and 2012. Checkpoints were randomly generated in the ArcGIS software and then loaded into buffering areas with a size of 2 ha. These areas were converted into the KML file format and loaded into Google Earth. Through visual image analysis, the land cover properties were assigned to

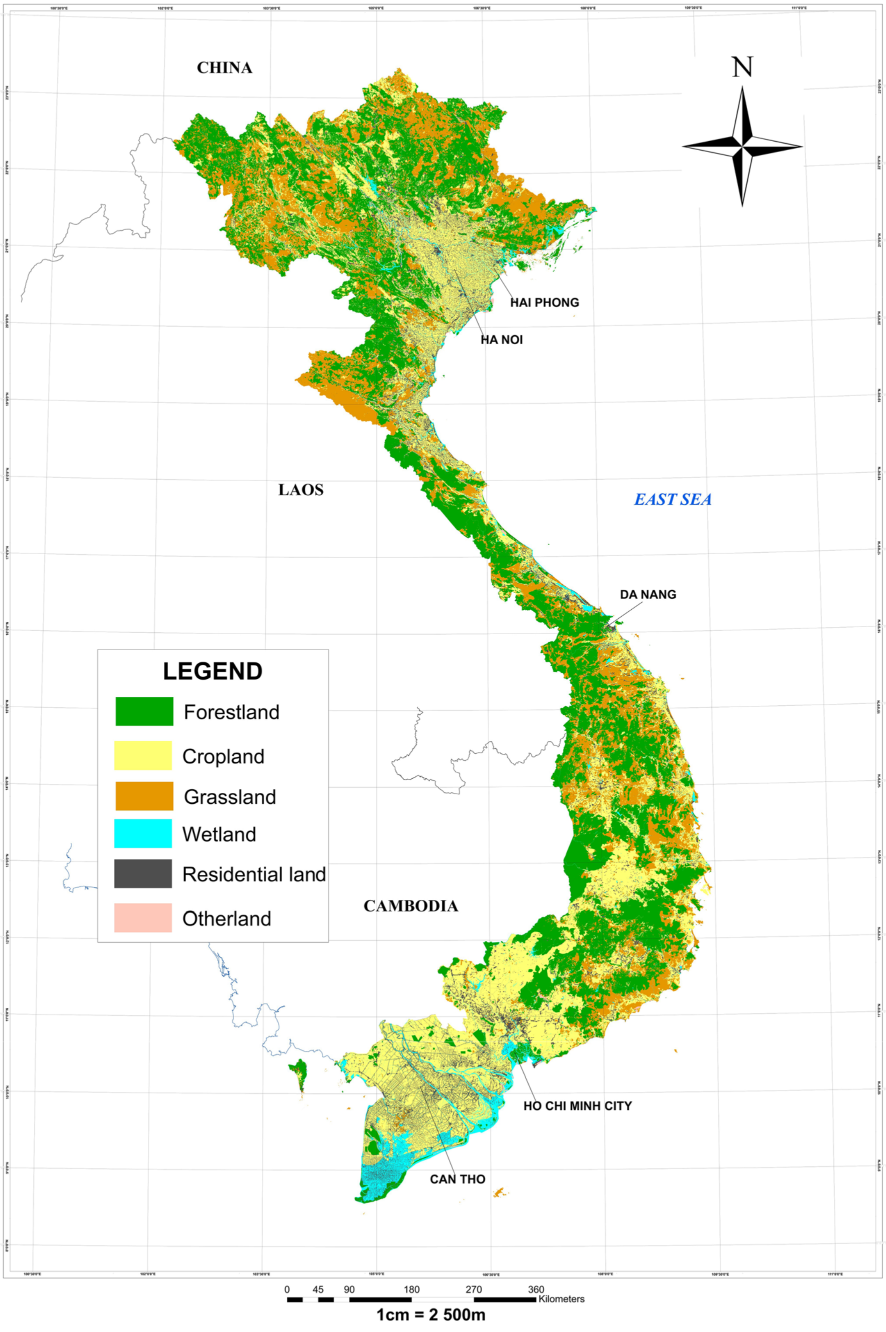

Fig. 3 Illustration of the land cover data for the Vietnam mainland from a Landsat image (2002)

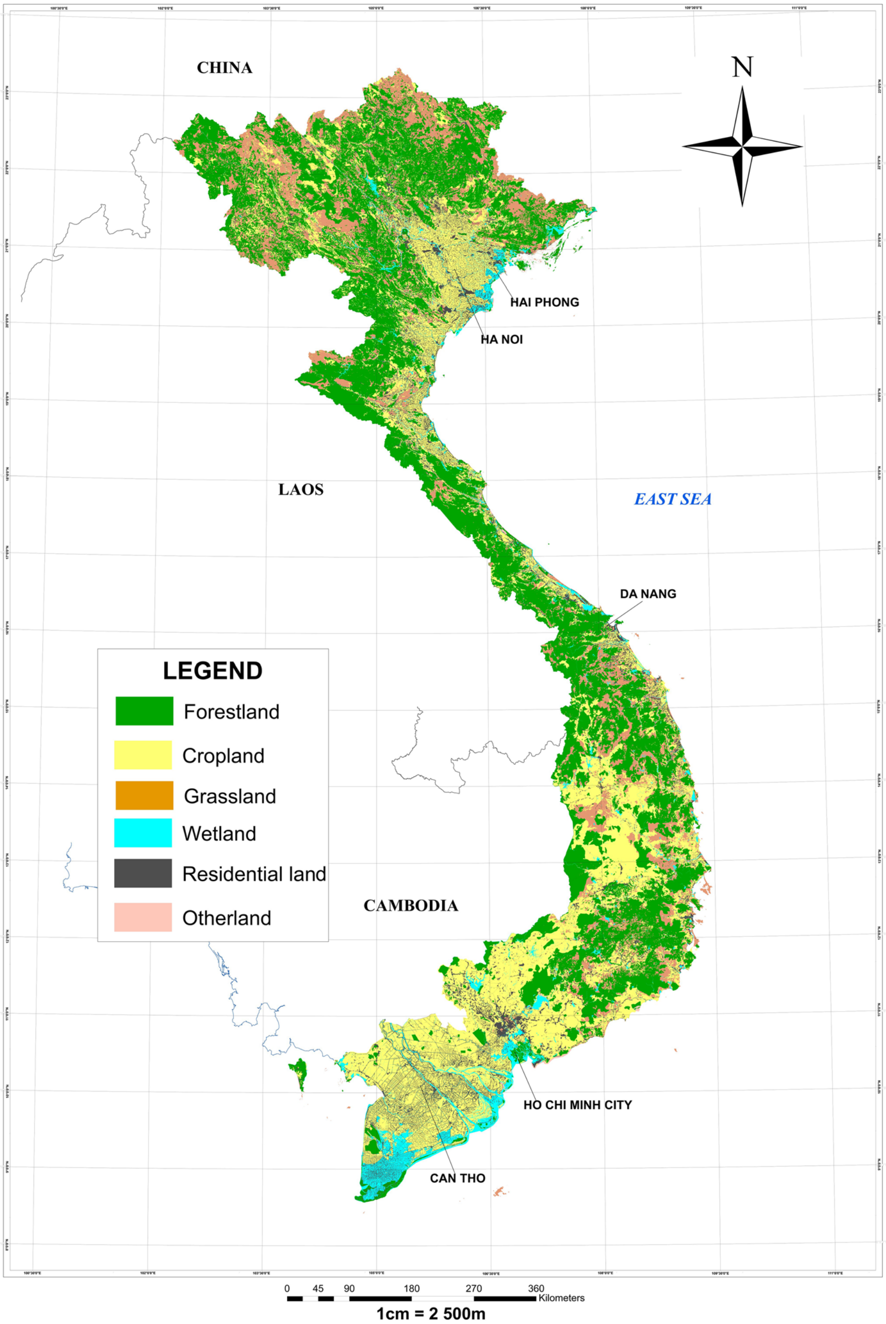

Fig. 4 Illustration of the land cover data for the Vietnam mainland from a Landsat image (2012)

Table 3 Illustration of the area changes of land cover categories between 2002 and 2012

Nº	Year 2002	Year 2012	Land cover change	Area (ha)
1	C	C	C = > C	8,743,952.618
2	C	F	C = > F	570,715.910
3	C	G	C = > G	549,604.945
4	C	O	C = > O	1,915.885
5	C	R	C = > R	323,894.536
6	C	W	C = > W	160,149.131
7	F	C	F = > C	667,572.770
8	F	F	F = > F	10,414,977.829
9	F	G	F = > G	478,134.988
10	F	O	F = > O	1,109.096
11	F	R	F = > R	8,335.051
12	F	W	F = > W	66,236.046
13	G	C	G = > C	1,156,804.325
14	G	F	G = > F	2,588,633.615
15	G	G	G = > G	3,620,420.588
16	G	O	G = > O	3,199.268
17	G	R	G = > R	17,257.741
18	G	W	G = > W	40,711.441
19	O	C	O = > C	1,750.739
20	O	F	O = > F	3,376.490
21	O	G	O = > G	42.318
22	O	O	O = > O	65,358.298
23	O	R	O = > R	1,877.407
24	O	W	O = > W	11,009.071
25	R	C	R = > C	72,233.622
26	R	F	R = > F	9,228.709
27	R	G	R = > G	12,400.963
28	R	O	R = > O	655.275
29	R	R	R = > R	2,199,306.274
30	R	W	R = > W	12,150.740
31	W	C	W = > C	27,402.485
32	W	F	W = > F	25,691.956
33	W	G	W = > G	3,732.770
34	W	O	W = > O	3,555.816
35	W	R	W = > R	10,330.362
36	W	W	W = > W	1,208,701.039

where *C* cropland, *F* forestland, *G* grassland, *R* residential land, *W* wetland, *O* other land, *Unit* ha

random checkpoints. The number of these checkpoints was then verified to attribute them to topographic mapping data at the same time. The checking process was conducted for the Vietnam mainland with the number of sampling points for each result.

Results

Land cover category system applied for the Vietnam mainland

Based on the IPCC guidelines and land use status map classification system with eight ecological zonings following MONRE (2018), a classification system of

Table 4 Matrix for evaluating the classification accuracy for 2002

Information extracted from remote sensing data Category	Information obtained from field surveys						Total
	Forestland	Cropland	Grassland	Wetland	Residential land	Other land	
Forestland	**45**		4	4			**53**
Cropland	2	**20**	6	2	2	1	**33**
Grassland	11	3	**14**		2	3	**33**
Wetland	3	2	2	**27**		1	**35**
Residential land		2	3		**12**	6	**23**
Other land	5		3		6	**40**	**54**
Total	66	27	32	33	22	51	231
Kappa coefficient = 0.684							

land cover objects was established. The combination of necessary classes to determine the six categories of land cover objects included forestland, grassland, cropland, wetland, residential land, and other land as shown in Table 2. For example, forestland includes evergreen broad-leaved forests, deciduous forests, planted forests, mangroves, and other forests; cropland includes annual cropland, perennial cropland, and wet rice.

Land cover maps

The land cover status of the six indicators based on the Landsat image classification results for 2002 is shown in Fig. 3.

The land cover status of the six indicators from the Landsat image classification results for 2012 is shown in Fig. 4 (Tables 3, 4).

Overlapping, separation, and establishment of land cover changes in the period 2002–2012.

Figure 5 shows the forestland changes for the Vietnam mainland for the period 2002–2012.

The area changes of different LULC categories between 2002 and 2012 were as follows.

The constructed results of the LULUFC data, according to the IPCC guidelines, show all main land cover objects and the required accuracy based on the regulations of Circular No. 10/2015/TT-BTNMT (MONRE 2015).

Following the method of accuracy evaluation, the first step in the accreditation process was to identify high-resolution image areas on Google Earth for 2002 and 2012. The checking process was conducted for the whole study area with a total of 231 sampling points for 2002 and 234 sampling points for 2012. The results were as follows.

Carbon emission estimation

The input data for the ALU software was taken from the ArcGIS software output data processed by the Landsat remote sensing data for soil and climate/ ecological zoning. After estimation via the ALU software, the total amount of negative greenhouse gas emissions (absorption) in the field of LULUCF was 34.24 million tons of CO_2. In particular, the forestland and cropland absorbed greenhouse gases with an uptake volume of 34.49 and 2.29 million tons of CO_2, respectively, whereas the greenhouse gas emissions for the other categories were as follows: grassland, 0.58 million tons of CO_2; wetland, 0.97 million tons of CO_2; residential land, 0.97 million tons of CO_2; other land, 15.3 thousand tons of CO_2 (Fig. 6).

Discussions

Forestland, grassland, cropland, wetland, residential land, and other land are with different spectral characteristics in the remote sensing images (Yu, 2017). The total carbon emissions always followed the overall world trend (Olivier et al. 2017). In this study, we focused on the proposed categories of land cover based on the IPCC guidelines applied for the Vietnam

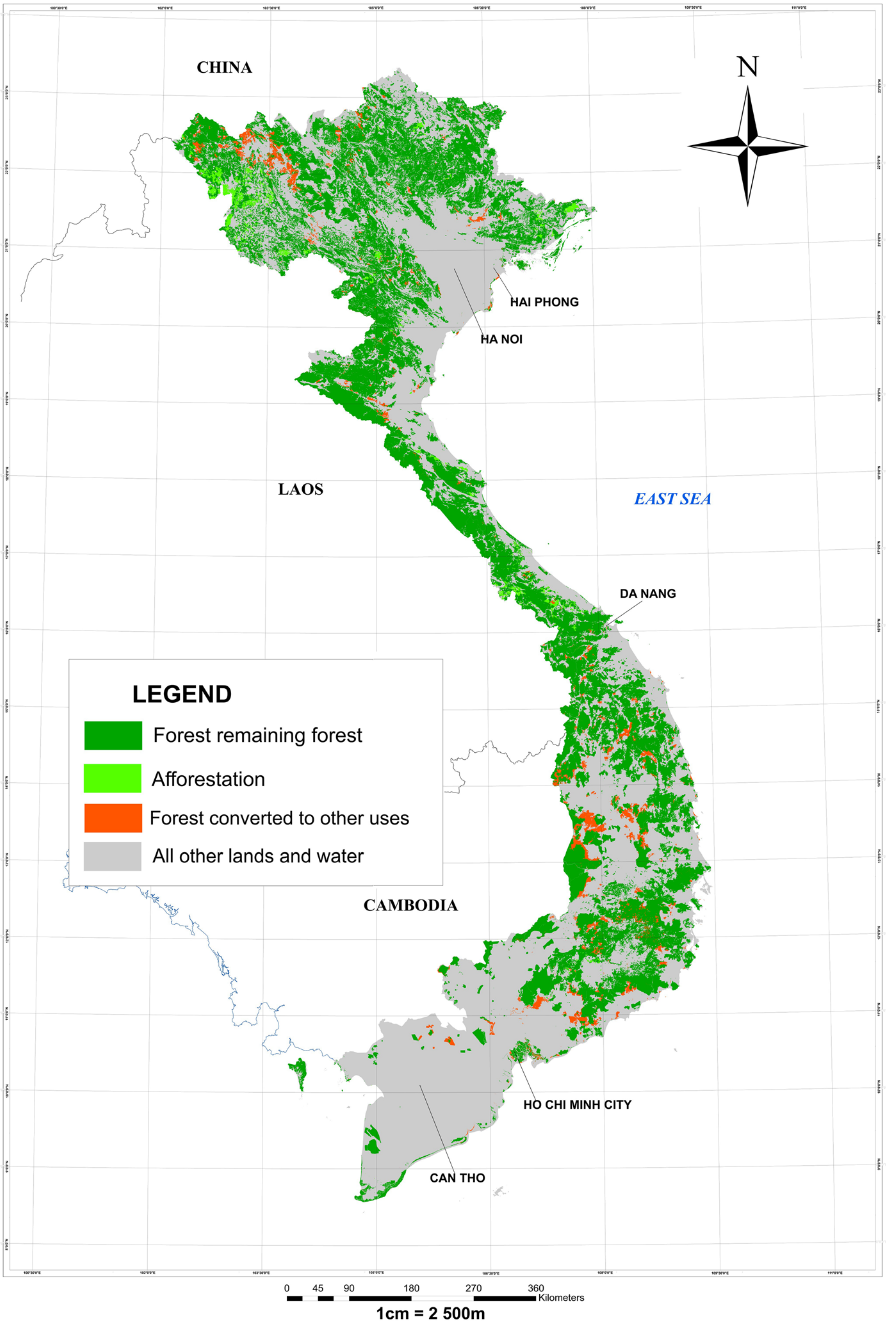

Fig. 5 Illustration of forestland changes for the Vietnam mainland for the period 2002–2012

mainland and illustrated the results of Vietnam's land cover and carbon emission calculations, which were estimated with ALU software using remote sensing data. As described in the Results section, with land cover object characteristics for an afforestation effort in Vietnam, the land cover classification was conducted using remote sensing imagery and the carbon emission/absorption following each specific period.

Using remote sensing data to estimate carbon emissions is useful (Lu et al. 2013); satellite-based measurements of greenhouse gases are an effective

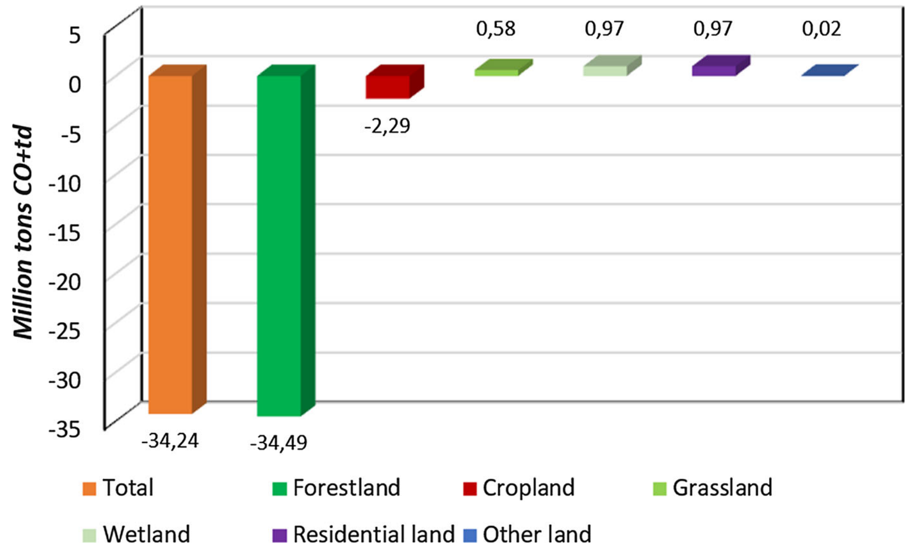

Fig. 6 Carbon emissions in the field of land use, land use change, and forestry in the Vietnam mainland

Table 5 Matrix for evaluating the classification accuracy for 2012

Information extracted from remote sensing data	Information obtained from field surveys						
Category	Forestland	Cropland	Grassland	Wetland	Residential land	Other land	Total
Forestland	**60**		6	3	1	1	71
Cropland	5	**24**	7	2	2		40
Grassland	8	6	**18**	1	2	2	37
Wetland	2	2		**14**	1	3	22
Residential land		3	3		**15**	5	26
Other land			4	4	5	**25**	38
Total	75	35	38	24	26	36	234
Kappa coefficient = 0.6667							

way of monitoring atmospheric constituents with the development of highly accurate sensors. This is also becoming a major data source for detecting changes of the atmospheric CO_2 concentration at regional and global scales (Yoshida et al. 2011; Crisp et al. 2015; Lei et al. 2014; Buchwitz et al. 2015). Statistical analysis showed that the results achieved a reliability of 68% for the year 2002 and 67% for the year 2012, which shows that this method obtained a relatively high accuracy. The matrix used for evaluating the classification accuracy of 2002 shows the percentage of errors in the classification process that were distributed over most layers; however, the largest error percentages were for the forestland and residential land. The cause of this confusion comes from the fact that these two objects have large spectral homogeneity for their subcategories, which created two of these categories. The grassland class was also easily confused with the forestland during classification.

The matrix for evaluating the classification accuracy of 2012 (Table 5) shows that the classification results achieved a lower accuracy compared to the year 2002 (Table 4). A large percentage of errors still came from forestland and residential land. The homogeneity in the spectra was the main cause of this percentage error. The skills of the technicians who extracted the samples also had a significant influence on these errors.

The classification process indicated that the grassland was easily confused with forestland due to its great spectral homogeneity, whereas the residential land and vacant land belonged to other land types (Yifan et al. 2018). The accuracy assessment matrix showed that the fact that the grassland is interspersed with forestland was also a cause of confusion during classification by spectral similarity. The mixed population with vegetation was also a cause of confusion when classifying, as the source of this error is difficult to avoid even with the traditional method (interpretation by eye). In some cases, the results of this error would be acceptable even with traditional methods.

The value of carbon emissions in Vietnam reached 19.38 million tons of CO_2 in 1994 and 15.11 million tons of CO_2 in 2000 (MONRE, 2003), and the absorption reached 20.72 million tons of CO_2 in 2010 (MONRE, 2010) and increased to 34.2 million tons of CO_2 in 2013. This indicates that the trend in the field of LULUCF applied for the Vietnam mainland changed from carbon emission to carbon absorption in 2010 and continued to increase its absorption due to afforestation and forest protection activities. This showed a difference compared to other countries. Most countries have shown a decrease in their CO_2 emissions in recent years, most notably the United States (–2.0%), the Russian Federation (–2.1%), Brazil (–6.1%), China (–0.3%), and countries within the European Union (–6.4%). In contrast, the largest absolute increases were seen in India (+ 4.7%) and Indonesia (+ 6.4%) with smaller increases in Malaysia, the Philippines, Turkey, and Ukraine. For many of the largest emitting countries, this is a continuation of a common trend. With an estimated 0.2% increase in CO_2 emissions, emissions in the European Union remained more or less the same in 2016 (Olivier and Peters 2018). In contrast to most of the main emitters, the collective emissions from the rest of the world show a rising trend.

Conclusions

Remote sensing technology has become a useful tool in greenhouse gas emission estimation due to its transparency, accuracy, multi-time qualities, and wide coverage. To create an inventory of greenhouse gas and carbon stock changes over time, the results from remote sensing technology cannot be directly calculated but must be used in combination with software to estimate carbon emissions, for instance the ALU software.

These results show that the total amount of carbon absorption in the field of LULUCF applied for the Vietnam mainland between 2002 and 2012 was 34.24 million tons of CO_2. In particular, forestland and cropland absorbed greenhouse gases with an uptake volume of 34.49 million tons of CO_2 and 2.29 million tons of CO_2, respectively, whereas the greenhouse gas emissions for others were as follows: grassland, with 0.58 million tons of CO_2; wetland, with 0.97 million tons of CO_2; residential land, with 0.97 million tons of CO_2; and other land, with 15.3 thousand tons of CO_2.

The proposed experimental process for greenhouse gas emission estimations in the field of LULUCF in Vietnam showed that the land cover information extracted from the remote sensing images had high accuracy, which was effective in determining land cover changes. Remote sensing technology applications also helped Vietnam to monitor the greenhouse gas emissions and absorption in the process of land use and forestry planning. In the long term, high-precision sources of greenhouse gas inventory information and data would be helpful for the identification of greenhouse gas emissions and absorptions in the field of LULUCF to quantitatively manage the carbon market in the future.

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