ASSESSING THE SIGNIFICANCE OF TREES OUTSIDE FORESTS IN NORTHEASTERN VIETNAM: INTEGRATION OF FIELD SURVEY AND REMOTE SENSING DATA

LUONG, N. V.[1*] – DUC ANH, N.[2] – TU, T. T.[1] – NANDY, S.[3] – LAP, Q. K.[4]

[1]*Space Technology Institute, Vietnam Academy of Science and Technology, 18 Hoang Quoc Viet str., Cau Giay dist., Hanoi 100000, Vietnam*

[2]*Vietnam National Space Center, Vietnam Academy of Science & Technology, 18 Hoang Quoc Viet str., Cau Giay dist., Hanoi 100000, Vietnam*

[3]*Indian Institute of Remote Sensing, Indian Space Research Organisation, Dept. of Space, Govt. of India, Dehradun - 248001, Uttarakhand, India*

[4]*Thai Nguyen University of Sciences, Tan Thinh Ward, Thai Nguyen City 250000, Vietnam*

[*]*Corresponding author*
e-mail: nvluong@sti.vast.vn; phone: +84-243-756-2985; fax: +84-243-791-4622

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Abstract. The study aims to assess the vital role of Trees Outside Forests (TOF) in daily life, sustainable socio-economic development, and their potential for sustainable adaptation to climate change. This study utilized field survey data and SPOT5 satellite data to assess the contribution and significance of TOF. The study recorded 101 species belonging to 41 families and 83 genera. The study also categorized TOF species into 10 use-value groups. Most tree species had multiple use values. Through the combination of field data and SPOT5 satellite images, using an object-based image approach, TOF was classified into 6 classes. The results showed that the total area covered by TOF was 35,998.68 ha, which accounted for 7.41% of the total natural land area. The timber volume was 2,336,951.89 m^3, and the carbon stock was 949,084.16 tons, with accuracy map results reaching 90.2%, 85.73%, and 84.35%, respectively.
Keywords: *TOF, biodiversity, use value, carbon, field data, satellite data, climate change*

Introduction

Trees outside forest (TOF) provide crucial services such as biodiversity conservation, medicinal resources, wood materials, fuel wood, carbon storage or CO_2 sequestration, landscape enhancement, land protection, water source maintenance, and livelihood benefits. They also enhance value of human habitats and offer shelter for wildlife (Ahmed, 2008; FAO, 2013; Filepné Kovács et al., 2014; Chakravarty et al., 2019; Skole et al., 2021; Santoro et al., 2022; Liu et al., 2023; Yilmaz et al., 2023). However, most countries lack strategic plans for managing, protecting, and developing TOF, except for those in urban areas and streets (Csete et al., 2012; Li et al., 2019; Shahtahmassebi et al., 2021; Neyns et al., 2022). Conducting comprehensive investigations and statistical analyses on TOF is challenging due to their dispersed nature, functional diversity, complex species composition, wide distribution, geospatial fragmentation, and ownership and management responsibilities (Schnell et al., 2015a; Thomas et al., 2021; Peros et al., 2022).

In 2010, the Food and Agriculture Organization (FAO) report "Other Land with Tree Cover" highlighted the importance of TOF in areas with agricultural or urban tree cover exceeding 10%. In 2013, FAO published another report based on a TOF assessment of

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36 countries. The report revealed some crucial findings: (i) The concept of TOF has not been fully integrated into assessments. (ii) Most assessments that are not specifically focused on TOF do not explicitly recognize the categories of TOF-covered land. (iii) No country has conducted an assessment that covers all sets of TOF. (iv) Only a few countries have carried out assessments specifically targeting one or more sets of TOF (FAO, 2013).

Currently, natural forest areas tend to decrease in area and quality in some places under the pressure of socio-economic development. Recognizing the role of trees in the environment, many countries have strategies, plans, and programs to develop TOF, such as Sweden, England, China, India, and Vietnam. Although there have been positive trends in recognizing the role of TOF, most countries have difficulty managing this TOF subject (Peros et al., 2022).

Notable previous efforts to evaluate the role of TOF have used different methods and can be divided into two main groups. (i) Traditional methods (field survey only) such as Marchetti et al. (2018) used sample plots to study species and ecological diversity of TOF in Molise, Central Italy, in which the main parameters of TOF such as diameter, height, and wood volume were measured and also the study recorded a total of 60 TOF species. Mulia et al. (2021) investigated the value of TOF, which included statistical analysis based on the grouping of TOF species of agroforestry systems such as timber-tree group, industrial tree crop group, and fruit-tree group. Luong et al. (2023) conducted an evaluation of the status and role of TOF in Thai Nguyen, Vietnam and provided an assessment of the use value, structure, and composition of TOF species, recording a total of 51 TOF species in this study area. Bhandari et al. (2021) recorded 38 TOF species belonging to 21 families in the middle hills of Nepal and found that the Moraceae family was dominant. However, the above studies did not mention the use of satellite image data and only focused on the structure and species diversity of TOF. (ii) The development and advancement of earth observation satellite technology has led to a diverse supply of satellite image data, effectively supporting natural resource management, and TOF resources are no exception (Schnel et al., 2015; Xiao et al., 2019; Wani et al., 2020). Several notable previous studies have used satellite image data for TOF evaluation such as Singh et al. (2012) used NDVI from IRS-P6 LISS-IV satellite data and an unsupervised ISODATA classification algorithm for TOF carbon estimation in southern Haryana, India; however, the study did not report the accuracy of the established TOF maps. Das et al. (2014) utilized IRS-P6 LISS-IV satellite data that had a spatial resolution of 5.8 m to assess the TOF cover in home gardens in Barak Valley, Assam, North-East India. This study used high-resolution satellite data with the support of visual interpretation techniques that are a better choice for identifying and mapping TOF, including even very small spatial units of the research object. Hussanin et al. (2020) used a Sentinel-2 MSI satellite data-based image analysis approach to build a TOF cover map for the Bandipora district, India, achieving an overall accuracy of over 90%; however, the study did not provide detailed information on TOF classifications and only presented one TOF layer. Malkoç et al. (2021) employed LiDAR data-based vegetation height model for countrywide mapping of TOF in Switzerland. Their study achieved an impressive overall accuracy of over 95%. While this approach is excellent, its full implementation is limited to small countries or small areas with extensive data availability. The above studies have employed remote sensing data as a reliable and effective approach. However, biodiversity values and use values of TOF are often not mentioned.

Overall, previous studies have some gaps that are as follows: (i) Studies using traditional methods only recorded species composition, biodiversity, and data on timber,

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biomass, and stored carbon at limited sample plots and lack assessment results across the entire area. (ii) Studies that utilize remote sensing provide information related to area, timber, biomass and carbon storage on a large scale. However, these studies often do not consider biodiversity factors, species composition, and utilized values, which are equally important to TOF. Nevertheless, previous studies serve as valuable reference sources and reinforce the methodological approach of this study. Therefore, the objectives of the study aim to assess the role and value of TOF through a combination of field survey data and satellite image data in Bac Kan province, Vietnam. The assessment covers various aspects such as biodiversity, species composition, structure, use values, area, timber volume, and carbon storage.

Method and material

Study area

Bac Kan province is a mountainous region in the central part of inland Northeastern Vietnam. The province covers a total natural land area of 485,942 hectares and comprises seven districts and a city. The region's tropical monsoon climate is conducive to plant species' growth. The geographical location of the study area is shown in *Figure 1* below.

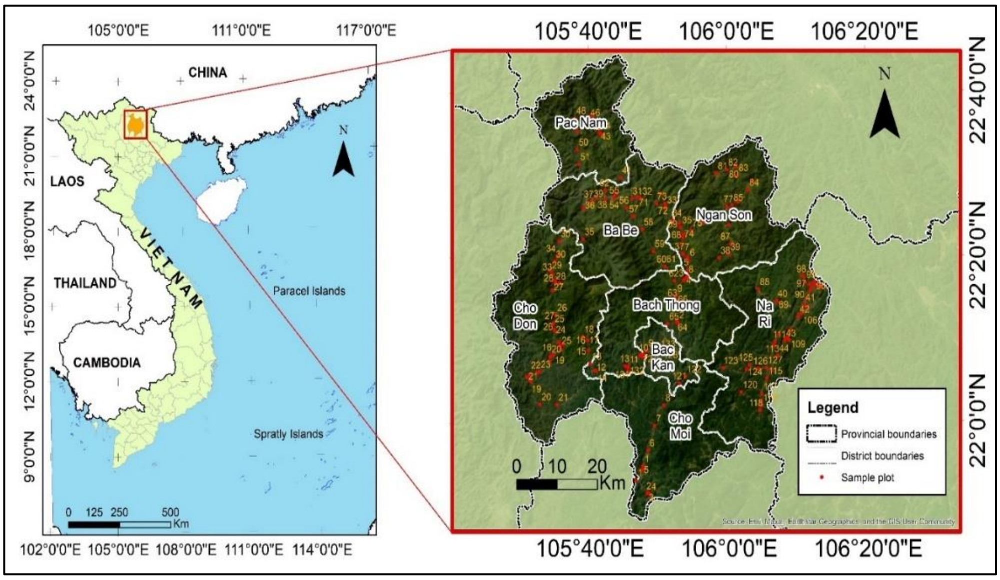

Figure 1. *Location map of the study area with sample plot positions (red colour)*

Methodology

TOF determination

This study aimed to identify TOF based on two primary criteria. Firstly, the definitions provided by the Food and Agriculture Organization (FAO) in 2013 were used. These definitions distinguish "Land with TOF" as a separate category from "Forest" and "Other Wooded Land" while also being related to "Other Land". A clearer definition for these three mutually exclusive categories necessary for characterizing the extent of TOF coverage is shown in *Figure 2* (FAO, 2013). Secondly, national forest areas were excluded from the research object.

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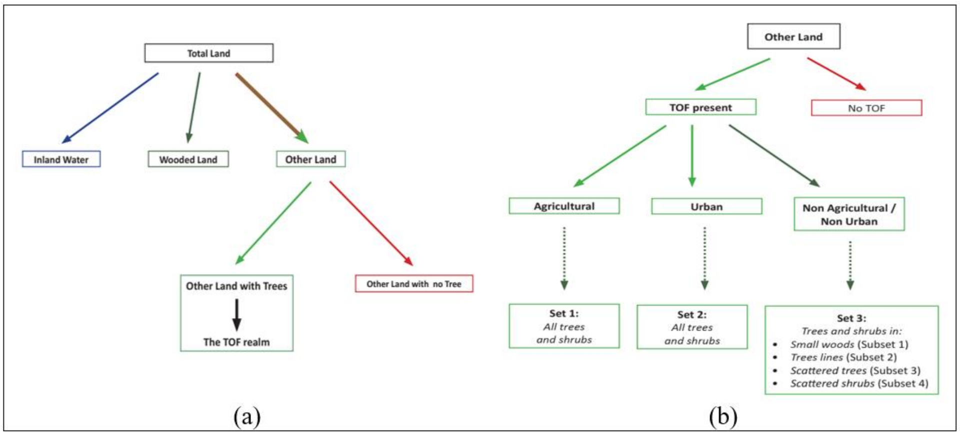

Figure 2. *(a) The FAO-FRA land classification framework and the position of TOF; (b) The formal position of TOF and TOF subsets within other land (FAO, 2013)*

This study classified TOF subjects into six classes: (i) Class 1: Trees on agricultural land – scattered woody trees within rice cultivation areas, which are cultivated once or twice per year; (ii) Class 2: Trees on shifting cultivation land – scattered woody trees within shifting cultivation areas; (iii) Class 3: Orchard and perennial trees – scattered woody trees intentionally planted together in orchards; (iv) Class 4: Trees in residential and household gardens – scattered woody trees planted in residential and household gardens; (v) Class 5: Trees along rivers, canals, streams, roads, and urban areas – scattered woody trees distributed along rivers, streams, canals, and roads, as well as trees planted in parks and urban areas; (vi) Class 6: Planted forest – planted by local communities. All scattered woody trees with a woody stem, a diameter greater than 5 cm, and not within the boundaries of national forests and forest lands were included.

Field survey

The main approach for fieldwork involves using a sample plot system. The selection of locations for sample plots is based on integrating of land use maps, topographic maps, traffic maps, and TOF pre-classification maps from satellite images. A strategy for selecting locations and distributing sample plots is implemented. The sample plot sizes used include 100 m^2, 500 m^2, 1000 m^2, 2500 m^2, and 10,000 m^2. Instruments were used during the field, including tape rope, handheld GPS, Criterion RD1000 Laser for measuring the diameter of the tree at breast height-1.3m position, and Trupulse 360B Laser for measuring the height. In addition, the scientific names and use values of the plant species were recorded according to Le et al. (1999), Ho (2001), Do (2006).

Timber volume calculation

The timber volume or woody volume of individual trees was calculated by *Equation (1)* (FAO-FRA, 2000; Vo Van Hong et al., 2006).

$$\text{Timber } (m^3 ha^{-1}) = G * H * F \qquad \text{(Eq.1)}$$

In *Equation (1)*: G is the basal area of the tree at breast height 1.3 m in squared meters (m^2); H is the total tree height (H) in meters (m), and F is the conversion factor.

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Biomass and carbon stock calculation

The allometric equation for calculating above-ground biomass (AGB) that was developed by the UN-REDD Vietnam program for individual trees in the Northeast region of Vietnam (Phuong et al., 2012), in *Equation (2)*.

$$\text{Biomass (AGB)} = 0.0547 * D^{2.11483} * H^{0.6131} \quad \text{(Eq.2)}$$

In *Equation (2)*: AGB is above ground biomass –unit is kg; D is diameter at the 1.3 m position of tree – unit is cm; H is height of tree – unit is meter.

Carbon stock is converted by *Equation 3* below (IPCC, 2003).

$$\text{Carbon stock (CBS)} = 0.5 * \text{AGB} \quad \text{(Eq.3)}$$

In *Equation (3)*: 0.5 is conversion factor (IPCC, 2003).

Satellite data and other maps

This research utilized SPOT 5 imagery having a spatial resolution of 2.5 meters, along with a topographic map, DEM map, traffic maps, TOF pre-classification maps, and a national forest map of the study region.

Mapping

This study used the object-based classification method: The important issue of the object-based classification method is the segmentation process. This process requires scrutiny to achieve an acceptable, accurate classification result. Image segmentation is the first step to divide the image into different "objects". Image segmentation requires specialized image processing software and expert knowledge. Processing images before segmentation and choosing parameters during the segmentation process is very important to ensure the accuracy of the results. The eCognition software was used in this study to perform segmentation. In this case, we have used different parameters to examine the effectiveness of the segmentation process: The eCognition Developer version 8.0 was used for segmentation in this study (https://geospatial.trimble.com/en/products/software/trimble-ecognition). The multiresolution segmentation algorithm and image object domain are “pixel level” and has been applied with specific parameters (Scale parameter: 50, Shape: 0.17, Compactness: 0.5).

The following segmentation step is classification or assigning write attribute values for the objects. To classify the segmented image, image statistical parameters for each polygon (object) were calculated, encompassing the mean value and standard deviation (STD) for every band (specifically Red, Green, and Blue). It can calculate for an unlimited number of image channels. Then, the sampling process has been carried out. Object-based classification is performed using these statistical values for each image based on a set of training samples. The sample set is taken directly from the image and is referenced in the field data. In reality, this is a process of image interpretation based on segmentation results. The number of polygons (objects) that would be entered attribute (i.e. interpretation) is about 5% to 10% of the total number of polygons. Naturally, the accuracy of results strongly depends on the accuracy of the sampling process. The

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attribute table with the “Sample_DA” column then is imported into Weka for classification, e.g., in *Figure 3*.

Sample_DA	Rowid_	FID_1	COUNT	AREA	MIN	MAX	RANGE	MEAN	STD	SUM	VARIETY	MAJORITY	MINORITY	MEDIAN	Rowid_1
RT-Ke	1775	1774	360	81000	0	87	87	32.827801	13.9255	11818	41	29	0	31	1775
RT-Ke	1879	1878	383	86175	3	118	115	23.5718	14.8132	9028	41	19	46	20	1879
RT-Ke	1958	1957	405	91125	0	67	67	22.037001	17.9303	8925	38	0	1	22	1958
RT-Ke	2072	2071	2214	49815	0	113	113	2.13911	9.00153	4736	40	0	34	0	2072
RT-Ke	2158	2157	860	19350	0	211	211	13.914	26.938601	11966	64	0	69	0	2158
RT-Ke	2269	2268	1208	27180	0	255	255	2.82864	12.0824	3417	38	0	40	0	2269
RT-Ke	2314	2313	787	17707	0	161	161	7.96696	19.2925	6270	50	0	45	0	2314
RT-Ke	2351	2350	1530	34425	0	255	255	55.522202	70.012001	84949	141	0	142	24	2351
RT-Ke	2425	2424	1697	38182	0	112	112	9.98821	17.2362	16950	50	0	83	0	2425
RT-ke	2467	2466	719	16177	0	255	255	61.6064	68.397797	44295	121	0	40	34	2467
RT-Ke	2514	2513	427	96075	0	209	209	44.278702	46.420101	18907	84	0	47	26	2514
RT-Ke	2523	2522	819	18427	0	239	239	49.243	52.7994	40330	106	0	49	29	2523
RT-Ke	2593	2592	533	11992	0	164	164	30.941799	28.3083	16492	68	0	70	24	2593
RT-Ke	2653	2652	488	10980	0	104	104	8.9918	16.8396	4388	41	0	57	0	2653
RT-Ke	2699	2698	455	10237	0	255	255	37.516499	56.573399	17070	89	0	24	12	2699
RT-Ke	2805	2804	628	14130	0	255	255	39.7118	41.245899	24939	85	0	75	29	2805
RT-Ke	2902	2901	363	81675	0	255	255	86.162498	56.923302	31277	106	66	12	76	2902
RT-ke	4271	4270	410	92250	0	163	163	29.2805	25.967699	12005	58	0	58	29	4271
RT-ke	4286	4285	790	17775	0	88	88	30.200001	9.26409	23858	36	28	0	28	4286
RT-ke	4361	4360	1310	29475	0	218	218	48.882401	29.284401	64036	92	38	1	40	4361
RT-ke	4375	4374	683	15367	0	146	146	31.122999	14.9282	21257	50	26	3	29	4375
RT-ke	4482	4481	947	21307	0	255	255	62.712799	33.196999	59389	96	55	1	55	4482
RT-ke	4483	4482	915	20587	13	147	134	45.558498	18.584	41686	62	37	13	40	4483

Figure 3. *The attribute table with the “Sample_DA” field*

The classification algorithm was chosen as Random Forest (RF), and classified results are stored as a new column in the attribute table. The RF algorithm is one of the machine learning algorithms that has been used widely (Gómez et al., 2016; Ha et al., 2018; Son and Thanh, 2018; Singh et al., 2021; Wang et al., 2022). The procedure implemented in this study is described in *Figure 4*.

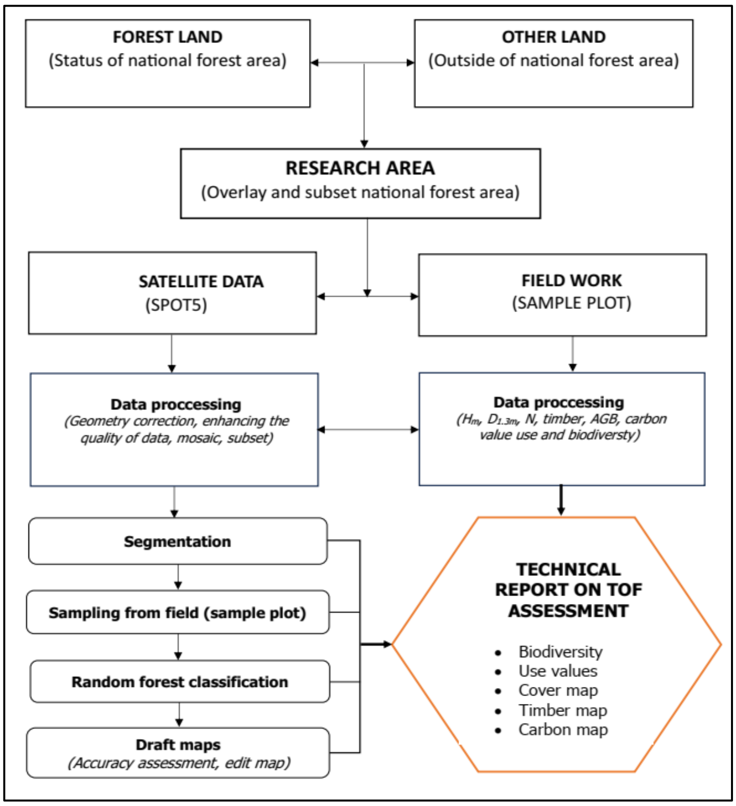

Figure 4. *The overall flowchart to describe the procedure implemented in this study*

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Result

A total of 136 sample plots were surveyed in the fieldwork. These sample plots were distributed among the six classes of Tree Outside Forest (TOF) as follows: Class 1: Trees on agricultural land - 20 sample plots; Class 2: Trees on shifting cultivation land - 26 sample plots; Class 3: Orchard and perennial trees - 12 sample plots; Class 4: Trees on residential and household gardens - 45 sample plots; Class 5: Trees along rivers, canals, streams, roads, and urban areas - 19 sample plots; Class 6: Planted forest - 14 sample plots. The survey results included statistical calculations and measurements of various parameters such as diameter at 1.3 meters ($D_{1.3m}$), height (H_m), use values and recorded the tree species, both in Vietnamese and scientific names. The spatial distribution position of sample plots are depicted in *Figure 1*.

Biodiversity flora

During the survey campaign, a total of 2,683 plants were measured, of which 101 plant species in the study area were recorded, belonging to 41 families and 83 genera, of which top ten tree species has the highest component rate: 2.42 *Melia azedarach* + 0.99 *Dimocarpus longan* + 0.59 *Acacia armata f. hybrida* + 0.51 *Manglietia conifera* + 0.50 *Pterocarya stenoptera* + 0.47 *Mangifera indica* + 0.40 *Artocarpus heterophyllus* + 0.35 *Liquidambar formosana* + 0.21 *Trema orientalis*+ 0.20 *Litchi chinensis*, the detailed see at *Table 1*.

Use value

The study categorized TOF species into 10 groups based on their use value and the statistical results of each group are as follows:

- Symbol number 1: Species for woody timber are 1.936 species, accounting for 72.20%;
- Symbol number 2: Species for fuel, temporary construction materials, household furniture, and knitting are 2.638 species, accounting for 98.32%;
- Symbol number 3: Species for foods and foodstuffs including food, vegetables, fruits, foodstuffs, drinks, and spices are 1.327 species, accounting for 85.20%;
- Symbol number 4: Species for medicinal purposes are 2.286 species, accounting for 27.33%;
- Symbol number 5: Species for tannins, and dyes are 36 species, accounting for 1.34%;
- Symbol number 6: Species for oils, resins, and essential oils are 314 species, accounting for 11.70%;
- Symbol number 7: Species for paper materials, fibres, raising silkworms, and paper binders are 290 species, accounting for 10.81%;
- Symbol number 8: Species for animal feed (cattle, poultry, aquatic) are 183 species, accounting for 6,82%;
- Symbol number 9: Species for landscape, shade, fences, and shade for industrial trees are 670 species, accounting for 24.97%;
- Symbol number 10: Species with other values including trees have parts of toxic, animal treatment, brewing yeast, stimulant plants, biological insecticides, insecticides that kill fish, shampoo, skin beauty, honey beekeeping, making green manure, covering the soil, substrate for growing mushrooms, ornamental plants are 214 species, accounting for 7.98%.

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Table 1. *List of TOF species, components, and use value in the research area*

No.	Name		Quantity (trees)	Components (1/10)	Use value
	Science	Family			
(1)	(2)	(3)	(4)	(5)	(6)
1	*Melia azedarach L.*	Meliaceae	648	2.42	1, 2, 10
2	*Dimocarpus longan Lour.*	Sapindaceae	265	0.99	1, 2, 3, 4, 9, 10
3	*Acacia armata f. hybrida (Lodd. ex Benth.) Siebert & Voss*	Fabaceae	158	0.59	1.2
4	*Manglietia conifera Dandy*	Magnoliaceae	138	0.51	1, 2, 7
5	*Pterocarya stenoptera C. DC.*	Juglandaceae	133	0.50	2, 4, 10
6	*Mangifera indica L.*	Anacardiacae	127	0.47	1, 2, 3, 4, 9
7	*Artocarpus heterophyllus Lamk.*	Moraceae	107	0.40	1, 6, 3, 4, 8, 9
8	*Liquidambar formosana Hance*	Hamamelidaceae	93	0.35	1, 2, 3, 4, 6
9	*Trema orientalis (L.) Blume*	Ulmaceae	57	0.21	2, 3, 4, 7, 10
10	*Litchi sinensis Sonn.*	Sapindaceae	53	0.20	2, 3, 4, 10
11	*Vernicia montana Lour.*	Euphorbiaceae	47	0.18	1, 2, 3
12	*Citrus grandis (L.) Osb.*	Rutaceae	46	0.17	2, 3, 4, 6
13	*Bombax ceiba L.*	Bombacaceae	42	0.16	2, 4, 7, 8
14	*Chukrasia tabularis A.Juss.*	Meliaceae	40	0.15	1, 2, 4
15	*Dalbergia lanceolaria L.f. var. lakhonensis (Gangep.) Phamh.*	Fabaceae	38	0.14	1, 2, 4
16	*Clausena indica (Dalz.) Oliv.*	Rutaceae	36	0.13	3, 4, 6
17	*Syzygium cinereum Wall. ex Merr. & Perry*	Myrtaceae	30	0.11	1, 2, 3
18	*Lagerstroemia speciosa (L.) Pers.*	Lythaceae	29	0.11	1, 2, 4, 9
19	*Prunus salicina Lindl. var. Salicina*	Rosaceae	29	0.11	2, 3, 4
20	*Diospyros kaki Thunb.*	Ebenaceae	27	0.10	2, 3, 4
21	*Delonix regia (Bojer ex Hook.) Raf.*	Fabaceae	27	0.10	2, 4, 9
22	*Castanea mollissima Blume*	Fagaceae	26	0.10	1, 2, 3, 4
23	*Pyrus pyrifolia (Burm.f.) Nakai*	Rosaceae	24	0.09	2, 3, 4
24	*Psidium guajava L.*	Myrtaceae	22	0.08	2, 3, 4
25	*Dracontomelon duperreanum Pierre*	Anacardiaceae	22	0.08	2, 3, 4, 9
26	*Macaranga denticulata (Blume) Muell.-Arg.*	Euphorbiaceae	19	0.07	2, 4, 7, 10
27	*Averrhoa carambola L.*	Oxalidaceae	19	0.07	2, 3, 4

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No.	Name		Quantity (trees)	Components (1/10)	Use value
	Science	Family			
(1)	(2)	(3)	(4)	(5)	(6)
28	*Annona squamosa L.*	Annonaceae	18	0.07	2, 3, 4, 10
29	*Toona sinensis (A. Juss.) M. Roem.*	Meliaceae	17	0.06	1, 2, 3, 4
30	*Cratoxylum cochinchinense (Lour.) Blume*	Hypericaceae	16	0.06	1, 2, 3, 4
31	*Aporosa dioica (Roxb.) Muell.-Arg.*	Euphorbiaceae	16	0.06	1, 2, 3, 4
32	*Alstonia scholaris (L.) R.Br.*	Apocynaceae	15	0.06	1, 2, 4, 9
33	*Schima wallichii (DC.) Korth.*	Myrtaceae	13	0.05	1, 2, 4
34	*Cinnamomum cassia Presl*	Lauraceae	12	0.04	1, 2, 4, 6
35	*Pinus merkusii Jungh. & de Vriese*	Pinaceae	12	0.04	1, 2, 4, 6, 7
36	*Styrax tonkinensis Craib ex Hartwiss*	Moraceae	11	0.04	2, 4, 6, 7
37	*Rhus chinensis Mill.*	Anacardiaceae	11	0.04	2, 3, 4
38	*Toxicodendron succedaneum (L.) Kuntze*	Anacardiaceae	11	0.04	1, 2, 4, 6
39	*Broussonetia papyrifera (L.) L'Her. ex Vent.*	Moraceae	10	0.04	2, 3, 4, 6, 7, 8
40	*Acacia mangium Willd.*	Fabaceae	10	0.04	1, 2, 7
41	*Litsea cubeba (Lour.) Pers.*	Lauraceae	10	0.04	2, 4, 6
42	*Syzygium cuminii (L.) Skells*	Myrtaceae	10	0.04	1, 2, 3, 4, 5
43	*Prunus persica (L.) Bartsch*	Rosaceae	9	0.03	2, 3, 4, 9
44	*Syzygium jambos (L.) Aston*	Myrtaceae	9	0.03	1, 2, 3, 4, 5, 9
45	*Ziziphus mauritiana Lamk.*	Rhamnaceae	9	0.03	2, 3, 4
46	*Dillenia indica L.*	Dilleniaceae	8	0.03	2, 3, 4
47	*Ceiba pentandra (L.) Gaertn.*	Bombacaceae	7	0.03	1, 2, 3, 4, 6, 7, 8, 9
48	*Pterospermum heterophyllum Hance*	Sterculiaceae	7	0.03	1, 2, 10
49	*Cassia splendida Vogel.*	Caesalpiniaceae	7	0.03	1, 2, 3, 4, 9
50	*Mischocarpus pentapetalus (Roxb.) Radlk.*	Sapindaceae	6	0.02	1, 2
51	*Oroxylum indicum (L.) Kurz*	Bignoniaceae	6	0.02	2, 3, 4, 7
52	*Duabanga grandiflora (DC.) Walp.*	Sonneratiaceae	6	0.02	1, 2, 3
53	*Ziziphus oenoplia (L.) Mill.*	Rhamnaceae	6	0.02	2, 4
54	*Pouteria sapota (Jacq.) H. Moore & Stearn.*	Sapotaceae	6	0.02	2, 3
55	*Mallotus paniculatus (Lam.) Muell.-Arg.*	Euphorbiaceae	5	0.02	2, 4, 6, 7, 10
56	*Allospondias lakonensis (Pierre) Stap.*	Anacardiaceae	5	0.02	2, 3, 6, 9

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No.	Name		Quantity (trees)	Components (1/10)	Use value
	Science	Family			
(1)	(2)	(3)	(4)	(5)	(6)
57	*Engelhardtia spicata Lesch.ex Blume*	Anacardiaceae	4	0.01	1, 2, 4, 10
58	*Illicium verum Hook.f.*	Illiciaceae	4	0.01	1, 2, 3, 4, 6
59	*Ficus racemosa L.*	Moraceae	4	0.01	2, 3, 4, 6, 8
60	*Alangium chinense (Lour.) Harms*	Alangiacea**e**	4	0.01	2, 4, 8
61	*Muntingia calabura L.*	Elaeocarpaceae	4	0.01	2, 4, 6
62	*Polyalthia longifolia (Sonn.) Thwaites*	Annonaceae	4	0.01	4, 9
63	*Terminalia catappa L.*	Combretaceae	3	0.01	1, 2, 3, 4, 5, 6, 9
64	*Cratoxylum formosum (Jack) Benth. & Hook.f. ex Dyer*	Hypericaceae	3	0.01	1, 2, 3, 4
65	*Mangifera foetida Lour.*	Anacardiaceae	3	0.01	2, 3, 4, 9
66	*Senna siamea (Lamk.) Irwin & Barneby*	Caesalpiniaceae	3	0.01	1, 2, 3, 4, 9
67	*Michelia alba DC.*	Magnoliaceae	3	0.01	1, 2, 6, 9
68	*Bischofia javanica Blume*	Euphorbiaceae	3	0.01	1, 2, 3, 4, 9
69	*Dalbergia tonkinensis Prain*	Fabaceae	3	0.01	1, 2, 9
70	*Pinus massoniana Lamb.*	Pinaceae	3	0.01	1, 2, 4, 10
71	*Canarium tramdeum Dai & Yakovl.*	Burseraceae	3	0.01	1, 2, 3, 4
72	*Eucalyptus camaldulensis Dehnhart*	Euphorbiaceae	2	0.01	1, 2, 4, 7
73	*Litsea monopetala (Roxb.) Pers.*	Lauraceae	2	0.01	1, 2, 4, 6, 10
74	*Litsea pierrei Lecomte*	Lauraceae	2	0.01	1, 2, 7
75	*Mallotus paniculatus (Lam.) Muell.-Arg.*	Euphorbiaceae	2	0.01	2, 4, 6, 7, 10
76	*Grewia paniculata Roxb. ex DC.*	Tiliaceae	2	0.01	2, 3, 4
77	*Micromelum minutum (Forst.f.) Wight & Arn.*	Rutaceae	2	0.01	2, 4
78	*Barringtonia acutangula (L.) Gaertn.*	Lecythidaceae	2	0.01	1, 2, 6, 9
79	*Ficus hirta Vahl*	Moraceae	2	0.01	2, 4
80	*Ficus benjamina L.*	Moraceae	2	0.01	2, 4, 9
81	*Alstonia scholaris (L.) R.Br.*	Apocynaceae	2	0.01	1, 2, 4, 9
82	*Sterculia foetida L.*	Sterculiaceae	2	0.01	2, 3, 4, 6, 9
83	*Erythrina variegata L.*	Fabaceae	2	0.01	2, 3, 4, 9
84	*Pongamia pinnata (L.) Merr.*	Fabaceae	1	0.00	1, 2, 4, 6, 9, 10
85	*Actinodaphne pilosa (Lour.) Merr.*	Lauraceae	1	0.00	2, 4, 6

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No.	Name		Quantity (trees)	Components (1/10)	Use value
	Science	Family			
(1)	(2)	(3)	(4)	(5)	(6)
86	*Microcos paniculata L.*	Tiliaceae	1	0.00	2, 3, 4, 6
87	*Schefflera heptaphylla (L.) Frodin*	Araliaceae	1	0.00	1, 2, 3, 4, 10
88	*Elaeocarpus tonkinensis DC.*	Elaeocarpaceae	1	0.00	1, 2, 5, 10
89	*Ficus altissima Blume*	Moraceae	1	0.00	2, 4, 7, 9
90	*Castanopsis indica (Roxb. ex Lindl.) A.DC.*	Fagaceae	1	0.00	1, 2, 3, 5
91	*Cipadessa baccifera (Roth) Miq.*	Oxalidaceae	1	0.00	2, 4
92	*Canthium parvifolium Roxb.*	Rubiaceae	1	0.00	1, 2, 3, 4
93	*Aphanamixis polystachya (Wall.) R.N. Parker*	Rubiaceae	1	0.00	1, 2, 4, 6, 9
94	*Eurya japonica Thunb.*	Theaceae	1	0.00	2, 3, 4
95	*Pyrus pashia D.Don*	Rosaceae	1	0.00	2, 3, 4
96	*Prunus armeniaca L.*	Rosaceae	1	0.00	2, 3, 4
97	*Cunninghamia konishii Hayata*	Cupressaceae	1	0.00	1, 2, 4
98	*Adenanthera pavonina L.*	Mimosaceae	1	0.00	1, 2, 4, 6, 9
99	*Syzygium cinereum Wall. ex Merr. & Perry*	Myrtaceae	1	0.00	1, 2, 3
100	*Nephelium lappaceum L.*	Sapindaceae	1	0.00	1, 2, 3, 6
101	*Saraca dives Pierre*	Caesalpiniaceae	1	0.00	2, 3, 4, 6, 9
			2683		

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Research results show that most tree species have use values, normally one species has 4 to 5 use values, and some species have 8-9 use values, more than details, see in Column 6, *Table 1*.

The structural parameters of each TOF class

The parameters of 6 classes include: Class 1: Trees on agricultural land; Class 2: Trees on shifting cultivation land; Class 3: Orchard and perennials trees; Class 4: Trees on residential and household gardens; Class 5: Trees along rivers, canals, streams, roads, and urban area; Class 6: Planted forest. The parameters to be measured and calculated include; diameter at the 1.3 m position of tree ($D_{1.3m}$); height of from bottom to top of trees (H_m); density of trees (N); above-ground biomass (AGB); Carbon (CBS), the detailed see at *Table 2*.

Table 2. *The structural parameters of TOF species in the research area*

Parameter / Class	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6
$D_{1.3}$ (cm ha^{-1})	18.04	13.74	14	18.91	23	12.41
H (m ha^{-1})	8.02	6.82	5.69	7.94	8.27	8.93
N (tree ha^{-1})	334	656	822	356	290	2984
M (m^3 ha^{-1})	29.88	23.10	50.25	35.40	35.40	135.64
AGB (Mg ha^{-1})	36.56	17.78	59.16	42.70	53.54	86.12
Carbon (Mg ha^{-1})	18.28	8.90	29.58	21.34	26.78	44.40

Mapping

After editing and updating the attributes, the background object was overlaid, and maps were created with six classes. Three types of resultant maps were established as follows:

TOF areas

The total area covered by trees outside the forest (TOF) is 35,998.68 ha, which is 7.41% of the total natural land area in the study area. The statistics obtained from the TOF cover map classification results indicate the following: Trees on agricultural land area is 4,967.74 ha (13.80%); Trees on shifting cultivation land area is 6,263.89 ha (17.40%); Orchard and perennial trees area is 3,571.84 ha (9.92%); Trees along rivers, canals, streams, road, and urban area is 5,761.68 ha (16.01%); Trees on residential and household gardens area is 6,318.33 ha (17.55 %) and Planted forests area is 9,115.20 ha (25.32%) with an overall classification accuracy is 90.52 %. *Figure 5* and *Figure 6* display the results of the TOF cover map of the study area.

TOF timber

The statistics obtained from the TOF timber volume map classification results indicate that the total timber volume of trees outside the forest (TOF) is 2,336,951.89 m^3. Trees on agricultural land area is 148,436.13 m^3 (6.35%); Trees on shifting cultivation land is 144,695.79 m^3 (6.19%); Orchard and perennial trees is 179,487.57 m^3 (8.73%); Tree along rivers, canals, streams, road, and urban is 203,963.65 m^3 (8.73%); Trees on

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residential and household gardens is 423,959.67 m^3 (18.14%) and Planted forests is 1,236,409.08 m^3 (42.91%) with an overall classification accuracy is 85.73%. *Figure 7* and *Figure 8* display the results of the TOF timber volume map of the study area.

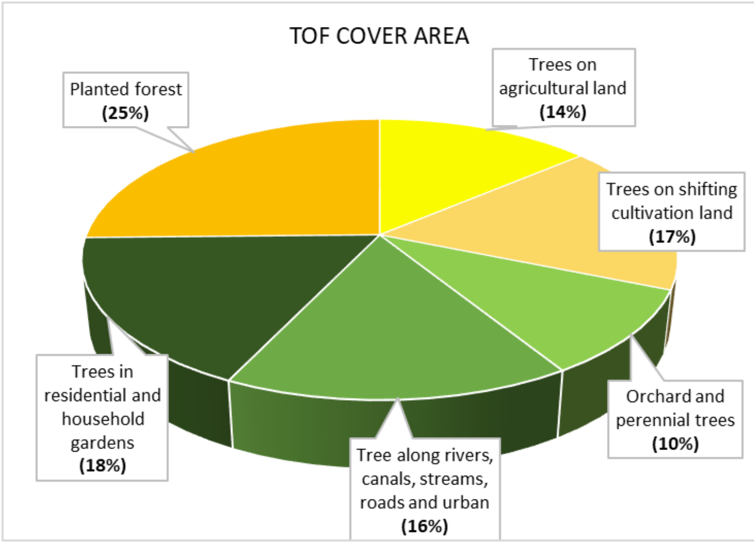

Figure 5. *The distribution of TOF areas in the research area*

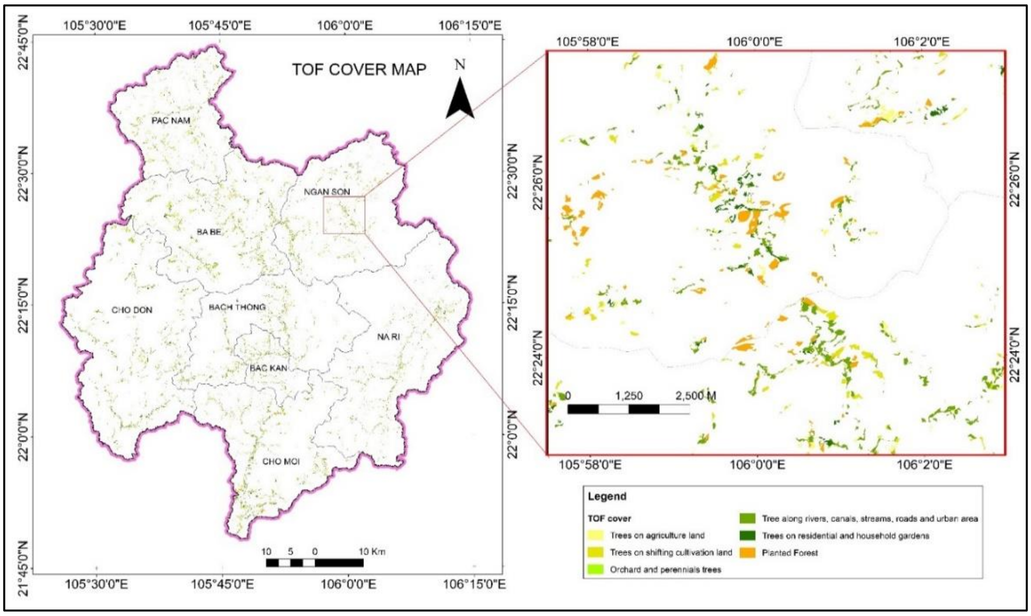

Figure 6. *Trees outside forest cover map*

TOF carbon stock

The statistics obtained from the TOF carbon storage map classification results indicate the following: The total carbon stock by trees outside the forest (TOF) is 949,084.16 tons, including: Trees on agricultural land area is 90,810.32 tons (9.57%); Trees on shifting cultivation land is 55,748.60 tons (11.13%); Orchard and perennial trees are 105,651.05 tons (12.96%); Tree along rivers, canals, streams, road, and urban is

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122,954.36 ton (12.96%); Trees on residential and household gardens is 169,204.77 tons (17.83%) and Planted forests is 404,715.07 ton (42.64%) with an overall classification accuracy of 84.35%. The results of the TOF carbon stock map of the study area are shown in *Figure 9* and *Figure 10*.

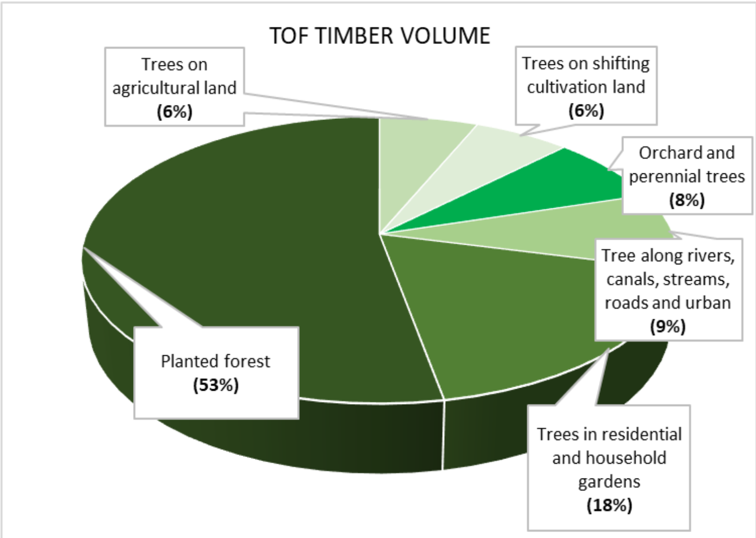

Figure 7. *The distribution of TOF timber volume in the research area*

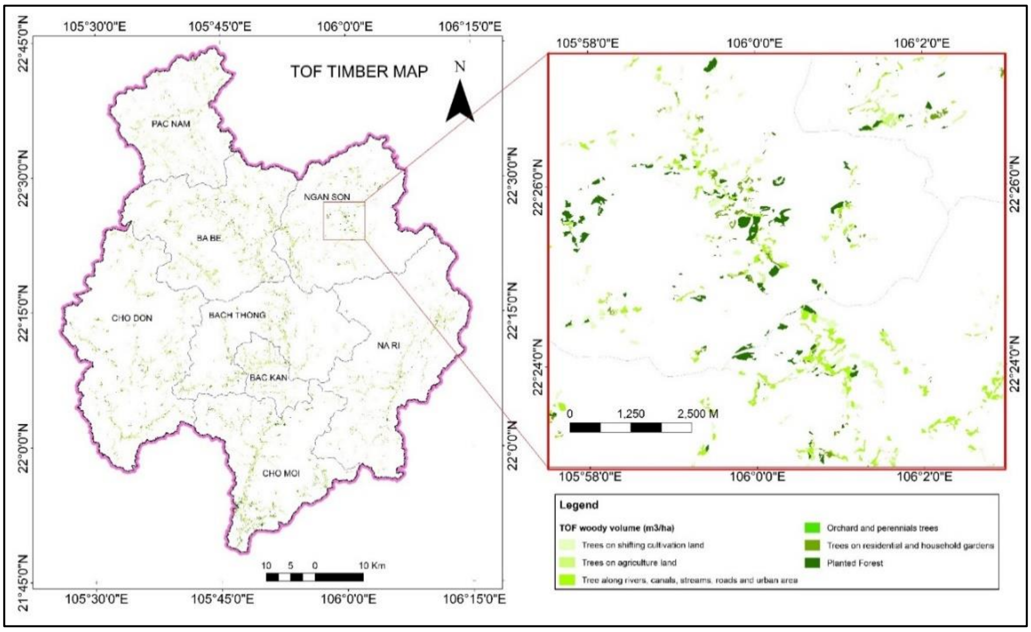

Figure 8. *Tress outside forest timber volume map*

These maps serve to visualize and communicate important information about the distribution areas, timber volume, and carbon stock of TOF in the study area. They offer valuable insights into land management, planning development, and decision-making processes in the study area.

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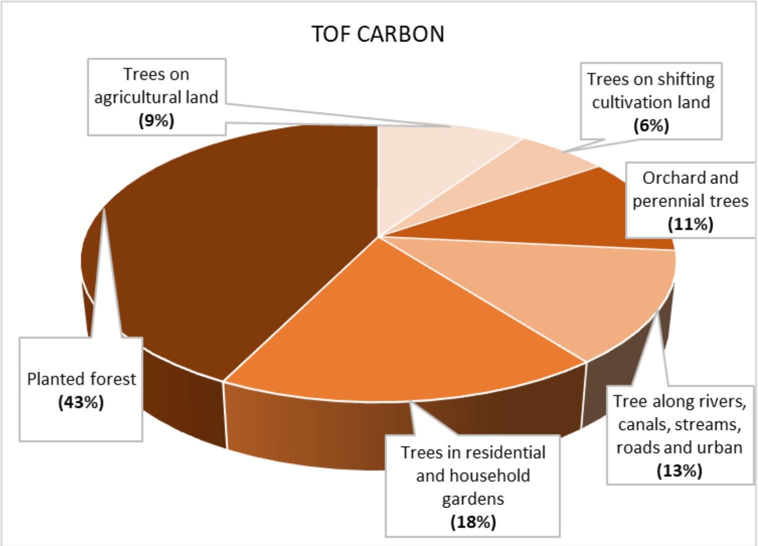

Figure 9. *The distribution of TOF carbon stock in the research area*

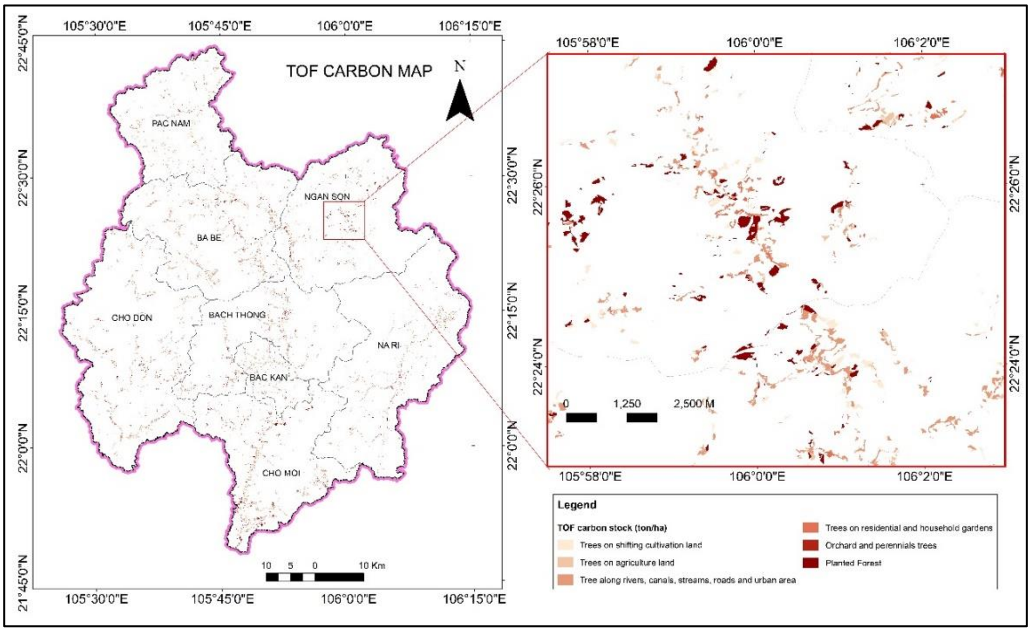

Figure 10. *Trees outside carbon stock map*

Discussion

TOF plays a crucial role in providing various products and services such as wood, fruits, and non-wood forest products. However, despite their significance, they are not currently considered a part of the forest according to the standard forest definition used by the FAO and most countries. This lack of official recognition has resulted in limited attention given to TOF, causing difficulties in action planning, investigation, and management of TOF at national and local levels. This section aims to discuss the results of the study, highlighting the value of TOF, as well as the limitations and gaps that this research has not yet addressed.

Firstly, regarding biodiversity value, the study recorded 101 species, belonging to 41 families and 83 genera. These families account for over one-third of Vietnam's flora; thus, this study exhibited higher species diversity compared to other studies, such as those by Herrera (2003; 50 species), Marchetti et al. (2018; 60 species), Tamang et al. (2019; 95 species); Bhandari et al. (2021; 38 species) and these studies also did not record the use values of TOF species. In addition, the study also found 10 tree species that have the highest component rate, including *Melia azedarach, Dimocarpus longan, Acacia armata f. hybrida, Manglietia conifera, Pterocarya stenoptera, Mangifera indica, Artocarpus heterophyllus, Liquidambar formosana, Trema orientalis*, and *Litchi chinensis*. This above information has often been overlooked in many previous studies but is essential for local authorities to formulate the right policies and strategies for selecting and supplementing plant species that ensure balance and suitability for the research area.

Secondly, this study has recorded the use value of TOF species and categorized TOF species into 10 groups based on their use value. Most of the TOF species in the research area were planted with clear purposes and values. Normally one species had 4 to 5 use values, some species even have 8 or 9 use values. The research results highlight the importance of TOF in the daily lives of local people in the study area. This is an important result for decision-makers, as it can help develop strategies and plans for additional planting of TOF species that suit natural conditions and cultural aspects and customs of the local people in the study area. However, most previous studies have not specifically focused on or recorded this value.

Thirdly, the structure of TOF species in the study area was highly diverse in size, height, diameter, and density. TOF objects were unevenly distributed across the research area and grew on land belonging to various owners, including the state, community, and private households. As a result, conducting survey measurements using traditional methods was not easy. Therefore, combining field investigation and satellite image data was necessary to investigate and assess TOF objects.

Fourthly, the study utilized field survey data and SPOT5 satellite imagery by object-based classification method to assess the area, timber volume, and carbon storage with 90.52%, 85.73%, and 84.35% accuracy, respectively. The classification method utilized in this study has enabled a more detailed classification of TOF objects and has improved accuracy compared to previous classification methods (Singh et al., 2012; Meneguzzo et al., 2013; Pujar et al., 2014; Hassanin et al., 2020; Bradt et al., 2021). The total area covered by TOF in the study was 35,998.68 ha, representing 7.41% of the total natural land area of the study area. Among the different categories, planted forests had the largest area of 9,115.20 ha (25.32%) and following by trees in residential and household gardens area, occupying 6,318.33 ha (17.55%), trees on shifting cultivation land area, covering 6,263.89 ha (17.40%), trees on agricultural land area of 4,967.74 ha (13.80%), and orchard and perennial trees area, with an area of 3,571.84 ha (9.92%). The results were within the range predicted by the FAO in 2013, which suggested coverage of 5–10% (FAO, 2013) and were consistent with findings from other studies (Wani et al., 2018; Hussanin et al., 2020). This remarkable tree-covered area requires improved management solutions, especially as the forest cover declines in some regions.

Fifth, the total timber volume of TOF was 2,336,951.89 m^3, with an average timber value of 56.90 m^3 ha^{-1}. The carbon stock was 949,084.16 tons, corresponding to an average timber value of 24.88 tons ha^{-1}. These values are consistent with previous research findings in some other locations (Schnell et al., 2015b; Marchetti et al., 2018), highlighting the importance of TOF as a valuable source of fuel and timber for the local

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communities. Moreover, the significant CO_2 sequestration capacity indicates a sustainable alternative that can contribute to developing strategies for mitigating and adapting to the current climate change, aligning with observations made by Skole et al. (2021) and Peros et al. (2022). Although previous studies have used remote sensing data to estimate the value of woody timber, biomass, or carbon stocks, however, they have not fully recorded information on biodiversity, composition, and use value of TOF species.

The previous studies using remote sensing data mentioned above usually only focused on assessing one aspect such as the current status of land cover (%), timber volume, biomass value, or carbon stock of TOF objects which didn’t fully exploit the advantage of remote sensing data. However, this study thoroughly evaluated the importance and benefits of TOF objects by combining field survey data and satellite images. The results of this study strongly demonstrate the correctness and potential of the practical application of this method. The study addressed the gaps identified in previous studies mentioned in this introduction and discussion sections. This is the highlight, distinction, and contribution of this study.

This study has limitations, such as the inability to use multiple types of satellite imagery, different spatial resolutions, and testing at varying scales in TOF object assessment. Additionally, this study didn't thoroughly evaluate the role of TOF in the environment, culture, and ecosystem services, e.g., the study did not fully assess their contribution to reducing the temperature and preventing soil erosion and landslides. Based on the process of this method, the authors aim to address these limitations in future research.

Conclusion

The present study has demonstrated an approach to fully assess the role and value of Trees Outside Forests (TOF) by using both field survey data and satellite image data. Field survey data contributes to evaluating the structure, biodiversity, and use value of TOF species in the study area. The satellite image data, combined with field data, helps in classifying and assessing the current cover status, timber volume, carbon stock, and the creation of TOF maps. This method provides a scientific basis for assessing the role and value of TOF and emphasizes the importance of having both field survey data and satellite image data to obtain significant results in evaluating TOF resources.

The results of this study highlight the role and importance of TOF in the daily lives and sustainable socio-economic development of local communities. TOF resources are an indispensable part of the non-forest landscape, serving economic, ecological, environmental, and cultural roles. Additionally, the study suggests that TOF can be a potential sustainable adaptation solution to global climate change.

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