ESTIMATION OF MANGRROVE CARBON STOCKS USING SENTINEL 2A AND FIELD- BASED DATA IN TIEN LANG DISTRICT, HAI PHONG CITY

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SUMMARY
Coastal mangroves along the coastal zone of Tien Lang were selected to estimate above-ground, underground carbon stocks and soil organic carbon. Field data was conducted to measure mangrove structures in 15 plots with a dimension of 900 m^2, each plot has 3 subplots with a dimension of 100 m^2 at three communes, Dong Hung, Tien Hung, and Vinh Quang. To select the most suitable classification method for Tien Lang district, this study used some classification methods, namely NDVI, SAVI, TVI indices and unsupervised classification approach. The accuracies of NDVI, SAVI, TVI and Unsupervised classification were assessed at 85.6%; 67.5%; 58.3%; and 81.8%, respectively. The NDVI index confirmed is the most suitable for mangrove mapping (85.6%), followed by Unsupervised classification (81.8%). A total of carbon stocks was calculated from 42.78 ton ha^{-1} to 117.95 ton ha^{-1} for mixed mangrove forests, while monoculture *Sonneratia caseolaris* ranged from 62.38 ton ha^{-1} to 389.9 ton ha^{-1}. Soil organic carbon stocks in 100 cm depth was estimated ranging from 100.95 ton ha^{-1} to 227.65 ton ha^{-1}. IDW interpolation of above-ground biomass had accuracy at 61.1%, while soil organic carbon was at 89.3%. Overall, mangrove forests in Tien Lang offer to potential amount of carbon stocks both above-ground carbon stocks and soil organic carbon for PFES.
Keywords: biomass, carbon, mangrove, soil organic carbon, unsupervised classification, vegetation indices.

1. INTRODUCTION

Mangroves have spatially distributed in the intertidal areas along the coastline in most of the tropics and subtropics (Kathiresan and Bingham, 2001). They are one of the most important ecosystems and provide critical habitats for sea creatures (Perillo et. al., 2018). They also play a significant role in reducing the damages caused by the natural disasters, such as storms and wave attacks, and Tsunami. Their ecosystems regulate water, prevent the soil erosion from wave attacks and provide a natural barrier against storms, cyclones, tides, and other potentially damaging natural forces (Dahdouh-Guebas et al., 2005; Bahuguna et al., 2008). For centuries, mangroves have contributed significantly to the socio-economic activities of coastal residents. They are considered as a source of firewood and construction materials, charcoal, food, honey, herbal medicines, and other forestry products (Hong and San, 1993; Alongi, 2002). In addition, this ecosystem can act as a highly efficient carbon pool in the tropics (Donato et al., 2011), because mangroves can sequester carbon in both above and below-ground biomass as well as within soil. Despite the large carbon storage potential in mangrove biomass and soil, mangroves have been under serious threats from coastal high population growth, aquaculture expansion, timber cutting, and other human activities (Duke et al., 2007).

In Vietnam, remote sensing applications have been applied in the forestry sector for a long time. For example, quantification of mangrove carbon stocks has carried out in the North Coast of Vietnam (Hanh and Tinh, 2017; Dung et al., 2020). Models for calculating mangrove carbon have been developed for an emphasis on some specific mangrove species. The calculation of carbon sequestration and the quantitative values of the mangrove forests are often conducted with conventional and traditional methods, thus taking time and cost. Although there have been a number of studies with traditional mangrove carbon calculation, a few studies using remote sensing data has been employed to carbon sequestration.

In recent years, mangroves and coastal resources in Tien Lang district have been under a great pressure to maintain the areas and ecosystem functions due to human and natural threats (Dat and Yoshino, 2016; Dat et al., 2017). Although the values of mangrove forests in terms of high carbon storage, their estimation has not been conducted yet in Tien Lang district. In this study, the current map of mangroves distribution was constructed in Tien Lang district by using 2A Sentinel imagery, carbon storages and soil organic carbon were then estimated based on the data collected from the fieldwork in combination GIS interpolation approach. These findings provide a scientific basis for estimating the total values of carbon stocks and PFES for mangrove forest services in Vietnam.

2. RESEARCH METHODOLOGY

2.1. Study site

This study was conducted in mangrove forests in Tien Lang district of Hai Phong City, which is located between $20^0 30'$÷ $20^0 01'$ N and $106^0 23'$ ÷ $107^0 08'$ E (Fig. 1). Hai Phong is the second largest city in the Northern region of Vietnam where Tien Lang district is located in the Southwest of Hai Phong city. The coastal area of Tien Lang lies between the mouths of Van Uc and Thai Binh rivers, which are filled with alluvium from these two estuaries so that there is an area of mangroves and abundant of natural aquatic resources. The total coastal areas of 3 communes, including Dong Hung, Tien Hung, and Vinh Quang belonging to Tien Lang District, are 9844 ha. The areas of mangrove forests are about 986 ha with dominant mangrove species identified as *Kandelia obovata* and *Sonneratia caseolaris*.

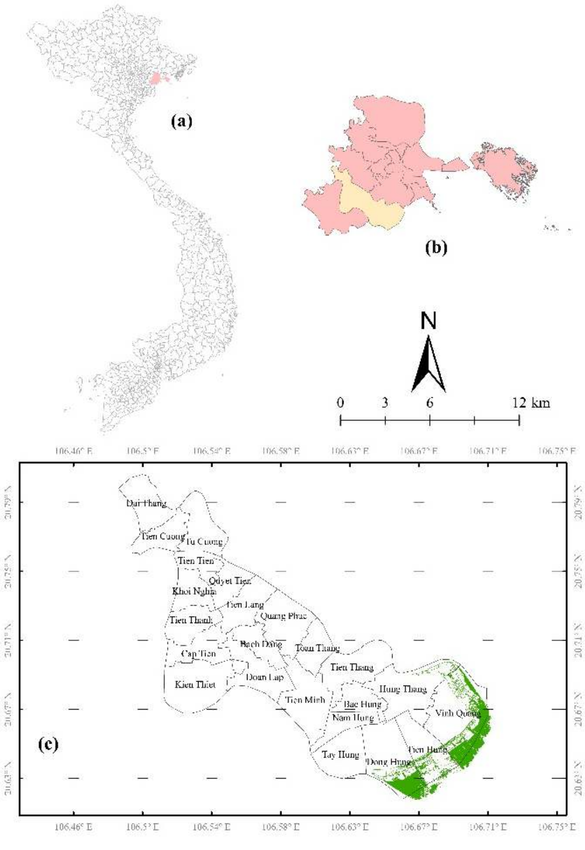

Figure 1. Study site (a) Vietnam (b) Hai Phong (c) Tien Lang District and mangrove forests distributing along the coast

2.2. Remote sensing data

The Sentinel 2A imagery of the study areas was acquired on July 5th 2018, which was freely provided by USGS (www.earthexplorer.usgs.gov). The date of the Sentinel 2A image was the same duration of field data collection with spatial resolution by 10 x 10 m.

2.3. Methods

Field survey and sampling plot selection:

A field survey on mangrove forests was conducted in July 2018. To select sampling plots, we examined firstly study areas entirely, selected randomly sampling plots, then used a GPS (Oregon 650) to determine the spatial position each plot. As a result, 15 plots with a dimension of 30 m x 30 m (equivalent to 900 m²) were randomly established across the whole of Tien Lang coast (Fig. 2) (Dat et al., 2017). Two sampling sites were chosen to collect the controlling soil samples where there were no mangrove forests.

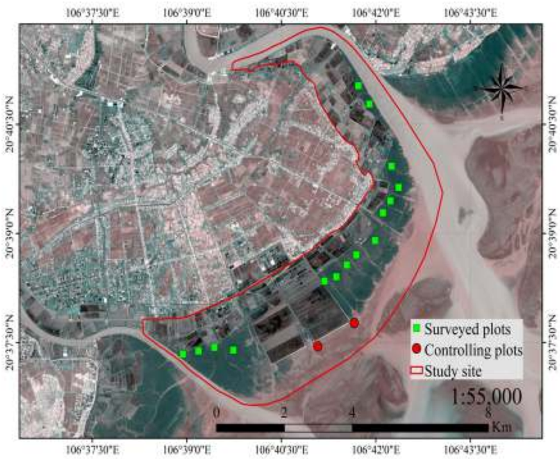

Figure 2. Distribution of the smapling plots in Tien Lang district

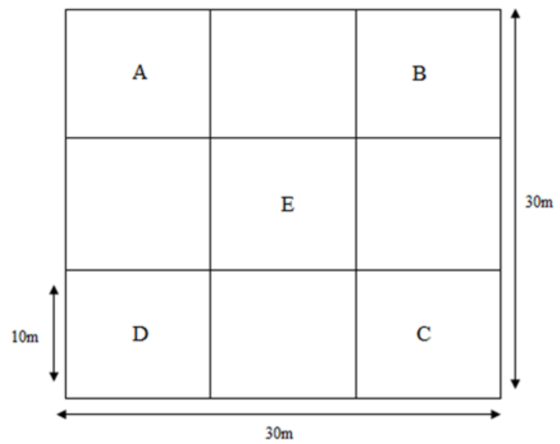

Figure 3. Layout of sampling plot and subplots in study site

At each sampling plot, three subplots (10 m x 10 m, equivalent to 100 m²) were established to measure the mangrove structures as shown in Fig. 3.

Under each sub-plot, tree height, DBH, and stem diameter at 30 cm height of *Kandelia obovata* and *Sonneratia caseolaris* were measured. Soil samples were taken at the centre of plot, named E as shown in Fig. 3 at the depth of 100 cm from the surface, using standard steel hand drill. Each soil sample plot was equally taken with 5 layers with depth intervals of 20 cm as 0 ÷ 20 cm; 20 ÷ 40 cm, 40 ÷ 60 cm, 60 ÷ 80 cm and 80 ÷ 100 cm. Soil plots were also used to assess the accuracy of interpolated soil organic carbon stocks.

Calculating biomass and carbon stocks:

In this study, mangrove above-ground (AGB) and below-ground biomass (BGB) were calculated individually for each species using existing published allometric equations. The concept behind allometric equations is that the diameter of a tree is correlated to its weight (Kominyama et al., 2005; Hanh et al., 2016). Therefore, taking information about mangrove biomass and carbon stocks is not necessary to require mangrove cutting, known as non-destructive methods. This approach is environmentally friendly, time and cost-effective, and requires less effort than others. This approach in combination with remote sensing approach is also reliable and applicable to estimate mangrove biomass and carbon stocks. Two mangrove species identified were measured using species-specific allometric equations (Table 1).

Table 1. Equations for calculating biomass of mangrove species

Species	Biomass Allometric Equation	Sources
Sonneratia caseolaris	$B\ (AGB) = 0.000318 \times D^{4.19917}$ $B\ (BGB) = 0.000431 \times D^{3.56175}$	(Komiyama et al., 2005)
Kandelia obovata	$B\ (AGB) = 0.04975 \times D^{1.94748}$ $B\ (BGB) = 0.01420 \times D^{2.12146}$	(Komiyama et al., 2005)

B - Biomass, D - Diameter at the breast height.

From the total biomass of trees, the amount of carbon accumulated in the biomass by multiple trees biomass was then converted with coefficients of 0.47 (Eggleston et al., 2006).

Calculating soil organic carbon by Walkley-Black method:

The soil sample in the central plot was taken at a depth of 100 cm from the soil surface. Each soil sample was equally divided into five layers by the depth (0 ÷ 20 cm; 20÷40 cm, 40÷60 cm, 60÷80 cm and 80÷100 cm). Then, the soil samples were covered by plastic bags and preserved in the suitable conditions until they were sent to the laboratory. The method to determine of total organic carbon in the soil was adapted from Vietnam standard TCVN 9294: 2012 (Meersmans et al., 2009). This standard is based on the Walkley-Black method, which was used for the determination of organic carbon content in the marine sediment. In the process, organic material was oxidized by using a redundancy amount of potassium dichromate solution in the sulfuric acid environment, using heat by dissolving the concentrated sulfuric acid into the dichromate solution, then titrating the redundant of dichromate by iron (II) solutions, thus deducting the organic carbon content. To calculate the amount of carbon in the soil sample, the following formula was used:

$$C = [(V_0 - V_1)*C_N*0.003*1.724*100*k]/W$$

(Kauffman and Donato, 2012)

Where: V_0 refers to the volume of Morh salt used for the titration of the sample (ml); V_1 is the volume of Morh used for the titration of the medium (ml); C_N is equivalent concentration of Morh salt; k is Drying coefficient; 1.742 is Experimental coefficient, which is the conversion coefficient from the carbon content to the organic matter content; W is Initial weight of soil (gram). By using the specific bulk density of the soil sample, the underground carbon stock in an area was calculated as follows:

$$a(h) = c(h) \times T(h)/100$$

$$A(H) = a(h) \times dh$$

$$C(H) = A(H) \times 100$$

Where: dh (cm) is depth of a soil sample; H (cm) is depth of experimental plot; c (h) (%) is carbon content in depth h; T (h) (g cm^{-3}) is bulk density at depth h; a (h) (g cm^{-3}) is carbon stocks in soil at depth h (20 cm/each); A (H) (g cm^{-3}) is carbon stocks in soil at depth H; C (H) (ton ha^{-1}) is forest carbon sequestration at the depth of H.

Image processing classification:

Pre-processing classification: This step included band combination and band clip. In this study, Band 2, Band 3, Band 4 and Band 8 were combined into multiple bands known as composite bands in ArcGIS 10.4.1, whereas composited bands were clipped according to the study boundary.

Image classification: This study applied some remote sensing indices as shown in Table 2. Besides, the common method was used as unsupervised classification based on iterative self-organizing data analysis (Isodata) (Shanmugam et al., 2006; Giri et al., 2007) in this study.

Table 2. Equations of vegetation indices used for mangrove extent mapping

Vegetation Indices	Equations	References
NDVI (Normalized Difference Vegetation Index)	(NIR - RED)/(NIR + RED)	(Rouse et al., 1974; Thu and Populus, 2007)
TVI (Transformed Vegetation Index)	√(NDVI + 0.5)	(Broge and Leblanc, 2001)
SAVI (Soil Adjusted Vegetation Index)	[(NIR -RED)/(NIR+RED+L)] x (1+L) , L = 0.5	(Hue, 1988)

Carbon stocks estimation by GIS interpolation:

The Inverse Distance Weighted (IDW) interpolation is a technique, which is largely a reflection of Waldo Tobler's first law in geography, stating everything is related to each other, but near things are more related than distant things (Tomislaw, 2009). The IDW is a mapping technique, an exact and convex interpolation method that fits only the continuous model of spatial variation. The IDW allows to derive the value of a variable at some new location using values obtained from known locations (Oke et al., 2013). This is expressed mathematically in the equations given below (Tomislaw, 2009).

To determine the values of unknown points by computing the weighted average of the accurate values in the neighborhood of each pixel. In particular, this method is very easy and fast. The formula is as follows (Amstrong and Marciano, 1994; Bartier and Keller, 1996):

$$Z_j = \frac{\sum_{i=1}^{N} W_{ij} Z_i}{\sum_{i=1}^{N} W_{ij}}$$

Where: Z_j is the estimated value at grid location J; Z_i is the known value at control point location i, and W_{ij} is the weight that controls the effect of control points on the calculation of z_j.

Accuracy assessments:

During the survey, study collected 424 points in the field and divided into 4 different status categories, namely mangrove forests (157 GPS points); aquaculture, including shrimp ponds, clam farming (103 GPS points); water (51 GPS points); others, including mudflats, non-mangrove plants (113 GPS points). Accuracy assessments were conducted by comparing a set of field GPS points in the different types of land uses/covers, which were collected by GPS with the satellite imagery classified by SAVI, NDVI, TVI indices; unsupervised classification approach. The accuracy of classified map was assessed as below:

Classified map accuracy = (Total accurate GPS points / Total GPS points) x 100

To evaluate accuracy of interpolated carbon and biomass maps, study randomly used 30% of sampling plots, which were identified by GPS 650. The IDW interpolated values were then compared with values calculated from field-based data collection as the equation below:

IDW map accuracy = Interpolated values - Measured values, where Interpolated values were calculated by IDW method, while measured values were obtained from field data survey.

3. Results and discussions

3.1. Current status of mangroves

As a result shown that NDVI (Fig. 4) and Unsupervised Classification (Fig. 5) were calculated at the highest accuracies of 85.6% and 81.8%, respectively. In comparison with a similar study, this study had higher accuracy with NDVI (85.6%) compared with similar study (83.5%) of Dat and Yoshino (2015). Classified maps showed clearly four categories. Mangrove forests mostly distribute outside of the aquaculture ponds. Small areas of mangrove forests sparsely distribute in some shrimp ponds and almost undeveloped due to no tide and lack of nutrient alluvium.

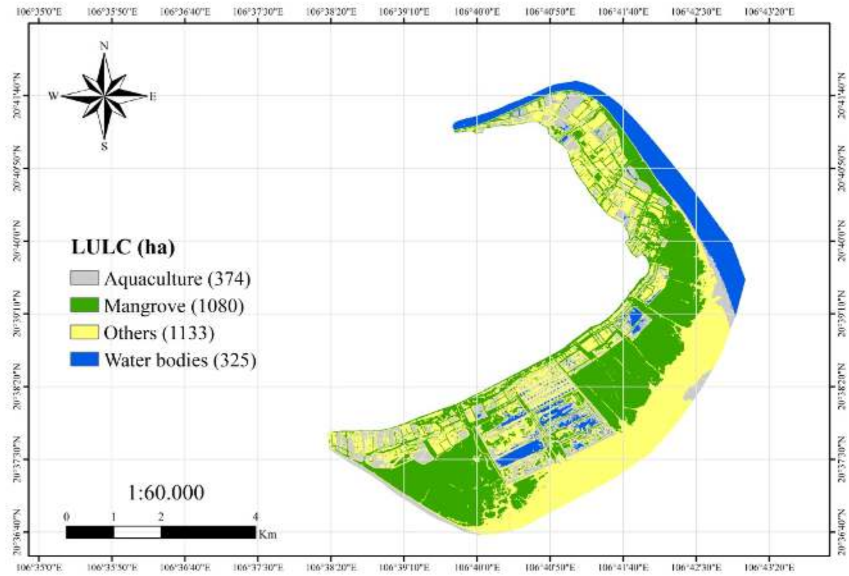

Figure 4. Mangrove extents classified by NDVI (Sentinel 2A 05 July 2018, 85.6%)

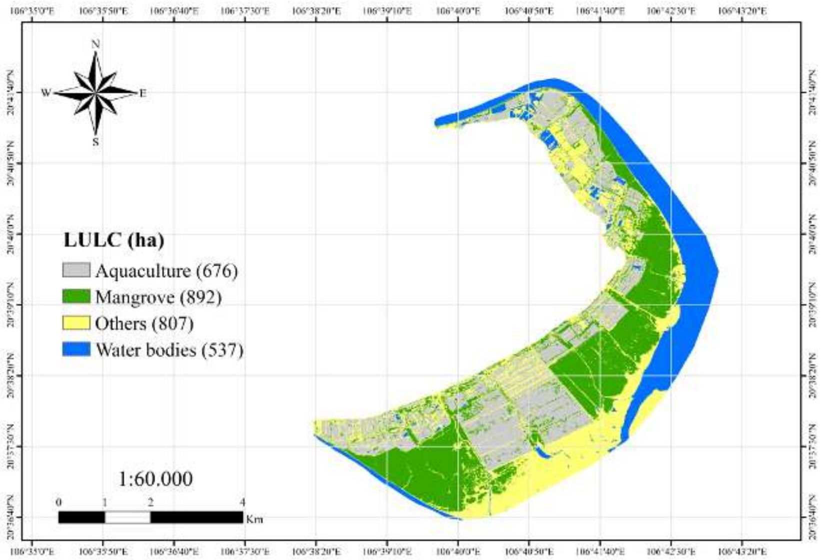

Figure 5. Mangrove extents classified by unsupervised classification (Sentinel 2A 05 July 2018, 81.8%)

Despite the large area of afforestation land (Table 3), the mangrove area of Tien Lang district is just 986 ha (2017). The main reason was the land use change for the purpose of aquaculture in the 1990s. Shrimp farming expansion and aquaculture development were encouraged and promoted by the government and the People's Committee of Hai Phong. As a consequence, mangrove areas were converted to shrimp farms led by the high economic benefits from shrimp exports (Tuan et al., 2003). In fact, large areas of mangroves were converted to shrimp aquaculture ponds not only in Tien Lang but also in Vietnam (Seto and Fragkias, 2007).

Table 3. Accuracy assessments of classified maps of mangrove extents

No	Method	Mangrove (ha)	Non-mangrove (ha)			Total	Accuracy (%)
			Others	Water bodies	Aquaculture		
1	UCM	892	807	537	676	2912	81.8
2	NDVI	1080	1133	374	325	2912	85.6
3	SAVI	1137	901	469	405	2912	67.5
4	TVI	1406	850	402	254	2912	58.3

NDVI: Normalized Difference Vegetation Index, SAVI: Soil Adjusted Vegetation Index, TVI: Transformed Vegetation Index, UCM: Unsupervised classification.

3.2. Mangrove structures, biomass, and carbon estimation-based field survey

The mangrove species identified is mainly *Sonneratia caseolaris* because of the influence of flooded tidal area and strong waves. From 1996 to 2009, the Mangrove Ecological Research Center together with ACTMANG of Japan supported the planting program of 1309 *Sonneratia caseolaris* trees in Hai Phong, most of which were planted in coastal Tien Lang District (People's Committees of Tien Lang, 2017).

As field measurement shown that *Sonneratia caseolaris* with the diameter at breast height ranged from 9.1 cm to 19 cm and the tree height was measured at from 6 m to 10.5 m, whereas *Kandelia obovata* had diameter at breast height from 3.3 cm to 6.2 cm and the height was measured at from 2.9 m to 4.9 m. The plots with mixed species distributing in the southern part had lower biomass, the lowest was calculated at 91 ton ha^{-1} and also carbon stocks had the lowest at 42.8 ton ha^{-1} (Table 5) than those of mangrove with pure *Sonneratia caseolaris* forest, locating in the eastern and northern part with the highest biomass of 829.6 ton ha^{-1} and 389.9 ton ha^{-1} of carbon stocks (Table 6).

Table 5. Mixed mangroves forest structure and data analysed

Plots	Species	DBH (cm)	Tree height (m)	Biomass (ton/ha)			Carbon stocks (ton/ha)
				AGB	BGB	Total	
1	SC	11.8	8.7	68.44	14.01	91.03	42.78
	KO	5.9	4.8	6.11	2.47		
2	SC	24.2	10.0	213.07	30.18	250.96	117.95
	KO	6.2	4.9	5.49	2.23		
5	SC	11.7	8.6	68.67	12.90	82.42	38.74
	KO	4.5	4.4	0.62	0.24		
6	SC	10.1	7.6	121.44	22.28	144.81	68.06
	KO	3.3	3.6	0.79	0.29		
7	SC	9.3	6.3	85.23	15.47	126.73	59.56
	KO	5.7	2.9	18.40	7.62		

SC: *Sonneratia caseolaris*, KO: *Kandelia obovata,* DBH: Diameter at breast height.

Table 6. Monoculture *Sonneratia caseolaris* in Tien Lang coast

Plots	DBH (cm)	Tree height (m)	Biomass (ton/ha)			Carbon stocks (ton/ha)
			AGB	BGB	Total	
3	14.8	7.5	202.91	36.17	239.07	112.36
4	16.9	7.9	248.63	41.52	290.16	136.37
8	11.4	8.7	111.91	20.81	132.72	62.38
9	12.1	6.6	223.55	35.82	259.37	121.91
10	9.1	7.2	115.95	21.52	137.47	64.61
11	10.7	6.6	134.52	22.36	156.88	73.73
12	11.2	7.4	138.65	26.52	165.17	77.63
13	11.4	8.3	194.97	30.71	225.69	106.07
14	16.9	6.0	733.66	95.91	829.57	389.90
15	19.0	10.5	376.14	54.09	430.24	202.21

DBH: Diameter at the breast height

However, the monoculture *Sonneratia caseolaris* forest had biomass and carbon stocks significantly higher than that of mixed mangrove forests. With mixed *Sonneratia caseolaris* and *Kandelia obovata*. As a result, the mean of above and below ground biomass and total were calculated at 117.2 ton ha^{-1}, 21.5 ton ha^{-1},139.2 ton ha^{-1}, respectively, while another study by Hanh et al., (2016) indicated that were 53.4 ton ha^{-1} and 10.99 ton ha^{-1}, 64.2 ton ha^{-1}, respectively.

Biomass and carbon estimation-based interpolation method:

IDW interpolation has shown that higher carbon stocks are found near the shorelines of the eastern and northern parts of the mangrove forests (Fig. 6). There is a positive correlation between above-ground biomass and above-ground accumulated carbon stocks and they have nearly the same accuracy at 61.1%.

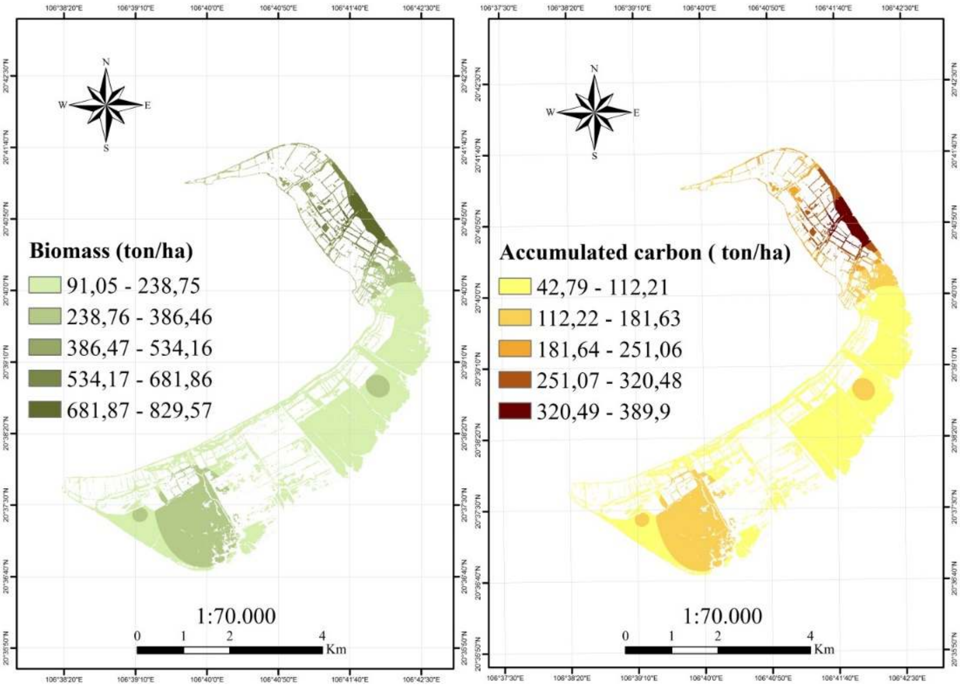

Figure 6. Above-ground biomass and accumulated carbon (ton/ha)

3.3. Soil carbon stocks estimation from field-based data collection

The results showed that soil organic carbon stocks in 100 cm depth ranged from 100.95 ton ha^{-1} to 227.65 ton ha^{-1} (Table 7). Soil carbon was the highest in mixed mangrove stands accouting for 227.65 ton ha^{-1} while mono *Sonneratia caseolaris* stand was from 100.95 to 157.93 ton ha^{-1} (Table 6). Another study in Ca Mau and Can Gio (in the South of Vietnam) showed that soil carbon stocks at the depth of 0÷100 cm ranged from 258.51 to 479.29 ton ha^{-1}, and from 245.2 to 309.9 ton ha^{-1} (Fujimoto et al., 2000), respectively which showed far higher soil carbon stocks of mangroves. However, the condition of mangroves between Hai Phong (in the North) and Ca Mau (in the South) are much different.

Table 7. Estimation of soil carbon stocks in different depths (cm, ton/ha)

Plots	GPS coordinates		0÷20	20÷40	40÷60	60÷80	80÷100	Total
	Latitude	Longitude						
1	20.6223	106.6489	71.85	56.33	38.98	32.85	27.64	227.65
2	20.6231	106.6531	60.82	44.65	43.98	37.36	27.10	213.91
3	20.6239	106.6573	40.00	32.28	29.49	27.96	24.02	153.74
4	20.6233	106.6623	39.05	31.60	30.63	22.70	16.02	100.95
5	20.6391	106.6864	44.61	30.38	30.68	24.10	15.40	145.17
6	20.6401	106.6896	34.40	28.92	24.52	22.72	19.67	95.83
7	20.6428	106.6923	34.60	26.13	22.15	25.15	13.11	121.13
8	20.6451	106.6949	31.08	20.08	20.64	19.35	15.01	106.15
9	20.6484	106.6998	28.67	28.07	22.33	16.98	19.86	115.90
10	20.6547	106.7019	36.28	25.32	26.59	21.77	20.28	130.25
11	20.6575	106.7038	34.73	33.37	20.27	22.66	21.05	132.08
12	20.6606	106.7060	52.98	29.02	21.95	19.38	15.26	138.58
13	20.6654	106.7042	39.98	38.29	21.63	20.03	15.29	135.22
14	20.6796	106.6983	51.42	34.97	28.37	21.64	21.53	157.93
15	20.6839	106.6954	44.12	43.26	21.09	25.81	22.16	112.32

The average of soil carbon among mangrove stands at the depth of 100 cm was estimated at 146.96 ton ha^{-1}, while soil carbon at the depth of 0÷20 cm was 42.98 ton ha^{-1}, which was represented around 29.2% of the total soil carbon stocks. On the contrast, soil carbon stocks at the depth of 80 ÷ 100 cm were more stable than other layers throughout all plots with a variation of 14.5.

Compared with 2 controlling plots set up in the mudflat areas where had the most affected of the sea waves and the tide, total soil carbon stocks were 79.17 and 58.73 tons ha^{-1}, much lower than forest land (Table 7). This is obvious, soil carbon storage and understory plant species richness increased with tree species richness (Gamfeldt et al., 2013).

Soil carbon interpolation:

As a result showed that the side of seaward mangroves and direct exposure to the sea had less amount of soil carbon stocks, as calculated at 115.9 ton ha^{-1} to 138.25 ton ha^{-1} in Fig. 7. In contrast, the southwest of study site had a small area directly exposed to the sea, so that mangroves had slightly forces of the sea waves, thus the values of soil surface carbon were higher than other areas. The interpolated of soil carbon was assessed at 89.3% accuracy. This result confirms that the interpolation method for soil carbon are reliable and this method can be used for this study site.

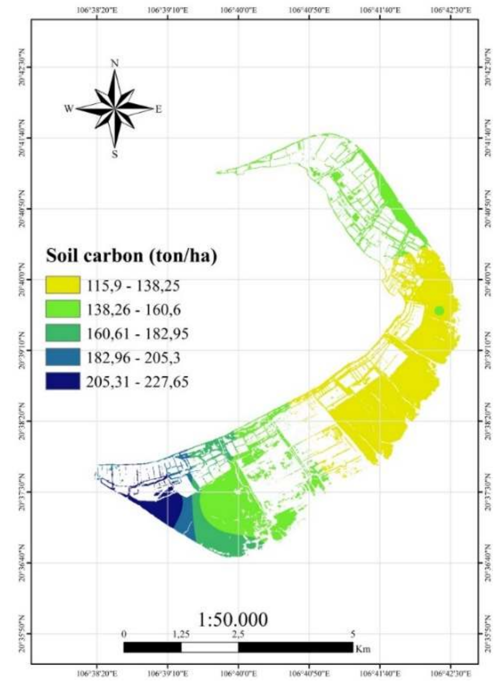

Figure 7. Inverse Distance Weighted interpolation of soil organic carbon stocks

4. CONCLUSION

Mangrove forests in Tien Lang district, Hai Phong City are dominated by two species, namely *Sonneratia caseolaris* and *Kandelia obovata*. There are two types of mangrove forests identified, including mixed mangrove forests (with two mangrove species) and monoculture *Kandelia obovata* forests. The NDVI index is the most suitable for mangrove mapping with accuracy of 85.6%, followed by Unsupervised classification with accuracy of 81.8%. A total of carbon stocks was calculated from 42.78 ton ha^{-1} to 117.95 ton ha^{-1} for mixed mangrove forests, while monoculture *Sonneratia caseolaris* ranged from 62.38 ton ha^{-1} to 389.9 ton ha^{-1}. Soil organic carbon stocks in 100 cm depth was estimated ranging from 100.95 ton ha^{-1} to 227.65 ton ha^{-1}. The study has also confirmed that the potential of using GIS IDW interpolation together with collecting field data approach used estimating carbon stocks is reliable and applicable in Tien Lang district. Thus, this method should be applied to other similarly coastal areas in the North of Vietnam.

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ƯỚC TÍNH TRỮ LƯỢNG CÁC BON RỪNG NGẬP MẶN BẰNG DỮ LIỆU VIỄN THÁM SENTINEL-2A VÀ ĐIỀU TRA THỰC ĐỊA TẠI HUYỆN TIÊN LÃNG, THÀNH PHỐ HẢI PHÒNG

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TÓM TẮT

Rừng ngập mặn ven biển huyện Tiên Lãng được lựa chọn để ước tính trữ lượng các bon rừng ngập mặn và các bon trong đất. Thực địa được tiến hành để điều tra cấu trúc rừng ngập mặn tại 15 OTC với kích thước 900m^2, trong mỗi OTC, 3 ô phụ với kích thước 100 m^2 được thiết lập tại xã Đông Hưng, Tiến Hưng và Vinh Quang. Để chọn phương phân loại phù hợp nhất cho huyện Tiên Lãng, nghiên cứu đã sử dụng một số phương pháp phân loại ảnh bao gồm các chỉ số viễn thám (NDVI, SAVI, TVI) và phương pháp phân loại không kiểm định. Kết quả đánh giá độ chính xác của NDVI, SAVI, TVI và phân loại không kiểm định lần lượt là 85,6%; 67,5%; 58,3%; và 81,8. Như vậy, chỉ số NDVI được xác nhận là phù hợp nhất để lập bản đồ rừng ngập mặn, tiếp theo là phân loại không kiểm định. Tổng trữ lượng các bon ước tính từ 42,78 tấn ha^{-1} đến 117,95 tấn ha^{-1} đối với rừng ngập mặn hỗn giao, trong cây bần chua thuần loài từ 62,38 tấn ha^{-1} đến 389,9 tấn ha^{-1}. Trữ lượng các bon hữu cơ trong đất ước tính từ 100,95 tấn ha^{-1} đến 227,65 tấn ha^{-1}. Kết quả nội suy không gian sinh khối trên mặt đất cho độ chính xác là 61,1%, trong khi các bon trong đất là 89,3%. Rừng ngập mặn ở Tiên Lãng có khả năng tích luỹ một lượng lớn trữ lượng các bon trên mặt đất và trong đất.

Từ khoá: các bon, các bon hữu cơ trong đất, chỉ số thực vật, phân loại không kiểm định, rừng ngập mặn, sinh khối.

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