ESTIMATION OF CARBON STORAGE IN PARA RUBBER PLANTATIONS USING THAICHOTE AND OBJECT BASED IMAGE ANALYSIS: EASTERN THAILAND

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Abstract: This study aims to estimate the carbon stock and sequestration in Para rubber plantation of East Thailand using the THAICHOTE (previously name is THEOS: Thailand Earth Observation System). For that purpose we identify the areas of every stage class Para rubber plantation by the analysis of object based classifications and we map the carbon stock and sequestration of each Para rubber class using specific biomass and carbon content equations. THAICHOTE data include Multispectral image (4 bands at 15x15 m spatial resolution), Panchromatic image (2x2 m spatial resolution) and Stereo image, data acquisition from December 2011-April 2012. The preliminary investigated area is located in Wangchun, (Eastern, Thailand) and covers about 20 Km^2. Classification the stage classes by object based image analysis approach with integrated watershed segmentation and stage class model. The stage class model was developed from variables such as reflectance, vegetation indices, texture and canopy height model (CHM). The stage class model has total accuracy at 90% and almost perfect agreement (kappa = 0.85) while the automatic generate of CHM has slight correlation (R^2 = 0.36). Thus, It was rejected of model construction suggesting that manual 3D stereo post edited or Light Detection And Ranging (LiDAR) both are able to construct the CHM. The results of this study indicate that for a total Para rubber biomass of 407,775 tons, the amount of stored carbon is of 203,888 tons C. Mature stage of Para rubber plantation exhibits the highest capacity of sequestering with a global flux of 891 tons C./ Km^2/year and average sequestering at 645 tons C./ Km^2/year.

1. INTRODUCTION

The removal of Carbon from the global atmosphere, its storage in more productive agricultural soils, grasslands and woody perennials, and the ability to trade carbon credits through market structures may potentially define a number of win–win opportunities (Skole and Simpson, 2010). This idea is now part of the Clean Development Mechanism (CDM) recommended by the Kyoto Protocol which invite countries and companies to offset their carbon emissions by supporting tree planting projects. Many tree species also yield additional high-value products offer the opportunity for creating synergistic benefits by removing carbon from the atmosphere and providing new sources of income for farmers worldwide. According to the Global Environmental Outlook Three 2002, the issue on climate change has directed attention to the role of land and forests as terrestrial store of carbon. Forests play an important role in the global carbon cycle as carbon source and sink, and their management or destruction significantly affects the course of global warming. This is because more than half of the terrestrial carbon stocks are contained in the forests, 20 percent of which is stored in tropical forests. As carbon source, the forest can release carbon from deforestation or removal of forest biomass. In 1980's and 1990's carbon emission due to forest biomass removal was estimated at 1.6 – 1.7 gigatons a year (Watson, 2000). According to report of office of agricultural economics, Thailand, Currently Thailand has a top of the world for exported product of para rubber. Since, 2006 Thailand has para rubber area as 2,032 km^2 and total exported were 3,056,770 ton. The product of para rubber was store carbon to long stay, that is environmental friendly (Chuntuma, 2005). Para rubber is a perennial plantation with very high growth rate potentially candidate to reduce CO^2 from air (Viriyabuncha, 2003). The quantification of the high biomass fast growth is one of the key to evaluate the potential plant ability to sink CO^2.

1.1 Object base image analysis

Most studies focused on pixel based classification. Legacy techniques of remote sensing classification such that supervised or unsupervised, are most often pixel based assigning a class label to each individual pixel. They are based on distance or similarity measures in feature space. That is disadvantage or class uncertainly of technique because was used reflectance information only for identify. However the real word object cannot represent by individual pixel such as pepper noise problem , explicit in case image high resolution classify. In contrast, segmentation in remote sensing, identifies homogeneous image objects based on spatial properties. Spatial relations between pixels are an important source of information that can help in object extraction from remotely sensed imagery. The focus of classification techniques, therefore, is on thematic pixel information, whereas, for segmentation techniques it is on spatial information. Segmentation is used to identify image objects. In a subsequent object-based classification, information about these objects, like reflectance distribution, object shape and size, and object semantics can be used to improve classification (Lucieer, 2004). The purpose of object based is semi-automate process of feature extraction from imagery. The field of image are construction variables used by a human knowledge or experimented for identification object image. An object based image approach may reduce uncertainty and more precisely for Carbon mapping.

2. OBJECTIVES

We purpose to main objectives such as

- Developed model for classification stage class of Para rubber plantations.
- Quantify the carbon storage capacity in each stage class of Para rubber plantation using an integration of field measurements and remote sensing.

This study focuses on the use of THAICHOTE (Thailand Earth Observation System) and object based image analysis was also utilized in the study. In addition we will use specific equation for determination of total biomass and secondary data for carbon content of Para rubber plantations. We selected preliminary investigated area is in Wangchun, (Eastern, Thailand) and cover to 20 km^2.

3. METHODOLOGY AND DATA SOURCES

The main data sources were selected THAICHOTE (previous name is THEOS : Thailand Earth Observation System) which include multispectral images, panchromatic images and stereo pair images which acquisition locate in Eastern Thailand and duration time at December 2011 to April 2012. The THAICHOTE data support by Geo-Informatics and Space Technology Development Agency (GISTDA), Thailand and details shown in Table 1.

Table 1: THAICHOTE data sources.

THECHOTE multispectral images. (spatial resolution 15 m.)			
Scene ID	Center of position	Bands	Acquisition date
SCENE T1 M 2011/12/27 03:22:18.0 0265-0323 3700	E101°31' 36" N12°53' 26"	1 (0.45-0.52 um.), 2 (0.53-0.60 um.) 3 (0.62-0.69 um.), 4 (0.77-0.90 um.)	December 27, 2011
THECHOTE panchromatic images. (spatial resolution 2 m.)			
SCENE T1 P 2011/12/27 03:22:17.9 0265-0324 5000	E101°31' 44" N12°53' 46"	0.45-0.90 um.	December 27, 2011
THECHOTE stereo images. (level 1A)			
Scene ID	Center of position	Viewing angle (degree)	Acquisition date
SCENE T1 P 2012/04/03 03:34:28.3 0265-0324 1200	E101°32' 44" N12°54' 53"	along 35.524439 across 21.101462	April 3,2012
SCENE T1 P 2012/04/03 03:34:24.9 0265-0324 1200	E101°35' 38" N13°06' 55"	along 35.521264 across 21.101122	April 3,2012

The steps of study is show in Figure 1 which include 5 topics such as Data preprocessing, Image enhancement, Forest Canopy Height Model (CHM) generation, Para rubber plantations classification and Determination of carbon sequestration and storage capacity.

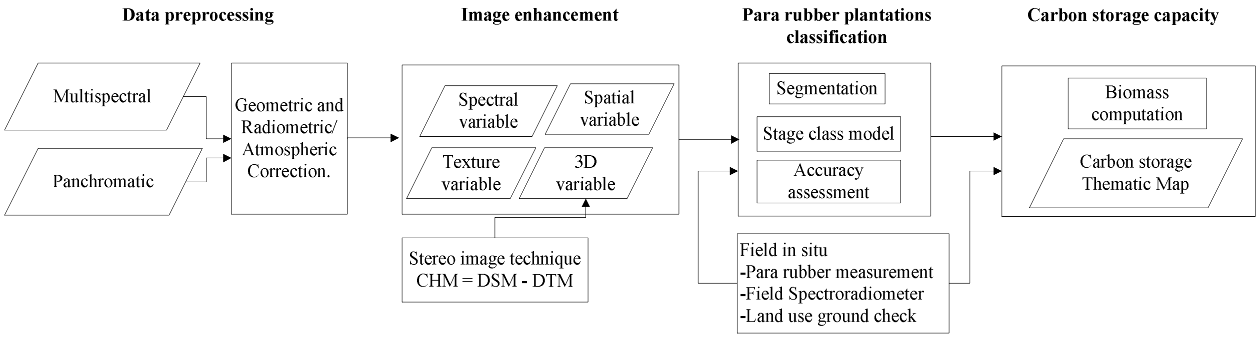

Figure 1: Flowchart of study.

3.1 Data preprocessing

- **Georeferencing**

The georeferencing was selected orthorectification approach (Grodecki and Dial, 2003) The rational polynomial coefficients (RPC) were build from physical sensor and exterior orientation (McGlone, 2004) and Digital Terrain Model obtained from Department of Land Development, Thailand. The projection selected Universal Transverse Mercator, World Geodetic System 1984 and Zone 48N datum (UTM WGS1984, 48N).

- **Atmosphere and Radiometric Correction**

The radiometric and atmospheric correction were selected COST model (Chavez, 1996). The fundamental is using two main steps process. The first step is to convert digital numbers (DN) to radiance using the bias and gain values which derive from header file of each scene. Then calibrated reflectance at the ground surface with COST model and aerosol 1% for atmospheric correction.

3.2 Image enhancement

The images enhancement are extend signal of spatial and spectral data. It useful to image classification for Para rubber plantations indicate vegetation indices, texture and color. First processes of enhancement were selected pan-sharpened High Pass Filter (HPF) approach (Ute G. et all., 2008) for THAICHOTE.

- **Vegetation indices**

The remote sensing indices or spectral enhancement derived from reflectance ratio at least two bands of spectral data. The study was select essential vegetation such as Normalized Difference Vegetation Index (NDVI) and Infrared Percentage Vegetation Index (IPVI).

Table 2: Equation of Vegetation Indices.

Index	Formula	Values Range	Sources
NDVI	(NIR-R)/(NIR+R)	-1 to +1	(Rouse et al.,1973)
IPVI	NIR/(NIR+R)	0 to +1	(Crippen, 1990)

Where : NIR = Near Infrared reflectance value (spectral band 0.77-0.9 µm)
RED = Visible Red reflectance value (spectral band 0.62-0.69 µm)

- **Texture analysis**

The study was selected Co-occurrence measures (Anys et al., 1994) to apply texture filters that are based on the co-occurrence matrix. We purposed necessary to types of texture measurement such as contrast, dissimilarity, entropy and variance. Then applied to THAICHOTE panchromatic data and design filter moving size 15 and shift value as 2 for computed.

- **Color Transformation**

The Intensity Hue Saturation (IHS) are color coordinate system advantageous in that it presents colors of eye recognition. This study was selected Red Green Blue (RGB) to IHS transform algorithm (Conrac Corporation, 1980). The process used 3 bands for transformations indicate Near Infrared (band 4) conversion to H (value range 0-360), Red (band 3) conversion to S (value range 0-1) and Green (Band 2) conversion to I (value range 0-1).

3.4 Estimation of Forest Canopy Height Model (CHM) generation

The study was selected stereo analysis approach to tree height of Para rubber plantations (object height). The image orientation was selected Rational Polynomial Coefficient (RPC). The parameter of THAICHOTE derived from header file (Camera model) of individual scene such as focal length (2,989 mm.), viewer along/across track angle from header file and camera lens pixel size (0.0065 mm.). The exterior orientation derived from manual Ground Control Point (GCP), Then calibrated X, Y, Z, omega, phi and kappa for RPC model. The stereo measurement depend on stereo image matching. This study was selected automated tie points base on hierarchical matching and control Root Mean Square (RMS < 2) of Y parallax geometry to obtained the point cloud (X,Y,Z). Then generated Digital Surface Model (DSM) using point cloud which derived from tie point and parallax geometry approach. The surface was selected Triangulated Irregular Network (TIN) for interpolation Z value (Height object). The Digital Terrain Model (DTM) generated by points cloud as bare ground data (non-tree/non-building pixel) or road network for interpolation. The points cloud for DTM generate derived from inverse data of remote sensing indices such as

Normalized Different Vegetation Index (NDVI), then calculate to difference surface between DSM and DTM to obtained Canopy Height Model (CHM).

3.5 Para rubber plantations classification

The classification of Para rubber plantations were selected object based image analysis approach. The object based image analysis is consist 3 steps such as Image segmentation, Para rubber plantations stage class model, Data refinement and Accuracy assessment. The prior segmentation was selected THAICHOTE pan-sharpened image and transformation to grey scale used independent components (IC) analysis (Hyvarinen and E, 2000). The image segmentation was selected watershed by immersion algorithm (Vincent and Soille, 1991). The watershed segmentation were calculates a gradient map for separate the object of image which indicate to vector boundary of Para rubber plantations areas. The merging of boundary segmentations base on the Full Lambda-Schedule algorithm (Robinson, Redding and Crisp, 2002) which there are focus on iteratively merges adjacent segments based on a combination of spectral and spatial information.

The Para rubber stage class model was developed by rule based approach. The rule based was constructed of training areas of zonal attribute of stage class which threshold determination and linked multi threshold by logical operation such as AND, OR, NOT. The zonal attribute are summarizes statistics and perform stage class model. The zonal attribute derived from variables such as Spectral, Vegetation indices, Color, Texture, Spatial and 3D information of determine to stage class of Para rubber plantations. This study define stage class to 3 classes base on physical characteristic of Para rubber plantation indicate Young stage (2 - 8 years) , Harvested stage (>8 - 20 years) and Mature stage (>20 years). The zonal were used boundary derived from image segmentation process and then calculate statistics into attribute of variables such as Minimum, Maximum, Mean, Range and Standard deviation. In addition the fuzzy logic was selected to threshold determinate for resolve uncertainly stage class of Para rubber plantation. The data refinement was selected the morphologic analysis such as operator dilate, erode, open and close for object boundary quality. In addition database of Forest, Non-forest, Urban, Water, Road, Bare soil were used to masking which derived from Geographic Information System (GIS) and Vegetation indices. Then, keep results for accuracy assessment.

The accuracy of Para rubber plantations classification was manipulated using Kappa index (Cohen, 1960) and confusion error matrix for comparison results. The Confusion error matrix using compared the actual result from ground truth data with result from Para rubber plantations stage class model.

3.6 Determination of carbon sequestration and storage capacity

- **Data Sampling**

A total of 60 sample plots were established on the plantation areas. Twenty sample plots with dimension of 20 x 20 meters were laid over in each identified stage class area. In each plot, average 19 trees in samples plot. Traditional cultivate of Para rubber plantation in study site as distance row (7 meters) x column (3 meters) or average amount 78 trees/Rai (Thai unit measurement as 1,600 m^2), 48,750 Trees/Km^2. Diameter-at-breast height (DBH) at 1.5 meters and total height of individual trees were measured. The geographic location or coordinates of each tree were also recorded.

- **Biomass Computation**

Diameter, Girth and height measured from the field were used to determine the biomass of individual trees. Species – specific *RRIM 600* equation (Table 3) developed by (Chuntuma et all., 2005) was used in the computation of biomass of individual trees in each stage class. The total biomass per plot sample was computed by summarized all part of Para rubber plantation.

Table 3: Biomass equations of Para rubber plantation.

Part	**Equation**	**R^2**	**Remark**
Dry mass (Y)	$Y = 0.0082\ X^{2.5623}$	r^2=0.96	(Chuntuma, et all, 2005)

Where : X = Girth (cm.)

So, that total biomass storage was computed by : biomass of each stage classes (kg) x Area of each stage class (m^2)

- **Carbon storage and sequestration capacity**

Secondary data for the average carbon content in Para rubber plantations at 50% was adapted from the study of (Srisunon, 2011) and (Nilubol, 2008) which is consistent with the default value of carbon content of Para rubber locate in East and South Thailand. The carbon content value was used to determine the carbon density for all stage classes. The rate of carbon sequestration or the quantity of carbon accumulated per year for each stage class.

4.RESULTS

This study, we purpose investigated to preliminary area. The preliminary investigate area is locate at the coordinates of 773149 E, 1470376 N and 778149 E, 1434376 N of Wangchun district, Rayong province, northern Thailand. It is covers about 20 Km^2. Multispectral band 1-4 and Panchromatic image of THAICHOTE were used in data pre-processing. The 4 bands and panchromatic of were geo-reference and radiometric/atmospheric correction prior to analysis. Then the image has been pan-sharpened with High Pass Filter (HPF) shown in Figure 2.

4.1 Enhancement

- **Vegetation indices**

The result of yielded NDVI and IPVI values as (-0.17) - (1.00), (0.41) - (1.00) respectively and shown in Figure 4a-4b. The NDVI was used to delineate masked data from non-vegetation areas. The masked data derived from threshold NDVI value > 0.23 which is meant para rubber plantation areas. Only vegetation areas were masked shown in Figure 3.

- **Texture analysis**

The texture analysis was designed to aid in stage class identification by differentiating physical characteristic from crown cover of para rubber or another plants. The result of co-occurrence measures contrast, dissimilarity, entropy and variance as (0) – (37.41), (0) – (4.62), (0 – 4.58) and (0 – 19.58) respectively and shown in Figure 4c-4f.

- **Color Transformation**

The color transformation was designed to aid in stage class identification by differentiating leaf color from para ruber. The result of color transform Hue (H), Saturation (S) and Intensity (I) as (0) – (360), (0) – (0.63) and (0) – (1) respectively and shown in Figure 4g-4i.

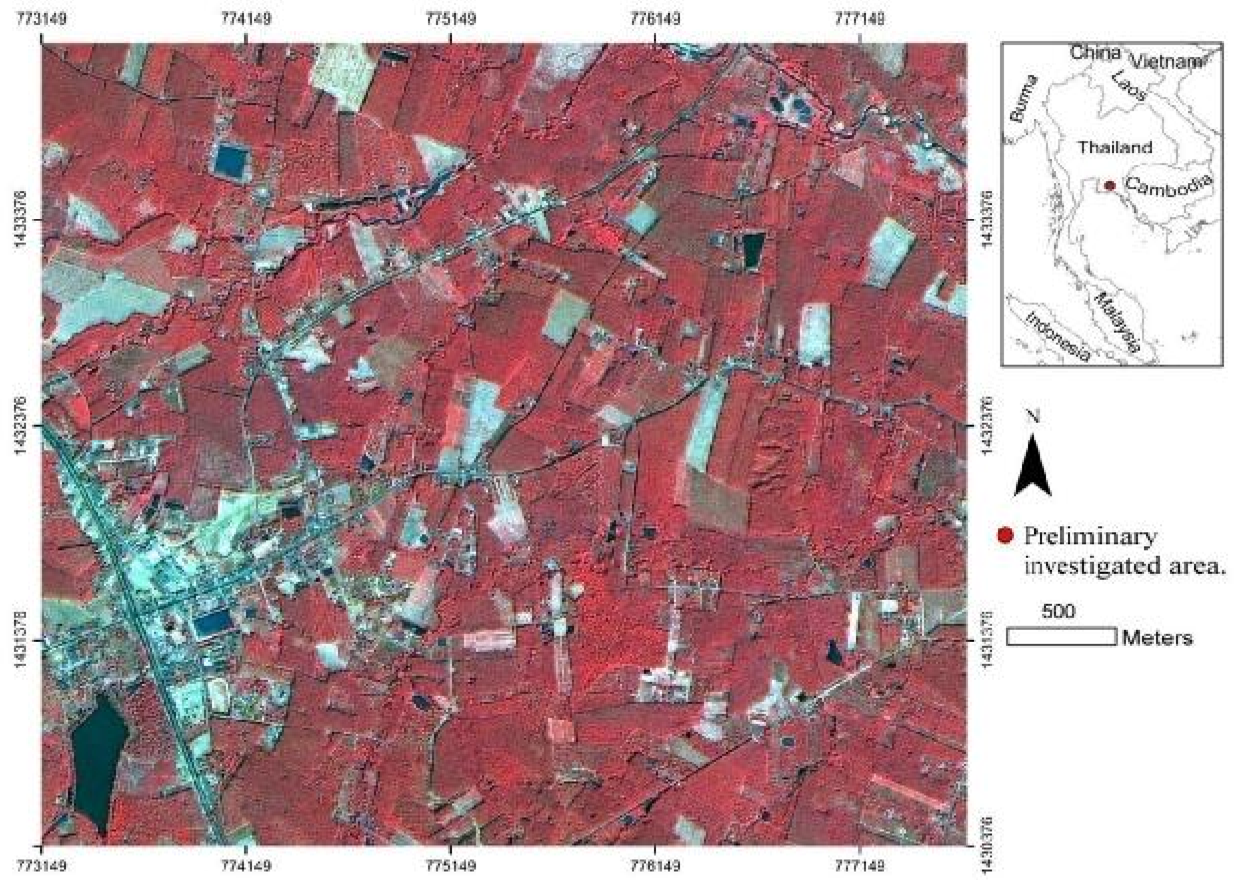

Figure 2: The preliminary investigate area of Wangchun district, Rayong province (false color composite RGB = NIR,R,G, map scale 1:20,000), © THAICHOTE Image Copyright 2011 GISTDA.

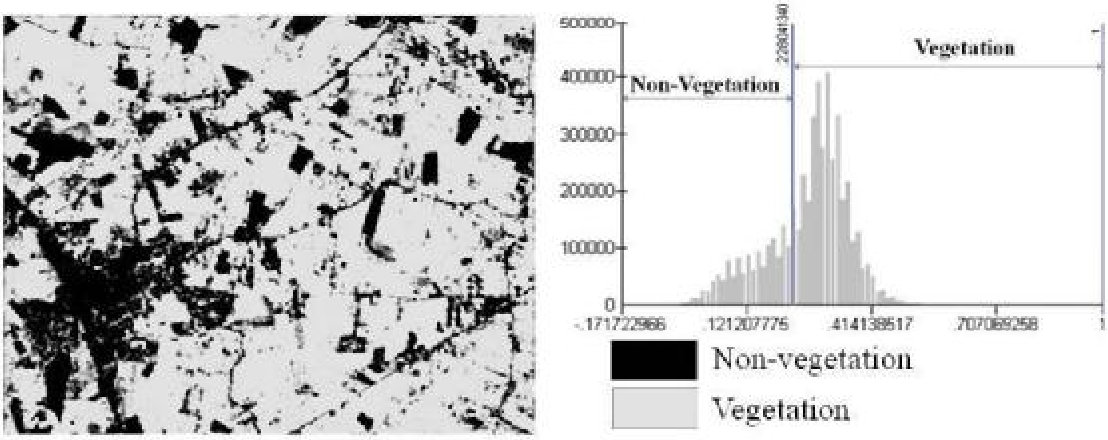

Figure 3: Non-vegetation mask areas, Threshold for vegetation and non-vegetation.

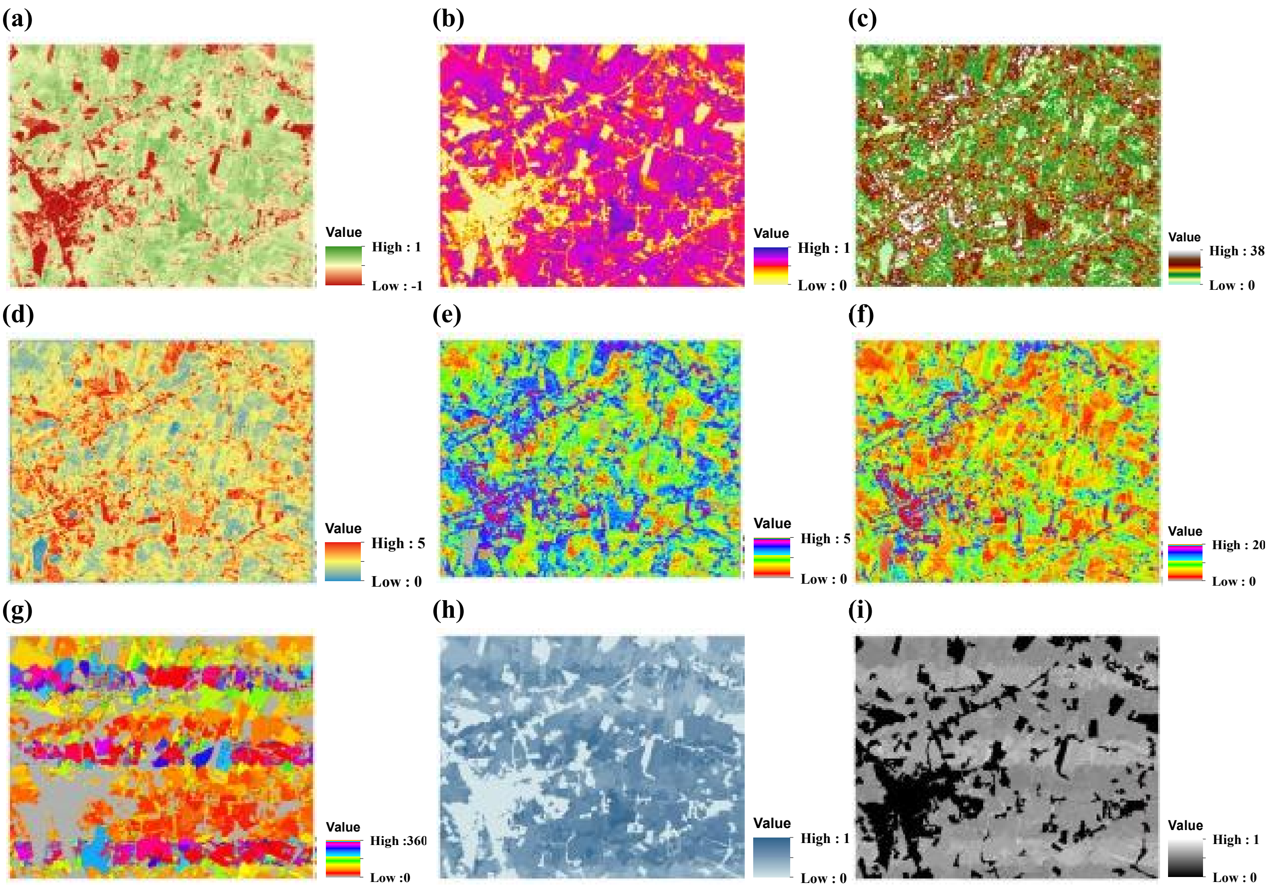

Figure 4: Images enhancement ; (a) NDVI, (b) IPVI , (c) contrast, (d) dissimilarity, (e) entropy, (f) variance, (g) hue , (h) saturation , (i) intensity.

4.2 Canopy Height Model (CHM) generation

Figure 5a. show the generated CHM of the investigated preliminary area with the green triangle presenting checking points (green symbol). The height accuracy was checked by the 236 checking points, which show a slight correlation (RMSE=2.95 m. and $R^2 = 0.36$) between actual measured and derived stand height for vertical accuracy shown in Figure 5b. The maximum differences between measurement and prediction were 24.7 meters.

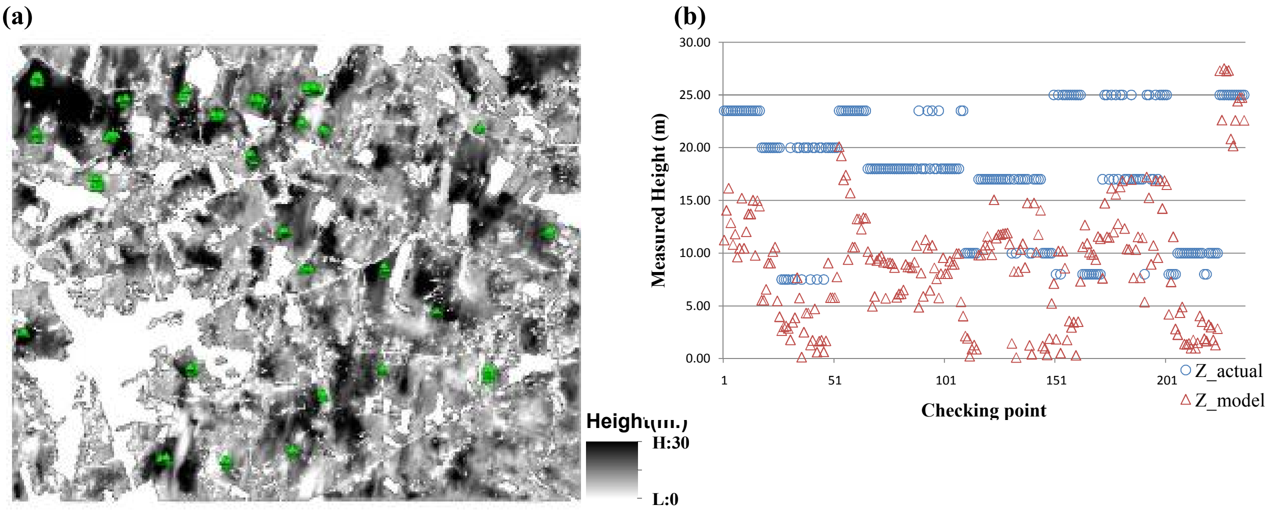

Figure 5: (a) CHM, (b) Comparison of the forest stand height between measurement (red) and prediction (blue).

4.3 Para rubber plantations classification

- **Stage class model**

The model developed are presented in Table 4. Variables from spectral bands (NDVI, IPVI) , texture (Contrast, Entropy, Dissimilarity, Variance), color (I,H,S) were used to developed rule based model that best describes the stage class of para rubber plantation. The CHM has been rejected to obtain these model because that is slightly correlation. Zonal statistic of variables were accepted Range, Mean and Max by highest covariance test. The vector boundary of zonal statistic derived from watershed segmentation image, shown in Figure 6. In addition fuzzy tolerance was utilized into rule stage class and replace uncertainly stage class with harvested stage.

Table 4: Stage class model.

Cate gories	stage class	Rule based statement (descript)
1	Young Stage (2-8 y.)	[NDVI-R (0.57- 0.65)] and [IPVI-R (0.27- 0.35)] and [Entropy-M (2.93-2.97)] and [Variance-M (2.89-2.97)] and [Contrast-R (17.90-17.98)] and [Dissimilarity-R (3.29 – 3.37)] and [I-R (0.6-1.4)] and [H-R (326-335)] and [S-Max (0.82 – 0.86)]
2	Harvested Stage (>8-20 y.)	[NDVI-R (0.48- 0.56)] and [IPVI-R (0.22- 0.30)] and [Entropy-M (2.69-2.77)] and [Variance-M (2.73-2.74)] and [Contrast-R (12.35-12.43)] and [Dissimilarity-R (1.07 – 1.15)] and [I-R (0.55-1.03)] and [H-R (277-286)] and [S-Max (0.71 – 0.79)]
3	Mature Stage (>20 y.)	[NDVI-R (0.05- 0.13)] and [IPVI-R (0.25- 0.34)] and [Entropy-M (3.82-3.90)] and [Variance-M (2.27-2.35)] and [Contrast-R (7.56 - 8.44)] and [Dissimilarity-R (1.78 – 2.58)] and [I-R (0.16-1.96)] and [H-R (346-356)] and [S-Ma (0.67 – 0.75)]

Remark : -R = Range, -M = Mean, -Ma = Max

THAICHOTE image was processed and used to classify various stage classes and its respective areas computed. The area of each stage class of Para rubber plantation was calculated based on the output thematic map of the object based image classification and data refinement, summarized in Table 5, Figure 7. The refinement data was post edited thematic map which used to subtract shadow object, build-up area, house, road, reservoir, natural forest and eliminate small area (<3200 m^2) with class neighborhood. In addition uncertainly data has been change to harvested stage class. The total area of para rubber plantation in Wangchun was computed at 13.38 Km^2. In general, mature stage class has the highest percentage (37%) in terms of area among the different stage classes in Wangchun. Young stage class has the least area (12.19%) and harvested stage class has area (19.94%).

Table 5: Summarized area of para rubber plantation.

Stage class	Young stage	Harvested stage	Mature Stage	Miscellaneous	Grand Total
Unit Km^2	2.44 (12.19%)	3.99 (19.94%)	7.40 (37%)	6.17 (30%)	**20.00**

(a) (b)

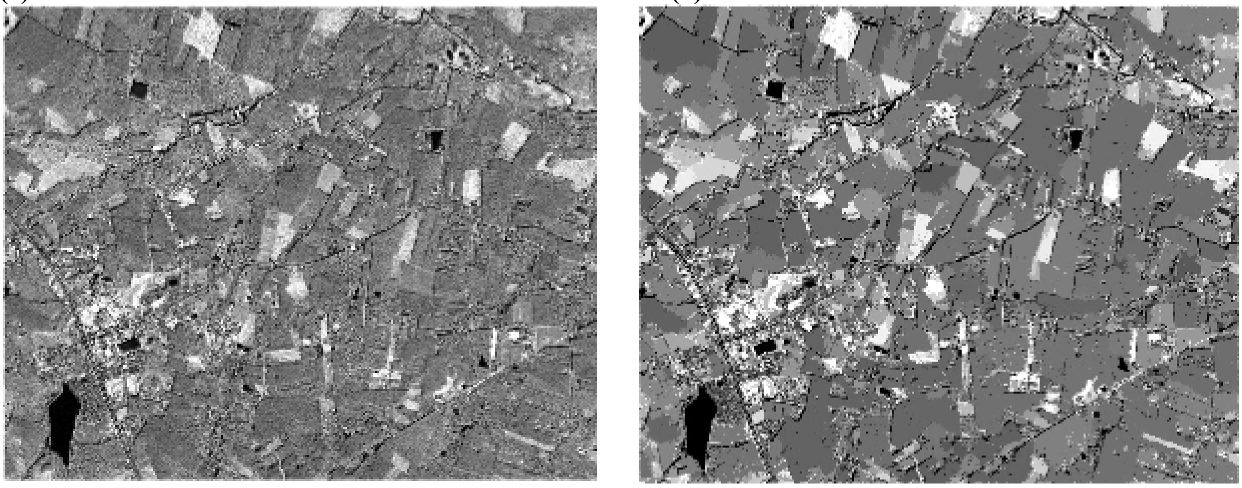

Figure 6: (a) IC image, (b) watershed segmentation image.

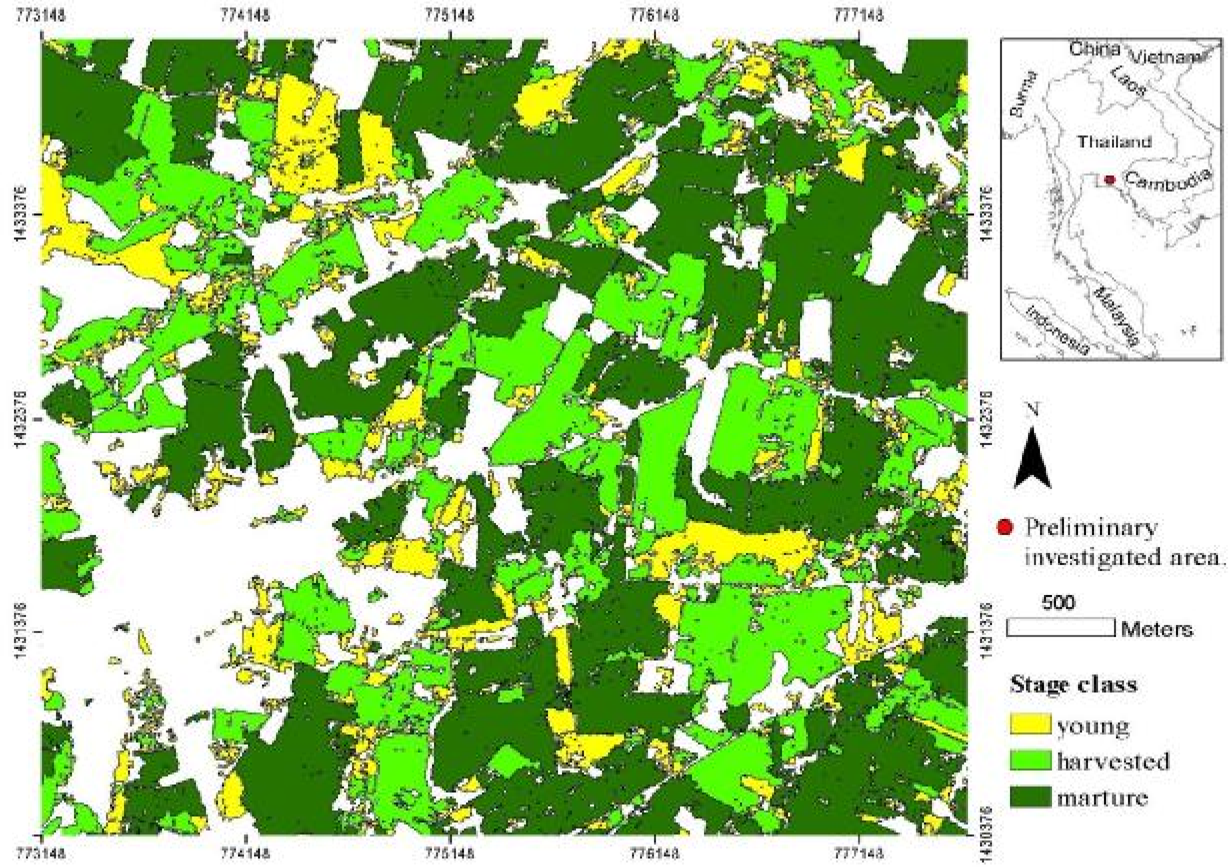

Figure 7: Thematic map of para rubber plantations (map scale 1:20,000).

- **Accuracy assessment**

A total of 14,233 sample checked points for all stage classes were selected from the ground truth data taken in April 2012. These sample points were used to assess the accuracy of the stage class classification based from the object based image analysis and the stage class model. The total accuracy (90.21%) and Kappa (0.85) was accepted almost perfect agreement, shows in Table 6.

Table 6: Accuracy assessment

		Ground truth			
		Young stage	**Harvested stage**	**Mature stage**	**Overall**
Stage class model	**Young stage**	2867			2867
	Harvested stage		4142		4142
	Mature stage	161	1232	5831	7224
	Overall	**3028**	**5374**	**5831**	**14233**
					Total accuracy = 90.21% , Kappa = 0.85

4.4 Carbon Sequestration and Storage Capacity of Para rubber Plantation

Based on the data collected from 60 sample plots for all stage classes, the biomass, carbon storage and sequestration capacity of Para rubber plantation were computed. The carbon stored and sequestered by para rubber was dependent on the amount of biomass produced by the plantation, shows in Table 7.

Table 7: shows biomass.

Stage class	Average Girth (cm)	Biomass (Kg/Tree)	Total Biomass (Ton/ Km^2)	Area (Km^2)	Total Biomass (Ton)
Young	35.47	76.74	3,741.09	2.44	9,128.25
Harvested	64.49	355.04	17,308.16	3.99	69,059.54
Mature	93.26	913.62	44,538.85	7.40	329,587.51
			Total	**13.83**	**407,775.30**

The carbon stored and sequestered for different stage classes of para rubber plantation varies. Para rubber plantations had total storage of 203,887.65 Ton C. of all stage class. Mature stage class has the highest capacity to store carbon since its biomass was also high at 890.78 tons C./ Km^2/year while young stage class has the least capacity at 467.64 tons C./ Km^2/year, average capacity of sequester at 645.12 tons C./ Km^2/year,shows in Table 8.

Table 8: shows C.storaged/sequestration.

Stage class	C.storaged (Ton C./ Km^2)	C.sequestration (Ton C./ Km^2/Year)
Young (average 4 years)	1,870.54	467.64
Harvested (average 15 years)	8,654.08	576.94
Mature (average 25 yeras)	22,269.43	890.78

5.CONCLUSIONS & RECOMMENDATIONS

The study using remote sensing was undertaken in order to classify stage classes of para rubber plantation and to quantify the capacity of the plantation to stored and sequester carbon. The pan sharpened of THAICHOTE was applied HPF technique which exhibit to realistic image.

Image classification on satellite imageries were performed based on object based image analysis. That approach like human eye interpretation with the use automated image recognition. The object based image analysis was used water-shed technique of segmentation. It is prior process for merged pixel to individual boundary of plantation. Then, identification by stage class model with the use variables of Vegetation indices, Texture and Color. The CHM was rejected of variables for construction stage class model because low accuracy. We suggestion to manual 3D stereo of post edited process. In addition the automatic estimation of height stand accuracy is dependent on stereo image quality of spatial, radiometric and view angle. Based on rule based of stage class model has accuracy assessment at 90.21% and almost perfect agreement, it is very high accuracy but not exactly into quality of boundary of plantation. However uncertainly class was force by harvested stage and small areas less than 3,200 sq. Km^2 were eliminate by border neighborhood class. Further research we will examine accuracy of boundary and will take different weight value of fuzzy tolerance.

In terms of carbon stored and sequestration, the mature stage has the maximum stored while the young stage has the minimum stored. Likewise, the mature stage could be highest capacity of carbon sequestration and young stage as lowest capacity. It can be concluded that the capacity of plantations to store and sequester carbon is dependent on its biomass and age of plantation. The trend in carbon sequestration for para rubber plantations is increasing until its rotation age is achieved (cycle ≈ 30 year). Then, the carbon accumulated by trees are kept in the wood and other by-products making the plantation as sink of carbon. Therefore, the para rubber plantations can be used to accumulate and reduce the carbon dioxide emitted to the atmosphere. Further research we will consider following are as :

- consider imagery and estimation canopy height model from drone platform and
- specific biomass equations of each part of para rubber plantation such as leaf, branch, trunk and root and
- calibration and refinement of the stage class model developed from multiple regression and machine learning.
- accuracy assessment for region boundary.

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