Mapping Tree Crown Dynamics and Biomass Accumulation Using LiDAR Derived Canopy Metrics

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Abstract: *Tropical forests are critical carbon reservoirs that contribute significantly to climate regulation. Accurate monitoring of above-ground biomass (AGB) and carbon stock changes is essential for understanding forest dynamics and supporting climate change mitigation policies. This study evaluates the temporal changes in AGB and carbon stock at the Forest Research Institute Malaysia (FRIM), Kepong, by utilizing high-resolution airborne Light Detection and Ranging (LiDAR) datasets acquired in 2009 and 2014. The methodology involved three main phases: LiDAR data pre-processing, generation of Canopy Height Models (CHMs), and individual tree crown (ITC) delineation using a watershed segmentation algorithm. Local maxima detection was applied to the CHM raster to identify tree tops, which served as seeds for watershed transformation. The delineated crowns enabled the extraction of tree height and crown projection area (CPA) for individual trees. Statistical analysis, including a paired sample t-test, revealed a significant increase in both tree height and CPA between 2009 and 2014. Mapping outputs visualized spatial distribution and changes in carbon stock, highlighting areas with the most significant growth. The integration of multitemporal LiDAR and remote sensing techniques proved effective for non-destructive, large-scale forest monitoring. This research underscores the value of LiDAR technology in enhancing the accuracy of forest biomass assessments and contributes to the development of robust methodologies for carbon accounting in tropical forest ecosystems.*

Keywords: LiDAR, Above-ground Biomass, Carbon Stock, Tropical Forest, Local maxima

Introduction

Forest and trees are essential in human life and impact on the ecosystem in protecting biodiversity and to ensure clean air and water. Forest also can be defined as a place that has a high density of trees and any area packed with tall and large vegetation is also regarded as a forest (Fremout et al., 2022). A forest ecosystem can be defined in terms of its structural, compositional, and functional characteristics, which can heavily affect the environment.

Tropical rainforests play a significance responsibility in climate change as the world's leading carbon storehouse. This is because in the photosynthesis process of carbon sequestration, trees and soils continue to contribute to the human breathing cycle by supplying oxygen (Nik Effendi et al., 2024). Mostly, the carbon kept in the above-ground living biomass (AGB) is the largest pool and most directly impacted by the negative activities such as degraded human-set fires, damaging logged timber, clear forests for agricultural and growth reasons would impact the carbon cycle, leading to global warming effect (Mohd Zaki & Abd Latif, 2016). In ancient times, conventional method or destructive sampling method which is using allometric equation to estimate the AGB (Basuki et al., 2009; J Chave et al., 2005; Jérôme Chave et al., 2014; Kato et al., 1978; Kenzo et al., 2009; Ketterings et al., 2001). In previous research, this method would be the most accurate method as compared to other methods, but the limitation is it would require a big number of resources and limited to small area coverage. Nowadays, there are a few techniques that are introduced which implement the new technology to estimate AGB with a short estimation time.

Additional advantages can be obtained via remote sensing (RS) and light detection and ranging (LiDAR) technologies, which assess the possibility of estimating biomass at various scales (Gudisa et al., 2025). On the other hand, these technological innovations are important for measuring forest characteristics and their structure due to the remoteness and vastness of many tropical forests (Nik Effendi et al., 2022). The ability of RS to quantify tree structure for individual trees has been demonstrated in numerous studies, and it is widely used to monitor AGB dynamics by fusing LiDAR and RS multitemporal data sets. (Mohd Zaki et al., 2018b). Estimation of AGB for forest is very crucial to identify the sustainability of the forest and at the same time it can also help to maintain the ecosystem. There is no instrument or specific technique which can ensure the accuracy and precision in retrieving the result of AGB, but by utilizing fusion of LiDAR and RS multitemporal data set, it is the closest high accuracy result one can obtain. This research aims to assess the above ground biomass changes in the years of 2009 and 2014 from multitemporal LiDAR at Forest Research Institute Malaysia (FRIM) forest, Kepong. Hence, the objective of this study is to produce the canopy height model (CHM) of two different years of LiDAR dataset between 2009 and 2014; to estimate the changes of above ground biomass (AGB) of these two different years of the dataset; and to generate a map of the above-ground carbon stock changes between the different years of the LiDAR dataset.

Literature Review

The quantification of forest structure is crucial for a multitude of fields as the vegetation structure is connected to a wide variety of ecosystem processes (Mohd Zulkiflee et al., 2023). There are different types of forest in this world such as Equatorial Moist Evergreen or Rainforest, Mediterranean Forests, Coniferous Forest, and Tropical Forest. Malaysia is a country with a wide variety of forests and tropical rainforests is the main forest in this country. Being the largest carbon storehouse in the world, tropical rainforests have a significant impact on climate change. Only found in South America, Central Africa, and Southeast Asia, it has been recognized as one of the world's most prolific forest types. The characteristics of forests, as highlighted by researchers like (Wan Mohd Jaafar et al., 2018) are essential for understanding their structure and function. Height, canopy closure, understory cover, diameter at breast height (DBH), and tree volume are key metrics that provide insights into the health and productivity of forest ecosystems.

Malaysia is one of the developing countries with a high cover of forested land. Statistically, there is about 62.3% or 456,000 ha of Malaysia is forested area, and about 18.7% (3,820,000) of Malaysian land is classified as primary forest, and carbon-dense form of forest (Elizabeth et al., 2025; FAO, 2015). Besides that, the areas of land that are more than 5.0 ha covered with trees which is greater than 5 m and canopy coverage of more than 30 percent; has been described as a forest in Malaysia. Mostly, Dipterocarpaceae family trees which are also known as 'Dipterocarp' are dominant in Malaysia tropical rainforest. However, according to Hansen et al., (2013) over the past century, forest losses have increased rapidly in most of the other areas of the tropics and South-East Asia showing the greatest deforestation rates. Because of that, this problem needs to be mitigated to prevent deforestation and to maintain a healthy ecosystem.

Methodology

Generally, there are three main phases for aboveground biomass estimation which is multitemporal LiDAR data collection, generating CHM and aboveground biomass estimation by using the equation.

a. Study Area

The Forest Research Institute Malaysia (FRIM), Kepong, Selangor, is located at 30o 14'7.22" N, 10o 38'3.37" E (Figure 1). Forest Research Institute Malaysia (FRIM) is one of the most well-established institutions in tropical forestry research area in the world. The Malaysian Forestry Research and Development Board (MFRDB), which is part of the Ministry of Primary Industries, now oversees the old Forest Research Institute as a full-fledged statutory entity. The Institute is located in the Kepong municipality, 16 km northwest of Kuala Lumpur, on a 545-ha plot of land next to the Bukit Lagong Forest Reserve. There are over 15,000 plant species there (FRIM, 2025). Its forest area, which provides nearly ancient generation of resources as the principal forest, was cleared of its original forest cover and logged more than a century ago.

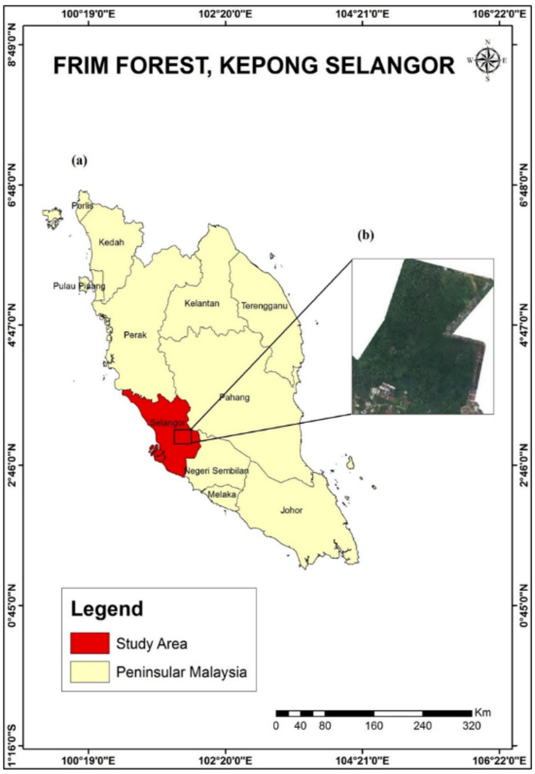

Figure 1. Location of the study area at FRIM Forest, Kepong, Malaysia. (a) Peninsular Malaysia and (b) FRIM forest.

b. Multitemporal Airborne LiDAR Data and WorldView-2 data

Multitemporal Airborne LiDAR data in the of years 2009 and 2014 at Forest Research Institute Malaysia (FRIM) were used for this study to estimate the AGB. The projection of this image in RSO and the datum are in Kertau 1948. The summarized of Multitemporal Airborne LiDAR data that is used in this study will be shown in Table 1.

In addition, WorldView-2 offers a high resolution with eight bands of multispectral imagery, four standard colours (red, green, blue, and near-infrared 1), four new bands (coastal, yellow, red edge, and near-infrared 2), and panchromatic imagery with a resolution of 0.46 meters. The description of WV-2 will be shown in Table 2.

Table 1. Multitemporal Airborne LiDAR Data

Instrument parameter		
Data acquired	April 2013	February 2009
Laser system	ALTM Gemini	ALTM Gemini
Camera system	DIMAC	DIMAC
Point Density	11.78 /m^2	3.24 /m^2

Table 2. Description of Worldview-2 Data

Satellite	WorldView-2
AOI	Kuala Lumpur
PO ID	052371640010
Resolution	0.5 m
Number of Bands	4
Georeferenced Units	RSO D085
Projection	Rectified Skew Orthomorphic
Datum - Ellipsoid	Kertau 1948 (West Malaysia & Singapore) - Everest (W. Malaysia and Singapore 1948)
Grid units	Meter
Sensor Bands	Panchromatic 8 Multispectral (4 standard colours: red, blue, green, near-IR), 4 new colours: red edge, coastal, yellow, near-IR2

c. Pre-processing

The satellite image data are required to undergo the pre-processing before proceeding for the further processed. This process was conducted to ensure the achievement of high result and correct information. The pre-processing purposes to improve and eliminate some unnecessary data. In this study, all the data used the coordinate system RSO, Kertau 1948.

d. Subset Image

Subset image processing was performed to the WV-2 imagery to focus on the study area ranging from the large area to the specific area. In this study, WV-2 image was subset by using MosaicPro tools in ERDAS Imagine 2014 software based on the study area in shapefile format. Additionally, LiDAR point cloud was processed using LASTool via Global Mapper and ArcMap 10.4 software. The LiDAR point cloud was merged and clipped based on the same shapefile and location. All the processes needed to be conducted for both years 2009 and 2014 with the same area and size.

f. Canopy Height Model

The Canopy Height Model (CHM) is the height of the objects above the ground as shown in Figure 2. The digital Canopy Height Model (CHM) was obtained from LiDAR data for tree height estimation technique, and it was used for individual crown delineation. It was created for image interpretation and visualization purposes, and it provided the absolute tree height point on z-axis. The trees Canopy Height Model (CHM) value was calculated based on Digital Elevation Model (DEM) and Digital Surface Model (DSM) that was extracted into raster format from the LiDAR point cloud using Equation 1.0.

$$CHM = DSM - DEM \qquad \text{Equation 1.0.}$$

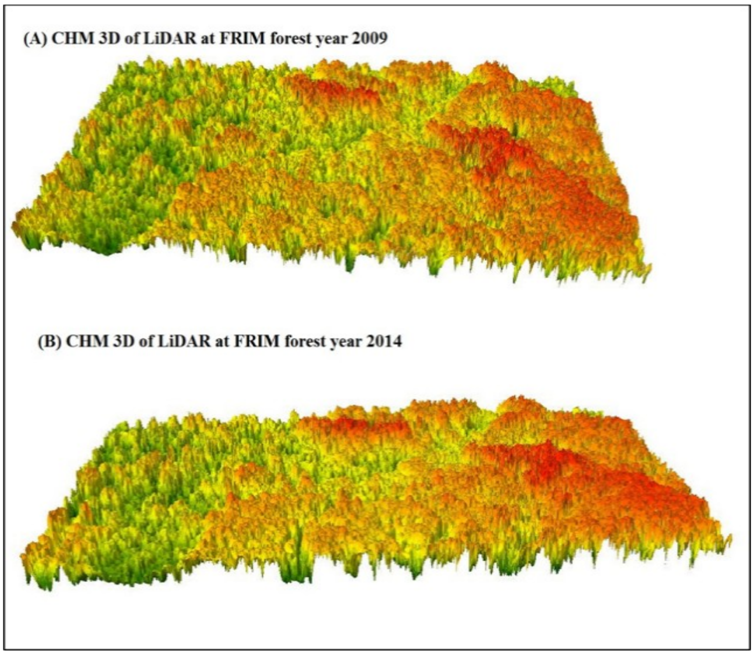

Figure 2. 3D visualization of DSM, DEM and CHM

g. Watershed transformation process

A prominent segmentation technique called "watershed transformation" treats an image as a topographic surface that is flooded into minimal, creating distinct catchment basins and dams that prevent water from two distinct catchment basins from combining. The location of the dams, or the watershed lines, determines the segmentation result. This method divided large crowns, clusters of crowns, and overlapping trees into separate tree crowns. When it comes to the fundamental of image segmentation, referring to local maxima, it defines the positions of the ‘seed’ which as the highest point in the pixel (Mohd Zaki et al., 2022) (Figure 3).

Local maxima are considered the same as radiometric crown centroids. It was assumed to be linked with geometric crown centroids as well. To distinguish local maxima, the maxima indicative of crown centres is a compulsory step in the process in crown delineation. In conjunction with that, it is important to make sure that the location of the tree crown is synchronized with the local maximum. This is because the tree crown peak itself is the ‘seed’ for local maxima. Besides, Local Minima is used to build a continuous network of absolute crown boundaries of one-pixel width between crowns. According to Culvenor (2002), only enclosed pixels defined by the local minima can be used for clustering ‘seed' within the enclosed region. If there are no seeds within the region, there will be no clustering and the search window for local minima identification is like local maxima. In this case, for local minima, any pixels identified as local minima is relevant within any of the search directions. Furthermore, the local minima are also defined when the pixel values in each of the search windows are greater than the ‘seed’ or the central local maxima pixel value.

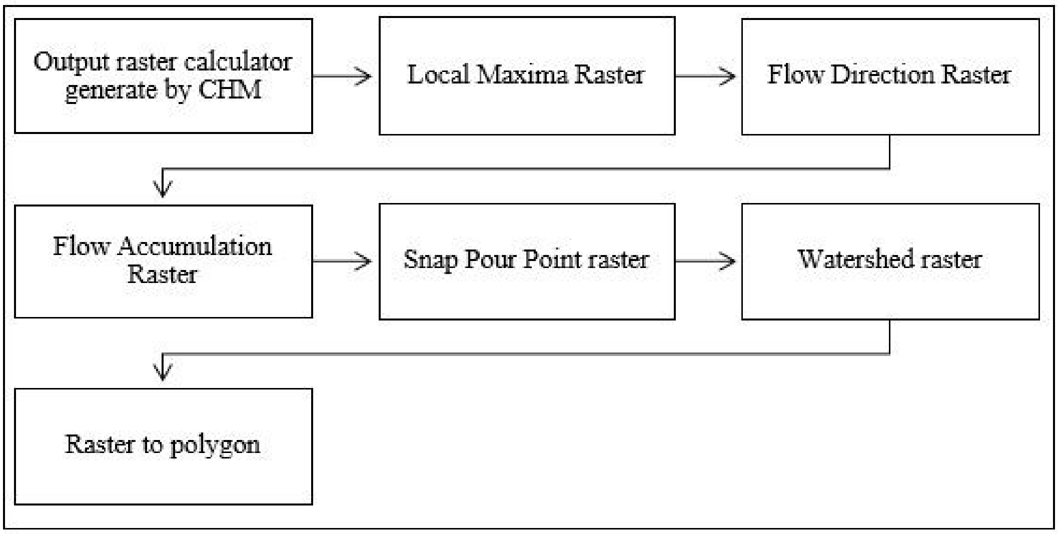

Figure 3. Watershed Transformation process

To identify the trees' highest, the CHM raster needed to be transformed into Local Maxima raster by using Focal Statistics tool in ArcGIS software. Refer Figure 4. The parameter was set up to four cells neighborhood in a circular radius. After the detection of local maxima in the raster was done, the flow direction for each Local Maxima detected was projected along with the Flow Direction tool with its feature as output raster. The raster contains a maximum change in height. Moreover, the other information needed to perform watershed transformation is Flow Accumulation raster in which it accumulates the weight of each cell which flows downslope in the output raster. It is shown that areas with high concentrated flow have high flow accumulation. With all the information obtained, watershed raster image was generated by using watershed tool. Finally, since the tree crown projection was done manually to make the contour lines of the tree crowns clearer, the contour of trees below 95 meters was removed.

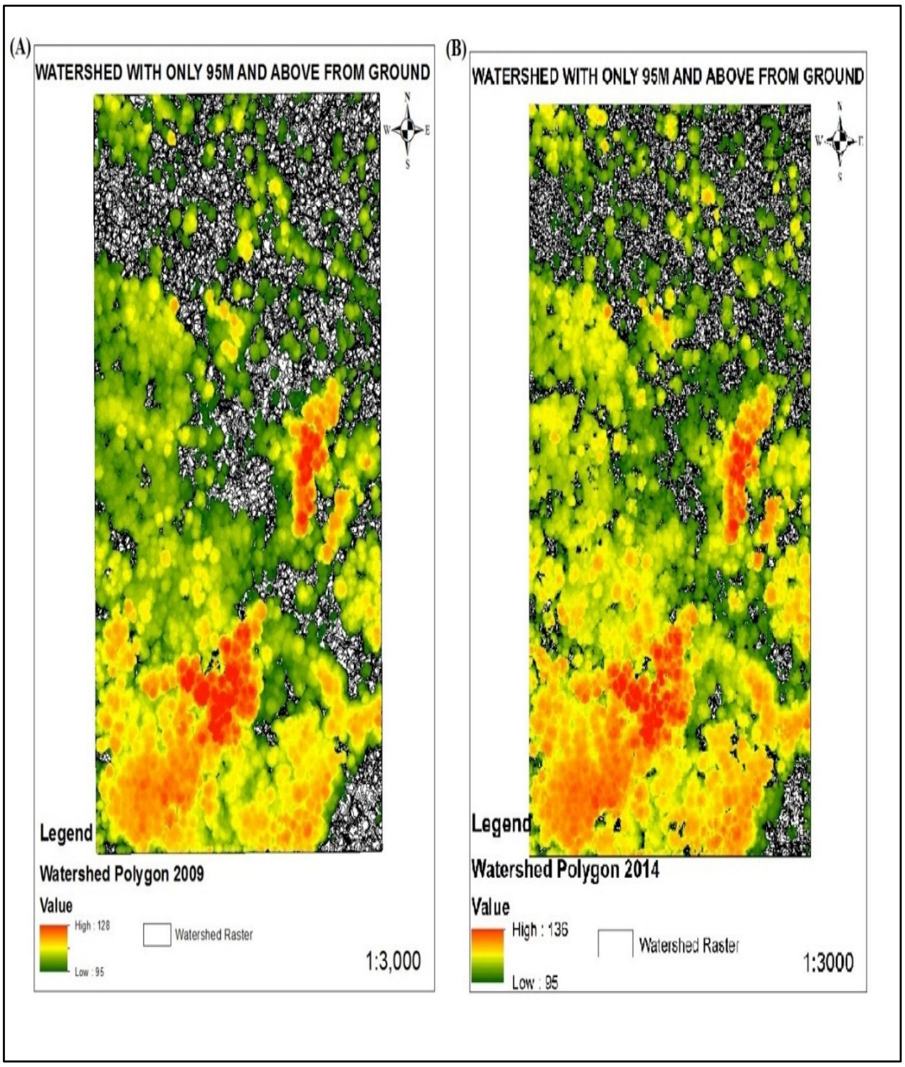

Figure 4. Watershed polygon with only 95m and above from ground (A) 2009 (B) 2014

h. Biomass estimation

AGB was estimated based on the volume and structure of trees which are the Diameter at Breast Height (DBH) and tree Height (H) and are considered as a significant parameter (Chave et al., 2014; Mohd Zaki et al., 2018). AGB was estimated using allometric equation that was developed from the previous research. The tree sampling was chosen from the important species with distinct DBH and estimated using the equation below;

$$AGB = a \times DBH \times b \qquad \text{Equation 2.0}$$

a and b = Statistical parameters

The total dry weight of the trunks, branches, leaves, and roots is known as aboveground biomass. Tree biomass in a sub-tropical forest has been successfully estimated using this approach. (Ma et al., 2018). Besides, there are many different types of allometric equation to estimate the aboveground biomass and carbon stock. In this study, the latest previous study of allometric equation is used which was be developed by (Mohd Zaki et al., 2016). The allometric equation is an important process in this study to estimate above-ground biomass (AGB) and produced the carbon stock to obtain the result of processing.

$$\ln \mathrm{Sc} = -5.963 + 3.130 \ln \mathrm{hL} + 0.524 \ln \mathrm{CPA} \qquad \text{Equation 3.0}$$

Results and Discussion

Comparison of DEM, DSM and CHM in years 2009 & 2014

All the raster data were generated from the LiDAR point cloud. The laser point data was converted to LAS dataset and all the points cloud of LiDAR data also calculated in that software. In this process, DEM data was extracted from the point cloud data while DSM data was extracted from the non-ground return from the point cloud data. Besides, to generate CHM data, Minus tools from ArcGIS software was used to generate CHM value of the trees for the years 2009 and 2014 study areas by using the specific formula that is CHM = DSM – DEM. Table 3 showed the comparison of DEM, DSM and CHM value in meters in the different years. Based on the result, DEM represents the result of the elevation or ground data value. In 2009, the lowest value of DEM was at 49.25m while the highest value of elevation was 301.08m. In comparison with the year 2014, the lowest DEM valued at the same area was 67.21 m and the highest value was 269.39m. Based on the result, there was a difference in values between these two different years. The lowest value of elevation increased between the years 2009 and 2014, which was at 17.96 m while the highest value of elevation on that area decreased to 31.69m. Besides, the lowest value of DSM in 2009 was 49.25m while the highest value was 332.1. In 2014, the lowest value of DSM was at 67.21m. On the other hand, the highest value was at 309.06m. Based on the result, the lowest value of DSM increased in 2014 compared to 2009 with 17.96m meanwhile the highest value decreased at 23.04m.

Table 3. Mean of height of tree and CPA in Year 2009 and 2014. (n =402)

	Year 2013	Year 2009
Mean of height	42.836	41.554
Standard Deviation of height	10.029	9.626
Mean of CPA	218.236	191.699
Standard Deviation of CPA	218.190	163.741

In addition, CHM can be calculated manually by using formulas or automatically by using tools. As stipulated in Table 4, it was shown that the CHM values for low and high also differed in both years 2009 and 2014. In 2009 the low value of CHM was -1.602m and high value was 64.595. In contrast, for the year 2014, the low value of CHM was -0.212m and the high value was 64.595m. The result indicated that the increasing values between the lowest and the highest in different years were 1.39m and 3.603m (see Table 4).

Hence, it can be concluded that the results are acceptable because the values of DMS in different years were higher than the DEM values. This is because DSM values refer to the non-ground while DEM value is to the ground. Besides, CHM signifies the height of an individual tree. This is since the tree canopy height model (CHM) was calculated as the difference between the tree canopy and Lidar-derived terrain elevation values (Karna, 2012).

Table 4. One-Sample Statistics of tree height 2009 and 2014

	t	df	Sig (2-tailed)	Mean Difference	95% Confidence Interval of the Difference	
					Lower	Upper
Year 2013	85.643	401	0.00	42.836	41.853	43.820
Year 2009	86.550	401	0.00	41.554	40.610	42.498
Year 2013	20.054	401	0.00	218.236	196.843	239.630
Year 2009	23.473	401	0.00	191.699	175.644	207.754

Image filtering or convolution filter

Convolution filtering, another name for image filtering, makes use of the variable square window to determine the local maximum of the trees. The noise of the image will be removed when the filtering techniques are applied to increase the accuracy in classification process. In an image filtering process, there are three categories which are low-pass, high-pass and edge-detection filter. For this study, local cell neighborhood was used for image-filtering techniques. Based on the result, the highest value of local maxima from the canopy height model in year 2009 was 127.588 and the lowest value was 62.782. Local maxima value was detected from the highest point at the neighboring cell with the lowest radius was 4 from the CHM. In 2014, the highest and lowest of local maxima values were 136.184 and 67.986, respectively. Based on the result, the value of local maxima had increased after four years from 2009 to 2014 about 8.596 and 5.204 accordingly. It can be concluded that after 4 years, the height of the trees had increased based on the local maxima result (Figure 5).

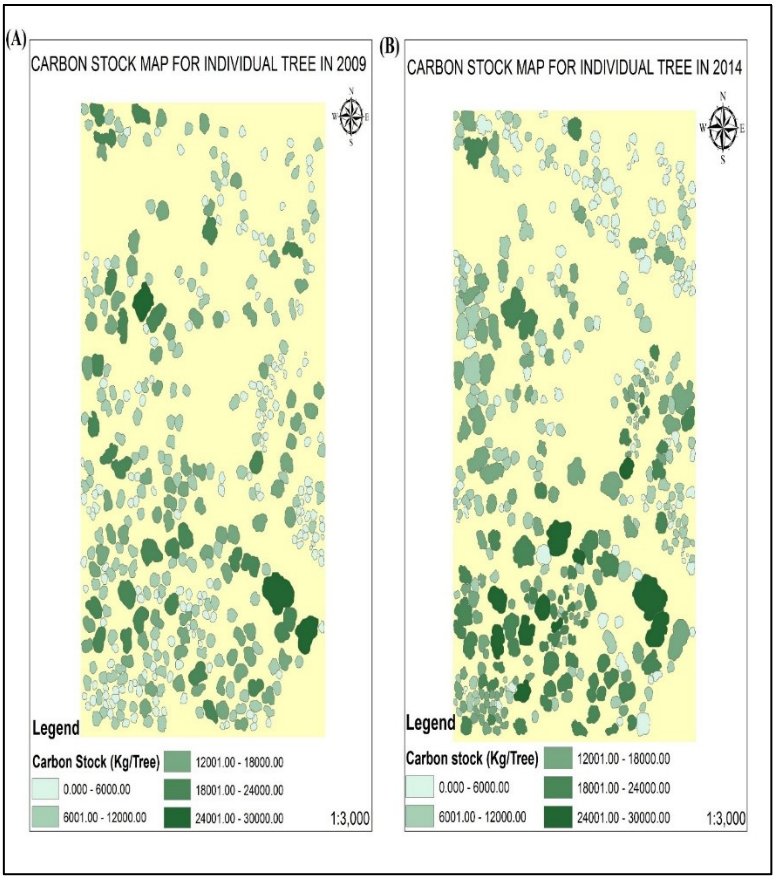

Figure 5: Maps of Carbon Stock Changes from 2009 to 2014

Flow Direction

Flow direction raster is one of the key factors in creating the watershed contour. Flow direction basically shows the flow on how the cell flows from the pour point. This raster will direct the cell changes that will occur during the process of watershed transformation.

Flow Accumulation

The accumulated flow within the raster was calculated using Flow Accumulation tool in ArcGIS. The computation was predicated on the total weight of all the cells that enter each downslope cell. Typically, each cell is given a weight of 1. The number of cells that flow into each cell is therefore the value of cells in the output raster. Ridges can be identified by looking for cells with a flow accumulation of 0, which are local topographic highs.

Watershed Transformation using ArcGIS Software.

In this study, the object picture was separated from the overlapping tree crown into a single tree crown via watershed transformation. Additionally, because it offers closed contour data, it is regarded as an appropriate technique for detecting individual tree crowns.

The data required to carry out watershed transformation has been finished by creating local maxima, flow direction, drop out raster, and flow accumulation raster. The upslope region that contributes flow, typically in the form of water, to a shared exit is known as a watershed. In this instance, the water's flow point within a region will be the pour point on the surface. When the watershed tool was used to insert the flow direction input and snap four points rastersraster for pour point data, the result showed the output following the application of the watershed algorithm. However, in order to enhance the polygon, SetNullSet Null function was used via raster calculator tool. The height that was below 95m was removed and set as no data using equation 4.0.

x=SetNull ("elev\""<0,"elev\"") Equation 4.0

Analysis of the paired sample T-Test between CPA 2009 and 2014

Statistical analysis T-test as inferential statistic was applied to determine the significant between different years. In this case, there are two sample variables used for T-test which are trees height and CPA from two different years in 2009 and 2014. A descriptive statistic is a statistical method in performing every single calculation by using the data set. There are several methods in descriptive statistical test such as mean, median, mode, maximum, minimum, standard deviation and variance. In this study, mean and standard deviation were bused to define the significant in two different years.

Mean and Standard Deviation of tree height and crown projection area in 2009 and 2014

The mean of trees height in years 2009 and 2014 which were 41.5540 and 42.8364, respectively. Besides, the standard deviation for years 2009 was 9.62629, and 10.02851 in the year 2014. Based on the result, the mean and standard deviation value of forest in 2014 were higher than the forest in 2009 which was about 2 meters. In addition, the mean of CPA in years 2009 and 2014 which were 191.6993 and 218.2362 accordingly. Moreover, the standard deviation value of CPA in 2009 was 163.74151 whereas in 2014 was 218.2362. In this case, the result indicated that the significant difference in between the two years' time based on the mean and standard deviation result.

On the other hand, the evaluation of methods was done based on the one-sample test of tree height between the years of 2009 and 2014.

Moreover, from the one-sample statistics of CPA result, the confidence interval of difference of CPA in 2014 was also higher than in 2009. The lower and upper value of confident interval in 2014 were 196.8427 and 239.6297, while in 2014 the lower and upper value of confident interval of CPA in 2009 were 175.6444 and 207.7541.

Paired Samples Statistics of tree height and crown projection area (CPA) 2009 and 2014

Finding of this result shows, the p-value for paired t-test is 0.000 which is less than the significant level α= 0.05, this study is reject the null hypothesis, results shows that there is a significant increase in tree height and crown projection area (CPA) for 2014 compare to before 2009 of tree height and CPA. Hence, the result indicated enough evidence to conclude that there is a significant increase in tree height and CPA for year 2009 and 2014 (p= 0.000).

Allometric equation to estimated AGB and Carbon Stock

There are many types of equations that can be used to estimate AGB and carbon stock were developed the previous researcher. Height variables is one of the most important predictors in estimating AGB and carbon stocks and it can be obtained from the LDAR. The height(ht) was extracted from CHM while CPA was extracted from the manual digitizing of the individual tree. All data are needed to get the AGB by using equation 5.0 that is shown below. After obtaining the AGB value, equation 6.0 will be used to estimate the carbon stock (Sc) of the trees.

$$AGBest = -5.963 + 3.130\, In\, hL + 0.524\, In\, CPA \qquad \text{Equation 5.0}$$

$$S_C = Exp\ (AGB_{est}) \qquad \text{Equation 6.0}$$

Table 5 shown that the total AGB and carbon stock of the same forest area is minimum, maximum and standard deviation values in different years. The result showed that the increment of AGB between both years of 2009 and 2014 which was 70.479kg. Besides, the carbon stock also increased after four years gap which was 290982.514kg. Based on the result, it can be concluded that the increment of AGB will lead to an increase in carbon stock (Figure 10). Besides, the changes of AGB can also be seen in the mean value which was 0.088 and in the standard deviation value was 0.158. whereas the changes of carbon stock in mean was at 628.603 and the standard deviation was 923.801 (Table 6). Hence, the result shown is acceptable.

Table 5. Comparison of DEM, DSM and CHM Between 2009 & 2013

	Unit	2009		2014	
	Meter (m)	Low	High	Low	High
DEM	(m)	49.25	301.08	67.21	269.39
DSM	(m)	49.25	332.1	67.21	309.06
CHM	(m)	-1.602	64.595	-0.212	68.198

Table 6. Above ground biomass and carbon stock estimation

	AGB Estimation		Carbon Stock Estimation	
	2009	2014	2009	2014
Sum	3478.095	3548.574	2078601.921	2369584.435
Min	-7.205	-1.666	0.000743	0.189093
Max	10.180	10.341	26368.8	30986.21
Mean	8.126	8.214	4856.546	5485.149
Standard deviation	1.301	1.144	3498.678	4422.479

Model Application – Carbon stocks and AGB mapping

In brief, the range of the predicted carbon was around 600-30000 C kg/tree in 2009 and 2014 for individual tree. Figure 10 shown the result of carbon stock which was visualized into map. There were five classes range of carbon stock in (A) 2009 and (B) 2014 with different colours. The dark colour on range indicated the height value of carbon stock. In addition, the same area was selected to get the accurate value of carbon stock. Table 7 shown the AGB and carbon stock changes between these two different years.

Apert from that, Figure 10 shown that the carbon stock changes between the year of 2009 and 2014. The result was visualized into map and the gap was eliminated and was displayed in the different colours. The dark colour was to indicate highest change of carbon stock and the low colour represented the lowest change of carbon stock in 4 years range in FRIM forest.

Table 7. AGB and Carbon Stock changes

	Mean	Std
AGB		
AGB 2009 (t/ha)	8.126	1.301
AGB 2014 (t/ha)	8.214	1.144
AGB change (t/ha)	0.088	0.158
Carbon Stock Carbon Stock 2009 (t/ha)	4856.546	3498.678
Carbon Stock 2014 (t/ha)	5485.149	4422.479
Carbon Stock change (t/ha)	628.603	923.802

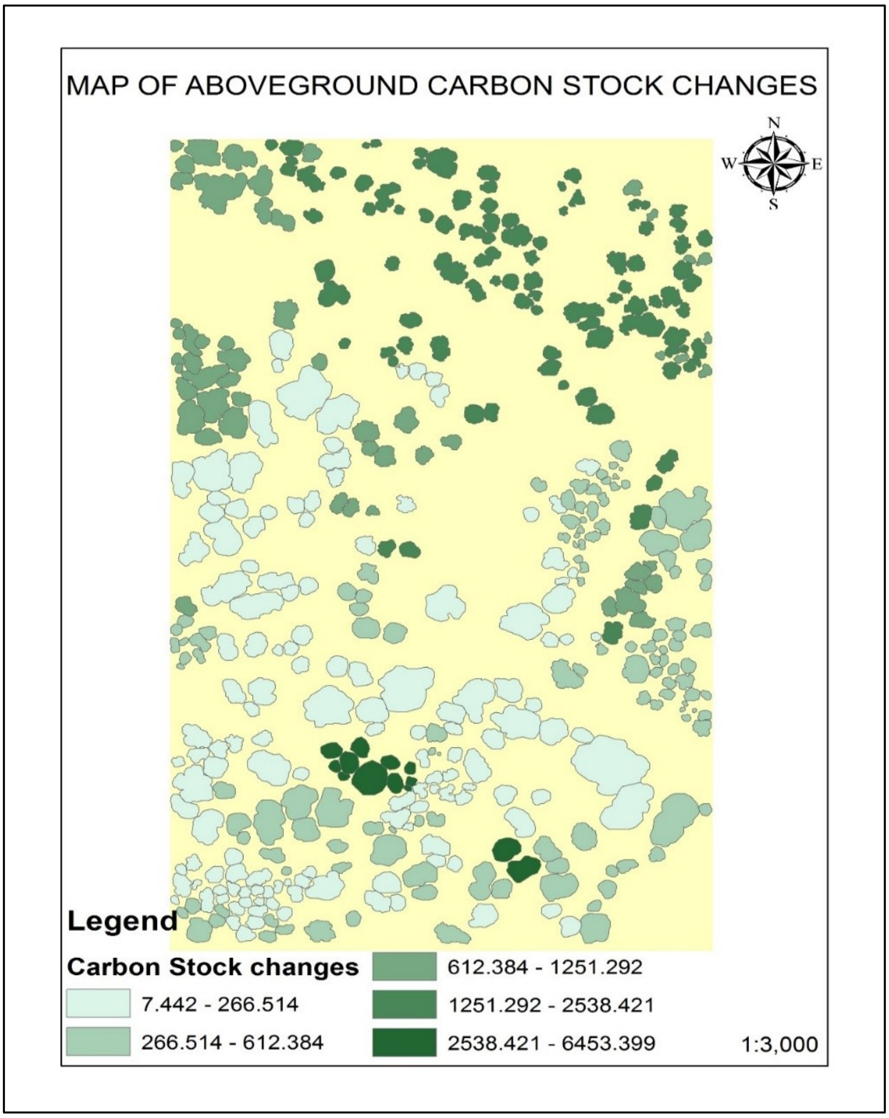

Figure 10. Maps of Carbon Stock Changes from 2009 to 2014

Conclusion and Recommendation

As far as remote sensing is concerned, LiDAR obtained DEM, DSM and CHM that were extracted from the laser point cloud to estimate the AGB and carbon stock of the forest. In this study, a high spatial resolution satellite data and airborne LiDAR data were used for different aspects of the environment. Generally, this research study has explored the forecasts for the carbon stock estimation in different years. In this study, WorldView-2 was used because this satellite image consists of multispectral and panchromatic bands with high spatial resolution mage which can produce high accuracy data. In addition, in methodology section of this research, the actual procedure from the beginning of the process until the end of the process had been thoroughly explained. Next, all the results were stipulated and well-elaborated in result and analysis section that and each analysis was presented in the form tables, graphs, and maps. In this study, the main reason of using remote sensing in agriculture activities is to produce the canopy height model (CHM) of two different LiDAR dataset which is in the years of 2009 and 2014. In this study, airborne LiDAR point cloud was used to extract the DEM, DSM and CHM of every individual tree in that particular area. Based on the T-test result, the results in both the years of 2009 and 2014 are significant, showing strong relationship with each other.

Based on the result, AGB increased from the year 2009 to 2014 at the same area with 70.479kg. Lastly, the final output of carbon stock estimation was shows in mapping and the difference between both years in 2009 and 2014 at the FRIM forest. In conclusion, CHM, CPA, and tree height data can be used to estimate the carbon stock of tropical rain forest because it produced a good result to prove and further strengthen the claim that remote sensing technique can be implemented in forest management field.

Six outputs are produced during watershed processing, including local maxima raster, flow direction raster, flow accumulation raster, snap pour point raster, watershed raster, and raster to the polygon, according to the results of tree delineation using the watershed method. To facilitate the digitization of individual tree crowns for future research, a raster calculator can be used to remove trees that are less than 95 meters in height. Because it establishes whether there is a substantial rise in CPA and tree height between these two years of data, the T-Test statistical analysis can be used for future research to examine the data on tree height and crown projection area between two years. Furthermore, there are also other formulas that can be used to estimate aboveground biomass and carbon stock. There is also a formula created specifically for the type of forest that can be used in future study. Likewise, for better understanding of the process phase to the analysis phase of the estimation of carbon, these are suggestions that can be extracted from this study. For further research in a similar scope, these recommendations can be applied to perform such as analysis towards carbon stock estimation in the forest.

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