ABOVE-GROUND BIOMASS AND CARBON STOCKS ESTIMATION USING ALLOMETRIC EQUATIONS IN TROPICAL FOREST

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ABSTRACT: Tropical forests contribute to the extensive amount of above-ground biomass (AGB) and carbon stocks for the whole world. Over the past few centuries, the concentration of carbon dioxide (CO_2) including greenhouse gases to the atmosphere has become increased due to anthropogenic activities and natural consequences, which has an enormous influence on the impact of climate change. Therefore, forests play an important role in human life in supplying oxygen (O_2) and absorbing carbon dioxide (CO_2) to stabilize the earth's ecosystem. In protecting forests that have a variety of trees, many researchers have developed a variety of methods and ways to estimate the above-ground biomass and carbon stock. In general, AGB was an estimate based on the structure and volume of the trees, which is the trees height and diameter at breast height (DBH) consider as major parameters. In the absence of species-specific biomass equation of the tree, many equations will be used to estimate for individual tree species in tropical forest type which had been developed by world global researchers. The aim of this study was to measure the estimation of AGB and carbon stock using regression model. Hence, the objective of this study: (1) to estimate AGB and carbon stock in a tropical forest using allometric equation, and (2) to investigate the relationship between Diameter at Breast Height (DBH) with AGB and carbon stock estimation. Based on the result, there was a relationship between DBH with AGB and carbon stock estimation by using different equation.

1.0 INTRODUCTION

Tropical forest is the world's largest forest with a different diversity with multi-layered canopies structure. It plays an important role in global carbon storage and contributes to the vast amount of AGB (N.A.M. Zaki et al, 2016). The uptake of carbon dioxide (CO_2) during photosynthesis which absorbs from the atmosphere, has caused a cooling impact on the global climate.

Nowadays, climate change is a major risk that needs to be faced by a human. Over the past few years, in the United Nations Climate Change Summit, 195 countries resolved to reduce carbon dioxide (CO_2) and other greenhouse gas emissions in order to curb global temperatures due to rising temperatures. (T. R. Anderson et al, 2016). The link between CO_2 and climate warming is detected through the impact of a greenhouse. Initially, this matter is the natural process of the earth to balance the temperature in the atmosphere. In the atmosphere there are several types of gases known as greenhouse gases for example nitrous oxide (N_2O), chlorofluorocarbons (CFCs), methane (CH_4) and carbon dioxide (CO_2) (M.J. Adegbeye et al, 2020). The processes of heating, reflection, heat absorption and release of geothermal into space will balance the temperature in the atmosphere.

Nevertheless, excessive human activities such as the rapid development of deforested areas for construction purposes, will lead to an increase in greenhouse gases dramatically. In peninsular Malaysia, illegal logging operations resulted in damages totalling RM15.2 million which is 256 cases were recorded, with 229 arrests made in connection to them in the years 2006 to 2016 (S.W. Jun, 2017). Due to overexploitation, the forest will face a great threat by several factors, which contributing to numerous pollution issues such as an increase in greenhouse gases, global temperatures, water erosion, and landslides. Consequently, forest is an important natural resource for all living things because in the global cycle, it absorbs a large stock of carbon and contributes to the huge volume of AGB.

There are various methods that have been developed by researchers to measure AGB and stock of carbon which is destructive sampling method and non-destructive method. The destructive sampling method also known as complete harvesting (N.A.M. Zaki et al, 2016) this is a method of cutting a small sample of trees in the plot of study area. Besides, the trees will over-dried until the weight is constant, it is applied globally by many types of research (Basuki et al, 2009) to estimate AGB and carbon stocks. However, dissecting, weighing, cutting, will use a lot of resources, an immense amount of work, quite expensive, time-consuming, and difficult to cover a large area (Y.T. Mustafa et al, 2015).

An alternative way by using non-destructive sampling method which is conversion method of volume data to develop an allometric equation and calculating from inventory data to estimate the AGB and stock of carbon in tropical forest. An abundance of equations has developed from the researchers that can be applied to estimating the AGB and carbon stock for tropical forest such as Chave et al, (2005). On his paper had developed the allometric equation for multispecies on huge dataset for tropical forest which is about 4004 of trees with diameters more than 5m from all over the world. Therefore, the objective of this paper are;(1) to estimate above-ground biomass (AGB) and carbon stock in tropical forest by using different allometric equations;(2) to identify the relationship between diameter at breast height (DBH) with AGB and carbon stock using variety of allometric equations.

1.1 Allometric Equation and Carbon Stock Estimation

There are a lot of available equations produced by previous researchers for estimate AGB and carbon stock in tropical forest. Table 1 shows equations for those estimation where some of the equation used Diameter Brest Height (DBH) as a predictor, height, and wood density specific.

Table 1: Allometric Equation

Researchers	Allometric Equation Above ground biomass (AGB)	
Chave et al, (2005)	$0.0509 \times (\text{Wood Density} \times \text{DBH}^2 \times \text{Height})$	(1)
Basuki et al, (2009)	$\text{EXP}\ ((2.196 \times \text{LN(DBH)}) - 1.201$	(2)
Kettering et al, (2001)	$\text{EXP}\ ((2.59 \times \text{LN(DBH)}) - 2.75$	(3)
Kenzo et al, (2009)	$0.0829 \times \text{DBH}^{2.43}$	(4)
Chave et al, (2014)	$0.0559 \times (\text{wood density} \times \text{DBH}^2 \times \text{Height})$	(5)
Kato et al, (1978)	$\text{MS}: 0.0313 \times (((\text{DBH2}) \text{ x Height})^{0.9733})$ $MB: 0.136 \times (MS)^{1.07}$ $1/M1: 1/((0.124 \times (MS^{0.794})) + (1/125))$ $M1: 1/(1/M1)$ $AGB: MS + MB + M1$	(6)

A different researcher will produce different allometric equation for AGB and carbon stock estimation, but the equation had been used in the whole world for AGB estimation. Based on the table above, some researchers have used wood density in their formula that is for specific species such as Chave et al, (2005) and Chave et al, (2014). Wood density of every species can get from global wood density database as published by Dryad (Zanne et al, 2009). For the wood specific gravity value for each species at global scale, great effort had been made in order to gather all the information on wood density for the world tropic. This wood specific gravity had been used as explanatory variables of tree biomass.

Moreover, the amount of the AGB estimation that had been get from the equation were converted to carbon stock of single trees using conversion factor of 47% of the dry biomass which is 0.47 as suggested by (IPCC,2006; N.A.M. Zaki et la, 2018) that is expected to be the carbon of all segment of the tree as a default value. The equation for carbon stock will be show in below.

$$\text{Total Carbon Stock (MgCha}^{-1}) = \text{Total AGB} \times 0.47 \qquad (7)$$

2.0 MATERIALS AND METHOD

2.1 Study Area

The study area of this research is located the Forest Research Institute Malaysia (FRIM), Kepong, Selangor which is located at 3° 14′ 13″N, 101° 38′ 16″E. The Institute sits on a 545ha site adjacent to the Bukit Lagong Forest Reserve in the Kepong municipality, 16 km northwest of Kuala Lumpur. The forest comprised of mixed forest with dominantly family of tree. Besides, it contains approximately 15,000 species of plants, in this study area was cover about 2 hectares, 48 species were cover in forest inventory data collection.

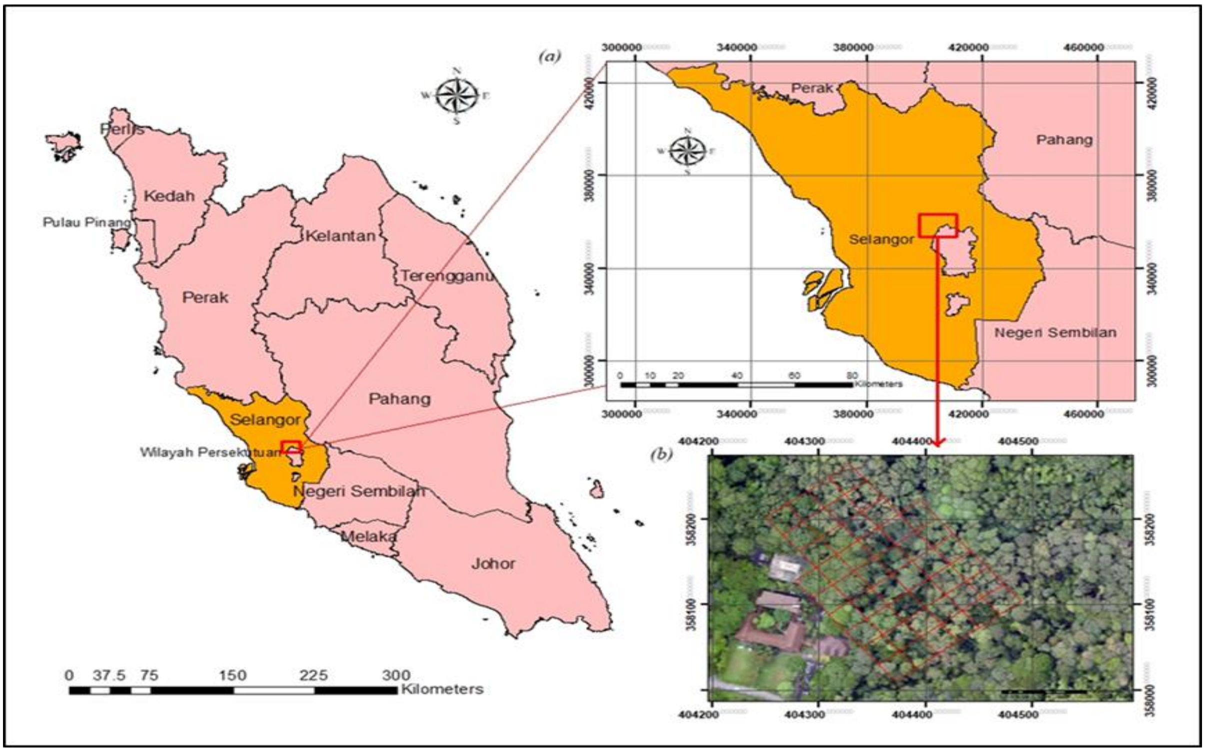

Figure 1: Map of location of study area (a) location of Selangor District, Peninsular Malaysia (b) location of Forest Research Institute Malaysia (FRIM) Kepong cover by Orthophoto

2.2 Experimental Design

In this research, the method is mainly consisting of fieldwork data collection and the calculation of AGB and carbon stock based on the forest inventory data that had been collected.

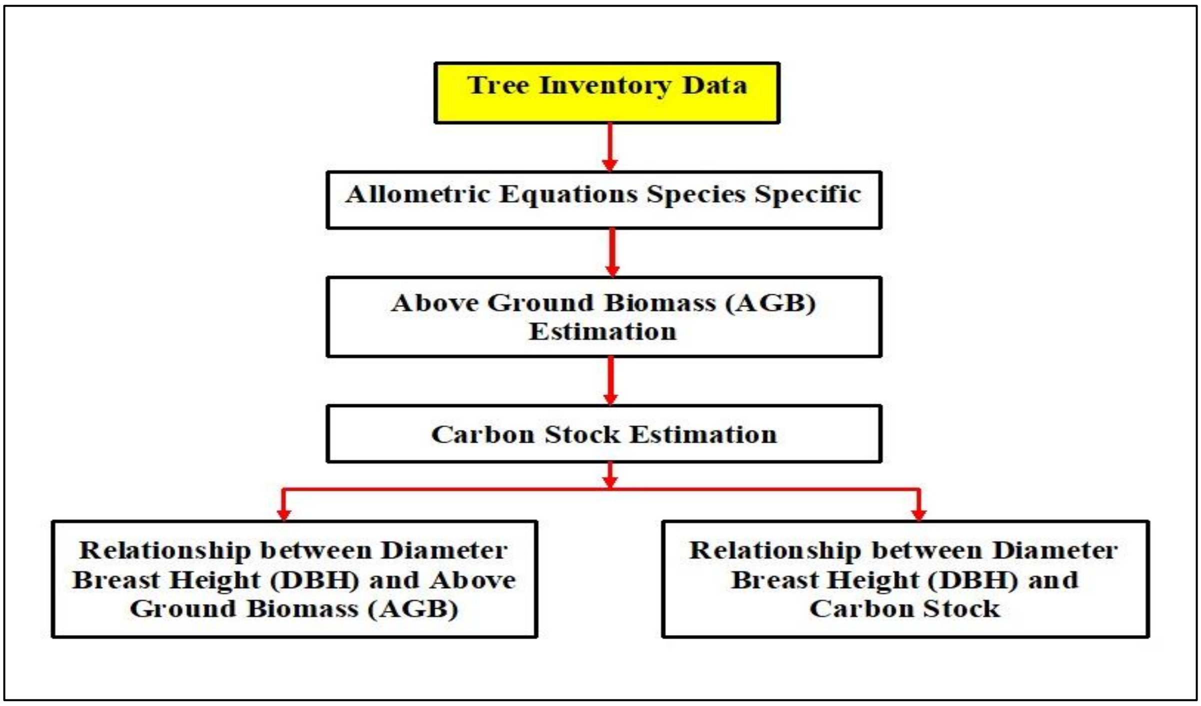

Figure 2: Methodology Workflow

2.3 Tree Sampling Data Collection

2.3.1 Implementation of the field survey

There are three main parts in the implementation of the filed survey which is navigation to the plots, field measurements and data collection. However, before starting all the field work, it will be divided into three teams which is two teams for field survey that will measure all position and detailed of the trees, and other team as a biometric team that will collect the information about the characteristics of the trees. All the field equipment required need to test or calibration, assessed and assured.

2.3.2 Plot measurement protocol

A consistent protocol was used in all plot measurement by following all steps and detail in a set sequence as shows in table. All survey team need to follow the steps of data collection without missing even one steps. First, the task is related to collect the general information, and the second is the measurements of trees inside plot.

Table 2: Plot measurement protocol

	Task	Equipment	Record
1	Locate and mark plot	Google Earth	Plot reference and coordinate
2	Establish the CRM for reference point	GPS	Coordinate of CRM
3	Delimit plot area and divide to subplot	Tape	locate the delimit for every subplot (25m x 25m)
4	Mark all the trees in study area with ID number	Tags number	Trees number (ID)
5	Field measurement (position of trees)	Total Station, Prism	Detail for all position of trees
6	Record the species and family of trees	-	list all the species and family of trees
7	Canopy cover at plot (Remark)	-	Remark the trees have crown overlay
8	Measure tree DBH	DBH tape	Stem DBH (cm)
9	Measure tree crown Diameter	Tape	Measure all for all trees in study area
10	Measure tree height	Distometer	Measure height of trees in (m)

2.3.4 Locate the plot

The plot locations selected in ArcGIS to get the coordinate and printed on the orthomaps. They were also converted to KMZ format for use in Google Earth. By using the internet access in mobile phone, the target locations are view in Google Earth application before visiting the study area.

2.3.5 Establish the Cadastral Reference Mark (CRM)

Before start survey measurement, three CRM was establish nearest the study area by using GPS instrument with static method, and the projections in Geocentric Datum of Malaysia (GDM2000) to facilitate the location on the map. The GPS data is processed using Topcon tools software to obtain coordinates as a known point before starting a traverse. The accuracy of the starting point is very important in the measurement work to avoid the occurrence of errors.

2.3.6 Delimit plot area

To delimit the plot area, the tape was used to measure and locate the subplot which is 25m x 25m rectangle shape for each plot. Besides, it can also delimit the plot area in ArcGIS by drawing the subplot before mark the position at the site. A subplot drawing needs to convert to KMZ format for use in Google Earth, and it will be easier to locate the position of subplot on the ground. Then, the subplot area will be marked using PVC pipe.

2.3.7 Field measurement and detailing

The position of trees was located and recorded via total station and the coordinate for all trees in study area were identified. To get the precise location of all tree sampling, accuracy is required. Each tree is marked with an ID number to prevent redundant occurrence.

2.3.8 Family and Species of trees

The species of all targeted trees were identified by the biomass team with the specialist. For the recording of the tree species and family, we were supported by the database of tree in FRIM which is available in specific and common name. when the species of a tree was the photo of leaves were capture for later identification. A simple form was used to record the name of species and family of trees based on the ID number.

2.3.9 Diameter at Breast Height (DBH) and Height of Trees Measurement

DBH was measured in stem 1.3m height above ground with diameter tape. This has one side with a centimeter (cm) scale and the other with the direct conversion into diameter. In DBH measuring process, a few measurement cases can be found such as trees leaning on flat terrain. The breast height is measured at the side where the tree leans. Besides, if trees on slope such as up and down, the breast height is measured at upper part of the slope. If forked trees where the fork, originates below 1.3 height. That stem with a diameter of 5cm shall be considered to be a stem to be measured and the diameter shall be measured at a height of 1.3m. The height of all trees was measured at the top of crown by using digital DISTO D2 laser ranger. Sometime, these measurements are not always possible in dense canopy especially in tropical rain forest.

3.0 RESULT AND DISCUSSION

In each individual sampled tree plot, forest stand parameter (Height, DBH and crown base height) had been measured in 48 sampling plots at FRIM forest study area. Based on the results, *Shorea leprosula (Meranti tembaga)* is the tree with the highest DBH value of 135cm. However, the height value is only 23.11m. In addition, the highest tree species is *Koompassia malaccensis (Kempas)* which is 45.66m, but its DBH value is 93.1cm. It shows that different species have their own characteristics. Table 3 show the descriptive statistic of the dataset:

Table 3: Descriptive Statistic of the 48 sampling plots

Statistic	Diameter at Brest Height (DBH)	Crown Based Height (CBH)	Height (H_t)
Minimum	18.7	1.47	9.79
Maximum	135	38.76	45.66
Standard Deviation	20.9	6.42	6.85

AGB was quantified from field inventory survey of DBH, height and specific wood density for the entire study. AGB of every individual trees species was estimated by using allometric equation which develop from the previous developers. Based on the result shown in figure below by using six different type of allometric equation, it shows that the highest coefficient of determination in regression (R^2) result which is Chave et al, (2005) = 0.6964; Basuki et al, (2009) = 0.9238; Kettering et al, (2001) = 0.8768; Kenzo et al, (2001) = 0.8991; Chave et al, (2014) = 0.0.6964, and Kato et al, (1978) which is 0.8112. The scatter plot graph shows the relationship between DBH and total AGB based on tree species even using different equation. Based on the graph, the greater the DBH, the higher the total AGB estimation and it was supported by (K. Calders et al, 2015). However, the equation that have been developed by Basuki et al, (2009) shows the highest result compared to other equation.

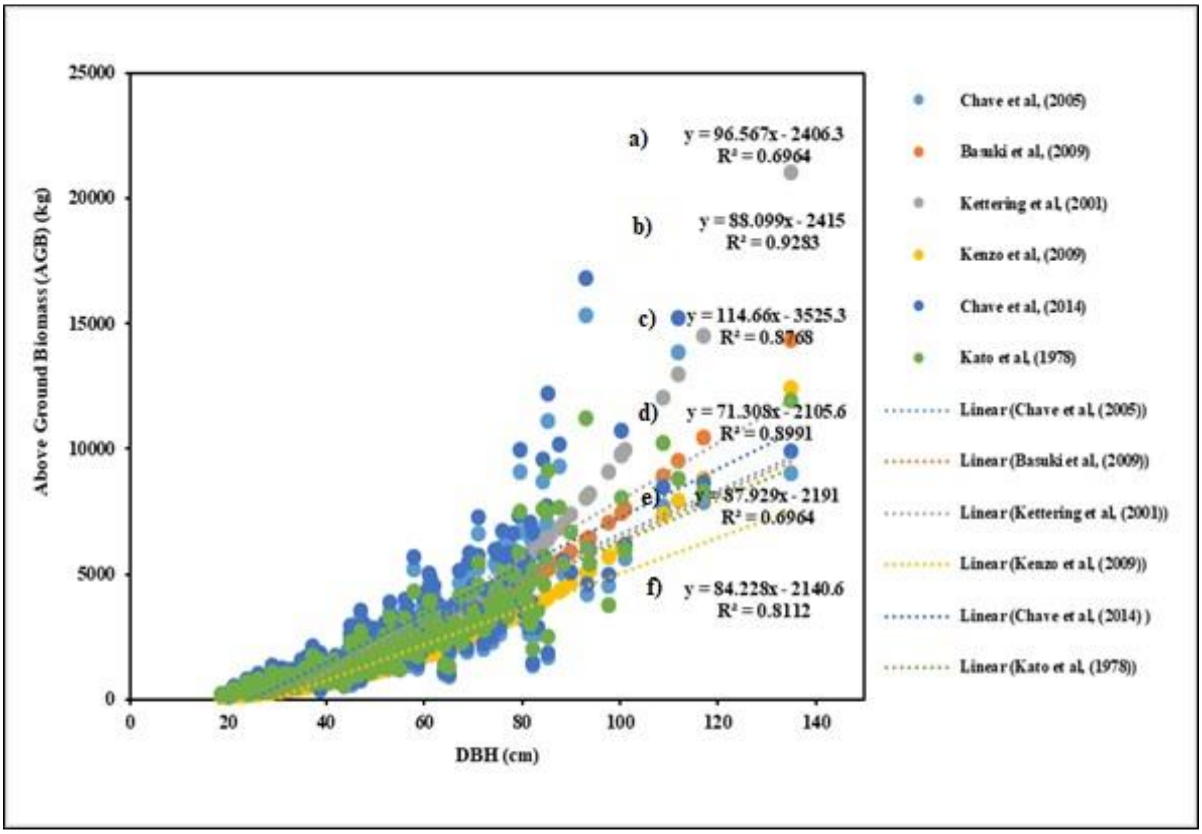

Figure 3: Relationship between DBH and Above-ground biomass (AGB) Estimation;(a) Chave et al, (2005);(b) Basuki et al, (2009);(c) Kettering et al, (2001);(d) Kenzo et al, (2001);(e) Chave et al, (2014);(f) Kato et al, (2001)

Moreover, Figure 4 shows that the highest coefficient of determination in regression (R^2) result between DBH and carbon stock which is Chave et al, (2005) = 0.6964; Basuki et al, (2009) = 0.9283; Kettering et al, (2001) = 0.8768, Kenzo et al; (2001) = 0.8991; Chave et al, (2014) = 0.0.6964, and Kato et al, (1978) which is 0.8112. The scatter plot graph shows the relationship between DBH with carbon stock based on tree species even using different equation. Based on the graph, the higher the DBH value, the higher the total carbon stock estimation. Nevertheless, the equation that had been developed by Basuki et al, (2009) also shown the highest result compared to other equation which is R^2 is 0.9283.

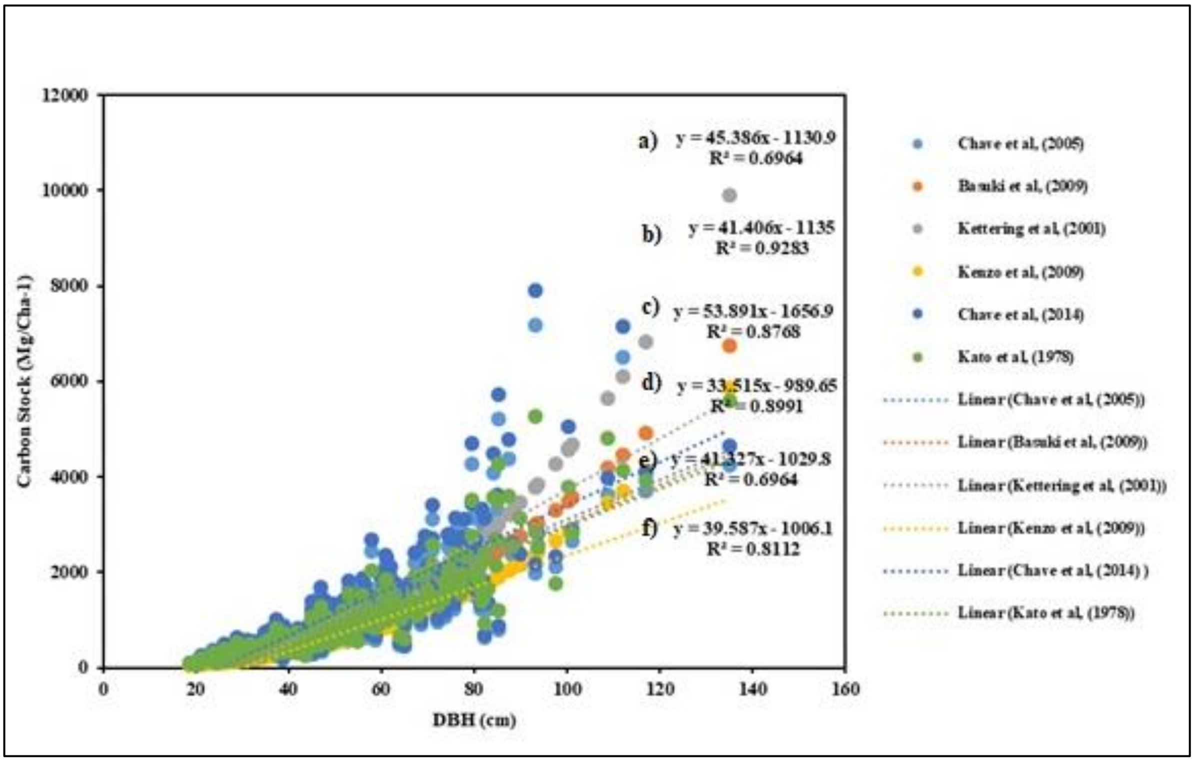

Figure 4:Relationship between DBH and Carbon Stock Estimation;(a) Chave et al, (2005);(b) Basuki et al, (2009);(c) Kettering et al, (2001);(d) Kenzo et al, (2001);(e) Chave et al, (2014);(f) Kato et al, (2001)

Table 4 shows the total of carbon stock and AGB in the study area which consist of 289 trees. Based on the result, there was a slight difference in estimation values based on the different allometric equations used. However, all the result obtained can be accepted because the equation used have been agreed globally in AGB and carbon stock estimation.

Table 4: Total AGB and Carbon Stock estimation

Researchers	Total AGB (Mg/ha)	Total Carbon Stock (MgCha-1)	Number of Tree
Chave et al, (2005)	646926.9092	304055.6473	289
Basuki et al, (2009)	584677.7407	274798.5381	289
Kettering et al, (2001)	650510.3233	305739.852	289
Kenzo et al, (2009)	429618.6759	201920.7777	289
Chave et al, (2014)	710475.7215	333923.5891	289
Kato et al, (1978)	607619.5626	285581.1944	289

4.0 CONCLUSION

There are various methods that have been developed by researchers in AGB and stock of carbon measurement such as destructive sampling method and non-destructive method. Destructive sampling method has a high degree of accuracy for biomass estimation but uses a lot of resources. Moreover, it required hundreds of years to recover the number of trees that are cut. In this paper, several allometric equations were used for forest biomass estimation. It can conclude that there was a relationship between DBH with AGB and carbon stock estimation. The results show that the increasing of the DBH would also affect the increasing of the estimation of the carbon stock of individual trees.

5.0 ACKNOWLEDGEMENT

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