International Journal of Multidisciplinary Research and Development
www.allsubjectjournal.com
Online ISSN: 2349-4182, Print ISSN: 2349-5979
Received: 18-06-2021, Accepted: 03-07-2021, Published: 20-07-2021
Volume 8, Issue 7, 2021, Page No. 128-134

Allometric equations for aboveground biomass estimation of *Apodytes dimidata* E. *Mey.* ex *Am.*, in south forest in Kaffa zone

Admassu Addi[1*], Teshome Soromessa[2], Tura Bareke[3]
[1] Department of Plant Biology and Biodiversity Management, Addis Ababa University, Ethiopia
[2] Center for Environmental Science, Addis Ababa University, Addis Ababa, Ethiopia
[3] Oromia Agricultural Research Institute, Addis Ababa, Ethiopia

Abstract

Apodytes dimidata E. *Mey.* Ex *Am.*,) is tree commonly grown in montane forest between 1200 to 3500 m and widely distributed in East Africa. It is used for firewood, for making charcoal and in traditional medicine. Forests are the major source of carbon pools which is released CO_2 to atmosphere due to natural and manmade factors. The reliable and accurate biomass assessments for tropical tree species are vital to implement climate change mitigation. The allometric model established by Chave *et al.* 2014 could not efficiently indicate the AGB in a particular area including the study area. The application of site specific allometeric model is crucial to attain higher level of precision. Therefore, the objective of the finding was to establish site specific allometric model for *A. dimidata* using semi-destructive sampling methods. The developed models relate AGB with denderometeric variables (DBH, H and WD). From evaluated models only four models were selected based on higher value of R^2, SE and AIC and the selected models are significant ($p < 0.000$). The fourth model is found to be the best model comprising DBH, Height and wood density, with higher R^2-adj 0.87 and SE (0.63) and AIC (37). Thus it is suggested that establishment of site specific biomass model are important for better biomass assessment for fulfillment of national and international reporting requirements. The specific allometeric equation developed in this study can be applied in moist forests of the country having similar forest structure for the benefit of the community from carbon trade.

Keywords: biomass model, carbon sink, AGB, southwest forest

Introduction

Apodytes dimidata E. *Mey.* Ex *Am.*, (Icaniaceae) is medium sized tree widely grown in dry and moist Afromontane forest at altitude between 1200 to 3500 m. It has wide area coverage in East and Central Africa and south extending from Ethiopia, to South Africa. In Ethiopia *Apodytes dimidata* grows in in central, Northern and South western montane forest and often found as solitary trees in grassland, secondary forest and farmland. *Apodytes dimidata* is a tall evergreen tree, up to 25 m high, with a rounded crown. Leaves: dark glossy-green, turning black when drying, alternate with variable shape, but usually oval with regularly wavy margins or even sometimes slightly toothed. Inflorescence a terminal panicle, sometimes axillary, many-flowered. The wood is tough and strong, easy to saw, and the wood is also sometimes used as fuel and for making charcoal. In tropical Africa *Apodytes dimidiata* is widely used in traditional medicine.

The role of forest in carbon sequestration

Forests are source of carbon pool which sequester carbon and store in plant biomass and soil. The release of CO_2 to the atmosphere is caused by manmade factors such as such as deforestation and fossil fuel burning. Tropical Forests sequester huge amount of carbon and contributes a great role in global carbon cycle and hence it acts as an important natural brake for climate change. The tropical forest stores large pools of carbon and holding 46% of the above ground carbon and 11.55% soil carbon pool of the world (Brown *et al.*, 1982) [9].

Biomass estimate of carbon pools in tropical forest is a great role to increase our understanding of the role of tropical forest in global carbon cycle and its contribution in combating global climate change and designing mitigation strategy (Mehari *et al.* 2016) [12].

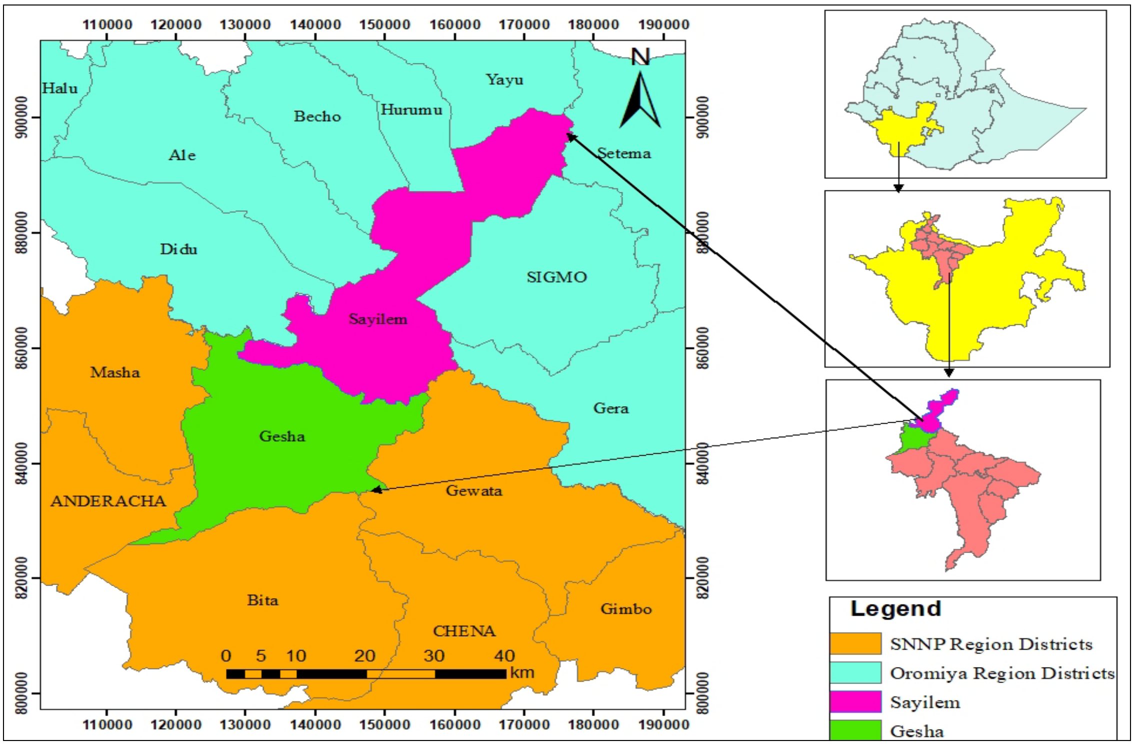
The reliable and accurate biomass assessments for tropical tree species are vital to implement climate change policies for benefiting the forest community from United Nations climate change polices (Ancelm *et al.* 2016) [2]. According to (IPCC, 2007) [16] every country have to report often the condition of their forest position by assessing the carbon stock level by making forest inventory record using suitable biomass models. The biomass models established for different forests based on relating the measured tree attributes such as DBH, H (height) and WD (Buski *et al*, 2009) [8].

The most commonly used generic models for tropical forest, are (Chave *et al.*, 2014 and, Brown *et al.* 1989) [10, 6] who established allometeric equation based on DBH, H and WD for assessment plant biomass. However, the generalized biomass equation may not precisely estimate carbon stock potential of the particular forest. Thus, the application of species based allometeric equations is vital to attain better estimates for biomass of woody plant since different woody plant species may have different crown structure and wood density (Berhanu *et al.* 2008) [5]. Therefore, developing species based biomass equation for dominant trees or frequently occurring trees in particular forest is very important to estimate the carbon sequestering potential of the forest (IBC 2005) [15]. Thus the study was aimed to establish species-specific biomass model for *Apodytes dimidata* for envisaging the above ground biomass.

Materials and Methods

Location and Description of Study Area

The study area is located in Kafa zone between 6^0 24’ to 7^0 70’ North and 35^0 69’ to $36^0$78’ East (Fig. 1). The southern part of study area is bordered by Bita district in the west by the Sheka Zone, in the North by Illuababor Zone of Oromia Region and in the east by Gewata district. The total area coverage of the forest in Gesha and Syilem districts are 705.20 and 856.60 square kilometers respectively (Ayele Kebede, 2011) [4]. The topography of the area is undulating, with valleys and rolling plateaus and some area with flat in the plateaus and the altitude ranges from 1,600m to 3000m (Addi *et al.* 2020) [1]. The common soil types in the study area are fertile soils of the volcanic origin of Precambrian and Metamorphic rock materials. The major soil groups, are Nitisols which are agriculturally important and are the dominant soils types in the study area with high organic matter and nitrogen content.



Source: (Admassu *et al.* 2020) [1]

Fig 1: Map of the study area showing administrative regions of the Ethiopia

Species Sampling and Data Collection

Preferential sampling techniques was used to select sample trees or individuals. For measuring tree biomass, a single tree was classified to woody plant and its diameter greater than five centimeters was considered for required data collection. A required sample tree was selected based on abundance and frequency of the tree in the area and trees without being damaged. Accordingly, a total of 30 individuals of *Apodytes dimidiata*, was selected. For the representation of sample size, five DBH Classes were established from minimum of 10cm up to > 50cm (Birhanu & Teshome 2018) [5].

Measurement of Tree Biomass in the Field

The methodology for measurement biomass of sample were used the procedure of (Picard, Saint- André, and Henry 2012) [19] for developing biomass models. None destructive sampling without destroying sample trees due to cost and the rare distribution of tree in the area. Before measurement of the required data, the individual tree was divided into separate section of the trees which include trunk, big branches and small branches and measurement was done by climbing to a point up to the apex of the tree Figure 2. After measurement of tree compartment, four branches having diameter < 10cm were cut down to the ground. The sample branches were processed into leaves and wood and their fresh weight was weighed using weighing balance and recorded.

The three replicates of leaves and wood samples were put in sample plastic containers, and then transported to drying room and kept in oven for moisture content determination (Picard, Saint- André, and Henry 2012) [19]. The oven dry weight of each tree compartment (leaves and wood) computed as the oven dry weight of the sample leaves and wood and divided by total fresh weight of sample leaves and wood and then multiplied by the total fresh weight of the respective components of trimmed branches in the field. The WD was measured by taking the sample of wood from different section of tree branches (lower, middle and upper) and cut into small pieces. The volume of each wood sample was measured by water displacement method Picard, *et al.* (2012) [19] and kept in drying oven for 72 hours. The wood density was computed as the oven dry weight of wood divided by volume of the wood.

Measuring Untrimmed Fresh Weight of Tree

The biomass of stem and big twigs were done by measuring the diameter and its length in the field. An interval of 2m in length between stem was used to measure diameter and height of each section of the stem. Then biomass of the stem and twigs were calculated from the volume of wood and mean WD with assumption that sections of stem or trunk were considered to be cylindrical and their density considered to be the same in all partitions of the trees (Picard *et al.* 2012) [19].

Fig 2: Field measurement of tree trunk and branches of *Apodytes dimidata*

Calculations Aboveground Biomass

All the necessary steps for the biomass calculation for trimmed, untrimmed and leaves and wood were followed from Manual of FAO (2012).

Data Analysis and Model Selection

Model Selection

Before selecting appropriate biomass model, fitting of data for fulfilling of the linear regression model assumptions were detected by observing the linearity of scatter plots and out layers. Moreover, analysis was carried out between the above ground biomass and predictable variables (DBH, H and wood density) using correlation analysis (Table3). Different arrangements of predictor variables were performed relating with AGB using multiple regression models and seven possible models were tested (Picard *et al*., 2012) [19]. The selected Allometeric model fitness was evaluated based on Adjusted R^2 (R^2- adj), standard error (SE) and Akaike information criterion (AIC).

Results and Discussion

Biomass Correlation in Relation to Tree Attributes

The result of tree attributes (DBH, H and WD and AGB of *A. dimidata* was indicated in Table1. The biomass of the tree was significantly correlated with Diameter at breast height (0.84). Similarly, tree height (H) is also correlated with biomass (0.69) and WD was weakly correlated (0.56). The stem dry weight also strongly correlated with above ground biomass and while big branches and small branches including leaves are also correlated with DBH the relationship was highly significant ($p < 0.05$) Table 2.

Table 1: The measured tree variables and mean biomass for *Apodytes dimidiata* in South west Forest

Variables	Mean	SD	Min	Max
Aboveground (kg)	959	320	4668	959±320
DBH	41	19	10	89.2
H	13	6	4	25
Density	0.53	0.64	0.22	0.86
N	30	30	30	30

Table 2: Correlation analysis between biomass components (stem, branches and AGB) and predictable variables

Plant species		Dendrometric variables		
	Biomass component	DBH (cm)	H(m)	WD (gcm–3)
Apodytes dimidata	stem	0.783***	-0.046ns	0.63***
	Big branch	0.37*	0.49ns	-0.080
	Small branch +leaves	0.74**	0.83**	0.48ns
	AGB	0.84***	0.69***	0.56**

ns not significant, p ≤ 0.05; ** p ≤ 0.001; ***p≤ 0.001

Biomass Distribution within Trees Compartments

The allocation of the biomass section of stem & branches were calculated and it ranges 0.37-16.6kg/per tree for branches, 2-2406kg/tree for stem. The average branch and stem biomass were 6.13kg and 416kg/tree respectively Figure 5. The percentage of dry biomass was stored in tree trunk and twigs because of its crown geometry that holds more branches and leaves and it might be less damaged by external biological factors like human disturbance and herbivory.

This is in line with previous findings of (Dieler and Pretzsch 2013) [11] and Mehari *et al*. 2016. The lesser biomass was stored in small twigs and leaves due to its computation for light and habitat to survive. The finding also agrees with (Henry *et al*. 2010) [14] who found that the branch and leaf biomass is lesser than trunk biomass.

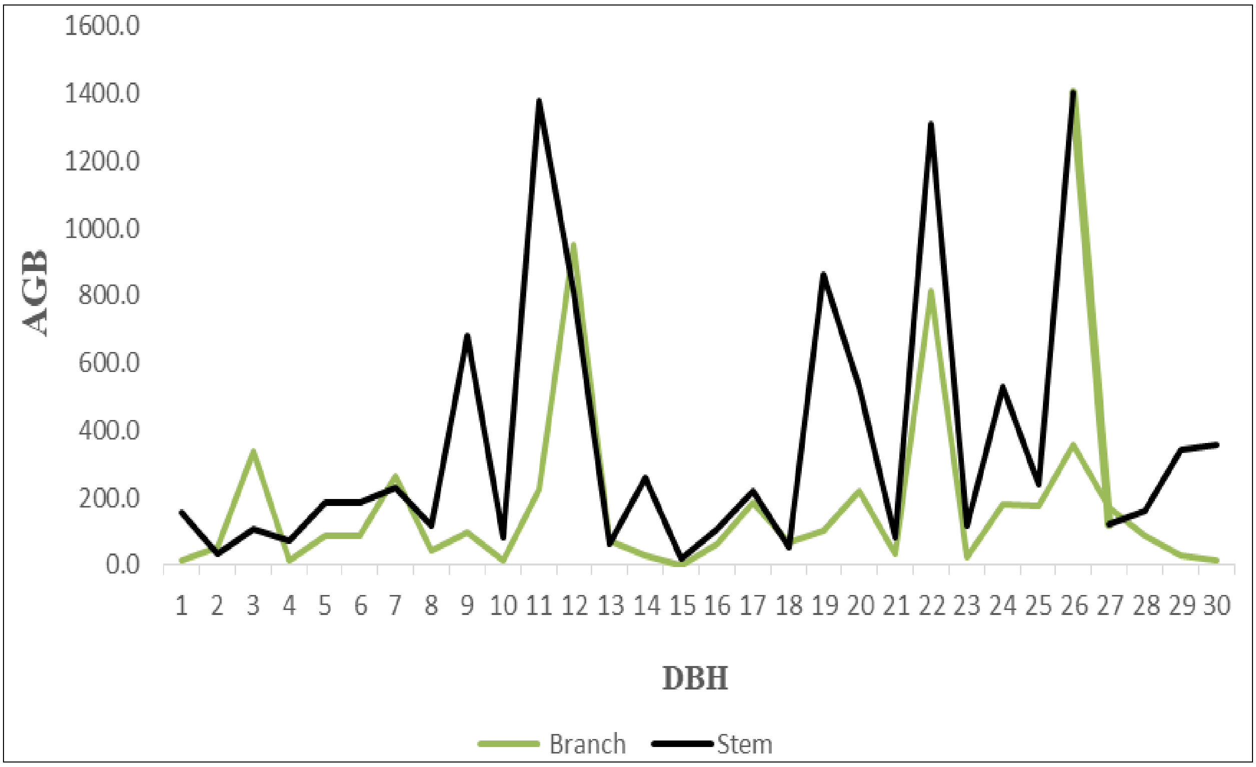
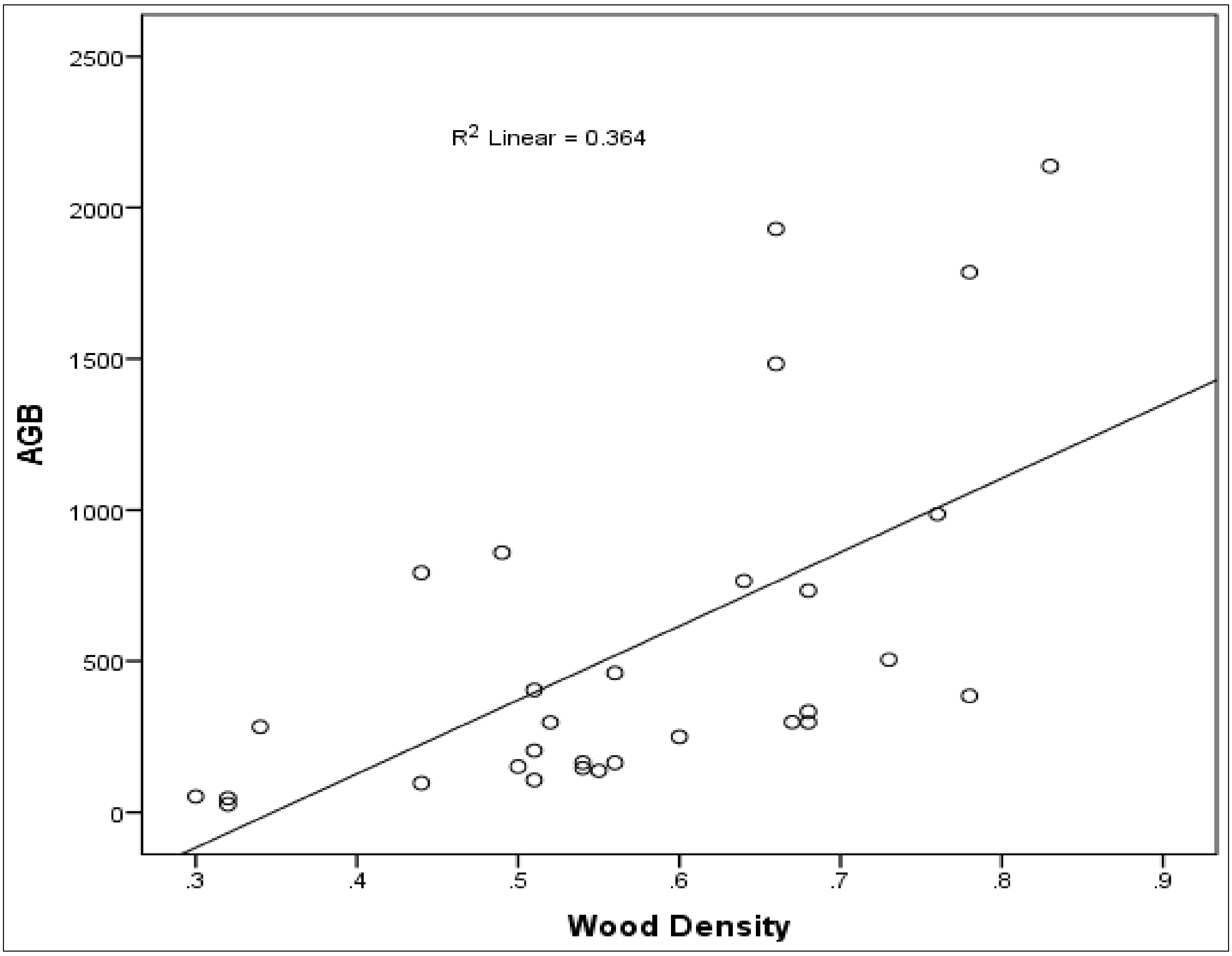


Fig 3: Aboveground biomass partitioning with in trunk and twigs of *Apodytes dimidata*

Scatter plot indicated in Fig 4 substantiates the relationship between AGB, DBH, Height and wood density representing an increment DBH of tree also there was unit of increment of AGB and indicating strong linear relationship. On the other hand, the linear relationship between height and AGB, has relatively has better relationship while wood density weak relationship with AGB. Based on this relationship Diameter at breast height and H are considered to be the most important predictive variable in developing appropriate biomass model at particular forest.



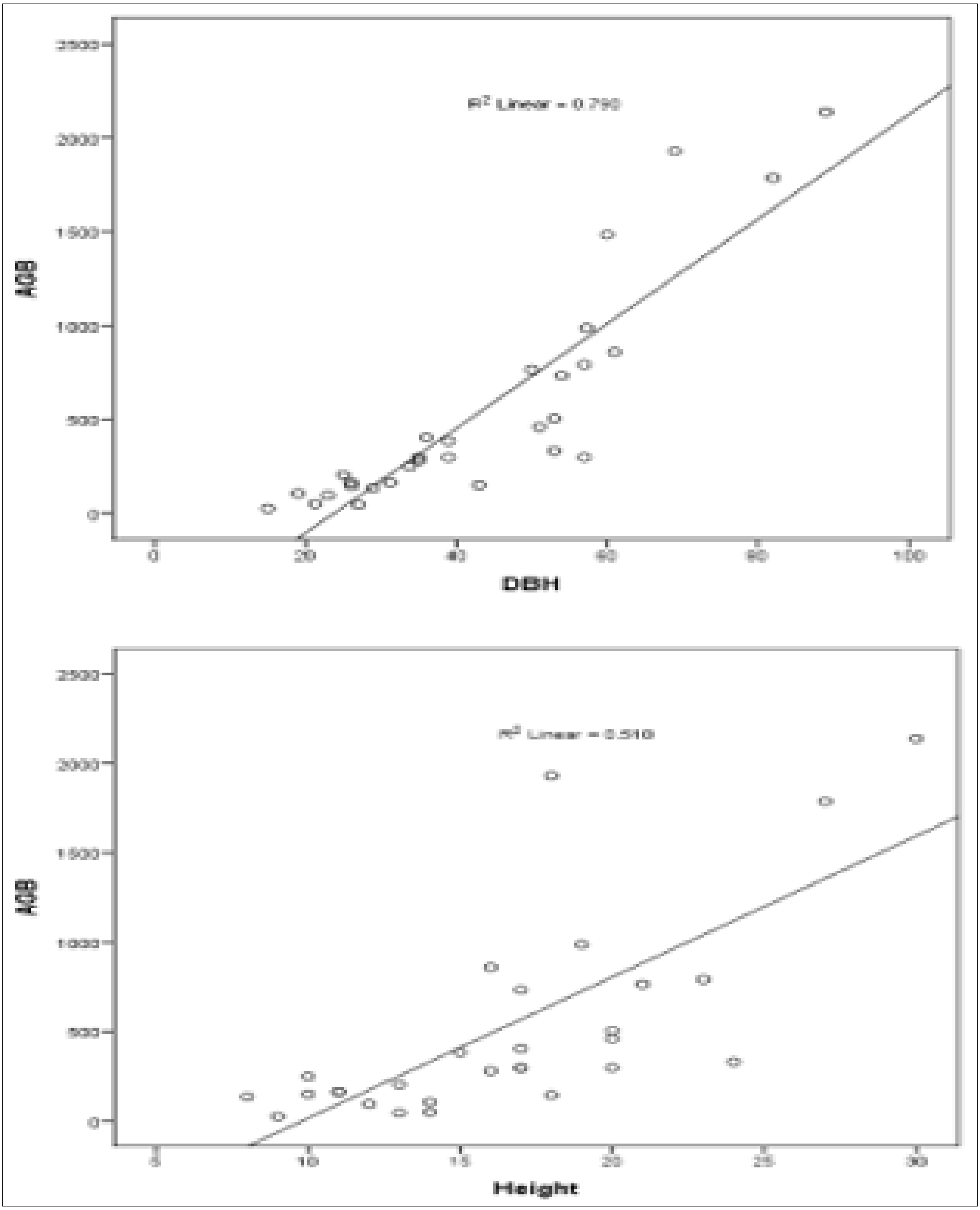


Fig 4: A correlation between AGB and dendrometric variables

Model Selection and Validation

For selection of appropriate model multiple regression analysis was undertaken between dependent variable (AGB) and independent variable (DBH, density, and height) independently and in grouping. As the result of this analysis, seven (7) biomass models were evaluated in all possible ways. Out of tested models only four biomass models were selected based statistical fitness of the data and three were rejected Table 3.

The computed model parameters for the AGB was significant ($p < 0.001$). Out of the selected model the fourth model is found to be the best model (Model 4) combing DBH, H^2 and wood density, with higher R^2-adj (0.87) and SE (0.63) and AIC (37). Model 2 in combination of DBH, WD and Height also found to be the second best fitted model with Adj. R^2 value of 0.85 and AIC (42) and lower values of SE (0.36) Table 4). In the equations AGBest =, $\beta 0+log\beta 1DBH+\varepsilon$ (M1) the predictable variable (DBH) explained the response variable (Above the ground biomass) by 81%. Hence DBH is the major limiting variable influencing the AGB of *Apodytes dimidata*. The wood density and H (height) alone or in combination are poorly explained the above the ground biomass and rejected due to lower Adj. R^2 (0.46) and higher AIC (81) and SE (0.54). Among the independent variables, DBH was found strong predictable variable influencing the AGB. This is in agreement with Brown (2002) [7], who indicated that DBH is highly pertinent variable for assessing AGB in a highly diverse ecosystem while (Navar, 2009) [18] showed that the perceived difference in biomass of the trees are elucidated DBH. On top of this the inclusion of the WD, DBH and H provided best fit in Model 4.

This is in agreement with finding of Brown *et al.* 1989 [6] and Chave *et al* 2014 [10] stated inclusion of wood density increased the biomass of the forest. This is also supported with Alvarez et *al*. 2012 who showed that inclusion of wood density and tree height increase the biomass in Amazonian forest.

Table 3: Biomass models evaluated for *Apodytes dimidata*

Model	Equation	Model	Equation
1	$AGB= \beta_0+log\beta_1 DBH+\varepsilon$	5	$\log(AGB)=\beta 0+\beta_1\log(DBH)+\beta_2\log(WD)+\varepsilon$
2	$\log(AGB)=\beta 1\log(H)+\varepsilon$	6	$\log(AGB)=\beta_1\log(H)+\beta_2\log(WD)+\varepsilon$
3	$\text{Log}(AGB)=\beta_0+\beta 1\log(WD)+\varepsilon$	7	$\log(AGB)=\beta 1\log(DBH)+\beta_2 log(H)+\beta_3\log(H)+\varepsilon$
4	$\log(AGB)=\beta_0+\beta_1 logDBH+\beta 2 log(\mathrm{H})+\varepsilon$		

Table 4: Model selected and fitted models of AGB of *Apodytes dimidata*

Model	Equation	*Parameter Estimates*				Model performance	
		β_0 (SE)	β_1 (SE)	β_2(SE)	β_3 (SE)	AIC	Adj R^2
1	$AGB= \beta 0+log\beta 1DBH+\varepsilon$	0.31(0.55)	0.74 (0.15) ***	-	-	48	0.81
2	$\log(AGB)=\beta 0+\beta 1logDBH+\beta 2log(\mathrm{H})+\varepsilon$	0.32 (0.51) **	1.35(0.212)*	-	-	44	0.84
3	$\log(AGB)=\beta 0+\beta 1\log(DBH)+\beta 2\log(WD)+\varepsilon$	1.91 (0.76)*	1.46 (0.17) ***	1.0 (0.36)*	-	42	0.85
4	$\log(AGB)=\beta 1\log(DBH)+\beta 2log(H)+\beta 3\log(H)+\varepsilon$	1.91(0.69)*	1.0 (0.2)***	0.55 (0.2)**	0.040 (0.33)	37	0.87

Correlation Analysis of Models

Correlation analysis was made between developed evaluated models for *A. dimidata* and generic model established by Chave *et al*. (2014) [10] and Brown *et al*. (1989) [6]. The first three models are significantly correlated to each other since DBH is common factor for both. The selected model (M4) is differing from the M1, M2, and M3 with average correlation coefficient of 0.63 Table 5. The current selected models are differed from Chave *et al.* (2014) [10] and Brown *et al.* (1989) [6] with correlation value of 0.51, 0.51 and 0.59 respectively.

The models established in the current study are accurate in predicting the AGB in moist forest of the study area since microclimate of the area is differed from site to site. The result also in agreement with Mehari *et al.* (2014) [17] who showed that the generic model shows low performance with 32–59% average deviation for AGB of five tree species in Ethiopia.

Table 5: Correlation analysis between evaluated models and generic models

Model	M1	M2	M3	M4	Measured	Chave *et al.*, (2014) [10]	Brown *et al*. (1989) [6]
M1	1	0.94**	0.94**	0.62**	0.79**	0.72**	0.87**
M2	0.94**	1	0.93**	0.67**	0.81**	0.77**	0.88**
M3	0.94**	0.93**	1	0.61**	0.79**	0.76**	0.86**
M4	0.62	0.67	0.61	1	0.51	0.51	0.59**
Chave *et al*. (2014) [10]	0.73	0.77	0.76	0.51	0.85	1	0.94
Brown *et al*. (*1989*) [6]	0.87	0.88	0.87	0.59	0.92	0.95	1

Conclusion and Recommendation

Out of the tested allometeric models only four models were recognized based on the statistical significance. As the Ethiopia encompassed with diversity of tree species and application of generalized models may create biased estimates of AGB. Therefore, it is recommended to establish species based models for better estimation of biomass to fulfill carbon stock data reporting requirements. Moreover, the model established in this investigation can be applied in similar forests in the country.

Conflict of Interest

No interest of the conflict between authors.

Funding

The research activity was funded by Oromia Agricultural Research Institute.

Acknowledgments

The authors like to acknowledge Addis Ababa University and Oromia Agricultural Research Institute for their un deserved support for the facilities and logistic.

References

1. Admassu A, Teshome S, Tura B. Plant diversity and community analysis of Gesha and Sayilem Forest in Kaffa Zone, southwestern Ethiopia. Biodiversitas, 2020, 21(7).
2. Ancelm MW, Edward ME, Luoga E, Ernest MR, Zahabu E, Santos SD *et al.* Allometric Models for Estimating Tree Volume and Aboveground Biomass in Lowland Forests of Tanzania. International Journal of Forestry Research, 2016.
3. Alvarez E, Duque A, Saldarriaga J, Cabrera K, del Valle G, Lema A *et al.* Tree above-ground biomass allometries for carbon stocks estimation in the natural forests of Colombia. Forest Ecol. Manage,2012:67:297-308.
4. Ayele Kebede. Delimiting the Interface between Garden Coffee Expansion and Forest Coffee Conservation and its Implication for Protected Area Management: The Case of Kafa Coffee Biosphere Reserve. Msc thesis, University of Klagenfurt, Austria, 2011.

5. Berhanu K, Teshome S. Allometric equations for aboveground biomass estimation of *Olea europaea* L. subsp. *cuspidata* in Mana Angetu Forest, 2018.
6. Brown S, Gillespie AJR, Lugo AE. Biomass estimation methods for tropical forests with applications to forest inventory data. Forest Science, 1989, 35(4).
7. Brown, S. Measuring carbon in forests: current status and future challenges. Environmental Pollution, 2002, 116(3).
8. Basuki TM, Van Laake PE, Skidmore AK, Hussin YA. Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forests. Forest Ecology and Management, 2009, 257(8).
9. Brown S, Lugo AE. The storage and production of organic matter in tropical forests and their role in the global carbon cycle. Biotropica, 1982.
10. Chave J, Réjou-Méchain M, Búrquez A, Chidumayo E, Colgan MS, Delitti WB *et al*. Improved allometric models to estimate the aboveground biomass of tropical trees. Global Change Biol, 2014, 2.
11. Dieler J, Pretzsch H. Morphological plasticity of European beech (*Fagus sylvatica* L.) In pure and mixed-species stands. For Ecol Manage,2013:295:97-108.
12. Mehari A, Andr´es B, Bravo.Fe. Ricardo Ru. Aboveground biomass equations for sustainable production of fuelwood in a native dry tropical afro-montane forest of Ethiopia,2016:3(2):411-423.
13. Henry M, Picard N, Trotta C, Manlay RJ, Valentini R, Bernoux M *et al*. Estimating tree biomass of sub-Saharan African forests: a review of available allometric equations. Silva Fennica, 2011, 477-569.
14. Henry M, Besnard A, Asante WA, Eshun J, Adu-Bredu S, Valentini R *et al*. Phytomass variations within and among trees, and allometric equations in a tropical rainforest of Africa. Forest Ecology and Management, 2010, (260).
15. IBC. National biodiversity strategy and action plan. Institute of Biodiversity Conservation, Addis Ababa, 2005.
16. IPCC. Climate change: synthesis report- contribution of Working Groups 1, 2 and 3 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, 2007.
17. Mehari AR, Ruiz-Peinado A, Bravo-Oviedo, F Bravo. “Aboveground Biomass Equations for Sustainable Production of Fuel Wood in a Native Dry Tropical Afromontane Forest of Ethiopia.” Annals of Forest Science, 2014, 73(2).
18. Springer Navar J. Allometric equations for tree species and carbon stocks for forests of Northwestern Mexico. Forest Ecology and Management, 2009, 257(2).
19. Picard N, Saint-André L, Henry M. Manual for building tree volume and biomass allometric equations: from field measurements to prediction. Rome: Food and Agricultural Organization of the United Nations, 2012.