Allometric equation for aboveground biomass estimation in moist Afromontane forest in Gesha and Sayilem district in Kaffa zone, southwestern Ethiopia

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Methodology

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Abstract

Background: Allometric equations which are regressions linking the biomass to some independent variables are used to estimate tree components from the forest. The generic equation developed by many authors may not adequately reveal the tree biomass in a specific region in tropics including in Ethiopia. Therefore, the use of species specific allometric equations is important to achieve higher levels of accuracy because trees of different species may differ. The objective of the study was to develop species-specific allometric equations for *Apodytes dimidiata*, *Ilex mitis*, *Sapium ellipticum* and shrubs (*Galiniera saxifraga* and *Vernonia auriculifera*) using semi-destructive method for estimating the aboveground biomass (AGB). For purpose of sampling trees, individual species were categorized into trees whose Diameter at breast height (DBH) is ≥ 5 cm.

Results: All the necessary biomass calculations were done, and biomass equations were developed for each species. The regression equations relate AGB with DBH, height (H), and density (ρ) were computed and the models were tested for accuracy based on observed data. The best model was selected based higher adj R^2 and lower residual standard error and Akaike information criterion than rejected models. The relations for all selected models are significant ($p<0.000$), which showed strong correlation AGB with selected dendrometric variables. Accordingly, the AGB was strongly correlated with DBH and was not significantly correlated with wood density and height individually in *Ilex mitis*. In combination, AGB was strongly correlated with DBH, height; DBH and wood density; are better for carbon assessment than general equations.

Conclusions: The specific allometeric equation developed for the Gesha-Sayilem Afromontane Forest which can be used in similar moist forests in Ethiopia for the implementation of Reduced Emission from Deforestation and Degradation ($REDD^+$) activities to benefit the local communities from carbon trade.

Background

Forest ecosystem is a major component of the carbon reserves and it plays an important role in moderating global climate change through process of carbon sequestration [1, 2]. Tropical forest is a major component of terrestrial carbon cycle and it has a great potential for carbon sequestration, accounting for 26% carbon pool in above ground biomass and soils [3]. Biomass estimation of tropical forest is crucial for understanding the role of terrestrial ecosystems to the carbon cycle and climate change mitigation. To implement mitigating policies and taking the advantage of the Reducing Emissions from Deforestation and Forest Degradation ($REDD^+$) needs well valid estimates of forest carbon stocks [4]. Under the United Nations Framework Convention on Climate Change (UNFCCC), countries have to report regularly the state of their forest resources through assessments of carbon stocks based on forest inventory data and allometric equations [5, 6]. The allometric equation, estimates the whole or partial mass of a tree from measurable tree dimensions, including trunk diameter, height, wood density, or their combination [7, 2, 9]. The most common allometric model used to predict biomass is the power function Y = a × Xb, where **Y**, dry biomass weight, **a** is the integration factor, **b** is the scaling factor and X is the diameter at breast height [10, 11]. This function is considered as the best applicable mathematical model for biomass studies because the growing plants maintain the different mass proportion between different parts. Allometric biomass equations have been developed for tree species in different ecological regions of the world, which are related to species-specific and stand-specific biomass models [12]. Allometric equations which are regressions linking the biomass to some independent variables such as diameter, height and wood density are used to estimate tree components from the forest [13, 14]. However, in tropical forests, the accurate estimates of carbon sequestration are lacking due to a scarcity of appropriate allometeric models. The generic equation developed by [15, 16, 17] may not adequately reveal the tree biomass in a specific region in tropics including in Ethiopia. Therefore, the use of species specific equations is important to achieve higher levels of accuracy because trees of different species may differ greatly in tree architecture and wood density. Being the study area is part of the tropical forest and no study was conducted to develop species-specific allometric equations to estimate the biomass for mitigating climate change effects. Thus, the aim of this study is to estimate aboveground and below biomass of the trees and shrubs in order to develop species specific allometric equations that could be used for biomass and carbon stock estimation in moist Afromontane forest of south west Ethiopia.

Materials And Methods

Description of the study area

The study area is located in the Southern Nations Nationalities Peoples Regional State (SNNPRS), in Kafa Zone at Gesha and Sayilem districts. It is located between 6^0 24' to 7^0 70' North and 35^0 69' to $36^0$78' East (Fig. 1). The topography of the landscape is undulating, with valleys and rolling plateaus and some area with flat in the plateaus. The altitude ranges from 1,600m to 3000m [18]. The monthly mean maximum and minimum temperature for Gesha is 29.5 $^{\theta}$C and 9.5 ^{0}C, respectively. On the other hand, the monthly maximum and minimum temperatures for Sayilem ranges 10^{o}C to 25^{o}C and the annual rainfall for both districts ranges 1853-2004mm.

Data collection and sampling techniques

A stratified random sampling method was used to select tree and shrubs in the study area. For sampling trees, individual plant species were categorized into woody plants who's Diameter at Breast Height (DBH) is ≥ 5 cm diameter at breast height, shrubs, saplings (height ≥ 1.3 m and DBH 2.5-5 cm following Lamprecht ́s classification [19, 20]. Based on the density and frequency of the species, a total of 150 individuals of five dominants plant species of *Apodytes dimidiata*, *Ilex mitis*, *Sapium ellipticum* and shrubs (*Galiniera saxifraga* and *Vernonia auriculifera*) were selected and 30 individuals from each trees and shrubs were used for the measurements. In order to represent the reasonable size of the diameter distribution and to minimize error of sampling, the trees were classified into five DBH classes and each class having six individuals per DBH class ranging from 10-20, 20.1-30, 30.1-40, 40.1-50, and greater than 50 cm were measured and recorded.

Field measurement

Non-destructive sampling method was used for the measurement of tree biomass, and the trees were divided into separate architectural elements (stem, branches and leaves). Serial measurements of the height and diameter of trunk were done at 2 m intervals by climbing on live trees using the ropes. For the determination of trimmed biomass, four branches whose circumference is less than 10cm were trimmed down from the live tree using the machete [21, 22, 23]. The trimmed branches were separated into leaves and wood and the fresh weight of leaves and wood were recorded Fig. 2.

Laboratory measurement

A three replicates of 1 kg of sample of the wood and leave were weighed and placed in plastic bag, brought to the laboratory and oven dried at 105 °C for 72 hr for wood, and 24 hours for leaves. The total dry weight of each AGB component was calculated using the ratio between the dry and fresh weight of the sub-samples, multiplied by the total fresh weight of the respective components. The basic wood density (gcm^{-3}) of branches of the different sizes of the tree was estimated according to the water displacement method Figure 3. The averaged WD (g/cm3) per sample tree was calculated as oven-dry weight divided by volume at saturation.

For determination of biomass shrubs (*Galiniera saxifraga* and *Vernonia auriculifera*), the shrubs were destructively sampled. The following parameters were measured such as stump diameter at 30 cm, DBH at 1.3 m, total height (h). The DBH of the shrubs ranged from 3.8-22.8 cm and 3.0 to 18.3 cm for *Galiniera saxifraga* and *Vernonia auriculifera* respectively. The fresh weight of each component was measured using a spring balance. To determine the dry matter content of the woods and leaves all branches from each stem were taken from thickest to the thinnest to make a composite sample and sealed in plastic bags and transported to laboratory. They were then oven-dried at 70^0 C for 24 hr and samples were weighed and the fresh to oven-dry weight ratios was calculated.

Biomass calculations

The data collected from field and laboratory measurements were organized in excel spread sheet and analyzed using Statistical Package R software [24].

Estimation of Aboveground biomass of tree

The above ground biomass of the tree was calculated by summing up of trimmed dry biomass and the untrimmed dry biomass of the sample trees.

Bdry = Btrimmed dry + Buntrimmed dry**……………………………………** (equ.1)

Calculations of trimmed biomass

The trimmed biomass of sample tree was calculated from the fresh biomass $_{\textbf{Baliquot fresh wood}}$ of a wood aliquot and its dry biomass $B_{\textbf{drywoodaliquot}}$, the moisture content was calculated as follow

……………………………………………… (**equ.2**)

Where is moisture content of the wood, and where **B**aliquot **dry wood**, is the oven-dried wood biomass of the aliquot in the sample and where **B**aliquot **fresh wood**, is the fresh wood biomass of the branch aliquot in the sample. Similarly, the moisture content of the leaves was calculated from the fresh biomass $\boldsymbol{B}_{\textbf{fresh leaf aliquot}}$ of the leaf aliquot and its dry biomass $\boldsymbol{B}$ dry $_{\textbf{leaf aliquot}}$ as follow.;

……………………………………………….. (equ3**)**
Trimmed dry biomass was then determined as

Btrimmed dry = B trimmed fresh wood *X wood+ B trimmed fresh leaf* X leaf………… (equ.4)

Where, **B trimmed fresh leaf** is the fresh biomass of the leaves stripped from the trimmed branches and Btrimmed **fresh wood** is the fresh biomass of the wood in the trimmed branches.

Calculating untrimmed biomass

Untrimmed biomass was calculated from two parts of the tree still standing (stem and large branches) and the other for small basal branches.

B untrimmed dry = B dry section+ B untrimmed dry branch**…………………..** (**equ5**)

Each section *i* of the stem and the large branches were considered to be a cylinder of volume and volume of stem and large branches were calculated using Smalian's formula.

$Vi = \frac{\pi\, Li\, (D^2_{1i} + D^2_{2i})}{8}$ ………………………………………………(**equ6**)

Where Vi is the volume of the section *i*, its length, D^2_{1i} and D^2_{2i} are the diameters of the two extremities of section *i*. The dry biomass of the large branches and stem were being calculated from the product of mean wood density and total volume of the large branches and the stem.

B dry section= *∑Vi…………………………………………. (equ7.)

Where the mean wood density was expressed in gcm−3, then volume Vi was expressed in cm^3 and the mean wood density was calculated by:

……………………………………………. (equ.8)

The dry biomass of the untrimmed small branches was then calculated using a model between dry biomass of trimmed branches and its basal diameter. This model is established by following the same procedure as for the development of an allometric model, using a simple linear regression model which is expressed as *B*dry branch = $a+bD^c$…………………………………………………………… (**equ. 9**)

Where *a*, *b* and *c* are model parameters and *D* branch basal diameter,

Estimation of below ground Biomass (BGB)

The total aboveground biomass of a tree has been good predictors of its belowground biomass. Total root biomass for each of the study trees were calculated following [25]. Thus, a conversion factor of 0.24 for tropical rain forest was used to calculate the below ground biomasses of each of the study trees from their total aboveground biomass.

BGB= AGB × 0.24 ……………………………………………………… (equ. 10)

Data analysis and Model selection

Relationships between basal diameters and dry weight of trimmed branches including twigs and leaves were computed using linear regression models. The assumptions of linear regression model were checked by observing the normal distribution of residuals on P-P plots. Because of the heteroscedasticity nature of biomass data, the data were transformed using a natural logarithm. Furthermore, Pearson correlation analysis was carried out between the response variable (Dry weight of the biomass) and the independent variables (DBH) to examine whether there was the linear relationship between dependent and independent variables (Table 2). In order to identify the multicollinearity with log-transformed models multi collinearity test was carried out using a variance factor [26]. A value greater than 10 (VIF > 10) is an indication of potential multicollinearity among independent variables. Then selection of the best fit model was based on the goodness fit statistics calculated for each species specific equation such as adjusted coefficient of determination (R^2 adj), standard error of the mean *(*SE*)* and Akaki information criterion (AIC).

Results

Above ground Biomass

The summary of the mean, maximum and minimum DBH, height and wood density and dry weight of five plant species were summarized in Table1. The highest mean dry weight of the above ground biomass was obtained for

Apodytes dimidiata, followed by *Sapium ellipticum* and *Ilex mitis*. Similarly, the highest mean above ground biomass shrubs were obtained for G*aliniera saxifraga* and least was obtained for *Vernonia auriculifera.* The analysis of the different sub biomass compartments of trees and shrubs indicated that the stem comprises the greater biomass as compared to branches and leaves accounting for 72%, 65.9% and 54.7% of the biomass stem in *Apodytes dimidiata, Ilex mitis* and *Sapium ellipticum* respectively (Table1).

Table 1: Summary of the tree variables and mean biomass for five dominant tree and shrubs species in Gesha and Sayilem forests.

Species	Diameter			Height			Wood density			Above ground (kg)		
	Min	Max	mean	Min	Max	mean	Min	Max	mean	Min	Max	Mean
Apodytes dimidiata	10	89.2	41±19	4	25	13±6	0.22	0.86	0.53	125	4668	959±320
Ilex mitis	7.3	80.2	38±18	6	25	15 ±5	0.21	0.82	0.45	14	6831	861±239
Sapium ellipticum	8	89.2	48.4±18	5	35	19±7	0.2	0.7	0.43	97	4226	553±167
Galiniera saxifraga	14	55	29±10	3	8	4±0.7	0.32	0.82	0.53	23	43.3	25.2±17
Vernonia auriculifera	2.2	19	36±25	2	9	3±1.7	0.23	0.6	0.33	7	40	19.6±10
N	30	30	30	30	30	30	30	30	30	30	30	30

Pearson correlation of dendrometric variables to biomass compartments

The person's correlation analysis between above ground biomass and dendrometric variables (DBH, height and wood density) were shown in Table 2. The above ground biomass was strongly correlated with DBH and it is the most influential factors affecting the biomass of the trees and shrubs. Height is second important factor correlated strongly with biomass while wood density was poorly correlated with above ground biomass. Furthermore, the analysis of sub biomass compartment of trees and shrubs showed that stem biomass is strongly correlated with DBH in all studied species but wood density is poorly correlated except for *Apodytes dimidiata* and *Sapium ellipticum* and no significant correlation were obtained with height. Both branches and foliage's were positively correlated with DBH and height but no significant correlation with wood density.

Table 2. Pearson's correlation coefficients between biomass compartments (stem, branches and above ground biomass) and dendrometric variables (diameter, height, wood density) for tree and shrub species

Plant species		Dendrometric variables		
Apodytes dimidata	**Biomass component**	**DBH(cm)**	**H(m)**	**WD** (g·cm−3)
	stem	0.783***	-0.046ns	0.63***
	Big branch	0.37*	0.49ns	-0.080
	Small branch +leaves	0.74**	0.83**	0.48ns
	Above	0.84***	0.69***	0.56**
Ilex mitis	Stem	0.75***	0.79***	0.43*
	Big branch	0.85***	0.75***	0.44ns
	Small Branch +leaves	0.50**	0.41*	0.04ns
	Above	0.84***	0.73***	0.43*
Sapium ellipticum	stem	0.6535***	0.54819**	0.336ns
	Big branch	0.46*	0.29ns	0.39ns
	Small branch+ leaves	0.69**	0.38ns	0.34ns
	Above	0.84***	0.88***	0.83***
Gallinaria saxifarga	**Biomass component**	**DBH**	**Height**	**CRA**
	Stem	0.69***	0.36ns	0.39ns
	Big branch	0.54**	0.34ns	0.33ns
	Small branches+ Leaves	0.58***	0.39ns	0.53**
	Above	0.72***	0.62***	0.41*
Vernonia auriculifera	Stem	0.85***	0.22ns	0.12ns
	Branch	0.82***	0.20ns	0.12ns
	Leaves	0.64***	0.09ns	0.08ns
	AGB	0.84***	0.55**	0.12ns

ns not significant, dbh diameter at breast height, DSH stump diameter at 30 cm CA, Crown area and wood density (WD).* $p \leq 0.05$; ** $p \leq 0.001$;***$p \leq 0.001$

Trimmed twigs and leave biomass of the tree

The average trimmed wood aliquot moisture content from oven dry biomass varied from 0.34% in *Sapium ellipticum* to 0.54% in *Apodytes dimidiata* while the average leaf aliquot moisture content ranged from 0.32%, in *Ilex mitis* to 0.4% in *Apodytes dimidiata* (Table 3*)*. The mean dry wood biomass was highest for *Ilex mitis* and followed by *Sapium ellipticum* and *Galiniera saxifraga*. The lowest dry wood biomass was obtained for *Vernonia auriculifera*. Similarly, the dry leaf biomass was higher for *Ilex mitis* and relatively lower for the rest of the species. The overall dry section of trimmed branch including twigs and leave biomass highest for *Ilex mitis* (5.5 kg) and followed by *Apodytes dimidiata* (4.2 kg) and *Sapium ellipticum* (3.4).

Table3. Allometeric equations for determining Trimmed twigs and leaves of the trees

Plant species	Mean basal diameter (cm)	Mean Fresh wood (Kg)	wood moisture	Dry wood (Kg)	Fresh leaf (Kg)	Leaf moisture	Dry leaf (Kg)	Total $B_{trimmed\ dry}$ (kg)
Ilex mitis	9	12	0.4	4.8	5	0.32	1.6	5.5
Apodytes dimidiata	10	8.8	0.54	3.6	3	0.4	4.7	4.2
Sapium ellipticum	6	5	0.34	2.7	2	0.36	0.72	3.4

Regression model for determination of biomass of the small branches

From the regression model between the dry biomass of trimmed biomass and the basal diameter, values of “a” and “b” were known and the biomass of untrimmed small branches which was on the tree were determined by inserting the basal diameter to the model equations “$a+bD^c$” Table 4. Accordingly, the average biomass of untrimmed small branches for *Ilex mitis*, *Apodytes dimidata* and *Sapium ellipticum* were 46, 121and 86 (kg) respectively.

Table 4 Allometric equations for determining untrimmed dry biomass of the small branches of the species

Plant species	Mean basal diameter	a	b	Allometric model	P-value	Biomass of untrimmed branch	R^2
Apodytes dimidata	8.8±2.7	-2.56	1.55	-2.56+1.55basalD	0.00	121	0.72
Sapium ellipticum	6.6±3.05	-3.38	1.53	-3.38+1.53basalD	0.00	85	0.90
Ilex mitis	4.5±1.6	-5.37	1.66	-5.37+1.66 basalD	0.00	46	0.87

Biomass distribution within trees compartments

The distribution of mean biomass fractions for the trees and shrubs showed that on average stem, branch and leaf biomass contributed 70.8%. 24.6% and 1.47% of above ground biomass in *Apodytes dimidata* (47.8%, 49.2% 2.9%) *Sapium ellipticum* (82.4, 34.7, 8.11%) in *Ilex mitis* (36.5%, 34.3 % 29.17%), *Gallinaria saxifraga*) and 34.6%, 49.8%, 15.6% *Vernonia auriculifera* respectively Fig. 4. The highest percentage of stem biomass accumulated in *Ilex mitis, Apodytes dimidata* and *Gallinaria saxifraga*. The branch biomass was also highest in *Sapium ellipticum* and *Vernonia auriculifera.* Foliage had the lowest contribution towards the total biomass in all species.

Model selection and validation

The calculated model parameters for the above ground biomass were statistically significant ($p < 0.001$) with independent variables and the adjusted R^2 value ranges between 70-87 % and lower value of AIC (Akaike information criterion) were obtained (Table 5). Accordingly, the combination of DBH, Height and wood density model provided the best fit in *Apodytes dimidata* with adj R^2 value of 0.87 and standard error percentage of 0.63. On the other hand, the DBH and height were found to be the best fit variables for *Gallinaria saxifraga* and *Sapium ellipticum with* R^2, value of 0.73 and 0.81and AIC value of 34.24 *and* 59.25 respectively. The DBH alone provided the best fit *in Ilex mitis* and *Vernonia auriculifera* with adj R^2 the value of 0.87 and 0.70 and lower standard error and AIC was obtained. The plot in a standard Q-Q plot (Fig. 5), showed that the residual errors were normally distributed without layers indicating the models are fitting normally with independent variables (Fig. 5a). The scale-location plot (Fig. 5b) shows the square root of the standardized residuals as a function of the fitted values and in this graph, there was no obvious trend which is one property of good model validation. The residual versus leverage plots (Fig. 5c) shows that how far away the independent variable values of an observation are different from those of the other observations. The contour lines for the Cook's distance, which is another measure of the importance of each observation to the regression. If the Cook's distances larger than 1 are suspicious and suggest the presence of a possible outlier but our model prediction of Cook's distance between 0.5-1(Fig.5d) indicating the good quality of the model. The graphical presentation of model validation for five plant species was indicated as in figure 5.

Table 5. Model description for the fitted models of the above ground biomass for the study species

Species	Model for total AGB	*Parameter Estimates*				Model performance		
		(*std. error*)	**(*std. error*)**	**(*std. error*)**	**(*std. error*)**	**AIC**	**R^2**	***Vif***
Apodytes dimidata	$\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_2 \log(H) + \beta_3 \log(D) + \varepsilon$	1.91(0.69) *	1.08(0.21)***	0.56(0.20)*	1.00(0.33)**	37.06	0.87	1.91
Galiniera saxifraga	$\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_2 \log(H) + \varepsilon$	-3.29(0.70)***	1.21(0.23)***	1.10(0.25)***	-	34.24	0.73	3.29
Ilex mitis	$\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \varepsilon$	-1.47(0.57)*	2.20(0.16)***	-	-	46.36	0.86	1.121
Sapium ellipticum	$\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_2 \log(H) + \varepsilon$	-0.22(0.63)	1.17(0.26)***	0.88(0.28)**	-	39.25	0.81	1
Vernonia auriculifera	$\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \varepsilon$	6.00(0.30)***	1.51(0.18)***	-	-	58.97	0.69	1

Discussion

The biomass models for moist Afromontane forest species of the southwest Ethiopia are valuable tools for the estimation of carbon stocks to mitigation climate change. Different authors have attempted to generate biomass equations for tropical forests for the estimation of aboveground biomass [15, 11, 17, 27, 28, 29, 30] and these equations may not accurately be revealed the tree biomass in a specific region due to variability in wood density and the architecture of trees among and within species. However, little attention has been given to develop the species-specific biomass equation and it is available for tropical trees [30]. On view of this, biomass equations were developed for the above-ground biomass of the study species (*Apodytes dimidiata*, *Ilex mitis*, *Sapium ellipticum*, *Galiniera saxifraga* and *Vernonia auriculifera*). A goodness of fit, statistics using multiple regression model showed that combination of DBH, height and wood density were provided best fit for *Apodytes dimidata* and while DBH and height provided the best fit for *Galiniera saxifraga and Sapium ellipticum.* On other hand only DBH showed the best fit for *Ilex mitis*, and *Vernonia auriculifera* (Table 5). The inclusion of the wood density provided best fit for *Apodytes dimidata*, which increased the aboveground biomass prediction significantly with an adjusted R^2 of values of 0.73 and an average standard deviation of 16.9% and 18.2% respectively. This is in agreement with (15, 17, 28) observed that the equation including wood density improved biomass in moist forest of tropical Africa and Asia. In addition to this, the most important predictor of above ground biomass is usually DBH [31]. A measurement of height, *wood density* and the higher diameter can also be included if they significantly reduce the volume prediction error [32]. Alvarez [33] also indicated in the Amazonian watershed, the inclusion of wood density and height revealed spatial biomass and carbon patterns of the forest. Thus, introducing wood density as a biomass predictor may explain the site variations, species variations and increase precision of the estimations. The addition of the height in the biomass model also affected the biomass estimation for *Sapium ellipticum* and *Galiniera Saxifraga*. The height of the trees could include information about competition or fertility of the site and may yield less-biased estimates. Though accurate measurement of total height may be challenging in the field. According to Chave [17] observed a standard error reduction across all tropical forests types from 19.5% when total height was not included to 12.5% when total height was available. The differences between allometric equation biomass predictions were frequently, but not always, largest for the biggest trees [34]. Allometric equations that don't utilize tree height can over predict large diameter tree biomass [35].

The variation in aboveground biomass was also explained by DBH for *Ilex mitis* and *Vernonia auriculifera*. Since DBH is the best predictor variable for above ground biomass in allometric models because it is strongly correlated with biomass and it can be easily measured in the field and is always available in forest inventories data [12, 36, 37].

The high proportion of biomass was accumulated in the stem and big branches of *Apodytes dimidata, Ilex mitis and Sapium ellipticum*. The branch biomass of *Ilex mitis* is largest as compared to others due to spreading canopy that holds more branches and leaves and also it might be protected from external disturbances. This is in agreement with Dieler and Pretzsch [38] and Mehari [39] reported that herbivores and inter-plant competition can affect the branch biomass and its geometry. The smaller biomass was accumulated in small branches and leaves. This is due to the fact that dense forests with strong competition for light and space, the trees tend to develop smaller branches and foliage which resulted for the lower biomass. This study is in agreement with [40] found percentage stem biomass is found to higher than for branch and leaf.

Conclusion And Recommendation

The study indicated that Dendrometric variables DBH, height and wood density model provided the best fit in *Apodytes dimidata* while the DBH and height were found to be the best fit variables for *Gallinaria saxifraga* and *Sapium ellipticum.* On the other hand, the DBH model provided the best fit *in Ilex mitis* and *Vernonia auriculifera.* The model developed in this study can be used for estimating forest carbon stocks, identifying carbon sequestration capacity and establishing carbon trade and to develop management value.

Declarations

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Authors' contributions

All authors have contribution. Admassu Addi perceived the research; contributed to data analysis and wrote the draft manuscript; TS and TB, edited and improved the manuscript and prepared for the publication. All authors read and approved the final manuscript.

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Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author when requested.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Authors give full permission for the publication, reproduction, and broadcast.

Competing interests

The authors declare no conflict of interest.

References

1. Addi A, Demissew S, Soromessa T, Asfaw Z. Carbon Stock of the Moist Afromontane Forest in Gesha and Sayilem Districts in Kaffa Zone: An Implication for Climate Change Mitigation. Journal of Ecosystem Ecography. 2019;9(1):1–8.
2. Tadese S, Soromessa T, Bekele T, Bereta A, Temesgen F. Above Ground Biomass Estimation Methods and Challenges. A Review Journal of Energy Technologies Policy. 2019;9(8):12–25.
3. Grace J. Understanding and Managing the Global Carbon Cycle. J Ecol. 2004;92:189–202. doi:10.1111/jec.2004.92.issue-2.
4. Ancelm MW, Edward ME, Luoga E, Ernest MR, Zahabu E, Santos SD, Sola G, Crete P, Henry M, Kashindye A. Allometric Models for Estimating Tree Volume and Aboveground Biomass in Lowland Forests of Tanzania. International Journal of Forestry Research 2016, 1–13.http://dx.doi.org/10.1155/2016/8076271.
5. Preece ND, Crowley GM, Lawes MJ, van Oosterzee P. Comparing above ground biomass among forest types in wet tropics: Small stems and plantation types matter in carbon accounting. For Ecol Manage. 2012;264:228–37.
6. Makungwa SD, Chittock A, Skole DL, Kanyama-Phiri GY, Woodhouse IH. Allometry for biomass estimation in *Jatropha* trees planted as boundary hedge in farmers' fields. Forests. 2013;4:218–33.
7. Kangas A, Maltamo M, editors, (2006). Forest inventory. Methodology and Applications. Managing Forest Ecosystems, Vol. 10. Springer, Dordrecht, the Netherlands 2006.
8. Brown S. Measuring carbon in forests: Current status and future challenges. Environ Pollut. 2012;116:363–72.
9. Kuyah S, Dietz J, Muthuri C, Jamnadass R, Mwangi P, Coe R, Neufeldt H. Allometric equations for estimating biomass in agricultural landscapes: I. Aboveground biomass. Agriculture Ecosystems Environment. 2012;158:216–24.
10. Pilli R, Anfodillo T, Carrer M. Towards a functional and simplified allometry for estimating forest biomass. For Ecol Manage. 2006;237:583–93.
11. Djomo A, Ibrahima A, Saborowski J, Gravenhorst G. Allometric Equations for Biomass Estimations in Cameroon and Pan Moist Tropical Equations Including Biomass Data from Africa. For Ecol Manage. 2010;260(10):1873–85.

12. Rebeiro CS, Fehrmann L, Boechat Soares CP, Gonçalves Jacovine LA, Kleinn C, de Oliveira Gaspar R. Above- and belowground biomass in a Brazilian Cerrado. For Ecol Manage. 2011;262:491–9.
13. Adrien N, Djomo C, Chimi D. Tree allometric equations for estimation of above, below and total biomass in a tropical moist forest: Case study with application to remote sensing. For Ecol Manage. 2017;391:184–93.
14. Altanzagas B, Luo Y, Altansukh B, Dorjsuren C, Fang J, Hu H. Allometric Equations for Estimating the Above-Ground Biomass of Five Forest Tree Species in Khangai. Mongolia Forests. 2019;10(661):1–17.
15. Brown S, Gillespie AJR, Lugo AE. Biomass estimation methods for tropical forests with applications to forest inventory data. Forest Science. 1989;35(4):881–902.
16. Brown S, Lugo AE. Above-ground biomass estimates for tropical moist forests of the Brazilian Amazon. Interciencia. 1992;17:8–18.
17. Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, Yamakura T. Tree allometry and improved estimation of carbon stocks and balance in tropical Forests. *Oecologia*1. 2005;45:87–99.
18. Addi A, Soromessa T, Bareke T. Plant diversity and community analysis of Gesha and Sayilem Forest in Kaffa Zone, southwestern Ethiopia. Biodiversitas. 2020;21(7):2878–88.
19. Lamrecht H. Silviculture in the tropics. Tropical forest ecosystems and their tree species Possibilities and methods in the long-term utilization. Germany, 1989; pp. 296.
20. 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. 2013; 2012.
21. David RV, Peter AP, Richard GS. Allometric equations for two South American Conifers: Test of non-destructive method. For Ecol Manage. 1997;106:55–71.
22. Worku E, Soromessa T. Allometric Equation for Biomass Determination in *Juniperus procera* and *Podocarpus falcatus* of Wof-Washa Forest: Implication for Climate Change Mitigation. American Journal of Life Sciences. 2015;3(3):190–202.
23. Tekele D. *Allometric* equation for biomass estimation of *Allophyllus abyssinicus* and *Croton macrostachyus* in Arba Gugu forest, Arsi Zone Oromia Region, Ethiopia. MSc Thesis, Addis Ababa University, Ethiopia 2014.
24. R Core Team. R: a language and environment for statistical computing. Vienna: R Foundation for Statistical Computing 2016; http://www.R-project.org/.
25. MacDicken K. A Guide to Monitoring Carbon Storage in Forestry and Agroforestry Projects. Arlington: Forest Carbon Monitoring Program. Winrock International; 1997.
26. Vahedi AA, Matajil A, Babayi-Kafakil S, Eshaghi-Rad J, Hodjati SM, Dojmo A. Allometric equations for predicting above ground biomass of beech-horn beam stands in the Hycanian forests of Iran. Journal of forest Science. 2014;60:236–47.
27. Brown S. Estimating biomass and biomass change of tropical forests. In: A Primer. FAO Forest Paper. Rome: FAO; 1997. P.134.
28. Chave J, Réjou-Méchain M, Búrquez A, Chidumayo E, Colgan MS, Delitti WB, Duque A, Eid T, Fearnside PM, Goodman RC, Henry M, Martínez-Yrízar A, Mugasha WA, Muller-Landau HC, Mencuccini M, Nelson BW, Ngomanda A, Nogueira EM, Ortiz-Malavassi E, Pélissier R, Ploton P, Ryan CM, Saldarriaga JG, Vieilledent G. Improved allometric models to estimate the aboveground biomass of tropical trees. Global Change Biol. 2014;20:3177–90.
29. Henry M, Picard N, Trotta C, Manlay RJ, Valentini R, Bernoux M, Saint-André L. Estimating tree biomass of sub-Saharan African forests: a review of available allometric equations. *Silva Fennica* 2011; p. 477–569.
30. Edae DD, Soromessa T. The accuracy of species–specific allometric equations for estimating aboveground biomass in tropical moist montane forests: case study of *Albizia grandibracteata* and *Trichilia dregeana*. Carbon

Balance Manage. 2019;14(18):1–13.

31. Nogueira SL, Soares BG, Ribeiro N, Sitoe A. Biomass allometric equation and expansion factor for a mountain moist evergreen forest in Mozambique. *Carbon Balance and Management* 2018; *13(23):1–16.*.
32. Köhl M, Magnussen SS, Marchetti M. Sampling methods, remote sensing and GIS multi-resource forest inventory. New York: Springer; 2006.
33. Alvarez E, Duque A, Saldarriaga J, Cabrera K, del Valle G, Lema A, Moreno F, Orrego S, Rodríguez L. Tree above-ground biomass allometries for carbon stocks estimation in the natural forests of Colombia. Forest Ecol Manage. 2012;267:297–308.
34. Vorster AG, Evangelista PH, Stovall AL, Ex S. Variability and uncertainty in forest biomass estimates from the tree to landscape scale: the role of allometric equations. *Carbon Balance Manage (2020) 15:8: 1–20.*.
35. Heath LS, Hansen MH, Smith JE, Smith WB, Miles PD. Investigation into Calculating Tree Biomass and Carbon in the FIADB Using a Biomass Expansion Factor Approach. In: McWilliams W, Moisen G, Czaplewski R, editors. 2008. For Invent Anal Symp USDA For Serv Proceddings - RMRSP-56. Park City. UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station; 2009.
36. Brown S. Measuring carbon in forests: current status and future challenges. Environ Pollut. 2002;116(3):363–72.
37. Zianis D, Mencuccini M. On Simplifying Allometric Analyses of Forest Biomass. For Ecol Manage 2003; 187: 311–32. doi:10.1016/j. foreco.2003.07.007.
38. Dieler J, Pretzsch H. (2013). Morphological plasticity of European beech (*Fagus sylvatica* L.) in pure and mixed-species stands. For Ecol Manage. 2013; 295:97–108.
39. 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.
40. Henry M, Besnard A, Asante WA, Eshun J, Adu-Bredu S, Valentini R, Saint-Andre L. Wood density, phytomass variations within and among trees, and allometric equations in a tropical rainforest of Africa. For Ecol Manage. 2010;260:1375–88.

Figures

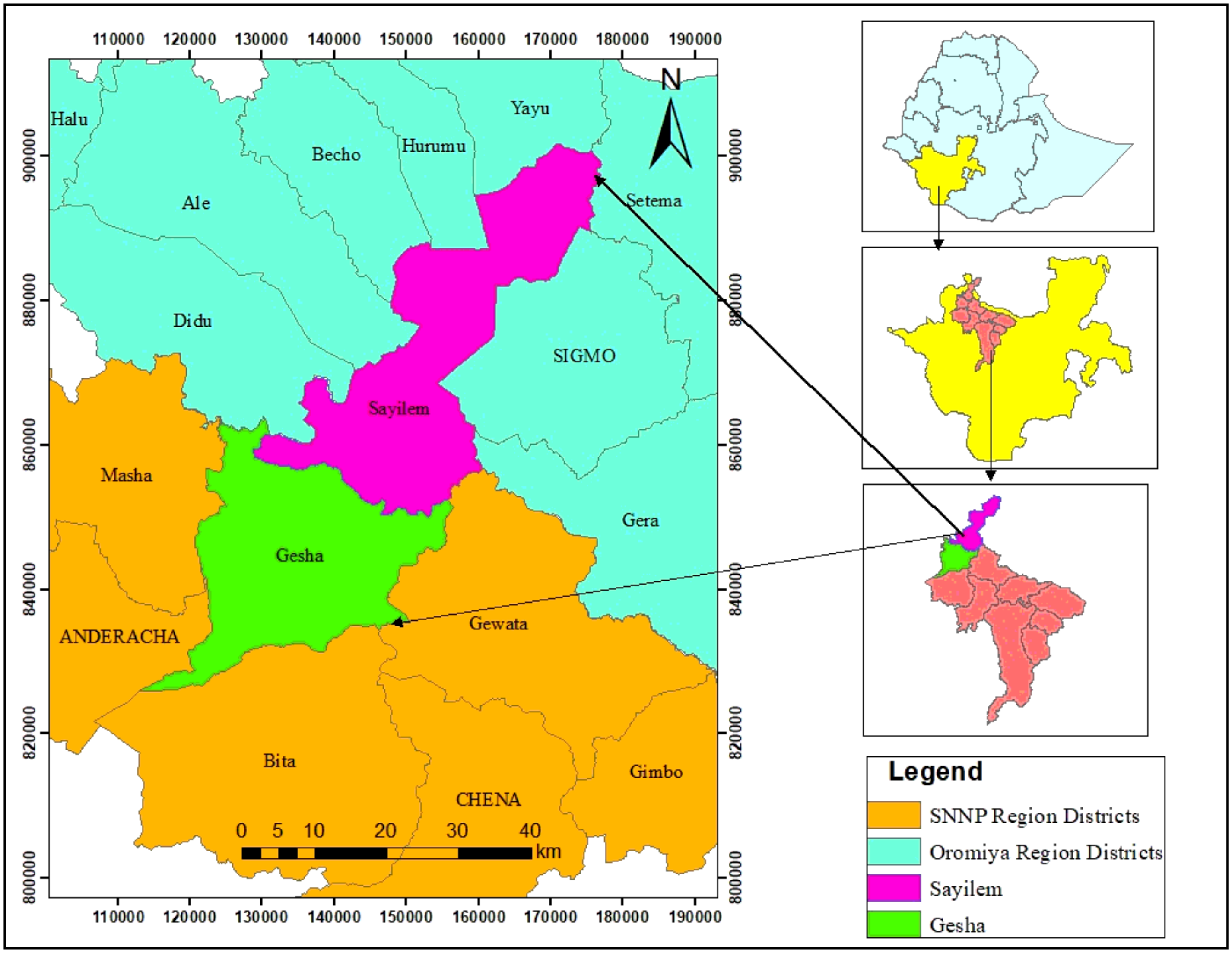

Figure 1

Map of Ethiopia, Oromia and SNNP Region, Kaffa zone, Gesha and Sayilem districts

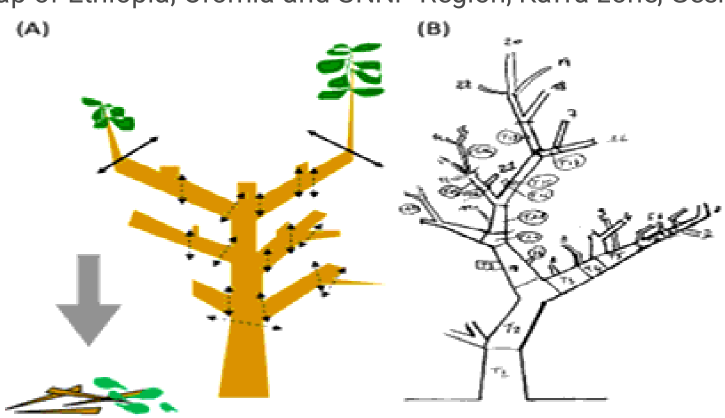

Figure 2

Determination of total fresh biomass. (A) Separation and measurement of trimmed and untrimmed biomass, (B) numbering of the sections and branches measured on a trimmed tree [5].

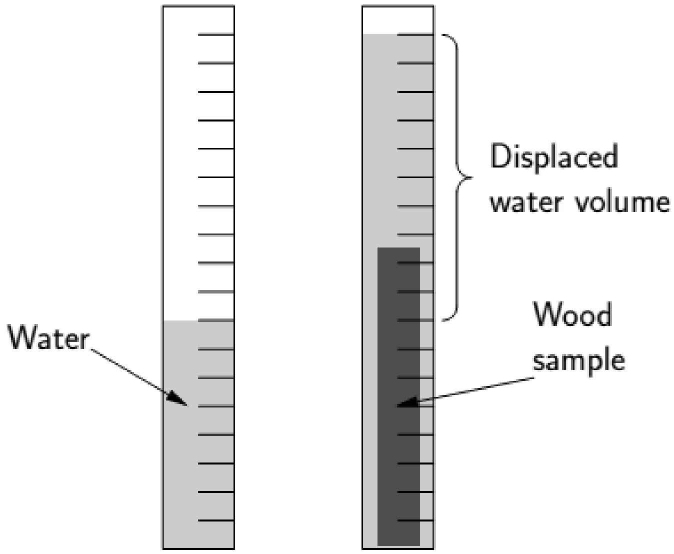

Figure 3

Measuring wood volume by water displacement

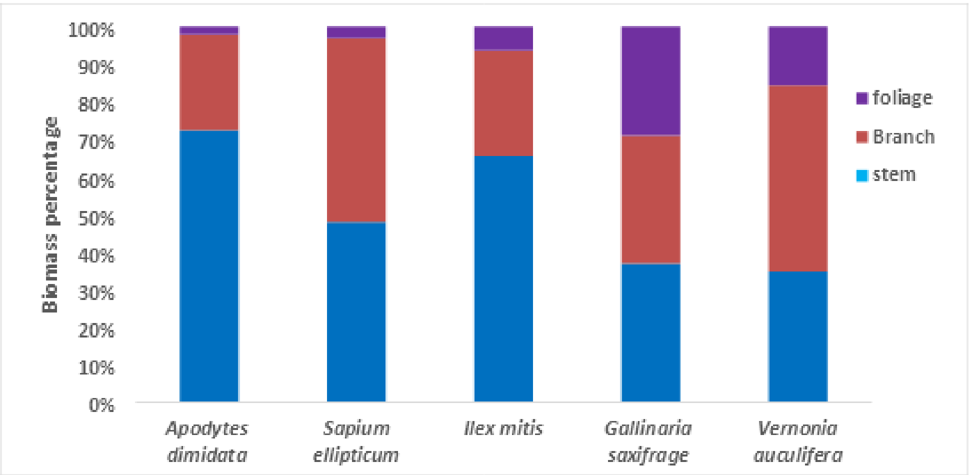

Figure 4

Aboveground biomass partitioning for the main sampled tree and shrub species

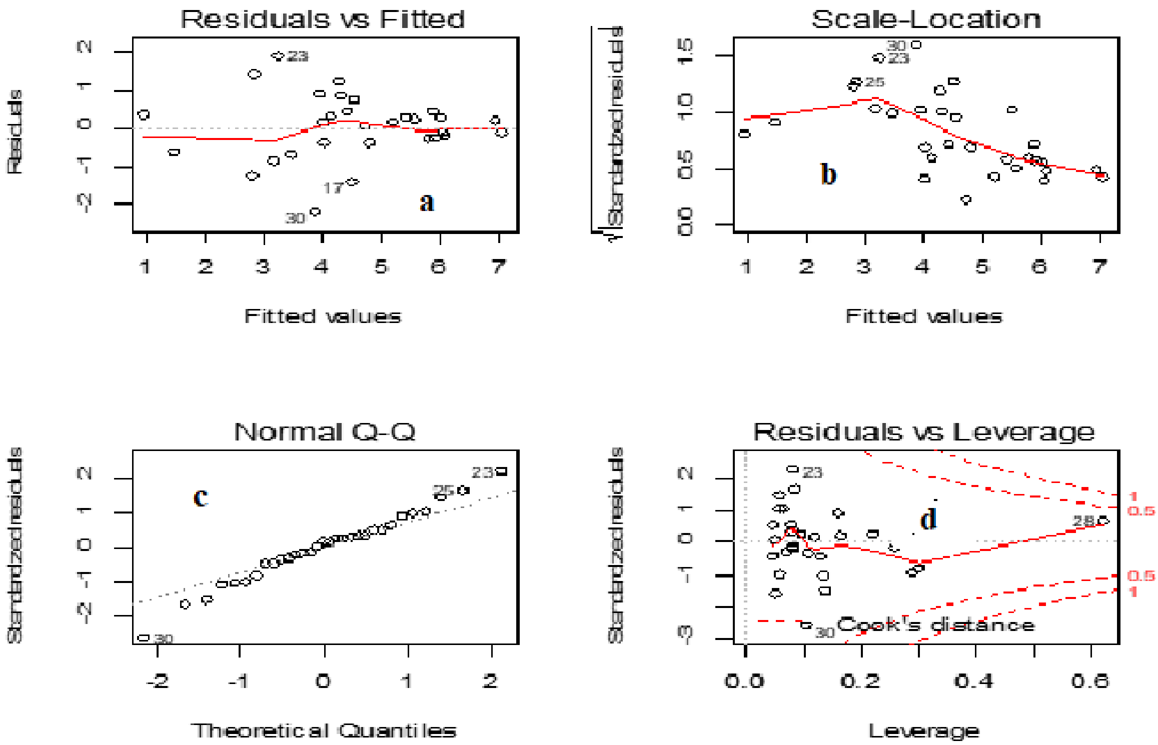

Figure 5

(a-d). Residuals plotted against fitted values (left) and quantile–quantile plot (right) and residuals versus leverage