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

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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 (Galineria 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 R² 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 allometric 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 $Y = a \times X^b$, 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 allometric 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° 24’ to 7° 70’ North and 35° 69’ to 36° 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 °C and 9.5 °C, respectively. On the other hand, the monthly maximum and minimum temperatures for Sayilem ranges 10°C to 25°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°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.

\[
B_{\text{dry}} = B_{\text{trimmed dry}} + B_{\text{untrimmed dry}} \quad \text{(equ. 1)}
\]

**Calculations of trimmed biomass**

The trimmed biomass of sample tree was calculated from the fresh biomass of a wood aliquot and its dry biomass, the moisture content was calculated as follow.

\[
\text{Where } w_{\text{wood aliquot}} \text{ is moisture content of the wood, and where } B_{\text{wood aliquot}} \text{, is the oven-dried wood biomass of the aliquot in the sample and where } B_{\text{fresh wood aliquot}} \text{, is the fresh wood biomass of the branch aliquot in the sample. Similarly, the moisture content of the leaves was calculated from the fresh biomass } B_{\text{leaf aliquot}} \text{ of the leaf aliquot and its dry biomass } B_{\text{leaf aliquot}} \text{ as follow.;}
\]

\[
\text{Trimmed dry biomass was then determined as}
\]

\[
B_{\text{trimmed dry}} = B_{\text{trimmed fresh wood}} \times X_{\text{wood}} + B_{\text{trimmed fresh leaf}} \times X_{\text{leaf}} \quad \text{(equ. 4)}
\]

Where, \(B_{\text{trimmed fresh leaf}}\) is the fresh biomass of the leaves stripped from the trimmed branches and \(B_{\text{trimmed fresh wood}}\) 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.

\[
B_{\text{untrimmed dry}} = B_{\text{dry section}} + B_{\text{untrimmed dry branch}} \quad \text{(equ. 5)}
\]

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.
\[ V_i = \pi L_i \left( D_{2i}^2 + D_{1i}^2 \right) \] ..................................................(equ6)

Where \( V_i \) is the volume of the section \( i \), its length, \( D_{2i}^2 \) and \( D_{1i}^2 \) 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.

\[ B_{\text{dry section}} = \bar{\delta} \cdot \sum V_i \] .................................................. (equ7.)

Where \( \bar{\delta} \) the mean wood density was expressed in g cm\(^{-3}\), then volume \( V_i \) was expressed in \( \text{cm}^3 \) 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

\[ B_{\text{dry branch}} = a + bD^c \] ................................................................. (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.

\[ B_{\text{BGB}} = AGB \times 0.24 \] ................................................................. (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 Galiniera 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) | Diameter  | Height     | Wood density | Above ground (kg) |
|---------------------|-----------|------------|--------------|-------------------|-----------|------------|--------------|-------------------|
|                     | Min       | Max        | mean         | Min               | Max       | mean       | Min          | Max               | 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       | Biomass component | DBH(cm) | H(m)  | WD (g·cm\(^{-3}\)) |
|--------------------|-------------------|---------|-------|------------------|
| 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         |
|                    | 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 | 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 ≤ 0.05; ** p ≤ 0.001; ***p ≤ 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.** Allometric 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 dimidia   | 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, 121 and 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+1.66basalD                 | 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% Vernoia 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 Vernoia 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 0.81 and AIC value of 34.24 and 59.25 respectively. The DBH alone provided the best fit in Ilex mitis and Vernoia 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)     | AIC     | R²   | Vif |
| Apodytes dimidiata | \( \log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_2 \log(H) + \beta_3 \log(D) + \varepsilon \) | 1.91(0.69)*        | 1.08(0.21)***     | 0.56(0.20)*      | 1.00(0.33)*** | 37.06 | 0.87 | 1.91 |
| Galiniera saxifraga | \( \log(AGB) = \beta_0 + \beta_1 \log(DBH) + \beta_2 \log(H) + \varepsilon \)         | -                  | 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 dimidiata 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 dimidiata, which increased the aboveground biomass prediction significantly with an adjusted R² 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 *Galinaria 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.

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**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