Allometric Equation for Aboveground Biomass Estimation for Selected Trees Shrubs in Gesha - Sayilem Moist Afromontane Forest.

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Research

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Allometric equation for aboveground biomass estimation for selected trees shrubs in Gesha - Sayilem Moist Afromontane forest.

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Abstract

Background: Allometric equations which are regressions linking the biomass to some independent variables that 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 in size and biomass. 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*) for estimating the aboveground biomass (AGB). Non-destructive sampling method was used for the measurement of tree biomass, accordingly the trees and shrubs whose Diameter at Breast Height (DBH) is ≥ 5 cm were sampled. For trees serial measurements of the height and diameter of trunk were done at 2 m intervals. For the determination of biomass of shrubs destructively sampled. Four branches were trimmed from tree and the trimmed branches were separated into leaves and wood and oven dried at 105^0C and recorded to estimate the biomass of untrimmed small branches. Nested model was used and the best fit model was selected based on higher Adjusted R^2, lower residual standard error and Akaike information criterion.

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 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.

Key words: Allometeric equation, Biomass, Afromontane forest, Gesha and Sayilem

Background

The estimation of above ground biomass in forest ecosystem is essential for assessing carbon sequestration potential of the forest for climate change mitigation. and to determine volume of fuel wood harvest for assessing forest productivity (Preece*, et al*. 2016, Makungwa *et al* 2013). The reliable and accurate biomass estimates are important to implement mitigating policies and taking the advantage of the Reducing Emissions from Deforestation and Forest Degradation ($REDD^{+}$), Ancelm *et al*. 2016. 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 (Preece*, et al*. 2016). 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 (Kangas 2006, Kuyah et al. 2012).

Allometric equations which are regression models that relate the biomass to some independent variables such as diameter, height and wood density that are easy to measure in the field and used to estimate tree components from the forest (Adrien *et a,l* 2017;Altanzagas 2019). Allometric biomass equations have been developed for tree species in different ecological regions of the world, (Rebeiro, 2011; Brown 1997; Arau´jo *et al*., 1999; Chambers *et al*. 2001; Ketterings et al. 2001; Chave et al. 2005). The accuracy of AGB estimation using allometric models is highly dependent on the use of appropriate models (Djomo *et al* 2010). The generic models can be developed for multiple species (general multispecies models) or for single species (general species-specific models). Species-specific models can result in accurate biomass estimates. As it is suggested by Chave et al. 2005, Pilli et al, 2006, use of multispecies AGB models is a more feasible solution for tropical forests, which are characterized by high species diversity. However, the generic equation developed by (Brown, *et al*. 1989; Chave *et al* 2005) 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.

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 (Grace,2004). However, in tropical forests, the accurate estimates of carbon sequestration are lacking due to a scarcity of appropriate allometeric models.

The Afromontane forests of Ethiopia covers more than 50% of the land area (Yalden, 1983; NBSAP, 2005). The dry Afromontane forest is concentrated in central and northern Ethiopia and around churchyards. On the other hand, the moist evergreen Afromontane forest (MAF) is widely distributed in south and southwestern Ethiopia (Sebsebe Demissew & Friis, 2009; Friis et al., 2010). These forests have different tree and shrub species diversity and developing species specific allometric equations for biomass estimation is very important to estimate the carbon sequestering potential of moist Afromontane forest of south west Ethiopia. Thus, the aim of this study is to estimate aboveground and below biomass of the trees and shrubs of Gesha-Sayilem forest in order to develop species specific allometric equations of the forest.

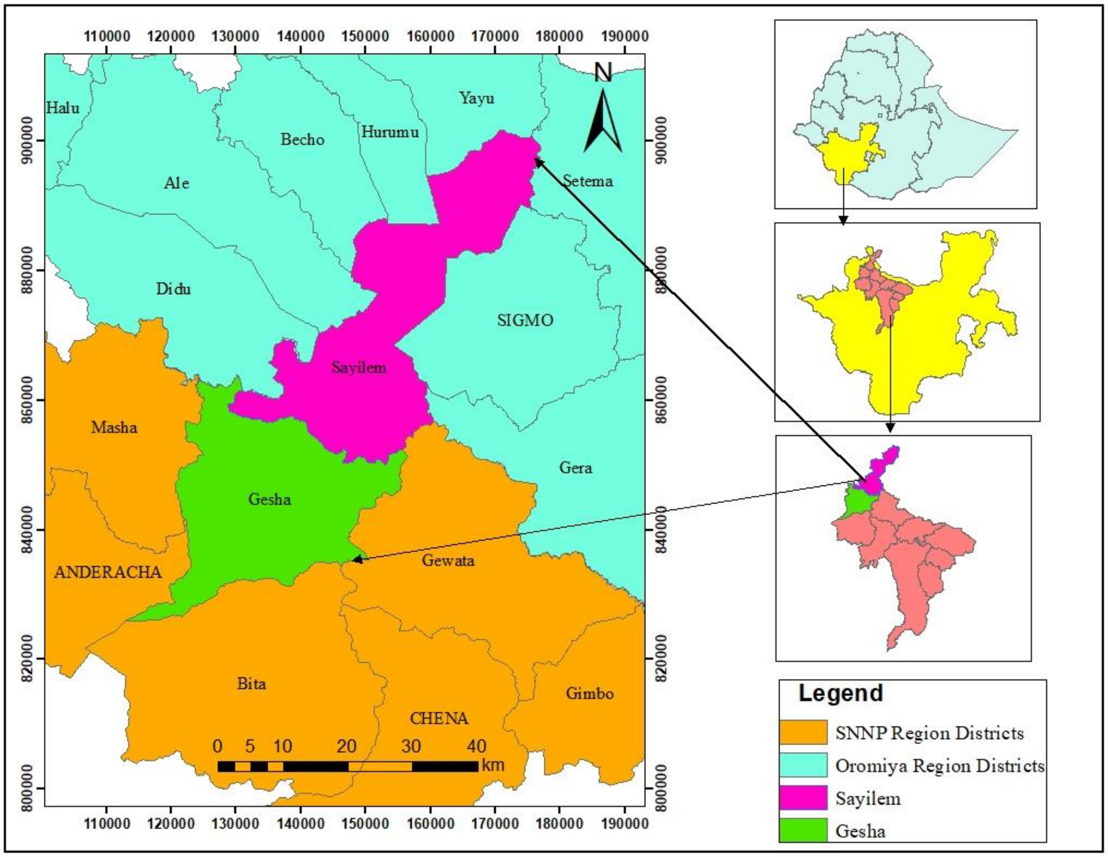
Materials and methods

Site description

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 (Addi et al. 2020). The monthly mean maximum and minimum temperature for Gesha is 29.5 ^{0}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.

Target species description

The selected plants are characteristic species of, moist Afromontane forest which comprise *Apodytes dimidata, Sapium ellipticum Ilex mitis*, *Gallinera saxifraga*, and *Vernonia aurcuiflera* and they are the dominant in the area. *Apodytes dimidata*, is tree up to 25m high with shining leaves growing in forest and open land. *Ilex mitis* is evergreen shrub, or more usually a tree 24-40m tall with attractive flower heads. *Sapium ellipticum* evergreen shrub or tree up to 25(-30) m high, branches drooping, buds protected by scales. *Gallinera saxifrage is shrub grow upto 5m high and* found under the shade of forest layer. *Similarly, Vernonia aurculifera* are shrubs growing grow up to 4-5 m high or sometimes small tree up to 10 m tall, grow at forest margin and very attractive for honeybees.



Source: (Admassu *et al.* 2020)

Fig. 1. Map of Ethiopia, Oromia and SNNP Region, Kaffa zone, Gesha and Sayilem districts

Sampling methods

The procedures of semi-destructive methodology in tree volume building manual and biomass allometeric equations (Dieler and Pretzsch, 2013) were followed. A random sampling method was used to select tree and shrubs in the study area in order to have an equal chance of being involved in the study. For sampling trees, individual plant species were categorized into woody plants whose Diameter at Breast Height (DBH) is ≥ 5 cm. For sampling shrubs and sapling destructive sampling method was used following Lamprecht ֹs classification (Lamrecht,1989). Based on the density and abundance 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 (David *et al.* 1997). The trimmed branches were separated into leaves and wood and the fresh weight of them were recorded Fig. 2.

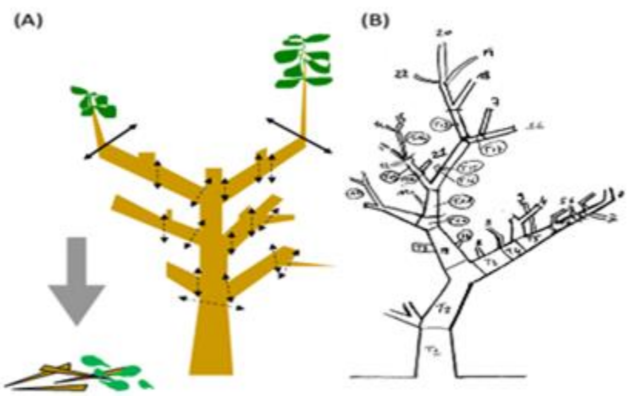


Fig.2. Determination of total fresh biomass. (A) Separation and measurement of trimmed and untrimmed biomass, (B) numbering of the sections and branches measured on a trimmed tree.

Source: Picard, et al. (2012).

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.

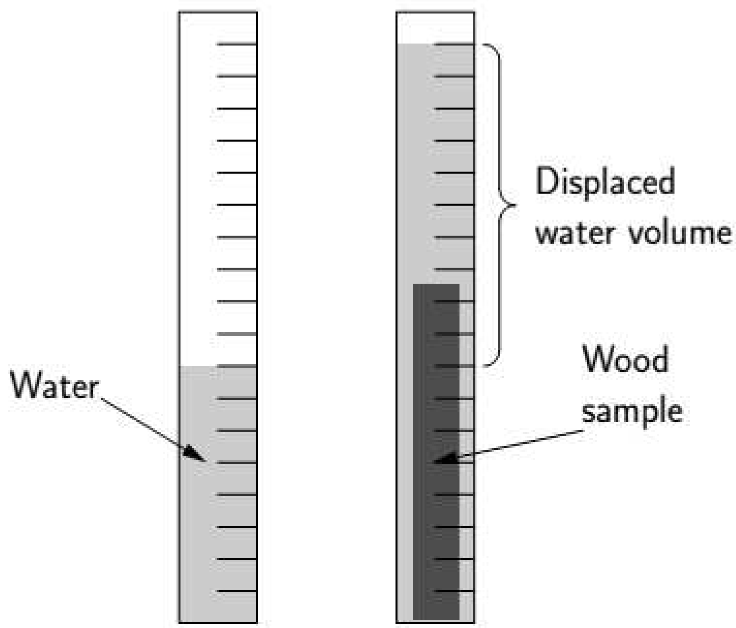


Fig. 3. Measuring wood volume by water displacement

Sampling of shrubs

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.

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 $B_{\text{aliquot fresh wood}}$ of a wood aliquot and its dry biomass $B_{\text{drywoodaliquot}}$, the moisture content was calculated as follow

$$X\ \text{wood} = \frac{B\ alliquot\ dry\ wood}{Baliquot\ \text{frehwood}} \quad \text{...} \text{(equ.2)}$$

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 ***B*** $_{\text{fresh leaf aliquot}}$ of the leaf aliquot and its dry biomass ***B*** dry $_{\text{leaf aliquot}}$ as follow:

$$X\ \text{leafi} = \frac{\text{Baliquot dry leafi}}{Baliquot\ fresh\ leafi} \text{..} \text{(equ3)}$$

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...................... (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.

$$V_i = \frac{\pi}{8} L_i \left(D^2_{1i}+D^2_{2i}\right) \text{...} \text{(equ 6)}$$

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.

$$B_{dry\ section} = \dot{\rho} * \sum Vi \quad \text{(equ7.)}$$

Where $\dot{\rho}$ 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:

$$\dot{\rho} = \frac{\mathbf{Baliquot\ drywood}}{\mathbf{Valiquot\ fresh\ wood}} \quad \text{(equ.8)}$$

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

$$B_{dry\ branch} = a + bD^c \quad \text{(equ. 9)}$$

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 (MacDicken 1997). 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.

$$BGB = AGB \times 0.24 \quad \text{(equ. 10)}$$

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 variance inflation factor (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**		
	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***
	Biomass component	**DBH**	**Height**	**CRA**
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).* $p \leq 0.05$; ** $p \leq 0.001$;***$p \leq 0.001$

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.

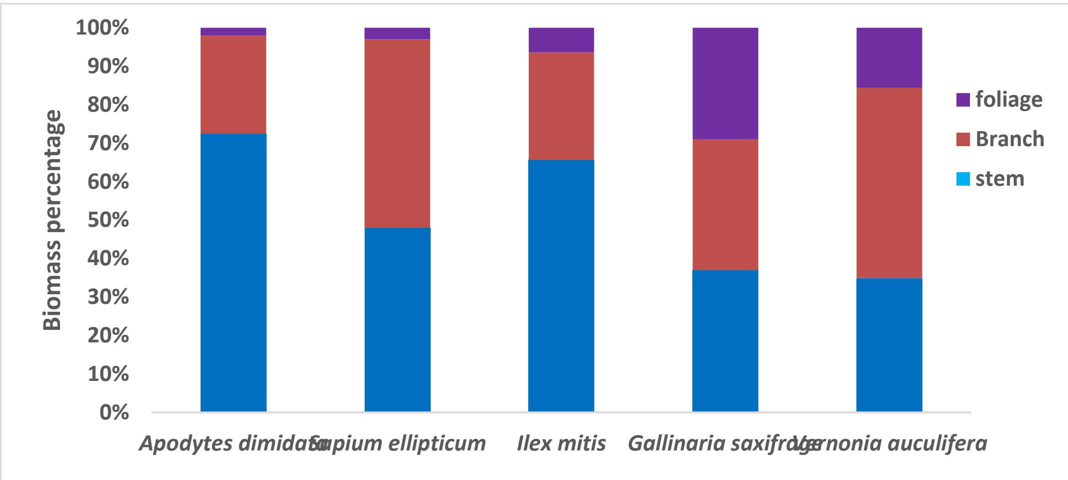


Fig. 4. Aboveground biomass partitioning for the main sampled tree and shrub species

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 and variance infilation factor was obtained.

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

Species	Model for total AGB	*Parameter Estimates* (*std. error*)	(*std. error*)	(*std. error*)	(*std. error*)	Model performance AIC	R^2
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
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
Ilex mitis	$\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \varepsilon$	-1.47(0.57)*	2.20(0.16)***	-	-	46.36	0.86
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
Vernonia auriculifera	$\log(AGB) = \beta_0 + \beta_1 \log(DBH) + \varepsilon$	6.00(0.30)***	1.51(0.18)***	-	-	58.97	0.69

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 (Brown, 1997, Chave *et al*. 2017 `, Henry *et al* 2011, Edae and Soromessa 2010) 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 (Edae and Soromessa 2010). 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* 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 (Brown et al 1989 Chave *et al* 2017) 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 (Nogueira *et al* 2018). A measurement of height, *wood density* and the higher diameter can also be included if they significantly reduce the volume prediction error (Köhl *et al* 2006). Alvarez *et al*. 2012 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 *et al.* ,2005 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. Allometric equations that don't utilize tree height can over predict large diameter tree biomass (Heath *et al* 2008).

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 (Rebeiro, *et al* 2011 and Zianis et al 2003).

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 2013) and Mehari et al. 2016 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 (Henry *et al*. 2010) found percentage stem biomass is found to higher than for branch and leaf.

Conclusion and recommendation

Developing an allometric equation is an important method for the assessment of tree biomass. It has also an indirect contribution for monitoring of the global carbon cycle. Adopting the generic allometeric equation for the specific forest stand has limitation due to ecological variation and diversity of trees and shrubs. Species-specific allometric equations were formulated for five tropical species (*Apodytes dimidata, Sapium ellipticum* Ilex *mitis*, *Gallinera saxifraga*, and *Vernonia aurcuiflera)* following the semi destructive sampling procedure.The formulated equations are proposed as a species-specific equation particularly in the Afromontane rainforest as well as in the montane moist forest ecosystem of southwestern Ethiopia. Thus the study indicated that combination of 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 model for *Gallinaria saxifraga* and *Sapium ellipticum.* On the other hand, the DBH alone provided the best fit *in Ilex mitis* and *Vernonia auriculifera.* Therefore, the specific allometeric equation model developed in this study can be used for estimating forest carbon stocks, identifying carbon sequestration capacity of trees and shrubs. As Ethiopia has many tree species, it is recommended to develop species-specific allometric equations for all of them for better assessment of carbon stock to meet national and international reporting requirements for greenhouse gas inventories.

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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

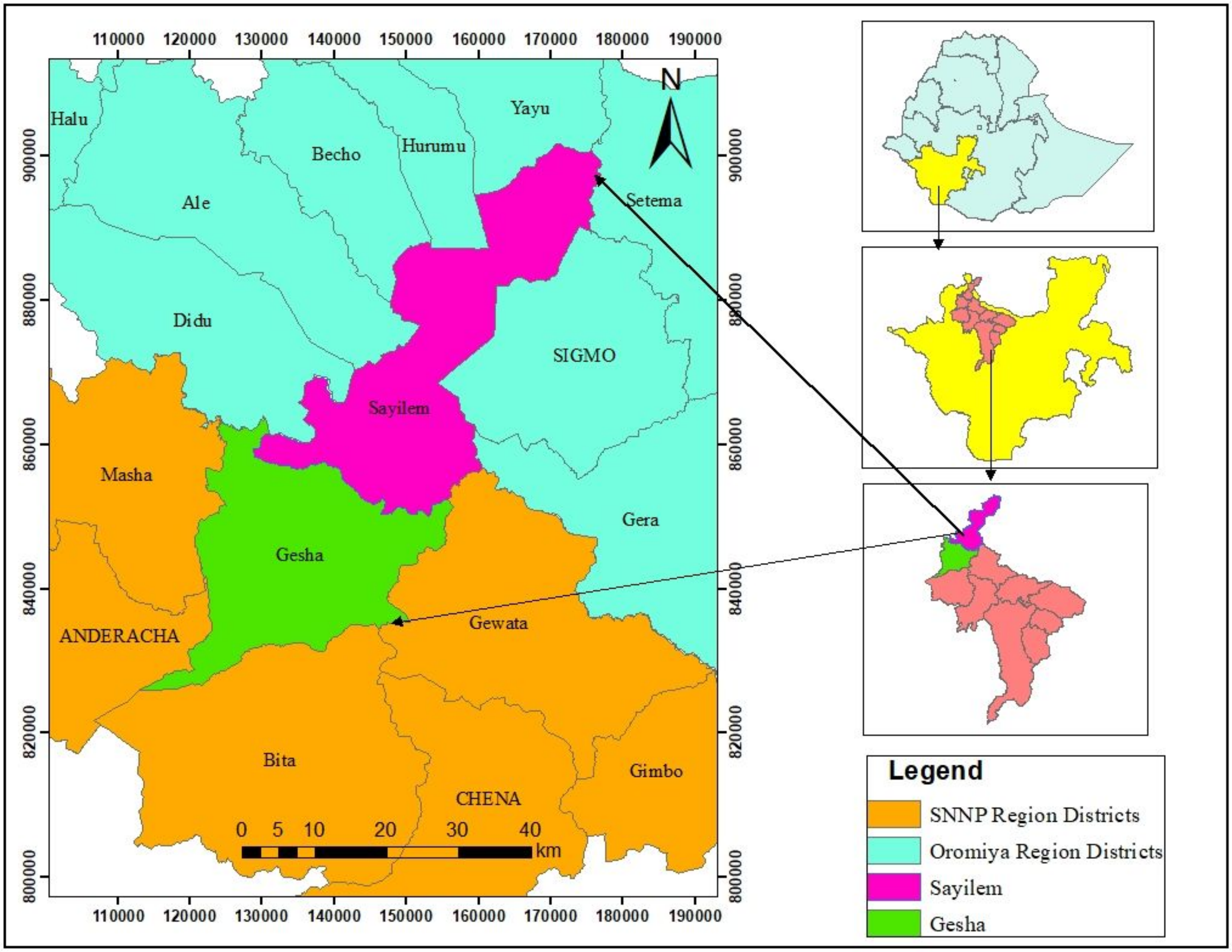

Figure 1

Map of Ethiopia, Oromia and SNNP Region, Kaffa zone, Gesha and Sayilem districts Source: (Admassu et al. 2020) Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

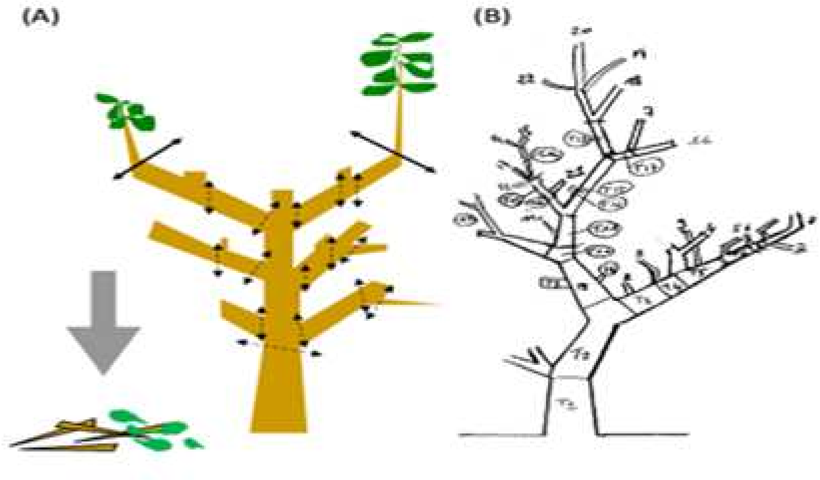

Figure 2

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. Source: Picard, et al. (2012).

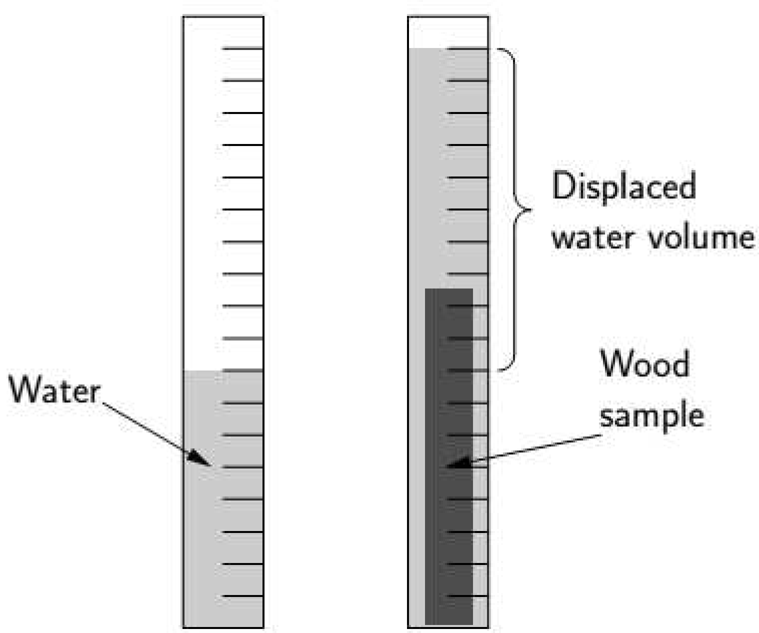

Figure 3

Measuring wood volume by water displacement

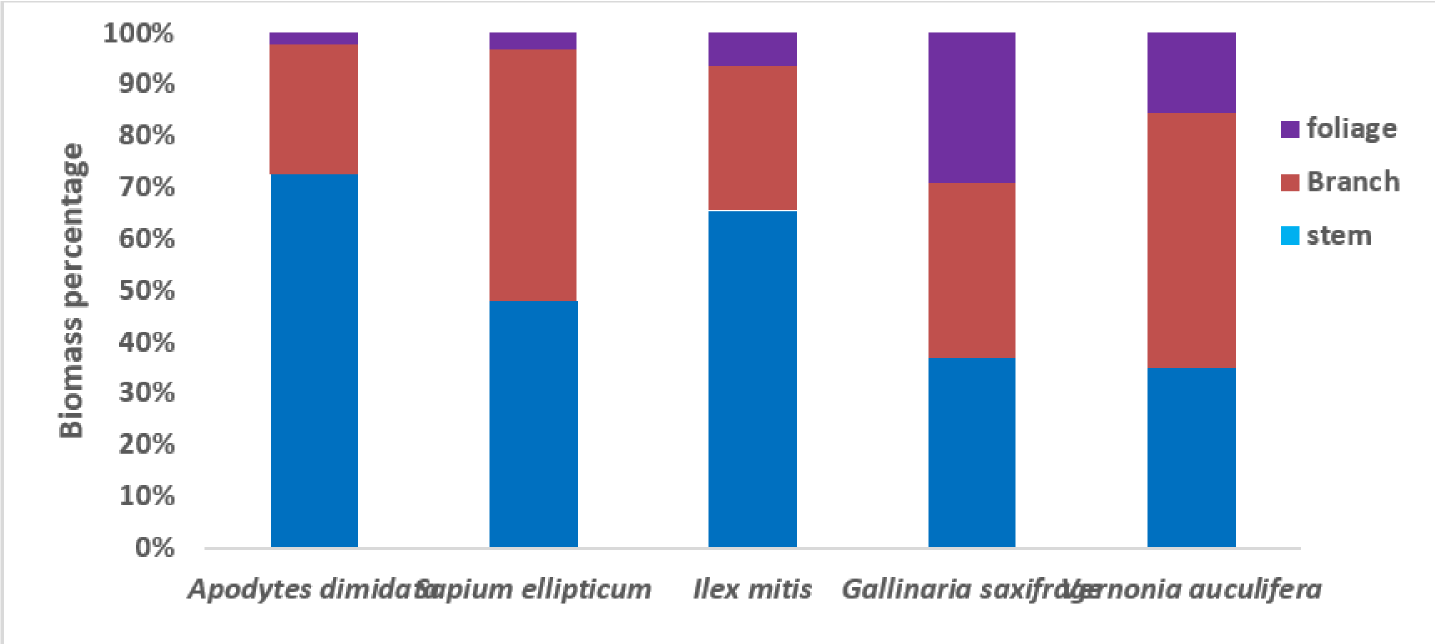

Figure 4

Aboveground biomass partitioning for the main sampled tree and shrub species