Species specific allometric equations, biomass expansion factor and wood density of native tree species in dry afromontane forest of Ethiopia

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Abstract

Forest is the second largest store house of carbon released from different sources. However, limited allometric equations are available to determine its contribution for carbon cycle. The objective of study was to develop species specific allometric equations, establish database for Biomass Expansion Factor (BEF) and Wood Density (WD) to five tree species, namely *Apodytes dimidiata*, *Cassiopourea malosana*, *Celtis africana*, *Ilex mitis* and *Myrica salicifolia* grown in dry afromontane forest of Ethiopia. The sampled tree diameter at breast height (dbh) and their total height (ht) ranged from 7 to 48 cm and 6.7 to 23.4 m respectively. A total of 62 sample trees harvested from different diameter classes of each species and divided in to different biomass compartments (stem, big branches >7cm), small branches (2-7cm) and twigs and foliage (<2cm). To determined WD, total of 186(stem position) and108 sample disks (big branches till 7cm dbh were sampled. Oven dried at temperature of 105ºc and 70ºc for 72 and 24hrs for wood and foliage respectively. A set of log transformed models relating total above ground biomass to dbh, ht, WD and average crown diameter as independent variables were fitted following R-software version 4.0.1. The best biomass models were found to be having lower AIC, residual standard error and higher adj.coefficient of determination. The BEF and WD of aforementioned tree species were ranged from1.19 to 1.40 and 0.53 to 0.74 gcm^{-3} respectively. Species specific allometric equations were better than generalized allometric equation for estimation of above ground biomass of Chilimo dry afromontane forest.

Keywords Aboveground biomass, Wood density, Chilimo forest, Dendrometric variables, Destructive sampling, Local model.

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Authors' contributions

Dereje Egeta Chaka: site selection, sampling design, data collection, data analysis, results interpretation and writing the manuscript

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1. Introduction

Forest is the second largest store house of carbon released from fossil fuels, industry and land use change (Brack, 2019) when sustainable forest management, planting and rehabilitation is undertaken . The world's forests store 283 gigatonnes of carbon in their biomass alone. Tropical forests account for about 60% of global forest cover and store from 229 to 263petagram carbon (Baccini et al., 2012; Pan et al., 2011). There are five carbon pools in forest ecosystems (aboveground biomass, belowground biomass, dead wood, litter and soil organic carbon)(FRA, 2005 and 2006).

The amount of carbon stored by forest decreased from time to time due to deforestation and forest degradation. This led to increasing the concentration of greenhouse gases in the atmosphere(Moges et al.,2010) and it is the main causes for climate change which is one of the major challenges to the societies and environment. This also brought critical challenges to Ethiopia (FDRE, 2011).

To address the climate change challenges Ethiopia developed and applied REDD⁺ (Reducing Emissions from Deforestation and forest Degradation; through forest conservation; Sustainable forests management and Enhancement of forest carbon stocks) strategies for the last 10 years (FDRE, 2011). Accordingly, measurement, reporting and verification (MRV) for Greenhouse Gas (GHGs) emissions, including GHGs from deforestation and forest degradation has been applied. The estimation of the contribution of the forestry sector in REDD⁺ requires accurate biomass estimation methods (Moges et al., 2010).

Most of the time tree biomass can be measured from destructive and non-destructive (allometric equation) methods (Ketterings et al., 2001). The direct measurements encompasses harvesting the tree and measuring the actual mass of each of its components (Kangas and Maltamo, 2006). It is very accurate (Henry et al., 2011) but cutting down trees is both costly and time consuming. In contrast, indirect methods adopted already developed allometric models and Biomass Expansion Factors (BEFs) to estimate tree biomass and are cost effective and time efficient (Peltier et al., n.d.). Basic wood density are also calculated as (dry weight divided by green volume) may also be used to predict biomass either when using allometric models or along with biomass expansion factors and volume data (Asrat et al., 2020).

Methods of biomass estimation are scarce in the tropics (Henry et al., 2011). Most biomass models are developed for tropical tree species grown particularly in Latin America and South Africa. Though, some studies in recently emerged in East África and Ethiopia(Mamo and Sterba, 2006; Zewdie et al., 2009; Henry et al., 2010; Ngomanda et al., 2014;Tesfaye et al., 2016; Fayolle et al., 2018; Asrat et al., 2020), Attempts to develop biomass equations in Sub-Saharan Africa in general and Ethiopia in particular are very limited (Moges et al., 2010; Henry et al., 2011; Tesfaye et al., 2016).

Pan-tropical allometric equations developed by many researchers may over or underestimate the biomass, due to tree species may differ greatly in tree architecture and wood gravity (Ketterings et al., 2001) and thus, species-

specific equations would improve the accuracy of the biomass estimates. Species-specific allometric equations use one or more measurable variables of tree dimensions such as trunk diameter, height, average crown diameter and wood specific density (Kangas and Maltamo, 2006; Asrat et al., 2020). This has high potential to increase the accuracy of biomass and carbon estimation for financial reward by improving MRV activities of the country.

The local allometric equation would help to accurately estimate the amount of biomass in the forest and enable the country to benefit from the carbon market opportunity. It also used for country to report accurate and consistent data that meet international standards and also to create favorable policy environment are most valid requirements to derive benefits from climate funds (Moges et al., 2010). In addition to the above it is also improving the role of dry afromontane forest in the global carbon cycle and the implementation of policies and mechanisms designed to mitigate climate change(Agarwal et al., 2012).

Species-specific equations were not formulated for many tree species in Ethiopia. Therefore now days, more effort is required to develop localized biomass models that are still needed (Moges et al., 2010) and established data base for biomass expansion factors and wood density for several species (Teobaldelli et al., 2009). For instance, allometric equations, biomass expansion factor and wood density for Apodytes dimidiata, Cassiopourea malosana, Celtis africana, Ilex mitis and Myrica salicifolia are lacking in Chilimo dry afromontane forest. Therefore, this study is aimed to develop species specific allometric equations and establish database for biomass expansion factor and wood density for aforementioned tree species.

2. Materials and methods

2.1. Study site location

Chilimo dry afromontane forest belongs to the state-owned Oromia Forest and Wildlife Enterprise. The forest is geographically located with latitude 038° 08' 679'' E - 038° 10' 283'' E and 09° 04' 038''- 09°05'765'' N' longitude with an altitude ranging from 2,470 to 2900m a.s.l. The mean annual temperature of the area ranged between 15 - 20 °C and receives a mean annual precipitation ranged from 1000 to 1,264 mm (Shumi, 2009). According to Köppen's classification system the climate of Chilimo forest could be categorized under warm temperate climate I (CWB) type (EMA, 1988). The forest is situated 97 km West of Addis Ababa, the capital city of the Ethiopia and with a total area of around 2500 ha(Soromessa and Kelbessa, 2014).

2.2. Vegetation description of study site

Chilimo forest is one of the few remnant forests of dry afromontane forests located in the Central Highlands of Ethiopia. The forest is composed of mixed broad leaved trees such as Podocarpus falcatus, Olea europaeasubspp.cuspidiata, Scolopia theifolia, Rhus glutinosa, Olinia rochetiana, Allophylus abyssinicus and Juniperus procera(Kelbessa and Soromessa, 2004; Kassa et al., 2008). While Shumi (2009) investigated 42 species made up of 27 tree and 15 shrub species in the forest, but Soromessa and Kelbessa, (2014) also reported that 213 different woody species which belong to 83 families, and 18 plant species are registered as endemic, from which one was endangered and three were considered as vulnerable to the Chilimo forest. In addition, Tesfaye et al., (2016) registered for Chilimo 33 different indigenous woody species (22 trees and 11 shrubs) in three forest patches.

2.3. Data collection and sampling

A. dimidiata, C. malosana, C. africana, I. mitis and M. salicifolia tree species were selected based on Importance Value Index (IVI) for developed aboveground biomass equations. Then based on previously collected tree data diameter distributions at 10cm was done and sample trees in each diameter classes and number of harvestable trees from each diameter class were determined(Tesfaye et al., 2019). Moreover basal area of each tree in each diameter class and total basal area of all species of different classes and total trees harvested in each diameter classes were calculated. The sampled trees diameter intervals were ranged from 5 to 55cm. Trees with broken top, excessive or less branching were excluded from cutting (Ali et al., 2016). A total of 62 sampled trees were cut and portioned in to different biomass components. For C. malosana 14 trees and 13 trees for A. dimidiata, C. africana, M.salicifolia and 9 trees for I. mitis were selected and cut. A total of 62 sampled trees were cut and portioned in to different biomass components. For C. malosana 14 trees and 13 trees for A. dimidiata, C. africana, M.salicifolia and 9 trees for I. mitis were selected and cut.

Table 1 Sample trees selected corresponding to tree size distribution

DBH class	DBH interval(cm)	List of species &number of trees were harvested					
		A. dimidiata	*C. malosana*	*C. africana*	*I. mitis*	*M. salicifolia*	*Total number of trees felled*

1	[5-15)	4	3	1	2	2	12
2	[15-25)	2	6	5	2	5	20
3	[25-35)	7	5	2	0	5	19
4	[35-45)	0	0	5	3	1	9
5	[45-55)	0	0	0	2	0	2
	Total trees	13	14	13	9	13	62

2.4. Biomass data collection

Prior to felling for selected trees to be cut environmental data such as slope (%), altitude and UTM coordinates were recorded using (Garmin 72 channel GPS) and DBH (cm) and average crown diameter (m), were measured. Then sample trees were felled with using a chainsaw and cut as close to the ground as possible. Diameter at 2m interval, total height (H) and commercial height (Hc) (height up to a top stem diameter of ≥ 7 cm) were measured using diameter tape and measuring tape. The branches and foliage were delimbed, the felled trees was portioned in to different biomass components such as; stem (from the ground base to top diameter ≥ 7cm), big branches (diameter ≥ 7cm), small branches as diameter < 7cm up to 2cm) and foliage diameter < 2 cm (Basuki et al., 2009). Total fresh weights of all components were measured and 200gram subsamples were taken from small branch and foliage using sensitive mass balance. Three and two discs were obtained from stem and big branch, respectively for wood density and volume determination (Ali et al., 2016).

Dry weight of each component was calculated as:

Total dry weight of the small branches = (Total fresh weight of the small branches) × $(\frac{sample\ fresh\ weight}{sample\ dry\ weight})$*-------eq.1*

Total dry weight of the foliage = (Total fresh weight of the foliage) × $(\frac{sample\ fresh\ weight}{sample\ dry\ weight})$*-----eq.2*

Stem and big branch biomass were estimated by multiplying wood density by volume. The volume of stem and big branch section was derived using Smalian's formula De Gier (2003). Finally dry weight of total aboveground biomass =(Total dry weight of stem) + (Total dry weight of big branches + Total dry weight of small branches + Total dry weight of foliage) (Diédhiou et al., 2017) .

2.5. Biomass Expansion Factor data collection

*Determined from total biomass of selected tree species and stem biomass (stem volume obtained from log section multiplying by wood density of corresponding log section (M= WD*V) where: M is biomass WD is wood density and V is volume of the tree.*

2.6. Wood density data collection and sampling

For wood density measurement three disks with thickness of 5cm were cut from stem at base, middle and top parts. For big branch two discs were collected from base and top. The fresh weights were measured in the field and taken in to laboratory using polytheten bags, and oven dried at105^{o}c and 70^{o}c for 72 and 48 hours for wood and foliage respectively until constant weigh reached. The volume of each disk was determined and wood density calculated using water displacement method.

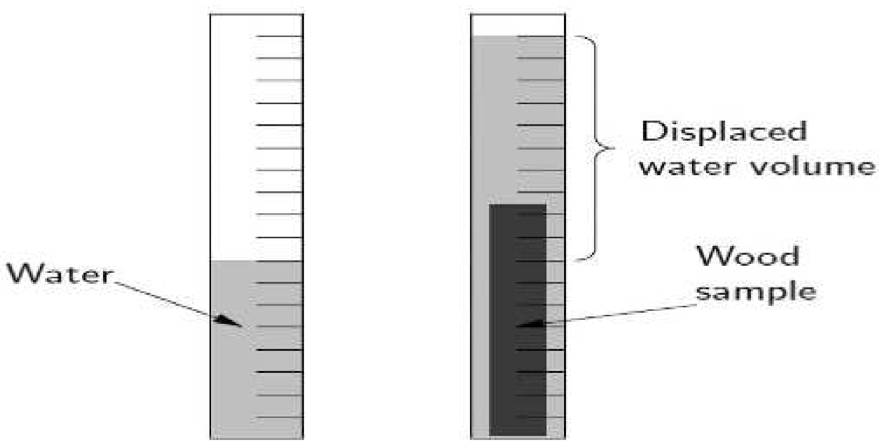

***Fig 1** Measuring sample volume by water displacement Source: Picard et al., 2012 and Henry (2012)*

2.7. Biomass equations

Allometric equations were developed for selected tree species and validated following appropriate procedure. First of all, descriptive and scatter plot analyses were carried out in order to determine the biomass and see their relationships with dendrometric variables. Spearman method used in order to identify the best predictor variables. Then the best dendrometric variables tested each total biomass were fitted individually using Statistical R software *version 4.0.1. Comparison was made using AIC, residual standard error, adj.R squared and p-value. Finally the results were compared with (Brown and Lugo, 1989; Chave et al., 2005 and 2014; Djomo et al., 2016; Asrat et al., 2020).*

3. Data analysis and model validation

The statistical analysis was conducted with R statistical software (http://www.r-project.org/ version R 4.0.1); SAS version 9.2 and Microsoft office excel 2007 and decided at a significant level (α) of 0.05 based on field and laboratory data. Transformed regression techniques were applied to developed allometric models to predict total biomass using independent variables including DBH, H, wood density and average crown diameter.

The model selection and validation was calculated based on statistical significance of model parameter estimates; AIC, adjusted coefficient of determination (adj.R^2), relative bias in percent, mean prediction error (MPE), RMSE, (Chave et al. 2005). Akaike information criterion (AIC) was estimated from (eq.3):

AIC = $2p - 2\ln(L)$ *---------------------------------------eq.3*

Where: L is the likelihood of the fitted model, p is the total number of parameters in the model and ln is natural logarithm. The developed allometric equation with the lowest AIC value is the best estimator.

Adjusted R-squared was estimated as;

adj.R^2= $[1-\sum (y_i-y_l)^2 / (y_i- y_j)^2]*n-1 /n-p$*-------------eq.4*

Adj. R^2 value indicates the variation explained by the model from total variation. It is value between 0 and 1, and the closer to 1, the better the quality of the fit.

Mean prediction error was calculated by (eq.5).

MPE= $\Sigma (y_i-y_l)/n$*--------------------------------eq.5*

Root mean square error was calculated by using (eq.6)

RMSE= $\sqrt{} (y_i-y_l)^2/n$*----------------------------eq.6*

Where: y_i is the observed aboveground biomass in kg; y_l is the predicted aboveground biomass in kg, y_j is mean observed biomass n is number of observation and p number of parameter.

3.1. Allometric biomass models

Many species site-specific and general allometric equation have been developed based on nonlinear regression model techniques (Brown and Lugo, 1989; Chave et al., 2005; Basuki et al., 2009; Henry et al., 2010). Logarithmic transformation was applied following(Packard and Boardman, 2008; Packard, 2013) to avoid hetereocedascity. The Correction Factor (CF) formula was developed by Sprugel was used (1983) to adjust under-estimation of biomass (Parresol, 1999; Chave et al., 2005). Thus, correction factor was computed using residual standard error of the regression (RSE) for each allometric model.

***CF =** exp ($RSE^2/2$) --eq.7*

Tested models

1. *AGB= exp [a +b ln (DBH)](Djomo et al., 2010)*
2. *AGB = exp [a +b ln (DBH^2*H)] (Djomo et al., 2010)*
3. *AGB = exp [a +b ln (DBH^2*WD)] (Fonton et al., 2017)*
4. *AGB = exp [a +b ln (DBH^2*H*WD)] (Chave et al., 2005)*
5. *AGB = exp [a +b ln (DBH)+c ln(H)] (Djomo et al., 2010)*
6. *AGB = exp [a +b ln (DBH)+c ln(CD)] (Zou et al., 2015)*
7. *AGB = exp [a +b ln (DBH)+c ln(H)+d ln(WD] (Chave et al., 2005)*
8. *AGB = exp [a +b ln (DBH)+c ln(H)+d ln(CD] (Zou et al., 2015)*
9. *AGB = exp [a +b ln (DBH)+c ln(H)+ d ln(WD +e ln(CD](Goodman et al., 2014)*

where AGB (in kg) is aboveground biomass of trees as response and DBH is diameter at breast height (cm), H is height (m), WD is wood density (gcm^{-3}) and (CD) average crown diameter(m) as independent variables, exp is exponential function, ln is natural logarithmic, a is intercept and b, c, d and e are model parameter estimates.

3.2. Biomass Expansion Factor determination

The BEF was calculated as the average ratio between total dry weight and total stem weight of all harvested trees using Eq. 8

$\boldsymbol{BEF} = 1/n \sum tDwi/tswi$ ……………………………………eq.8

where BEF is Biomass Expansion Factor(unit less), tDW,i (kg tree^{-1}) is total (stem, branches and foliage) dry weight of each individually sampled tree, tSW,i (kg tree^{-1}) is total dry weight of the stem alone and of each individually sampled tree, and n is the total number of sampled trees for each species (Lisboa et al., 2018).

3.3. Wood density determination

Wood density calculated using the formula (Tsoumis 1991).

WD =*m /v*----------------------------*eq.9*

Where: WD: wood density in g/cm^3, m: oven-dry mass of wood in gram and v, green volume of wood in cm^3.

3.4. Model validation and evaluation

Model comparison were done by using our dataset to selected pantropical model and tested by paired t-test for comparison of actual total biomass with predicted total biomass by general models.

4. Results and discussions

4.1. Results

4.1.1 Correlations between aboveground biomass and tree variables

The total above ground biomass of A. dimidiata tree species was strongly correlated with tree height however poorly correlated with average (CD) and WD of their total biomass (Table 2). But total biomass of C. malosana was strongly correlated with DBH than H while poorly correlation was observed between total biomass and average (CD) and WD (Table 2). Total biomass of C. africana was strongly correlated with DBH following H and average (CD). Total biomass of M.salicifolia and I.mitis were strongly correlated with DBH following H and poorly correlated with average (CD) and WD (Table 2).

Table 2 Spearman correlation coefficient among aboveground biomass and tree variables

Species	*Biomass*	*Tree variable*				*p-values*			
		Correlation in %							
		DBH	*H*	*CD*	*WD*	*DBH*	*H*	*CD*	*WD*
A. d	*AGB*	*0.84*	*0.90*	*0.53*	*-0.15*	*0.00*	*0.00*	*0.63*	*0.06*
C. m	*AGB*	*0.94*	*0.80*	*0.53*	*-0.10*	*0.00*	*0.01*	*1.00*	*0.52*
C. a	*AGB*	*0.96*	*0.85*	*0.92*	*0.32*	*0.00*	*0.00*	*0.00*	*0.29*
I. m	*AGB*	*0.98*	*0.85*	*0.73*	*0.20*	*0.00*	*0.03*	*1.00*	*0.26*
M. s	*AGB*	*0.89*	*0.82*	*0.55*	*0.37*	*0.00*	*0.01*	*1.00*	*0.52*

Where: AGB; Aboveground Biomass; tree species: Apodytes dimidiata (A.d), Cassiopourea malosana (C.m), Celtis africana (C.a), Ilex mitis (I.m) and Myrica salicifolia (M.s); DBH: diameter at breast height (cm), H: total tree height (m), CD: average crown diameter (m) and WD: wood density (gcm^{-3})

4.1.2 Species specific allometric equations for studied tree species

The relationship between aboveground biomass versus dendrometric predictors variables such as DBH, H, WD and CD were formulated for A. dimidiata, C. malosana, C. africana, I. mitis and M. salicifolia. The prediction accuracy and validation potential of fitted allometric equations for total aboveground biomass presented in (Table 3 and Appendix 1). The selected models had high adjusted coefficient of determination > 89%, p-value less than 0.01 and relatively low standard residual error.

Table 3 the best regression equations for TAGB for studied tree species

Sp name	*Equations*	*Adj.R^2*	*AIC*	*CF*	*RSE*	*p-value*
A. d	$TAGB_{est}=exp\ (-3.03+1.20*ln\ (dbh)\ +1.70*ln\ (ht))$	*0.92*	*5.66*	*1.03*	*0.25*	*0.01*
C. m	$TAGB_{est}=exp\ (-2.02+1.52*ln\ (dbh)\ +1.07*ln\ (ht))$	*0.97*	*6.05*	*1.01*	*0.17*	*0.001*
C. a	$TAGB_{est}=exp\ (-1.39+0.80*ln\ (dbh^2*ht*wd))$	*0.96*	*-2.65*	*1.02*	*0.18*	*0.001*
I. m	$TAGB_{est}=exp\ (-2.73+0.98*ln\ (dbh^2*ht*wd))$	*0.99*	*-11.59*	*1.00*	*0.10*	*0.001*
M. s	$TAGB_{est}=exp\ (-3.06+1.93*ln\ (dbh)\ +1.97*ln\ (cd))$	*0.95*	*10.35*	*1.05*	*0.30*	*0.001*

Where: TAGB: Total above ground biomass, Adj. R^2: Coefficient of determination, AIC: Akaike information criterion, CF: Correction Factor, RSE: Residual Standard Error.

Observed vs predicted total biomass of targeted species

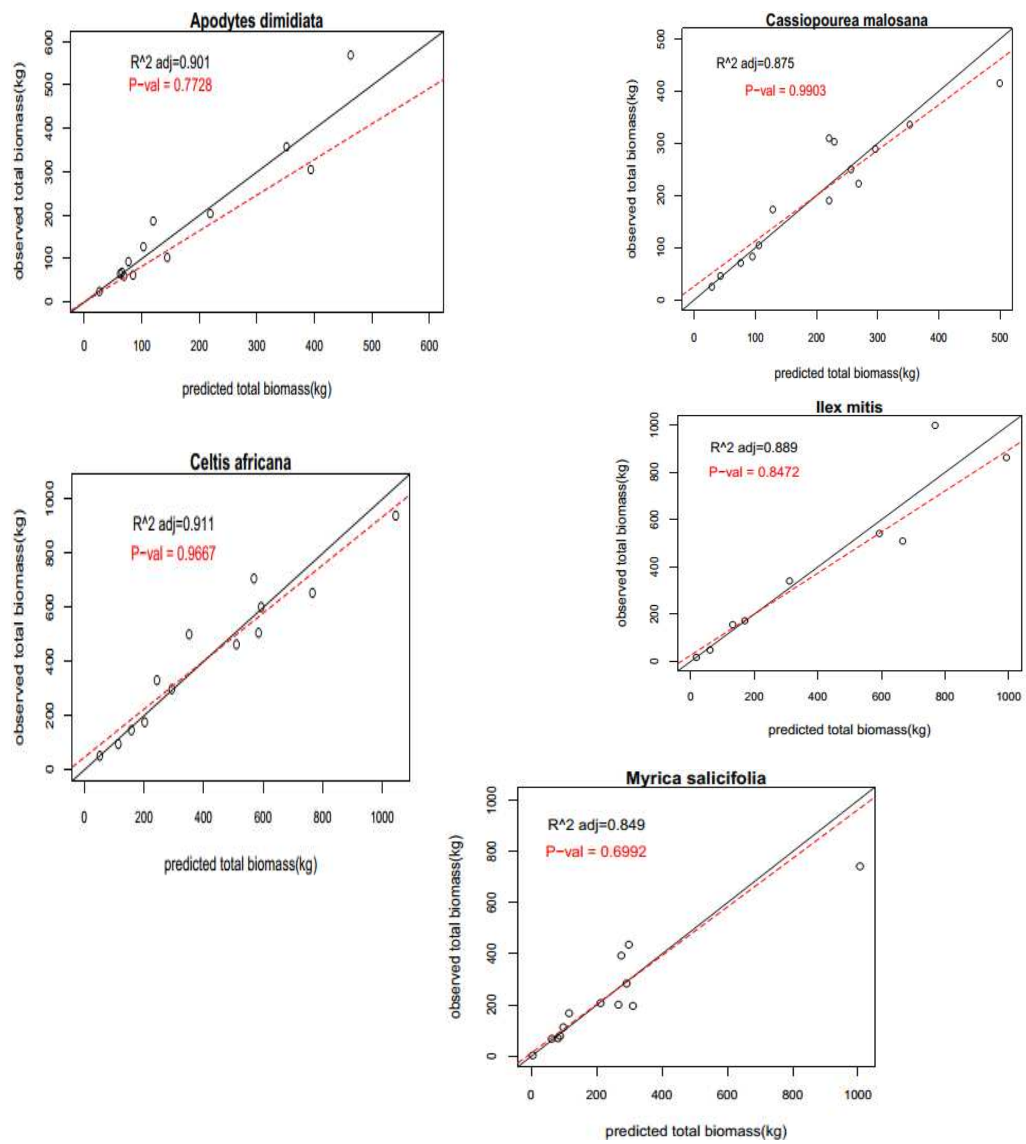

Fig 2 *observed versus predicted total biomass for studied tree species*

Dashed line is showing the adjusted line to the residuals and continuous line the 1:1 line

The results of the paired t-test did not show a significant difference between observed and predicted total biomass for the developed models (Table 3 and Figures 2).The validation of observed and predicted values showed linear relationship for all the targeted tree species. Based on the hypothesis one to one relationship between the observed and predicted aboveground biomass showed the better prediction accuracy of the model. The mean difference between observed and predicted total biomass of studied tree species were ranged between 0.14 and -11.03 (Table 5). Over-estimation of aboveground biomass was seen in all studied tree species except A. dimidiata.

4.1.3 Biomass expansion factor and wood density of studied tree species

The biomass expansion factor (BEF) of selected tree species ranged from 1.02 to 1.95 and the results revealed that the mean of BEF varied among species. The highest BEF was found for C. Malosana and A.dimidiata while the lowest was found for C. africana (Table 4).

The mean wood density (WD) values for selected tree species are summarised and the value was ranged from 0.53 to 0.74gcm^{-3}(Table 4). The mean wood density of selected tree species ranged from 0.53 to 0.74gcm^{-3} and varied among the targeted species. The highest mean WD was recorded in A. dimidiata while the lowest was recorded by I. mitis (Table 4).

Table 4 Mean and range of biomass expansion factor and wood density (mean±SD) for studied tree species

Species name	*Mean per species*		*Range per species*	
	BEF	*WD*	*BEF*	*WD*
A. d	*1.24±0.10*	*0.74±0.17*	*1.01-1.85*	*0.52-1.09*
C. m	*1.40 ±0.24*	*0.71±0.13*	*1.02-1.95*	*0.51-0.90*
C. a	*1.19±0.09*	*0.74±0.14*	*1.05-1.41*	*0.59-1.00*
I. m	*1.37±0.14*	*0.53±0.10*	*1.12-1.54*	*0.42-0.74*
M. s	*1.27 ±0.15*	*0.55±0.07*	*1.07-1.56*	*0.42-0.64*

Where: SD: standard deviation

4.1.4 Comparison of species specific model with pantropical

There is no significant difference between species specific model and observed above ground biomass for A.dimidiata (p>0.05). The total above ground biomass of relative bias of A. dimidiata ranged between -0.17 to

2.44kg while the root mean square error ranged from 14 to 195.61 kg (Table 5). While for all generalized model the $p < 0.05$ showed significant difference between observed and predicted biomass. Positive mean prediction error values and significant different from zero, implying that under-estimation of total aboveground biomass of selected tree species and vice-verse. The species specific allometric equations were more accurate for C. malosana than generalized while the root mean square error ranged was from 4.34 to 285.7kg (Table 5). The total biomass predicted by species specific allometric equation, Brown et al., 1989 and Chave et al., 2005 and 2014 for C. malosana had no significance difference between observed and predicted total biomass. The Brown et al., 1989 and Djomo et al., 2016 under estimate the biomass and the remaining were over estimate the biomass (Table 5). The species specific allometric equations were more accurate for C. africana than generalized one. The observed and predicted total biomass by species specific allometric model and generalized model Brown et al., 1989 and Chave et al., 2005 and 2014 had no significant difference for I. mitis at ($p \leq 0.05$). The species specific allometric equation were more accurate for M. salicifolia than generalized model with the lowest value of relative bias in percent ranged from 0.37 to 4.1 and root mean square ranged from 39.78 to 438. There is no significant difference between total above ground biomass predicted by species specific allometric equation, Djomo et al., 2016 and observed biomass for M. salicifolia. But there is significant difference between observed and predicted biomass by others generalized model (Table 5).

Table 5: Comparison of species specific model with pantropical

Species	*Model reference*	*Rel bias%*	*MPE*	*RMSE*	*t-statistic*	*p-value*
A. d	*This study*	*-0.17*	*3.88*	*14.00*	*0.30*	*0.39*
Generalized	*Brown et al.,(1989)*	*-2.46*	*54.80*	*197.60*	*4.16*	*0.01*
Generalized	*Chave et al., (2005)*	*2.14*	*-47.60*	*171.44*	*-2.55*	*0.01*
Generalized	*Chave et al., (2014)*	*2.22*	*-49.40*	*178.00*	*-2.26*	*0.02*
Generalized	*Djomo et al.,(2016)*	*-2.04*	*45.36*	*163.50*	*2.33*	*0.02*
Generalized	*Asrat et al., (2020)*	*2.44*	*-54.30*	*195.61*	*-2.34*	*0.02*
C. m	*This study*	*-0.04*	*1.16*	*4.34*	*-0.01*	*0.50*
Generalized	*Brown et al.,(1989)*	*-0.81*	*22.71*	*85.00*	*1.60*	*0.07*
Generalized	*Chave et al., (2005)*	*0.70*	*-19.62*	*73.42*	*-1.20*	*0.13*
Generalized	*Chave et al., (2014)*	*0.71*	*-20.00*	*74.70*	*-1.08*	*0.15*
Generalized	*Djomo et al.,(2016)*	*-1.20*	*32.50*	*121.50*	*2.25*	*0.02*

Generalized	*Asrat et al., (2020)*	*2.70*	*-76.35*	*285.70*	*-2.68*	*0.01*
C. a	*This study*	*1.43*	*-1.00*	*3.53*	*-0.04*	*0.48*
Generalized	*Brown et al.,(1989)*	*-20.10*	*46.10*	*166.20*	*1.82*	*0.05*
Generalized	*Chave et al., (2005)*	*28.54*	*-160.20*	*577.60*	*-2.36*	*0.02*
Generalized	*Chave et al., (2014)*	*33.10*	*-201.53*	*726.61*	*-2.35*	*0.02*
Generalized	*Djomo et al. (2016)*	*-21.33*	*70.70*	*254.83*	*2.24*	*0.02*
Generalized	*Asrat et al., (2020)*	*45.60*	*-265.5*	*957.40*	*-2.63*	*0.01*
I. m	*This study*	*0.26*	*-9.60*	*28.68*	*-0.20*	*0.42*
Generalized	*Brown et al.,(1989)*	*0.34*	*-12.21*	*36.64*	*-0.28*	*0.39*
Generalized	*Chave et al., (2005)*	*-0.17*	*6.20*	*18.50*	*0.34*	*0.37*
Generalized	*Chave et al., (2014)*	*0.40*	*-12.90*	*38.67*	*-0.73*	*0.24*
Generalized	*Djomo et al.,(2016)*	*-4.32*	*157.50*	*472.4*	*3.33*	*0.01*
Generalized	*Asrat et al., (2020)*	*1.82*	*-66. 30*	*198.81*	*-1.84*	*0.05*
M. s	*This study*	*0.37*	*-11.03*	*39.78*	*-0.40*	*0.35*
Generalized	*Brown et al.,(1989)*	*1.97*	*-58.44*	*210.70*	*-2.058*	*0.03*
Generalized	*Chave et al., (2005)*	*2.35*	*-69.73*	*251.40*	*-3.09*	*0.01*
Generalized	*Chave et al., (2014)*	*2.60*	*-76.90*	*277.32*	*-2.99*	*0.01*
Generalized	*Djomo et al.,(2016)*	*-1.20*	*34.75*	*125.30*	*1.56*	*0.07*
Generalized	*Asrat et al., (2020)*	*4.10*	*-121.5*	*438.00*	*-2.90*	*0.01*

4. 2. Discussion

4.2.1 Species specific allometric equations for aboveground biomass

Appropriate allometric equations are required for quantification of carbon storage which is important for carbon credit market. Total biomass estimated using diameter and height have lower residual standard error. Our results are agree with the findings of Ali et al. (2015); Brown et al.(1989; 1997); Overman et al. (1994) and Tesfaye et al. (2016) where they reported that combining diameter and height as independent variables provided better results. But in contrast with our findings that the inclusion of height did not increase neither the coefficient of determination (Hofstad 2005) nor improve the models(Tetemke et al., 2019). The combined squared diameter and height improved the prediction efficiency agrees with the findings of Ogawa et al., (1965). They found that dbh^2ht was a suitable predictor of total AGB estimation and disagree with the finding of other studies (Henry et al., 2010; Picard et al., 2015; Djomo et al., 2016). In most cases, Spearman correlation of wood density and total biomass were weak and statistically no significant at ($p > 0.05$). However we included wood density in addition to diameter and height for total biomass its residual standard error decreased for C. africana, I. mitis and M. salicifolia (Appendix1). This *finding similar to the reports of (Brown and Lugo, 1989; Ali et al., 2015; Chave et al., 2014; Goodman et al., 2014) and in contrast with the finding of other studies elsewhere (Baker et al., 2004; Njana et al., 2016;Tetemke et al., 2019). Wood density did not improve the model for the C. malosana species. These findings is in line with the findings(Baker et al., 2004; Njana et al., 2016;Tetemke et al., 2019).*

Crown diameter was also important for biomass estimation to improve coefficient of determination from 0.89 to 0.94 for M. salicifolia (Appendix 1). Our results similar to the finding of Hofstad (2005) and Conti et al. (2013). Diameter and crown width are better pairs of independent variables than traditionally used diameter and height(Tetemke et al., 2019). This is due to diameter of the crown was the easiest field measurement variables (Segura and Kanninen, 2005)and species might be have the same architectures and branching patterns and disagree with the report of(Ali et al., 2015) they found that crown variables have less important, as compared with diameter and height, for estimating the AGB.

All models with significant model parameter estimates (Appendix 1) can potentially be applied for estimating total above ground biomass depending on the availability of data from forest inventory.

4.2.2 Biomass Expansion Factor

The Biomass Expansion Factor (BEF) for the targeted tree species ranged from 1.19 and 1.40 (Table 4). Our result was similar to the findings of(Levy, 2004) who reported a BEF of 1.31 and 1.69 for 129 conifers species in Great Britain. This similarity might be due to estimation method applied. The result of A. dimidiata was very similar to the findings of (Giri, 2014) he recorded that 1.23 for Ailanthus excels species. Our results estimated were lower than the value of 3.4 reported by the IPCC for tropical forest stand. The difference might be due to biomass expansion factor highly correlated with basal area, volume and tree height (Iranmanesh et al., 2019) and our result also higher than the findings of (Momba and Bux, 2010) he found that 0.8731 of tropical dry trees of eastern Sinaloa, Mexico. This was due to biomass expansion factors are tree size dependent or directly proportional to total biomass of trees. Our result is far from the findings of (Iranmanesh et al., 2019) who reported a BEF for single stem vegetation of Brant's Oak species 2.37.

4.2.3 Wood density

The mean wood density of the sampled tree species were varying between 0.53 and 0.74 g cm^{-3} (Table 4). This result was similar with finding of (Olale et al., 2019) he reported mean wood density (0.42 to 0.73 g cm^{-3}) for selected tree species in Western Kenya. However, our findings are far from the finding of (Tesfaye et al., 2019) studied at Chilimo forest for the five dominant native tree species(0.44 to 0.67g cm^{-3}.This difference might be due to diameter range and species nature (Gartner and Meinzer, 2005). The Apodytes dimidiata, Cassiopourea malosana and Celtis africana had higher wood density than others selected tree species (Table 4).This might be due to variation of floristic composition(Chave et al., 2006). In our results the wood density of Apodytes dimidiata and Ilex mitis had 0.74 and 0.53 g cm^{-3} respectively (Table 4). But this result is far from the report of Merti et al. (2020) 0.53 and 0.45 g cm^{-3} respectively. These difference might be due to estimation method (semi-destructive method) used and vegetation type (moist afromontane forest).

The basic wood density of Cassiopourea malosana was 0.71 g cm^{-3}. This result far from the report of Genus average recorded as 0.673 g cm^{-3}.This difference might be due to number of sampled trees and stem position we sampled. The basic wood density of Celtis africana 0.74gcm^{-3} is in line with report of http://db.wordagroforestry.org//wd/species/Celtis africana and Getachew Desalegn et al., 2012. The basic wood density of Ilex mitis was 0.53 g cm^{-3} which is far from the report of Vreugdenhil et al., 2012. Finally the basic wood density of Myrica salicifolia was 0.55 g cm^{-3} far from the report of http://db.wordagroforestry.org//wd/species. The overall mean wood density for studied tree species was 0.656 g cm^{-3}.This result similar to the finding of (Chave et al., 2006) overall mean 0.645 g cm^{-3} of 2456 tree species from Central and South America.

4.2.4 Species specific model comparison with pantropical

The finding of actual biomass and general model by Brown et al. 1989; Chave et al. 2005 and 2014; Djomo et al. 2016) were comparable to, but they were not identical with actual mean value. This similarity probably due to the allometry of the trees in the Brown et al. 1989; Chave et al. 2005 and 2014; Djomo et al., 2016) sample may have included trees with similar allometry to the trees of our study area. The result is similar to the finding of Ares and Fownes (2000). When the equations of Brown et al. (1989); Chave et al. (2005and 2014); Djomo et al. (2016); Asrat et al. (2020) were applied to our data set; the predicted values were over and under estimated. The numerical differences in the results might be arose because of agro-ecology and diameter range.

5. Conclusions and recommendation

The result of the present study identified that combination form of tree diameter; height; wood density and average crown diameter were better predictors for total aboveground biomass. Coefficients of determination were greater than 0.85 for all selected tree species for total biomass models. Among selected tree species the maximum biomass expansion factor were recorded for C. malosana tree species and wood density was recorded for A. dimidiata. Species specific allometric equations were better than generalized allometric equation for estimation of total aboveground biomass estimation. The species specific models can potentially be applied in dry afromontane forests elsewhere in Ethiopia. The species composition; Juniperus procera and Olea europaea, and growing conditions related to rainfall and temperature of the studied area should be studies.

Appendix

Appendices 1 List of fitted allometric equation for studied tree species

S. name	TAGB	Fitted model	RSE	AIC	Adj-R^2
A.d	Total biomass	AGB=exp(-3.03+1.20*ln(dbh)+1.70*ln(ht))	0.25	5.66	0.92
		AGB=exp(-2.25+0.86*ln(dbh^2*ht))	0.27	6.43	0.91
C.m	Total biomass	AGB=exp(-1.77+0.82*ln(dbh^2*ht))	0.16	-7.22	0.96
		AGB=exp(-1.57+0.83*ln(dbh^2*ht*wd))	0.19	-3.21	0.95
		AGB=exp(-2.13+1.55*ln(dbh)+1.32*ln(ht)+- 0.53*ln(cd))	0.21	1.19	0.94
C.a	Total biomass	AGB=exp(-1.39+0.80*ln(dbh^2*ht*wd)	0.18	-3.81	0.96
		AGB=exp(-1.93+0.83*ln(dbh^2*ht)	0.19	-2.66	0.95
I. m	Total biomass	AGB=exp(-2.73+0.98*ln(dbh^2*ht*wd))	0.10	-11.59	0.99
		AGB=exp(-2.74+1.99*ln(dbh)+0.92*ln(ht)+0.90*ln(wd))	0.12	-7.86	0.99
		AGB=exp(-3.51+0.99*ln(dbh^2*ht))	0.19	-0.72	0.98
		AGB=exp(-3.41+1.63*ln(dbh)+1.29*ln(ht)+0.74*ln(wd)+0.45*ln(cd))	0.07	-16.64	0.99
		AGB=exp(-1.37+1.187*ln(dbh^2*wd))	0.17	-2.64	0.98
		AGB=exp(-2.31+2.43*ln*(dbh))	0.23	3.18	0.97
		AGB=exp(-4.16+0.93* ln(dbh^2*ht*wd))	0.51	17.10	0.86

M.s	*Total biomass*	*AGB=exp(-3.06+1.93*ln(dbh)+1.20*ln(cd))*	*0.30*	*10.35*	*0.95*
		*AGB=exp(-3.18+0.99*ln(dbh^2*ht*wd))*	*0.33*	*11.49*	*0.92*
		*AGB=exp(-4.27+1.05*ln(dbh^2*ht))*	*0.36*	*14.11*	*0.92*
		*AGB=exp(-5.02+1.64*ln(dbh)+1.89*ln(ht))*	*0.36*	*14.87*	*0.92*
		*AGB=exp(-1.86+1.22*ln(dbh^2*wd))*	*0.39*	*16.39*	*0.91*
		*AGB=exp(-3.17+2.62*ln(dbh))*	*0.42*	*18.15*	*0.90*
		*AGB=exp(-3.45+1.85*ln(dbh)+1.45*ln(cd))*	*0.37*	*15.46*	*0.93*

Where; TAGB: Total aboveground biomass; A.d: Apodytes dimidiata, C.m: Cassiopourea malosana, C.a: Celtis africana, I.m: Ilex mitis and M.s: Myrica salicifolia.

Appendix 2: Summary of main variables of the sampled trees for studied tree species

T .v	***Apodytes dimidiata***				***Cassiopourea malosana***				***Celtis africana***				***Ilex mitis***				***Myrica salicifolia***			
	Mean	*SD*	*min*	*max*	*Mean*	*SD*	*min*	*max*	*Mean*	*SD*	*min*	*max*	*Mean*	*SD*	*min*	*max*	*Mean*	*SD*	*min*	*max*
dbh	*17.1*	*6.8*	*8*	*32*	*20.56*	*7.2*	*8*	*31.5*	*27.46*	*10.3*	*10*	*43*	*27.7*	*13.2*	*9*	*48*	*24.2*	*9.7*	*7*	*44*
ht	*14.5*	*3.6*	*9.3*	*20*	*11.2*	*2.5*	*7.2*	*15*	*16.4*	*3.1*	*11.5*	*23.4*	*14.1*	*3.4*	*7.4*	*19*	*13.6*	*3.3*	*6.7*	*19*
wd	*0.7*	*0.2*	*0.5*	*1.1*	*0.7*	*0.1*	*0.5*	*0.89*	*0.74*	*0.14*	*0.59*	*1.0*	*0.53*	*0.09*	*0.42*	*0.74*	*0.55*	*0.07*	*0.42*	*0.66*
cd	*3.8*	*1.6*	*1.5*	*6.6*	*5.7*	*1.7*	*3.2*	*9.3*	*4.5*	*2.3*	*2.5*	*11.3*	*5.9*	*2.2*	*3.8*	*9.5*	*5.7*	*1.7*	*2*	*9.3*
tb	*171.2*	*156.3*	*24.3*	*569.4*	*201.1*	*121.9*	*24.9*	*415*	*420.5*	*266.1*	*50.8*	*939.3*	*413.9*	*358.8*	*17.4*	*1023.5*	*228.4*	*199.8*	*3.8*	*742*
n	*13*	*13*	*13*	*13*	*14*	*14*	*14*	*14*	*13*	*13*	*13*	*13*	*9*	*9*	*9*	*9*	*13*	*13*	*13*	*13*

Where ; T.v: tree variables; dbh: diameter at breast height(cm); ht:height(m);wd:wood density(g/cm^3);av.cd:average crown diameter(m);tb:total biomass(kg);sb:stem biomass(kg);bb:branch biomass(kg);fb:foliage biomass(kg);tv:total volume(m^3);sv :stem volume(m^3);n:number of observation.

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