# Allometric models for prediction of aboveground biomass of single trees in miombo woodlands in Tanzania

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## Abstract

*Allometric models for prediction of above ground biomass of miombo trees was developed using data from four sites in Tanzania. A total of 167 sample trees were collected from four sites representing both wet and dry miombo woodlands in Tanzania. Ten randomly selected sample trees from each site were kept for model validation while the remaining trees were used for calibration of the biomass models. Site, miombo categories, and general models (combining all data) were developed. The Pseudo-$R^2$ of the final site specific models was 0.96, 0.96, 0.92 and 0.95 for Babati, Lindi, Mpanda, and Tabora, respectively. The Pseudo-$R^2$ of both the miombo categories and the general biomass model was 0.95. Site specific, miombo categories and general biomass models have been developed and tested in this study. Models validation shows that the developed biomass models can sufficiently be applied to their respective sites and miombo categories. While acceptable bias% (< 10%) was mostly found which was not significantly higher than zero ($p > 0.05$), unacceptable bias% (> 10%) were found when Babati site specific biomass model had applied to Lindi and wet miombo biomass model was applied to dry miombo. This leads to the conclusion that for precise biomass estimation, the site specific and miombo category biomass model may not be applied to other site and miombo category respectively. A significant fit of general biomass model were found to each separate study sites and miombo categories when tested to their respective independent data. Since the general biomass models covered both wet and dry miombo woodlands, which are the major categories of miombo woodlands, the developed general model are recommended to be applied to entire miombo woodlands of Tanzania with similar conditions as the study sites. However, for improved biomass estimates of study sites, the site specific biomass model should preferably be used than the general biomass model. In addition, it should be noted that the developed biomass models predict total above ground tree biomass where separate tree components models i.e. stem and branch, and below ground also need to be developed.*

**Key words:** *Biomass allometric models, miombo woodland*

## 1.0 Introduction

Tanzania has a total land area of about 94 million hectares out of which 33.4 million hectares are covered by forests and woodlands. Miombo woodlands accounts for about 95% of the total forest and woodland cover (URT, 1998). The miombo woodlands are physiognomically divided into dry and wet miombo, which differ in terms of tree size and stand structure (White, 1983). While the dry miombo receives rainfall below 1000 mm per year and is most common present in south western Tanzania, the wet miombo receives rainfall above 1000 mm and are commonly found in coastal areas, east and north eastern Tanzania (White, 1983). Forests and woodlands offer both direct tangible benefits and indirect benefits including environment services such as biodiversity and carbon storage (Burges *et al*., 2010; Munishi and Shear, 2004; Zahabu, 2008; Williams *et al*., 2008; Dewee *et al*., 2010). Carbon storage function is important for mitigation of climate change. Thus, quantification of quantities of amounts of carbon stored in various vegetation types has recently gained importance all over the world (Chave *et al*., 2004). Technically, this requires development of reliable models that can be used for the estimation of carbon stored in different sites and forest types.

In addition, biomass models are useful tools in assessing forest structure and conditions. They may provide valuable information on supply of both industrial wood and biomass for domestic energy, and they are elements in all attempts of identifying sustainable management of forests and woodland ecosystems (Chamber *et al.*, 2001). Biomass models are also needed to describe changes over time for forest carbon stocks at national as well as local level. The models are also relevant for remote sensing and for all field inventories related to conventional management planning. Moreover, biomass models are components of implementation of the emerging carbon credit market mechanism such as Reducing Emission from Deforestation and Forest Degradation (REDD).

Methods of estimation of carbon stocks and changes over time have been developed. They range from direct field measurements through conventional forest inventories and growth modeling to remote sensing (Chave *et al.*, 2004). All of these methods require application of reliable biomass allometric models (Chave *et al.*, 2004). There are two biomass models (Malimbwi *et al.* 1994; Chamshama *et al.* 2004) available for Tanzania miombo woodlands. Both models were developed using sample trees from a single miombo woodland site of Kitulangalo Training Forest in Morogoro region (Hofstad 2005). A number of shortcomings are pertinent to these models. First, they were developed from small samples (i.e. few sample trees). Secondly, the sample covered a narrow diameter range that excluded small or bigger trees, which means that the models often must be applied beyond their valid diameter ranges. Furthermore, the models were developed for dry miombo woodland site that limit their application in wet miombo woodlands. This suggests the need for development of more reliable and replicated biomass models for both dry and wet miombo woodlands of Tanzania.

The objective of this study was therefore to develop reliable single tree biomass models for both wet and dry miombo woodlands of Tanzania using data collected from both dry and wet miombo woodlands from four different sites. This paper will not consider biomass models for separate tree components such as stems, branches and roots. Site specific, miombo categories (wet and dry) and generic biomass models are developed and validated to show their reliability. Where necessary, the paper provides empirical analysis of strength and weaknesses of the existing miombo biomass allometric models.

## 1. Material and methods

### 2.1 Site descriptions

Biomass data were collected from four sites of Lindi (southern Tanzania), Manyara (north eastern Tanzania), Tabora (western central Tanzania) and Mpanda (western Tanzania). The selection of sites was based on the fact that these areas are mostly dominated by miombo woodland and they have different mean annual precipitation, miombo types and soils. This will facilitate comparison among developed miombo woodlands biomass models. Site details are described in Table 1.

### 2.2 Selection of sample trees

In each studied forest, it was aimed to cover all dbh class distribution of trees and collect some information for the description of the forest stand characteristics. For this purpose plots of 15 m radius were laid out randomly in each forest. Within the plot at most two trees were selected for destructive sampling. The dbh class where each selected tree fall was recorded to ensure the trees are spread out uniformly to all dbh classes. Descriptive statistics for number of sample trees, dbh, basal area and height distribution of the trees for the four sites are shown in Table 2.

**Table 1. Study site description of rainfall, miombo categories and soil characteristics**

| Study sites | Region | Category | Mean annual rainfall (mm) | Dominant soil types |
|---|---|---|---|---|
| Mpanda | Rukwa | Wet miombo | 1050 | Sandy clay soils |
| Ayasanda and Duru Haitemba | Manyara | Dry miombo | 790 | Clay alluvial soils |
| Angai Forest Reserve | Lindi | Wet miombo | 1034 | Sandy loam soils |
| Nyahua Forest Reserve | Tabora | Dry miombo | 880 | Sandy clay loam soils |

## 2.3 Destructive sampling

The sample trees were measured for dbh, total height, and root collar diameter (30 cm height from the ground) and then felled. Stems (including branches) were trimmed and cross cut into manageable billets ranging from 1 to 2.5 m in length. Mid-diameter and length of each billet were measured for stem volume estimation and measured for green weight. Small samples (disk) were extracted from the mid-section of each billet for basic density determination. Twigs and leaves were collected into separate bundles where the green weight of each was weighed. Small samples from each bundle were collected, labeled and measured for green weight ready for laboratory analysis.

## 2.4 Laboratory procedures

The collected samples were analyzed for biomass in the laboratory. Samples include discs from stems, and branches and samples from twigs. The volume of the disc was determined by the water-displacement method (Brown, 1997). Following the volume measurement, the disk was oven dried to constant weight at 70 $^0$C for 48 hours.

**Table 2. Statistical summary for number of sample trees (N), diameter at breast height (Dbh), height of sample trees, Basal area (Ba) and Stem density (N/ha) from the four study sites**

| Site | N | Dbh (cm) | | | | | Height (m) | | | | | Ba (m$^2$) | | | N/ha | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Min | Max | Std | | Mean | Min | Max | Std | | Ba | Std | | N/ha | Std |
| Babati | 40 | 35.5 | 1.7 | 78 | 20.9 | | 11.3 | 2.7 | 19.5 | 5.0 | | 14.8 | 4.2 | | 1352 | 451 |
| Lindi | 47 | 35.1 | 1.1 | 110 | 25.9 | | 13.6 | 1.9 | 27.5 | 6.4 | | 7.4 | 3.7 | | 189.9 | 71 |
| Mpanda | 40 | 36.2 | 3.5 | 79 | 19.2 | | 12.9 | 3.3 | 26 | 4.8 | | 9.8 | 3.6 | | 239 | 80 |
| Tabora | 40 | 32.1 | 1.2 | 95 | 23.3 | | 12.7 | 1.9 | 26 | 6.5 | | 7.0 | 3.4 | | 513 | 262 |

## 3.0 Data analysis

## 3.1 Computation of observed biomass

The ratio of dry weight (biomass) to green weight for stems branches and twigs were computed. Tree component/billets biomass was computed as a product of component total green weight and the ratio of dry weight (biomass) to green weight. Total tree biomass was computed as a sum of stem, branches and twigs biomass.

## 3.2 Biomass allometric model development, selection and validation

In each site, 10 randomly selected sample trees were left aside for model validation while the remaining sample trees were used to fit the biomass models. Models for individual sites, miombo categories i.e. wet and dry miombo as well as for combined sites were developed and validated. Different models were tested (Table 3) where the model with the best fit was selected. PROC NLIN procedure in Statistical Analysis System (SAS Institute Inc 2004) was used to fit the models. Multiple initial values of model parameters were provided to ensure the least square solution is global rather than local.

**Table 3. Selected non-linear biomass models**

| Model | Expression |
|---|---|
| 1 | Biomass = $\exp[a+b.\mathrm{dbh}^2]$ |
| 2 | Biomass = $\exp[a+b.In(\mathrm{dbh})]$ |
| 3 | Biomass = $\exp[a+b.In(\mathrm{dbh})+c.In(\mathrm{dbh}).\mathrm{height}]$ |
| 4 | Biomass = $a+b.\mathrm{dbh}+c.\mathrm{dbh}^2$ |

NOTE: Biomass are given in Kg, dbh in cm and height in m

The selection of the models was based on magnitude of Pseudo coefficient of determination (Pseudo-$R^2$), and root mean square error (MSE). Model with insignificant parameter estimates were not considered for selection. Computation of these criteria was as follows:

$$\text{Pseudo-}R^2 = 1 - [SSR/CSST]$$

$$\text{RMSE} = [SSR/(n-2)]^{1/2}$$

Where SSR is sum of residual squares; CSSR is corrected total sum of squares; and $n$ is number of observations. Increase in Pseudo-$R^2$ and decrease in MSE, implied the improved fit statistics.

The biomass model validation basing on bias and percentage bias (*bias %*) followed the Huang *et al.,* (2003) protocol. In this protocol bias % of < ± 10 % at 95% confidence level is accepted provided no adverse pattern is displayed. They further urge that bias % between 10 % and 20 % indicate a level of uncertainty that calls for additional data and testing. The computation of bias and *bias* % was as follow:

$$Bias = [\sum (B-Bp)/n]$$

$$Bias\ \% = [(\sum (B-Bp)/n)/\hat{E}]\ \mathrm{x}100$$

Where $B$ is observed biomass, $Bp$ predicted biomass, $n$ is number of observations and $\hat{E}$ is mean tree biomass.

In addition to computation of bias%, a paired *t*-test between observed biomass of independent data of each site and predicted value computed by other site specific biomass allometric model was carried out to test the correlation among sites. Similar test were carried out to test the model performance among miombo categories and the performance of general model to both sites and miombo categories independent data.

## 4.0 Results and discussion

The developed biomass models are presented in Table 4. For models 3 and 4, some of the parameter estimates were found to be insignificant. Basing on Pseudo-$R^2$ and RMSE, model 2 had a good fit for all sites. The best models have Pseudo-$R^2$ above 0.92 for all sites. Similarly, model 2 had a good fit for the both categories of miombo as well as general biomass allometric model accounting to 95% of all variation.

The selected biomass models have percentage bias below 10% when tested to the independent data from respective sites (Table 6). Basing on Huang *et al.* (2003) protocol, these biomass models are therefore acceptable to be applied to their sites.

### 4.1 Evaluation of site specific, miombo categories and general biomass allometric models to other study sites

Paired *t*-test of site independent observed biomass against predicted biomass with other sites specific biomass allometric models are presented in Table 5. Insignificant difference (*p*-value > 0.05) was found between observed biomass values and predicted biomass value computed by other sites biomass models for all sites except Lindi biomass prediction using Babati biomass model. These results however, supports to the need to develop a general biomass model irrespective of sites that can be applied in other areas with similar miombo woodland in Tanzania.

The general biomass model had bias % below 10 irrespective of site. Compared to the results obtained using site specific models for Mpanda and Tabora, the absolute bias % decreased from 5.89% and 5.46% to 0.33% and 3.64%, respectively for these two sites when the general model was applied (Table 6). However, for Lindi the bias % increased from 4.39% to 7.69% when the general model was applied. This could be explained by the fact that Babati biomass allometric model could not significantly explain the variation in Lindi site (Table 5) suggesting that Babati data are significantly different from that of Lindi (Figure 1). In addition to that, inspite of insignificance *p*-value, a relatively lower *p*-value is found when predicted value computed by Babati biomass model is compared to the observed value of the other two sites (Mpanda and Tabora) (*p*-value > 0.05). This observation coincides with the pattern displayed in Figure 1 where the Babati curve passes below and crosses the other sites curves at dbh greater than 65 cm. Similarly, the higher *p*-value obtained when Lindi, Tabora and Mpanda biomass model where evaluated to each of the site, correspond with the pattern in Figure 1 where the three curves passes in more or less the same path/location except for Babati. The other possible reason is that tree species with dbh above 40 cm in Babati were found to be dominated mainly by two species i.e. *Julbernadia globiflora* and *Brachystergia spiciformis* (Appendix 1). This was not the case for the other sites where more than three tree species with dbh above 40 cm were found.

Insignificant difference (*p*-value > 0.05) was found between observed biomass values and predicted biomass value when paired *t*-test was carried out between wet miombo and dry miombo (Table 5). A bias% of 12.29% was found when biomass of wet miombo was computed with dry miombo woodland biomass model and below (-5.14) when the vice versa was carried out (Table 6).

This suggests that the biomass model of two categories of miombo is not significantly different although the bias of 12.29% is indication of uncertainty that calls for additional data and testing (Huang et al., 2003). In addition to that, relatively similar curves lines are displayed by both wet and dry miombo (Figure 2). Regardless of these variations, following Huang *et al.* (2003) protocol, the general biomass model is therefore acceptable to be applied to other miombo woodlands of Tanzania with similar conditions as studied sites. In addition to that improved prediction of general biomass model could be attributed with the increased sample trees (127 sample trees) which hence accounting more biomass variation in miombo woodlands compared to sites specific biomass models which had fewer sample trees (40-47 sample trees). The plot of studentized residuals against predicted biomass of general biomass model did not show any systematic pattern (see e.g. Figure 3).

**Table 4. Estimated model parameters and performance criteria measures of four selected non-linear model forms for both site specific and general biomass models**

| Site | Model Number | Parameter estimates | | | Performance criteria | |
|---|---|---|---|---|---|---|
| | | **a** | **b** | **c** | **Pseudo-$R^2$** | **RMSE** |
| Babati | 1 | 5.9246 | 0.00046 | | 0.86 | 524.3 |
| | 2 | -2.86554 | 2.620583 | | 0.96 | 379.7 |
| | 3 | 0.02199$^{NS}$ | 1.48342 | 0.02552 | 0.96 | 280.8 |
| | 4 | 347.9599 $^{NS}$ | -42.0944 | 1.3638 | 0.94 | 377.5 |
| Lindi | 1 | 6.8874 | 0.00022 | | 0.83 | 1215 |
| | 2 | -1.4995 | 2.307472 | | 0.96 | 491.4 |
| | 3 | 0.48465 $^{NS}$ | 1.61307 | 0.01067 | 0.96 | 558.4 |
| | 4 | 246.4733 $^{NS}$ | -35.1759 | 1.3206 | 0.96 | 594.9 |
| Mpanda | 1 | 6.3632 | 0.00038 | | 0.81 | 636.8 |
| | 2 | -2.60297 | 2.574005 | | 0.92 | 396.2 |
| | 3 | 0.6656 $^{NS}$ | 1.61676 | 0.009052 | 0.94 | 364.9 |
| | 4 | 102.3913 $^{NS}$ | -20.6025 $^{NS}$ | 1.1540 | 0.95 | 442.1 |
| Tabora | 1 | 6.4701 | 0.00031 | | 0.89 | 768. |
| | 2 | -1.87952 | 2.38939 | | 0.95 | 396.2 |
| | 3 | 1.16393 $^{NS}$ | 1.270047 | 0.019058 | 0.96 | 471.8 |
| | 4 | 242.8433 $^{NS}$ | -32.3024 | 1.3160 | 0.95 | 561.6 |
| Wet Miombo | 1 | 6.8527 | 0.00022 | | 0.79 | 1089 |
| | 2 | -1.6557 | 2.3427 | | 0.95 | 425.9 |
| | 3 | 0.4830 $^{NS}$ | 1.6439 | 0.0095 | 0.96 | 474.7 |
| | 4 | 214.86 $^{NS}$ | -30.7818 | 1.2781 | 0.95 | 522.3 |
| Dry Miombo | 1 | 6.4277 | 0.00032 | | 0.86 | 722.5 |
| | 2 | -2.2453 | 2.4735 | | 0.95 | 386.0 |
| | 3 | -1.0303 $^{NS}$ | 2.0279 | 0.0084 | 0.95 | 423.3 |
| | 4 | 328.1815 $^{NS}$ | -40.3508 | 1.3829 | 0.94 | 475.8 |
| General | 1 | 6.78595 | 0.000236 | | 0.77 | 1038.9 |
| | 2 | -1.86744 | 2.388567 | | 0.95 | 407.4 |
| | 3 | -0.03148 $^{NS}$ | 1.78609 | 0.008587 | 0.96 | 459.5 |
| | 4 | 257.9213 $^{NS}$ | -34.394 | 1.31477 | 0.95 | 497.2 |

NOTE: $^{NS}$, Represent insignificant parameter estimates

**Table 5. Paired *t*-test of site independent observed biomass against predicted biomass computed by other sites biomass models**

| Site with observed Biomass | Predicted biomass obtained by site specific biomass model | *df* | *t*-value | *p*-value |
|---|---|---|---|---|
| Babati | Lindi | 9 | 0.56 | 0.5859 |
| | Mpanda | 9 | 1.09 | 0.3041 |
| | Tabora | 9 | -0.62 | 0.5506 |
| Lindi | Babati | 9 | 2.32 | 0.0453$^{S}$ |
| | Mpanda | 9 | 0.20 | 0.8432 |
| | Tabora | 9 | 0.89 | 0.3953 |
| Mpanda | Babati | 9 | 1.20 | 0.2620 |
| | Lindi | 9 | 0.01 | 0.9910 |
| | Tabora | 9 | 0.05 | 0.9624 |
| Tabora | Babati | 9 | 1.70 | 0.1229 |
| | Lindi | 9 | 0.18 | 0.8615 |
| | Mpanda | 9 | 0.28 | 0.7835 |
| Wet miombo | Dry miombo | 19 | 1.2 | 0.2430 |
| Dry miombo | Wet miombo | 19 | -0.73 | 0.4736 |

NOTE: $^{S}$**,** represent significant *p*-value

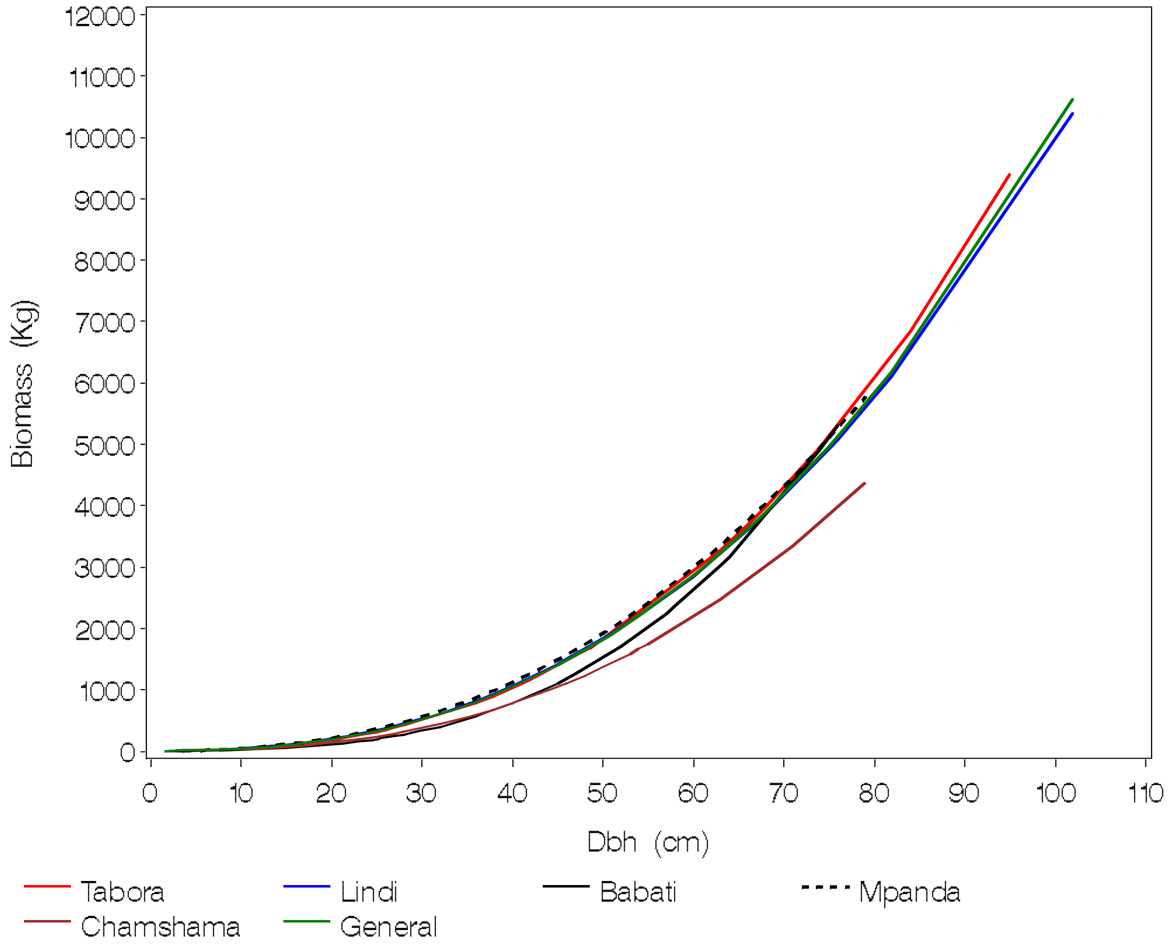

**Figure 1. Display of developed site specific, general, and Chamshama *et al*., 2004 biomass models**

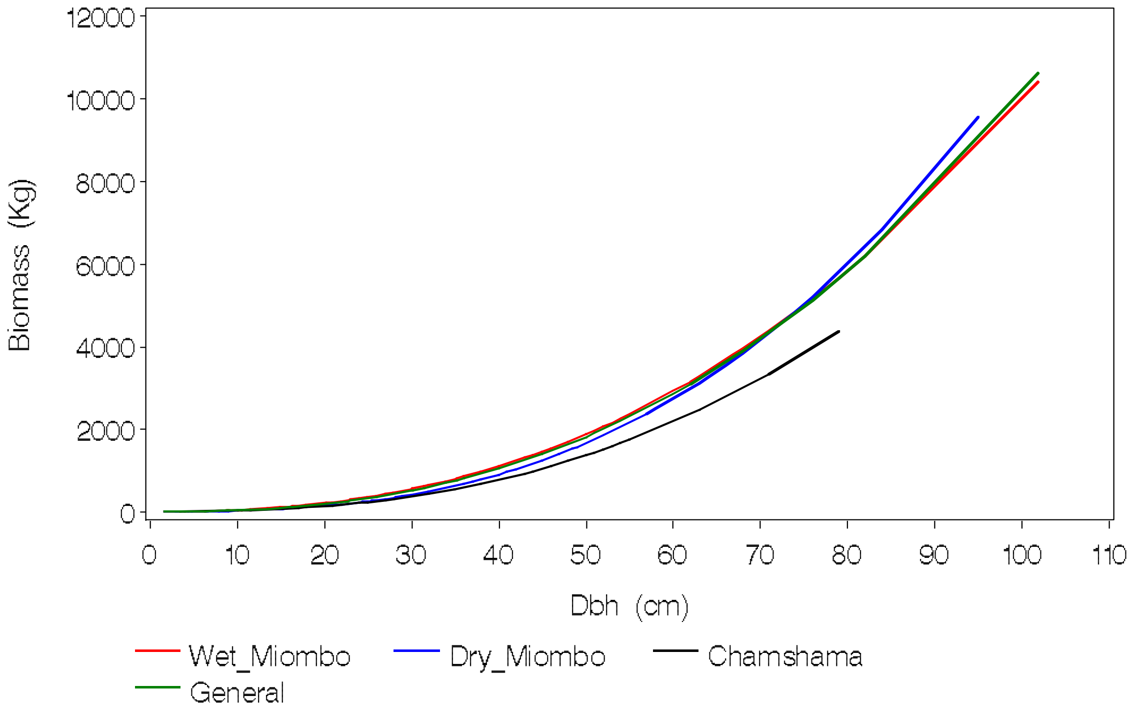

**Figure 2. Display of developed wet and dry miombo, general, and Chamshama *et al*., 2004 biomass models**

**Table 6. Selected biomass models performance on independent biomass data**

| Models | Site tested | Developed models | |
|---|---|---|---|
| | | **Bias (kg)** | **Bias %** |
| Site specific models | Babati | 41.34 | 2.6 |
| | Lindi | 20.67 | 4.4 |
| | Mpanda | -75.83 | -5.9 |
| | Tabora | 40.16 | -5.5 |
| General equations | Babati | -74.27 | -3.7 |
| | Lindi | 29.48 | 7.7 |
| | Mpanda | 4.32 | 0.3 |
| | Tabora | 26.73 | 3.6 |
| | Dry Miombo | -23.77 | -2.05 |
| | Wet Miombo | 16.89 | 2.02 |
| Chamshama *et al.*, 2004 | Babati | 319.80 | 20.2 |
| | Lindi | 126.31 | 33.0 |
| | Mpanda | 321.14 | 25.0 |
| | Tabora | 208.43 | 28.4 |
| Malimbwi et al., 1992 | Babati | 602.73 | 38.1 |
| | Lindi | 106.83 | 27.9 |
| | Mpanda | 516.82 | 40.2 |
| | Tabora | 246.38 | 33.5 |
| Wet Miombo | Dry miombo | -59.55 | -5.145 |
| Dry Miombo | Wet Miombo | 102.62 | 12.29 |

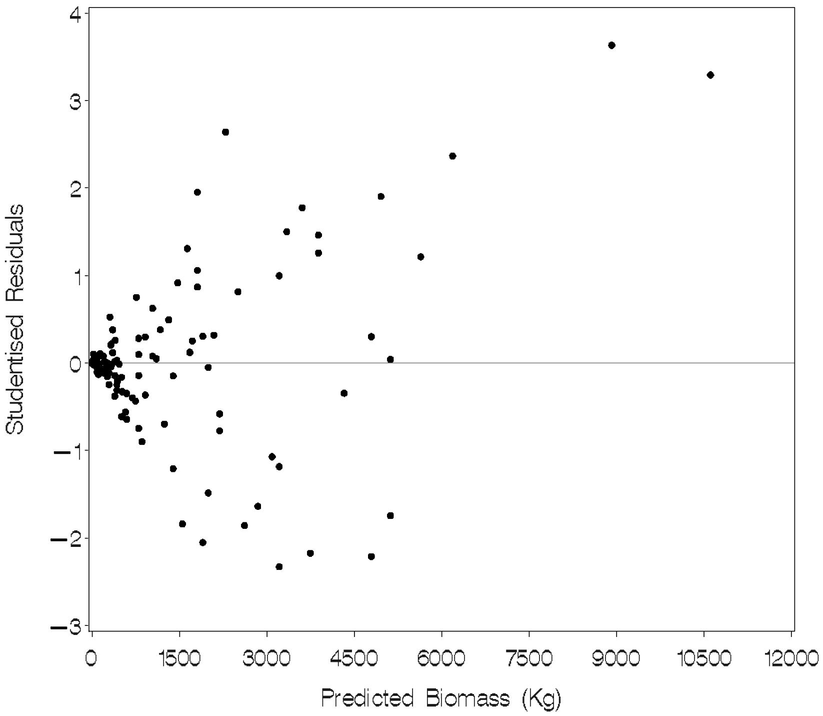

**Figure 3. Plot of studentized residuals against predicted biomass as per developed general biomass allometric model.**

## 4.2 Comparison with available biomass allometric model

The biomass model developed by Chamshama *et al* (2004) and Malimbwi *et al* (1994) underestimated the biomass by over 20.2 % and 27.9 % respectively when tested to the independent dataset (Table 6). This observation is supported further with Figure 1 and 2 where the Chamshama *et al.,* 2004 biomass model passes below the other biomass model curves. The fact that Malimbwi *et al* 1994 did not include small branches, twigs, leaves and small trees with dbh below 8 cm and Chamshama *et al* (2004) did not include twigs and leaves could probably explain why these biomass models underestimates the individual tree biomass. In addition to that, both previously developed models did not include large trees with dbh greater than 50 cm. In this study tree samples with maximum dbh of 78, 110, 79 and 95 cm and minimum dbh of 1.7, 1.1, 3.5, and 1.2 cm for Babati, Lindi, Mpanda and Tabora respectively were used (Table 2).

## 5.0 Conclusion

Site specific, miombo categories and general biomass models have been developed and tested in this study. Models validation shows that the developed biomass models can sufficiently be applied to their respective sites and miombo categories. While acceptable bias% (< 10%) which was not significantly higher than zero ($p > 0.05$) were mostly prominent, unacceptable bias% (> 10%) were found when Babati site specific biomass model had applied to Lindi and wet miombo biomass model was applied to dry miombo. This leads to the conclusion that for precise biomass estimation, the site specific and miombo category biomass model may not be applied to other site and miombo category respectively. A significant fit of general biomass model were found to each separate study sites and miombo categories when tested to their respective independent data. Since the general biomass models covered both wet and dry miombo woodlands, which are the major categories of miombo woodlands, the developed general model are recommended to be applied to entire miombo woodlands of Tanzania with similar conditions as the study sites. However, for improved biomass estimates of study sites, the site specific biomass model should preferably be used. In addition, it should be noted that the developed biomass models predict total above ground tree biomass where separate tree components models i.e. stem and branch, and below ground also need to be developed.

## Acknowledgement

This work presents some preliminary results regarding above ground biomass models for miombo woodland in Tanzania. The work has been done as part of the project “Development of biomass estimation models and carbon monitoring in selected vegetation types of Tanzania” under the CCIAM-programme at Sokoine University of Agriculture. We thank CCIAM and Department of Ecology and Natural Resource Management at the University of Life Sciencies (UMB), Norway for funding this study.

## References

Brown, S., (1997) Estimating Biomass and Biomass Change of Tropical Forests: a Primer. Forestry Paper 134, FAO, Rome.

Burgess, N. D., Bahane, B., Clairs, T., Danielsen, F., Dalsgaard, S., Funder, M., Hagelberg, N., Harrison, P., Haule, C., Kabalimu, K., Kilahama, F., Kilawe, E., Lewis, S. L., Locett, C. J., Lyatuu, G., Marshall, A. R., Meshack, C., Miles, L., Milledge, S. A. H., Munishi, P. K. T., Nashanda, E., Shirima, D., Swetnam, R. D., Willcock, S., Williams, A. and Zahabu, E., (2010) Getting ready for REDD+ in Tanzania: A case study of progress and challenges. Fauna and Flora International, Oryx, 44: 339-351.

Chambers, J.Q., dos Santos, J., Ribeiro, R.J., Higuchi, N., (2001) Tree damage, allometric relationships, and above-ground net primary production in central Amazon forest. For. Ecol. Manage. 152, 73–84

Chamshama, S.A.O, Mugasha, A.G. and Zahabu, E., (2004) Biomass and volume estimation for miombo woodlands at Kitulangalo, Morogoro, Tanzania. *Southern African Forestry Journal* 200: 49-60.

Chave J., Condit R., Aguilar S., Hernandez A., Lao S., Perez R. (2004) Error propagation and scaling for tropical forest biomass estimates. Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences 359:409-420

Dewees, P.A., Campbell, B.M., Katerere, Y. Sitoe, A. Cunningham, A.B. Angelsen, A. and Wunder, S. (2010) Managing the Miombo Woodlands of Southern Africa: Policies, Incentives and Options for the Rural Poor. Journal of Natural Resources Policy Research 2(1): 57 – 73

Hofstad, O. (2005) Review of biomass and volume functions for individual trees and shrubs in Southeast Africa. J. Trop. For. Sci. 17(1):151-62.

Huang S., Yang Y., Wang Y. (2003) A critical look at procedures for validating growth and yield models. Modelling Forest Systems. Instituto Superior de Gestao, Lisbon, Portugal. Michigan Technological University, USA. Instituto Superior de Agronomia, Lisbon, Portugal:271-293.

Malimbwi, R.E., Solberg, B. and Luoga, E. (1994) Estimate of Biomass and Volume in Miombo Woodland at Kitulangalo Forest Reserve, Tanzania. *Journal of Tropical Forest Science* 7(2): 230-242.

SAS Instute Inc. (2004). SAS Institute Inc., Cary, NC, USA.

United Republic of Tanzania (URT), (1998) National Forest Policy. Forestry and Beekeeping Division, Ministry of Natural Resources and Tourism, Dar es Salaam. 59 p.

White, F., 1983.The vegetation of Africa. Natural Resources research XX:86-01. Unesco, Paris, 356 pp.

Williams, M., Ryan, C.M., Rees, R.M., Sambane, E., Fernando, J. and Grace, J. (2008) Carbon sequestration and biodiversity of re-growing mambo woodlands in Mozambique. Forest Ecology and management 254: 145 – 155.

Zahabu, E. (2008) Sink and Source. A strategy to Involve Forest Communitiesin Tanzania in Global Climatic Policy. A PhD Dissertation at University of Twente