Journal of Forests
2017 Vol. 4, No. 2, pp. 16-26
ISSN(e): 2409-3807
ISSN(p): 2413-8398
DOI: 10.18488/journal.101.2017.42.16.26

VARIATION OF WOOD DENSITY IN TROPICAL RAINFOREST TREES

Adrien N. Djomo[1+]
Guylene Ngoukwa[2]
Louis Zapfack[3]
Cédric D. Chimi[4]

[1]*Department of Geography and Planning, Queen's University, Kingston, ON, Canada*
[2,3,4]*Laboratory of Plant Systematic and Ecology, Department of Plant Biology, Faculty of Science, University of Yaoundé I, Yaoundé, Cameroon*
[1]*Email: djomoa@queensu.ca Tel: +1 613 533 6000 ext. 75287*
[2]*Email: guylnengoukwa@yahoo.fr Tel: (+237) 674 840 507 / 691900633*
[3]*Email: lzapfack@uy1.uninet.cm Tel: (+237) 99 92 33 96*
[4]*Email: chimicedric10@yahoo.fr Tel: (+237) 676 50 71 17 / 696 68 56 38*

(+ Corresponding author)

Article History
Received: 4 October 2017
Revised: 14 November 2017
Accepted: 21 November 2017
Published: 30 November 2017

Keywords
Drying temperature
Vertical variation
Wood density

ABSTRACT

Measurement of wood density in Congo Basin forests are needed to reduce uncertainties on estimations of carbon stocks. The purpose of this study was to test vertical variation and temperature variation (80 °C, 105 °C) effects on wood density of species in a semi-deciduous forest of eastern Cameroon. Wood samples were collected on felled trees, at the base, middle of the trunk and on the branches in plots of 10 m x 10 m for trees <5 cm diameter, of 20 m x 10 m for trees with diameter between 5 and 10 cm and, of 20 m x 250 m for trees with diameter ≥ 10 cm. 162 trees with diameter between 1 cm and 146 cm were used. The highest wood density (0.912) was found in Ficus sp. and lowest (0.295) in Enantia chlorantha. Using 80 °C as temperature to estimate wood density increased the value of about 10% when compare to the reference temperature of 105 °C. A significant difference was observed between wood density of the base and the top of trees studied. 10 species did not have wood density reported in the Global Wood Density database. This study recommends further research on wood density to cover as many tree species as possible in the Congo Basin.

1. INTRODUCTION

Tropical forests are particularly important because of the extent of anthropogenic transformations and the amount of carbon that they contain per unit area. Currently, almost all tropical regions are experiencing major changes that modify their structure either through shifting cultivation or through logging activities (Cuny, 2011). Uncertainties remain on the contribution of forests in the Congo Basin to the global carbon cycle due to its floristic diversity estimated at more than 500 species per hectare (dbh> 10 cm), its high variability in size and density of trees, the types of forests, the natural disturbances such as mortality, recruitment, etc. (Chave *et al.*, 2005; GIEC, 2007; Lewis *et al.*, 2009). Malhi *et al.* (1999) estimated that tropical forests contribute at about 32-36% of terrestrial net primary carbon production and for this purpose Picard *et al.* (2012) indicated that special emphasis should be placed on these forests. Therefore, Fearnside (1997) and Reyes *et al.* (1992) highlighted the need of developing wood density databases for the estimation of tropical biomass.

Dry wood density can be defined as the ratio of the anhydrous mass of a sample to the mass of a volume of water corresponding to the volume of the anhydrous sample (Fearnside, 1997). Different ways of calculating wood density include *apparent density* or *density at X%* (the ratio of weight to volume at a given moisture level), *green density* (green weight / green volume), *basic density* obtained by the ratio between the dry weight and the volume of green wood (Fearnside, 1997; De Souza *et al.*, 2002; ASTM, 2007). In addition of being an excellent indicator of the amount of wood present in a sample and its workability (Silva, 1984; Trugilho *et al.*, 1990; Chimelo, 1992; ASTM,

2007) wood density is linked to other wood properties such as strength, porosity, organization of anatomical elements, and also the number, size and chemical composition of cells (Kollmann and Cote, 1968; Trugilho *et al*., 1990; Simpson and Tenwolde, 1999; Ilic *et al*., 2000; Hacke *et al*., 2001; ASTM, 2007). Although wood density has recently emerged as a key variable in carbon cycle research (Ilic *et al*., 2000; Chave *et al*., 2006) wood density data published in the tropics are very often limited to commercial species that represent only a fraction of the forest biomass (Maniatis *et al*., 2011).

One of the difficulties in using wood density data when available is that they have frequently been collected using different sampling procedures in similar or different stands (Balodis, 1994; Downes *et al*., 1997; Ilic *et al*., 2000). Studies of Chave *et al*. (2006) and Maniatis *et al*. (2011) showed that tropical woods densities range from 0.08 for light wood to 1.39 g / cm^3 for heavy wood. However, the wood density of many tropical trees remains unknown (Slik, 2006). There is very little information on the relationship between crown width and wood density throughout ontogeny (Aiba and Nakashizuka, 2009). However, there could be a relationship between wood density and tree architecture that should be taken into account when estimating biomass. In general, studies including radial and longitudinal variations in species wood density in the Amazon showed either results for some species limited to certain functional groups, or only radial variation or only longitudinal variation (Amorim, 1991; De Macedo, 1991; Higuchi and Carvalho, 1994). The wood density measured at breast height decreases from the center to the bark (Nogueira *et al*., 2005; Henry *et al*., 2010). Moreover, the portions of the trunk which are the most recent have a lower wood density creating a decreasing longitudinal pattern on the tree. However, the study of Nogueira *et al*. (2005) and De Macedo (1991) have shown that in some cases the wood density of trees can increase longitudinally with the height of the tree. For these authors, these observations are a consequence of wood degradation that precedes the formation of a hollow nucleus which would be more advanced near the base of the tree, where hollow nuclei are the most common. In general, different biological and eco-physiological aspects such as structural requirements, climatic zone, light and rapid growth have been reported as responsible for variation in trunk density (De Zeeuw, 1965; Favrichon, 1994; Ter Steege and Hammond, 2001).

Henry *et al*. (2010) and Nogueira *et al*. (2005) showed that along the same tree, the wood density varies from the base to the top of the trunk and, also radially from the cambium to the heartwood. However, in global databases the wood density reported do not take into account these variations and are also often restricted to commercial species (Zanne *et al*., 2009). Although 105 °C is the recommended temperature in the Official Wood Density Protocol (ASTM, 2007) tests at 80 °C were carried out as part of the density estimation in the Amazon (Nogueira *et al*., 2005). Based on these differences, the objectives of this study were to test 1. the effect of vertical variation (base to the crown), 2. the differences in wood density between species, 3. the effect of temperature variation (80 °C, 105 °C) on the specific wood density of the species in a semi-deciduous forest of the Eastern Cameroon.

2. MATERIALS AND METHODS

2.1. Study Area

The study was carried out in a forest management unit located in the district of Belabo, Division of Lom and Djerem, in the Eastern Cameroon at about 80 km from Bertoua. It is located in a dense humid forest at Sterculiaceae and Ulmaceae (Letouzey, 1985). The relief of the area is fairly diverse and not very rugged and has been strongly influenced by the different tectonic activities. It is characterized by the presence of small hills of low altitude with an average between 500 and 800 meters (PCB, 2012). The hills are separated from valleys which serve as beds for most of the rivers that cross the study area and fall into the Sanaga river. The river system is very dense characterized by the presence of the Sanaga river and its tributaries. There are also numerous streams and backwaters that dry up during the great dry season. The soils of the zone are mainly ferralitic, sandy clay or silty clay, which are generally found in the plains with a laterite cuirass. They are characterized by the low nutrient retention and can be depleted rapidly. The lateritic texture characterizes the presence of rocky blocks covered with a laterite mantle of altered rocks. There is also the presence of hydromorphic soils encountered in the lowlands, very rich in organic matter. However, these soils are most often flooded with water during rainy seasons and poorly drained in dry seasons (PCB, 2012). The climate is equatorial, of Guinean type with temperatures varying from 20 °C between July-August and 30 °C between January-February. The average annual rainfall is 1500 mm, characterized by the presence of four seasons which are the great dry season (mid-October to March), the small dry season (June to mid-August), the great rainy season (mid-August to October) and the small rainy season (March to June) (CTFT, 2013).

3. DATA COLLECTION

3.1. Sampling Design

The data were collected in plots of 100 m^2 (10 m × 10 m) for trees with diameter below 5 cm and in plots of 200 m^2 (20 m × 10 m) for trees with diameter between 5 and 10 cm. Trees of diameter ≥ 10 cm were collected in plots of 5000 m^2 (20m × 250m). For each tree inventoried, vernacular or scientific names were recorded, specimens collected, pressed, impregnated with ethyl alcohol diluted at 95 °C and dried in the laboratory of ecology and systematics of the University of Yaounde 1. These specimens were then sent to the national herbarium of Yaoundé to confirm the identification of species. For each tree selected, total height was measured with the Suunto clinometer or Relascope of Bitterlich and diameter measured at 0.30 cm aboveground for trees of diameter <5 cm and at 1.30 for trees with dbh (diameter at breast height) ≥ 5 cm and at 0.30 cm above the buttresses for the trees having buttresses above 1.30 cm. Trees were felled using a machete or chainsaw depending on size to collect samples having average weight of 38 g at the levels of tree breast height (base), trunk and branches. The samples were then labeled (names, numbers, plots) and transported to the Laboratory of Ecology and Systematics at the University of Yaoundé 1. 356 samples were collected at the base, middle and branch levels from 162 trees with diameter between 1 cm and 146 cm.

3.2. Wood Density

The wet weight was directly measured in the field using a high-precision electronic balance and the volume calculated using Archimedes principle. According to this principle, a solid immersed in water experiences an upward force equal to the weight of the water it displaces because the wood density of water is 1 g/cm^3 (Djomo *et al*., 2010). For determination of volume, each green sample was fully immersed in water on a graduated cylinder and the weight of the displaced water read from the electronic balance calibrated at 0. The dry weight was obtained by drying the samples in an oven to a constant weight for 48 to 72 hours depending on the type of species. The constant weight was known after multiple weighing of the samples at regular intervals every six (6) hours until it repeats at least 3 consecutive times. The volume and the dry mass measurements were used to calculate wood density using the formula $WD_i = \frac{M_i}{V_i}$

where M_i is the dry mass (g), V_i is the green volume (cm3) and WD_i is the basic wood density (g/cm^{-3}) of the wood sample i. The wood density was calculated by dividing the dry weight over the wet volume. In order to test the effect of temperature on the wood density, the same samples were dried at 105 °C and then rehydrated for 7 days and dried again at 80 °C. The green volume and dry weight were recalculated for determination of the wood density at 80 °C. For the determination of average wood density of each species, the temperature of 105 °C was considered (ASTM, 2007).

3.3. Data Analysis

The mean wood density of each tree was obtained using the formula $WD = \frac{WD_b \times V_b + WD_m \times V_m + V_b + WD_{br} \times V_{br}}{V_b + V_m + V_{br}}$

where WD_b is the wood density at the base, WD_m the wood density at the middle of the trunk, WD_{br} the wood density at the level of the branches and V_b, V_m, V_{br} the volume at the base, middle and branches respectively (Nogueira *et al.*, 2007). The longitudinal variation of wood density in each tree species was analyzed by comparing the wood density obtained at the base, the middle and the level of the branches. To analyze intra-specific variation, the species that repeated at least five times in the dataset were used and their average densities compared. Interspecific variation was analyzed by comparing the average wood density of different species. ANOVA was used to test these variations with R software. The densities obtained from this study were compared with the Global Wood Density database.

4. RESULTS

4.1. Effect of Vertical Variation on Wood Density

ANOVA test ($p > 0.05$) showed that there was a variation in wood density at different levels of the tree. The wood density decreased considerably from the base to the branches. There was no significant difference between the base and middle of the trees as well as between the middle of the trees and the branches; however, there was a significant difference between the wood density of the base and the branches (Fig. 1). Table 1 shows the vertical variation in wood density of 30 species estimated at 105 ° C. There was a general pattern of decreasing wood density except few cases such as *Petersianthus macrocarpus* where the wood density at the base 0.567 g/cm^3 increased to 0.594 g/cm^3 and then decreased to 0.450 g/cm^3 at the level of branches. There was a different pattern for *Celtis adolfi-friderici* where the wood density at the base 0.566 g/cm^3 decreased to 0.496 g/cm^3 and then increased to 0.508 g/cm^3 at the branches level. The average difference between the densities considered at breast height and those at the branches level was 15%. This difference was 8% (min 1.5% and max 22.3%) between the average wood density of trees and the wood density only taken at breast height.

4.2. Variation of Wood Density within and Among Species

There was no significant variation between individuals of the same species. The following variations were observed *Mallotus opposifolium* (0.597 ± 0.029), *Microdesmis puberula* (0.633 ± 0.072), *Piptostigma sp.* (0.549 ± 0.034), *Erythropheum ivorensis* (0.708 ± 0.129), *Scyphocyse manniana* (0.576 ± 0.032), *Trichilia rubescens* (0.501 ± 0.113), *Triplochiton scleroxylon* (0.443 ± 0.062). At 5% level, there was a significant difference between the wood density of *Triplochiton scleroxylon*, *Erythropheum ivorensis* and *Scyphocyse manniana*. There was also a significant difference between the wood density of *Trichilia rubescens* and *Piptostigma sp.* However, there was no significant difference between the densities of *Mallotus opposifolium* and *Microdesmis puberula* (Fig. 2).

4.3. Effect of Drying Temperature (80°C and 105°C)

As can be seen in Table 2, wood density decreased from 0.639 (80 °C) to 0.579 (105 °C) at the base level, from 0.609 (80 °C) to 0.553 (105 °C) at the middle of the trunk, and from 0.572 (80 °C) to 0.525 (105 °C) at the branches level. Overall wood density at 80 °C was 9 to 10% greater than at 105 °C showing that there could be an overestimate of the wood density measured if the drying temperature of 80 °C instead of 105 °C. Therefore, for the estimate of average density of tree species of the study area, the temperature of 105°C was used.

4.4. Average Density of Tree Species (105°C)

Wood densities varied from 0.159 to 0.986 g/cm^3 with an average of 0.561 g/cm^3. 184 samples were analyzed at the base with the densities varying from 0.227 to 0.986 g/cm^3 and an average of 0.584 g/cm^3. 83 samples were analyzed at the middle of the trunks with densities ranging from 0.273 to 0.912 g/cm^3 and an average of 0.561 g/cm^3. 89 samples were analyzed at branches level with densities ranging from 0.159 to 0.909 g/cm^3 and an average of 0.514 g/cm^3. The average wood density of tree species ranged from 0.295 g/cm^3 for *Enantia chlorantha*

(Annonaceae) to 0.912 g/cm³ for *Ficus* sp. (Moraceae) (Table 1). The mean wood density of the study area was 0.561 g/cm³.

4.5. Species Not Listed in the Global Wood Density Database

10 species from the study area were not included in the Global Wood Density database. These species were *Trichilia rubescens*, *Greenwayodebdron suavealens*, *Piptostigma sp*, *Enantia chlorantha*, *Ghyphae brevis*, *Mallotus oppositufolium*, *Microdesmis puberula*, *Lasiodiscus mannii*, *Scyphocyse manniana*, *Rhabdophyllum arnoldianium* (Table 3).

5. DISCUSSION

5.1. Average Wood Density

The wood density of this study varied from 0.295 to 0.912 g/cm³ with an average of 0.561 g/cm³. This result was in accordance with other studies in tropical forests. The wood density in the dense wet-evergreen forest of Ghana (Henry *et al.*, 2010) at 105 °C varied from 0.110 to 1.010 g/cm³ with an average of 0.590 g/cm³; wood density variation ranged from 0.284 to 1.152 g/cm³ with an average of 0.630 g/cm³ in a dense rainforest of Cameroon (Fayolle *et al.*, 2013). However, this mean value was lower than the average wood density of 0.700 g/cm³ found by Fearnside (1997) in Amazonian forests. Henry *et al.* (2010) mentioned that wood densities in moist tropical forests of Africa are lower than those of tropical Amazon rainforests.

Guarea sp. was found in the 186 species listed by Nogueira *et al.* (2005) measured at 103°C. The wood density of this species was 0.691 (0.619) g/cm³ at the base, 0.605 (0.466) g/cm³ at the top and 0.648 (0.533) g/cm³ on average; the values in bracket are the results of this study showing lower wood density in the Cameroon forest site. The top level in this study (branches) differed from Nogueira *et al.* (2005) which was the top of the trunk and justified the significant difference at that level. *Piptadeniastrum africanum* was in common between this study and the 16 species sampled by Henry *et al.* (2010). The average wood density of this species 0.580 g/cm³ found by these authors was close to 0.570 g/cm³ of this study and was smaller compare to 0.632 g/cm³ found by Fayolle *et al.* (2013). The temperature used by Fayolle *et al.* (2013) was not reported and may explain the difference.

5.2. Species Variation in Wood Density

The wood density of the species analyzed showed decreasing trend within an individual from the base to the top of the tree, and a variation between different species. There was no significant variation in the mean of individuals of the same species. Major variations in the environment (abiotic and biotic factors) such as physiological, mechanical, anatomical, genetic and morphological constraints observed in a forest stand would explain the causes of variation in species wood density (Fearnside, 1997). However, this variation in wood density between individuals of different species is more important than variations within individuals of the same species (Zanne *et al.*, 2009; Henry *et al.*, 2010; Quentin *et al.*, 2013) in accordance with this study expressed that intra-species variation though small should not be neglected.

The results obtained from this study showed that non-consideration of longitudinal variation in the wood density would result to an overestimation of the biomass. This variation was not taken into account in most studies (Chave *et al.*, 2005; Djomo *et al.*, 2010; Fayolle *et al.*, 2013; Chave *et al.*, 2014; Djomo *et al.*, 2016) developing allometric equations for the estimation of biomass. This study resulted in an average overestimation of 8% when wood density was only estimated at the breast height and was 15% greater than the wood density estimated at the level of the branches with extreme value reaching a difference of 37%. Our results were greater than those of Nogueira *et al.* (2005) which showed that considering the wood density only at breast height resulted to values 4.3% on average higher than the ones taking into account the longitudinal variation. Nogueira *et al.* (2005) indicated that the wood density of 87% of the trees studied decreased from the bottom to the top with extreme difference reaching 57%. 13% of the trees studied by these authors increased with height. This pattern was different from this study where 100% decrease from base to the branches. However, the wood density of two species *Petersianthus macrocarpus* and *Piptadeniastrum africanum* increased from the base to the middle before decreasing at the branches. This could not be considered as general trend for these species because in each case only an individual was analyzed and it was far insufficient to make a conclusion.

There may be a relationship between wood density and tree architecture that should be taken into account in estimating biomass. Variations in wood density and characteristics of heartwood are related to several factors: tree age, altitude, compartment on which the sample was measured within the tree (Williamson, 1984). However, there is a difference between fast-growing and slow-growing species with higher densities. Fast growing species are characterized by low density conducting tissues (Wright *et al.*, 2003; Muller-Landau, 2004) which allows rapid growth in size (Favrichon, 1994; Santiago *et al.*, 2004). On the other hand, high-density wood tissue leads to slow growth, which results in a stronger defense against physical damage, predators and pathogens (Rowe and Speck, 2005). In this study, it was not possible to test the variation of wood density in diameter class within individuals of the same species.

10 species did not have wood density appearing in the Global Wood Density database (Zanne *et al.*, 2009). This may indicate an under-representation of Congo Basin wood density data in this database. Reyes *et al.* (1992) and Fearnside (1997) emphasized the need for an elaborate wood density database for the estimation of tropical biomass.

One of the factors in the variation of wood density is the drying temperature which affects the dry weight of the samples. The results obtained in this study showed that at drying temperature of 80 °C the wood density was on average 9 to 10% higher than at 105 °C drying temperature. This result was higher than the study of Nogueira *et al.* (2005) which found a mean density difference at 80 °C higher by 1.1% than at 103 °C in the Amazonian forests.

6. CONCLUSION AND PERSPECTIVES

This study showed that accurate estimation of biomass and carbon stocks is based on reliable estimates of wood density. The vertical variation within individuals of the same species showed the importance of integrating this factor in the estimation of the wood density. This study resulted to an overestimation of the wood density of 8% in average that can reach 20% in extreme case. The variation is much greater between the base (breast height) of the tree and the top that can be 15% on average and 30% in extreme case. Drying temperature is another varying factor in wood density. This can result to an overestimate of up to 9 to 10% if 80 °C is used instead of 105 °C for wood density. 10 species did not have wood density data in the Global Wood Density database. This highlights the need for further wood density studies in the Congo Basin to have a more elaborated database of wood density for biomass studies. This study recommends that future studies of wood density should include the analysis of the effect of radial variation, the effect of diameter class in the same species and to use a large sampling size including individuals of same and different species to facilitate the analysis of the horizontal structure.

Funding: This study received no specific financial support.
Competing Interests: The authors declare that they have no competing interests.
Contributors/Acknowledgement: This work was completed under the partnership between the University of Yaoundé 1 (Cameroon), Queen's University (Canada), Association of Universities and Colleges of Canada (AUCC) and the International Development Research Centre (IDRC). Our heartfelt gratitude and appreciation are addressed to the Canada-Africa Research Exchange Grants (CAREG) which provided the financial assistance for the realization of this work. Our thanks are extended to Prof. Neal Scott who helped designing this project. We are indebted to La Cotiere Forestiere that accepted this study and provided in-kind and logistic support for the data collection. This study would not have been possible without the support of the local technicians who helped for data collection. Please, receive our heartfelt thanks for your contribution and support. The authors address their thanks to Toyin Bamidele Olukayode who has proofread this study.

REFERENCES

Aiba, M. and T. Nakashizuka, 2009. Architectural differences associated with adult stature and wood density in 30 temperate tree species. Functional Ecology, 23(2): 286-279. *View at Google Scholar* | *View at Publisher*

Amorim, L., 1991. Variation de la densité dans la direction radiale dans les bois tropic de l'Amazonie. Rapport Final, Perıodoabril-90/marco-91 (Initiation Scientifique/Conseil National Scientifique et Technologique), Institution National de Recherche de l'Amazonie (INPA), Manaus, Amazonas, Brazil.

ASTM, 2007. Standard test methods for specific gravity of wood and wood-based materials. West Conshohocken, PA. USA: ASTM International, Designation: D 2395-07a.

Balodis, V., 1994. Quality assurance in pulpwood testing: the sample. In Australian Tree Species Research in China Brown, A.G. (ed.). Proceedings of an International Workshop held from 2–5 November 1992, Zhangzhou, Fujian Province, PR China. Australian Centre for International Agricultural Research, Proceedings No. 48. pp: 191–195

Chave, J., S. Andalo, M.A. Brown, J.Q. Cairns, D. Chambers, F. Folster, N. Fromard, T. Higuchi, J.P. Kira, B.W. Lescure, H. Nelson, H. Ogawa, B. Riera and T. Yamakura, 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145(1): 87–99. *View at Google Scholar* | *View at Publisher*

Chave, J., H.C. Muller-Landau, T.R. Baker, T.A. Easedale, H. Ter Steege and C.O. Webb, 2006. Regional and phylogenetic variation of wood density across 2,456 neotropical tree species. Ecological Applications, 16(6): 2356–2367. *View at Google Scholar* | *View at Publisher*

Chave, J., M. Rejou-Mechain, A. Burquez, E. Chidumayo, S.M. Colgan, B. Delitti, A. Duque, T. Eid, M.P. Fearnside, C.R. Goodman, H. Matieu, A. Martinez-Yrizar, A. Mugasha, C.H. Muller-landau, M. M., W.B. Nelson, A. Ngomanda, M.E. Nogueira, E. Ortiz-malavassi, R. Pelissier, P. Ploton, M.C. Ryan, G. Juan, G.J. Saldarriaga and G. Vieilledent, 2014. Improved allometric models to estimate the aboveground biomass of tropical. Global Change Biology, 20(10): 3177-3190. *View at Google Scholar*

Chimelo, J.P., 1992. Anatomie du bois de la relation avec leurs propriétés physiques et mécaniques "Luis de Queiroz", Ecole supérieure agricole "Luis de Queirroz. Piracicaba, Sao Paulo, Brazil: Université de Sao Paulo (ESALQ/USP). pp: 25.

CTFT, 2013. Etude socio-économique dans le cadre de l'aménagement de la réserve forestière Belabo-Diang. Centre technique de la forêt communale cameroun (CTFC). Belabo-Cameroun.

Cuny, P., 2011. Etat des lieux de la foresterie communautaire et communale au Cameroun. Tropenbos International Programme du Bassin du Congo, Wageningen, Pays- Bas.

De Macedo, C.S.M., 1991. Variation longitudinale de la densité de base et de la composition chimique du bois et de son bilan énergétique. Rapport Final, avril/1990-Mars/1991 (Initiation Scientifique/Conseil National Scientifique et Technologique), Institution National de Recherche de l'Amazonie, Manaus, Amazonas, Brazil.

De Souza, M.H., M.M. Magliano, J.A.A. Camargos and M.R. De Souza, 2002. Madeiras tropicais brasileiras (Brazilian Tropical Woods), 2nd Edn., Instituto Brasileiro do Meio Ambiente dos Recursos Naturais Renovaveis. Brasılia, DF, Brazil: Edicoes IBAMA.

De Zeeuw, C., 1965. Variability in wood. In cellular ultrastructure of woody plants Cote´ W.A. (Ed.), NY, USA: Syracuse University Press, Syracuse. pp: 457–471

Djomo, N.A., I. Adamou, J. Saborowski and G. Gravenhorst, 2010. Allometric equations for biomass estimations in Cameroon and pan moist tropical equations including biomass data from Africa. Forest Ecology and Management, 260(10): 1873-1885. *View at Google Scholar* | *View at Publisher*

Djomo, N.A., N. Picard, A. Fayolle, M. Henry, A. Ngomanda, P. Ploton, J. Mclellan, J. Saborowski, I. Adamou and P. Lejeune, 2016. Tree allometry for estimation of carbon stocks in African tropical forests. Forestry, 89(4): 446-455. *View at Google Scholar* | *View at Publisher*

Downes, G.M., I.L. Hudson, C.A. Raymond, G.H. Dean, A.J. Michell, L.S. Schimleck, R. Evans and A. Muneri, 1997. Sampling plantation eucalypts for wood and fibre properties. Melbourne, Australia: CSIRO Publishing.

Favrichon, V., 1994. Classification des espèces à grave arborées en groupes fonctionnels en vue de la réalisation d'un modèle de dynamique de peuplement en forêt Guyanaise. Revue d'Ecologie Terre et Vie, 49: 379–402. *View at Google Scholar*

Fayolle, A., J.L. Doucet, J.F. Gillet, N. Bourland and P. Lejeune, 2013. Tree allome-try in Central Africa: Testing the validity of pantropical multi-species allometric equa-tions for estimating biomass and carbon stocks. Forest Ecology and Management, 305: 29–37. *View at Google Scholar* | *View at Publisher*

Fearnside, P.M., 1997. Wood density for estimating forest biomass in Brazilian Amazonia. Forest Ecology and Management, 90(1): 59–87. *View at Google Scholar* | *View at Publisher*

GIEC, 2007. Bilan 2007 des changements climatiques. Contribution des groupes de travail i, ii et iii au quatrième rapport d'évaluation du groupe d'experts intergouvernemental sur l'évolution du climat. Groupe d'experts intergouvernemental sur l'évolution du climat. Cambridge, Royaume-Uni: GIEC. Cambridge University Press.

Hacke, U.G., W.T. Sperry, S.D. Pockman and K.A. Mcculloh, 2001. Trends in wood density and structure are linked to prevention of xylem implosion by negative pressure. Oecologia, 126(4): 457–461. *View at Google Scholar* | *View at Publisher*

Henry, M., A. Besnard, W.A. Asante, J. Eshun, S. Adu-Bredu, R. Valentini, M. Bernoux and L. Saint-André, 2010. Wood density, phytomass variations within and among trees, and allometric equations in a tropical rainforest of Africa. Forest Ecology and Management, 260(8): 1375-1388. *View at Google Scholar* | *View at Publisher*

Higuchi, N. and J. Carvalho, 1994. Biomasse et teneur en carbone des espèces d'arbres de l'Amazonie. In Actes du séminaire « amission et la séquestration du CO2 une nouvelle opportunité pour le Brasil (Ed.). Rio de Janeiro, Brazil: Société Vale do Rio Doce (CVRD). pp: 127–153

Ilic, J., D. Boland, M. Mcdonald, G. Downes and P. Blakemore, 2000. Wood density phase 1: State of knowledge, national carbon accounting system. Australian Greenhouse Office, Commonwealth of Australia. Technical Report No. 18.

Kollmann, F.F.P. and W.A.J. Cote, 1968. Principles of wood science and technology solid wood. New York, USA: Springer-Verlag, 1.

Letouzey, R., 1985. Notice de la carte topographique du Cameroun au 1/50000. Domaine de la Forêt dense humide toujours verte. Toulouse, France: IRA-Yaoundé, Institut International de la Végétation. pp: 95-142.

Lewis, S.L., G. Lopez-Gonzalez, B. Sonke, K. Affun-Baffoe, T.R. Baker, L.O. Ojo and O.L. Phillips, 2009. Increasing carbon storage in intact African tropical forests. Nature, 457(7232): 1003-1006. *View at Google Scholar*

Malhi, Y., D.D. Baldocchi and P.G. Jarvis, 1999. The carbon balance of tropical, temperate and boreal forests. Plant, Cell Environment, 22(6): 715-740. *View at Google Scholar* | *View at Publisher*

Maniatis, D., A.L. Saint, M. Temmerman, Y. Malhi and H. Beeckman, 2011. The potential of using xylarium wood samples for wood density calculations: A comparison of approaches for volume measurement. Forests, 4(4): 150-159. *View at Google Scholar* | *View at Publisher*

Muller-Landau, H.C., 2004. Interspecific and inter-site variation in wood specific gravity of tropical trees. Biotropica, 36(1): 20–32. *View at Google Scholar* | *View at Publisher*

Nogueira, E.M., P.M. Fearnside, B.W. Nelson and M.B. Franca, 2007. Wood density in forests of Brazil's 'arc of deforestation: Implications for biomass and flux of carbon from land-use change in Amazonia. Forest Ecology and Management, 248(3): 119–135. *View at Google Scholar* | *View at Publisher*

Nogueira, E.M., B.W. Nelson and P.M. Fearnside, 2005. Wood density in dense forest in central Amazonia, Brazil. Forest Ecology and Management, 208(1): 261–286. *View at Google Scholar* | *View at Publisher*

PCB, 2012. Plan communal de développement de Belabo. Belabo-Cameroun: PCD.

Picard, N., L. Saint-Andre and M. Henry, 2012. Manuel de construction d'équations allometriques pour l'estimation du volume et la biomasse des arbres: De la mesure de terrain à la prédiction. Organisation des Nations Unies Pour l'Alimentation et l'Agriculture, et Centre de Coopération Internationale en Recherche Agronomique pour le Développement, Rome, Montpellier.

Quentin, M., R. Vivien and B. Lilian, 2013. Error propagation in biomass estimation in tropical forests. Methods in Ecology and Evolution, 4(2): 175–183. *View at Google Scholar* | *View at Publisher*

Reyes, G., S. Brown, J. Chapman and A.E. Lugo, 1992. Wood densities of tropical tree species. United States Department of Agriculture, Forest Service Southern Forest Experimental Station, New Orleans, Louisiana. General Technical Report SO-88. Southern Forest Experiment Station, New Orleans, LA, U.S.A.

Rowe, N. and T. Speck, 2005. Plant growth forms: An ecological and evolutionary perspective. New Phytologist, 166(1): 61–72. *View at Google Scholar* | *View at Publisher*

Santiago, L.S., K. Kitajima, S.J. Wright and S.S. Mulkey, 2004. Coordinated changes in photosynthesis, water relations and leaf nutritional traits of canopy trees along a precipitation gradient in lowland tropical forest. Oecologia, 139(4): 495–502. *View at Google Scholar* | *View at Publisher*

Silva, J.C., 1984. Parametros da densidade na qualidade da Madeira. Piracicaba, Sao Paulo, Brazil: Escola Superior de Agricul tura Luis de Queirroz, Universidade de Sao Paulo (ESALQ/USP).

Simpson, W. and A. Tenwolde, 1999. Physical properties and moisture relations of wood. Chapter. 3. in Forest Products Laboratory. Wood Handbook-wood as an engineering material. Gen. Tech. Re FPL-GTR-113. U.S. Madison, WI, USA: Department of Agriculture, Forest Service. Forest Products Laboratory.

Slik, J.W.F., 2006. Estimating species specific wood density from the genus average in Indonesian trees. Journal of Tropical Ecology, 22(4): 481–482. *View at Google Scholar* | *View at Publisher*

Ter Steege, H. and D.S. Hammond, 2001. Character convergence, diversity, and disturbance in tropical rain forest in Guyana. Ecology, 82(11): 3197–3212. *View at Google Scholar* | *View at Publisher*

Trugilho, P.F., D.A. Silva, F.J.L. Frazão and J.L.M. Matos, 1990. Comparacão de metodos de determinacão de densidade basica em Madeira. Acta Amazonica, 20: 307-319. *View at Google Scholar* | *View at Publisher*

Williamson, G.B., 1984. Gradients in wood specific gravity of trees. Bulletin of the Torrey Botanical Club, 111: 51–55. *View at Google Scholar* | *View at Publisher*

Wright, S.J., H.C. Muller-Landau, R. Condit and S.P. Hubbell, 2003. Shade tolerance, realized vital rates, and size distributions of tropical trees. Ecology, 84(12): 3174–3185. *View at Google Scholar* | *View at Publisher*

Zanne, A.E., G. López-González, D.A. Coomes, J. Ilic, S. Jansen, S.L. Lewis, R.B. Miller, N.G. Swenson, M.C. Wiemann and J. Chave, 2009. Data from: Towards a world¬wide wood economics spectrum. South Africa: Dryad Digital Repository.

LIST OF TABLES

Table-1. Wood density vertical variation of 30 species (105 °C)

Family	Scientific Names	N	Base	Middle	Crown	Average	Global
Lecythidaceae	*Petersianthus macrocarpus*	1	0.567	0.594	0.450	0.537	0.677
Fabaceae	*Piptadeniastrum africanum*	1	0.561	0.608	0.540	0.570	0.605
	Entandophragma cylindricum	1	0.704	0.674	0.605	0.661	0.572
	Erytropheum ivorensis	7	0.750	0.736	0.590	0.692	0.872
Sterculiaceae	*Triplochiton scleroxylon*	11	0.412	0.409	0.385	0.402	0.335
	Mansonia altissima	1	0.596	0.506	0.496	0.533	0.564
	Eribroma oblonga	1	0.598	0.428	0.474	0.500	0.638
	Carappa sp.	1	0.624	0.613	0.602	0.613	-
	Sterculia rhinopetala	2	0.672	0.599	0.459	0.577	0.673
Meliaceae	*Guarea thompsonii*	1	0.560	0.529	0.490	0.526	0.552
	Lovoa trichiliodes	2	0.534	0.498	0.469	0.500	
	Trichilia cf. monodelpha	2	0.579	0.523	0.439	0.514	0.481
	Guarea sp.	1	0.619	0.513	0.466	0.533	-
	Trichilia rubescens	19	0.517	0.476	0.468	0.487	-
Annonaceae	*Greenwayodebdron suavealens*	3	0.670	0.601	0.547	0.606	-
	Piptostigma sp.	20	0.551	0.536	0.534	0.540	-
	Enantia chlorantha	5	0.303	0.294	0.289	0.295	-
Ulmaceae	*Celtis adolfi-friderici*	2	0.566	0.496	0.508	0.523	0.684
Combretaceae	*Terminalia superba*	1	0.442	0.349	0.300	0.364	0.459
Tiliceae	*Ghyphae brevis*	1	0.620	0.476	0.394	0.497	-

Euphorbiaceae	*Trilepisium madagascariensis*	3	0.519	0.413	0.451	0.461	0.499
	Mallotus oppositufolium	9	0.608	0.570	0.558	0.579	-
	Microdesmis puberula	24	0.613	0.578	0.523	0.571	-
Rhamnaceae	*Lasiodiscus mannii*	1	0.573	0.435	0.359	0.456	-
Violaceae	*Rinorea sp.*	3	0.521	0.511	0.471	0.501	-
Moraceae	*Scyphocyse manniana*	23	0.579	0.568	0.559	0.569	-
	Ficus sp.	1	0.917	0.912	0.908	0.912	-
Apocynaceae	*Tarbernaemontanna crassa*	1	0.704	0.621	0.555	0.627	0.550
Clusiaceae	*Garcinia punctata*	3	0.676	0.605	0.578	0.620	0.824
Ochnaceae	*Rhabdophyllum arnoldianum*	1	0.710	0.636	0.625	0.657	-

Source : Result of this research

Table-2. Wood density at drying temperature of 80 °C and 105 °C

Level on the tree	Number of samples	Drying temperature	
		80°C	105°C
Base	189	0.639	0.579
Middle	81	0.609	0.553
Crown (branches)	90	0.572	0.525

Source: : Result of this research

Table-3. Average wood density at 105 °C of species not included in the Global Wood Density database

Scientific Names	Family	Number of samples	Average Density
Trichilia rubescens	Meliaceae	19	0.519
Greenwayodebdron suavealens	Annonaceae	3	0.606
Piptostigma sp	Annonaceae	20	0.559
Enantia chlorantha	Annonaceae	4	0.294
Ghyphae brevis	Tiliceae	1	0.497
Mallotus oppositufolium	Euphorbiaceae	7	0.597
Microdesmis puberula	Euphorbiaceae	22	0.633
Lasiodiscus mannii	Rhamnaceae	1	0.389
Scyphocyse manniana	Moraceae	23	0.582
Rhabdophyllum arnoldianium	Ochnaceae	1	0.595

Source: Result of this research

LIST OF FIGURES

Captions

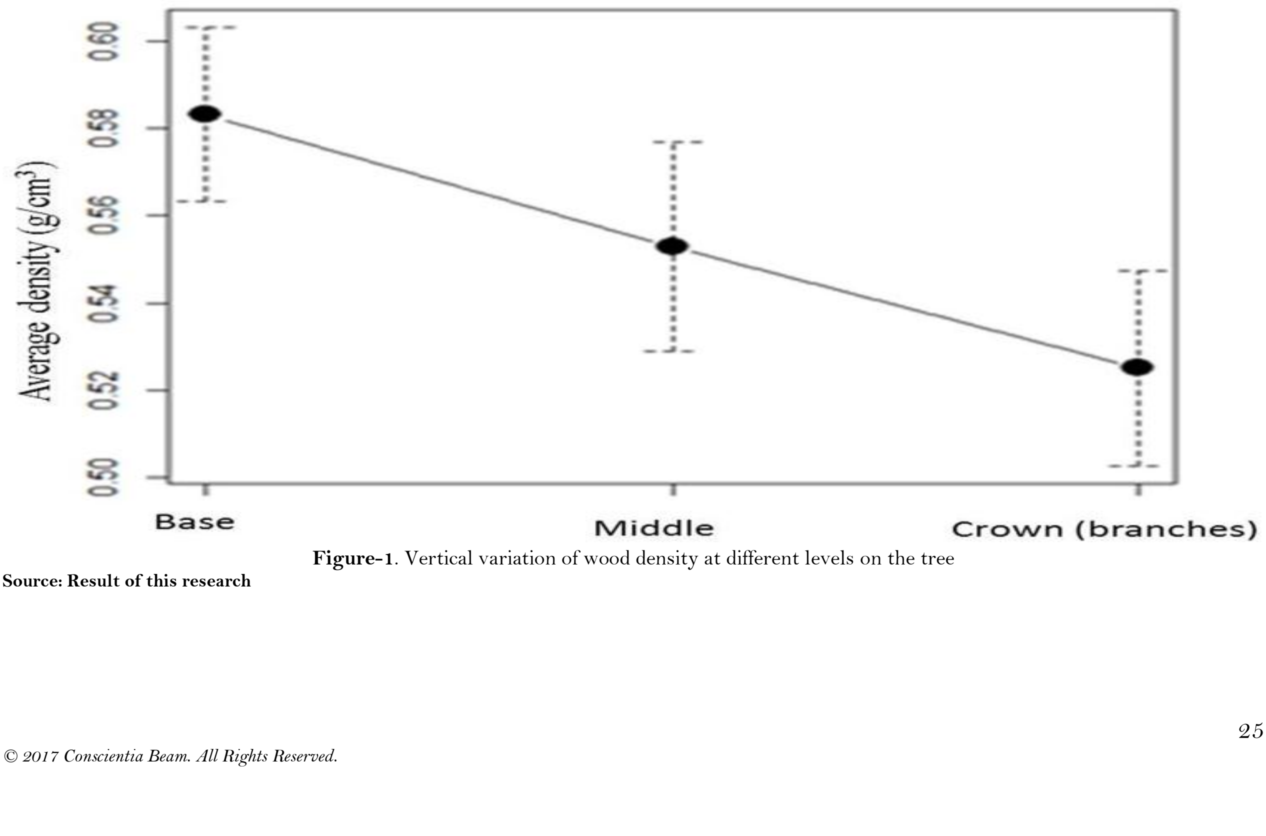

Figure-1. Vertical variation of wood density at different levels on the tree

Source: Result of this research

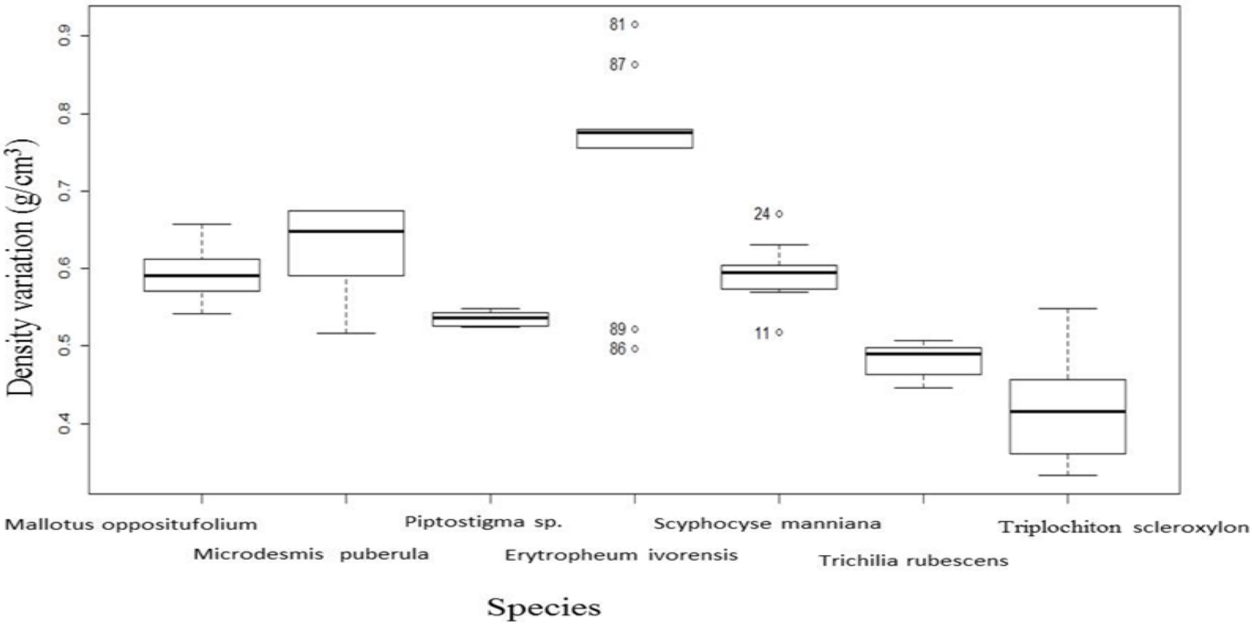

Figure-2. Interspecific variation of wood density of 7 tree species most represented in the study sample with a minimum of 7 individuals for *Erythropheum ivorensis* and a maximum of 24 for *Microdesmis puberula.*
Source: Result of this research