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A simple field based method for rapid wood density estimation for selected tree species in Western Kenya

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A B S T R A C T

Wood density is an important variable for accurate quantification of woody biomass and carbon stocks. Conventional destructive methods for wood density estimation are resource intensive, prohibiting their use, limiting the application of approaches that would minimize uncertainties in tree biomass estimates. We tested an alternative method involving tree coring with a carpenter's auger to estimate wood density of seven tropical tree species in Western Kenya. We used conventional water immersion method to validate results from the auger core method. The mean densities (and 95% confidence intervals) ranged from 0.36 g cm^{-3} (0.25–0.47) to 0.67 g cm^{-3} (0.61–0.73) for the auger core method, and 0.46 g cm^{-3} (0.42–0.50) to 0.67 g cm^{-3} (0.61–0.73) for the water immersion method. The auger core and water immersion methods were not significantly different for four out of seven tree species namely; *Acacia mearnsii, Mangifera indica, Eucalyptus grandis* and *Grevillea robusta*. However, wood densities estimated from the auger core method were lower ($t\,(61) = 7.992$, $P = <0.001$). The ease of the auger core method application, as a non-destructive method in acquiring wood density data, is a worthy alternative in biomass and carbon stocks quantification. This method could protect trees outside forests found in most parts of Africa.

Introduction

Wood density is a functional parameter for forest inventories, reporting carbon stocks for United Nations Framework Convention on Climate Change (UNFCCC), and climate financing [1]. Under the UNFCCC, countries are required to report on regular basis the state of their forest resources and emerging mechanisms. These reports require information on wood density [2]. Additionally, reliable models for assessing biomass, carbon stocks and conversion of tree bio-volume to mass require wood density measurements [3]. Previous study by Chave et al. [4] using destructively sampled trees have shown

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that, in predicting the biomass of a tree, wood density is the second most important parameter after tree diameter and has an appreciable influence on many solid wood properties including cutting, gluing, finishing, rate of drying and paper making [5]. Additionally, important variables in carbon inventories are the mass and amount carbon, which are depended on wood density [2]. However, rapid wood density measurement methods are limited in use due to costs involved, techniques and instruments in use.

Conventional technique of sampling for wood density estimation requires felling down trees and cutting discs from tree sections at breast-height (i.e. 1.3 m above the base of the tree) [6]. This method is accurate, but destructive, laborious, time consuming, expensive, tedious and may not be applicable where cutting of trees is restricted. In addition, the method may not be applicable for wood quality surveys or genetic improvement programs as that require extensive density analyses [7]. Consequently, the discs cutting method is impractical for country-level analysis. Besides, the method is influenced by the number of discs used and the height along the stem from where the discs were taken [8]. Repola [8] found that wood density at breast height was higher than the average stem density of pine, spruce and birch species. Furthermore, wood density is correlated to a number of plant functional traits [9] and varies during plant life, between and within individuals of the same species as well as amongst and within given provenances [10]. Branches and the outer part of the trunk tend to have a lighter wood than the pith [4] with each species having its own characteristic wood density [11].

Other methods commonly referred to as non-destructive techniques have been proposed as alternative to the destructive disc cutting methods of wood density estimation. However, the term “non-destructive” is a relative term, since damage occurs whenever the protective covering of bark is removed, therefore the term is used in comparison with sampling methods that require the felling of trees [7]. These proposed non-destructive techniques include penetrometer and SilviScan which uses combination of X-ray densitometry, X-ray diffractometry and image analysis [12]. Another non-destructive technique widely in application involves the use of increment borers to extract samples from the trunk. An increment borer device was originally developed in Germany by Max Pressler (1815–1886) in the mid- nineteenth century [13]. The sample extraction procedures using increment borers comes with challenges; the increment borer is expensive and borers with smaller diameters compress the wood samples, moreover, after coring, the cores need to be put into suitable containers and transported to a laboratory [7].

In this study, we aimed at comparing a non-destructive carpenters auger method previously reported by Francis [14] with the destructive discs cutting method. A carpenter’s auger consists of a handle and a borer bit, which comes in various diameters depending on the users need. . The auger is drilled by hand from the bark to the centre (pith) of the tree, and then cores are collected into suitable containers and transported to a laboratory. While measurements of tree biovolume and wood density are possible from field surveys destructively or non-destructively, quite a number of measurement methods are influenced by how the volume of the sample is determined [14]. We slightly modified carpenters auger method by having a fixed auger borer bit diameter for coring.

Materials and methods

Study site

The study was conducted at three sites of Yala area in western Kenya, hereafter referred to as Lower Yala, Middle Yala, and Upper Yala (Fig. 1). The three sites were each 100 km^2 in size and all the sites differ in their land use and altitude. The altitude ranges from1200 m in Lower Yala to 2400 m in Upper Yala [15]. The area of Lower Yala, Middle Yala, and Upper Yala regions receive total annual rainfall of 1874 mm, 1977 mm, and 1043 mm, respectively [16]. There is a general decrease in mean annual temperature with increasing elevation across the Yala regions; Lower Yala (23.4 °C), Middle Yala (20.8 °C) and Upper Yala (23.4 °C), the mean temperatures vary during the year by 1.9 °C [16]. Lower Yala area is dissected by a number of important tributaries of the River Yala; the soil texture in this area is mainly clay loam and farming is the major land-use and drives land cover in the area [15]. Middle Yala is made up of mountainous highlands with numerous small streams and clusters of wetlands, Soils are predominantly loamy to clayey in texture [15]. The Upper Yala is characterized by medium gradient hills, wetlands and flood plains. Soil texture in this area is mainly silty clay to clay [15].

Wood cores sampling for non-destructive wood density calculation

Seven different tree species (*Mangifera indica, Grevillea robusta, Markhamia lutea, Eucalyptus camaldulensis, Eucalyptus grandis, Eucalyptus saligna, and Acacia mearnsii)* were used for this study. These species were sampled in 2012 by randomly selecting individual tree species with different diameters at breast height (DBH) i.e. above 10, 15, 20, 25, 30, 35 cm and above 40 cm at the selected sites. Large trees (DBH > 40 cm) were scarce across the Yala basin landscape. Auger cores were collected using a carpenter’s auger by coring at DBH (1.3 m above the ground) through the bark to the heartwood (as noted by a colour change) (Fig. 2). The first chips produced in coring the preparatory hole were discarded to remove the tree bark and inner bark parts. The cored hole was then brushed out and its depth measured with a stick, then the stick length measured with a ruler to determine the starting depth of the sample. Short cylindrical cores of 30–100 mm length (depending on tree diameter) from the periphery into the inner portion of the trunk were obtained using a 25-mm diameter auger bit. Upon withdrawal of the auger bit, chips remaining in the hole were collected using a thin spatula and added to the sample. The fresh samples were weighed to the nearest 0.01 g then oven dried at 105 °C [17] and reweighed.

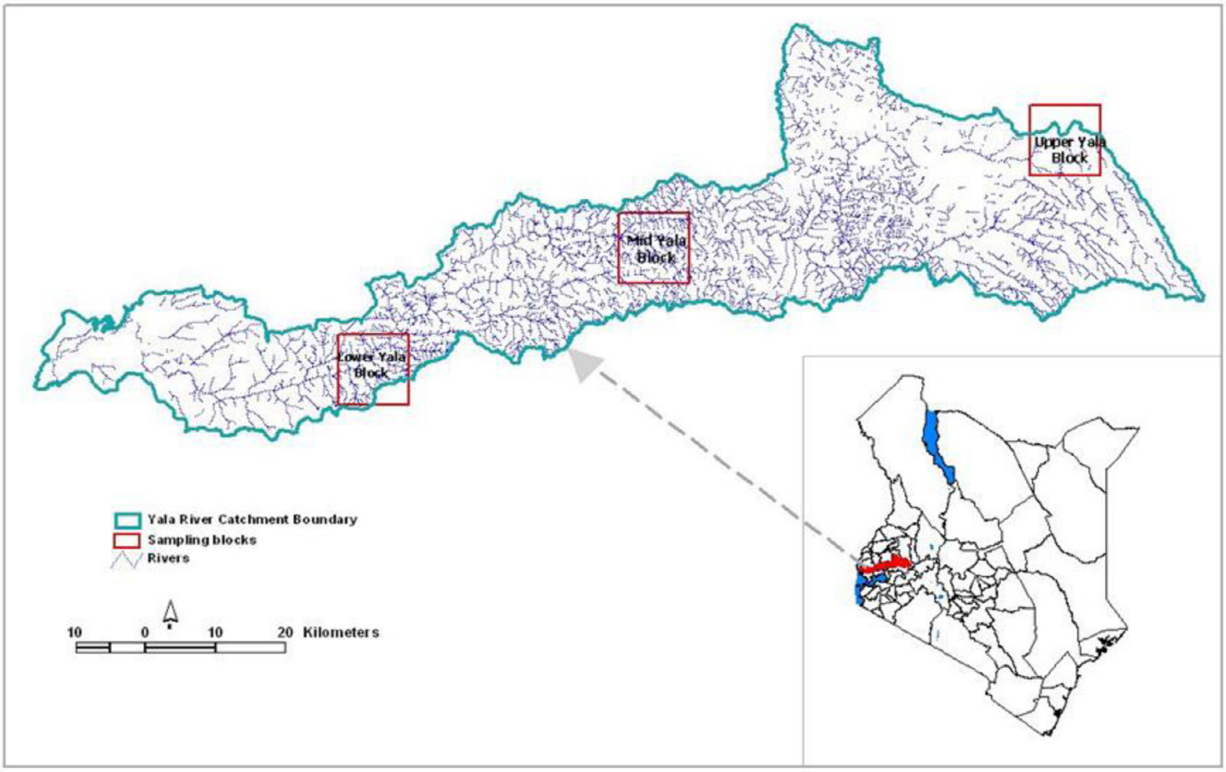

Fig. 1. Location of Yala basin in Western Kenya showing the three sampling points; Lower Yala, Middle Yala and Upper Yala.

Fig. 2. The two methods for wood density sampling (a) Auger method involving coring the tree trunk (b) conventional destructive method involving cutting discs.

Wood discs sampling for destructive wood density calculations

For destructive sampling, wood discs were taken from the same trees that were sampled for wood cores as described above. Trees were felled and their stem diameter at breast height (DBH) measured. A total of 62 trees were sampled by cutting circular discs of 2–3 cm thickness, knot-free at breast height of the tree trunks. Discs per tree corresponded to the number of cores obtained using carpenters' auger.

The discs were stored in plastic bags and taken to the laboratory for separation into wood and bark sections. Bigger discs were further sectioned by cutting the disc at cross-section. The fresh discs were weighed then oven dried at 105 °C [17] to a constant weight.

Wood density calculations

Wood density was calculated for both destructive and non-destructive methods. Here, wood density refers to the mass of oven-dry wood per unit of volume of green wood [18].

Table 1
Mean (and 95% confidence intervals) of oven dry wood densities (g cm^{-3}) of seven tree species in western Kenya obtained by the water immersion method and auger method compared with the range of values reported in the African wood density database [21] or Global wood density database [20].

Species	Number of trees	Water immersion method	Auger method	Range reported
Mangifera indica	6	0.66^a (0.64–0.68)	0.58^a (0.50–0.66)	0.53–0.65 [21]
Grevillea robusta	5	0.61^a (0.54–0.68)	0.58^a (0.55–0.61)	0.42–0.53 [21]
Markhamia lutea	6	0.51^a (0.49–0.53)	0.36^b (0.30–0.42)	0.36–0.43 [20]
Eucalyptus camaldulensis	26	0.59^a (0.55–0.63)	0.52^b (0.47–0.55)	0.56–0.80 [21]
Eucalyptus grandis	5	0.46^a (0.42–0.50)	0.37^a (0.25–0.47)	0.45–0.63 [21]
Eucalyptus saligna	6	0.54^a (0.48–0.60)	0.40^b (0.34–0.46)	0.32–0.53 [21]
Acacia mearnsii	8	0.73^a (0.70–0.76)	0.67^a (0.61–0.73)	0.53–0.65 [21]

Means within the same row followed by the same letter are not significantly different at the 0.05 level, as determined by the *t*-test.

Auger non-destructive method

Cored volume (v) was determined by assuming the core produced by the auger is cylindrical and hence using

$$v = \frac{\prod d^2}{4} \times l \tag{1}$$

Where, d is the bit diameter (2.5 cm) and l is the core depth in cm.

Relative wood density (w_d) or specific gravity in g cm^{-3} was then calculated as the ratio of wood dry mass (d_m) obtained by the auger method to core volume (v).

$$w_d = \frac{d_m}{v} \tag{2}$$

Where, d_m is wood dry mass (g) and v is core volume (cm^3)

Destructive method (water immersion method)

For the water immersion method, a container filled with water was first weighed on a digital balance. The balance was zeroed before the disc was carefully immersed in water, ensuring the disc was not in contact with the sides or bottom of the container. The measured weight of displaced water was taken to be equal to the sample's volume. The wood density calculation using this destructive method was determined as the dry matter weight per unit volume according to ASTM [19].

Calculated and reported densities

The Global Wood Density database (GWD), which has wood densities for 8412 species from around the world [20], and the African wood density database [21] were used as a basis for comparison with the wood density values estimated using the two methods. Since these densities were reported in units of mass of wood per unit volume at 12% moisture content, a correction equivalent to the oven dry densities was done using a calibration equation developed by Rayes et al. [22] by multiplying reported values by 0.88.

Data analyses

An unpaired *t*-test was used to compare wood densities derived by the two methods. The data were then subjected to a two way ANOVA tests to determine how wood density differed according to species and location, while treatment effects of factors were separated using Fisher Least Significant Difference (LSD). All analyses were done using the "R" statistical software [23].

Results and discussion

Wood density

The highest mean (95% confidence intervals) wood density values were calculated for *Acacia mearnsii* with 0.73 g cm^{-3} (0.70–0.76) using water immersion method and 0.67 g cm^{-3} (0.61–0.73) using auger method (Table 1). In contrast, the lowest mean (95% confidence intervals) wood density was found for *Eucalyptus grandis* with 0.36 g cm^{-3} (0.25–0.47) (water immersion method) and 0.36 g cm^{-3} (0.25–0.47) (auger method). The density of the two species as reported in the African wood density database ranges from 0.53–0.65 g cm^{-3} for *Acacia mearnsii* and from 0.45–0.63 g cm^{-3} for *Eucalyptus grandis. Markhamia lutea* had wood density within those reported in African wood density database (Table 1). The difference in ranges between the calculated wood density values using auger method and water immersion method for the two species may suggest that wood density determined using samples taken at 1.30 m (breast height) often introduces sampling bias, an additional factor of variation due to the different height growths of individual trees [24]. Additionally, lack of precision in coring would also introduce a bias in wood density calculation as well as a challenge of immersing stem discs in water. However, the differences between the derived wood density ranges for the two species with those reported in African wood density database could be as a result of sampling sites and methods for the determination of wood density [25]. Additionally, sampling sites for the present study and sites collated for wood density of the species might be different. Furthermore, approaches for wood density determination in the database might also be completely different from that of the authors.

Calculated mean (95% confidence intervals) wood densities for *Grevillea robusta* 0.61 g cm^{-3} (0.54–0.68) (water immersion method), 0.58 g cm^{-3} (0.55–0.61) (auger method) and *Eucalyptus saligna* 0.54 g cm^{-3} (0.48–0.60) (water immersion method), 0.40 g cm^{-3} (0.34–0.46) (auger method) had density values comparable to the reported ranges and those reported for tropical species in Africa (0.60 g cm^{-3}) [26]. On average wood density values from auger method were lower in comparison with those of the conventional water immersion method.

A comparison of the wood density values derived from the two methods produced no significant difference for some species namely, *Mangifera indica* and *Grevillea robusta* as the 95% CIs completely overlap. In particular, the auger method was precise for *Grevillea robusta* and *Eucalyptus saligna* as the 95% confidence intervals overlapped. It should be emphasized, however, that from the practical point of view, auger method technique was satisfactory.

This eliminates the need to determine wood density using water immersion method which is destructive and time-consuming. Because of its simplicity, the auger method is well suited for acquiring wood density from live trees both on farm and in the forest [27]. However, measurements obtained by this non-destructive method must accurately represent the whole tree [28].

Wood density variation within the sampled locations and species

Analysis of the data showed that location has an influence on wood density ($P < 0.001$). Wood density (±standard error) from Upper Yala location ($n = 12$) had the highest density value of 0.69 ± 0.07 g cm^{-3} using the water immersion method and 0.64 ± 0.08 g cm^{-3} using the auger method. In Lower Yala ($n = 8$), mean wood density was 0.60 ± 0.09 g cm^{-3} and 0.54 ± 0.10 g cm^{-3} for the water immersion method and the auger method, respectively. However, in Middle Yala ($n = 42$) densities were lower 0.56 ± 0.10 g cm^{-3} (water immersion method) and 0.46 ± 0.12 g cm^{-3} (auger methods) compared to the other two sites.

The coefficients of variation within species were modest (3.02–36.11%) for both methods, while the Fisher's Least Significant Difference (LSD) amongst the different species was significantly different ($P < 0.001$). These points to the fact that the variations in wood density values are not only based on methods but could be as a result of location and species differences. Moreover, Upper Yala location was dominated by *Acacia mearnsii* unlike Middle Yala which was dominated by fast growing *Eucalyptus camaldulensis.* In Lower Yala some of the species like *Eucalyptus camaldulensis* and *Acacia mearnsii* were completely missing, hence a challenge of getting all the seven species in the three locations. Additionally, the difference in the tree species mean wood density values from different locations could suggest the possibility of random sampling variability, although wood density of different species may also be affected by site-specific growth conditions and age differences [29]. The results are in disagreement with those reported by Knapic et al.[30] Where, the location (site) was not statistically relevant and did not contribute to the total variation of the wood density components. However, Knapic et al.[30] reported wood density variation between trees. Amongst the environmental factors that could explain differences in wood density variations is the temperature [31]. The temperature has been found to have a direct effect on the anatomy of the wood and therefore on its density [31]. "Extractable" compounds also affect wood density [32].

Auger method validation

The auger method is particularly important for trees outside forests (TOF), which are defined by FAO as "trees on land not defined as forest or other wooded land" [33]. Hence, the method could protect felling of trees on agricultural lands, on settlement areas, along roads, in home gardens, in hedge rows, scattered in the landscape and on pasture and rangelands. In addition, the tree need only be cored at a single point, to estimate wood density of the whole live tree [17].

The variances of both water immersion and auger methods of density measurements at 95% probability level using the F-test for equality showed that the two methods were not equal for some species. Similarly, an unpaired *t*-test carried out to test the differences between the means of auger method and water immersion method showed that densities obtained by the auger method were significantly lower than those obtained by water immersion method ($t\,(61) = 7.992$, $P = <0.001$) with all the tree species pooled. However, when species where not pooled together, mean densities estimated by the two methods were not significantly different ($P > 0.05$) for four out of seven tree species (Table 1).

This could suggest that interspecies differences in wood density were much larger and stronger driver of variations than might be attributed to the two methods used for wood density estimations [12]. Similarly, Francis [14] showed no significant differences between auger method and the conventional method but noted numerical differences in values within species and attributed the numerical differences to the fact that water immersion method measured density at a point midway between the cambium and the pith, while the auger method measures a rough average across most of that radius. The results obtained in this study indicate a possibility of acquiring wood density data for tropical tree species in a relatively short time. However, the auger method is unrealistic to use while coring trees of smaller diameter (DBH < 5 cm) [27], additionally for older trees, bark coring is relatively time-consuming especially when the tree bark is thick.

Conclusions

The ease of application of auger method can provide an alternative to the existing conventional destructive method of wood density estimation. Further, estimation of wood density for trees outside forests can easily be achieved without felling down the trees. In comparison to forests, little attention has been given to tree resources outside the forest. The short sample collection time (2–5 min) can be easily accomplished in the field. In addition, the method is non-destructive since one does not need to cut down the trees; however, samples must still be dried in the laboratory after collection. In the present study, wood density was not classified according to hardwood and soft wood because of the sampling approach that was used; however, future studies should try this classification approach in using this method.

Declaration of Competing Interest

The authors declare that they have no competing interests

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