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Above-ground bole carbon stock estimation using forest inventory of the secondary forest ecosystem in Ibadan, Nigeria

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Abstract

Secondary forest ecosystem contributes by sequestration of carbon to global climate change mitigation. Above-Ground Bole Biomass (AGBB) is the major component used to monitor and estimate Carbon Stocks (CS) and tropical forest fluxes. However, information for the International Institute of Tropical Agriculture (IITA) on Above-Ground Bole Carbon Stock (AGBCS), which hosts relics of the undisturbed forest ecosystem in south-western Nigeria, has not been documented. Hence, AGBCS of the forest ecosystem was estimated using the technique of forest inventory. Using systematic sampling technique at 10% sampling intensity, one hundred and forty plots of 50m x 50m were laid in IITA secondary forest ecosystem. Trees were enumerated in each plot and identified by species level. In order to determine Tree Volume (TV), Total Height (TH) and Diameter at Breast Height (DBH) of trees ≥ 10cm were measured. Sixty wood core samples were collected randomly for estimation of Wood Density (WD) from dominant species of trees at breast height. Using standard forest inventory technique, TV and WD were used to determine AGBB which were converted to CS. Analysis of data using descriptive statistics, correlation matrix and linear regression analysis. A total of 9,985 individual trees were recorded, consisting of 121 species of tree and 30 families. Cordia alliodora (1/ha) and Funtumiaelastica (61/ha), respectively, were the highest and lowest species recorded. The TH and DBH ranged from 4.70 to 39.30m respectively, and from 10.76 to 74.50cm, while the TV ranged from 129.57 to 167.186m^3/ha. The WD of tree species varied between 0.23 and 0.89 kg/cm^3. The AGBB and CS ranged from 101.06 to 881,834.92kg/ha, respectively, and from 50.53 to 440,917.46kg/ha. The most accurate techniques of AGBCS estimation is based on forest inventory measurements. They are, however, difficult to perform over large areas and are expensive, labour-intensive and time-consuming.

Keywords: Carbon stock, inventory, secondary forest ecosystem, species, above-ground.

Introduction

Tropical forests forma significant source of biodiversity and carbon storage. They account for about 44.0% of the world's forest [1]. They also contain one of the major carbon pools and have a substantial function in the global carbon cycle. Forests store carbon and comprise about 80% of the entire above-ground organic carbon and 40% of the total below-ground organic carbon worldwide[1]. Deforestation and forest degradation account for between 15% - 20% of global carbon emissions, and most of which comes from tropical regions of the world. Approximately 60% of the carbon sequestered by forests is released into the atmosphere through deforestation. Deforestation of tropical forest releases about 1.5 Gt of carbon into the atmosphere every year[2]. Deforestation and forest degradation are the main sources of greenhouse gas (GHG) emissions in most tropical regions[2].

Above-ground biomass (AGB) is an indicator of carbon sequestration. The amount of carbon sequestered by a forest reserve can be inferred from its AGB accumulation because about 50% of forest biomass is carbon[3]. The majority of AGB assessments are achieved for the AGB of trees because it largely signifies the highest fraction of the total living biomass in a forest reserve and does not pose significant logistic glitches during forest inventory measurements[4]. Assessments of AGB can also be used to forecast root below-ground biomass, which is generally estimated to be about 20% of the total above-ground biomass[5]; this figure was based on a prognostic relationship determined from literature review[6]. In addition, dead laying trees, standing dead or broken branches and leaves are normally supposed to correspond to range between 10% - 20% of the above-ground carbon stock in advanced forests[7].

There are uncertainties with regard to the precise estimation of above-ground bole biomass in the forest. In addition, the choice of techniques that can standardize and improve the accuracy of such estimates is far from being decisive. These uncertainties are accountable for overestimation or underestimation of above-ground biomass, typically ascribed to the complexity of the forest[8]. These increased the problems of deriving forest parameters mainly in those areas located in tropical and subtropical regions[9].

As the problem of CO_2 emissions continues, part of the mitigation efforts rely on the development and availability of accurate environmentally benign and cost-effective techniques for measuring the quantity and quality of carbon sequestered. Although, conventional techniques for the estimation of biomass may be very precise, their use in carbon sequestration quantification is inadequate. Therefore, the study is aimed at estimating above-ground bole carbon using forest inventory measurements of the secondary forest ecosystem in Ibadan, Nigeria.

Materials and methods

Study Area: Location: The International Institute of Tropical Agriculture (IITA) Secondary Forest Ecosystem lies at 07° 30' 0"N and 03° 53'30"E and approximately 227m altitude in the city of Ibadan. Ibadan lies in the rainforest zone to the south and savanna zone to the north. To the west lies the Dahomey Gap, where savanna reaches almost to the coast in neighbouring Benin Republic[10].

Vegetation: The secondary forest ecosystem is known for its trees, climbers, shrubs, lianas and grasses. The forest area is classified as dry semi-deciduous rainforest, with a mixture of fast growing pioneer tree species, such as *Ceibapentandra, Albizia spp.*, *Newbouldia laevis, Anthocleista vogelii*, and interspersed with slow growing emergents, including *Triplochiton scleroxylon, Milicia excelsa, Antiaris africana,* and together with abundant climbers and lianas, especially of the genera *Dioscorea and Combretum* and an under storey of shrubs such as *Sphenocentrum jollyanum, Mallotus oppositifolius* and *Chassalia kolly*[10].

Forest inventory data collection: Reconnaissance was undertaken in the IITA secondary forest ecosystem to obtain preliminary information on ground.

Laying of sample plots: Systematic sampling technique was used to select temporary sample plots (TSPs) of 50m x 50m (0.25ha) in size. The sample plots were primarily established with 10% sampling intensity. The total area of IITA secondary forest ecosystem was 350ha. One hundred and forty (140) sampling plots were systematically laid in the secondary forest ecosystem, trees in all of the plots with a diameter at breast height (DBH) equal to or greater than 10cm were measured. Trees within a sample plot were measured for DBH, D@top and BH. A botanist identified some of the local and botanical names of trees species, respectively. Plots need to be allocated systematically so as to achieve above-ground biomass[11]. The number of sample plots and the distance between plots were determined by the formula[12];

$$N = \frac{T_A X S_i}{P_S X\ 100} \quad (1)$$

Where: N = number of sample plots, P_S = Plot size, T_A = Total area of the forest and S_i = Sampling intensity, while the distance between plots was determined by the formula[12]:

$$D = \sqrt{\left(\frac{Af\ X\ 10000}{N}\right)} \quad (2)$$

Where: D = inter plots distance (m), N = number of plots and Af = Area of the forest (ha).

Lu et al. demonstrated that the precision of forest above-ground biomass estimates due to sampling error can increase by about 10% when the size of sample plots is increased from 0.25 ha to 1 ha[13].

Bole height (BH): Distance between the ground level and First Branch (FB) of tree species. It was achieved by Reading at Base (RB) and Reading @ FB and which is usually negative and positive. It was measured with Haglof EC II. BH was computed via:

$$BH = FB - RB \quad (3)$$

Where: BH = Bole height, RB = Reading at the base, FB = First branching.

DBH and D@top: The measurement was taken at height 1.30m above the surface level. The top diameter was also taken at the thin end of the tree. Criterion RD1000 was used for measurement.

Volume estimation: Frequently used volume equations include Smalian, Huber and Newton functions. Volume of bole sections are often calculated using Smalian's formula, or alternatively by using the geometric formula for the truncated cone.

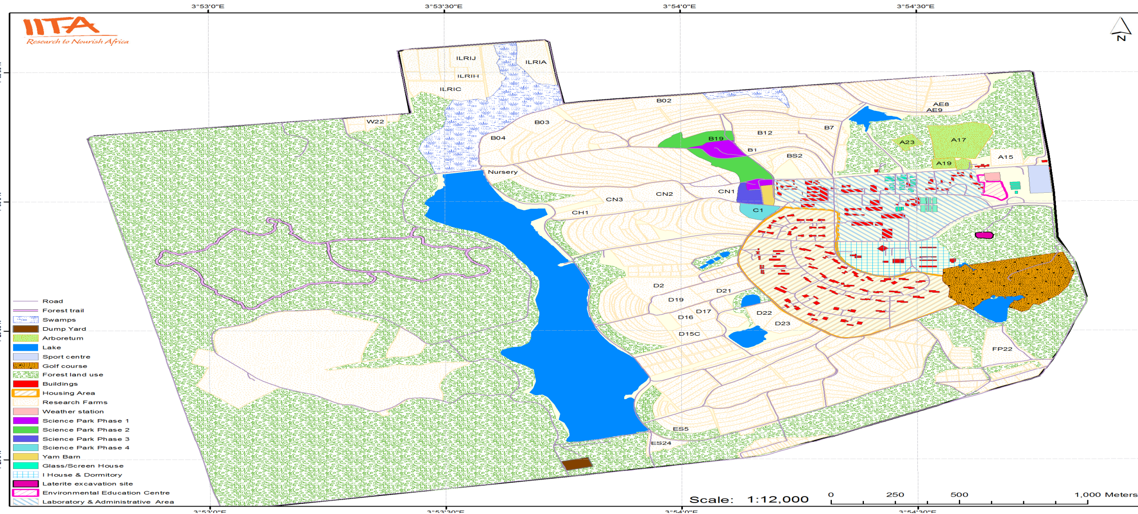
The above-ground bole biomass models were computed as a product of tree volume. The volume of trees was estimated using geometric formula for truncated cone as shown below;

$$V = \frac{\pi l}{3}(R^2 + Rr + r^2) \quad (4)$$

Where; V= Volume of the tree (m^3), l = length of bole sections (m), R,r = the diameters at the thick and the thin end (cm), π = 3.143.

Estimation of wood density: Wood density is defined as the ratio of the oven-dry mass of a wood sample divided by the mass of water displaced by its green volume[14]. Sixty (60) core samples were randomly selected from the different dominant trees using an increment borer. Seventy percent (70%) of the core samples were used for computation of wood density. An estimate of wood density requires the collection of cores of wood from randomly selected trees species[14].

Thirty percent (30%) of the Global Wood Density Databasewas used for core samples that could not be collected [15]. Mitchard et al. reported that the information base has been widely used by scientists in above-ground forest biomass and carbon research work[16].



Source: GIS and Database Unit, IITA

Figure-1: Map of IITA.

The core samples were oven-dried to a constant weight at 105°C[17]; volume of core sample and density of the sample were compiled using equation 3.5 and 3.6.

$$V = \frac{\pi}{4} D^2 TL \quad (5)$$

Therefore,

$$\rho = \frac{M}{V} \quad (6)$$

Where: ρ = wood density, M = oven-dry mass of core sample, V = volume of the core sample, TL = total length of the core sample, D = diameter of core sample, π = pi (3.143)[14].

Above-ground bole biomass (AGBB) estimation: Above-ground bole biomass of the different trees was carried out using tree volume and wood density. Generally, AGBB was estimated as:

$$AGBB = \text{Tree Volume} \times WD + \mathcal{E} \quad (7)$$

Where, WD and Ɛ, represent wood density and error[18].

Estimation of AGBCS within a sample plot: The plot of AGBB for individual tree in the secondary forest ecosystem of International Institute of Tropical Agriculture was computed and then multiplied by 0.25 (the number of 50mx50m plots/ha.) to acquire AGBB/ha. However, half of the value gave AGBCS/ha for the secondary forest ecosystem[10].

Results and discussion

Forest Composition and Vegetation Structure: A total of one hundred and twenty one tree species were found in the temporary sample plots from 9,985 individual species. The dominant tree species included *Funtumia elastica* (2146), *Blighia sapida* (1400), *Newbuldia laevis* (1011), *Antiaris africana* (927), *Ficus exasperata* (823), *Gambeya albidum* (715), *Spondias laevis* (670), *Lecanodiscus cupanioides* (351), *Celtis africana* (237), Albizia *zygia* (236), *Holarrhena floribunda* (146), *Nauclea diderrichii* (107), *Millettia thonningii* (86), *Morus mesozygia* (66), *Milicia excelsa* (36), respectively (Table-1). The tree species belonged to thirty families (Table-2). Some dominant species in this study were similar to the previous studies carried out by Aghimien *et al.,* which included *Newbouldia leavis* (193), *Blighia sapida* (148), *Funtumia elastic* (139), *Ficus exasperate* (78), respectively[10].

Above-Ground Bole Carbon Stocks Estimation from Forest Inventory: The DBH and BH of individual species ranged from 10.76 to 74.50cm and 4.70 to 39.30m with error value of 0.08 and 0.04. The histogram on the distribution of tree BH and DBH are presented in Figures-2 and 3. The densities of wood are indirect indicators of carbon storage capacity of trees. Standard wood density varies among the tree species ranging from 0.25kg/cm^3 to 1.00kg/cm^3, with about 90.00% of wood density falling between 0.51kg/cm^3 and 0.75kg/cm^3. The histogram on the distribution of WD is presented in Figure 4. In this study, the DBH, WD and BH values of individual species in the plots were used to estimate the above-ground bole biomass as revealed in Table-3.

The WD values for tree species estimated in these studies were similar with density values obtained in previous studies carried out by Zanne *et al.,* which included 16,469 entries from tropical America, tropical Asia, and tropical Africa[15]. Reyes *et al.,* used 1,280 entries from tropical America (40 percent), tropical Asia (36 percent), and tropical Africa (24 percent)[19]. Wood density of core samples taken at breast height were not assumed to represent the wood density of the whole tree but is only used as statistical predictors of the above-ground bole biomass of tree and has been shown to be significantly correlated with the above-ground bole biomass of trees.

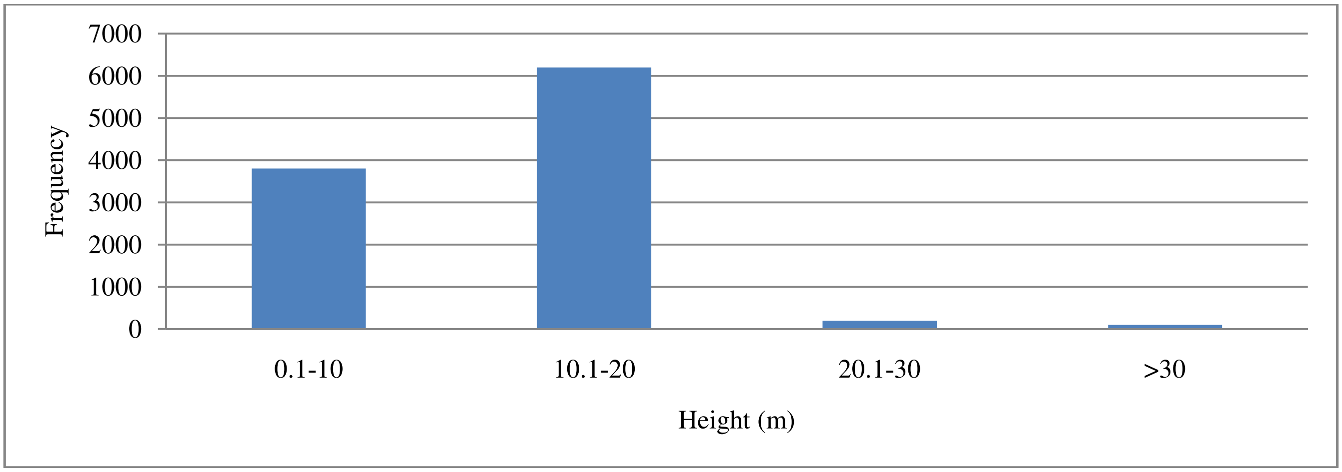


Figure-2: Histogram of Bole Height in the Secondary Forest Ecosystem.

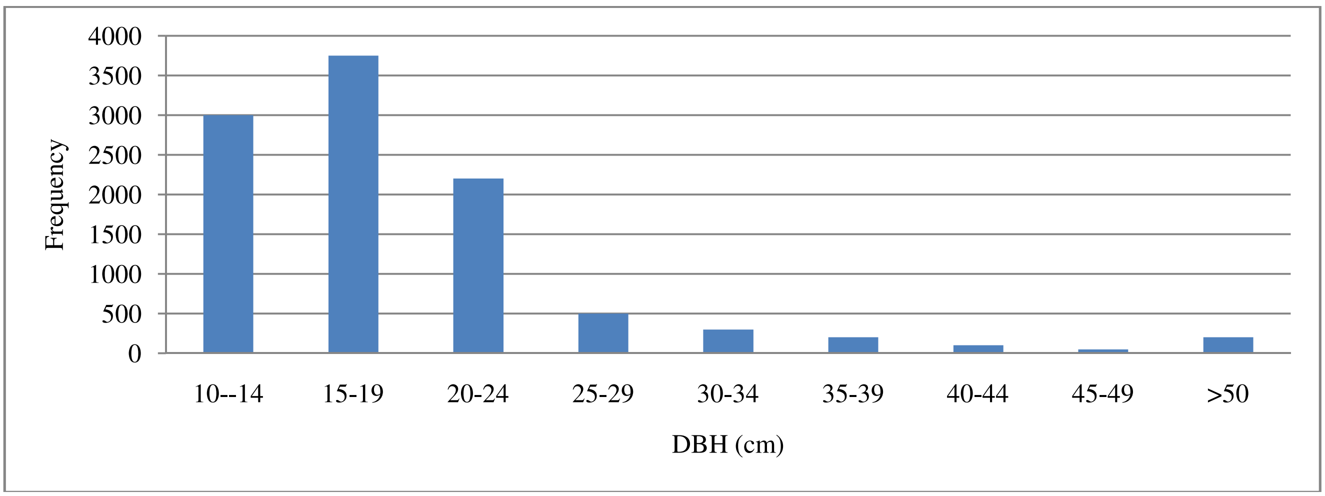


Figure-3: Histogram of Diameter at Breast Height in the Secondary Forest Ecosystem.

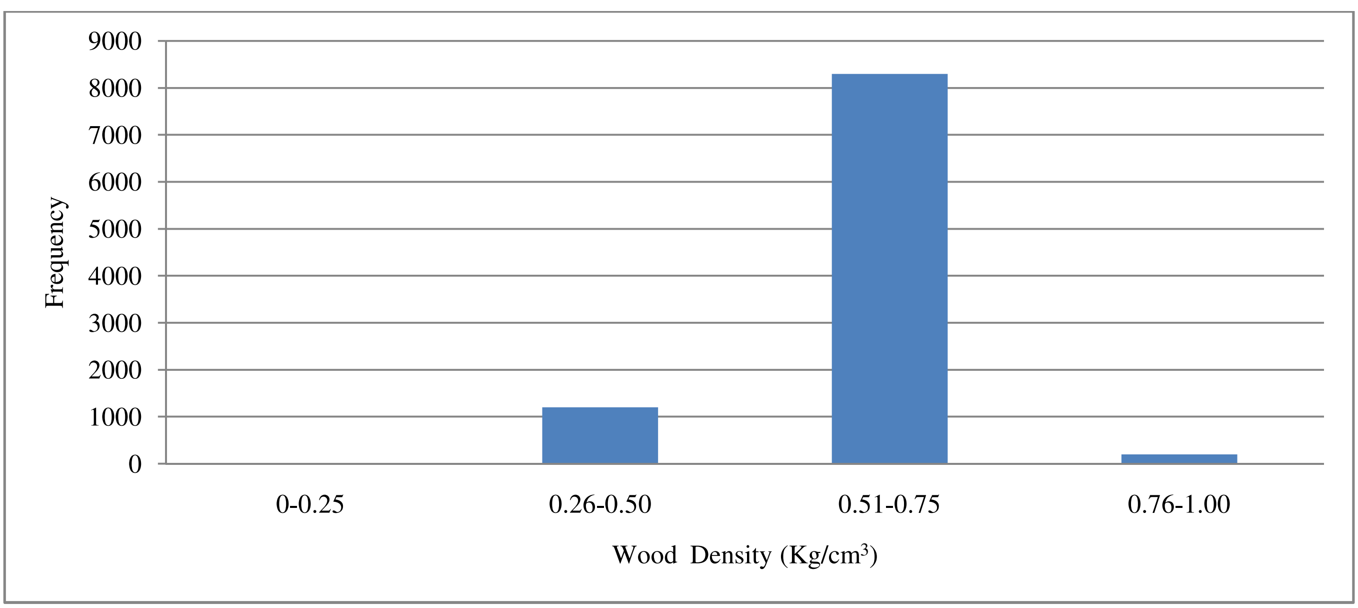


Figure-4: Histogram of Wood Density of Tree Species in the Secondary Forest Ecosystem.

Table-1: Summary of species composition.

Species	Family	frequency	%
Adenanthera pavonina	Fabaceae -Mim	1	0.01
Afzelia africana	Fabaceae -Caes	3	0.03
Afzelia bella	Fabaceae -Caes	4	0.04
Afzelia bipindensis	Fabaceae -Caes	4	0.04
Afzelia quanzensis	Fabaceae -Caes	4	0.04
Aganope leucobotrya	Fabaceae -Pap	2	0.02
Albizia falcataria	Fabaceae -Mim	6	0.06
Albizia ferruginea	Fabaceae -Mim	7	0.07
Albizia lebbeck	Fabaceae -Mim	7	0.07
Albizia niopoides	Fabaceae -Mim	7	0.07
Albizia zygia	Fabaceae -Mim	236	2.35
Alchornea cordifolia	Euphorbiaceae	7	0.07
Anacardium occidentale	Anacardiaceae	5	0.05
Anthonotha macrophylla	Fabaceae	4	0.04
Antiaris africana	Moraceae	927	9.22
Artocarpus heterophyllus	Moraceae	7	0.07
Baphia laurifolia	Fabaceae -Pap	7	0.07
Baphia nitida	Fabaceae -Pap	7	0.07
Baphia pubescens	Fabaceae -Pap	7	0.07
Bauhinia monandra	Fabaceae	7	0.07
Bauhinia tomentosa	Fabaceae	7	0.07
Berlinia grandiflora	Fabaceae -Caes	7	0.07
Blighia sapida	Sapindaceae	1400	13.92
Brachystegia eurycoma	Fabaceae -Caes	4	0.04
Caesalpinia pulcherrima	Fabaceae	5	0.05
Calliandra calothyrsus	Fabaceae	2	0.02
Calliandra haematocephala	Fabaceae	5	0.05
Calotropis procera	Apocynaceae	1	0.01
Cassia fistula	Fabaceae	4	0.04
Ceiba pentandra	Bombacaceae	4	0.04

Species	Family	frequency	%
Celtis africana	Ulmaceae	237	2.36
Celtis zenkeri	Ulmaceae	37	0.37
Cola millenii	Sterculiaceae	4	0.04
Cordia alliodora	Boraginaceae	1	0.01
Dactyladenia barteri	Chrysobalanaceae	4	0.04
Dalbergia albiflora	Fabaceae -Pap	4	0.04
Dalbergia lacteal	Fabaceae -Pap	2	0.02
Dalbergia latifolia	Fabaceae -Pap	2	0.02
Dalbergia sissoo	Fabaceae -Pap	2	0.02
Daniellia ogea	Fabaceae -Caes	1	0.01
Daniellia oliveri	Fabaceae -Caes	1	0.01
Delonix regia	Fabaceae	2	0.02
Dialium guineense	Fabaceae -Caes	12	0.12
Diospyros crassiflora	Ebenaceae	15	0.15
Dipteryx odorata	Fabaceae	1	0.01
Enterolobium cyclocarpum	Fabaceae	6	0.06
Erythrina abyssinica	Fabaceae	3	0.03
Erythrina barteroana	Fabaceae	3	0.03
Erythrina fusca	Fabaceae	3	0.03
Erythrophleum suaveolens	Fabaceae	3	0.03
Ficus exasperata	Moraceae	823	8.18
Ficus mucuso	Moraceae	27	0.27
Funtumia elastica	Apocynaceae	2146	22.03
Gambeya albidum	Sapotaceae	715	7.11
Gambeya cainito	Sapotaceae	7	0.07
Gliricidia maculata	Fabaceae	3	0.03
Gliricidia sepium	Fabaceae	3	0.03
Glypha eabrevis	Malvaceae-Tiliaceae	3	0.03
Gmelina arborea	Verbenaceae	14	0.14
Grevillea robusta	Proteaceae	4	0.04

Species	Family	frequency	%
Grewia mollis	Malvaceae-Tiliaceae	4	0.04
Grewia pubescens	Malvaceae-Tiliaceae	4	0.04
Holarrhena floribunda	Apocynaceae	146	1.45
Irvingia edulis	Irvingiaceae	4	0.04
Irvingia gabonensis	Irvingiaceae	8	0.08
Lecanodiscus cupanioides	Sapindaceae	351	3.49
Leucaena diversifolia	Fabaceae -Mim	4	0.04
Leucaena esculenta	Fabaceae -Mim	4	0.04
Leucaena leucocephala	Fabaceae -Mim	4	0.04
Leucaena macrophylla	Fabaceae -Mim	4	0.04
Lonchocarpus sericeus	Fabaceae -Pap	33	0.33
Markhamia lutea	Bignoniaceae	1	0.01
Milicia excelsa	Moraceae	36	0.36
Millettia aboensis	Fabaceae -Pap	3	0.03
Millettia drastica	Fabaceae -Pap	3	0.03
Millettia griffoniana	Fabaceae -Pap	6	0.06
Millettia pallens	Fabaceae -Pap	3	0.03
Millettia stuhlmanii	Fabaceae -Pap	3	0.03
Millettia thonningii	Fabaceae -Pap	86	0.86
Moringa oleifera	Moringaceae	2	0.02
Morus mesozygia	Moraceae	66	0.66
Napoleonaea imperialis	Leycithidaceae	25	0.25
Nauclea diderrichii	Rubiaceae	107	1.06
Nauclea latifolia	Rubiaceae	5	0.05
Newbouldia laevis	Bignoniaceae	1011	10.06
Newtoniagriffoniana	Fabaceae -Mim	5	0.05
Ostryoderrisleucobotrya	Fabaceae -Pap	5	0.05
Parkia bicolour	Fabaceae -Mim	10	0.10
Parkia biglobosa	Fabaceae -Mim	10	0.10
Parkia clappertoniana	Fabaceae -Mim	5	0.05

Species	Family	frequency	%
Peltophorum pterocarpum	Fabaceae	4	0.04
Pentaclethra macrophylla	Fabaceae -Mim	5	0.05
Pericopsis elata	Fabaceae	4	0.04
Philenoptera cyanescens	Fabaceae -Pap	3	0.03
Pithecellobium dulce	Fabaceae	1	0.01
Platy sepalum violaceum	Fabaceae -Pap	1	0.01
Prosopis africana	Fabaceae -Mim	1	0.01
Pterocarpusbrenanii	Fabaceae -Pap	1	0.01
Pterocarpusindicus	Fabaceae -Pap	1	0.01
Pterocarpusmildbraedii	Fabaceae -Pap	1	0.01
Pterocarpusosun	Fabaceae -Pap	1	0.01
Pterocarpusrotundifolia	Fabaceae -Pap	1	0.01
Pterocarpussantalinoides	Fabaceae -Pap	3	0.03
Pterocarpussoyauxii	Fabaceae -Pap	1	0.01
Pycnanthusangolensis	Myristicaceae	194	1.93
Sennasiamea	Caesalpiniaceae	1	0.01
Sennaspectabilis	Caesalpiniaceae	2	0.02
Spondiasmombin	Anacardiaceae	670	6.66
Stemonocoleusmicranthus	Caesalpiniaceae	1	0.01
Sterculiasetigera	Sterculiaceae	1	0.01
Tamarindusindica	Fabaceae	1	0.01
Terminaliaivorensis	Combreteceae	1	0.01
Terminalia superb	Combreteceae	1	0.01
Tetrapleuratetraptera	Fabaceae -Mim	1	0.01
Treculiaafricana	Moraceae	1	0.01
Trichilamonadelpha	Meliaceae	297	2.95
Trilepisiummadagascariense	Moraceae	1	0.01
Triplochitonscleroxylon	Helicteraceae	34	0.34
Vitellariaparadoxa	Sapotaceae	5	0.05
Zanthoxylumleprieurii	Rutaceae	1	0.01
Zanthoxylumxanthoxyloids	Rutaceae	1	0.01

Table-2: Family Distribution of Tree Species in the IITA Secondary Forest Ecosystem.

Family	Number of Fam.	Number of Observation	%
Anacardiaceae	2 (1.65%)	675	6.76
Apocaceae	3(2.48%)	2292	22.95
Bombacaceae	1(0.83%)	6	0.06
Bignoniaceae	2(1.65%)	1013	10.15
Boraginaceae	1(0.83%)	1	0.01
Chrysobalanaceae	1(0.83%)	4	0.04
Combreteceae	2(1.65%)	2	0.02
Caesalpinaceae	3(2.48%)	4	0.04
Ebenaceae	1(0.83%)	15	0.15
Euphorbiaceae	1(0.83%)	7	0.07
Fabaceae	20(16.53%)	71	0.71
Helicteraceae	1(0.83%)	34	0.34
Irvingiaceae	2(1.65%)	12	0.12
Fabaceae–Caes	9(7.44%)	40	0.40
Fabaceae–Mim	17(14.05%)	315	3.15
Fabaceae–Pap	25(20.66%)	188	1.88
Leycithidaceae	1(0.83%)	25	0.25
Malvaceae-Tiliaceae	3(2.48%)	11	0.11
Moraceae	8(6.61%)	1888	18.91
Myristicaceae	1(0.83%)	194	1.94
Meliaceae	1(0.83%)	297	2.97
Moringaceae	1(0.83%)	2	0.02
Proteaceae	1(0.83%)	4	0.04
Rutaceae	2(1.65%)	2	0.02
Rubiaceae	2(1.65%)	112	1.12
Sapindaceae	2(1.65%)	1751	17.54
Sapotaceae	3(2.48%)	727	7.28
Sterculiaceae	2(1.65%)	5	0.05
Ulmaceae	2(1.65%)	274	2.74
Verbenaceae	1(0.83%)	14	0.14

The highest above-ground bole carbon stock (AGBCS) per hectare were found in the family of Moraceae with a value of 440917.46kg/ha, followed by Apocaceae with a value of 265596.71kg/ha, while Boraginaceae had the lowest AGBCS per hectare with a value of 50.53kg/ha. The results also showed that the highest above-ground bole biomass per hectare were found in the family of Moraceae with a value of 881834.92 kg/ha, followed by the family of Apocaceae with a value of 531193.41kg/ha, while Boraginaceae had the lowest value of above-ground bole biomass per hectare with a value of 101.06 kg/ha. The highest tree volume per hectare was recorded in the family of Moraceae with a value of 1671858m^3/ha, followed by Apocaceae with a value of 965763.80m^3/ha, while Boraginaceae recorded the least tree volume/ha of 129.57m^3/ha. The total AGBB and bole carbon stock/ha for all the trees species were calculated to be 3381754.16kg/ha and 1690877.08kg/ha as presented in Table-3.

Aghimien *et al.,* reported that the above-ground tree biomass at whole stand level accounted for 838036.15g/ha through allometric equations, while above-ground tree biomass and carbon per hectare accounted for 736560.83g/ha and 368280.40 g/ha through standard technique[10]. The difference in the current and previous studies could be due to the variation in distribution characteristics across the temporary sample plots covering a wider area in IITA secondary forest ecosystem. The percentage carbon content in wood biomass of the tree ranged between 48.5% to 54.4%, with an average carbon content of 52.3%. Intergovernmental panel on climate change (IPCC) recommended carbon content of 49% (in wood and tree ≥ 10 cm) for tropical forests[20]. The generic assumption that tree above-ground biomass consist of 50% carbon remain common place in forest carbon estimates and have been widely used by researcher[21,22]. However, the use of wood carbon content value of 49% would result in an underestimation of carbon content.

Earlier studies have also shown that the use of these values may result to either an underestimation or overestimation in carbon content by between 2%-8%[23]. A review of carbon content reported in previous studies in the tropics found the carbon content ranges of 41% to 59%. Martin *et al.,* found that carbon content varied from 41% to 51.6% with a mean of 47.4% for 59 rain forest tree species in tropical forest in Panama[24]. The mean carbon content of 46.53% in tropical forest in Cameroon[25]. The average carbon content of 50.8% and 48.2% for some conifers and broadleaf species respectively were found in a tropical forest in Costa Rica[26]. Based on the values obtained from the previous studies, the generic 50% average carbon content was used for the evaluation of AGBCS.

A very strong linear relationship was observed between AGBB/ha and tree volume with correlation value of 0.99, followed by TH and DBH with a value (0.99). However, the lowest linear relationship between above-ground bole biomass per hectare and wood density had a value of 0.89 as presented in Table-4. This implies that all the indicators were suitable predictors for estimating above-ground bole biomass.

Table-3: Tree Volume and Above-Ground Bole Carbon Stocks per Hectare.

Fam.	TV m^3 per ha	AGBB kg per ha	AGBCS kg per ha
Anacardiaceae	435502.50	235052.11	117526.06
Apocaceae	965763.80	531193.41	265596.71
Bombacaceae	1434.96	330.04	165.02
Bignoniaceae	338345.70	189461.29	94730.65
Boraginaceae	129.57	101.06	50.53
Chrysobalanaceae	1302.51	1159.23	579.62
Combreteceae	587.43	322.86	161.43
Caesalpinaceae	1909.76	1268.32	634.16
Ebenaceae	24033.14	16823.20	8411.60
Euphorbiaceae	1355.12	528.50	264.25
Fabaceae	45570.81	27928.83	13964.42
Helicteraceae	107186.70	34299.74	17149.87
Irvingiaceae	7493.70	4562.14	2281.07
Leg-Caes	15261.25	11718.97	5859.49
Leg-Mim	238228.50	141756.64	70878.32
Leg-Pap	431822.40	250141.16	125070.58
Leycithidaceae	6223.47	2551.62	1275.81
Malvaceae-Tiliaceae	3056.72	1719.84	859.92
Moraceae	167186	881834.92	440917.46
Myristicaceae	159071	95442.61	47721.31
Meliaceae	87430.18	52458.11	26229.05
Moringaceae	361.62	216.97	108.49
Proteaceae	7739.12	4488.69	2244.34
Rutaceae	811.87	267.92	133.96
Rubiaceae	26465.86	16673.49	8336.75
Sapindaceae	716009.80	418476.63	209238.32
Sapotaceae	496678.40	347414.65	173707.32
Sterculiaceae	3838.53	3336.64	1668.32
Ulmaceae	140491.20	105487.43	52743.72
Verbenaceae	11553.96	4737.12	2368.56

Table-4: Pearson correlation matrix for forest inventory variables.

	BH (m)	DBH (cm)	WD (kg/m^3)	TV (m^3)	AGBB per ha
BH (m)	1				
DBH (cm)	0.99* 0.0000	1			
WD (kg/m^3)	0.99* 0.0000	0.99* 0.0000	1		
TV (m^3)	0.92* 0.0000	0.92* 0.0000	0.87* 0.0000	1	
AGBB per ha	0.93* 0.0000	0.93* 0.0000	0.89* 0.0000	0.99* 0.0000	1

= Significant level at 0.05.

Conclusion

Forests are the world's largest carbon pool. It acts in nature as a major source and sinks of carbon. Thus, a chief component in mitigating global warming and adapting to climate change can be formed. The main element for estimating carbon stocks in forests is estimation of above-ground bole biomass in forests. Global measurement can be enhanced of forest area, structure, biomass and carbon using remote sensing techniques that are currently available. Using high-resolution forest imagery will enhance the quality of information generated, but the most accurate techniques are above-ground bole carbon stock estimation based on secondary forest ecosystem inventory measurements. They are, however, difficult to perform over large areas, time consuming, expensive and labour-intensive.

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