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# Timber Merchantable Residue Quantities and Harvesting Efficiency in Tropical Forests of Ghana; Drivers of Wood Residue Utilization for Forest Conservation

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*Keywords:* *deforestation in ghana, efficient wood utilization, forest conservation, harvesting efficiency, merchantable residues.*

*GJSFR-D Classification :* *FOR Code: 820199*

TIMBERMERCHANTABLERESIDUEQUANTITIESANDHARVESTINGEFFICIENCYINTROPICALFORESTSOFGHANADRIVERSOFWOODRESIDUEUTILIZATIONFORFORESTCONSERVATION

*Strictly as per the compliance and regulations of :*

# Timber Merchantable Residue Quantities and Harvesting Efficiency in Tropical Forests of Ghana; Drivers of Wood Residue Utilization for Forest Conservation

Dadzie Peter Kessels [α] & Martin Amoah [σ]

*Abstract-* The practice of continuous extraction of only the main boles from felled trees to meet high demand for timber is one major cause of deforestation in Ghana, but merchantable residues (branchwood and stem off-cuts) left un-extracted can be utilized to increase efficient wood utilization to conserve the forests and the entire ecological system. This study assessed harvesting efficiency, and quantified residues left in the forests after harvesting, to ascertain the extent to which residues utilization can affect forest preservation. Volumes of timber sections of 154 trees from 3 forest ecological sites were quantified using Smalian's equation, after which harvesting efficiencies were determined. Results indicated merchantable residue quantity of 742.57m$^3$ (24.69%) ranging from 16.34% for *C. pentandra* to 40.45% for *Khaya ivorensis* and overall harvesting efficiency of 75.31% (ranging from 59.54%- *Khaya ivorensis* to 83.66% -*Ceiba pentandra*). ANOVA indicated significant difference P=0.000 at 95% confidence level in harvesting efficiencies among species but not sites (P=0.435), and in both branchwoods and off-cuts volumes among species and sites P=0.000. Stronger positive correlation existed between extracted log volume and total merchantable wood ($R^2$=0.866) than extracted log volume and total merchantable residue volume ($R^2$=0.128). Extraction and utilization of merchantable residues were found to have the potential of conserving about 8 hectares of forest land. It was concluded that, extraction and eventual commercialization of merchantable residues can substantially improve efficiency in wood utilization and could conserve the forest vegetation and ecology.

*Keywords: deforestation in Ghana, efficient wood utilization, forest conservation, harvesting efficiency, merchantable residues.*

## I. Introduction

Assessment of wood residue quantity and logging efficiency is an integral part of biomass and raw material availability assessment and is necessary for many applications including commercial exploitation of timber to the global carbon cycle (Basuki, et. al., 2009). On account of the importance of such assessment, it is reported that under the United Nations Framework Convention on Climate Change (UNFCCC), countries have to report regularly on the state of their forest resources and emerging mechanisms, such as Reducing Emissions for Deforestation and Degradation (REDD) in developing countries (UNFCCC 2008; Basuki et al. 2009).

Besides the demand from UNFCCC, in the face of dwindling timber resources and the effects of deforestation, inventory on total merchantable wood and residues provide indications on potential timber resources (raw materials) availability for industry and efficient utilization of wood (Amoah and Becker 2009) which have all become issues of much concern to stakeholders in sustainable wood utilization and forest management, as well as environmentalists (Peskette et al. 2008; Marfo 2010; The REED Desk 2014). Similarly, it is reported that the timber resources play very important environmental and economic roles in many countries, including Ghana, and for that matter their efficient utilization is of vital importance. Environmentally, the forest cover protects the soil from erosion, protects rivers and streams to ensure quality water availability for consumption, and also helps to provide continuous and sustainable clean air for living organisms including man (Okai 2003; Oregon Forest Resources Institute 2011; Antwi 1999). The forest is therefore responsible for the protection and preservation of the entire forest ecosystem and climate including carbon sequestration (Rinebolt 1996), but tropical forests hold an average of about 50% more carbon and therefore sequester more carbon than those outside the tropics (Peskette et al. 2008; Houghton 2005). Meanwhile, in the wake of Ghana's continuous increase in oil exploration and production activities, the environmental role of carbon sequestration of the tropical forests in Ghana becomes extremely crucial and essential (Ministry of Lands and Natural Resources-MLNR 2012).

Again, and even more importantly in this regard, adolescent and matured trees, rather than young ones, are the major sources of carbon sink in the tropics

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(Oregon Forest Resources Institute 2011; Ministry of Lands and Natural Resources-MLNR 2012). However, there appears a gloomy picture about green house gas (especially $CO_2$) emissions (GHGEs) in Ghana in the near future. In 2006 the total GHGE was about 24 metric tonnes of $CO_2$ equivalent. This emission level, which is ranked low (i.e. $108^{th}$ globally), has the potential to increase as the country emerges as crude oil producer (Ministry of Lands and Natural Resources 2012). Thus GHGEs in Ghana are forecasted to increase above the 2006 levels and will gradually put the climatic structure and conditions in danger for all living organisms, including man (Ministry of Lands and Natural Resources 2012) and therefore, the forests need to be conserved to avert any environmental and health consequences from carbon dioxide emissions.

Economically, forests in Ghana provide timber and other products that serve as one major foreign exchange earner for the country's economy and raw material base for the timber related industries, and also provide jobs for the population. Export of timber products is ranked third after cocoa and minerals, in Ghana's export products mix and provided about 7% by value of all exports in 2011 (Ministry of Lands and Natural Resources 2012). It is however reported that, deforestation and dwindling trend of Ghana's wood resources have led to a fall in forest products contribution to GDP to a current level of 4% (Ministry of Lands and Natural Resources –MLNR. 2012). Additionally, the wood processing sector employs more than 100,000 people and supports the livelihoods of about 15% of the population (Agyarko 2001; Asumadu 2004).

However, deforestation of Ghana's forests appears to threaten the aforementioned benefits and essential environmental responsibilities of the forests. It is reported that deforestation has been identified as a critical environmental issue and Ghana has lost more than 33.7% of its forests, equivalent to 2,500,000 hectares, since the early 1990s (FAO 2010). Between 2005 and 2010, the rate of deforestation has been estimated at 2.19% per annum; the sixth highest deforestation rate globally for that period (FAO 2010). Also, deforestation in Ghana generally translates into about €877,346.903 loss in revenue per annum (World Bank 1988). Moreover, the continuous deforestation situation and its associated timber shortages among other factors, have resulted in some wood processing industries to either fold-up or not operating at full capacity and these have led and are still leading to loss of jobs (Oteng-Amoako et al. 2008). Therefore, since timber resources are major factors in wood products industries' operations, it is evident that the dwindling trend is not only negatively affecting the GDP of the country but also the general economic lives of a lot of people and their dependants.

It is however reported that the major causes among several causes of deforestation include inefficient logging -where only stemwood is extracted for processing to meeting increasing demand for wood and wood products, and misuse of wood residues like branches and off-cuts (World Bank 1988; Hawthorne and Abu-Juam 1995; Ayarkwa et al. 2000 a, b; Okai 2002; Agyarko 2001). From the aforementioned issues it stands to be only a necessity that, cogent steps are taken towards obtaining additional or supplementary raw materials for the continuous existence of the remaining wood products industries (WPIs) while safeguarding the environment and climate. One readily available way of achieving this is to use almost all parts of felled trees (whole tree utilization concept) especially harvesting residues (branches and off-cuts) all of which can possibly serve as supplements or alternatives to stemwood in wood products manufacturing (Haygreen and Bowyer 1996).

Meanwhile, efforts to promote branchwood and off-cuts' utilization triggers the questions of 'what is the current merchantable quantity of the materials, and how much contribution can that make in reducing depletion or conserving the forests?' However, in Ghanaian forests, there have been some studies on quantity of residues (Nketiah 1992; Ofori et al.1993; Eshun 2000). But the most recent studies on 135 felled trees indicated availability of about 25% of merchantable logging residues with Small-End Diameter (SED) averaging 31 cm and 60cm and varied lengths of between 3.0 and 8.5m (Amoah and Becker 2009). Meanwhile normal branchwoods comprise those with diameters of equal or larger than 5cm (Gurau et al. 2008) and therefore there appear to be some normal branchwoods that were not covered in the previous studies. Moreover, the sighted previous studies recommended regular studies to be conducted to ascertain current quantity of residues and this is supported by Basuki et al. (2009) that such inventory should be done over relatively short periods of time, usually 2 to 10 years. Again, trees differ in anatomical properties through physical properties to mechanical properties as a result of genetic, systematic, site soils and climatic or environmental conditions (Haygreen and Bowyer 1996; Pillsbury and Pryer 1989; Ofori et al. 2009; Zobel and Talbert 1991; Tsoumis 1991). It is therefore possible that there can be significant variations in quantity of branchwood and off-cuts among species and sites. But these appear to be limited, not established or unpublished.

It is therefore still important for branchwoods and off-cuts, left after harvesting operations to be quantified to provide information on the current quantity of merchantable residues and timber harvesting efficiency in Ghana and how far the extraction of the residues for commercial processing and utilization can help reduce depletion of Ghana's forests. It is however reported that stump harvesting disturbs the soil structure, increase the risk of soil erosion, and depletes soil nutrient and carbon capital, and all these adversely affect woodland biodiversity and tree health which consequently pose risk to sustainable forest management (Moffat et al. 2011). These effects could be more in tropical forests resulting from complex buttresses on the stumps. The main aim of this present study was to ascertain the current timber harvesting efficiency and quantity of residues that can be commercialized to reduce the undue pressure on stemwood which has led to the continuous felling of trees and subsequent deforestation and degradation, while at the same time avoiding further disturbances of the forest ecosystem and environment. Specific objectives are to estimate: 1) above stump residue quantities; 2) harvesting/logging efficiency and whether there are significant differences in branchwoods, stem off-cuts, and logging efficiency among wood species, and study sites or not; 3) the relationship between extracted log volume and total merchantable wood, and extracted log volume and total merchantable residues.

## II. Methodology

### a) *Study sites*

This study was carried out in four natural forest reserves located in three ecological zones/sites in Ghana. They included Asukawkaw ($1^0$ $0^0$ and $0^0$ $0^0$ W; $6^0$ $0^0$ and $7^0$ $0^0$ N, Moist Semi-Deciduous -South-East zone forest -referred to as site 1 in this study) located at Nkawkaw in the Eastern Region; Abonyere, and Bosambepo reserves ($2^0$ $0^0$ and $3^0$ $0^0$ W, and $7^0$ $0^0$ and $8^0$ $0^0$ N, Moist Semi-Deciduous North-West zone forests - referred to as site 2 in this study) located at Akordie in the Brong-Ahafo Region; and Suii river reserve ($2^0$ $0^0$ and $3^0$ $0^0$ W and latitude $6^0$ $0^0$ and $7^0$ $0^0$ N, Moist Evergreen zone forest - referred to as site 3 in this study) and located at Sefwi Wiawso in the Western Region (Abeney et al. 2012; Ministry of Lands and Natural Resources - MLNR 2012). The 3 regions where these reserves are located form about 60% of the 5 main regions that have forest reserves in Ghana and which are home to about 71.62% of total forest estate of the country (Antwi 1999).

The range of annual temperature and precipitation of the 3 sites were 23.9-26.9°C and 1200-1400mm; 24.3-27.8°C and 1400-1600mm; and 24.5-28.2°C and 1600-1800mm respectively for sites 1, 2 and 3 (Logah et al. 2013).

### b) *Data collection*

Estimation of above-stump total merchantable wood volumes'.

In this study, total above-stump merchantable wood volume (TMWV) refered to extracted log volume (ELV) plus total merchantable residue volume (TMRV) but do not include stumps. Hence *TMWV= TMRV+ ELV.* Smalian's formula was used for the estimation of all volumes in this study (Briggs 1994; Forest Products Management Development Institute 1998). Smalian's formula has acceptably been used to estimate volume of all tree sections (except stumps) as done by Eshun (2000). Though the formula is reported to overestimate stem logs by about 6%, it is considered relatively accurate among cubic scaling formulae (Forest Products Management Development Institute 1998; Patterson *et al.* 2007).

i. *Estimation of merchantable residue volume*

Total merchantable residue volume (TMRV) of each tree and species comprised; 1) Total volume of stem off-cuts ($TV_{sof}$) which also consisted of volume of stem butt-end off-cuts ($V_{sbt}$) and volume of stem crown-end off-cuts ($V_{scr}$), and 2) Volume of branch logs ($V_{bch}$), of trees and species. i.e. TMRV = $TV_{sof}$ ($V_{sbt}$ + $V_{scr}$) + $TV_{bch}$.

a. *Estimation of Volume of stem off-cuts ($V_{sof}$)*

For each tree, $V_{sof}$ was determined by adding/combining the volume of stem butt-end off-cut ($V_{sbt}$) and volume of stem crown-end off-cuts ($V_{scr}$), i.e. $V_{sof} = V_{sbt} + V_{scr}$. For both $V_{sbt}$ and $V_{scr}$, two diameters (at near right-angles to each other) were measured from both the top end (where the first log was cut), and at the base end (where the tree was felled off the stump). The distance between the two ends was measured as the total length of each, after which the diameters and lengths were substituted into Smalian's formula to determine the volume for each off-cut for each tree. The total for each species was found as the sum of the volumes of each tree within the species. At instances where measurements of diameters at any end and full lengths of some sections were not possible, such measurements were estimated and added, as proposed by Dean (2003).

b. *Volume of merchantable branchwood*

Merchantable branch logs volume ($V_{bch}$) in terms of suitability for lumber production, were considered to be branches without sweeps or crooks and also excluding the basal portions of branch forks (which are basically knots) and damaged branches. As a result, measurements on branches were done in segments (short lengths or billets) to avoid major natural defects (like curvature, sweeps, crooks etc. that can have influence on measurements) similar to what was proposed by Pillsbury and Pryor (1989).

For each tree within the sample, all merchantable branches with diameters ≥ 15cm were measured. For each branch/segment, diameters were

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taken at the base just above the fork and at the top, just before the next branching. The distances between these two points where diameters were taken, were measured as the length of the branch/segment. Although Pillsbury and Pryor (1989) measured branch segments to include the basal area of branch forks, because such areas are basically knots, they were therefore not considered in this study as being part of merchantable branch log for lumber production. This is also because, knots reduce mechanical strength of wood and can also pose sawing difficulties like blunting of saws. (Haygreen and Bowyer 1996). All visible branches on each tree were measured, but in some cases, there were identified branches which were not accessible for measurements of diameters at each end or full length owing to their locations and the volume of foliage that covered them. For such branches those measurements were estimated and added, as was proposed by Dean (2003). Afterwards, volumes of all segments for each tree were tallied together as the volume of branchwood ($V_{bch}$) for that tree. The total volume of branchwood ($TV_{bch}$) for each species was found as the sum of the volume of each tree within the species.

ii. *Volume of extracted log (main boles delivered at the mill's gate)*

Stock survey numbers and species' names recorded on stumps of all trees whose off-cuts and branchwoods were measured, were used to trace their utilised/extracted logs volume (ELV) from log loading yard records (otherwise called felling records) of the respective logging sites (reserves). This was done so as to obtain the exact volumes of logs actually extracted from the sampled trees and which was of much importance in this study for regression analysis. The ELV for each species was found as the sum of the volume of each tree within the species.

c) *Data analysis*

All the 154 sampled trees were used for analyses of; TMRV (branchwood and stem off-cuts) and ELV from the three ecological zones/sites, and the harvesting efficiencies among the various timber species and the 3 sites. Both descriptive and inferential statistical analyses (comprising means and standard deviations, percentages and analysis of variance-ANOVA) using MS-excel 2003 and 2007, and SPSS 16.0 version were done to compare group means and determine differences among obtained values. Linear regression analyses were also conducted to establish the relationship between ELV and TMWV, and ELV and TMRV for the 7 species found to be common to all the 3 sites (species specific model), all species within the 3 sites (site specific model) and all species and sites together (mixed species and site model) to predict TMWV and TMRV using ELV as an indirect predictor variable. Equations 1 and 2 depict the relationship between ELV and TMWV, and ELV and TMRV respectively.

$$TMWV = \alpha\, ELV + C \quad (1)$$

$$TMRV = \alpha\, ELV + C \quad (2)$$

Where $\alpha$ indicates the quantum of increase/decrease in either TMWV or TMRV for each cubic meter ($m^3$) rise/fall in ELV and C is a constant {i.e.; intercept indicating the value of TMWV or TMRV at situations where ELV is zero}.

## III. Results

a) *Total merchantable residue quantity and harvesting efficiency*

The 154 randomly sampled trees consisted of 20 different species and their distribution across the 3 study sites are: site 1=11, site 2= 10 and site 3=19 species with only 7 species being common to all the 3 sites (Table 1). The 11 species from site 1 provided the highest mean extracted log volume (ELV) of 15.51$m^3$ per tree but a mean total merchantable residue volume (TMRV) of 4.85$m^3$ per tree whereas the 10 species from site 2 provided the least mean ELV of 13.40$m^3$ per tree and a mean TMRV of 4.34$m^3$ per tree. However, the 19 species from site 3 produced the highest TMRV of 5.13$m^3$ per tree.

For the individual species, (Table 1) *Triplochiton scleroxylon* out numbered the other species across the sites and represented about 23.4% of the total sample size. The ELV for the various species ranged from the highest of 33.91$m^3$/tree for *Ceiba pentandra* from site 1 to the lowest of 6.74$m^3$/tree for *Celtis mildbraedii* from site 2. However, the TMRV ranged from the highest of 14.2/tree for *Entandrophragma angolense* from site 3 to the lowest of 1.32$m^3$/tree for *Nesorgodonia papaverifera* also from site 3.

*Table 1 :* Summary of data collected on extracted log volume and merchantable residue from the 3 study sites

| Wood Species | N | Mean ± SD of Extracted log volume (ELV) per tree ($m^3$) | | | Mean ± SD of Total merchantable residue volume (TMRV) per tree ($m^3$) | | |
|---|---|---|---|---|---|---|---|
| | | Site 1 | Site 2 | Site 3 | Site 1 | Site 2 | Site 3 |
| *P. africanum* ( dahoma) | 24 | 13.39 ±7.46 | 23.89±5.70 | 9.60±2.26 | 6.03±3.71 | 7.69 ±0.77 | 4.37 ±1.03 |
| *A. toxicaria* ( kyenkyen) | 11 | 20.92±10.12 | 17.37 | 17.77±1.35 | 5.47±3.05 | 4.61 | 7.26±0.55 |
| *T. scleroxylon* ( Wawa) | 36 | 15.26 ±4.59 | 14.91±4.19 | 14.89±4.00 | 3.07±1.36 | 4.19±3.25 | 5.18±1.39 |
| *C. mildbraedii* ( Esa) | 11 | 12.52 ±3.84 | 6.74 ±1.87 | 7.20 | 1.68 ±1.02 | 3.45±4.10 | 2.34 |
| *E. angolense* (edinam) | 7 | 19.56 ±6.69 | - | 13.95±3.76 | 6.78 ±2.75 | - | 14.20±3.44 |
| *Khaya spp.* (mahogany) | 6 | 10.71 ±7.55 | 16.61 | 12.87 ±3.70 | 8.03±4.61 | 9.00 | 7.53±2.16 |
| *E. cylindricum* (sapele) | 14 | 14.25 ±3.27 | - | 15.06 ±4.35 | 4.15 ±1.78 | - | 3.73±0.94 |
| *T. superba* (ofram) | 15 | 9.23 ±1.91 | 10.6 ±1.35 | 13.99±3.78 | 4.46 ±2.04 | 3.33±4.39 | 4.13±1.18 |
| *A. pterocarpoides* (yaya) | 2 | 18.19 ±4.67 | - | - | 8.98 ±6.56 | - | - |
| *C. pentandra* (onyina) | 6 | 33.91±0.85 | 14.82 | 16.79 | 4.48±1.03 | 4.92 | 6.06 |
| *N. papaverifera* (danta) | 3 | 9.25 | 10.58 | 8.00 | 4.13 | 5.04 | 1.32 |
| *C. gabunensis* (denya) | 3 | - | 18.09 ±0.46 | 12.96 | - | 7.74±3.28 | 4.26 |
| *P. macrocarpa* (koto/kyere) | 7 | - | 7.08 ±1.03 | 8.32 ±2.21 | - | 0.77 ±0.34 | 1.92±0.61 |
| *E. utile* ( utile) | 1 | - | - | 20.56 | - | - | 5.34 |
| *A. ferruginea* (albizia) | 2 | - | - | 13.87±5.56 | - | - | 2.27±0.91 |
| *Milicia excelsa* (Iroko/odum) | 1 | - | - | 19.83 | - | - | 0.59 |
| *Guarea spp*. (guarea ) | 1 | - | - | 7.70 | - | - | 3.10 |
| *G. ehie* ( hyedua) | 1 | - | - | 7.50 | - | - | 1.34 |
| *T. heckelii* ( Baku) | 1 | - | - | 20.90 | - | - | 7.05 |
| *A. robusta* ( Asanfena) | 2 | - | - | 8.47±4.18 | - | - | 3.13 ±1.55 |
| TOTAL | 154 | 15.51±7.85 | 13.40±6.78 | 13.64±4.57 | 4.85±3.14 | 4.34 ±3.52 | 5.13±3.45 |

The total merchantable wood volume (TMWV) of the 154 samp 154 timber trees was about 2,964m$^3$ out of which the volume of logs delivered at the mills gate or extracted log volume (ELV) was about 2,221m$^3$ (Table 2). The ELV averaged 75.31% of the TMWV and this represents the general average harvesting efficiency of the 3 sites/ecological zones in this study. On the average, harvesting efficiencies of the various wood species found in all 3 sites however, ranged from the highest of about 83.66% for *Ceiba pentandra* (onyina) to the lowest of 59.54% for *Khaya ivorensis* (mahogany). The general TMRV (stem off-cuts + branchwoods) was found to be 742.57m$^3$ representing about 25% of the TMWV.

*Table 2 :* Merchantable wood quantities and logging efficiencies among various wood species

| Species | | Extracted log volume –ELV (m$^3$) | Merchantable residue volume- MRV | | | Total merchantable wood- TMWV (m$^3$) |
|---|---|---|---|---|---|---|
| Names | N | | Branchwoods (m$^3$) | Stem off-cuts (m$^3$) | Total –TMRV (m$^3$) | |
| *P. africanum* (dahoma) | 24 | 345.17 (67.76) | 132.40(29.31) | 13.94(2.93) | 146.35(32.24) | 491.52 |
| *A. toxicaria* (kyenkyen) | 11 | 213.98(76.04) | 43.37 (15.70) | 23.16(8.26) | 66.52(23.96) | 280.50 |
| *T. scleroxylon* (wawa) | 36 | 540.67(78.27) | 90.83 (13.51) | 58.56(8.21) | 149.39(21.72) | 690.06 |
| *C. mildbraedii* (esa) | 11 | 109.28(81.92) | 22.30 (14.98) | 3.92 (3.10) | 26.21(18.08) | 135.50 |
| *Khaya spp.* (Mahogany) | 6 | 74.48 (59.54) | 34.39 (29.25) | 13.76(11.20) | 48.15(40.45) | 122.64 |
| *T. superba* (ofram) | 15 | 162.69(76.07) | 34.09 (13.98) | 23.89 (9.95) | 57.97(23.93) | 220.66 |
| *C. pentandra* (onyina) | 6 | 167.24(83.66) | 14.03 (7.94) | 14.88 (8.40) | 28.90(16.34) | 196.14 |
| Total of 7species common to all sites | 109 | 1613.51(75.06) | 371.41(17.98) | 152.09(6.95) | 523.50(24.93) | 2137.01 |
| Total of other species | 45 | 607.90(75.90) | 184.59(19.23) | 34.47 (4.87) | 219.07(24.09) | 826.97 |
| Total of all species | 154 | 2221.41(75.31) | 556.01(18.35) | 186.56(6.34) | 742.57(24.69) | 2963.98 |

*Numbers in parentheses are volume in relation to TMWV expressed in percentages (efficiencies)*

b) *Differences in merchantable branchwood, stem (off-ctus) and harvesting efficiencies among species and study sites*

Analyses of variance (ANOVA) indicated significant differences at 95% confidence level, in branchwood among the various wood species (P = 0.000; Table 3) and the study sites (P= 0.013; Table 4). Moreover, there were also significant differences in the quantity of stem off-cuts among the various wood species (P = 0.004; Table 5) and among the study sites (P= 0.000; Table 6 ) all at 95% confidence level.

*Table 3* : ANOVA of merchantable branchwood in total merchantable wood volume among species

| Source | Type III Sum of Squares | df | Mean Square | F- Value | P-Value | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 9730.221[a] | 19 | 512.117 | 3.487 | .000*** | .331 |
| Intercept | 14898.219 | 1 | 14898.219 | 101.439 | .000*** | .431 |
| Wood Species | 9730.221 | 19 | 512.117 | 3.487 | .000*** | .331 |
| Error | 19680.449 | 134 | 146.869 | | | |
| Total | 81245.048 | 154 | | | | |
| Corrected Total | 29410.670 | 153 | | | | |

*a. R Squared = .331 (Adjusted R Squared = .236). Significant ** * P< 0.001*

Table 4 : ANOVA of merchantable branchwood in total merchantable wood volume among study sites

| Source | Type III Sum of Squares | df | Mean Square | F-Value | P-Value | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 1654.699[a] | 2 | 827.350 | 4.501 | .013** | .056 |
| Intercept | 46219.727 | 1 | 46219.727 | 251.448 | .000*** | .625 |
| Study sites | 1654.699 | 2 | 827.350 | 4.501 | .013** | .056 |
| Error | 27755.971 | 151 | 183.814 | | | |
| Total | 81245.048 | 154 | | | | |
| Corrected Total | 29410.670 | 153 | | | | |

*a. R Squared = .056 (Adjusted R Squared = .044). Significant *** P< 0.001; ** P< 0.05*

Table 5 : ANOVA of off-cuts in total merchantable wood volume among species

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 1448.450[a] | 19 | 76.234 | 2.276 | .004*** | .244 |
| Intercept | 1811.105 | 1 | 1811.105 | 54.078 | .000*** | .288 |
| Wood Species | 1448.450 | 19 | 76.234 | 2.276 | .004*** | .244 |
| Error | 4487.772 | 134 | 33.491 | | | |
| Total | 11994.268 | 154 | | | | |
| Corrected Total | 5936.222 | 153 | | | | |

*a. R Squared = .244 (Adjusted R Squared = .137). Significant *** P< 0.01*

Table 6 : ANOVA of off-cuts in total merchantable wood volume among study sites

| Source | Type III Sum of Squares | df | Mean Square | F-Value | P-Value | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 2407.514[a] | 2 | 1203.757 | 51.511 | .000*** | .406 |
| Intercept | 5647.571 | 1 | 5647.571 | 241.670 | .000*** | .615 |
| Study sites | 2407.514 | 2 | 1203.757 | 51.511 | .000*** | .406 |
| Error | 3528.707 | 151 | 23.369 | | | |
| Total | 11994.268 | 154 | | | | |
| Corrected Total | 5936.222 | 153 | | | | |

*a. R Squared = .406 (Adjusted R Squared = .398). Significant *** P< 0.01*

Moreover, analyses of variance indicated significant difference (P= 0.000; Table 7) in logging efficiencies among the species but not among the study sites (P = 0.435; Table 8) with $R^2$ values of 0.292 and 0.011 respectively. Wood species therefore explained 29% of the variation in logging efficiencies among the species.

Table 7 : ANOVA of Logging efficiencies among the wood species.

| Source | Type III Sum of Squares | df | Mean Square | F-Value | P-Value | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 7646.085[a] | 19 | 402.426 | 2.910 | .000*** | .292 |
| Intercept | 285817.412 | 1 | 285817.412 | 2066.850 | .000*** | .939 |
| Wood Species | 7646.085 | 19 | 402.426 | 2.910 | .000*** | .292 |
| Error | 18530.385 | 134 | 138.286 | | | |
| Total | 899585.443 | 154 | | | | |
| Corrected Total | 26176.470 | 153 | | | | |

*a. R Squared = .292 (Adjusted R Squared = .192). Significant *** P< 0.001*

*Table 8 :* ANOVA of Logging efficiencies among the study sites.

| Source | Type III Sum of Squares | df | Mean Square | F-Value | P-Value | Partial Eta Squared |
|---|---|---|---|---|---|---|
| Corrected Model | 286.834[a] | 2 | 143.417 | .836 | .435[ns] | .011 |
| Intercept | 815794.179 | 1 | 815794.179 | 4758.079 | .000*** | .969 |
| Study sites | 286.834 | 2 | 143.417 | .836 | .435[ns] | .011 |
| Error | 25889.636 | 151 | 171.455 | | | |
| Total | 899585.443 | 154 | | | | |
| Corrected Total | 26176.470 | 153 | | | | |

*a. R Squared = .011 (Adjusted R Squared = .002). Non-Significant [ns] P> 0.1; Significant *** P< 0.001*

c) *Relationship between total merchantable wood and extracted log, and total merchantable residue and extracted log*

Linear regression analyses of the relationships between ELV and TMWV, and between ELV and TMRV, for the 7 species found common in all 3 study sites indicated strong, positive and significant correlation between ELV and TMWV at 95% level of confidence with $R^2$ values from 0.50-*Terminalia superba* to 0.99-*Ceiba pentandra* and P values of 0.000 generally (Table 9). The relationship between ELV with TMRV of the species, were though positive, they were generally not strong and not significant at 95% level of confidence with $R^2$ values ranging from 0.01to 0.48 espectively for *Piptadeniastrum africanum* and *Celtis mildbradii* (Table 9).

*Table 9 :* Relationship between extracted log volume and total merchant wood volume, and total merchantable residue volume for seven species common to all 3 study sites (species specific model),

| Species | Total merchantable wood vol. (TMWV) | | | Total merchantable residue Vol. (TMRV) | | |
|---|---|---|---|---|---|---|
| | Regression Equation | $R^2$ | P-Value | Regression Equation | $R^2$ | P-Value |
| *P. africanuum* | y =1.308 x +1.654 | 0.95 | 0.000 | y=0.284 x + 1.425 | 0.48 | 0.000 |
| *A. toxicaria* | y=1.072 x + 4.642 | 0.92 | 0.000 | y=0.044 x + 3.075 | 0.02 | 0.510 |
| *T. scleroxylon* | y = 1.121 x+ 2.324 | 0.89 | 0.000 | y =0 .043 x + 1.875 | 0.06 | 0.079 |
| *C. mildbraedii* | y= 0.948 x + 2.892 | 0.71 | 0.001 | y = -0.065 x + 2.681 | 0.01 | 0.804 |
| *Khaya spp.* | y = 1.522x+ 1.539 | 0. 98 | 0.000 | y = 0.414 x+ 0.584 | 0.30 | 0.007 |
| *T. superba* | y=1.189 x + 1.806 | 0.50 | 0.003 | y = 0.151 x+ 3.916 | 0.02 | 0.572 |
| *C. pentandra* | y = 0.943 x + 6.392 | 0.99 | 0.000 | y = -0.015 x+ 2.774 | 0.001 | 0.289 |

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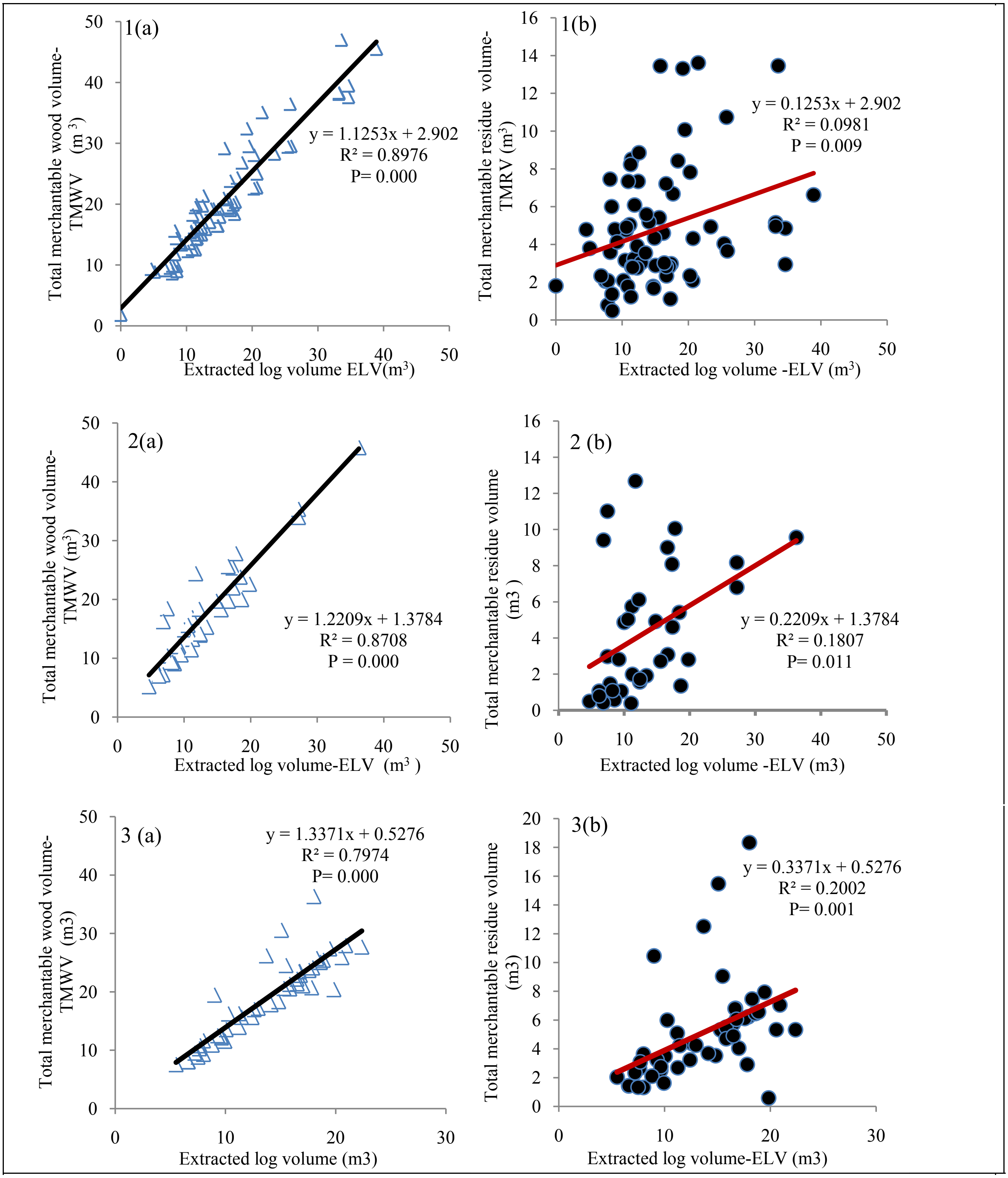


*Figure 1 :* Relationship between: (a) extracted log volume and total merchantable wood volume, and (b) extracted log volume and total merchantable residue volume at each site (site specific models); 1=Site 1, 2= Site 2, 3= Site 3

The relationship between ELV and TMWV, and TMRV at the 3 study sites were all positive (site specific model-Fig. 1). From Fig.1, the correlation of ELV and TMWV were stronger and highly significant ($R^2$ ranging from 0.797-site 3 to 0.898-site 1 and P=0.000 for all) at 95% confidence level. But the relationships of ELV and TMRV, though were not strong at any site, they appeared significant ($R^2$ ranging from 0.098-site 1 to 0.200-site 3; and P=0.009-site 1 to 0.001-site 3). The $R^2$ values point out that, at each forest reserve/site, ELV can predict the TMWV more accurately than it can predict the TMRV.

Moreover, the final model that looked at all the 20 species together (154 trees in all) and from the 3 study sites combined (mixed species and sites model), also indicated positive, strong ($R^2$= 0.867) and highly significant (P= 0.000) correlation between ELV and TMWV at 95% confidence level (Fig. 2). However, the correlation between ELV and TMRV was not strong ($R^2$= 0.128) but significant (P=0.000) at 95% confidence level. These $R^2$ values suggest that whereas ELV is a weak predictor variable for TMRV, it is a strong predictor variable for TMWV.

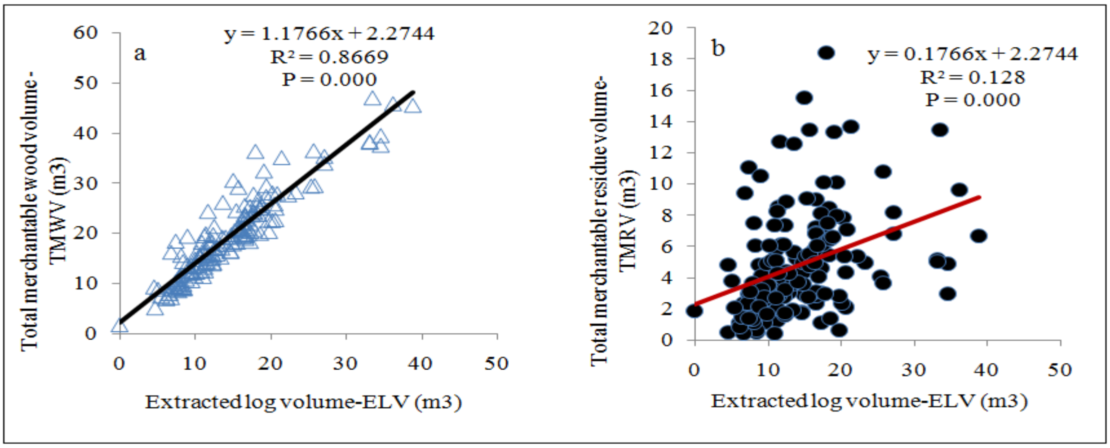


*Figure 2 :* Relationship between: (a) extracted log volume and total merchantable wood volume, and (b) extracted log volume and total merchantable residue volume for all species (154 Trees) from all 3 sites altogether (mixed species and sites model)

## IV. Discussions

### a) *Total merchantable residue quantity and harvesting efficiency*

The total merchantable residue quantity (25%) and harvesting efficiency (75%) obtained in this present study appear to corroborate findings of earlier studies in Ghanaian tropical forests (Eshun 2000; Ofori et al. 1993; Amoah and Becker 2009). These seem to indicate that from the 1990s, the general harvesting efficiency or logging recovery in Ghanaian tropical forests has generally not changed much. The findings could also mean that, although harvesting efficiency in some Ghanaian forests could be about 50% (Acquah and White 1998; Adam et al. 1993), generally, it appears that the consciousness of timber firms about the need to extract much of the main bole since the 1990s due to scarcity of timber has not changed. This consciousness was reflective in observed efforts by forest managers at the study sites as they continuously impressed upon loggers to reduce stump heights as much as possible, based on which loggers tried to fell trees close to the ground (≤1m above ground). Meanwhile it is worth noting that the 50% recovery rate obtained in the stated previous studies could be attributed to differences in methodologies and how merchantable wood was also defined in those studies. The consistency of the total merchantable residue quantity (about 25%) with previous studies, though this study did not include stumps in contrast with previous ones, for environmental reasons, could be ascribed to the inclusion of branchwoods of less than 30cm diameters down to a minimum of 13.5cm. These inclusions were based on reports that normal branchwoods are those of diameter ≥5cm (Gurau et al. 2008; Haygreen and bowyer 1996), but the previous studies covered only branchwoods ≥30cm in diameter. In support of these reports, Okai, (2003) successfully produced prototype furniture from 10cm to 25cm diameter branchwoods. Since the previous studies did not cover branchwoods of diameter < 30cm, the inclusion of branchwoods of diameters below 30cm in this present study, appeared to have increased branchwood quantity relative to findings from the other previous studies (Eshun 2000; Ofori et al. 1993; Amoah and Becker 2009) and this might have compensated for the stumps that were not covered.

On accounts of the covered diameters being within the normal branchwood bracket, the total merchantable residue volume (TMRV) obtained was considered to be of adequate quality to guarantee their extraction and subsequent utilization. Thus from the data in Table 2, an equivalent volume of about 38 trees {i.e., (743/2964) x154} could have been saved if firms had extracted the TMRV from the felled trees for processing and eventual utilization. According to Amoah and Becker (2009), about 5 trees per hectare are felled during felling cycles in tropical forests. To this end, the 38 trees that would have been saved should the TMRV were extracted, translates into about 7.6 hectares (i.e, 38/5). This implies that, should firms had extracted the merchantable residues for processing, about 7.6 hectares of forest land would have remained unlogged or conserved. This quantum of forest area would have then been available to provide the other service functions of forests (i.e. protection of soil and water bodies, shielding biodiversity, maintaining climate and protecting the entire ecological system), at least till the next felling cycle. It also means that, timber volume equivalent to 38 trees would have been added to the volume obtained already from the main boles for production, if the firm had extracted the TMRV from the felled trees. Better still, it implies that, the extraction of the residues will make available to the firms additional quantity of wood equivalent to logging about 8ha. of forest land. Meanwhile, the running cost of machinery and equipment in logging additional 8ha. may possibly be higher than extracting the residues from the already logged trees, which is an added advantage to residue extraction.

*b) Differences in merchantable branchwood, stem (off-cuts) and harvesting efficiencies among species and study sites*

The significant differences of branchwoods (P = 0.013) and stem off-cuts (P= 0.000) among study sites (Tables 4 and 6 respectively) were not so expected but the non-significant difference (P=0.435) of logging efficiency among study sites (Table 8) was expected. This is because, all the sites were being logged by the same firm and apparently with similar logistics and equipment for operations, except that worker groups were different among the sites. Hence the significant differences could be attributed to some attributes or attitudes of the different worker groups. Although worker groups from the same firm were expected to have similar skills, training and orientation on harvesting practices, there is the possibility of some workers disregarding any orientation and training on harvesting practices that avoid waste etc, especially in the absence of their superiors at the sites.

It is also reported that, differences in timber yield among different forest sites could basically be due to environmental factors like temperature, relative humidity, rainfall patterns, soil type and nutrients, and land topography (low or high lands) differentials (Chave et al. 2001; Basuki, et al. 2009; Ketterings et al 2001). In fact soil nutrient content and fluctuations account for a third of biomass variability among different forest sites ('Laurance et al. 1999). Additionally, water retention and drainage capacity are factors that also have greater influence on biomass variability among sites as they could lead to leaching of soil nutrients (Chave et al. 2001) and also destruction of various tree parts. Therefore some of these factors/variables might have led to the differences in the harvesting efficiency, branchwood and stem off-cuts quantity among the sites.

The significant differences in branchwood and stem off-cut quantities, and efficiencies among various species (Tables 3, 5 and 7 respectively) could also be partly due to tree architecture and genetics (canopy areas, plant/tree form or geometry, bole height, branching type and size of branches, buttress height and sizes)- Ketterings et al. 2001; Ford 1985). This appears to have been manifested in this study. The species with relatively large canopy areas and grow to about 50-65m high like *P. africanum* and *K. ivorensis* (Lemmens 2008; Richter and Dallwitz 2000) were those that had higher percentages of branchwoods but relatively lower logging efficiencies as compared to *C.pentandra*, a species that is branchless up to 35m high and grows over 60m high (Duvall 2011). This might have led to *Ceiba pentandra's* high extracted log volume and highest harvesting efficiency (83.66%; Table 2), but it was observed that due to its height before branching, most branches got damaged resulting from ground impact upon felling and making many of them not merchantable. This might have also made *Ceiba* had the least branchwood quantity (7.94%). Moreover, in all, tree canopy disturbances from past logging operations and tree positions within the forest canopy are among other factors that could also lead to significant differences in TMRVs among species (Ford 1985; Ketterings et al. 2001).

*c) Relationship between total merchantable wood and extracted log, and total merchantable residue and extracted log*

The relationship resulted in 3 models that predicted total merchantable wood volume (TMWV) and total merchantable residue volume TMRV from extracted log volume (ELV) for; individual species, all species at each study sites, and all (mixed) species and sites. These have some practical and theoretical implications. First, they will enable stakeholders (both industrialists and academics) in the wood industry to easily predict TMWV and TMRV from logs delivered at the mill gate (ELV) without necessarily having to spend energy, time and money to go to the forests to take inventory. Again, they will make negotiations on above-stump residue easier for both sellers and buyers, as the models could be used to easily estimate the volumes of such residues for; the species, all species from particular forest site, and all species from any of the 3 study sites for pricing and other purposes.

The $R^2$ values of the models for TMWV (0.50 for *T. superba*-Table 9 and 0.866 for all species-Fig. 2) appeared to be within the range found in previous studies (Amoah and Bercker 2009). This may therefore suggest that the $R^2$ value (0.02 for T. superba – Table 9 and 0.128 for all species-Fig. 2) is a true reflection of the weak correlation between ELV and TMRV. On account of the $R^2$ values obtained from the 3 models developed in this study, it could be concluded that ELV is a better predictor variable for TMWV but not too good for TMRV. However, the species specific model appeared to have a higher degree of predictive accuracy for both TMWV and TMRV relative to the other 2 models, at least for the 7 species that were common to the 3 study sites.

It is however necessary to indicate that, since the species covered in this study were dominated by

*Triplochiton scleroxylon and Pitadiniastrum africanum* (Table 1), the site specific, and the mixed species and sites specific models could be said to be basically applicable to *T. scleroxylon and P. africanum* than the other species (as found by Amoah and Becker 2009). Again the use of the models may have some limitations. For instance, should the harvesting efficiency changes substantially over some period of time, the models may not be accurate for that period within which such changes occurred since the ELV, which determines the harvesting efficiency, is the sole predictor variable. In the light of this, the models could be validated periodically based on new samples and data to assess current situation of the estimates. Moreover, an alternative variable to ELV could also be used either alone or in combination with ELV in models to estimate both TMWV and TMRV. This step may see a variable or a combination of variables that can estimate TMRV to a better level of accuracy than as has been done by ELV. However, until this is done, it will be appropriate to apply the model for TMWV after which the ELV could be subtracted to obtain the above-stump TMRV (i.e; TMWV-ELV=TMRV) without necessarily having to go to the forests before the residues could be quantified and priced.

## VI. Conclusions

Based on the results obtained in this study, the following conclusions were drawn;

1. On the average, harvesting efficiency from the 3 sites was 75% and it is within the range of previous studies.
2. Total merchantable residues quantity that can be extracted for eventual utilization (25% of total above stump merchantable wood) found in this present study agrees with previous studies.
3. Extraction and utilization of merchantable residues can result in improvement in the harvesting efficiecy and also lead to the conservation of a substantial quantity of forest land to protect the ecosystem or provide a substantial additional quantity of timber to augment timber raw materials available to the firms and this is also consistent with previous studies.
4. If timber processing firms in Ghana happen not to be much interested in utilizing the merchantable residues, at least, cottage industries or firms could be established in the forest communities to create jobs, improve the economic lives of the people, provide timber for the communities so as to reduce illegal chainsaw operations in the forest which will in turn contribute towards reducing depletion of the forests and also contribute to their conservation.
5. Generally, total merchantable wood quantity, total merchantable residue quantity and harvesting efficiency are significantly different among species.
6. Except harvesting efficiency, both total merchantable wood and residue quantities are significantly different among forest sites/ecological zones and this was consistent with literature.
7. Volumes of logs delivered at the mill gate (extracted log volume) is a better predictor variable for total merchantable wood volume than total merchantable residue volume. However, the species specific model happened to have higher prediction accuracy ($R^2$ from 0.50 to 0.99) and should therefore be considered first in predicting TMWV and TMRV. Nonetheless, it will be better to use the extracted log volume to quantify total merchantable wood volume after which the extracted log volume could be deducted to obtain the merchantable residue volume.

## V. Acknowledgement

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## References Références Referencias

1. Agyarko T (2001) FAO Corporate Document Repository FOSA Forestry Outlook Study for Africa. Country Report – Ghana, 2nd draft FOSA/WP/12. Ministry of Lands and Forestry 1-49.
2. Amoah M, Becker G (2009) Assessment of logging efficiency and development of allometric models for predicting stumpage volume of some commercial tree species in Ghana. International Forestry Review 11: 1; 1-11.
3. Antwi L B (1999) What We Have; Our Forest Heritage, in Owusu JGK, Abeney EA, Frimpong E A (eds.) Workshop for media personnel on forestry and wildlife reporting proceedings, Department of Silviculture and Forest Management-FRNR-KNUST, Kumasi, Ghana 24-29.
4. Asumadu K (2004) Development of Wood-Based Industries in sub-Saharan Africa, Asumadu and Associates, East Brighton. Australia 1-40.
5. Ayarkwa J, Hirashima Y, Sasaki Y (2000a) Effects of Finger Geometry and end Pressure on the Flexural Properties of Finger-Jointed Tropical African Hardwoods, Forest Products Journal 50: 11/12; 53-63.
6. Ayarkwa J, Hirashima Y, Sasaki Y (2000b) Predicting Tensile Properties of Finger-Jointed Tropical African Hardwoods Using Longitudinal Vibration Method, Ghana Journal of Forestry 9: 45-56.

7. Abeney EA, Boakye EA, Adane S A (2012-unpublished) Social Impact Assessment Report on Logs and Lumber Limited, Forest Fringe Communities and Forest Workers. Logs and Lumber Limited (LLL); 2-43.32.
8. Basuki TM, Van-Laake PE, Hussin YA (2009) Allometric equations for estimating the above-ground biomass in Tropical lowland Dipterocarp forests, Forest ecology and management 257: 1684 – 1694.
9. Briggs D G (1994) Forest Products Measurements and Conversion Factors: with Special Emphasis on the U.S. Pacific Northwest pp 2 - 23 in: Rural Technology Initiative (RTI)-Measurements of Logs. www.ruraltech.org/projects/conversions/.../chapter 02_combined.pdf. (Accessed, 06-November-2013).
10. Chave J, Riera B, Dobois M (2001) Estimation of biomass in a neotropical forest of French Guiana: spatial and temporal variability, Journal of Tropical Ecology 17: 79-96.
11. Dean C (2003) Calculation of Wood Volume and Stem Taper using Terrestrial Single-Image Close-Range Photogrammetry and Contemporary Software tools, Silva Fennica 37: 3; 359-380.
12. Duvall C S (2011) Ceiba pentandra (L.) Gaertn [internet]. Record from PROTA4U, Brink, M & Achingan – Dako, E. G. (Editors). PROTA (plant Resources of Tropical Africa, Wageningen, Netherlands.<http://www.prota4u.org/search.asp>. (Accessed, 15-January-2014).
13. Eshun A A (2000) Logging residue from the tropical high forests in the Western Region of Ghana, a graduate thesis submitted for the degree of master of science in Forestry, Faculty of Forestry and Forest Environment, Lakehead University. Canada. www.collectionscanada.gc.ca/obj/s4/f2/dsk1/tape2/mQ52054.pdf (Accessed, 20- June,-2012).
14. FAO - Food and Agriculture Organization (2010) Global Forest Resources Assessment, 2010. Country Report, Ghana. http://fao.org/docrep/03/al513E/al513E.pdf (Accessed 16-September-2012).
15. Ford E D (1985) Branching crown structure and the control of Timber production. In: Cannel, M. G. R., Jackson, J.E.,(eds). Attributes of trees as crop plants. Abbots Ripton, Institute of Terrestrial Ecology 228 – 252.
16. Forest Products Management Development Institute. (1998). Wood Measurement – volume measurement of log, University of Minnesota http://www.forestprod.org/cdromdemo/wm/wmhp.html (Accessed 29- December-2012).
17. Gurau L, Cionca M, Mansfield-Williams H, Sawyer G, Zeleniuc O (2008) Comparison of the mechanical properties of branch and stem wood for three species; Wood and Fibre Science 40: 4; 647-656.
18. Hawthorne W D, Abu-Juam (1995) Forestry Protection in Ghana with particular reference to vegetation and plant species IUCN/ODA/Forestry Department, Ghana 1-30.
19. http://en.climate-data.org/location/717637; Tempera -ture and rainfall/precipitations of Ghana. (Accessed 14-June 2014).
20. Haygreen J G, Bowyer J L (1996) Forest Products and wood science-an introduction, 3rd edition, IOWA State University Press, Ames. U.S.A 155-276.
21. Houghton R A (2005) Aboveground forest biomass and the global carbon balance, Global Change Biology 16: 6; 945-988. http://en.climate-data.org/location/717637. Temperature and rainfall/precipitations of Ghana. (Assessed, 14-June-2014).
22. Ketterings Q M, Coe R, Noordwijk M V, Ambagae Y, Palm C A (2001) Reducinguncertainty in the use algometric biomass equations for predicting above-ground tree biomass in mixed secondary forests. Forest Ecology and Management 146: 199 – 209.
23. Laurance W F, Fearnside PM, Laurance S G, Delamonica P, Lovejoy T E, Rankin-De-Merona J M. Chambers, J.Q. and Gascon, C (1999) In; Chave, J. Riera, B., Dubois Marc-A (2001) Estimation of biomass in a neotropical forest of French Guiana and temporal variability. Journal of Tropical Ecology. 17, 79 – 96.
24. Lemmens, R. H. M. J. 2008. Khaya ivoransis A. Chev. [internet] Record from PROTA4U. Louppe, D., Oteng – Amoako, A. A. $ Brink, M., (Editors). PROTA (Plant Resource of Tropical Africa), Wagenningen,Netherlands.
25. Logah FY, Obuobie E, Ofori D, Kankam-Yeboah K (2013) Analysis of Rainfall variability in Ghana. International Journal of Latest Research in Engineering and Computing (IJLREC) 1: 1; 1-8.
26. Marfo E (2010) Chainsaw milling in Ghana: Context, driversandimpacts.Tropenbos International, Wageni ngen, the Netherlands.
27. Ministry of Lands and Natural Resources-MLNR (2012). Ghana-Forest Investment Program(FIP) Plan. Draft-March 2012. http://www.fcghana.org/assets/file/Programmes/Forest_Investment_Plan_fip/Ghana%(accessed, 28- November-2012).
28. Moffat A, Nisbet T, Nicoll B (2011) Environmental effects of stump and Roots harvesting, Forestry Commission Research Note (FCRN009. www.forestry.gov.uk/forestresearch. (Accessed, 15-September-2012).
29. NKetiah A S (1992) In; Eshun A A (2000) Logging residue from the tropical high forests in the Western Region of Ghana, a graduate thesis submitted for the degree of master of science in Forestry, Faculty of Forestry and Forest Environment, Lakehead

University.Canada. www.collectionscanada.gc.ca /obj/s4/f2/dsk1/tape2/mQ52054.pdf (Accessed, 20-June-2012).

30. Ofori J, Adam A R., Ofosu-Asiedu A (1993) In; Amoah, M. & Becker (2009) Assessment oflogging efficiency and development of allometric models for predicting stumpage volume of some commercial tree species in Ghana. International Forestry Review, 11, 1, 1-11.
31. Ofori J, Brentuo B, Mansah M, Mohammed A I, Boamah-Tawiah R. (2009) Properties of 10Ghanaian high density lesser-used species of importance to bridge construction – part 1: green moisture content, basic density and shrinkage characteristics, Ghana Journal of Forestry 25: 66 – 77.
32. Okai R (2002) A study on the milling and strength properties of branchwood and stemwood of *Terminalia ivorensis* (emire) and *Aningeria robusta* (asanfona), Fellowship Report, ITTO Tropical Forest Update 12: 1; 23 – 25.
33. Okai R. (2003) Can logging residues be used to help meet timber demands for the downstream processing sector? Conference paper for xii World Forestry Congress, Quêbec city. Canada. 1 – 6. www.fao.org/dicreo/ARTICLE/WFC/XII/0236-B4. HTM. (Accessed 1- February-2013).
34. Oregon Forest Resources Institute (2011) Environmental benefits of wood products,Oregon Forest Resources Institute, 317 SW Sixth Ave., Suite 400, Portland, Oregon U.S.A. 2-7.
35. Oten-Amoako A A, Odoom F K, Birikorang G, Ghartey P K, Poku O K B, Bitar G, Cardoso R., Kwofie J H S, Opoku F Y (2008) Voluntary Partnership agreeement timber industry restructureing group final report, June, 2008. www.fcghana.org/vpa/assets/file/IRWG Final Draft july.pdf (20-November-2013).
36. Patterson D W, Doruske P F, Hartley J, Hurd M (2007) Validating the patterson and doruska equation for estimating the volume of hardwood butt logs, Forest Product Journal 57: ½; 67-70.
37. Peskette L, Huberman D, Bowen-Jones E, Edwards G, Brown J (2008) Making REDD workfor the poor, A poverty Environment Partnership (PEP) Report. www.odi.org.uk/sites/odi.org.uk/files/odi-assets /publications-opinion-files/3451.pdf. (Accessed, 8-December-2013).
38. Pillsbury N H, Pryor D R. (1989) Volume equations for young growth softwood andhardwood species at BOGGS Mountain Demonstration State Forest, Natural Resource Management Department, California Polytechnic State University, San Luis Obispo.
39. Richter H G, Dallwitz (2000) Commercial timber; descriptions, illustrations, identification, and information retrieval. In England version 4th May, 2000.http://biodiversity.un.edu/delta. (Accessed, 15-April-2014).
40. Rinebolt D C (1996) The potential for using wood for energy and the implications forclimate change. In: Sampson R N, Hair D, eds. Forests and global change. Forest management opportunities for mitigating carbon emissions. Washington, DC. American Forests 2: 117-130.
41. The REDD Desk (2014) REDD in Ghana. http://thereddesk.org/what-redd-desk (Accessed 08-April-2014)
42. Tsoumis G (1991) Science and Technology of Wood; Structure, properties, utilization. Verlag Kessel, Thessalomiki, Greece 1-480.
43. UNFCCC (United Nations framework Convention on Climate Changer) (2008) Report of theConference of the parties on its thirteenth session, held in Bali from 3rd to 15th December, 2007. Adendum, Part 2. Document FCCC/CP/2007/6/Add. 1. UNFCCC, Bonn, Germany.
44. World Bank (1988) In Murray C H (1993) The Challenge of Sustainable Forest Management-What Future for World's Forest, FAO of the UN Commonwealth Forestry Review 34-60.
45. Zobel and Talbert (1991). In; Ayarkwa J (1998) The influence of site and axial position in the tree on the density and strength properties of the wood of Pterygota marcrocarpa, Ghana Journal of Forestry vol. 6; 34 – 40.