

Research Article

Evaluating Biomass And Carbon Stock Measurement From High-Density Uav Lidar Data For Teak (Tectona Grandis) Plantation: A Case Study In Rangamati, Bangladesh.

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Abstract

Tectona grandis plantations are generally managed for timber production and presently there is an increasing interest in understanding the carbon stocks of Teak plantations. The study was developed on carbon yield table for Teak in Rangamati, Bangladesh. In the study high-density UAV LiDAR field data was taken from 48.38 hectares in 44 sample plots and the leave size determined the 30 cm × 30 cm size in an average lifetime was 40 years. The average tree height and diameter respectively 11 meters and 35.70 cm from ground level to top height were measured. Approximately 9.94 Mt ha⁻¹ of biomass are estimated based on the allometric equation $Y = \exp\{-2.4090 + 0.9522 \ln(D^2 H^* S)\}$ and approximately 4.96 Mt ha⁻¹ of Carbon Stock in sample plots. The carbon yield table was constructed using the age, top height class and diameter class. The overall observation of the study concluded that the best-fit carbon yield models were developed for T. grandis with 85 percent accuracy by comparing actual carbon stock and predicted carbon stock.

Keywords : Biomass, Carbon Stock, LiDAR, Tectona grandis, Bangladesh.

INTRODUCTION

Tropical forest ecosystems play a key role in global carbon sequestration (Phillips and Lewis, 2014; Sullivan et al., 2017) by absorbing atmospheric carbon and storing it in tree biomass (Gebeyehu et al., 2019; Mackey et al., 2020). The climate of Bangladesh is tropical with a mild winter from December to February and a hot, humid summer with a warm and humid monsoon from June to September (Farukh, M.A et al., 2023). Bangladesh's CO₂ emissions in 2016 were estimated at 74 Mt, making it the 48th largest CO₂-emitting country in the world (Worldometers, 2022). It has been estimated that 367 tons of C ha⁻¹ are deposited by the trees in the forest of Bangladesh (Alamgir et al., 2009) which covers about 17.4% of the country's entire land area (Farukh, M.A et al., 2023). The trees of only the Chittagong Forest division of Bangladesh can seize 1.9 million tons of C yr⁻¹ (Alamgir et al., 2005). Likewise, the total

consumption by terrestrial ecosystems of 0.7 Gt C yr⁻¹ is minor compared to the fluctuation of about 60 Gt C yr⁻¹ consumed by plants, but a nearly the identical quantity is delivered by respiration and forest fires (Farukh, M.A et al., 2023).

Tectona grandis has always been the principal species in the plantation programs of Bangladesh more than 70% of the total plantation in hill forests is composed of teak (Rahman, 1982). Teak is not indigenous to Bangladesh and was introduced from Myanmar (former Burma) in 1871 at Sita Pahar Range, Kaptai forests of Chittagong Hill Tracts. Till 1998, 216000 hectares were raised by teak (Sajjaduzzaman et al., 2005). The age was considered as 40 years where the maximum top height was observed at 23 m and the minimum was 3.5 m. (Sajjaduzzaman et al., 2005). The area of total forest cover of Rangamati was 463120 hectares in 2015 from the Department of Forest and the Mixed Hill Forest class was the dominated class of the area that was 175916 hectares.

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Teak is a large, deciduous tree with gray to grayish brown branches whose leaves are ovate-elliptic to ovate, 15–45 cm long by 8–23 cm wide, and are held on robust petioles that are 2–4 cm long. Leaf margins are entire (FOC, 2014). Fragrant white flowers are borne on 25–40 cm long by 30 cm wide panicles from June to August. The corolla tube is 2.5–3 mm long with 2 mm wide obtuse lobes. *Tectona grandis* sets fruit from September to December; fruits are globose and 1.2–1.8 cm in diameter (FOC, 2014). Flowers are weakly protandrous in that the anthers precede the stigma in maturity and pollen is shed within a few hours of the flower opening (Tangmitcharoen and Owens, 1996). The flowers are primarily entomophilous (insect-pollinated), but can occasionally be anemophilous (wind-pollinated) (Bryndum and Hedegart, 1969).

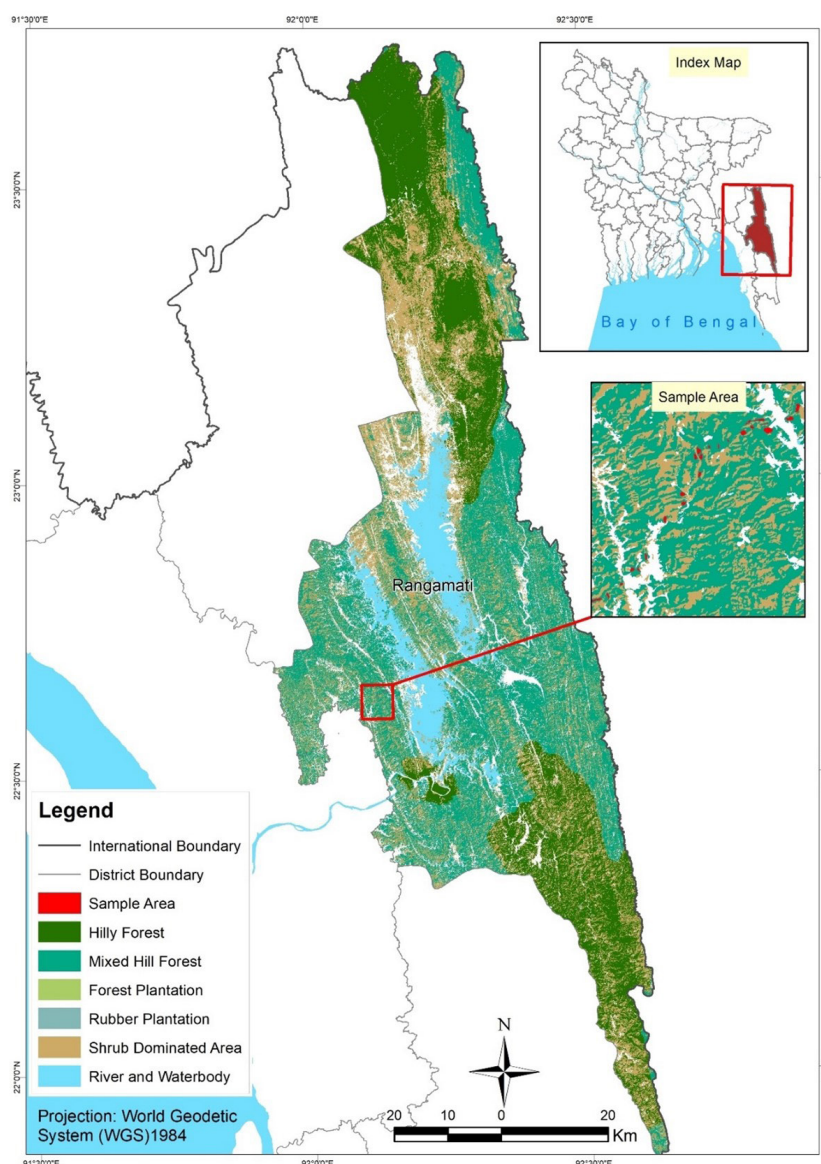
The present study is conducted in the scattered forest of the Rangamati district of the south-eastern region of Bangladesh. This study had a specific objective to use high-density UAV LiDAR data to explore the carbon stock associated with the Teak (*Tectona grandis*) in the tropical forest ecosystems of Bangladesh.

RESEARCH SITES AND DATA

Research sites

The study area Rangamati District is in Chattogram division and the area 6116.11 sq km, located between 22°27' and 23°44' North Latitudes and between 91°56' and 92°33' East Longitudes (**Fig.1**). It is bounded by Tripura state of India on the North, Bandarban district on the south, Mizoram state of India and Chinpradesh of Myanmar on the east, Khagrachhari and Chattogram districts on the west. The total sample area is 48.38 hectares in 44 sample plots. All sample plots are positioned in the Mixed Hill Forest class in the Forest Department (2015).

Figure 1. Study Area.



Data acquisition

LiDAR data were collected from 44 plots (Total area), which were selected through purposive sampling from various mono-specific plantations and forests at Rangamati in Bangladesh. In each plot, DBH (stem diameter at 1.3 m height) and H (height) of all individual trees were measured using diameter tape and the Criterion RD 1000 (Laser Technology Inc., USA), respectively. The total leaves count in the sample area is 5365360 the size is 30cm X 30 cm in raster resolution. The wood density of different species was obtained from the Global Wood Density Database (Chave et al., 2009; Zanne et al., 2009). The statistics of the samples on stand-level carbon stocks used in this study are presented in **Table 1**.

Table 1 Statistics of sources (basal area, mean height, max height and wood density) of stand-level carbon stocks based on sample plots from nine tree species.

Species	Variable	n	Mean	Minimum	Maximum	SD	CV (%)
Tectona grandis L. f.	BA	28	32.1	1.6	76.8	19.5	60.8
	H	28	19	3.8	25.1	5.5	28.9
	Hmax	28	24.2	5.5	38.3	7	28.9
	WD	28	0.72	0.72	0.72	0	0
	AGC	28	159.1	1.7	341.2	100.5	63.2
	BGC	28	29.9	0.6	60	17.4	58.1
	TC	28	189	2.3	401.2	117.9	62.4

Note: n ¼ number of plots (0.04 ha each), BA ¼ basal area ($m^2 ha^{-1}$), H ¼ mean height (m), Hmax ¼ max height (m), WD ¼ wood density ($g cm^{-3}$) AGC ¼ aboveground carbon ($Mg ha^{-1}$), BGC ¼ belowground carbon ($Mg ha^{-1}$), TC ¼ total carbon (aboveground þ belowground) ($Mg ha^{-1}$).

Lidar Data Analysis

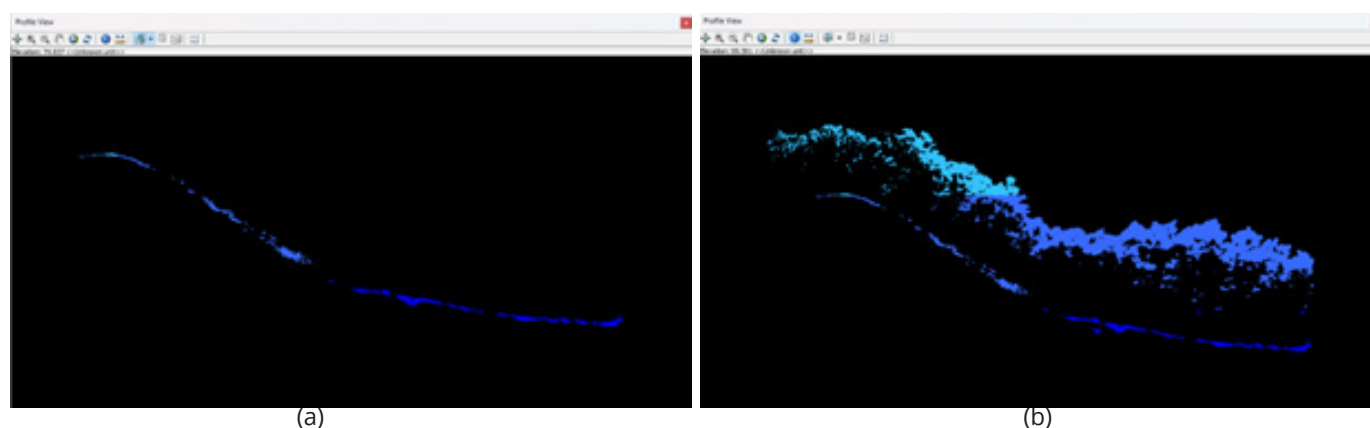
LiDAR point clouds were acquired from an aerial viewpoint and then merged into a single mesh by setting overlapping regions. The registration of each scan into a reference system was performed through ground control points (GCPs) in a similar way done in Photogrammetry. Four common control points were searched in the overlap region of scans based upon high reflective targets in the overlapping area between two scans (G.S. Maan et al., 2015). For transforming registered point cloud data into a geodetic coordinate system field GCPs were captured using DGPS and auto level. This transformation was the part of direct georeferencing of point cloud data (Lichti et al. 2005). Canopy height gives a possibility to estimate the Above Ground Biomass (AGB) and volume of the canopy. From LiDAR data, the height of the trees, diameter, and location can be measured directly (Liang et al. 2012). The values of these measurements are summarized in **Table 2**.

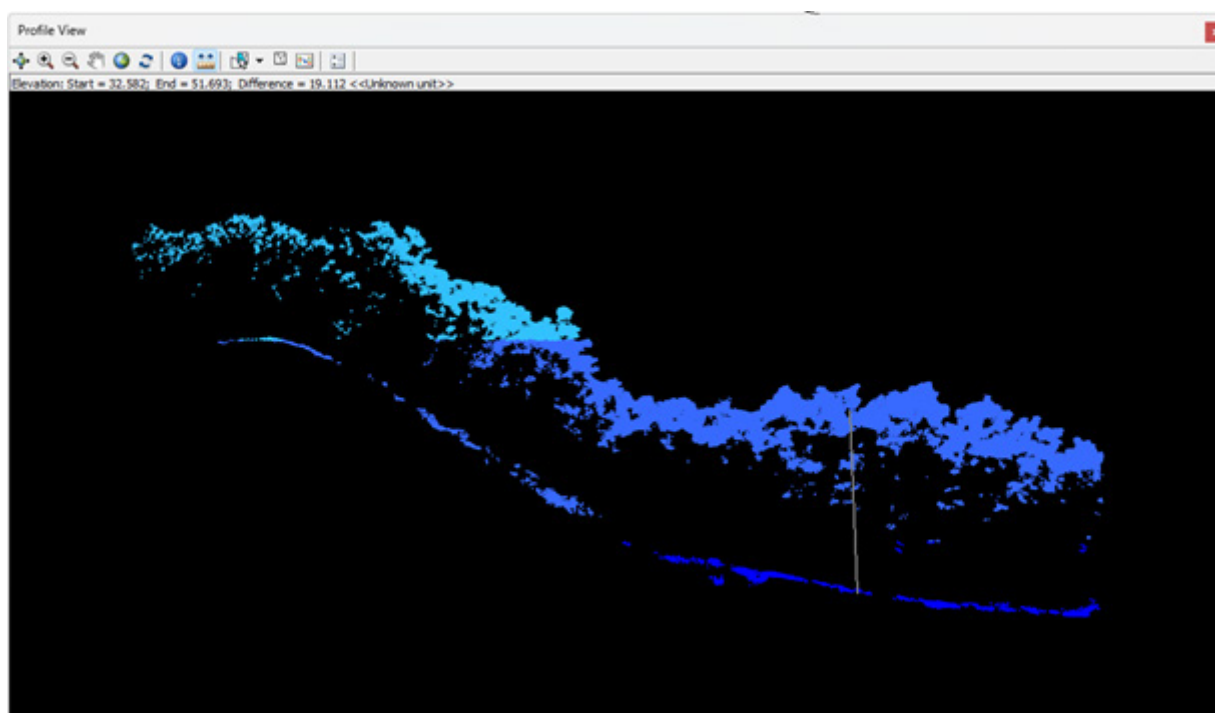
Table 2 Statistics of LiDAR detected tree height and DBH. (G.S. Maan et al., 2015).

Tree species	Average height (m)		Average DBH (cm)		Wood density (gm/cm^3)
	LiDAR	Manual	LiDAR	Manual	
Tectona grandis	11.92	11.00	37.30	35.70	0.58

Note: m = meter, cm = centimeter, gm = gram.

Figure 2. (a) Classified LiDAR data Ground Point Clouds (b) Classified LiDAR data Ground and Tectona grandis Point Clouds (C) Height of Tectona grandis



(C) Height of *Tectona grandis*

The DBH was estimated by selecting all LiDAR point styling having values starting from 17.085 m above the ground level. Then a cylindrical primitive was defined over the tree stem to measure the diameter. A cylindrical least square regression method was used to get the best fit of laser points on the cylinder reflected from the tree stem (G.S. Maan et al., 2015). Where Y is the AGB (kg), H is the height of the trees (meter), D is the diameter at breast height in cm, and S is the wood density (gm/cm³). Wood densities were obtained from the Food and Agriculture Organization website (<http://www.fao.org/docrep/w4095e/w4095e0c.htm>).

Brown et al. (1989) developed mathematical different equations to estimate forest biomass and individual tree species biomass, which are species-specific and general and easily applicable to field data (Schroeder et al. 1997). The model developed by Brown et al. (1989) is used in this study to estimate Above Ground Biomass (AGB). This non-destructive method is most applicable and appropriate for biomass estimation studies (Schroeder et al. 1997). The equation used for computing Above Ground Biomass (AGB) is:

$$Y = \exp \{-2.4090 + 0.9522 \ln(D^2 \cdot H \cdot S)\}$$

By estimating the number of trees from the Total Leaf Count and applying the Per Tree Biomass, we've calculated the Total Biomass to be approximately 480,731 kg. This estimation provides valuable insights into the carbon storage capacity of the tree population, which is crucial for ecological assessments and carbon sequestration studies. Typically, carbon constitutes about 50% of the dry biomass. The trees collectively store approximately 240,366 kg of carbon. Approximately 85 % accuracy by comparing actual carbon stock and predicted carbon stock between Satchari National Park and Khadimnagar National Park with the sample area of Rangamati district.

Table 3 Species-specific tree carbon stock (*Tectona grandis*) (Md.S.R. Saimun et al., 2021)

Area	Tree ha ⁻¹	MAGC (kg tree ⁻¹)	MBGC (kg tree ⁻¹)	MTC (kg tree ⁻¹)	TC (t ha ⁻¹)
Satchari National Park	34.17	281.08	42.16	323.24	13.09
Khadimnagar National Park	55.83	223.01	33.45	256.46	22.97

Note: MAGC – Mean above-ground carbon, MBGC – Mean below-ground carbon, MTC – Mean total carbon, TC – Total carbon.

CONCLUSIONS

High-density UAV LiDAR approach with secondary field measured forest attribute is suitable and provides a non-destructive technique to estimate biomass and carbon stock in forest inventory. This study has emphasized the high-density UAV LiDAR for the estimation of tree height, biomass and carbon stock. The quantitative forest measurement (tree GBH, height, location and species) is manually recorded based on an aerial UAV survey. It investigates the use of UAV LiDAR for providing quantitative tree height and DBH at the sampling secondary tree level for different tree species. It is stated that the estimation of tree height using a ground-based LiDAR in tropical regions is very complex and challenging for large regions. It is analyzed that UAV LiDAR-based tree measurement would increase the accuracy of biomass estimation in tropical regions. The result of this study indicates that the AGB and carbon stock are estimated very accurately. Although species-specific and regionally calibrated allometric equations to improve measurement precision and sampling techniques. Incorporating additional biomass components and conducting thorough uncertainty analyses. Studies have been done to estimate tree biomass and carbon stock. Results suggest that a robust method is needed to quantify tree species based on automatic processing of ground LiDAR data.

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