International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 4,2025
https://theaspd.com/index.php

Allometric Model for above Ground Biomass of Eucalyptus Clonal from Tropical dry Deciduous Forest of Odisha in India

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Abstract:
Global carbon stock through carbon credits were calculated according to the REDD+. Accurate biomass estimates for the various forest components are crucial. Directly or indirectly wood volume and mixed species allometric equations have been used for biomass calculation in India. Because, there is still lacking of biomass estimation equations in across India, specifically on species-specific equations, which are required to predict the above ground biomass (AGB) stocks non-destructively. Therefore, the objective of this article is to develop the species- specific allometric model for eucalyptus clonal trees. We have selected 2216 individual trees belonging to 21 sampling units of eucalyptus groups at the plantlet from a tropical dry deciduous forest of Odisha and developed tree specific allometric model for aboveground biomass assessment. The combination of height and girth at breast height are the parameters used to predict above-ground biomass. For each plot (strata) we have generated allometric equations and select the best allometric model to avoid the changes in the dependent variable (AGB) associated with the independent variables height and girth of eucalyptus species. Further, the belowground biomass (BGB) was estimated for 21 plots using above ground biomass and root to shoot ratio variable. We also compared with the existing volume equation and developed allometric equation for above-ground biomass which gives most accurate results; thus we recommend using the species-specific allometric model developed with girth and height for the above ground biomass estimation.
Keywords: *Above ground biomass (AGB), allometric model, carbon, below ground biomass (BGB), species specific equation, Tropical dry deciduous forest.*

1. INTRODUCTION:

Global climate change is widely recognized as the biggest hazard to all life on Earth, and despite numerous attempts, its severity is growing every day. The UN Framework Convention on Climate Change (UNFCCC) has developed REDD+ (Reducing Emissions from Deforestation and Forest Degradation), which values forests' ability to retain carbon for the purposes of conservation and restoration of forests (Pothong et al., 2021). To improve carbon sequestration, it strives for sustainable management, restoration, and conservation of forests (Mardiatmoko et al., 2019; Pothong et al., 2021). Accurate data on the pace of deforestation and the carbon stocks at a specific point in time are needed to quantify carbon emissions or prevented emissions. Accurate assessments of the carbon stocks in forests are necessary in order to provide carbon credits under REDD +. The National Mission for Green India (GIM) seeks to address the current climate change crisis by increasing the amount of land covered by forests up to 33% of the country's total land area and reducing 3 to 2.5 billion tons of carbon dioxide equivalents. Smaller individuals would be more common if more forests were planted on vacant land and secondary forests were restored with more natural regeneration.

Eucalypt has come up as one of the most widely planted tree species owing to its fast growth rate, capability of overtopping weeds, coppicing ability, fire hardiness, browse resistance and wide adaptability (Saxena, 1992). Eucalypt is an excellent source of pulpwood, firewood, charcoal, hardboard, particle board and also has medicinal values. According to the State of Forest Report, approximately 1,48,945,000 stems of

Eucalyptus species exist which accounts for 2.44% of the 3 trees by number and 26.07 million m^3 stock which would be 1.59% of the growing stock volume of trees outside forest at country level (FSI, 2019). The most accurate approach for estimating biomass is the destructive or harvesting method. But it results in the death of trees. The selection of the regression model is the primary cause of inaccuracy in the assessment of biomass and carbon stock (Chave et al., 2004, 2005, 2014; Molto et al., 2013). A common volume equation is applied over a wide area is used to compute tree biomass (Houghton, 2003; Chaturvedi and Raghubanshi, 2013). In India, attempts have been undertaken to measure the carbon stock at a macro level, primarily using secondary sources. Assessing AGB and soil carbon sequestration at the micro level in any particular Indian forest system has been attempted these kind of studies occasionally. As per our investigation and reference of various papers we came to know that till now there is no study related to eucalyptus clonal specific regression model based on non destructive procedure. Previous works related to volume allometric models which based on wood cutting method or destructive procedure. With this back drop we are motivated to make a study on eucalyptus clonal based on the region where the growth eucalyptus given prominence in forest. On the other hand, field data validation is necessary for the remote sensing method. Since the only measurable quantities used as inputs are girth at breast height and height of the tree, the non-destructive regression model based approach is one of the best choices for biomass and carbon stock estimation. Since carbon sequestration affects the global carbon balance, estimating above-ground biomass (AGB) is a crucial component of studies on carbon stocks. Studies estimating carbon stores are necessary to comprehend its entire potential in the forest system. As a result, estimating AGB is a helpful metric for contrasting the functional and structural characteristics of forest ecosystems under various environmental circumstances. Based on the relationship between whole-stand and individual-tree biomass estimations and the presumption that wood mass contains roughly 50% carbon, the habitat-site-specific biomass equations is conducted as part of the efforts to enhance carbon budget calculations. In three circles inside the Odisha woods, the species that contribute most to the growing stock had their AGB and CS (Carbon Stock) estimated in this study. Present study carried out on eucalyptus clonal species data from Odisha and developed regression equations also choose the best model among all the equations.

2. MATERIALS AND METHODS

2.1. **Study Area**

Odisha State lies between latitudes 17°49'N and 22°34'N and longitudes 81°27'E and 87°29'E. The geographical area of the state is 155,707 km², which is 4.87% of the landmass of the country, and the state has a coastline of 480 km. The climate of this state is tropical, with temperature ranging from 12°C to 45°C and the annual rainfall is about 1,200-1,500 mm, received mainly from the southwest monsoon. The recorded forest area of the state is 58,136 km², which is 37.3% of the geographical area, and the reserve forests constitute 43.3%, protected forests 10.2%, and unclassified forests 46.5%. Sample plots were located through geographic coordinates which are start from 18.65'N to 82.65'E. .
[Government of Odisha. (n.d.). Odisha at a Glance. Retrieved from odisha.gov.in Ministry of Environment, Forest and Climate Change. (2020). India State of Forest Report 2019. Forest Survey of India. Retrieved from fsi.nic.in India Meteorological Department. (n.d.). Climate of Odisha.]

2.2 Field of Sampling:

Eucalyptus is the species most widely introduced is a long and ever green tree belonging to family Myrtaceae (Rassaeifar et al., 2013). Eucalyptus, a genus of more than 500 species, has become the most planted genus of tree in the world (Teketay, 2000). Eucalyptus is cultivated in almost all states and Union territories of India, and the most suited variety from the 700 available species are picked according to the region of cultivation. Large-scale plantations of Eucalyptus were grown in India on forest and farmland, community lands, field borders and road/rail/canal strips. Eucalyptus tereticornis Sm. (Syn. Eucalyptus hybrid) has been the most outstanding and favored of some 170 species, varieties and provenances tried in India (Bhatia, 1984). Many eucalypt-based agro-forestry models with various spacing's and crop combinations have been into practice in India (Kulkarni, 2014). We have selected sample plots by the statistical procedure of sample size formula with the plot size 16X16 m which was generally followed by the India's National Forest Inventory (NFI). It provides an efficient and representative sampling of forest resources while allowing for easy extrapolation to a hectare scale. (Subhash Ashutosh, DG, Sushant Sharma, JD*et.al.*FSI Technical Information Series,2020). Hence, precisely the 16 X 16 m plot size allows for efficient and practical way of assessment while facilitating straightforward scaling up of results to the hectare level commonly used in forestry projects in India. The scaling factor of 40 makes extrapolation simple. These sample plots were laid, and coordinates were collected at each corner. The details of the trees were collected as mentioned in the diagram below. The numbers at the extremities near the arrows are of the corners. The trees at the edges had their stems painted with the corner number and the direction of the next corner. Any number of trees within the plots had their details collected as mentioned in the below (Fig:1).

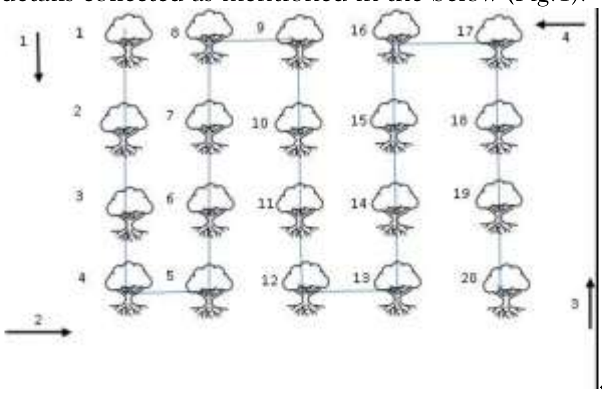

Figure 1

Figure2

Figure3

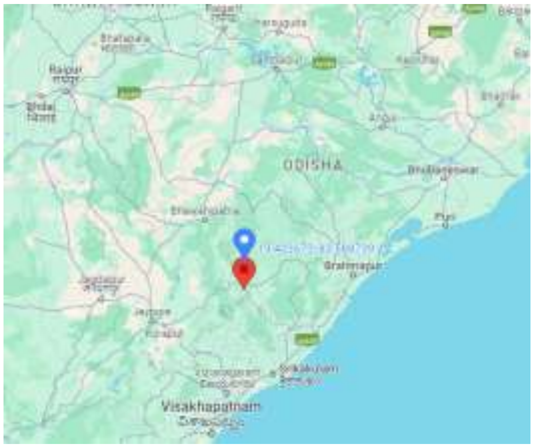

Figure 4

2.3 Model development and statistical analysis

In this study, we have selected 2216 individuals belonging to 21 sampling units of eucalyptus trees at the plantlet and sapling of various age groups from Odisha forest was maintained by the Non-Government organization entitled "Veda Climate Change solution Ltd." This is capable of generating carbon revenues. For each tree girth was measured at breast height from the ground level and total height of the tree from the above ground level was considered by the technique of similar triangles principle. Data was collected from each plot with non-destructive method. A non-destructive method involves using measurements like DBH (Diameter at Breast height) or girth at breast height or 1.3 m log stick from the ground and total height of the tree without tree cutting. . A manual for building tree volume and biomass allometric equation for Bangladesh, Bangladesh Forest Department was given by Mahmood, H., Siddique, *et.al* (2017). Based on this procedure in our study we consider two measurements like girth at breast level and total height of the trees to develop biomass equations. In our study area shown in the above (Figures:2,3,4). Each plots exists 70 to 185 tress all the information for each tree was summarized on separate excel file. Generally, tree allometric equations are in the form of power relation or transformed to logarithmic to get the normality in the data. Procedure is explained in the following :

$Y = a + b\,X$ (I)

$Y = a + \ b\ ln\ (g2x\ h).$ (II)

Where Y = above ground biomass

$X = ln\ (g^2 x\ h)$

Y is the Above Ground Biomass (AGB) the predicted variable and X represents the predictor variables using logarithms of girth and height, 'a' is the stable / intercept and 'b' is the angle (slope). Line of regression was fitted by using the natural logarithms of transformed data. The logarithmically transformed predictor variable (i.e. girth at breast height, total height) of each tree was individually used to develop eucalyptus clonal specific biomass regression model. Furthermore, variables for the individual of all the trees were employed against logarithmically transformed biomass to create tree-specific regression models. To know the best fitted allometric/regression model we have developed different allometric models for the entire 21 sample plots. If the number of equations is more, then best fit regression equation is obtained by using mean square error (MSE) principle. For each plot we will get different allometric equations as shown in the Table.1 out of which we need to decide the best fitted allometric model for the data and decide the best fitted model for eucalyptus clonal variety to calculate the biomass. Similarly Below ground biomass (BGB) was estimated for the study area using the AGB and root to shoot ratio (RSR) of the species specific value is 0.35 (IPCC 2003 - Anx_3A_1_Data_Tables). From the developed biomass allometric equation AGB was calculated with the following procedure:

AGB(t)=Volume of tree (m^3) X Wood density (kg/ m^3) (III)

BGB(t)=AGB(t)X0.35 (IV)
Carbon stock (tones) = AGB (t) X 0.47 (V)
For each sample plot various regression models were computed out of which the best model was defined by considering the mean square error shown below.
Y=-63.7879+9.862924X (VI)
Y=-28.71+5.989807X (VII)
V = 0.00258 + 0.0281*((pi*D)^2) * H (VIII)
Equation (VIII) was developed by Chaturvedi, A.N. (1995): Volume tables and the volume equation for clonal plants. Equations (VI) and (VII) are the required allometric models for the study area. Further we have given bet fitted allometric equation for biomass calculation by considering the R^2 (0.98) value. Based on the least square error principle we can find the best allometric model for biomass calculation of selected trees and estimates are tested based on statistical procedure including R^2 value, adjusted R^2 value, residual standard error (RSE) and p-value. The models were validated and compared by mean square error (MSE) specify the line of best fit. It was observed that based on R^2 value equation of plot 1 and 2 are most reliable and same. Based on the least square criterion, which equation best summarized the data? The sum of the squared prediction errors (RSE) is 15.82 for the equation (VI) and 15.71 for the (VII) equation of the plot 2. Therefore, of the two models, the equation (VII) Y =-28.71+5.989807X be the best summarized the data. The following are formulae used to predict RSE and MSE.
Residual Standard Error = $\sqrt{\sum(y - \hat{y})^2/(n-1)}$
Where y: The observed values
$\hat{y}$: The predicted values
Mean Square Error = $\sum(y - \hat{y})^2/n$
It can be predicted that the equation (VII) having minimum error square value and best fitted to the given data are shown in Table.2 and the best fitted regression model shown in (Fig.5).

3. RESULTS

From the field data of Eucalyptus Species girth rages 8cm to 26 cm and their height rages 4m to 13m.The species-specific equation accounted for over 80% of the variability in above-ground biomass, outperforming the allometric equation (VII) when comparing with the other equations. Best fitted allometric model was obtained using residual standard error method and it was observed that the equation (VII) is having least error compared to equation (VI). Therefore equation (VII) was assumed to be the best fitted allometric model for the selected samples of eucalyptus clonal variety of Odisha region. It was observed that average increases of tons of carbon stock in above ground per hectare (t/ha) of selected sample plots 0.00164 for volume equation (VIII) and for eucalyptus specific equation it was 5.1046 t/ha. Our study specifies that the measurements (Girth at breast height, total height) variables are direct positive relation with AGB. The above ground biomass calculation using eucalyptus clonal allometric model was compared with the volume equation (VIII) for clonal plants. We found that the eucalyptus clonal specific allometric model forecast AGB for study area is better and can be applied for biomass calculation shown in (Fig.6). Corresponding BGB by using the AGB and root to shoot ratio (RSR) of the species specific value is shown in (Fig7). We focused on the AGB values obtained by the eucalyptus clonal specific allometric model those estimated using the best fit. We found that the best fit eucalyptus regression equation (VII) able to predict biomass precisely in least variation. Further best fit eucalyptus allometric model of the present study with the comparison of volume equation (VIII) of carbon stock are showed the lowest variation from volume equation (VIII) to equation (VI) and equation (VII) results are shown in Table.3.

Table: 1 Regression Model for predicting AGB in Eucalyptus species in Odisha

Plot No	Regression Equation	R-Square
1	y=-63.7879+9.862924X	0.978969

2	y=-28.71+5.989807X	0.977016
3	y=-32.3624+6.364926X	0.950024
4	y=-39.3994+7.280822X	0.972107
5	y=-15.4992+4.100388X	0.91756
6	y=-19.9725+4.975052X	0.950528
7	y=-26.9296+5.756343X	0.930089
8	y=-12.3856+3.579677X	0.888304
9	y=-38.0911+7.100162X	0.964929
10	y=-11.1613+3.450552X	0.885062
11	y=-34.5713+6.637184X	0.961022
12	y=-17.1527+4.2763X	0.959401
13	y=-53.6153+9.054078X	0.949595
14	y=-37.8137+7.051653X	0.931895
15	y=-7.90793+2.858106X	0.872248
16	y=-13.5588+4.004113X	0.905865
17	y=-13.7710+4.15701X	0.900915
18	y=-34.3299+6.60055X	0.927172
19	y=-12.348+3.866247X	0.921515
20	y=-6.47699+2.704059X	0.930828
21	y=-12.2638+3.774033X	0.933895

Table:2 Residual Error Square(RSE) for each sample plot

Observed Girth and Height	Expected AGB (VI)	RSE (VI)	Expected AGB (VII)	RSE (VII)
9.10996276	26.07187	1.787942	25.85692	1.765284
7.47332487	9.929835	0.18012	16.05377	0.629149
8.32558758	18.33564	1.037994	21.15866	1.330728
8.45964719	19.65786	1.200574	21.96165	1.447567
6.55663817	0.888624	0.515274	10.563	0.364214
6.52318145	0.558643	0.491947	10.3626	0.31667
8.53430833	20.39423	1.301796	22.40886	1.52293
7.04605996	5.715754	0.163749	13.49454	0.793753
8.5688207	20.73463	1.275323	22.61558	1.472501
6.77431149	3.035519	0.423335	11.86682	0.576613
8.14204963	16.52542	0.864678	20.05931	1.229171
6.70389358	2.340993	0.497199	11.44503	0.540302
8.92761586	24.2734	1.512065	24.7647	1.560474
8.26932762	17.78075	1.153429	20.82168	1.522196
6.33681799	-1.27945	0.903884	9.246317	0.345294
6.70855762	2.386994	0.320336	11.47297	0.353161
6.84787471	3.761068	0.239583	12.30745	0.423745
8.87304499	23.73517	1.789189	24.43783	1.87378

6.22466917	-2.38556	0.869765	8.574567	0.237376
5.75445844	-7.02321	1.099727	5.758095	0.000313
6.49327102	0.263639	0.591291	10.18344	0.350255

4. DISCUSSION

In the current research, certain sample plots shown lower specific values for saplings of observed eucalyptus species. This could be attributed to potential influences from climate, location, and management practices on these values(Ketterings et al., 2001).The variation in the above ground biomass can also depend on the tree age, stand, and other ecological factors (Slik et al., 2013). Precipitation, temperature, geographic range, forest succession stage, forest type, plot sampling, inter site variation, edaphic factors, annual rainfall, low soil fertility, low disturbance rates, and high diversity are other significant factors that can affect above ground biomass and the corresponding carbon stock (Chaturvedi and Raghubanshi, 2013; Morataya et al., 1999; Parez and Kanninen, 2002, 2003). Attiwill (1962) also identified a connection between the volume of branches and their diameter. Simple measurements like girth at breast height and total height of the trees were used to find the best fitted models by applying the linear and logarithmic equations for estimating biomass. Additionally, we have discovered comparable patterns. The combination of diameter with height, height and wood specific gravity (WSG) in the volume equation showed the highest modified R^2 value. The combination of girth and height in species-specific allometric equations are more accurately predicts above-ground biomass. In order to estimate the specific gravity of wood, smaller trees must be destroyed. Therefore, using total height and girth at breast height by non-destructive method to estimate biomass will assist preserve re-growth. Species specific model gives more carbon stock compared to wood specific equations because; it was most relevant parameters are used for carbon calculation. In the majority of the equations specific to certain species, as well as the volume equations, incorporating height alongside diameter at breast height or diameter has reduced the coefficient of determination (R^2) value. Previous research has shown that adding height to diameter or diameter has enhanced the effectiveness of model selection criteria when choosing the most accurate model for each tree component (Mahmood et al., 2021; Rutishauser et al., 2013; Kusmana et al., 2018).In this current research, employing height along with girth yield gives superior outcomes compared to utilizing a universal volume allometric equation or wood specific gravity with diameter for broad models. The application of wood specific gravity in biomass estimation may lead to discrepancies (Ramananantoandro et al., 2015). Moreover, our findings indicated that the application of wood specific gravity and the universal volume model for estimating above-ground biomass in broad models led to a reduction in the coefficient of determination (R^2) value. However, the model incorporating eucalyptus clonal specific equation with parameters girth at breast height and height (Plot no. 4) demonstrated a R^2 value that was nearly identical to that of the model with the sample plot number 9. This similarity could be explained by the significant differences in wood specific gravity among various species, highlighting their importance in a universal model for reducing variability. Chaturvedi and Raghubanshi (2013) suggested that including wood specific gravity in a universal model is essential for accurate prediction of above-ground biomass in specific trees. This notion is further reinforced by Chave et al. (2005), who discovered that wood density was a critical predictor in numerous allometric/regression models aimed at estimating above-ground biomass in tropical forests. Therefore, the broadly used volume equations (Chave et al., 2005, 2014 and Brown, 1997) failed to predict the above ground biomass accurately for small diameter individuals. It was found to be included as a predictor along with girth and total height to calculate biomass of tree species within a universal allometric model.

Table: 3 Comparison of Carbon in AGB per hectare (t/ha) using developed equations with the Volume equation

Volume EQ-VIII	EQ-VI	EQ-VII
0.00341153	8.33257	8.263871
0.001328077	3.173575	5.130786

0.00200527	5.86007	6.762309
0.002174654	6.282651	7.018945
0.001025892	0.284004	3.375934
0.001019268	0.178542	3.311886
0.002279312	6.517997	7.161872
0.001153002	1.826755	4.312855
0.002330395	6.626787	7.22794
0.00107485	0.970152	3.792635
0.00180729	5.281523	6.410954
0.001057832	0.748181	3.657831
0.002980315	7.757778	7.914797
0.001940677	5.682728	6.654608
0.000986163	-0.40891	2.955123
0.001058922	0.762883	3.66676
0.001093956	1.202037	3.93346
0.002865826	7.58576	7.81033
0.00096902	-0.76243	2.740432
0.000914832	-2.24462	1.840287
0.00101353	0.084259	3.254627
0.00164241	3.130586	5.104678

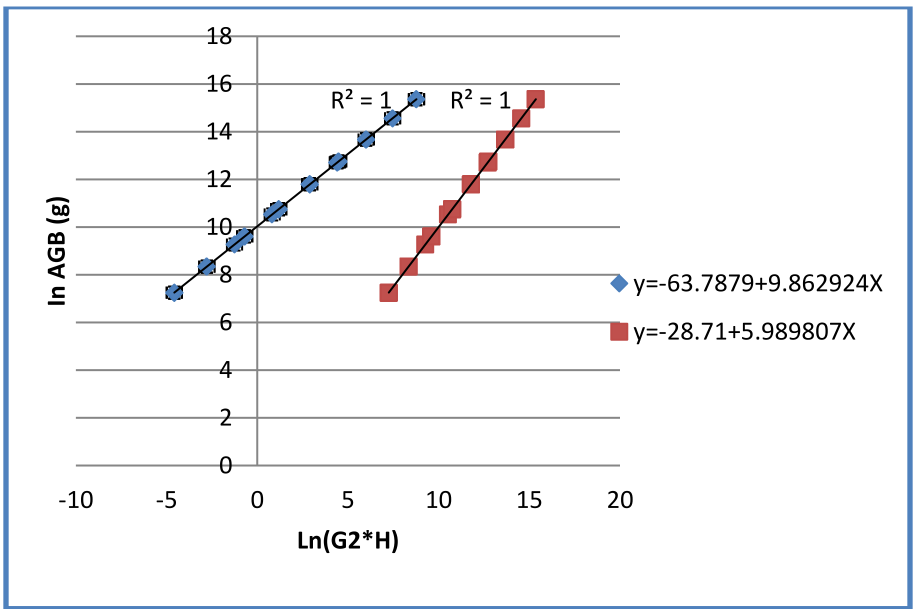

Figure 5: Relationship between biomass observed for predicted regression models with ln (G^2*H) respectively.

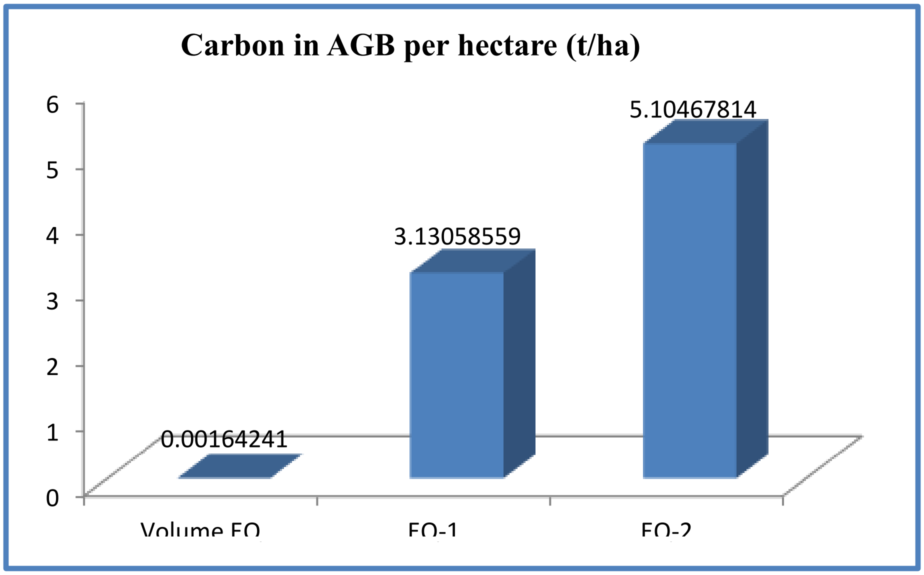

Figure 6: Assessment of above ground biomass (AGB) dominant Eucalyptus.

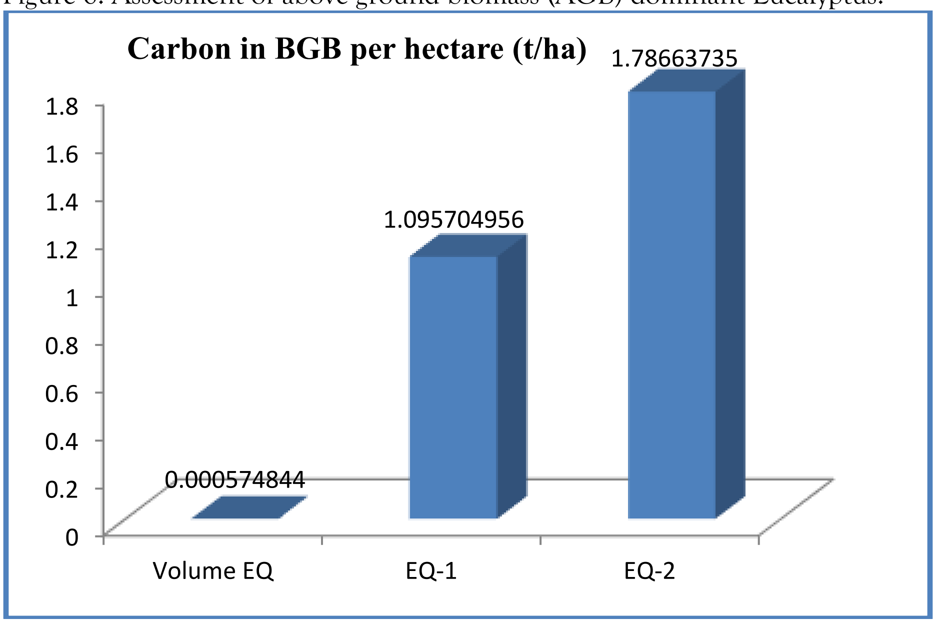

Figure 7: Assessment of below ground biomass (BGB) dominant Eucalyptus.

5. CONCLUSION

When Compared to the well-established volume allometric or wood biomass estimation models, the specific biomass model, we developed for the eucalyptus clonal allometric model in this study proved that it is more accurate for the site in a tropical dry deciduous forest. Our findings indicate that the allometric model incorporating both girth at breast height and total height (VI) achieves a nearly R^2 value similar to that of the second equation (VII) for the second plot. However, the volume equation (VIII) requires the exclusion of small diameter trees for accurate determination. Using volume equations and wood specific gravity in biomass estimation creates inconsistency, where as tree-specific equations are more likely to provide precise biomass predictions than general models that rely on just two easily measurable parameters (Girth and total height). Thus, we recommend the adoption of tree -specific equations for the estimation of biomass in eucalyptus trees as a superior method. Moreover, in situations where species-specific equations are not available, general volume models based on height and diameter can still be employed for biomass estimation without compromising the generation. In conclusion, the suggested allometric model can be utilized for biomass estimation of eucalyptus clonal species in the Odisha region.

Funding This research did not receive any specific grant from funding agencies in the public, commercial or not-for-profit sectors.

Declaration of Competing Interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements The authors thank the editorial team and the reviewer(s) for their helpful comments/ suggestions which helped in bringing the final version of this paper. The authors also thank the contributors of the research paper and information cited in the paper, VEDA Climate Change Solutions Ltd., Non Governmental organization for providing sufficient data to develop this research work.

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