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Carbon sequestration potential of tropical deciduous forests of Nallamalais, India

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ABSTRACT

We estimated the standing biomass and carbon sequestration potential of tropical deciduous forests of Nallamalais, a centre of plant diversity located in the state of Andhra Pradesh, India. A total of 30 randomly stratified sample sites comprising 12 ha area were inventoried following a non-destructive method. The total standing biomass and carbon stocks of the study area are estimated as 56.047 Mt and 26.34 Mt respectively. Among all life forms, trees are the main contributors of standing biomass and carbon stocks in the study area accounting for 96.72% of the above-ground live biomass. The carbon stock accounted for Nallamalais is equivalent to 97.568 Mt of sequestered atmospheric carbon dioxide. With respect to total carbon stock of Indian forests worked out in different studies, Nallamalais share 0.26% to 0.90% of the total carbon stocks of India.

Key words: Carbon stocks, Eastern Ghats, Nallamalais, standing biomass, tropical deciduous forests.

INTRODUCTION

Tropical forests harboring rich biodiversity are responding in several ways to global climate change leading to shifts in species composition and overall increase in turnover [1]. Forest vegetation contains over 350,000 Tg (Tera gram=10^{12} grams) of carbon, of which tropical forests accounts for 40% and play a major role in global carbon cycle [2]. Estimation of above-ground biomass (AGB) is an essential aspect of carbon sequestration studies since it constitutes about 60% of total phytomass [3]. Tree inventories are still an efficient way of assessing forest carbon stocks and emission to the atmosphere during deforestation [4]. The major carbon pools in India are estimated based on very coarse resolution data and extrapolation because the primary data for the many regions of the country are non-existed or over-estimated [5]. Due to the lack of reliable data on standing biomass and rates of forest degradation, the net carbon emission estimates for India are highly variable [6]. Thus, the improved quantification of carbon pools and fluxes in forest ecosystems is important for understanding the contribution of forests to net carbon emissions and their potential for carbon sequestration [7]. The present study is oriented to estimate carbon sequestration potential of Nallamalais, as a part of Vegetation Carbon Pool (VCP) assessment under National Carbon Project under Geosphere Biosphere Programme of Indian Space Research Organization.

MATERIALS AND METHODS

Study Area

Nallamalais, one of the 234 Centers of Plant Diversity of the world [8], lies between 15° 20' to 16° 30' Northern Latitude and 78° 30' to 80° 10' Eastern Longitudes and located in the Eastern Ghats of Andhra Pradesh, India (Fig.

1). It spreads in five districts such as Guntur, Kurnool, Nalgonda, Mahaboobnagar and Prakasam. The hill ranges extended over an area of 7640 sq. km. The elevation ranges 300-950m above MSL. The average annual temperature varies from 24 to 29°C and average annual rainfall is 740 mm. The geological formation known as the 'Archaens', the non-fossiliferous rocks formed about 2000 million years ago. The major rivers are Krishna and Gundlakamma. The soils are red, black and mixed type. The vegetation is tropical deciduous and scrub type [9]. The primitive tribe 'Chenchus' live amidst the forests of Nallamalais. There are two Protected Areas in the study area are Nagarjuna Sagar-Srisailam Tiger Reserve (NSTR) which is the largest tiger reserve in India and Gundlabrahmeswaram (GBM) Wildlife Sanctuary.

Methodology

In the present study, a non-destructive approach of biomass estimation was done in 30 randomly stratified sampled sites comprising 12 ha area. A comprehensive format design of Vegetation Carbon Pool Assessment Project by Indian Institute of Remote Sensing (IIRS) [10] was followed and this has been the source of identifying the sample sites (250×250 m) based on forest type (available at IIRS under different projects), forest density and IRS LISS III data for Normalized Difference Vegetation Index (NDVI) values ranging between 0.0-0.5. On field, the sites were located with the help of Global Positioning System (GPS) and Survey of India reference topographic maps.

Sampling Design

For trees/liana enumeration, 250×250 m site area was divided into 4 plots (NE, NW, SE and SW) of size 31.62×31.62 m (i.e., 0.1 ha), about 75-90 m away from the centre [11], [12]. Girth at Breast Height (GBH) measurements were taken with measuring tape and height was measured using Opti-logic digital hypsometer. For enumeration of shrubs, two quadrates of 5×5 m were laid in opposite corners in each 0.1 ha plot and in each quadrate, the number of bushes and tillers in each bush were counted. For herbs and litter, 5 quadrates (4 in corners and 1 in centre) of 1×1 m were laid in each 0.1 ha sample plot and the material is harvested for determining fresh and dry weight.

Estimation of Biomass

Basal area of each tree/liana was calculated by using standard formula and treated as the critical parameter for estimating trees/liana above ground biomass [13].

Basal Area ($m^2\ ha^{-1}$) = $\pi r^2 \times 10$

Volume of each tree/liana with ≥10 cm diameter was estimated using species specific volumetric equation and for species without specific volumetric equations, common equation is applied based on Forest Survey of India [14]. Specific gravity values of different species were selected from literature [15], [16], [17]. Specific gravity values are available for 75-80% stems. For species with unknown specific gravity, the arithmetic mean of all known species was substituted and used in particular sample plot following Brown *et al.*, [18]. Volume of trees/liana with ≥10 cm diameter was converted into biomass by multiplying with specific gravity [19]. Biomass of all the trees was summed to obtain biomass for 0.1ha plot.

Biomass (tonnes) = Volume (m^3) × Specific Gravity

Since volumetric equations for trees/liana with <10 cm diameter are not available, we followed the methodology developed for Vegetation Carbon Pool Assessment Project [11], [12] to estimate biomass of this class. The regression equation developed by correlating basal area and biomass of trees ≥10cm diameter is as follows (Fig. 2).

$Y=3.6808*X+0.264$.

Where,
Y=Biomass,
X=Basal area of trees (>10cm diameter and <10cm diameter),
3.6808 & 0.264=Coefficients

The biomass of trees with ≥10 cm diameter and <10 cm diameter in each plot were added together to get biomass of 0.1ha plot.

For shrubs, herbaceous and litter, the mean dry weight (g) is directly taken as biomass. Biomass of trees/liana, shrubs and herbaceous were added to get above-ground live biomass (AGLB). A conversion factor of 20% is used to calculate dead wood biomass from AGLB following Achard *et al.*, [20]. Litter and dead wood biomass were summed up to get above-ground dead biomass (AGDB) and Total above-ground biomass (TAGB) is calculated by adding AGLB and AGDB. In the present study, 20% of the TAGB was considered as below ground biomass (BGB) following Ramankutty *et al.*, [21]. Total biomass (TB) for each sample plot was obtained by addition of TAGB with BGB.

Estimation of Carbon Stocks

Carbon stocks were estimated from the total biomass by multiplying with IPCC default carbon fraction of 0.47 [22] as follows.

Carbon (tonnes) = Biomass (tonnes) × Carbon %

We used Mean Biomass Density Method (MBM) [23] for extrapolation in which mean density is multiplied with forest area.

RESULTS AND DISCUSSION

Species Diversity

A total of 306 plant taxa belonging to 215 genera and 61 families were recorded in the sampled inventory. The dominant family is Fabaceae (54 species) followed by Poaceae (32 species). With respect to life forms, trees are represented by 124 species; liana 6 species; shrubs 18 species and herbs 158 species.

Standing Biomass

Trees/liana Biomass

A total of 14199 trees/liana individuals were enumerated in the sampled plots in a range of 26-357 individuals per plot. The mean basal area of trees/liana is 17.47±10.99 m^2 ha^{-1} and ranges 1.66-85.62 m^2 ha^{-1} (Table 1), these mean values are on par with tropical dry evergreen forests of Peninsular India [24]. The growing stock density of trees/liana having ≥10 cm diameter is 106.15±65.95 m^3 ha^{-1} and ranges 4.70-372.73 m^3 ha^{-1} in the sampled plots. The total growing stock of the study area is accounted for 81.098 Mm^3. While in dry deciduous and secondary dry deciduous forests of Kolli hills [25], the estimated mean volume density is 316.060 m^3 ha^{-1} and 216.673 m^3 ha^{-1} respectively, it is 59.79 m^3 ha^{-1} for Indian forests in 2005 [26].

The mean biomass density of trees/liana with ≥10cm diameter is 55.38±41.30 Mg ha^{-1} and ranges 0.74-205.95 Mg ha^{-1} in the sampled plots. Correlation of basal area and biomass of trees with ≥10 cm diameter revealed a determination coefficient of R^2 as 0.8704 (Fig. 2**)**. High correlation of biomass with basal area was reported by [12], [18], [27], [28] and according to Clark *et al.*, [29] tree above-ground biomass is strongly correlated with trunk diameter. The mean biomass density of trees/liana <10 cm diameter is 8.80±9.6 Mg ha^{-1} and ranges 1.25-93.35 Mg ha^{-1} in the sampled plots. For Indian forests, 29.7% biomass was estimated for the same diameter class [27] which is comparatively higher than the present estimates.

Trees/Liana is contributing 49.041Mt biomass with a mean density of 64.19±42.63 Mg ha^{-1}, in a range of 5.20-299.30 Mg ha^{-1} across sampled plots (Table 1). In comparison, tropical dry evergreen forests of peninsular India [17] registered a range of 39.69-170.02 Mg ha^{-1} mean density with respect to basal area and 73.06-173.10 Mg ha^{-1} when basal area and height combined. The present study results are fall in the range with respect to former and found lower with respect to latter.

Shrub Biomass

Shrubs contribute 0.58 Mt biomass, with a mean density of 0.76±0.64 Mg ha^{-1} in a range of 0.01-2.82 Mg ha^{-1} (Table 1) across the plots sampled. These estimates are within the range (0.26-1.43 Mg ha^{-1}) reported from disturbed tropical dry deciduous teak forests of India [30]. Shrub biomass density of 0.116-2.496 Mg ha^{-1} and 1.08±0.8 Mg ha^{-1} was reported for mixed dry deciduous forests [31] and mixed plantation [32]. Present study results were within this range compared with former and lower than the latter.

Herbaceous Biomass

A total of 1.41Mt biomass is contributed by herbs with a mean biomass density of 1.85±1.11 Mg ha^{-1} and varied between 0.20-6.00 Mg ha^{-1} (Table 1) in the sampled plots. Herb biomass range of 1.00-1.59 Mg ha^{-1} was reported from disturbed tropical dry deciduous teak forests of India [30] and in mixed deciduous forests it was 0.038-0.213 Mg ha^{-1} [31].

Above-Ground Live Biomass (AGLB)

AGLB constitutes 50.69 Mt with mean density of 66.36±42.87 Mg ha^{-1} and ranges 6.22-302.58 Mg ha^{-1} (Table 1) in the sampled plots. A total biomass of 14.904-63.249 Mg ha^{-1} was reported in mixed dry deciduous forests of India [31] and present study values are near to the upper end of these estimates.

Litter Biomass

Litter constitutes 0.33 Mt with a mean density of 0.44±0.36 Mg ha^{-1} and ranges 0.02-1.34 Mg ha^{-1} (Table 1) across the sampled plots. However, higher values of litter biomass density (1.52±1.1 Mg ha^{-1}) from the mixed plantation of India [32] and tropical wet evergreen forests (3.5-4.2 Mg ha^{-1}) of Western Ghats [33] are estimated.

Dead Wood Biomass

Mean density is 3.20±2.13 Mg ha^{-1} **(**equaling 1.51 Mg C ha^{-1}**)** and ranges 0.26-14.97 Mg ha^{-1} (Table 1) in the plots sampled and accounts for 2.44 Mt for the study area. Dead wood is generally tends to ignore in many forest carbon budgets, because it does not correlate with any index of stand structure [34]. However, it is having its importance in aspects related to biological diversity [35] and to atmospheric carbon cycle [36].

Above-Ground Dead Biomass (AGDB)

The mean density is 3.65±2.21 Mg ha^{-1} and ranges 0.31-15.94 Mg ha^{-1} (Table 1) in plots and accounts for 2.78 Mt for the study area. It is 3.6 Mg ha^{-1} in case of South and South-East Asia [37]. The AGDB of world forests [38] was estimated from none to >600 Mg ha^{-1}. When compared, the present study estimates are absolutely as such that of South and South-East Asia forests and at the lower end of the world forests.

Total Above-Ground Biomass (TAGB)

The TAGB density is 70.02±45.05 Mg ha^{-1} and ranges 6.53-318.52 Mg ha^{-1} (Table 1) across the sampled plots and accounts for 53.49 Mt for the study area. Our results are within the range when compared with disturbed tropical dry deciduous teak forests (28.12-85.26 Mg ha^{-1}) of India [30] and Indian forests (14-210 Mg ha^{-1}) [27]. However, Indian tropical deciduous forests registered high TAGB (97.3 Mg ha^{-1}) [27]. Corresponding to Indian forests TAGB (9793.794 Mt) [39], Nallamalais accounts for 0.54% of the total. Deciduous forests of Western Ghats [40] registered a mean AGB of 280±72.5 Mg ha^{-1} based on ground data and 297.6±55.2 Mg ha^{-1} based on Remote Sensing, both values are greater than the present study. In dry deciduous and secondary dry deciduous forests of Kolli hills [25], estimated total biomass density is 251.653 Mg ha^{-1} and 241.773 Mg ha^{-1} respectively which are higher than the present study.

Below Ground Biomass (BGB)

BGB accounts for 2.551 Mt with a mean density of 3.34±2.14 Mg ha^{-1} and ranges 0.31-15.18 Mg ha^{-1} (Table 1) in the sampled plots. BGB of Indian forests [39] was estimated at 2605.149 Mt, and Nallamalais accounts for 0.09%. BGB density in a range of 9.01-15.62 Mg ha^{-1} was reported from disturbed tropical dry deciduous teak forests of India [30] which is greater than the present study.

Total Biomass (TB)

The mean density is 73.36±47.20 Mg ha^{-1} and varied between 6.84-33.69 Mg ha^{-1} (Table 1) in the sampled plots and accounts for 56.047 Mt for the study area. Nallamalais contribute 0.62% to total biomass of Indian forests (8955.434 Mt) [39]. Total biomass in a range of 37.12-100.88 Mg ha^{-1} was reported from disturbed tropical dry deciduous teak forest of India [30] and present study results fall within this range. Biomass represents the largest organic carbon pool in mature tropical forest ecosystem. The change in forest biomass is considered as key characteristic of forest ecosystem [41]. Biomass variability can be explained by several factors like climate, topography, soil fertility, water supply and wood density, distribution of tree species, tree functional type and forest disturbance [42].

TABLE 1: Standing Biomass (Mg ha^{-1}) and Carbon stocks (Mg ha^{-1}) in various components of the sampled inventory

S. No.	Plot ID	Trees/Liana			Shrub	Herbaceous	AGLB	Litter	Dead Wood	AGDB	TAGB	BGB	TB	Carbon
		TNI	BA	AGB	AGB	AGB								
1	1a	167	8.05	24.36	-	0.75	25.11	0.35	1.22	1.57	26.68	1.26	27.94	13.13
2	1b	229	6.16	20.03	-	0.82	20.85	0.31	1	1.31	22.16	1.04	23.2	10.91
3	1c	238	10.88	35.28	-	0.71	35.99	0.49	1.76	2.25	38.24	1.8	40.04	18.82
4	1d	239	9.69	34.57	-	1	35.57	0.52	1.73	2.25	37.82	1.78	39.6	18.61
5	2a	343	14.46	54.79	-	1.6	56.39	0.55	2.74	3.29	59.68	2.82	62.5	29.37
6	2b	214	10.81	31.64	-	0.89	32.53	0.43	1.58	2.01	34.54	1.63	36.17	17
7	2c	188	9.36	32.43	-	1.8	34.23	0.2	1.62	1.82	36.05	1.71	37.76	17.75
8	2d	357	12.63	45.81	-	0.95	46.76	0.29	2.29	2.58	49.34	2.34	51.68	24.29
9	3a	76	7.59	30.92	-	0.42	31.34	0.51	1.55	2.06	33.4	1.57	34.97	16.43
10	3b	170	12.59	46.85	-	0.2	47.05	0.44	2.34	2.78	49.83	2.35	52.18	24.53
11	3c	194	12.44	75.54	-	0.38	75.92	0.27	3.78	4.05	79.97	3.8	83.77	39.37
12	3d	131	11.05	43.44	-	0.4	43.84	0.54	2.17	2.71	46.55	2.19	48.74	22.91
13	4a	152	7.22	26.98	-	2.2	29.18	0.04	1.35	1.39	30.57	1.46	32.03	15.05
S. No.	Plot ID	Trees/Liana			Shrub	Herbaceous	AGLB	Litter	Dead Wood	AGDB	TAGB	BGB	TB	Carbon
		TNI	BA	AGB	AGB	AGB								
14	4b	117	14.93	34.51	-	0.6	35.11	0.07	1.73	1.8	36.91	1.76	38.67	18.17
15	4c	60	8.43	19.79	-	5.5	25.29	0.04	0.99	1.03	26.32	1.26	27.58	12.96
16	4d	65	9.44	40.2	-	6	46.2	0.08	2.01	2.09	48.29	2.31	50.6	23.78
17	5a	84	7.95	20.05	-	3.902	23.95	0.46	1	1.46	25.41	1.2	26.61	12.51
18	5b	107	2.91	11.69	-	3.305	14.99	0.27	0.58	0.85	15.84	0.75	16.59	7.8
19	5c	26	7.67	26.38	-	0.5	26.88	0.34	1.32	1.66	28.54	1.34	29.88	14.05
20	5d	73	13.98	76.46	-	1.3	77.76	0.47	3.82	4.29	82.05	3.89	85.94	40.39
21	6a	101	3.04	10.63	-	1.223	11.85	0.26	0.53	0.79	12.64	0.59	13.23	6.22
22	6b	62	1.66	5.2	-	1.025	6.22	0.05	0.26	0.31	6.53	0.31	6.84	3.22
23	6c	102	3.44	8.99	-	2	10.99	0.27	0.45	0.72	11.71	0.55	12.26	5.76
24	6d	90	2.44	7.7	-	0.964	8.66	0.38	0.39	0.77	9.43	0.43	9.86	4.64
25	7a	134	19.83	71.76	-	3.272	75.03	0.45	3.59	4.04	79.07	3.75	82.82	38.93
26	7b	141	21.89	62.57	-	1.628	64.19	0.3	3.13	3.43	67.62	3.21	70.83	33.29
27	7c	155	19.82	57.02	-	1.061	58.08	0.17	2.85	3.02	61.1	2.9	64	30.08
S. No.	Plot ID	Trees/Liana			Shrub	Herbaceous	AGLB	Litter	Dead Wood	AGDB	TAGB	BGB	TB	Carbon
		TNI	BA	AGB	AGB	AGB								
28	7d	143	18.65	68.93	-	1.285	70.21	0.38	3.45	3.83	74.04	3.51	77.55	36.45
29	8a	44	2.88	11.05	-	0.846	11.89	0.06	0.55	0.61	12.5	0.59	13.09	6.15
30	8b	105	5.3	22.09	-	0.629	22.71	0.17	1.1	1.27	23.98	1.14	25.12	11.8
31	8c	93	3.86	13.02	0.25	0.648	13.91	0.1	0.65	0.75	14.66	0.7	15.36	7.22
32	8d	112	4.59	22.96	-	0.904	23.86	0.07	1.15	1.22	25.08	1.19	26.27	12.35
33	9a	134	10.07	29.27	-	1.21	30.48	0.08	1.46	1.54	32.02	1.52	33.54	15.77
34	9b	131	10.64	30.63	-	1.806	32.43	0.2	1.53	1.73	34.16	1.62	35.78	16.82
35	9c	61	5.5	13.52	-	1.615	15.13	0	0.68	0.68	15.81	0.76	16.57	7.79
36	9d	65	10.35	24.28	-	1.486	25.76	0.04	1.21	1.25	27.01	1.29	28.3	13.3
37	10a	129	16.03	63.2	-	1.224	64.42	0.13	3.16	3.29	67.71	3.22	70.93	33.34
38	10b	140	19.49	78.35	-	1.302	79.65	0.26	3.92	4.18	83.83	3.98	87.81	41.27
39	10c	138	13.97	54.47	-	1.487	55.95	0.09	2.72	2.81	58.76	2.8	61.56	28.93
40	10d	113	6.52	33.25	-	1.245	34.49	0.19	1.66	1.85	36.34	1.72	38.06	17.89
41	11a	156	30.29	133.55	-	1.118	134.66	0.52	6.68	7.2	141.86	6.73	148.59	69.84
S. No.	Plot ID	Trees/Liana			Shrub	Herbaceous	AGLB	Litter	Dead Wood	AGDB	TAGB	BGB	TB	Carbon
		TNI	BA	AGB	AGB	AGB								
42	11b	147	27.5	110.8	-	1.54	112.34	0.22	5.54	5.76	118.1	5.62	123.72	58.15
43	11c	159	26.42	95.66	-	1.498	97.15	0.28	4.78	5.06	102.21	4.86	107.07	50.32
44	11d	143	23.32	107.6	-	0.994	108.59	0.1	5.38	5.48	114.07	5.43	119.5	56.16
45	12a	89	37.16	104.78	1.88	0.782	107.43	0.98	5.24	6.22	113.65	5.37	119.02	55.94
46	12b	96	31.1	106.53	0.9	1.016	108.43	0.75	5.33	6.08	114.51	5.42	119.93	56.37
47	12c	102	21.73	62.72	0.42	1.066	64.2	0.82	3.14	3.96	68.16	3.21	71.37	33.54
48	12d	98	29.39	71.68	1.43	1.028	74.12	0.67	3.58	4.25	78.37	3.71	82.08	38.58
49	13a	107	30.48	116.97	-	0.41	117.38	0.13	5.85	5.98	123.36	5.87	129.23	60.74
50	13b	106	33.84	138.65	-	0.765	139.41	0.2	6.93	7.13	146.54	6.97	153.51	72.15
51	13c	114	28.66	97.17	-	0.425	97.59	0.05	4.86	4.91	102.5	4.88	107.38	50.47
52	13d	114	37.51	158.06	-	0.392	158.45	0.08	7.9	7.98	166.43	7.92	174.35	81.95
53	14a	136	31.22	142	-	4.32	146.32	0.15	7.1	7.25	153.57	7.32	160.89	75.62
54	14b	84	15.07	59.25	-	4.3	63.55	0.24	2.96	3.2	66.75	3.18	69.93	32.87
55	14c	118	32.76	114.59	-	3.62	118.21	0.1	5.73	5.83	124.04	5.91	129.95	61.08
S. No.	Plot ID	Trees/Liana			Shrub	Herbaceous	AGLB	Litter	Dead Wood	AGDB	TAGB	BGB	TB	Carbon
		TNI	BA	AGB	AGB	AGB								
56	14d	93	21.14	76.09	-	5.2	81.29	0.15	3.8	3.95	85.24	4.06	89.3	41.97
57	15a	94	26.52	107.31	1.5	2.416	111.21	0.47	5.37	5.84	117.05	5.56	122.61	57.63
58	15b	87	23.81	96.35	0.76	2.01	99.12	0.38	4.82	5.2	104.32	4.96	109.28	51.36
59	15c	92	26.71	109.18	0.85	2.128	112.14	0.67	5.46	6.13	118.27	5.61	123.88	58.22
60	15d	95	21.92	108.16	0.6	2.044	110.8	0.43	5.41	5.84	116.64	5.54	122.18	57.42
61	16a	68	12.08	34.7	0.12	0.921	35.74	1.08	1.74	2.82	38.56	1.79	40.35	18.96
62	16b	81	15.81	45.4	0.28	1.244	46.92	0.86	2.27	3.13	50.05	2.35	52.4	24.63
63	16c	95	16	44.77	0.15	1.358	46.26	0.92	2.24	3.16	49.42	2.31	51.73	24.31

64	16d	87	14.51	41.47	0.17	1.058	43.68	1.01	2.07	3.08	46.76	2.18	48.94	23
65	17a	96	14.06	36.65	0.2	1.152	38	0.85	1.83	2.68	40.68	1.9	42.58	20.01
66	17b	98	21.12	78.26	0.29	1.457	79.99	1.06	3.91	4.97	84.96	4	88.96	41.81
67	17c	93	12.62	39.97	0.62	1.657	42.23	0.92	2	2.92	45.15	2.11	47.26	22.21
68	17d	96	24.63	143.65	0.45	1.4	145.49	0.64	7.18	7.82	153.31	7.27	160.58	75.47
69	18a	87	14.27	35.09	0.91	1.234	37.22	1.2	1.75	2.95	40.17	1.86	42.03	19.75
S. No.	**Plot ID**	**Trees/Liana**			**Shrub AGB**	**Herbaceous AGB**	**AGLB**	**Litter**	**Dead Wood**	**AGDB**	**TAGB**	**BGB**	**TB**	**Carbon**
		TNI	**BA**	**AGB**										
70	18b	97	15.88	48.97	0.71	1.536	51.2	0.64	2.45	3.09	54.29	2.56	56.85	26.72
71	18c	92	7.88	27.3	0.59	1.554	29.44	0.82	1.37	2.19	31.63	1.47	33.1	15.56
72	18d	88	22.88	80.75	0.59	1.41	82.74	1.07	4.04	5.11	87.85	4.14	91.99	43.23
73	19a	104	19.21	52.69	2.14	1.156	55.97	1.34	2.63	3.97	59.94	2.8	62.74	29.49
74	19b	101	17.55	47.27	0.38	1.208	48.85	0.91	2.36	3.27	52.12	2.44	54.56	25.64
75	19c	93	18.23	51.7	0.35	1.35	53.4	0.87	2.59	3.46	56.86	2.67	59.53	27.98
76	19d	88	13.87	38.24	2.83	1.134	42.19	1.08	1.91	2.99	45.18	2.11	47.29	22.23
77	20a	97	15	50.17	1.16	1.738	53.05	1.19	2.51	3.7	56.75	2.65	59.4	27.92
78	20b	86	85.62	299.3	1.21	2.07	302.58	0.97	14.97	15.94	318.52	15.13	333.65	156.82
79	20c	101	21.95	98.63	2.24	1.914	102.78	0.85	4.93	5.78	108.56	5.14	113.7	53.44
80	20d	96	15.79	51.03	2.14	1.42	54.59	1.09	2.55	3.64	58.23	2.73	60.96	28.65
81	21a	139	12.59	42.47	-	1.2	43.67	0.25	2.12	2.37	46.04	2.18	48.22	22.67
82	21b	120	11.91	39.97	-	2.726	42.69	0.05	2	2.05	44.74	2.13	46.87	22.03
83	21c	173	10.06	33.88	-	2.182	36.06	0.04	1.69	1.73	37.79	1.8	39.59	18.61
S. No.	**Plot ID**	**Trees/Liana**			**Shrub AGB**	**Herbaceous AGB**	**AGLB**	**Litter**	**Dead Wood**	**AGDB**	**TAGB**	**BGB**	**TB**	**Carbon**
		TNI	**BA**	**AGB**										
84	21d	167	6.04	20.63	-	1.2	21.83	0.15	1.03	1.18	23.01	1.09	24.1	11.33
85	22a	99	8.35	29.1	-	3.423	32.52	0.36	1.46	1.82	34.34	1.63	35.97	16.9
86	22b	113	7.56	29.01	0.19	1.86	31.06	0.05	1.45	1.5	32.56	1.55	34.11	16.03
87	22c	114	7.04	26.2	-	1.978	28.17	0.08	1.31	1.39	29.56	1.41	30.97	14.56
88	22d	133	9.31	33.16	-	2.567	35.72	0.2	1.66	1.86	37.58	1.79	39.37	18.5
89	23a	125	36.09	125.14	-	2.723	127.86	0.11	6.26	6.37	134.23	6.39	140.62	66.09
90	23b	123	14.4	53.16	-	3.11	56.27	0.24	2.66	2.9	59.17	2.81	61.98	29.13
91	23c	123	26.33	81.23	0.02	2.992	84.23	0.05	4.06	4.11	88.34	4.21	92.55	43.5
92	23d	129	23.92	89.09	-	2.315	91.4	0.15	4.45	4.6	96	4.57	100.57	47.27
93	24a	98	19.15	74.56	0.23	2.914	77.69	0.06	3.73	3.79	81.48	3.88	85.36	40.12
94	24b	92	21.83	95.43	0.56	1.991	97.97	0.92	4.77	5.69	103.66	4.9	108.56	51.02
95	24c	97	14.52	60.64	0.24	2.731	63.6	1.08	3.03	4.11	67.71	3.18	70.89	33.32
96	24d	89	11.38	37.66	0.2	2.392	40.25	0.72	1.88	2.6	42.85	2.01	44.86	21.09
97	25a	87	17.78	73.76	1.09	1.052	75.8	0.64	3.68	4.32	80.12	3.79	83.91	39.44
S. No.	**Plot ID**	**Trees/Liana**			**Shrub AGB**	**Herbaceous AGB**	**AGLB**	**Litter**	**Dead Wood**	**AGDB**	**TAGB**	**BGB**	**TB**	**Carbon**
		TNI	**BA**	**AGB**										
98	25b	91	19.44	75.92	1.55	1.19	78.66	1.28	3.8	5.08	83.74	3.93	87.67	41.21
99	25c	84	17.35	67.56	1.01	1.142	69.7	1.05	3.38	4.43	74.13	3.49	77.62	36.48
100	25d	92	13.01	104	0.65	1.222	105.86	0.83	5.2	6.03	111.89	5.29	117.18	55.08
101	26a	100	27.91	118.52	0.48	2.807	121.8	0.71	5.93	6.64	128.44	6.09	134.53	63.23
102	26b	88	17.57	64.07	0.23	2.866	67.16	0.82	3.2	4.02	71.18	3.36	74.54	35.03
103	26c	92	19	57.32	0.4	3.396	61.11	1.05	2.87	3.92	65.03	3.06	68.09	32
104	26d	117	24.87	79.56	0.43	2.82	82.8	0.46	3.98	4.44	87.24	4.14	91.38	42.95
105	27a	116	27.76	86.92	1.04	2.492	90.45	0.33	4.35	4.68	95.13	4.52	99.65	46.84
106	27b	95	23.21	72.94	0.01	4.226	77.17	0.24	3.65	3.89	81.06	3.86	84.92	39.91
107	27c	103	45.5	153.51	-	3.109	156.61	0.28	7.68	7.96	164.57	7.83	172.4	81.03
108	27d	104	22.92	85.55	1.42	3.385	90.34	0.1	4.28	4.38	94.72	4.52	99.24	46.64
109	28a	102	14.77	92.76	0.31	2.745	95.8	0.84	4.64	5.48	101.28	4.79	106.07	49.85
110	28b	119	15.11	100.08	0.4	2.744	103.22	0.92	5	5.92	109.14	5.16	114.3	53.72
111	28c	97	19.35	58.67	0.5	2.514	61.68	0.46	2.93	3.39	65.07	3.08	68.15	32.03
S. No.	**Plot ID**	**Trees/Liana**			**Shrub AGB**	**Herbaceous AGB**	**AGLB**	**Litter**	**Dead Wood**	**AGDB**	**TAGB**	**BGB**	**TB**	**Carbon**
		TNI	**BA**	**AGB**										
112	28d	86	18.01	111.39	0.21	2.455	114.05	0.85	5.57	6.42	120.47	5.7	126.17	59.3
113	29a	117	24.93	77.74	-	3.41	81.15	0.41	3.89	4.3	85.45	4.06	89.51	42.07
114	29b	135	31.07	117.35	-	1.67	119.02	0.31	5.87	6.18	125.2	5.95	131.15	61.64
115	29c	139	40.16	148.79	-	1.76	150.55	0	7.44	7.44	157.99	7.53	165.52	77.79
116	29d	104	21.92	71.49	-	2.19	73.68	0.1	3.57	3.67	77.35	3.68	81.03	38.09
117	30a	189	10.5	26.4	-	2.23	28.63	0.02	1.32	1.34	29.97	1.43	31.4	14.76
118	30b	146	7.62	23.93	-	3.15	27.08	0.08	1.2	1.28	28.36	1.35	29.71	13.97
119	30c	178	10.98	37.81	-	2.765	40.57	0.14	1.89	2.03	42.6	2.03	44.63	20.98
120	30d	187	11.54	42.34	-	2.486	44.82	0	2.12	2.12	46.94	2.24	49.18	23.12
Mean		**-**	**17.47**	**64.19**	**0.76**	**1.85**	**66.36**	**0.44**	**3.2**	**3.65**	**70.024**	**3.31**	**73.34**	**34.47**
±SD		**-**	**±10.99**	**±42.63**	**±0.64**	**±1.11**	**±42.87**	**±0.36**	**±2.13**	**±2.21**	**±45.05**	**±2.14**	**±47.20**	**±22.18**

ABBREVIATIONS: *TNI-Total Number of Individuals, BA-Basal Area, AGB-Above-Ground Biomass, AGLB-Above Ground Live Biomass, AGDB-Above Ground Dead Biomass, TAGB-Total Above-Ground Biomass, BGB-Below Ground Biomass, TB-Total Biomass, SD-Standard Deviation*

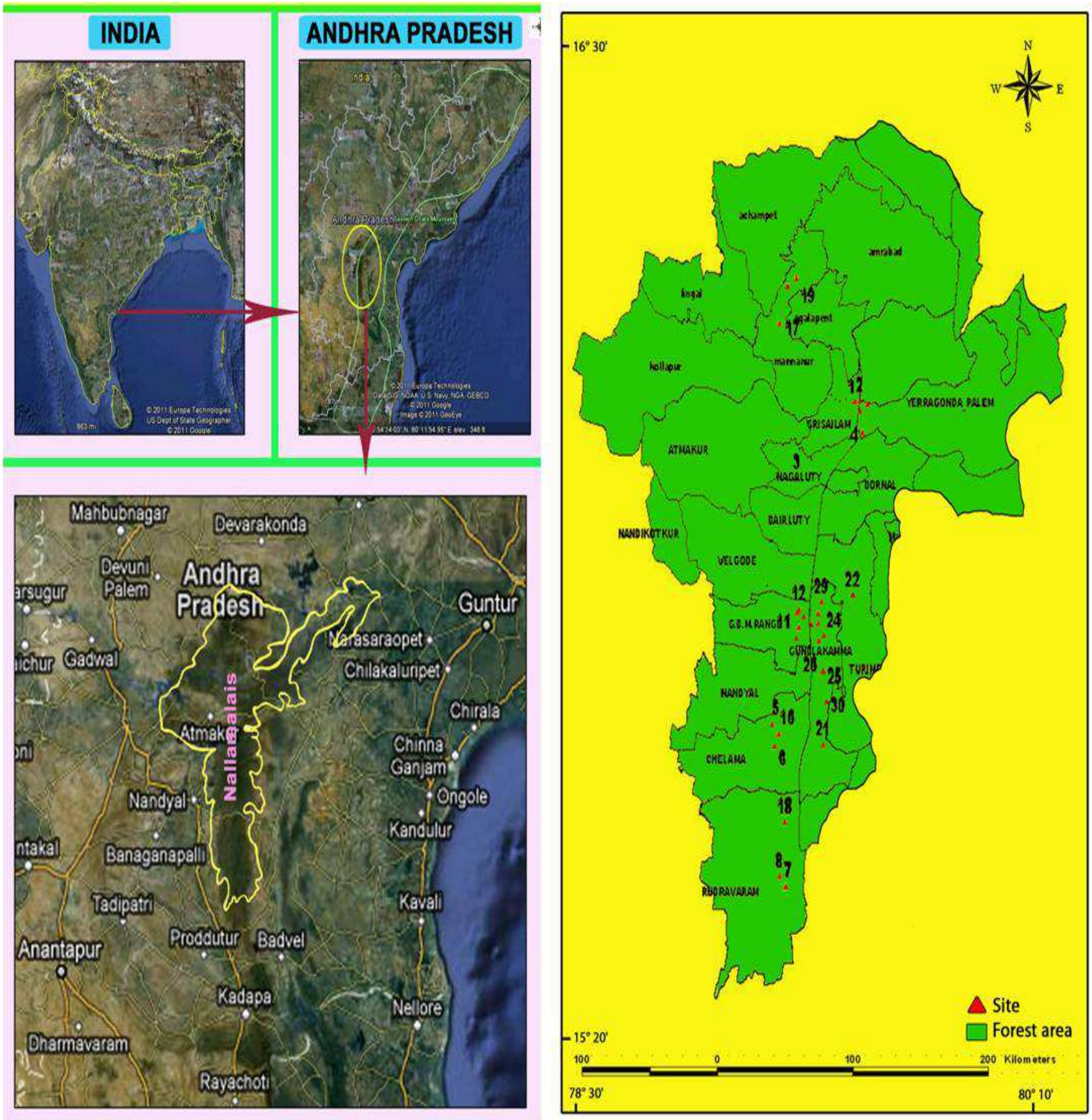

Fig. 1: Location map of the study area (Source: Google Earth) and sampled sites located with ARC-VIEW GIS (3.2 Version)

Carbon Stocks

The total carbon stock density of the sampled inventory is 34.48±22.18 Mg C ha^{-1} and ranges 3.22-156.84 Mg C ha^{-1} across the plots (Table 1). Carbon densities in different components of the study area are as follows: trees/liana 30.17 Mg C ha^{-1}, shrubs 0.35 Mg C ha^{-1}, herbaceous 0.87 Mg C ha^{-1}, above-ground live 31.19 Mg C ha^{-1}, litter 0.20 Mg C ha^{-1}, dead wood 1.51 Mg C ha^{-1}, above-ground dead 1.71 Mg C ha^{-1}, total above-ground 32.91 Mg C ha^{-1} and below ground 1.55 Mg C ha^{-1}. The percentage values shared by these components are represented in Fig. 3. The total carbon pool is extrapolated as 26.34 Mt for Nalllamalais.

The carbon density of 34 Mg C ha^{-1} was reported for Indian forests [27] and this is similar to the estimates of the present study. However, it is found lower than the estimates of dry deciduous forests (64.35 Mg ha^{-1}); mixed deciduous forests (129.0 Mg ha^{-1}) of East Godavari district of Andhra Pradesh [43] and tropical deciduous forests of India (99.44 Mg ha^{-1}) [44].

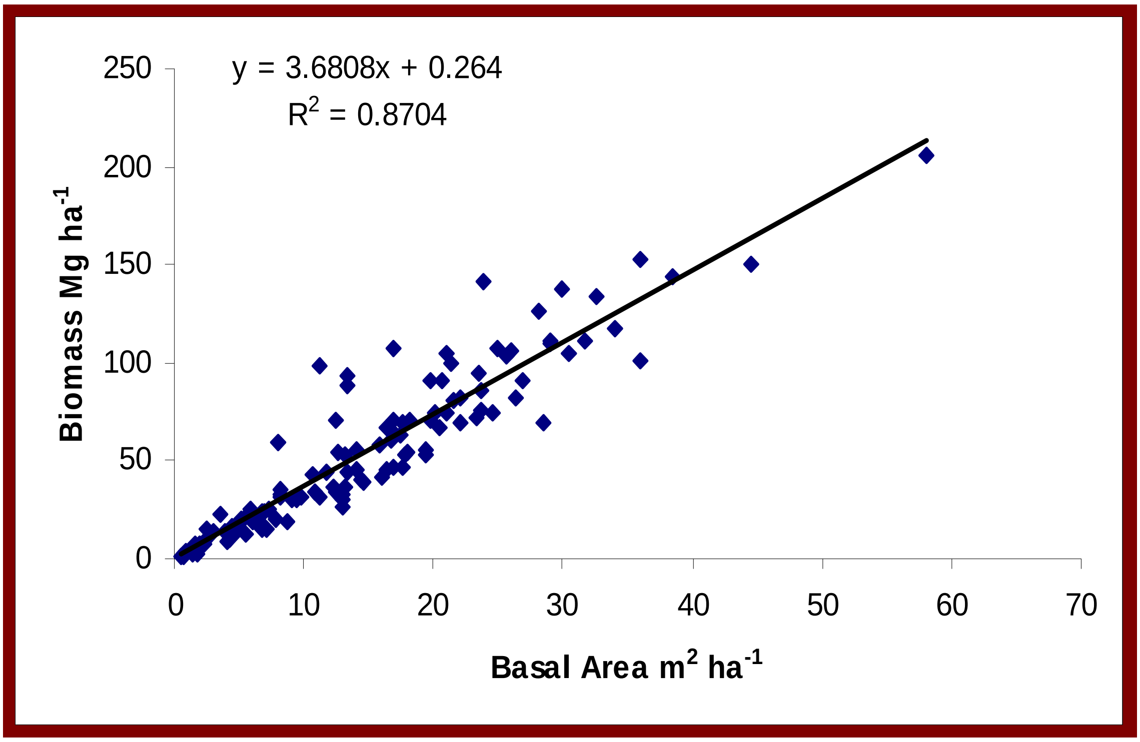

Fig. 2: Correlation between basal area and biomass of trees ≥10 cm diameter

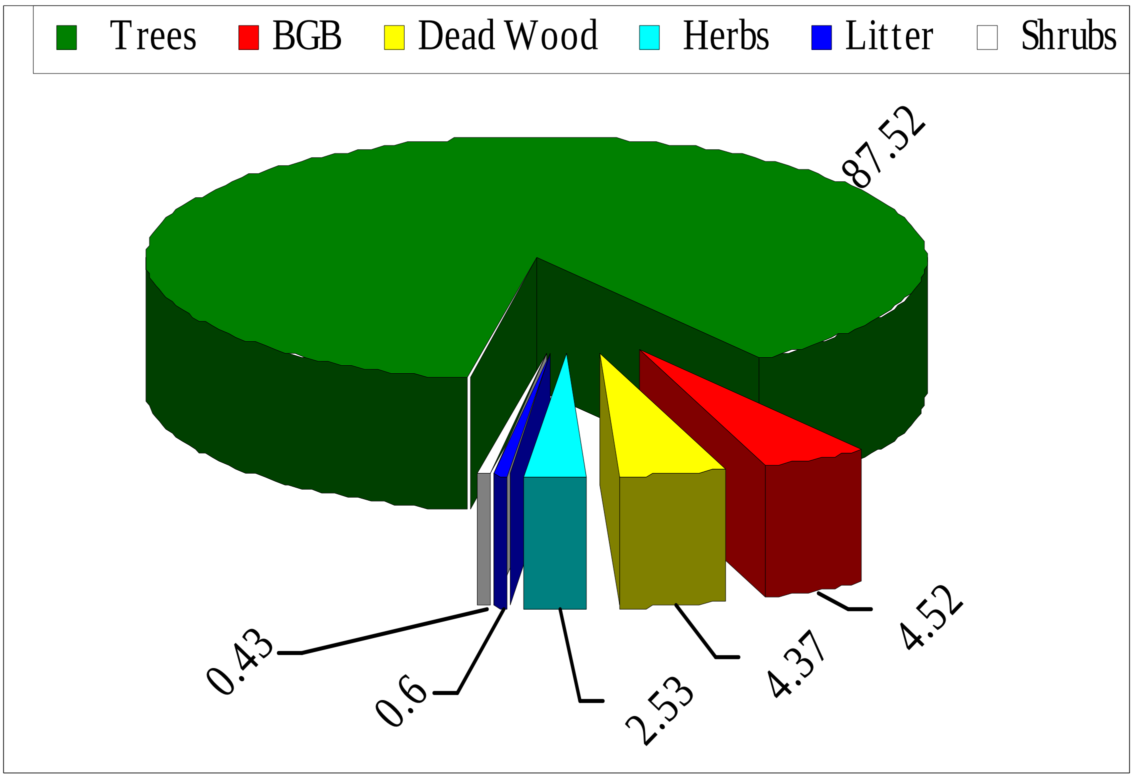

Fig. 3: Percentages shared by different components of Carbon stocks

The total carbon stock in Indian forests worked out in different studies and respective share of carbon stock of Nallamalais estimated in our study are: 9585 Mt by Ravindranath *et al.,* [6] (Nallamalais, 0.27%); 2940 Tg by Haripriya [45] (0.89%); 10.01 Gt by FAO [46] (0.26%); 2865.739 Mt by Kishwan *et al.*, [39] (0.9%) and 6622 Mt by FSI [26] (0.39%). Nallamalais by having an estimated carbon stocks of 26.34 Mt had the sequestration potential of 97.568 Mt of atmospheric carbon dioxide based on Frederick M. O'Hara [47].

CONCLUSION

The present study pertaining to estimation of carbon sequestration potential of tropical deciduous forests of Nallamalais in Eastern Ghats of Andhra Pradesh covered 120 sampled plots of size 0.1ha and recorded a total of 306 plant species. The total aboveground biomass (TAGB) estimated for Nallamalais is 53.49 Mt of which AGLB is 50.69 Mt and AGDB is 2.78 Mt. Of the AGLB, trees/liana comprises 49.041 Mt (97.3%), shrubs contribute 0.58 Mt (0.47%) and herbaceous 1.41 Mt (2.79%). Of the AGDB, litter contributes 0.33 Mt (12.97%) and dead wood 2.44 Mt (87.81%). BGB of Nallamalais is estimated at 2.551 Mt and accounts for 4.52% of the total biomass. Thus, the total biomass density of Nallamalais is 73.36±47.20 Mg ha^{-1} and accounts for 56.047 Mt. The total carbon pool density of the study area is 34.48±22.18 Mg ha^{-1} and the total carbon stocks of the study area are estimated at 26.34 Mt which equals 97.568 Mt of sequestered atmospheric carbon dioxide. When compared with the total carbon stock in Indian forests worked out in different studies Nallamalais share 0.26% to 0.9% of the total national carbon stocks. It is observed that anthropogenic fire and illegal cutting of trees for timber has major impact on the carbon stocks of the forests of Nallamalais.

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