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Carbon stocks of trees outside forests in Anantapuramu District, Andhra Pradesh

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ABSTRACT

In the present study, carbon stocks of trees outside forest in Anantapuramu district of Andhra Pradesh was estimated through sampling of 255 hectare area in 655 plots. A total of 97 species belonging to 78 genera of 36 families were recorded in the sampled plots. The total mean biomass and carbon stocks were calculated as 1078.217 tons and 512.448 tons respectively and 0.890 Mt of biomass and 0.422 Mt of carbon stocks were extrapolated to the study area. The carbon sequestration potential of the trees outside forests of Anantapuramu district is estimated at 1.544 Mt CO_2.

1. Introduction

Climate change is one of the most important global environmental challenges affecting all natural ecosystems (Bujarbarus and Baruah, 2009), because climate and natural ecosystems are closely related and depend on each other (Bharali and Khan, 2011). Unabated burning of fossil fuels over the past one century has increased the concentration of greenhouse gases in the atmosphere especially CO_2 consequently resulting in enhanced greenhouse effect, the global warming. During 2005-2014, 91% of the total emissions were caused by fossil fuels and industry and 9% by land-use change (Le Quere *et al.*, 2015). Carbon dioxide levels which were under 300 ppm during the past 6,50, 000 years are now touching 407 ppm, average for May, 2016 (Tans and Keeling, 2016). Due to these increased levels of CO_2 concentration, rise of atmospheric temperature by 0.5°C is recorded over the past hundred years and it is projected to rise by 0.6 to 5°C in the next 100 years according to latest report of Intergovernmental Panel on Climate Change (IPCC, 2014).

Atmospheric CO_2 removed from atmosphere by capturing and securing it during photosynthesis and subsequently to dead organic matter is called as 'carbon sequestration. Apart from forest ecosystems, trees outside forests also have great potential in sequestration of atmospheric carbon (Dhyani *et al.,* 2009). Trees Outside Forests (from now onwards, abbreviated as TOF) refers to trees found on lands not defined as 'Forest' and 'Other Wooded Land' irrespective of their patch size (FSI, 2009; FAO, 2010). TOF include agricultural land (including meadows and pastures), built-on land (including settlements and infrastructure) and barren land (including sand dunes and rocky outcroppings), orchards and plantations. In spatial terms they may be scattered on farmland and pasture, or growing continuously in line-plantings along roads, canals and watercourses, around lakes, in towns, or in small aggregates with a spatial continuum such as clumps of trees, sacred woods, urban parks (Alexandrov *et al.*, 1999). In recent decades, TOF has begun to attract more and more attention with growing acknowledgements of their potential

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economic importance and political interest in their environmental services (de Foresta *et al.*, 2013). A major challenge to for a better evaluation of trees and their services globally is to improve our understanding of the status and dynamics of all tree resources including trees outside forests (de Foresta *et al.*, 2013; FAO, 2001).

There are five carbon pools of terrestrial ecosystem: above ground biomass, below ground biomass, dead mass of litter, woody debris and soil organic matter (Eggleston *et al*., 2006). Indian Space Research Organization (ISRO) has initiated National Carbon Project under the auspices of Indian Geosphere Biosphere Programme (IGBP) (Singh and Dadhwal, 2008). The objective of the project is to collect data for biomass and carbon pool assessment following uniform methodology for a specific time frame. 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 (Dadhwal and Nayak, 1993). 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 (Ravindranath *et al.*, 1997). Precise information on TOF at micro level is lacking and this has become a major hindrance in estimating TOF potential in carbon sequestration.

The present study is oriented with this background, to estimate the carbon stocks of TOF of Anantapuramu district, Andhra Pradesh following as a comprehensive format design of Vegetation Carbon pool Assessment (VCP) National Carbon Project (Singh and Dadhwal, 2008). Accordingly, TOF are classified into 3 categories: linear, scattered and block; under linear structures, roads, canals, river bunds, rail tracks are included; scattered structures are agricultural fields (field bunds), wastelands, settlements (towns/villages); and block structures are: orchards/government and private plantations.

2. Study area

Anantapuramu district is located between 76^{r} 50Œ§ to78^{o} 30Œ§ E longitudes and 13^{o}40Œ§ to 15^{o}15Œ§ N Latitudes and has geographical area of 19,130 km$^{2.}$ The district has 3.58% of forest cover to its total geographical area and remaining is under different land use systems. The average elevation varies 280 to 1018 m above MSL. The annual average temperature range from 14^{o} C to 41^{o} C and average annual rainfall is about 553 mm. The major soil types are red and in some Mandals red and black soils are in equal proportion. Rivers of major importance are Pennar, Jayamangala, Chitravathi, Vedavathi and Thungabhadra Project Higher Level Canal. The remaining geographical area after deducting forest area is considered to be the area outside forest. It represents 18,443.3 Sq. km (18.443 lakh hectares) of the study area. This area is mainly used for many activities i.e. laying roads, canals, railway tracks, cultivating crops, establishment of industries, settlements and for many other purposes. There is 10832.12 km road found all over the district, of which 181.52 km National highway, 791.75km State highway, 1489.59km Major district road and 1502.11km other district road are under the maintenance of Roads and Buildings Department 349.18km railway track is occurred in the district 257.52km length of canal found, of which 83.520km is under the name of Tungabhadra Project Higher Level Canal, 112km is under Pennar (Anon., 2011) and remaining area is under Chitravathi and Hagari. The total cropped area in the district 11.79 lakh hectares (Anon., 2011). Cultivated orchards comprise 84,965 hectares of land (Personal comm. with Horticultural Officer)**.**

3. Materials and methods

In the present study, a non-destructive approach of above ground biomass estimation was done. A comprehensive format design of Vegetation Carbon pool Assessment (VCP) of Indian Institute of Remote Sensing (IIRS) (Singh and Dadhwal, 2008) was adopted for ground data collection. Sampling plots were identified randomly and located with the help of google earth software and Survey of India toposheets. The geographical co-ordinates for each plot were identified with the help of Global positioning system (GIS). All taxa inventoried in the sampled plots were identified following regional and local floras. For the present study, field data collected from outside forest area in Anantapuramu district. A total of 655 sampled plots were laid across the study area. Among them, 344 plots in linear category of 0.1 ha (100×10 m) size, 211 sample plots in scattered category with 100x100 m (i.e., 1 ha) dimensions and 100 sample plots of size 31.6 x31.6 m (i.e., 0.1 ha) were laid in block category, across the study area. A total area sampled in the present study is 255 hectare which is equivalent to 0.01% of the total geographical area of TOF of the Anantapuramu district 18,443.3 km^{2} Girth of all enumerated trees was measured at breast height (gbh at 1.37m) by measuring tape and height was measured using Opti-logic meter. On slopes, the observations have been taken from elevated site.

3.1. Biomass Estimation

In the present study, non-destructive approach of above ground biomass estimation was used. Basal area, volume and specific gravity for trees have been estimated as follows.

(i) Basal area: Basal area of each tree was calculated by using following standard formula: Basal Area (m^2 ha^{-1}) = ðr^2 × area (ha)

(ii) Growing Stock (Volume) Estimation: Volume of each tree was estimated using the selected species specific volumetric equation developed and compiled by Forest Survey of India (FSI, 1996).

(iii) Specific Gravity: Specific gravity values of different species were selected from literature (Reyes *et al.,* 1992; FRI, 1996; Mani and Parthasarathy, 2007). For stems with unknown specific gravity, the arithmetic mean of all known species was substituted and used in particular sample plot following Brown *et al.,* (1989).

3.2. Estimation of above ground biomass

(i) Bole biomass ≥10cm diameter

The estimated volume was converted into biomass by multiplying with specific gravity (Rajput *et al*., 1996; Limaye and Sen 1956). Biomass of all the trees was summed to obtain biomass for 1 ha.

Biomass (tons) = Volume (m^3) × Specific gravity

(ii) Bole biomass <10 cm diameter

Volume equations for trees <10cm diameter are not available, hence a methodology for trees of this class developed following Singh and Dadhwal (2008) and Patil *et al*. (2011) by relating basal area and biomass. The model developed was Y=3.6808*X+0.264 and used for assessing the AGB of trees <10cm diameter; where, Y= biomass, X= basal area of trees (>10cm diameter and <10cm diameter) and 3.6808 and 0.264 are coefficients

The biomass of trees having≥10cm diameter and <10cm diameter in each plot were added together to get biomass of 1 ha plot.

3.3. Estimation of below ground biomass

In the present study, 26% of the total above ground biomass was considered as root biomass following Houghton *et al*. (2001) and Ramankutty *et al*. (2007).

3.4. Total biomass

Total biomass for each 1 ha plot was obtained by the addition of total above-ground biomass and below ground biomass. Further the mean was calculated and extrapolated for the whole study area.

3.5. Extrapolation of biomass of TOF area

Based on the mean biomass estimation of sampled plots, total carbon stock of TOF of Anantapuramu district was estimated by extrapolating the same for the whole district area. For this, tree covered area under each TOF sub category and sub-sub category was determined on 2011 official statistics of Anantapuramu district (Anon., 2011) as follows and the same has been used for the estimation of biomass and carbon stocks of respective category.

3.6. Category-wise tree covered area

(a) Linear category (Sampled unit: 100 × 10 m = 0.1 ha)

$$\text{Estimated area (ha)} = \frac{\text{Length of linear category (m)} \times 2 \text{ (both sides)} \times 10 \text{ m (transect width)}}{10{,}000}$$

Tree covered area (ha) =Estimated area × percentage of mean basal area of sampled plots

Tree covered area of linear category was calculated using above formulae in sub category wise. The total tree covered area is 1356.21 ha of which 1238.4 ha, 75.35 ha, 42.46 ha under roads, along canals and rail track respectively.

(b) Scattered category (Sampled unit: 100×100 m =1 ha)

(i) Settlement-Village

Settlement area= 10 % of non-agricultural land of the district after deduction of town and Linear category area

Tree covered area (ha) = Settlement area×percentage of mean basal area of sampled plots

Tree covered area of settlement village category was calculated using above formulae. The projected tree covered area of this category is 485.020 ha.

(ii) Settlement-Town

Settlement area for TOF is considered as 50% of a town area

Tree covered area (ha) = Settlement area×percentage of mean basal area of sampled plots

Tree covered area of settlement town category was calculated using above formulae. The projected tree covered area of this category is 754.586 ha.

(iii) Agriculture- field bund

Field bund area of one hectare = 1m width of perimeter of a hectare =199 m^2

$$\text{Total field bund area (ha)} = \frac{\text{Field bund area of a hectare} \times \text{Total cropped area of the district}}{10{,}000}$$

Tree covered area (ha) = Total field bund area × percentage mean basal area of sampled plots

Tree covered area of agriculture field bund category

was calculated using above formulae. The projected tree covered area of this category is 701.516 ha.

(iv) Settlement-Wasteland

Settlement area for TOF is considered as 10% of a waste land area

Tree covered area in ha = Settlement area x percentage of mean basal area of sampled plots

Tree covered area of waste land category was calculated using above formulae. The projected tree covered area of this category is 1112.265 ha.

(c) Block category (Sampled unit: 31.62 × 31.62 m)

(i) Orchard

Tree covered area (ha) = Orchard area × percentage of mean basal area of sampled plots

Orchards area was estimated based on the information taken from Horticulture department of Anantapuramu district (pers. comm. with Horticultural Officer). A total of 84965 ha orchard area is available in the district and the projected area of tree cover under this category is 8505 ha

(ii) Government and Private Plantation

Tree covered area (ha) = Settlement area × percentage of mean basal area of sampled plots

Government and Private Plantations area information was taken from Revenue department of Ananatapuramu district (Personal comm. with Anantapuramu Revenue Officer). A total of 1958 ha plantation area is available in the district and the projected area of tree cover under this category is 647.12 ha.

3.7. Extrapolation of biomass

Extrapolated biomass was estimated by multiplying the tree covered area with mean biomass of sampled plots of respective category.

3.8. Carbon stocks of TOF of Anantapuramu district

Carbon stock was estimated by multiplying the extrapolated biomass with IPCC default carbon fraction (0.475) of each category and finally, all the three TOF categories are added to get the carbon stocks of TOF of the Anantapuramu district.

3.9. Carbon sequestration potential

Carbon sequestration potential of trees was calculated following Eneji *et al.* (2014) and Chavan and Rasal (2012) through the ratio of CO_2 to C, i.e. multiplying carbon content with 3.666.

4. Results

4.1. Species diversity

In the present study, a total of 97 species belonging to 78 genera and 36 families were recorded in 655 sampled plots (Table-1). In Linear category, 66 species were belonging to 53 genera and 26 families; in scattered category, 89 species belonging to 71 genera and 35 families and in block category, 13 species belonging to 13 genera and 8 families were recorded. In total 17,720 tree individuals were inventoried in 655 sampling plots in Anantapuramu district.

Table1

Trees inventoried in the TOF sampled plots

Sl. No.	Name of the Species	Family (As per APG-IV, 2016)	Linear	Scattered	Block
1	*Acacia auriculiformis* Benth.	Fabaceae - Mimosoideae	-	+	-
2	*Acacia holosericea* G.Don	Fabaceae - Mimosoideae	-	+	-
3	*Acacia leucophloea* (Roxb.)Willd.	Fabaceae - Mimosoideae	-	+	-
4	*Acacia nilotica* (L.) Delile	Fabaceae - Mimosoideae	+	+	+
5	*Aegle marmelos* (L.) Corrêa	Rutaceae	+	+	-
6	*Ailanthus excelsa* Roxb.	Simaroubaceae	+	+	-
7	*Alangium salvifolium* (L.f.) Wangerin	Cornaceae	-	+	-
8	*Albizia amara* (Roxb.) B.Boivin	Fabaceae - Mimosoideae	+	+	-
9	*Albizia lebbeck* (L.) Benth.	Fabaceae - Mimosoideae	+	+	-
10	*Albizia saman* (Jacq.) Merr.	Fabaceae - Mimosoideae	+	+	-
11	*Anacardium occidentale* L.	Anacardiaceae	-	-	+
12	*Annona reticulata* L.	Annonaceae	+	+	-
13	*Annona squamosa* L.	Annonaceae	+	+	-

Sl. No.	Name of the Species	Family (As per APG-IV, 2016)	Linear	Scattered	Block
14	*Areca catechu* L.	Arecaceae	-	+	+
15	*Artocarpus heterophyllus* Lam.	Moraceae	+	+	-
16	*Araucaria araucana* (Molina) K.Koch	Araucariaceae	-	+	-
17	*Azadirachta indica* A.Juss.	Meliaceae	+	+	-
18	*Balanites aegyptiaca* (L.) Delile	Zygophyllaceae	+	+	-
19	*Bauhinia purpurea* L.	Fabaceae - Caesalpinioideae	+	+	-
20	*Borassus flabellifer* L.	Arecaceae	+	+	-
21	*Callistemon citrinus* (Curtis) Skeels	Myrtaceae	-	+	-
22	*Cascabela thevetia* (L.) Lippold	Apocynaceae	+	+	-
23	*Cassia fistula* L.	Fabaceae - Caesalpinioideae	+	+	-
24	*Cassia roxburghii* DC.	Fabaceae - Caesalpinioideae	+	-	-
25	*Casuarina equisetifolia* L.	Casuarinaceae	-	+	-
26	*Ceiba pentandra* (L.) Gaertn.	Bombacaceae	-	+	-
27	*Citrus aurantiifolia* (Christm.) Swingle	Rutaceae	-	+	-
28	*Citrus sinensis* (L.) Osbeck	Rutaceae	+	-	+
29	*Cocos nucifera* L.	Arecaceae	+	+	+
30	*Cordia dichotoma* G.Forst.	Boraginaceae	+	+	-
31	*Cycas revoluta* Thunb.	Cycadaceae	-	+	-
32	*Dalbergia latifolia* Roxb.	Fabaceae - Faboideae	+	+	-
33	*Dalbergia sissoo* DC.	Fabaceae - Faboideae	+	+	-
34	*Delonix elata* (L.) Gamble	Fabaceae - Caesalpinioideae	+	+	-
35	*Delonix regia* (Hook.) Raf.	Fabaceae - Caesalpinioideae	+	+	-
36	*Dendrocalamus strictus* (Roxb.) Nees	Poaceae	-	+	-
37	*Dypsis lutescens* (H.Wendl.) Beentje & J.Dransf.	Arecaceae	-	+	-
38	*Erythrina variegata* L.	Fabaceae - Faboideae	-	+	-
39	*Eucalyptus camaldulensis* Dehnh.	Myrtaceae	+	+	+
40	*Euphorbia tirucalli* L.	Euphorbiaceae	+	+	-
41	*Ficus amplissima* Sm	Moraceae	+	+	-
42	*Ficus benghalensis* L.	Moraceae	+	+	-
43	*Ficus benjamina* L.	Moraceae	+	+	-
44	*Ficus drupacea* Thunb.	Moraceae	+	-	-
45	*Ficus racemosa* L.	Moraceae	+	+	-
46	*Ficus religiosa* L.	Moraceae	+	+	-
47	*Gliricidia sepium* (Jacq.) Walp.	Fabaceae - Faboideae	+	+	-
48	*Grevillea robusta* A.Cunn. ex R.Br.	Proteaceae	-	+	-
49	*Hardwickia binata* Roxb.	Fabaceae - Caesalpinioideae	+	+	+
50	*Holoptelea integrifolia* Planch.	Ulmaceae	-	+	-
52	*Jacaranda mimosifolia* D.Don	Bignoniaceae	+	-	-
51	*Kigelia africana* (Lam.) Benth.	Bignoniaceae	+	+	-
53	*Lannea coromandelica* (Houtt.) Merr.	Anacardiaceae	+	+	-
54	*Lawsonia inermis* L.	Lythraceae	+	+	-
55	*Leucaena leucocephala* (Lam.) de Wit	Fabaceae - Mimosoideae	+	+	-

Sl. No.	Name of the Species	Family (As per APG-IV, 2016)	Linear	Scattered	Block
56	*Limonia acidissima* Groff	Rutaceae	+	-	-
57	*Madhuca longifolia* var. *latifolia* (Roxb.) A.Chev.	Sapotaceae	+	+	+
58	*Magnolia champaca* (L.) Baill. ex Pierre	Magnoliaceae	-	+	-
59	*Mangifera indica* L.	Anacardiaceae	+	+	+
60	*Manilkara zapota* (L.) P.Royen	Sapotaceae	+	+	+
61	*Melia azedarach* L.	Meliaceae	+	+	-
62	*Millingtonia hortensis* L.f.	Bignoniaceae	+	+	-
63	*Mimusops elengi* L.	Sapotaceae	-	+	-
64	*Moringa oleifera* Lam.	Moringaceae	+	+	-
65	*Muntingia calabura* L.	Muntingiaceae	+	-	-
66	*Murraya koenigi*i (L.) Spreng.	Rutaceae	-	+	-
67	*Parkinsonia aculeata* L.	Fabaceae - Caesalpinioideae	-	+	-
68	*Peltophorum pterocarpum* (DC.) K.Heyne	Fabaceae - Caesalpinioideae	+	+	-
69	*Phoenix dactylifera* L.	Arecaceae	+	+	-
70	*Phoenix sylvestris* (L.) Roxb.	Arecaceae	-	+	-
71	*Phyllanthus acidus* (L.) Skeels	Euphorbiaceae	-	+	-
72	*Phyllanthus emblica* L.	Euphorbiaceae	-	+	-
73	*Pithecellobium dulce* (Roxb.) Benth.	Fabaceae - Mimosoideae	+	+	-
74	*Plumeria alba* L.	Apocynaceae	-	+	-
75	*Plumeria rubra* L.	Apocynaceae	-	+	-
76	*Polyalthia longifolia* (Sonn.) Thwaites	Annonaceae	+	+	-
77	*Pongamia pinnata* (L.) Pierre	Fabaceae - Faboideae	+	+	-
78	*Prosopis cineraria* (L.) Druce	Fabaceae - Mimosoideae	+	+	-
79	*Prosopis juliflora* (Sw.) DC.	Fabaceae - Mimosoideae	+	+	-
80	*Psidium guajava* L.	Myrtaceae	+	+	+
81	*Punica granatum* L.	Lythraceae	-	+	-
82	*Roystonea oleracea* (Jacq.) O.F.Cook	Arecaceae	-	+	-
83	*Roystonea regia* (Kunth) O.F. Cook	Arecaceae	-	+	-
84	*Santalum album* L.	Santalaceae	+	+	-
85	*Sapindus emarginatus* Vahl	Sapindaceae	-	+	-
86	*Senna siamea* (Lam.) Irwin & Barneby	Fabaceae-Caesalpinioideae	+	+	-
87	*Sesbania grandiflora* (L.)Pers.	Fabaceae-Faboideae	+	-	-
88	*Sterculia foetida* L.	Malvaceae	+	+	-
89	*Syzygium cumini* (L.) Skeels	Myrtaceae	+	+	-
90	*Tamarindus indica* L.	Fabaceae-Caesalpinioideae	+	+	+
91	*Tectona grandis* L.f.	Verbenaceae	+	+	+
92	*Terminalia arjuna* (Roxb. ex DC.) Wight & Arn.	Combretaceae	+	+	-
93	*Terminalia catappa* L.	Combretaceae	+	+	-
94	*Thespesia populnea* (L.) Sol. ex Correa	Malvaceae	-	+	-
95	*Vitex negundo* L.	Lamiaceae	+	+	-
96	*Wrightia tinctoria* R.Br.	Apocynaceae	+	+	-
97	*Ziziphus jujuba* Mill.	Rhamnaceae	+	+	-

Table 2

TOF Sub-category-wise mean values per hectare for Basal Area, Volume, Biomass and Carbon Stock of Linear, Scattered and Block Categories

Sl.No.	TOF type	Sub category	Sub-sub category	TNI/ha	Basal area (m^2 ha^{-1})	Volume (m^3 ha^{-1})	Above ground biomass (t ha^{-1})	Below ground biomass (t ha^{-1})	Total tree biomass (t ha^{-1})	Carbon (t ha^{-1})
1	Linear	Road	National High way	10.83	11.472	9.048	65.449	17.019	82.478	39.177
			State High way	11.96	22.338	18.451	132.258	34.388	166.648	79.157
			Major District road	12.84	15.622	12.346	88.654	23.050	111.710	53.416
			Approach road	13.40	12.585	7.688	97.317	25.303	122.619	58.188
		Canal	–	20.60	14.630	14.917	137.866	35.845	173.711	82.512
		Rail track	–	7.140	6.083	5.341	44.502	11.571	56.072	26.634
2	Scattered	Settlements	Village	63.731	4.977	23.972	23.972	6.227	30.176	14.334
			Town	58.526	3.400	21.267	21.267	5.512	26.714	12.689
		Agriculture	Field Bund	32.250	2.990	13.510	13.510	3.480	16.517	7.845
			Waste land	25.50	2.637	12.983	12.983	3.375	16.358	7.770
3	Block	Orchard	–	54.506	10.012	8.909	47.676	12.396	60.072	28.534
		Govt./private plantation	–	31.684	33.052	22.924	170.748	44.394	215.142	102.192

Table 3

Biomass and Carbon Stock of TOF of Anantapuramu District

Sl.No.	TOF type	Structure Sub category	Sub-sub category	Tree covered area (ha)	Mean biomass (tons ha-1)	Extrapolated Biomass (tons)	Carbon stock (tons)
1	Linear	Road	National High way	41.54	82.478	3426.136	1627.414
			State High way	353.59	166.648	58925.066	27989.406
			Major District roads	465.34	111.710	51983.131	24691.987
			Approach road	377.93	122.619	46337.997	22010.540
		Canal	–	75.35	173.711	13089.123	6217.333
		Railway track	–	42.46	56.072	2380.732	1130.888
					Sub total	176142.27	82819.558
2	Scattered	Settlements					
			Village	485.496	31.300	15181.126	7211.034
			Town	754.586	25.018	18878.232	8967.160
		Agriculture	Field bund	701.516	16.517	11586.939	5503.796
			Waste land	1112.265	16.358	18194.430	8642.354
					Sub total	63840.727	30324.344
3	Block	Orchard	–	8505	60.072	510912.36	242683.371
		Govt./private plantation	–	647.12	215.142	139222.691	66130.778
					Sub total	650135.051	3,08,814.149
					Total	890118.648	422806.069
						0.890 (Mt)	0.422 (Mt)

4.2. Basal area

Sub- sub category wise mean basal area was calculated in linear plots. The mean basal area of national high way is 11.472 m^2 ha^{-1}, 22.338 m^2 ha^{-1}in state high way, 15.622m^2 ha^{-1}in major district road, approach roads is 12.585 m^2 ha^{-1}, 14.63 m^2 ha^{-1} along canals and 6.083 m^2 ha^{-1} in rail track. Sub-sub category wise mean basal area was calculated in scattered plots. The mean basal area of villages was 4.977m^2 ha^{-1}, 3.400 m^2 ha^{-1} in towns and 2.990 m^2 ha^{-1} in field bunds and waste lands was 2.637 m^2 ha^{-1}. Sub category wise mean basal area was calculated in block plots. The mean basal area in orchards is 10.012 m^2 ha^{-1} and 33.052 m^2 ha^{-1} in plantations (Table-2).

4.3. Growing stock

The mean growing stock of trees with ≥10 cm diameter in linear plots was 13.82 m^3 ha^{-1}, 23.66 m^3 ha^{-1} in scattered plots and 11.09 m^3 ha^{-1} in block plots. In linear category, the correlation between basal area and biomass of trees with e”10 cm diameter revealed the determination of coefficient of R^2 is 0.805 (Fig.1), in scattered category, it is 0.751 (Fig.2) and in block category, it is 0.955 (Fig.3).

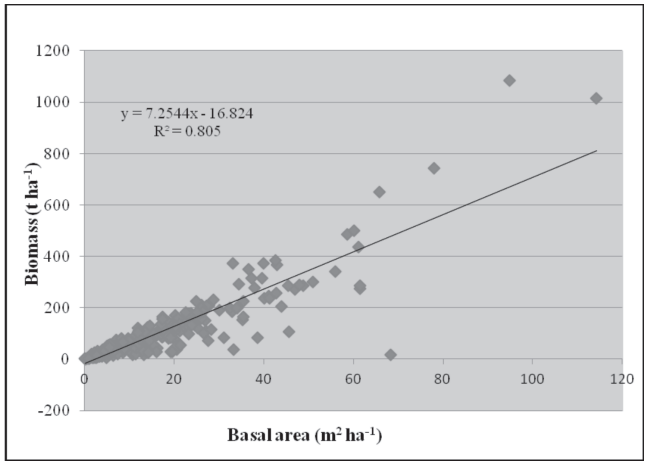

Fig. 1: Correlation between basal area and biomass of ≥10 cm diameter of trees sampled in linear plots

4.4. Biomass

The total mean biomass was 1078.22 tons ha^{-1} In all plots, sub- sub category wise biomass was calculated. In linear plots mean biomass of national high ways was 82.478 tons ha^{-1}, 166.648 tons ha^{-1}in state high ways, 111.710 tons ha^{-1}in major district roads, 122.619 tons ha^{-1}in approach roads 173.711tons ha^{-1} along canals and 56.072 tons ha^{-1}in rail track. In Scattered plots the mean biomass of villages was 30.176 tons ha^{-1}, 26.714 tons ha^{-1} in towns and 16.517 tons ha^{-1}in field bunds, 16.358 tons ha^{-1} in wastelands. In block plots the mean biomass in orchards is 60.072 tons ha^{-1} and 215.142 tons ha^{-1} in plantations (Table-2).

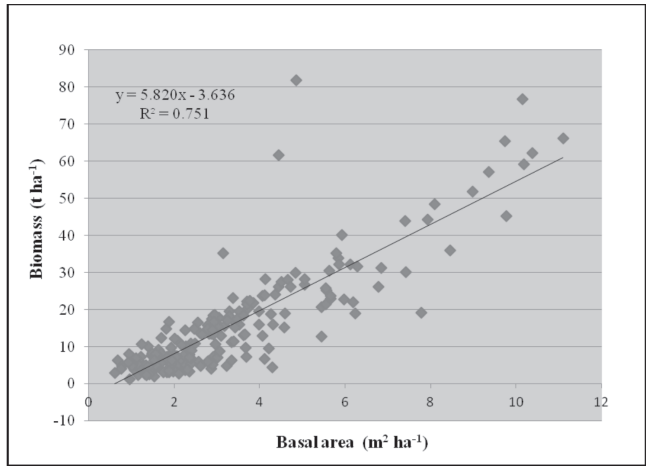

Fig. 2: Correlation between basal area and biomass of ≥10 cm diameter of trees sampled in scattered plots

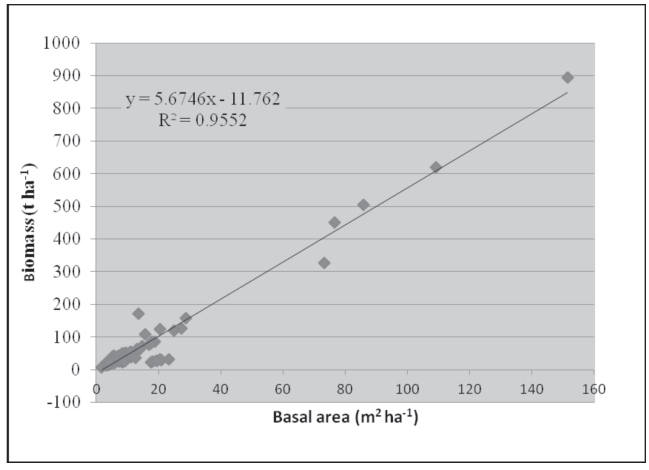

Fig. 3: Correlation between basal area and biomass of ≥10 cm diameter of trees sampled in block plots

4.5. Carbon Stocks

The total mean carbon stocks was 512.448 tons ha^{-1} of which in linear plots mean carbon stocks of national highways was 39.177 t ha^{-1}, 79.157 t ha^{-1} in state highways, 53.416 t ha^{-1} in major district roads, 58.188 t ha-^{1} approach roads 82.512 t ha^{-1} along canals and 26.634 t ha^{-1}in rail track. In Scattered plots the mean carbon stocks was 14.334 t ha^{-1} in villages, 12.689 t ha^{-1} in towns,7.845 t ha^{-1} in field bunds and 7.770 t ha^{-1}. In block plots the mean carbon stocks in orchards was 28.534 t ha^{-1} and 1021.19 t ha^{-1} in plantations (Table-2).

4.6. Extrapolated biomass of different categories

Extrapolated biomass was estimated by multiplying the tree covered area with mean biomass of sampled plots of respective category. All sub categories in a category were summed. Total biomass of TOF area of Anantapuramu district

was 0.890 Mt, of which 0.1761Mt under linear category, 0.0638 under scattered category and 0.6501 Mt under block category (Table-3).

4.7. Carbon stocks of TOF of Anantapuramu district:

The extrapolated carbon stocks TOF of Anantapuramu district is 0.422 Mt, of which 0.0828 Mt is under linear category; 0.0303 Mt under scattered category and 0.308 Mt under block category (Table-3). Anantapuramu district carbon stock is almost less by 0.6 Mt, when compared to Kurnool district TOF carbon stock (1.012 Mt) as estimated by Ramesh (2015). Further 0.422 Mt carbon stocks of TOF of Anantapuramu district represent the ability of sequestering 1.544 Mt CO_2.

5. Discussion

In the present study, a total of 97 species belonging to 78 genera and 36 families were recorded in 655 sampled plots and a total of 17,720 tree individuals were inventoried in 655 sampling plots in Anantapuramu district. In linear, scattered and block categories, the R^2 values are very high as reported by Haripriya (2000), Brown *et al*. (1989) and Cannell (1984). Anantapuramu district carbon stock is almost less by 0.6 Mt, when compared to Kurnool district TOF carbon stock (1.012 Mt) as estimated by Ramesh (2015). A critical analysis revealed that out of 63 mandals, 40 mandals have less than 300 tree individuals in the sampled plots and these are mostly distributed in northern parts of the district and hence low carbon stocks for the district with respect to TOF. Settur mandal recorded highest number of individuals (971) followed by Dharamvaram (808).

6. Conclusion

Evaluation of trees biomass potential in TOF area of Anantapuramu district highlight the importance of trees outside forests in maintaining recognisable amounts of carbon stocks and their ability in sequestering carbon dioxide. The present work may be considered as a model and the present study is the first of its kind especially in arid zone of Anantapuramu district of Andhra Pradesh to understand the potential of TOF in any area. TOF carbon stocks of Anantapuramu is less when compared to Kurnool district due to better climatic conditions, diversified water resources and high density of trees in Kurnool. Further this work advocates planting more broad leaved trees, outside the forests.

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