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Carbon stocks of linear structures of trees out side forest in Kurnool District, Andhra Pradesh, India

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ABSTRACT

In the present study, carbon stocks of linear structures of trees outside forest in Kurnool district were estimated through sampling of 236 0.1 ha plots. A total of 3922 tree individuals belonging to 51 angiosperm species were enumerated in the sampled plots. The mean tree density was 150.50 per ha; mean basal area is 24.54 m^2 ha^{-1}; mean volume of trees with $\geq$10 cm diameter is 20.07 m^3 ha^{-1}; mean total tree biomass is 176.20 tons ha^{-1} and mean carbon stock is 83.66 tons ha^{-1}. Extrapolated biomass and carbon content for linear structures are calculated as 0.528 Mt and 0.251 Mt respectively. The carbon sequestration potential is estimated as 0.918 Mt CO^2.

1. Introduction

Earth's climate is warming at an unprecedented rate. Burning of fossil fuels and consequent increase of carbon dioxide concentration in the atmosphere is identified as the prime cause for climate change. Due to 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). Carbon dioxide levels which was below 300 ppm during the last 600,000 years is now touching 401.30 ppm, average for July, 2015 (Tans and Keeling, 2015).

The main natural carbon sinks are plants, the ocean and soil. The uptake of carbon dioxide (CO_2), one of the principle greenhouse gases, during photosynthesis is the major pathway by which carbon is removed from the atmosphere and this 'capturing and securing of atmospheric carbon in the form of CO_2 during photosynthesis and subsequently to dead organic matter is called as 'carbon sequestration'. Carbon sequestration has been recognized as an effective and low-cost method of mitigating carbon emissions. Vegetation in the form of forests and especially trees plays a pivotal role in sequestration and trees are the largest component of aboveground biomass in terrestrial ecosystems. 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 that are not categorized as 'forest' nor 'other wooded land' irrespective of their patch size (FSI, 2009; FAO, 2010). TOF includes 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). TOF offers a range of ecological,

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economic, and social functions including carbon sequestration and offers a win-win land-use strategy for climate change mitigation and adaptation. Despite wide spread distribution, TOF are neglected in terms of their carbon sequestration potential (de Foresta *et al.*, 2013).

Forest Survey of India has started inventory of trees outside forests in the country since 1991 and national level estimates of growing carbon stock were initiated from 2002 (FSI, 2009). Indian Space Research Organisation (ISRO) has initiated National Carbon Project under the auspices of Indian Geosphere Biosphere Programme (IGBP) (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. 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 linear structures of TOF of Kurnool district, Andhra Pradesh following as a comprehensive format design of Vegetation Carbon pool Assessment (VCP) National Carbon Project (Singh and Dadhwal, 2008). The present study is the first of its kind with reference to estimating carbon stock of TOF at district level through intensive sampling.

2. Study area

Kurnool district is located between 76^0 58′E to79^0 34′E longitudes and 14^0 54′ to 16^0 18′ N Latitudes and has a geographical area of 17,658 km^2. The average elevation varies 300 to 900 m above MSL. The annual average temperature range from 19^0 C to 41.5^0 C and rainfall is about 670 mm. The major soil types are black cotton, red and saline soils. Rivers of major importance are Thungabadra, Krishna, Hundri, Kunderu and Gundlakamma. The district has 19.29% of forest cover to its total geographical area and remaining is under different land use systems. The remaining geographical area after deducting forest area is considered to be the Area outside forest and accounts for 14,251 Sq. km. This area covers roads, canals, railway tracks, cropped area, industrial areas, human settlements etc. There is 10119.31 km road found all over the district including 264 km National highway, 790.24 km State highway, 1966.23 km Major district roads, 815.85 km other district road under the maintenance of Roads and Buildings Department and remaining 6546.99 km road under the maintenance of Zilla Parishad. Railway track in the district accounts for 264.04 km. Canals cover 356.64 km length, of 234.64 km under the name of KC Canal and remaining 122 km as Tungabhadra Lower Level Canal (Anon., 2011).

3. Materials and methods

For the purpose of the present study, field data was collected from randomly laid linear structures outside the forests in Kurnool district. 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. A total of 236 linear plots of size 100×10 m were laid along the roads, canals, railway tracks in different parts of the district covering varied topographic terrain and different density classes. The geographical co-ordinates for each plot were identified with the help of Global Positioning System. All the tree taxa in the sampled plots were inventoried and identified following regional and local floras. Enumeration of trees was done and girth at breast height (gbh) measurements was taken with measuring tape and height was measured using opti-logic meter.

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.

Basal area

Basal area of each tree was calculated by using following standard formula:

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

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).

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

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) x Specific gravity

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

3.3. Estimation of total above ground biomass

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

3.4. 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).

3.5. 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.

3.6. Estimation of carbon stocks

3.6.1. Extrapolation of linear structures of TOF area

Based on the mean biomass estimation of sampled plots, total carbon stock of linear structures of TOF of Kurnool district was estimated by extrapolating the same for the whole district area. For this, tree covered area under each sub category and sub-sub category was determined based on 2011 official statistics of Kurnool district (Anon., 2011).

Estimated area (ha) = Length of linear category (m) x 2 (both sides) x 10 m (transect width)/ 10,000

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

Considering both sides of the roads, canals and railway track, 1631.6 km length was estimated for approach roads; 3932.46 km for major district roads; 480 km for national highway, 1540.28 km for state highways, 713.28 km length of canals and 528.08 km railway track. As transect width is 10 m, estimated area under each above sub-sub category is calculated my multiplying 10. As the mean basal area of the sampled plots is 11.71 for approach road, the tree covered area is projected for the same at 191 ha. In case of others the projected figures are: major district roads, 1276 ha; national highway, 51.5 ha; state highway, 511 ha; canals 102 ha and railway track, 148 ha.

3.6.2. Estimation of carbon stocks and carbon sequestration potential

Estimation of carbon stocks from the biomass has been calculated by multiplying the total biomass by a conversion factor that represents the average carbon content in biomass. In the present study, the IPCC default of 0.475 carbon fraction (Mc Groddy *et al.,* 2004) has been used.

Carbon (tons) = Biomass (tons) × Carbon %

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 and discussion

In the present study, a total of 51 angiosperm species belonging to 43 genera and 23 families were recorded (Table 1). A total of 3922 tree individuals ranging 2 to 43 per sample plot of 0.1 ha were encountered in 236 inventory plots laid all over the district. The mean tree density was 150.50 per ha. The highest values of tree density were observed along major district roads and state highways (Table-2). *Azadirachta indica*, *Pongamia pinnata*, *Tectona grandis*, *Tamarindus indica*, *Albizia lebbeck*, *Albizia saman*, *Dalbergia sissoo*, *Senna siamea* and *Acacia nilotica* are the dominant trees which contribute more than 75% of total number of individuals (TNI) (Table-1).

The mean basal area is 24.54 m^2 ha^{-1} ranging between 0.99 - 189.76 m^2 ha^{-1} across the plots. Lowest values of basal area were recorded in approach road and national highways as many trees in the latter case are planted recently after widening. Mean volume of trees with >10 cm diameter is 20.07 m^3 ha^{-1}. The correlation between basal area and biomass of trees with >10 cm diameter revealed the determination coefficient (R^2) 0.863 (Figure-1).

The mean total tree biomass is 176.20 tons ha^{-1} and varies between 8.16 and 1400.48 tons ha^{-1} across the sampled

Table 1
Inventory of tree species in sampled linear structures in Kurnool district

Name of the Species	Family	No. of individuals in all sampled plots
Acacia holosericea G.Don	Fabaceae - Mimosoideae	1
Acacia nilotica (L.) Delile	Fabaceae - Mimosoideae	198
Adansonia digitata L.	Malvaceae	1
Aegle marmelos (L.) Corrêa	Rutaceae	1
Ailanthus excelsa Roxb.	Simaroubaceae	23
Albizia lebbeck (L.) Benth.	Fabaceae - Mimosoideae	226
Albizia saman (Jacq.) Merr.	Fabaceae - Mimosoideae	178
Annona squamosa L.	Annonaceae	6
Artocarpus heterophyllus Lam.	Moraceae	1
Azadirachta indica A.Juss.	Meliaceae	771
Balanites aegyptiaca (L.) Delile	Zygophyllaceae	50
Bauhinia purpurea L.	Fabaceae - Caesalpinioideae	3
Borassus flabellifer L.	Arecaceae	188
Cocos nucifera L.	Arecaceae	66
Cordia dichotoma G.Forst.	Boraginaceae	2
Dalbergia sissoo DC.	Fabaceae - Faboideae	207
Delonix elata (L.) Gamble	Fabaceae - Caesalpinioideae	24
Delonix regia (Hook.) Raf.	Fabaceae - Caesalpinioideae	89
Eucalyptus camaldulensis Dehnh.	Myrtaceae	42
Ficus benghalensis L.	Moraceae	6
Ficus benjamina L.	Moraceae	4
Ficus glomerata Roxb.	Moraceae	8
Ficus religiosa L.	Moraceae	58
Gyrocarpus americanus Jacq.	Hernandiaceae	1
Hardwickia binata Roxb.	Fabaceae - Caesalpinioideae	5
Kigelia africana (Lam.) Benth	Bignoniaceae	19
Leucaena leucocephala (Lam.) de Wit	Fabaceae - Mimosoideae	98
Limonia acidissima Groff.	Rutaceae	7
Madhuca longifolia var. *latifolia* (Roxb.) A.Chev.	Sapotaceae	4
Mangifera indica L.	Anacardiaceae	14
Morinda pubescens Sm.	Rubiaceae	1
Moringa oleifera Lam.	Moringaceae	2
Parkinsonia aculeata L.	Fabaceae - Caesalpinioideae	1
Peltophorum pterocarpum (DC.) K.Heyne	Fabaceae - Caesalpinioideae	73
Phoenix dactylifera L.	Arecaceae	1
Phoenix sylvestris (L.) Roxb.	Arecaceae	1
Phyllanthus emblica L.	Euphorbiaceae	1
Pithecellobium dulce (Roxb.) Benth.	Fabaceae - Mimosoideae	2

Polyalthia longifolia (Sonn.) Thwaites	Annonaceae	2
Pongamia pinnata (L.) Pierre	Fabaceae - Faboideae	411
Prosopis cineraria (L.) Druce	Fabaceae - Mimosoideae	18
Prosopis chilensis (Molina) Stuntz	Fabaceae - Mimosoideae	19
Santalum album L.	Santalaceae	8
Sapindus emarginatus Vahl	Sapindaceae	4
Senna siamea (Lam.) H.S.Irwin & Barneby	Fabaceae - Caesalpinioideae	263
Simarouba amara Aubl.	Simaroubaceae	3
Syzygium cumini (L.) Skeels	Myrtaceae	2
Tamarindus indica L.	Fabaceae - Caesalpinioideae	397
Tectona grandis L.f.	Verbenaceae	399
Terminalia catappa L.	Combretaceae	5
Ziziphus mauritiana Lam.	Rhamnaceae	8
Total		3922

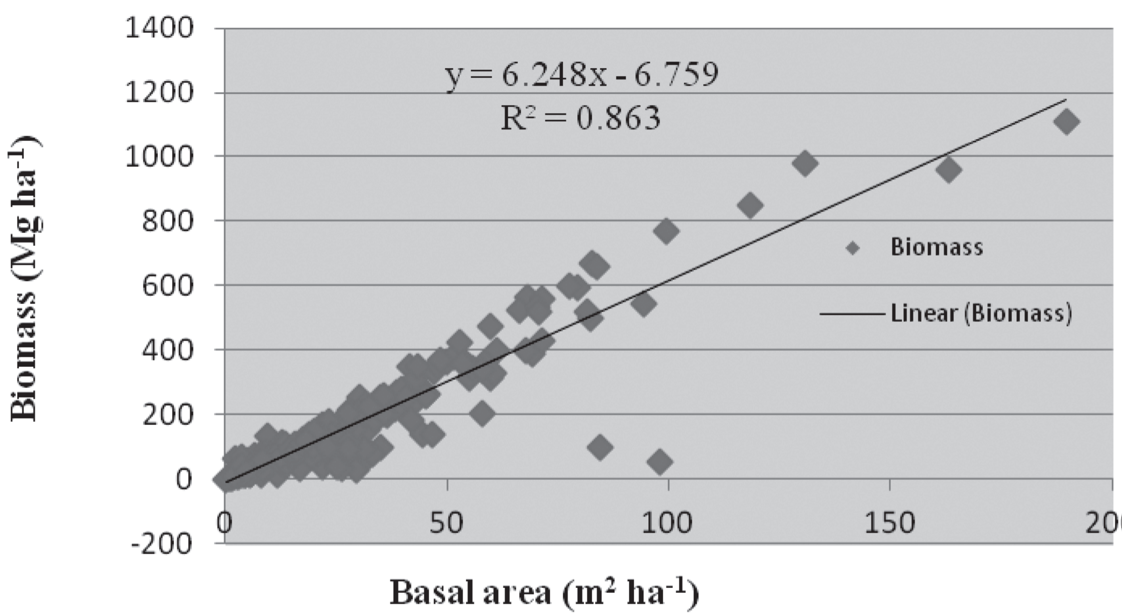

Fig. 1. Correlation between basal area and biomass of trees of >10 cm diameter

plots. The maximum biomass content has been found along major district roads, state highways and canals due to relatively less disturbance and growth of huge mature old trees. The mean carbon stock for linear structures is 83.66 tons ha^{-1} ranging from 3.87 to 665.23 tons C ha^{-1} across the sampled plots. For the total estimated area under all categories of linear structures of trees outside forests in Kurnool district, the projected biomass and carbon content are calculated as 0.528 Mt and 0.251 Mt respectively (Table-2), of which 91.7% was contributed by dominant trees. The carbon sequestration potential is estimated as 0.918 Mt CO^2.

Although studies on different categories of TOF were initiated throughout India data for comparison was available with two districts in Andhra Pradesh. In Prakasam district of Andhra Pradesh linear plots registered a mean of 7.95 ± 9.66 Mg ha^{-1} ranging between 0.10 to 30.84 Mg C ha^{-1} across the sampled plots (Srinivasa Rao et al., 2012a). In Kadapa district, linear plots registered 59.36 ± 121.61 Mg C ha^{-1} ranging between 7.03 to 403.67 Mg C ha^{-1} across the sampled plots (Srinivasa Rao et al., 2012b). Compared to both the districts, Kurnool district has registered more carbon stocks in TOF.

Table-2
Subcategory-wise Linear Structures tree density, basal area, volume, biomass and carbon stocks

Sub category	Sub-sub category	Tree covered area (ha)	Tree density (trees/ha)	Basal area (m^2 ha^{-1})	Volume (m^3 ha^{-1})	Mean Biomass (tons ha^{-1})	Carbon stock (tons ha^{-1})	Extrapolated Biomass (tons)	Carbon stock (tons)
Road	Approach Road	191	140	11.71	8.69	72.74	34.42	13841.77	6574.84
	Major District Road	1276	179	32.45	29.60	259.92	123.46	331657.92	157537.51
	National High way	51.5	128	10.73	7.91	64.93	30.84	3343.89	1588.34
	State High way	511	151	33.24	28.78	253.97	120.57	129778.67	61644.86
	Canal	102	143	30.97	24.91	221.69	105.30	22612.38	10740.88
	Rail track	148	162	28.19	20.57	183.98	87.39	27229.04	12933.79
	Total	2279.5	903	147.29	120.46	1057.18	501.98	528463.67 (0.528Mt)	251020.22 (0.251Mt)
	Mean	150.5	24.54	20.07	176.20	83.66	-	-	

Srinivasa Rao and Ravi Prasad Rao (2015) estimated the carbon stocks of Nallamalais at 26.34 Mt. Since 60% of Nallamalais fall in Kurnool district about 15.78 Mt of Carbon stocks can be projected for forests of Nallamalais. Excluding unknown but minor fraction of carbon stocks of other forests in the district especially Erramalais, TOF shared almost 8% of the total carbon stock of Kurnool district which is near to the general perception that TOF share up to 10% of total carbon stocks of any country.

Conclusion

Evaluation of trees biomass potential in linear structures of Kurnool district highlights 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 especially in Andhra Pradesh to understand the potential of TOF in any area. Further this work advocates planting more broad leaf trees outside the forests.

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