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Adaptation of Forest Ecosystems to Air Pollution and Climate Change
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Carbon stock in Kolli forests, Eastern Ghats (India) with emphasis on aboveground biomass, litter, woody debris and soils

Mohanraj R, Saravanan J, Dhanakumar S

The efficacy of tropical forest sinks in India continues to diminish in spite of several conservation efforts carried out at both governmental and non-governmental level. Lack of proper periodical and complete spatial inventory of carbon stock in India is a disturbing aspect at this aim. Carbon stock assessments are available only for few patches of Western Ghats of India, while assessment is almost negligible for Eastern Ghats. This paper focuses on estimation of existing carbon stock in the above ground biomass, litter, debris and soils (up to 30 cm) of different forest types of Kolli forest, located in Eastern Ghats of Tamilnadu, India (78°20' to 78°30'E Long and 11°10' to 11°30' N Lat), within an area of 503 km^2. Floristic diversity of Kolli hills is rich of endemisms and includes about 150 tree species. To estimate the carbon stock, about 26 quadrates of 25 X 25 m size were established. The organic carbon content of forest soil varied from 1.71 to 12.59%. The total carbon stock of soil, surface litter, coarse wood debris and total above ground biomass were estimated as 5.54, 0.034, 0.001 and 4.49 Tg C, respectively.

Keywords: Above ground biomass, Carbon stock, Eastern Ghats India, Soil carbon, Tropical forest

Introduction

Forest ecosystems play a crucial role in global carbon cycling acting as sink and source. Forests form an active carbon pool that accounts for 60 per cent of carbon storage in the earth's land surface (Wilson & Daff 2003). Tropical forests dominate the role of forests in the global carbon flux and stocks, and therefore require researchers and policy makers to estimate the carbon sequestration potentials. The tropical forests, both moist and dry types, account for approximately 60% of global forests (Dixon et al. 1994). While covering only 22% of potential vegetation by area, tropical forests have been estimated to account for 43% of the world's terrestrial net primary productivity (Melillo et al. 1993).

Unprecedented increase in anthropogenic activities since globalization and subsequent industrialization and urbanization has reportedly lead to a corresponding decline and degradation of tropical forest ecosystems of the world (Eraldo et al. 2010, Mingxia et al. 2010, Vaidyanathana et al. 2010).

Current population growth and rapid infrastructure development are expected to put additional pressures on tropical forests leading to rapid rise in the release of CO_2 into atmosphere and decline in atmospheric carbon sequestration. Despite unresolved controversies over observed changes in biomass and gas fluxes, current observations indicate the likelihood that additional climate change would have substantial impacts on tropical forests (Fearnside 2004).

India has a diverse range of forests covering 64 Million hectare, of which 72% are tropical moist deciduous, dry deciduous, and wet evergreen forest (Ravindranath & Sukumar 1998). Unlike developed countries, India does not have any carbon inventories and databank to monitor and enhance the carbon sequestration potential in diverse forests. Currently attempts are made to evaluate carbon stock assessment at macro level, mostly based on secondary data. Only few attempts have been made so far to assess above ground biomass and soil carbon sequestration at micro-level in any specific forest system in India (Baishya et al. 2009, Jana et al. 2009, Natha et al. 2009, Chavan & Rasal 2010). Such kinds of studies are essential to understand the carbon stock potential in the forest system. This paper aims to evaluate the carbon stock of above ground biomass, litter, woody debris and soils in different forest systems of Kolli hills, Eastern Ghats, India.

Materials and Methods

Study area

The Eastern Ghats are uneven terrain running nearly parallel to eastern coast of India. Eastern Ghats are divisible into three zones such as northern Eastern Ghats, middle and the southern Ghats (Rao 1998). Kolli hills, the present study area, is one among eight hills in southern region (Fig. 1). It lies at a longitude of 78°20' to 78°30' E and a latitude of 11°10' to 11°30' N, covering about 500 km^2. Forests cover 44 % of the total geographical area, agricultural activities take place in 51.6% and other activities cover less than 5% of the area. Annual rainfall varies between 300 to 750 mm and the soil type varies between red to black clay. Highest point in Kollimalai is 1400 m a.s.l., but the general level of the upper surface of the hill is not more than 1000 m. The altitude range of Kolli hills varied from 200 to 1415 m a.s.l. The geology of area is characterized by charnockite associated with gneisses and metamorphic rocks. In order to estimate the carbon stock in above ground biomass, litter, woody debris and soil, about 26 quadrates of 25 x 25 m size were established during September 2009 in different forest types, *i.e.*, evergreen, deciduous, mixed, open scrub and plantation forest.

Evergreen forests are represented by forest patches in high-elevation sites (above 1000 m a.s.l) which receive high rainfall (about 2000 mm year^{-1}). In general, trees of these forests do not shed their leaves in any season of the year. Major evergreen tree species of Kolli forests are *Terminalia paniculata, Myrstica dactyloides, Scolopia crenata, Prunus ceylanica, Syzygium cumini*. Deciduous forests are generally present in regions with annual rainfall ranging between 750-2000 mm. They are called "deciduous forests" because trees shed their leaves in the dry season of the year. Common deciduous trees in Kolli forests are *Tectona grandis, Terminalia chebula, Spondias pinnata, Anogeissus latifolia, Albizia anara, Albizia*

Department of Environmental Management, Bharathidasan University Tiruchirappalli, IND-620024 (India)

@ Rangaswamy Mohanraj (mohan.bdu@gmail.com)

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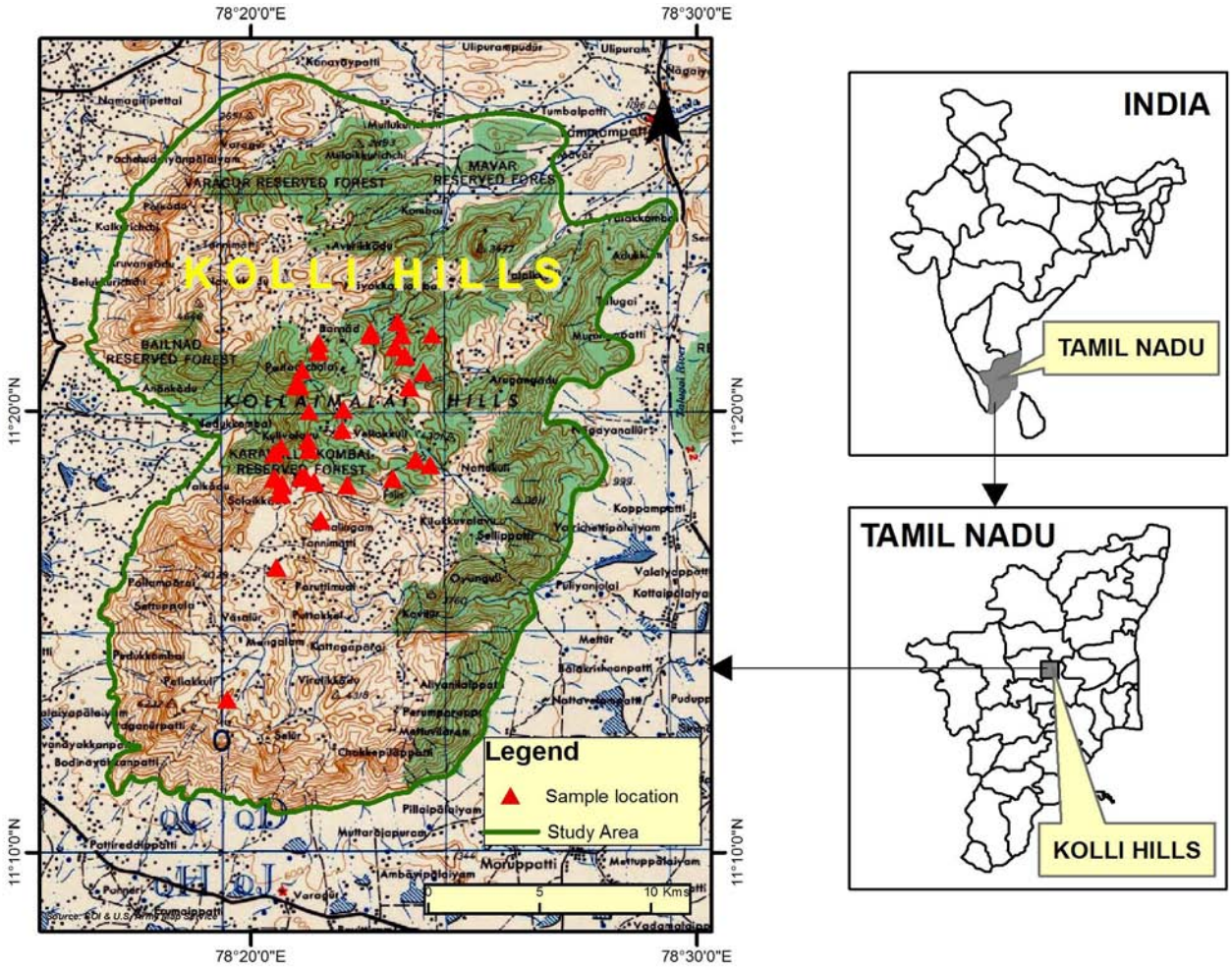

Fig. 1 - Study area and sampling sites.

lebbeck. Mixed forest patches analyzed in this study contain both evergreen and deciduous tree species. Scrub forests are confined to areas with a rainfall lower than 750 mm. Thorn, cactus*, Lantana camara, Euphorbia* species, are common among scrub. Plantation forests of Kolli include silver oak, eucalyptus, pines, etc.

The study plots were representative of forest types relating to species abundance, altitude and other factors such as stand density, microclimate and crown conditions. Results obtained in the plots were extrapolated to respective forest types and geographical area. Statistical analysis of the results was carried out using SPSS® and MS-Excel®. The land use and cover map (Fig. 2) for Kolli forest was generated based on secondary data and maps obtained from forest department (Govt. of Tamilnadu) and earlier satellite observations (Jaya Kumar et al. 2002). Mapping techniques including classification of forest cover were followed to prepare the forest cover density map of the study area. Normalized Difference Vegetation Index (NDVI) was prepared and recoded into four classes based on the density, *i.e.*, very dense (>70%), dense (40-70%), open (10-40%) and degraded (<10% - State Forest Report 2003).

Estimation of above ground biomass carbon

Aboveground biomass (AGB) and its existing carbon stock was estimated in 26 quadrates during September 2009. All trees with diameter at breast height (DBH) greater than 0.3 m were enumerated, measured, and classified. Ravi's altimeter was used to measure tree height and AGB was calculated by the allometric equation developed by Mani & Parthasarathy (2007). Carbon content of AGB was calculated by the conversion factor 0.5 (Atjay et al. 1979, Brown & Lugo 1982, Iverson et al. 1994, Dixon et al. 1994, Cannell & Milne 1995).

Estimation of soil organic carbon, surface litter and coarse wood debris

Soil samples were collected at three depths (0-10 cm, 10-20 cm and 20-30 cm). Samples were air dried and ground to fine powder using an agate pestle and mortar. The SOC content in the 0.5 mm sieved soil samples was estimated following Walkley & Black (1934) wet oxidation method.

Coarse wood debris and surface litter samples were collected as per standard procedures (Van Wagner 1968, Cheney et al. 1992, Bell et al. 1996, O'Heir & Leech 1997). Estimation of organic carbon storage in woody debris and litter was performed as per Allen et al. (1986). In brief, after taking the fresh weight collected samples (woody debris, leaf litter) were dried in the oven for 48 hours at 65ºC and dried weight was measured. Oven-dried samples were taken in pre-weighed crucibles. The samples were ignited at 550ºC for one hour in muffle furnace. After cooling, the crucibles with ash were weighed and percentage of organic carbon was calculated as follows (eqn. 1, 2):

$$Ash\,\% = \frac{W_c - W_a}{W_b - W_a} \cdot 100$$

$$C\,\% = (100 - Ash\,\%) \cdot 0.58$$

where C is the organic carbon, W_a the weight

of crucible, W_b the weight of oven dried grind samples + crucibles, W_c the weight of ash + crucibles.

Results and Discussion

In Kolli hills, evergreen forests and semi-evergreen occurs in upper plateau of 900 m a.s.l., while slopes are covered by deciduous and thorn forest types. Land use and land cover analysis showed abundance of different forest cover in the order deciduous > mixed > evergreen > open scrub > plantation (Fig. 2), with total area under forest cover extending up to 26 587.8 ha. Anthropogenic disturbances such as mining, exotic plantation, agriculture extension, shifting cultivation, over grazing, tourism developments and firewood collection occurred at many places. An earlier study also reported that the extensive mining activities in Kolli hills take away about 600 Mg of soil per day for cement and aluminum factories (Sundaram & Parthasarathy 2002).

In the present investigation, AGB analysis using DBH and height of trees yielded different size classes of trees (Fig. 3). In general, DBH of trees in class size 30-60 cm was found dominant followed by 60-90 cm, above 120 cm, 90-120 cm and less than 30 cm. Stand density observed in the Kolli hills varied from plantation> deciduous> evergreen > mixed forest > open scrub. Maximum stand density was observed in the forest plantation (2 220 trees ha^{-1}) followed by deciduous (1 960 trees ha^{-1}) and evergreen forest (1 680 trees ha^{-1}). Tree height was recorded in the range of 3 to 19.88 m. Aboveground biomass (AGB) in different forest types ranged between 15.61 to 597.13 t ha^{-1} (Tab. 1) with minimum in open scrub and maximum in evergreen forest. Carbon stock in AGB varied between 7.80 to 298.56 t ha^{-1}, with average value of 170.65 t ha^{-1}. Overall of extrapolation analysis showed 4.49 Tg C stock in aboveground biomass for entire Kolli hills.

Surface litter carbon stock varies between 0.16 to 3.26 t ha^{-1} (Tab. 2). The maximum mean of surface litter carbon stock was recorded in evergreen forest (1.58 t ha^{-1}), followed by forest plantation (1.38t ha^{-1}) and deciduous forest (1.37 t ha^{-1}). The total carbon stock of surface litter after extrapolation for the entire Kolli forest was found to be 34.13 Gg C in Kolli Hills. The Coarse Wood Debris (CWD) carbon stock ranged between 0.0006 to 0.0977 t ha^{-1}, with the higher values recorded for deciduous forests (52%), followed by mixed (21%) and evergreen forest (18%). Irrespective of forest types, SOC content ranged between 1.71 to 12.59% and decreased with soil depth. The SOC concentration was observed in the order: deciduous > mixed > evergreen > open scrub > plantation (Tab. 4). Analysis of variance showed statistically significant difference among forest types ($p< 0.05$). The total soil carbon stock of Kolli Hills after extrapolation accounted to 5.54 Tg C. High carbon content of the surface layer (0-10 cm) is indicative of rich inputs from litter fall, wood and fine roots (Jeong et al. 1998).

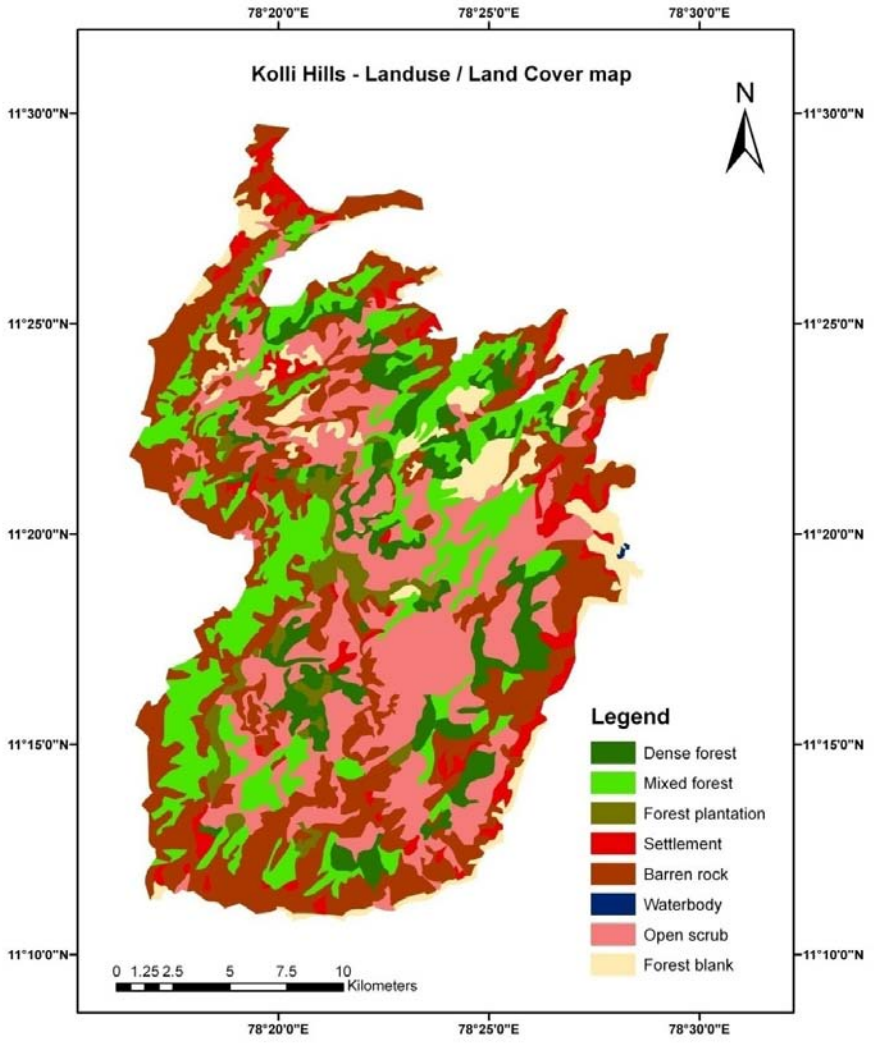

Fig. 2 - Land use and land cover map of Kolli Hills.

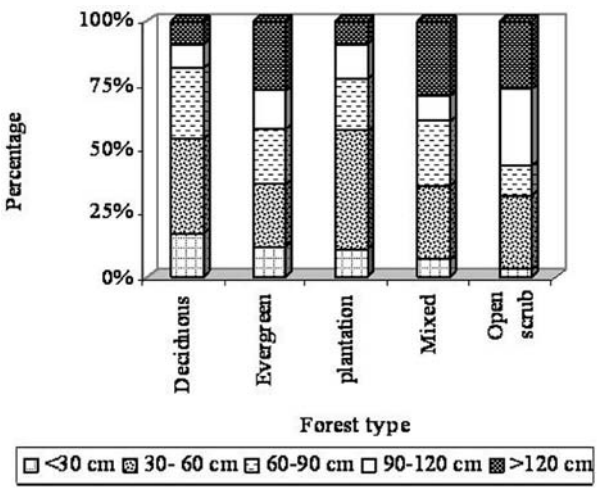

Fig. 3 - Distribution of above ground biomass with respect to DBH.

Tab. 1 - Above ground biomass and its carbon stock. (n): number of plots in the respective forest type.

Forest type	Above ground biomass (AGB, t ha^{-1}) estimated experimentally			Total carbon stock in AGB (Tg) (extrapolated for the total Kolli forest)
	Minimum	Maximum	Mean ± std. dev	
Evergreen (n= 6)	314.80	597.13	412.52 ± 96.67	0.82
Decidouus (n =5)	243.91	418.49	348.08 ± 68.75	2.21
Mixed (n =6)	142.63	455.01	290.34 ± 124.99	0.97
Open scrub (n =5)	15.61	568.40	293.72 ± 260.30	0.43
Plantation (n = 4)	317.23	416.37	361.91 ± 41.88	0.06
Total				4.49

Tab. 2 - Surface litter carbon stock in various forest types of Kolli hills.

Forest type	Surface litter carbon stock (t ha^{-1}) estimated experimentally			Total stock (Gg C) (extrapolated for the total Kolli forest)
	Minimum	Maximum	Mean ± std.dev	
Evergreen (n=6)	1.04	2.00	1.58 ± 0.37	6.25061
Deciduous (n=5)	1.03	2.11	1.37 ± 0.44	17.4286
Mixed (n=6)	1.03	2.05	1.07 ± 0.82	7.16314
Open scrub (n=5)	0.16	2.54	0.97 ± 0.95	2.86238
Plantation (n=4)	0.29	3.26	1.38 ± 1.40	0.42101
Total				34.125

Tab. 3 - Coarse wood debris carbon stock in various forest types of Kolli hills.

Forest type	Coarse Wood debris C stock (t ha^{-1}) estimated experimentally			Total Carbon Stock (Gg C) (extrapolated for the total Kolli forest)
	Minimum	Maximum	Mean ± std.dev	
Evergreen (n=6)	0.0312	0.0600	0.0473 ± 0.0112	0.188
Deciduous (n=5)	0.0310	0.0632	0.0412 ± 0.0133	0.523
Mixed (n=6)	0.0006	0.0614	0.0322 ± 0.0247	0.215
Open scrub (n=5)	0.0047	0.0761	0.0290 ± 0.0284	0.086
Plantation (n=4)	0.0087	0.0977	0.0415 ± 0.0421	0.013
Total				1.024

Tab. 4 - Soil carbon stock in various forest types of Kolli hills.

Forest type	Soil carbon stock (t/ha) estimated experimentally			Total stock (Tg C) (extrapolated for the total Kolli forest)
	Minimum	Maximum	Mean± std.dev	
Evergreen (n=6)	118.78	259.49	209.54 ± 49.55	0.83
Deciduous (n=5)	175.00	368.89	246.02 ± 80.28	3.12
Mixed (n=6)	90.03	228.74	148.86 ± 48.69	0.99
Open scrub (n=5)	102.75	296.00	181.43 ± 86.07	0.54
Plantation (n=4)	77.92	217.49	175.53 ± 65.48	0.05
Total				5.54

Despite the rich biodiversity of Kolli forests, a comparatively lower carbon stock reflects potential threat from anthropogenic pressures, including mining, shifting cultivation and other tourism-related activities. Unregulated and unsustainable exploitation for fuel wood and other wood and non-wood products and excessive overgrazing in many regions of Kolli forests may also account for forest degradation.

Conclusion

Regional terrestrial carbon accounting is very important to address global climate change mitigation, particularly in tropical areas. In this perspective, the current study attempted an estimation of carbon stock in different forest Types of Kolli hills of Tamilnadu State (India), with emphasis on above ground standing biomass, litter, woody debris and soil by terrestrial field-based experiments. The land cover analysis revealed a total area of 26 587.8 ha covered by forests in Kolli Hills. Among different forest types, mixed deciduous forest cover the major portion of forested land. Total carbon stock distribution varied in the following order: deciduous > mixed > evergreen > open scrub > plantation. Above ground carbon stock of Kolli hills recorded 4.49 Tg C, while soil C stock showed 5.54 Tg C and surface litter and woody debris carbon stock registered 34.125 Gg C and 1.02 Gg C, respectively.

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