Carbon sequestration: estimation of carbon stock in natural forests using geospatial technology in the Eastern Ghats of Tamil Nadu, India

A. Ramachandran, S. Jayakumar, R. M. Haroon, A. Bhaskaran and D. I. Arockiasamy

The need for a carbon databank is addressed in this article in the context of mitigating climatic changes. As a pilot study, carbon stock in a natural forest area of Kolli hills, part of the Eastern Ghats of Tamil Nadu, India has been estimated using geospatial technology. The total biomass, both above and below ground, is calculated and the total carbon stock estimated. Likewise, the sequestered soil organic carbon is also estimated. The biomass carbon estimated is 2.74 Tg and the soil carbon is 3.48 Tg. The lesser soil organic carbon indicates that the forest area is severely affected by degradation due to various need-based forestry practices and anthropogenic disturbances. A national-level carbon databank is envisaged for all types of forest in India to study the temporal change and carbon sequestration potential for better management of forests.

Keywords: Biomass carbon, carbon sequestration, natural forest, Eastern Ghats, soil organic carbon.

Carbon management in forests will probably be the single most important agenda of the first half of the 21st century in India in the context of the greenhouse effect and mitigation of global climatic changes. According to the Intergovernmental Panel on Climate Change (IPCC), there has been an unprecedented warming trend during the 20th century. Scientists now have estimated that the average global surface temperature is likely to rise by 1.4 to 5.8°C by the end of the 21st century. The IPCC estimates that the level of carbon dioxide in today’s atmosphere is 31% higher than it was at the start of the Industrial Revolution about 250 years ago. Atmospheric levels of CO₂ have risen from 280 ppm at the pre-industrial to the present level of 375 ppm. Evidence suggests that, a rise in atmospheric CO₂ level and temperature is due to expanding use of fossil fuel for energy. Most of the increase has occurred in the second half of the 20th century.

In response to the growing concern and the mounting evidence of global climate change, the United Nations Framework Convention on Climatic Change (UNFCCC) was adopted at the United Nations Conference on Environment and Development at Rio in 1992. The objective of the convention was ‘to stabilize atmospheric greenhouse gas concentration at the level that would prevent dangerous anthropogenic interference with the climate system’. The most significant protocol to date has been the Kyoto Protocol (KP), tabled at the December 1997 meeting of the Third Conference of Parties in Kyoto, Japan. The KP proposes to set up legally binding commitments for emission reduction for the so-called Annex 1 countries (the developed countries and the eastern European countries of the former Soviet Union) to levels relative to their 1990 levels. The KP identifies three possible ‘flexibility mechanisms’ for countries to meet the emission reduction target: joint implementation, a clean development mechanism (CDM), and emission trading. The CDM would facilitate carbon sequestration and storage investments in reforestation, afforestation and in reducing deforestation to qualify as emission reductions credits. The concept behind this mechanism is that it does not matter where the emission reductions occur in the world for the global atmosphere to benefit.

The terrestrial ecosystem is a major biological scrubber of atmospheric carbon dioxide that can be significantly increased by careful management. Absorbing carbon dioxide from atmosphere and moving into the physiological system and biomass of the plants, and finally into the soil is the only practical way of removing large volumes of the major greenhouse gas (CO₂) from the atmosphere into the biological system. Thus, the carbon is sequestered into the plants and then from the plants to the animals. Eventually, after the death of the animals, the detritus decomposes into the soil organic carbon by microbial activities. These sequestered carbons finally act as ‘sinks’ in the forest lands.
The fact that carbon is stored for long periods of time in living biomass and soil is well documented extensively since 1992, although studies were carried out in this field since 1980. Several studies have established the fact that carbon sequestration by trees could provide relatively low-cost net emission reductions\textsuperscript{1–4}. Houghton\textsuperscript{5} predicted that carbon dioxide emission to the atmosphere would increase from 7.4 Gigatons (Gt) C per yr in 1997 to approximately 26 Gt C per yr by 2100. Many scientists agree that a doubling of atmospheric CO\textsubscript{2} could have a variety of serious environmental consequences\textsuperscript{1,6,7}. This global scenario has generated interest in strategies to reduce emissions of carbon dioxide to the atmosphere or to offset emissions by storing additional carbon in forests\textsuperscript{8}.

**Estimation of biomass carbon (above and below ground)**

Estimates of carbon stock are generally produced by first measuring the total biomass of the population using one of the two approaches. The first is to estimate wood volume for each tree using a volume equation, convert wood volume to mass using an estimate of timber density, and then convert wood mass to total tree biomass using biomass expansion factors. The second approach is to apply a regression equation that directly converts external measurements, such as stem diameter and sometimes height, to total tree biomass. Individual tree biomass values produced using either of the approach are summed to produce the biomass of the entire population, which is then multiplied by a standard value of carbon concentration to produce an estimate of carbon stock\textsuperscript{9–11}.

**Estimation of soil carbon**

Soil carbon is an important determinant of site fertility due to its role in maintaining soil physical and chemical properties (e.g. aggregate stability, cation exchange capacity)\textsuperscript{12}. Soil stores 2 or 3 times more carbon than that which exists in the atmosphere\textsuperscript{13} as CO\textsubscript{2} and 2.5 to 3.0 times as much as that stored in plants in the terrestrial ecosystem\textsuperscript{14,15}. Land-use and soil-management practices can significantly influence soil organic carbon (SOC) dynamics and C flux from the soil\textsuperscript{16,17}. Spatially distributed estimates of SOC pools and flux are important requirements for understanding the role of soils in the global C cycle and for assessing potential biospheric responses to climatic change or variation\textsuperscript{18}.

The terrestrial ecosystem, especially plants and the pedosphere can be effective sinks\textsuperscript{19–21}. The potential of the pedosphere to sequester carbon can play an important role in the overall management of C\textsuperscript{22–27}. There is a major potential for increasing SOC through restoration of degraded soils and widespread adoption of soil conservation practices\textsuperscript{25,28}. Soil organic matter is a key component of the terrestrial ecosystem and any variation in its abundance and composition has important effects on many of the processes that occur within the system. SOC is concentrated in the upper 12 inches of the soil. Thus it is readily depleted by anthropogenic (human-induced) disturbances such as land-use changes and cultivation\textsuperscript{29,30}. In India, the magnitude of soil carbon depletion is increased by soil degradation due to different need-based forestry practices over a period of time, especially clear felling and uprooting of the existing species for reforestation purposes.

**SOC estimation – Indian scenario**

In India, Jenny and Raychaudhuri\textsuperscript{31} studied organic carbon status and reported the effects of climate on carbon reserves in virgin and cultivated soils. Based on different approaches, estimates of total and forest SOC stocks in India are in the range of 23.4–47.5 Pg C\textsuperscript{32,33} and 5.4–6.7 Pg C\textsuperscript{32,34}. Recent studies on Indian forest biomass and phytomass carbon pools\textsuperscript{34–37} and litter fall\textsuperscript{38} are available, but SOC pool estimates with reference to forest types based on Indian datasets, have not been studied. Chhabra et al.\textsuperscript{36} attempted to estimate the SOC based on different forest types. However, the bulk density, which is the key factor for SOC estimation, has been calculated indirectly in their method.

Unlike in the developed countries, we do not have carbon inventories and databank to monitor and enhance carbon sequestration potential of different forests. In India, attempts were made to assess carbon sequestration studies at macro level\textsuperscript{34,38}, mostly with the available data. No attempt has been made so far to assess the biomass and soil carbon sequestration at micro-level. Such kind of micro-level study is essential for sustainable forest management, especially in a country like India, where heavy degradation had been caused by anthropogenic activities and different forest management prescriptions of the past warranted in different periods of time to meet the local and national needs. Therefore, a pilot study is taken up to estimate the carbon stock available in a natural forest in Kolli hills, Eastern Ghats of Tamil Nadu.

**Study area**

Kolli hills, one among the range of hills of the Eastern Ghats, situated in the Namakkal district of Tamil Nadu (at the eastern side above the river Cauvery), India was chosen for the study. Geographically it is situated between 11°10’00”–11°30’00”N and 78°15’00”–78°30’00”E, covering an area of about 503 sq. km. Being a hilly terrain, the altitude ranges from 200 to 1415 m amsl. It is a structural hill and the composite slopes are completely occupied by reserved forests of deciduous and thorn types and the upper plateau is occupied by broad-leaved hill forests (semi-evergreen) and agricultural lands.
Materials and methods

In the present study, IRS 1D LISS III digital data of 28 February 2002 of path: 101 and row: 65 and 66, Survey of India (SOI) toposheets, 58 I/7, I/8, IBM – Workstation, Leica GS 20 PDM Global Positioning System, Erdas Imagine 8.6, ArcGIS 8.3 and MstatC statistical software were used.

Forest cover mapping

Expert classification technique was 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, viz. very dense (>70%), dense (40–70%), open (10–40%) and degraded (<10%)\textsuperscript{39}. Digital elevation model (DEM) was prepared using the 20 m contours. Based on the field knowledge and secondary data of altitudinal distribution of forest type in the Eastern Ghats, the DEM was recoded into three classes, viz. < 450 m, 450–1000 m and >1000 m. Knowledge classifier module was used to classify the forest using the above recoded DEM and NDVI. Final field check was carried out in the field with classified map, FCC, toposheets, compass and GPS. Corrections were made in the classified map and final forest type and cover density map of February 2002 was prepared.

Estimation of biomass carbon

Plot sampling technique was followed to estimate the stand density in different forest types. Twenty-five 20 × 20 m quadrates in each forest type were laid and variables such as girth at breast height were recorded. Using Smalian’s formula\textsuperscript{38}, timber volume of about 1000 trees was worked out and bivariate regression equations were derived using calculated volume, gbh and height for different girth class. For gbh 30–50 cm (\(r^2 = 0.79\))
\[
\text{Equation} = -0.191 + 0.004936 \times \text{GBH} + 0.01222 \times \text{length}. 
\]

For gbh 51–100 cm (\(r^2 = 0.83\))
\[
\text{Equation} = -0.609 + 0.008246 \times \text{GBH} + 0.0409 \times \text{length}. 
\]

For gbh 101–150 cm (\(r^2 = 0.80\))
\[
\text{Equation} = -2.328 + 0.01902 \times \text{GBH} + 0.103 \times \text{length}. 
\]

For gbh 151–200 cm (\(r^2 = 0.83\))
\[
\text{Equation} = -4.771 + 0.02683 \times \text{GBH} + 0.211 \times \text{length}. 
\]

For gbh > 201 cm (\(r^2 = 0.96\))
\[
\text{Equation} = -13.194 + 0.05515 \times \text{GBH} + 0.368 \times \text{length}. 
\]

Growing stock of each species recorded in different forest types in the 1 ha area was estimated based on the regression equation. Biomass of stem (timber volume) of each tree species was calculated by multiplying the volume with the wood density of each species published by Forest Research Institute. For certain non-timber species, wood density was calculated\textsuperscript{40} based on the universal mean wood density of 0.2 t/m. From the timber biomass, the biomass of crown as well as the stump and root was calculated using biomass expansion factors\textsuperscript{41}. Finally, the total biomass of each species present in the 1 ha area in different forest types was summed up and the total biomass of each forest type was estimated. Carbon estimation from the biomass was calculated based on the methodology described by Koch\textsuperscript{42} and the minimum value of 49.1 was adopted as the conversion factor.

Estimation of SOC

Systematic random sampling technique was adopted to estimate SOC, using georeferenced satellite data (2002). The total area in the satellite data was divided into 2 sq. km grids and random value of longitude and latitude was noted for each grid for soil sampling. With the help of GPS, the pre-determined sampling points (longitude and latitude) were located and soil samples were collected at 145 locations. Removing the top organic litter, soil samples were collected at the surface (0 to 30 cm), middle (30 to 60 cm) and bottom (60 to 90 cm) layers\textsuperscript{43–45}. Soil samples were collected from each layer separately, dried, processed using a wooden mallet and sieved through 2 mm sieve. The per cent coarse fraction (>2.0 mm size) was worked out for each layer. Undisturbed soil clods were collected from each layer and preserved for determination of bulk density. Bulk density was determined using the Clad method and the determined bulk density was corrected for per cent coarse fractions. The corrected bulk density (mg m\(^{-3}\)) was used for the estimation of SOC density (mg ha\(^{-1}\)) and SOC stock.

The stored soil samples were sub-sampled and ground to fine powder using an agate pestle and mortar, and sieved through 0.5 mm sieve. The SOC content in the 0.5 mm sieved soil samples was estimated by following Walkley and Black’s wet oxidation method as described by Page\textsuperscript{44}.

The data were statistically analysed for the computation of standard deviation, frequency distribution and analysis of variance (ANOVA) for each forest type using Microsoft\textsuperscript{38} Excel\textsuperscript{38} worksheet. The least significant difference (LSD) was worked out using MstatC software\textsuperscript{46} to compare the SOC mean values of different forest types at different depths. SOC density was calculated for each layer in each profile as follows\textsuperscript{47}:
**SOC density (mg ha\(^{-1}\)) =**

\[
\frac{\text{SOC(\%)} \times \text{corrected } \rho_b (\text{mg m}^{-3}) \times \text{layer depth (m)} \times 10^{4} (\text{m}^{2} \text{ ha}^{-1}),}{100}
\]

where \(\rho_b\) = bulk density.

Corrected bulk density (mg m\(^{-3}\)) =

\[
\frac{\text{bulk density (Mg m}^{-3}) \times \left(\frac{100 - \text{per cent coarse fraction}}{100}\right)}{}
\]

Data on SOC content (%) and SOC density (mg ha\(^{-1}\)) of surface, middle and bottom were mapped using the ArcGIS software.

Total SOC storage = SOC density (mg ha\(^{-1}\)) \times forest area (ha).

**Results and discussion**

In Kolli hills, the reserve forests (RF) occupy about 27,103 ha and there are five forest types, namely Tropical broadleaved hill forest (8A/C1; semi-evergreen), Southern dry mixed deciduous forest (5A/C3), Secondary deciduous forest (5/2S1), Southern thorn forest (6A/C1) and Euphorbia scrub forest. The total area under the semi-evergreen forest type is about 3962 ha that comprises 15% of the total forest area (Table 1). This forest type has been classified further into four subclasses based on the crown density, viz. very dense (> 70%), dense (40–70%), open (10–40%) and degraded (< 10%). The very dense semi-evergreen forest occupies 1984 ha which is 50% of the total semi-evergreen forest. About 25 and 21% of the semi-evergreen forests are under dense and open respectively. Only 4% is under degraded semi-evergreen. The deciduous forest comprises 46% of the total forested area. The very dense deciduous forest cover occupies 1772 ha, which is 14% of the total deciduous forest type. The dense and open deciduous density classes occupy 35 and 51% of the area respectively (Table 1).

The secondary deciduous forest is a secondary type derived from the deciduous forest by persistent exploitation of the commercially valued species by the way of removal of timber and fuel wood under a prescribed forest management system. It occupies an area of about 2960 ha, which is 11% of the total forest area. Southern thorn forest is the largest category and occupies 6676 ha, which is 24% of the total forest area. The Euphorbia scrub forest occupies only 304 ha, which is about 1% of the total forest area. Apart from these forest types, tank and rock outcrop areas are also present. The tank is situated in the eastern side of the hill and the rock outcrop occupies an area of about 515 ha, which is distributed invariably in all reserved forest.

**Accuracy assessment**

Accuracy assessment was undertaken following Congalton\(^{48}\) by estimating commission and omission errors. About 160 randomly distributed checkpoints were verified. The number of checkpoints for each cover class was proportionate to the area of different forest types. The geographic coordinates of these points were noted from the classified digitized image and checked in the field with the help of GPS. The accuracy assessment shows that the semi-evergreen forest could be delineated with 90% accuracy by the methodology adopted in the present study. Deciduous forest could be delineated with 87% accuracy. Secondary deciduous and southern thorn forest types could be demarcated with 81% accuracy each and the Euphorbia scrub forest with 83% accuracy. The overall accuracy of forest type classification of this study is 85%.

**Estimation of carbon stock**

Plants take CO\(_2\) from the atmosphere. Then, through the process of photosynthesis, the energy is trapped in the organic molecules and used by the plants themselves. In this process, a number of organic substances are stored temporarily as constituents of the standing vegetation, most of which is eventually added to the soil as plant organic litter and then to the soil as SOC by microbial activity. Hence, estimation of this carbon content both in vegetation and in soil becomes imperative to assess the carbon sequestration potential.

<table>
<thead>
<tr>
<th>Forest type</th>
<th>Volume (m(^3)/ha)</th>
<th>Timber biomass (tons/ha)</th>
<th>Branch and foliage (tons/ha)</th>
<th>Stumps and root (tons/ha)</th>
<th>Biomass (ton/ha)</th>
<th>Area of each forest (ha)</th>
<th>Total biomass (M tons)</th>
<th>TOC A/G (Tg)</th>
<th>SOC stock (Tg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evergreen forest</td>
<td>428.229</td>
<td>196.988</td>
<td>47.277</td>
<td>63.036</td>
<td>307.302</td>
<td>3962.23</td>
<td>1.22</td>
<td>0.60</td>
<td>1.01</td>
</tr>
<tr>
<td>Deciduous forest</td>
<td>316.060</td>
<td>161.316</td>
<td>38.716</td>
<td>51.621</td>
<td>251.653</td>
<td>12684.74</td>
<td>3.19</td>
<td>1.57</td>
<td>1.63</td>
</tr>
<tr>
<td>Secondary deciduous</td>
<td>216.673</td>
<td>154.983</td>
<td>37.196</td>
<td>49.595</td>
<td>241.773</td>
<td>2960.28</td>
<td>0.72</td>
<td>0.35</td>
<td>0.35</td>
</tr>
<tr>
<td>Southern thorn</td>
<td>73.025</td>
<td>42.282</td>
<td>10.148</td>
<td>13.530</td>
<td>65.960</td>
<td>6676.15</td>
<td>0.44</td>
<td>0.22</td>
<td>0.47</td>
</tr>
<tr>
<td>Euphorbia scrub</td>
<td>52.72</td>
<td>36.859</td>
<td>8.846</td>
<td>11.795</td>
<td>57.500</td>
<td>304.40</td>
<td>0.02</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td></td>
<td>1086.707</td>
<td>592.428</td>
<td>142.183</td>
<td>189.577</td>
<td>924.188</td>
<td>26587.80</td>
<td>5.58</td>
<td>2.74</td>
<td>3.48</td>
</tr>
</tbody>
</table>
Table 2. Soil organic carbon content (%) of different forest types in Kolli hills

<table>
<thead>
<tr>
<th>Forest type</th>
<th>Area (ha)</th>
<th>Surface (0 to 30 cm)</th>
<th>Middle (30 to 60 cm)</th>
<th>Bottom (60 to 90 cm)</th>
<th>From (%)</th>
<th>To (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very dense evergreen</td>
<td>1984.23</td>
<td>3.70 (2.73)</td>
<td>2.21 (1.64)</td>
<td>1.82 (1.68)</td>
<td>1.92</td>
<td>5.48</td>
</tr>
<tr>
<td>Dense evergreen</td>
<td>978.42</td>
<td>3.43 (2.91)</td>
<td>1.62 (1.49)</td>
<td>1.39 (1.45)</td>
<td>1.28</td>
<td>5.59</td>
</tr>
<tr>
<td>Medium evergreen</td>
<td>851.74</td>
<td>1.83 (0.76)</td>
<td>1.13 (0.36)</td>
<td>0.76 (0.45)</td>
<td>1.30</td>
<td>2.35</td>
</tr>
<tr>
<td>Degraded evergreen</td>
<td>147.84</td>
<td>2.40 (1.04)</td>
<td>1.10 (0.50)</td>
<td>0.91 (0.33)</td>
<td>1.49</td>
<td>3.31</td>
</tr>
<tr>
<td>Total evergreen</td>
<td>3962.23</td>
<td>2.90 (2.21)</td>
<td>1.58 (1.24)</td>
<td>1.27 (1.23)</td>
<td>2.09</td>
<td>3.70</td>
</tr>
<tr>
<td>Very dense deciduous</td>
<td>1772.34</td>
<td>1.72 (0.52)</td>
<td>1.31 (0.48)</td>
<td>0.98 (0.50)</td>
<td>1.40</td>
<td>2.04</td>
</tr>
<tr>
<td>Dense deciduous</td>
<td>4471.51</td>
<td>1.45 (0.73)</td>
<td>0.89 (0.41)</td>
<td>0.66 (0.32)</td>
<td>1.14</td>
<td>1.77</td>
</tr>
<tr>
<td>Medium deciduous</td>
<td>6440.89</td>
<td>1.14 (0.85)</td>
<td>0.66 (0.57)</td>
<td>0.42 (0.48)</td>
<td>0.64</td>
<td>1.65</td>
</tr>
<tr>
<td>Total deciduous</td>
<td>12684.74</td>
<td>1.44 (0.74)</td>
<td>0.93 (0.52)</td>
<td>0.67 (0.45)</td>
<td>1.21</td>
<td>1.66</td>
</tr>
<tr>
<td>Secondary deciduous</td>
<td>2960.28</td>
<td>0.92 (0.49)</td>
<td>0.60 (0.36)</td>
<td>0.39 (0.29)</td>
<td>0.71</td>
<td>1.14</td>
</tr>
<tr>
<td>Southern thorn</td>
<td>6676.15</td>
<td>0.78 (0.54)</td>
<td>0.55 (0.43)</td>
<td>0.44 (0.34)</td>
<td>0.62</td>
<td>0.94</td>
</tr>
<tr>
<td>Euphorbia scrub</td>
<td>304.40</td>
<td>0.68 (0.67)</td>
<td>0.40 (0.38)</td>
<td>0.37 (0.24)</td>
<td>0.28</td>
<td>1.07</td>
</tr>
<tr>
<td>Total Kolli hills</td>
<td>26587.80</td>
<td>1.40 (1.38)</td>
<td>0.86 (0.78)</td>
<td>0.66 (0.71)</td>
<td>1.18</td>
<td>1.63</td>
</tr>
</tbody>
</table>

Value within parenthesis is standard deviation of respective layers.

Estimation of biomass carbon (above and below ground)

The total above and below ground biomass carbon stock in Kolli hills in different forest types is 2.74 Tg, of which the semi-evergreen forest contributed 22%, the deciduous forest contributed to the maximum of 57% and the other forest types contributed 21%. Vegetation biomass carbon density of 0.60 Tg ha⁻¹ in semi-evergreen forests, 1.57 Tg ha⁻¹ in deciduous forests, 0.35 Tg ha⁻¹ in secondary deciduous forests, 0.22 Tg ha⁻¹ in thorn forests and 0.01 Tg ha⁻¹ in *Euphorbia* forests was recorded (Table 1). This estimate is similar to the average carbon density of the tropical forests. The average biomass carbon density recorded in tropical degraded forests was from 63.33 to 156 t ha⁻¹ and 70 t ha⁻¹ adapted from German Budestag.

Estimation of SOC

The SOC content of Kolli hills soils ranged from 0.1 to 9.7%, 0.1 to 5.38% and 0.1 to 4.92% in surface, middle and bottom soil layers respectively. The mean SOC contents of surface, middle and bottom layers were 1.40 (CI: 1.18, 1.63), 0.86 (CI: 0.73, 0.99) and 0.66 (CI: 0.55, 0.78) per cent respectively (Table 2). In general, the distribution of SOC followed the order of surface > middle > bottom layer.

**SOC in semi-evergreen forest**

The very dense semi-evergreen forest type occupied an area of 1984 ha, which is 7.46% of the total study area. The SOC content varied from 1.06 to 9.77%, 0.64 to 5.38% and from 0.34 to 4.92% in surface, middle and bottom layers respectively. The average SOC content in different layers was 3.70 (CI: 1.92, 5.48), 2.21 (CI: 1.14, 3.28) and 1.82% (CI: 0.73, 2.92) in surface, middle and bottom layers respectively. The distribution of SOC in different profiles studied is given in Table 2.

Among the profiles studied, SOC content of dense semi-evergreen forest ranged from 0.98 to 8.52%, 0.30 to 4.70% and 0.12 to 4.09% in the surface, middle and bottom layers respectively. The mean SOC content of dense...
Table 3. Soil organic carbon density (t/ha) of different forest types of Kolli hills

<table>
<thead>
<tr>
<th>Forest type</th>
<th>Area (ha)</th>
<th>Mean</th>
<th>SD</th>
<th>Confidence interval (t/ha) (α = 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very dense evergreen</td>
<td>1984.23</td>
<td>274.06</td>
<td>175.57</td>
<td>From 159.35 to To 388.76</td>
</tr>
<tr>
<td>Dense evergreen</td>
<td>978.42</td>
<td>233.65</td>
<td>193.92</td>
<td>From 89.99 to To 377.31</td>
</tr>
<tr>
<td>Medium evergreen</td>
<td>851.74</td>
<td>143.02</td>
<td>54.85</td>
<td>From 105.01 to To 181.03</td>
</tr>
<tr>
<td>Degraded evergreen</td>
<td>147.84</td>
<td>193.49</td>
<td>80.62</td>
<td>From 122.83 to To 264.15</td>
</tr>
<tr>
<td>Total evergreen</td>
<td>3962.23</td>
<td>184.00</td>
<td>123.13</td>
<td>From 139.19 to To 228.82</td>
</tr>
<tr>
<td>Very dense deciduous</td>
<td>1772.34</td>
<td>146.14</td>
<td>45.45</td>
<td>From 117.98 to To 174.31</td>
</tr>
<tr>
<td>Dense deciduous</td>
<td>4471.51</td>
<td>111.41</td>
<td>45.50</td>
<td>From 91.95 to To 130.87</td>
</tr>
<tr>
<td>Medium deciduous</td>
<td>6440.89</td>
<td>91.60</td>
<td>76.18</td>
<td>From 46.59 to To 136.62</td>
</tr>
<tr>
<td>Total deciduous</td>
<td>12684.74</td>
<td>114.49</td>
<td>57.17</td>
<td>From 97.20 to To 131.78</td>
</tr>
<tr>
<td>Secondary deciduous</td>
<td>2960.28</td>
<td>84.37</td>
<td>45.60</td>
<td>From 63.82 to To 104.91</td>
</tr>
<tr>
<td>Southern thorn</td>
<td>6676.15</td>
<td>76.85</td>
<td>50.77</td>
<td>From 61.85 to To 91.85</td>
</tr>
<tr>
<td>Euphorbia scrub</td>
<td>304.40</td>
<td>63.19</td>
<td>50.81</td>
<td>From 33.17 to To 93.22</td>
</tr>
<tr>
<td>Total Kolli hills</td>
<td>26587.80</td>
<td>96.05</td>
<td>77.91</td>
<td>From 83.37 to To 108.73</td>
</tr>
</tbody>
</table>

Table 4. Test of significance of mean soil organic carbon content of different forest types of Kolli hills

<table>
<thead>
<tr>
<th>Forest type</th>
<th>Surface</th>
<th>Middle</th>
<th>Bottom</th>
<th>Test of significance (ANOVA)</th>
<th>LSD (α = 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total evergreen</td>
<td>2.90</td>
<td>1.58</td>
<td>1.27</td>
<td>**</td>
<td>0.49</td>
</tr>
<tr>
<td>Total deciduous</td>
<td>1.44</td>
<td>0.93</td>
<td>0.67</td>
<td>**</td>
<td>0.14</td>
</tr>
<tr>
<td>Secondary deciduous</td>
<td>0.92</td>
<td>0.60</td>
<td>0.39</td>
<td>**</td>
<td>0.15</td>
</tr>
<tr>
<td>Southern thorn</td>
<td>0.78</td>
<td>0.55</td>
<td>0.44</td>
<td>**</td>
<td>0.09</td>
</tr>
<tr>
<td>Euphorbia scrub</td>
<td>0.68</td>
<td>0.40</td>
<td>0.37</td>
<td>*</td>
<td>0.24</td>
</tr>
<tr>
<td>Significance</td>
<td>**</td>
<td>**</td>
<td>**</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Significant (α = 0.05) (means are significantly different at 95% probability).
**Highly significant (α = 0.01) (means are significantly different at 99% probability).

Semi-evergreen forest was 3.43 (CI: 0.32, 2.46), 1.62 (CI: 0.57, 2.72) and 1.39% (CI: 0.32, 2.46) in surface, middle and bottom layers respectively.

The SOC content of open semi-evergreen forest ranged from 0.76 to 2.85%, 0.45 to 1.59% and from 0.23 to 1.36% in surface, middle and bottom layers respectively. The mean SOC content was 1.83 (CI: 1.30, 2.35), 1.13 (CI: 0.88, 1.38) and 0.76% (CI: 0.44, 1.07) in surface, middle and bottom layers respectively. Except in one profile, in all other profiles the ratio between surface to middle layer was >1.0.

The SOC content of the degraded semi-evergreen forest varied from 0.91 to 3.58%, 0.30 to 1.60% and 0.45 to 1.24% in surface, middle and bottom layers respectively. The mean SOC content was 2.40 (CI: 1.49, 3.31), 1.10 (CI: 0.66, 1.53) and 0.91% (CI: 0.62, 1.20) in surface, middle and bottom layers respectively.

The total area under semi-evergreen forest is 3962 ha, which is 14.9% of the total forest area. Of the 29 profiles studied in the semi-evergreen forest area, the mean SOC content was 2.90 (CI: 2.09 to 3.70), 1.58 (CI: 1.13, 2.03) and 1.27% (CI: 0.82, 1.72) in surface, middle and bottom layers respectively. ANOVA studies revealed that the difference between the mean SOC content of the three layers was significant at 99% probability (α = 0.01; Table 3).

SOC in deciduous forest

The total area under all types of deciduous forests is 12,685 ha (47.7% of total Kolli hills RF), which is subdivided into very dense deciduous, dense deciduous and open deciduous, which occupy an area of 1772, 4472 and 6441 ha respectively. Of the 42 profiles studied under different types of deciduous forests, the average SOC was 1.44 (CI: 1.21, 1.66), 0.93 (CI: 0.77, 1.09) and 0.67% (CI: 0.54, 0.81) in surface, middle and bottom layers respectively (Table 2). The difference between the mean SOC of three layers was found to be highly significant as revealed by the ANOVA studies (Table 4). The distribution of SOC in different types of deciduous forests was as follows:

The range of SOC among the soil profiles in very dense deciduous forest studied was 1.03 to 2.56%, 0.85 to
2.27% and 0.30 to 2.04% in surface, middle and bottom layers respectively. The average SOC content was 1.72 (CI: 1.40, 2.04), 1.31 (CI: 1.02, 1.61) and 0.98% (CI: 0.67, 1.29) in surface, middle and bottom layers respectively. Of the 21 profiles studied in dense deciduous forest, the SOC content ranged from 0.57 to 2.75%, 0.30 to 1.63% and 0.21 to 1.27% in surface, middle and bottom layers respectively. The mean SOC content was 1.45 (CI: 1.14, 1.77), 0.89 (CI: 0.71, 1.06) and 0.66% (CI: 0.53, 0.80) in surface, middle and bottom layers respectively.

In the open deciduous forest, the SOC content ranged from 0.47 to 3.34%, 0.10 to 2.13% and 0.10 to 1.67% in surface, middle and bottom layers respectively. The average SOC content was 1.14 (CI: 0.64, 1.65), 0.66 (CI: 0.33, 1.00) and 0.42% (CI: 0.13, 0.70) in surface, middle and bottom layers respectively. The difference between the SOC contents of the three layers was highly significant.

**SOC in secondary deciduous forest**

This forest occupies an area of 2960 ha. Of the 19 profiles studied, the SOC content varied from 0.10 to 1.97%, 0.10 to 1.24% and 0.10 to 1.06% in surface, middle and bottom layers respectively (Table 2). The average SOC content was 0.92 (CI: 0.71, 1.14), 0.60 (CI: 0.44, 0.76) and 0.39% (CI: 0.26, 0.52) in surface, middle and bottom layers respectively. The difference between the SOC contents of the three layers was highly significant.

**SOC in southern thorn forest**

The southern thorn forest in Kolli hills occupies an area of 6676 ha, which is the largest among different forest types studied. Of the 44 profiles studied, the SOC varied from 0.10 to 2.27%, 0.10 to 1.97% and 0.10 to 2.7% in surface, middle and bottom layers respectively. The average SOC content was 0.78 (CI: 0.62, 0.97), 0.55 (CI: 0.42, 0.67) and 0.44% (CI: 0.34, 0.54) in surface, middle and bottom layers respectively. The difference between the SOC content of different layers was highly significant (α = 0.01). A plot of the frequency distribution of SOC content showed two distinctive peaks in the range of 0.25 to 0.5% and 1.0 to 1.5% respectively (Table 2).

**SOC in Euphorbia scrub forest**

This forest type occupies an area of 304 ha. The number of profiles studied in this forest type was 11. The SOC content ranged from 0.1 to 2.39%, 0.10 to 1.36% and 0.10 to 0.87% in surface, middle and bottom layers respectively. The average SOC content of *Euphorbia* scrub was 0.68 (CI: 0.28, 1.07), 0.40 (CI: 0.17, 0.62) and 0.37% (CI: 0.23, 0.51) in surface, middle and bottom layers respectively (Table 2). The difference between the mean SOC content of different layers was significant at α = 0.05. The lower limit confidence interval at 95% probability for various forest types of SOC content in the surface layers was 2.09, 1.21, 0.71, 0.62 and 0.28% in semi-evergreen, deciduous, secondary deciduous, southern thorn and *Euphorbia* scrub respectively. The mean SOC content between different forest types and between the three layers was significantly different as revealed from the ANOVA studies (Table 4).

**Soil organic carbon density**

Data on SOC density of different forest types of Kolli hills is presented in Table 3. The maximum mean SOC density was found in semi-evergreen forest, 184 mg ha\(^{-1}\) (CI: 139.19, 228.82). Among the other forests, the mean SOC densities were 114.49 (CI: 97.20, 131.78), 84.37 (CI: 63.82, 104.91), 76.85 (CI: 61.85, 91.85) and 63.19 mg ha\(^{-1}\) (CI: 33.17, 93.22) in semi-evergreen, deciduous, secondary deciduous, southern thorn and *Euphorbia* scrub respectively. The mean SOC density in the total Kolli hills was 96.05 mg ha\(^{-1}\) (CI: 83.37, 108.73).

**Total SOC stock**

The total SOC stock of Kolli hills was 3.48 Tg (Table 1). The SOC stock distribution in different forest types was as follows: semi-evergreen forest which occupies 14.9% of geographical area had a SOC stock of 1.005 Tg. The deciduous forest with an area occupying 47.7% of total RF had a SOC stock of 1.62 Tg. The SOC stock of other forest types are secondary deciduous, 0.35 Tg; southern thorn forest, 0.46 Tg, and *Euphorbia* forest, 0.03 Tg.

**Net carbon stock**

The total biomass carbon of Kolli hills was 2.74 Tg and total SOC was 3.48 Tg. The ratio between SOC and biomass carbon was 1.18. Post et al.\(^{15}\) reported that the ratio between SOC and biomass carbon is 2.5 to 3 times in the terrestrial ecosystem. However, in the tropical forest, the carbon in the soil is roughly equivalent or lesser than the above ground biomass due to degradation\(^{15}\). In the case of Kolli hills, the carbon content in the soil was higher than the above-ground biomass carbon due to heavy exploitation of timber and sandal wood. Higher content of SOC than the above ground biomass carbon indicates that the sequestered SOC was the result of its original vegetation in the past before exploitation.

The present study indicates that the SOC is higher than the above-ground biomass carbon but not 2.5 to 3 times of biomass carbon as recorded in well-managed terrestrial ecosystems\(^{14,15}\). Degradation occurred both in vegetation as well as in soil due to land-use changes over the period of time with need-based forestry practices such as fuel wood...
coupes, pulp wood plantations, sandal wood trees extraction, cumri and shifting cultivation and anthropogenic disturbances. The mistake of our past management strategies was restocking the failure area by uprooting of the original species and planting of miscellaneous species, ignoring the original biodiversity and soil loss. Thus, there had been a continuous loss of forest cover and depletion of top soil. Therefore, one could not conclude the sequestration potential of this forest unless we have a previous databank of carbon stock for the same area. Hence, to study temporal changes in carbon stock, its sequestration potential and to enhance biodiversity, we need national-level carbon databank for all forests. Such a databank will certainly help the foresters to enhance the biodiversity and soil carbon for sustainable management of forest in the context of mitigating climatic changes.

42. Koch, P., Estimates by species group and region in the USA of: (I) below ground root weight as a percentage of over dry complete tree weight and (II) carbon content of tree portions. Consulting report, 1989, p. 23.

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MEETINGS/SYMPOSIA/SEMINARS

Fifteenth National Symposium on Solid State Nuclear Track Detectors and Their Applications (SSNTD-15)

Date: 21–23 June 2007
Place: Tehri Garhwal

Themes include: Basic studies and methodologies; Heavy ion nuclear physics and cosmic rays; Instrumentation, devices and software; Radon, thoron studies; Radiation measurements and dosimetry; Microanalysis; Latent tracks in materials and ion track technology; Nuclear filters; Fission track dating.

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CSIR Sponsored National Seminar on Environmental Biotechnology – Opportunities and Challenges

Date: 22–23 February 2007
Place: Madurai

Themes include: Biodiversity, Bioremediation, Phytoremediation, Biotechnology for pollution abatement, Biosensor, Biosur- factants, Bioscrubber, Bioleaching, Bioaugmentation, Vermicomposting, Solid waste management, Bioethics and bio-safety, Biotechnology for pesticide industry (Biopesticides, Biofertilizers, Bioenergy) and Biofuel and Intellectual Property Rights.

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VIII–Sir Dorabji Tata Symposium

Date: 10–11 March 2007
Place: Bangalore

The diseases covered in the symposium are: Dengue/Dengue hemorrhagic fever; Japanese Encephalitis; West Nile Disease; Chandipura Virus; Chikungunya; Kyasanur Forest Disease; Blue Tongue and other Veterinary Arboviruses; VEE, EEE, WEE.

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