Above- and below-ground carbon stock estimation in a natural forest of Bangladesh

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ABSTRACT: The research was aimed to estimate above- and below-ground carbon stock in Tankawati natural hill forest of Bangladesh. A systematic sampling method was used to identify each sampling point through Global Positioning System (GPS). Loss on ignition and wet oxidation method were used to estimate biomass and soil carbon stock, respectively. Results revealed that the total carbon stock of the forest was 283.80 $t \cdot ha^{-1}$ whereas trees produce 110.94 $t \cdot ha^{-1}$, undergrowth (shrubs, herbs and grass) 0.50 $t \cdot ha^{-1}$, litter fall 4.21 $t \cdot ha^{-1}$ and soil 168.15 $t \cdot ha^{-1}$ (up to 1m depth). The forest in the study area is a reservoir of carbon, as it has a good capacity to stock carbon from the atmosphere. To realize the forest sector potentiality in Bangladesh, the carbon sequestration should be integrated with the Clean Development Mechanism (CDM) carbon trading system of the Kyoto Protocol.

Keywords: Tankawati natural hill forest; carbon stock; geo-position

Abbreviation: Sl. No. – serial number; TAGB, TBGB – total above- and below-ground biomass; TB – total biomass; TAGC, TBGC – total above- and below-ground carbon; TC – total carbon; TBC – total biomass carbon; LBC – litter fall biomass carbon; SOC – soil organic carbon.

The increasing carbon emission is one of today's major concerns, which was well addressed in the Kyoto Protocol (Ravindranath et al. 1997) because it is the main causal factor for global warming (Lal 2001). Since forest ecosystems contain from 62% to 78% of the total terrestrial carbon (Hagedorn et al. 2002), the response of forests to the rising atmospheric CO_2 concentrations is crucial for the global carbon cycle. FAO (2001) proposes three possible strategies for the management of forest carbon, and these are to create carbon sinks, to minimize carbon release rate and to reduce the fossil fuel demand. The Kyoto Protocol provides for the involvement of Bangladesh in an atmospheric greenhouse-gas reduction regime under its CDM concept. Through the CDM, carbon credits can be gained from natural forests and afforestation/reforestation activities in developing countries (Unfccc 2004). In the current National Forest Assessment supported by FAO, out of the total area of Bangladesh 14.757 million ha (BBS 2005) only 1.442 million ha is covered by forest (Altrell 2007), and much of the forest land does not have the satisfactory tree cover (World Bank 1997, Chowdhury 1999, Ahmed 2001). The hilly forests are subject to severe degradation due to overpopulation, shifting cultivation and extension of agriculture (Salam et al. 1999). Alamgir and Al-Amin (2007) mentioned that the natural forest of Bangladesh was facing such a serious onslaught that its major parts were already lost, remaining only a small percentage. With a massive pool of existing bared hills in Bangladesh, it may be assumed that Bangladesh is playing a major role in mitigating global warming and earning carbon credits. Furthermore, communities can also get benefits from forests in several ways such as to adapt changing climate, conserve natural resources and promote sustainable development (Sohel et al. 2009). Now it is high time to incorporate the

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existing forest management strategies with the climate change through the sequestration of carbon. However, very few researches have been conducted sporadically to measure the potentiality of forests of Bangladesh in carbon sequesters to process. This may be due to the very poor method of biomass determination of forest vegetation, particularly in the context of Bangladesh. Therefore, this study aims to measure the above- and below-ground carbon stock potential of a natural forest in Bangladesh.

MATERIAL AND METHODS

The study area is located in Tankawati natural hill forest, which is under the administrative control of Padua forest range of Chittagong (South) Forest Division, Bangladesh (Fig. 1). It lies between 21°57'08''N and 22°09'13''N latitude and between 92°07'32''E and 92°02'22''E longitude, and area of the forest is 1,123.72 ha (Motaleb, Hossain 2007). The elevation of the study area ranges between 14 m and 87 m above m a.s.l. (Islam et al. 1999). The study area has the moist tropical maritime climate with high rainfall. The mean minimum and maximum temperature is 21.97°C and 30.51°C, respectively (Alamgir, Al-amin 2008).

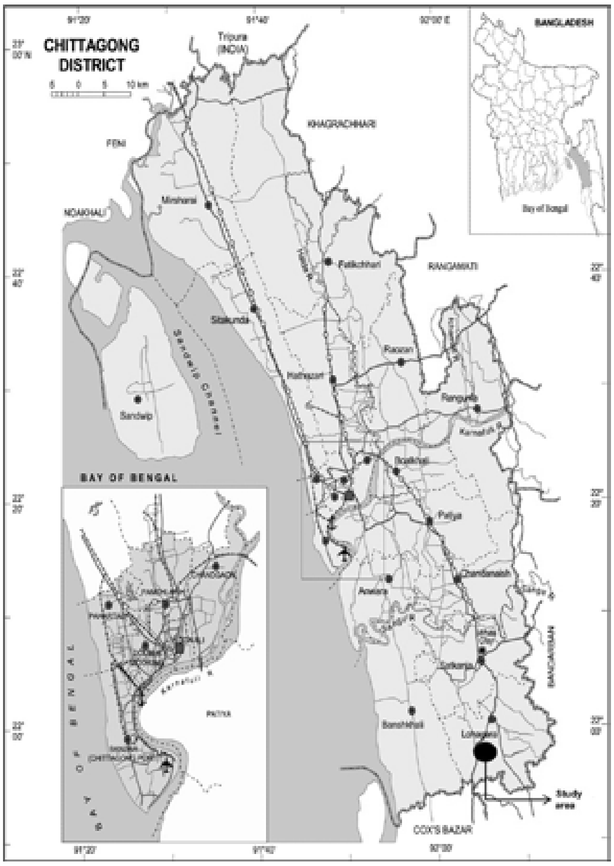

Fig. 1. Study area in the Chittagong district of Bangladesh

The highest concentration of precipitation is found from May to September, pre- and post-monsoon periods of rain during April, May and October. The mean monthly relative humidity is high throughout the year. Soil is brown sandy loams, somewhat excessively drained, Barkal soil series and classified according to the USDA Taxonomy by Alam et al. (1993) as Udic Utochrept.

The study was based on field data collection through physical measurement, field observation and laboratory analysis, and it was conducted from January to December 2009. A systematic sampling method was used for identification of each intersection point in the field. The geo-position of the study area was mapped out, and then one-minute intervals were inserted in the map and finally, a total of 72 intersection points was located in the map. Each point was identified using GPS in the field. Primarily land use of each intersection point was identified in the field. After that a total of 20 intersection points was taken in the natural forest, following that four sampling plots of 20 m × 20 m sizes were selected for tree species around each intersection point. A sampling plot of 2 m × 2 m in size was selected in the centre of the intersection point for shrubs, herbs and grass species, and litter fall collection. Finally, a total of 80 plots for tree species, 20 plots for shrubs, herbs and grass species, and 20 plots for litter fall collection were considered. In the fixed grid lines, to estimate carbon stock, the number of stems was counted, Spiegel Relascope and diameter tape were used to measure tree height and diameter, respectively. Tree increment core sample from each tree was collected with wood borer at breast height (1.3 m). In each sampling plot of shrubs, herbs and grass species, the number of each species was counted and their samples were uprooted for laboratory analysis. The litter fall included leaves, fruits, seeds, barks and twigs, etc. In the litter fall sampling plot, all weeds and brushes were cleared, and fresh weight of the collected litter fall was measured in the field using a field balance. Fallen litter was collected after six months and the average litter fall for six months was converted to annual litter fall per ha to estimate the biomass of the litter fall in the forest. The carbon stock in soil was estimated to a depth of 1 m using an earth augur from selected geo-position (plot size of 2 m × 2 m) and a total of 20 plots were sampled at five different depths: 0–1 cm, 1–3 cm, 3–14 cm, 14–30 cm and 30–100 cm.

About 774 individuals of 56 tree species were measured in the sampling plots. A model of Brown et al. (1989) was used to determine aboveground biomass of each tree; so far literature showed that this method is one of the most suitable methods for biomass carbon stock estimation in tropical forests (Alves et al. 1997, Brown 1997, Schroeder et al. 1997). The model:

$$Y = \text{Exp.}\{-2.4090 + 0.9522 \ln (D^2 \times H \times S)\}$$

where:
Y – aboveground biomass (kg),
H – height of tree in meters,
D – diameter (cm) at breast height (1.3 m),
S – wood density ($t \cdot m^{-3}$) for specific species (Sattar et al. 1999).

Belowground biomass was calculated considering 15% of the aboveground biomass (Macdicken 1997). Collected undergrowth samples, in total of 817 individuals, were divided into above- and below-ground identifying the collar region and then fresh weight was taken. After that, the weight value was multiplied by the number of individuals of each species in all sampling plots. The loss on ignition method was used to estimate biomass carbon stock. In this method, initially fresh weights of vegetative samples were taken, then dried at 65°C in the oven for 48 hours to take dry weight. Oven-dried grind samples were taken (1 g) in pre-weighted crucibles, after that put in the furnace and that was followed by ignition for one hour. After cooling, the crucibles with ash were weighted and then the percentage of carbon was calculated according to Allen et al. (1986).

$$\text{Ash (\%)} = (W_3 - W_1)/(W_2 - W_1) \times 100,$$

$$\text{C (\%)} = (100 - \text{Ash}) \times 0.58$$ (considering 58% carbon in ash-free litter material)

where:
C – biomass carbon stock,
W_1 – weight of crucible,
W_2 – weight of the oven-dried grind sample and crucible,
W_3 – weight of ash and crucible.

During field work, soil from each depth was collected to determine organic carbon, and soil core was used to calculate bulk density for different depths. Field's moist soil cores were dried in an oven at 105°C for eight hours, and re-weighted to determine moisture content and dry bulk density. To estimate the percentage of carbon in the soil, samples were analysed by the wet oxidation method (Huq, Alam 2005). Duncan's Multiple Range Test (DMRT) was done for data of each of the parameters using SPSS package to determine levels of significance.

RESULTS

Results showed that *Dipterocarpus turbinatus* has the highest total (above- and below-ground) biomass and total carbon (81.42 and 45.40 $t \cdot ha^{-1}$, respectively) whereas the lowest values were determined in *Antidesma acidum* (0.06 and 0.04 $t \cdot ha^{-1}$, respectively) among the 56 tree species studied (Table 1).

In the study area, among 12 shrub species, the highest total biomass and total carbon stock (134.42 and 69.47 $kg \cdot ha^{-1}$, respectively) were found in *Melastoma melabathricum* and the lowest in *Leea* spp. (12.07 and 5.11 $kg \cdot ha^{-1}$, respectively) (Table 2). Among the 14 herbs and grass species, *Cynodon dactylon* contains the highest total biomass and total carbon (34,911 and 76.05 $kg \cdot ha^{-1}$, respectively) whereas the lowest values were found out in *Derris trifoliate* (17.82 and 1.50 $kg \cdot ha^{-1,}$ respectively) in the study area (Table 2).

Bulk densities at different soil depths varied significantly ($P < 0.05$), and it was highest at 30–100 cm depth (1.19 ± 0.078 $g \cdot cm^{-3}$) and lowest at both 0–1 cm and 1–3 cm depths (1.12 ± 0.046 $g \cdot cm^{-3}$ in each). The study illustrates that the soil organic carbon stock at 0–1 cm depth (0.13 ± 0.01 $t \cdot ha^{-1} \cdot cm^{-1}$) was significantly higher ($P < 0.05$) and lower (0.08 ± 0.01 $t \cdot ha^{-1} \cdot cm^{-1}$) at 30–100 cm depth. There were no significant differences in the organic carbon stock at 1–3 cm and 3–14 cm soil depths (Table 3).

In the study area, total aboveground carbon, total belowground carbon and total biomass carbon were found to amount to 96.48, 14.61 and 111.44 $t \cdot ha^{-1}$, respectively, in different strata of vegetation. Furthermore, carbon stock in litter fall was 4.21 $t \cdot ha^{-1}$, and in soil it was 168.15 $t \cdot ha^{-1}$ (to a soil depth of 1 m). To sum up, the total carbon stock in the Tankawati forest of Bangladesh was found 283.80 $t \cdot ha^{-1}$ (Table 4).

Carbon stock was found to be 38% in the trees, 3% in the undergrowth and 59% in the soil and litter fall (Fig. 2).

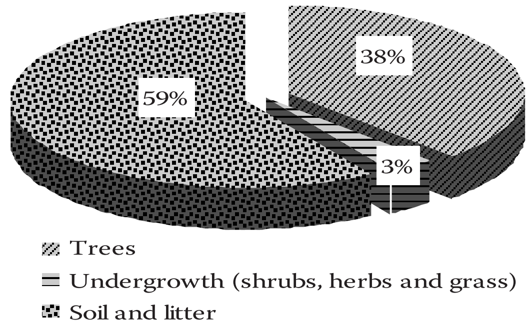

Fig. 2. Organic carbon stock in percentage of different forest strata

Table 1. Biomass carbon stock of tree species ($t \cdot ha^{-1}$) in Tankawati forest in 2009

Sl. No.	Scientific name	TAGB	TBGB	TB	TAGC	TBGC	TC
1	*Albizia chinensis*	0.78	0.12	0.90	0.41	0.06	0.47
2	*Albizia falcataria*	0.08	0.02	0.10	0.05	0.01	0.06
3	*Albizia lebbeck*	0.42	0.06	0.49	0.21	0.03	0.24
4	*Albizia procera*	1.70	0.25	1.95	0.83	0.12	0.95
5	*Alstonia scholaris*	0.19	0.03	0.22	0.08	0.02	0.10
6	*Anthocephalus chinensis*	1.88	0.28	2.16	1.03	0.16	1.19
7	*Antidesma acidum*	0.04	0.02	0.06	0.03	0.01	0.04
8	*Aporusa wallichi*	0.56	0.08	0.64	0.24	0.04	0.28
9	*Artocarpus chaplasha*	0.80	0.12	0.91	0.45	0.07	0.52
10	*Artocarpus lakoocha*	1.30	0.20	1.50	0.65	0.10	0.75
11	*Bombax ceiba*	0.15	0.02	0.17	0.08	0.01	0.09
12	*Callicarpa tomentose*	0.26	0.04	0.30	0.13	0.02	0.15
13	*Cassia fistula*	1.25	0.19	1.43	0.56	0.08	0.64
14	*Castanopsis indica*	0.07	0.01	0.08	0.04	0.01	0.05
15	*Cinnamomum cecidodaphne*	0.11	0.02	0.12	0.05	0.01	0.06
16	*Crateva nurvala*	0.06	0.02	0.08	0.04	0.01	0.05
17	*Dillenia pentagyna*	5.22	0.78	6.00	2.83	0.42	3.25
18	*Dipterocarpus alatus*	10.74	1.61	12.35	5.89	0.88	6.77
19	*Dipterocarpus costatus*	15.53	2.33	17.85	8.25	1.24	9.49
20	*Dipterocarpus turbinatus*	70.80	10.62	81.42	39.48	5.92	45.40
21	*Duabanga grandiflora*	0.13	0.02	0.15	0.06	0.01	0.07
22	*Elaeocarpus floribundus*	2.37	0.36	2.73	1.09	0.16	1.25
23	*Emblica officinalis*	0.46	0.07	0.53	0.23	0.03	0.26
24	*Eurya acuminata*	0.12	0.02	0.14	0.05	0.01	0.06
25	*Ficus benghalensis*	1.92	0.29	2.21	0.78	0.11	0.89
26	*Garcinia cowa*	0.27	0.04	0.31	0.15	0.02	0.17
27	*Gardenia coronaria*	0.46	0.07	0.53	0.20	0.03	0.23
28	*Glochidion multiloculare*	0.06	0.02	0.08	0.04	0.01	0.05
29	*Gmelina arborea*	1.07	0.16	1.23	0.55	0.08	0.63
30	*Holarrhena antidysenterica*	0.12	0.02	0.14	0.06	0.01	0.07
31	*Holarrhena pubescence*	0.18	0.03	0.21	0.09	0.01	0.10
32	*Lagerstroemia speciosa*	1.42	0.21	1.63	0.67	0.10	0.77
33	*Lannea coromandelica*	1.72	0.26	1.97	0.93	0.14	1.07
34	*Mangifera sylvatica*	1.73	0.26	1.98	0.89	0.13	1.02
35	*Meliosma simplicifolia*	0.07	0.01	0.08	0.04	0.01	0.05
36	*Michelia champaca*	0.18	0.03	0.21	0.09	0.01	0.10
37	*Microcos paniculata*	1.13	0.17	1.29	0.62	0.09	0.71
38	*Mitragyna parvifolia*	0.52	0.08	0.60	0.25	0.04	0.29
39	*Protium serratum*	1.86	0.28	2.13	0.69	0.10	0.79
40	*Pterospermum acerifolium*	2.65	0.40	3.05	1.30	0.20	1.50
41	*Quercus speciata*	3.94	0.59	4.53	2.14	0.32	2.46
42	*Randia dumetorum*	0.29	0.04	0.34	0.13	0.02	0.15
43	*Schima wallichii*	0.39	0.06	0.45	0.21	0.03	0.24
44	*Sterculia villosa*	0.09	0.01	0.10	0.05	0.01	0.06
45	*Stereospermum chelonoides*	0.88	0.13	1.01	0.38	0.06	0.44
46	*Suregada multiflora*	0.45	0.07	0.52	0.18	0.03	0.21
47	*Swintonia floribunda*	8.21	1.23	9.44	4.46	0.67	5.13
48	*Syzygium balsameum*	0.63	0.09	0.72	0.33	0.05	0.38
49	*Syzygium cumini*	7.43	1.11	8.55	3.73	0.56	4.29
50	*Syzygium fruticosum*	16.48	2.47	18.95	8.13	1.22	9.35
51	*Syzygium grandis*	8.08	1.21	9.29	4.13	0.62	4.75
52	*Terminalia belerica*	0.67	0.10	0.77	0.34	0.05	0.39
53	*Terminalia chebula*	0.52	0.08	0.60	0.24	0.04	0.28
54	*Tetrameles nudiflora*	0.22	0.03	0.25	0.12	0.02	0.14
55	*Vitex glabrata*	0.28	0.04	0.32	0.14	0.02	0.16
56	*Vitex peduncularis*	3.59	0.54	4.12	1.71	0.26	1.97

Sl. No. – serial number; TAGB, TBGB – total above- and below-ground biomass; TB – total biomass; TAGC, TBGC – total above- and below-ground carbon; TC – total carbon

Table 2. Undergrowth biomass carbon stock (kg·ha^{-1}) in Tankawati forest in 2009

Sl. No.	Scientific name	TAGB	TBGB	TB	TAGC	TBGC	TC
	Shrub species						
1	*Melastoma melabathricum*	98.16	36.26	134.42	53.81	15.66	69.47
2	*Clerodendron viscosum*	90.13	19.75	109.88	48.34	10.15	58.49
3	*Adhatoda vassica*	31.36	23.13	54.48	17.69	12.07	29.76
4	*Rivinia humilis*	15.56	8.37	23.93	8.63	4.38	13.01
5	*Cassia occidentalis*	8.13	5.36	13.49	4.64	2.94	7.58
6	*Solanum xanthocarpum*	7.47	4.72	12.19	3.70	2.00	5.70
7	*Lantana camera*	15.84	4.06	19.91	8.28	2.02	10.30
8	*Holarrhena antidoisenterica*	13.17	8.17	21.33	5.61	2.82	8.42
9	*Grewia microcosm*	10.65	4.95	15.60	5.19	1.81	6.99
10	*Ricinus communis*	19.95	9.10	29.05	10.46	4.52	14.97
11	*Urena lobata*	17.60	7.65	25.25	8.07	3.02	11.08
12	*Leea* spp.	7.61	4.46	12.07	3.38	1.73	5.11
	Herb and grass species						
1	*Beaumontia khasiana*	16.70	5.58	22.28	1.38	0.43	1.81
2	*Centella asiatica*	35.44	19.24	54.68	1.72	0.65	2.36
3	*Colcocasia esculenta*	120.96	76.48	197.44	3.81	2.24	6.05
4	*Combretum latifolium*	49.64	43.20	92.84	4.32	3.54	7.85
5	*Combretum* spp.	30.40	17.36	47.76	1.75	0.92	2.67
6	*Curcuma aromatica*	263.08	195.84	458.92	7.32	5.23	12.54
7	*Cynodon dactylon*	23004	11907	34911	51.27	24.77	76.05
8	*Derris trifoliate*	10.89	6.93	17.82	0.93	0.57	1.50
9	*Diplazium esculentum*	149.14	52.81	201.96	5.92	2.02	7.95
10	*Doemia extensa*	200.10	108.05	308.15	4.11	2.03	6.14
11	*Micania cordata*	4549.81	2918.27	7468.08	41.70	24.85	66.55
12	*Mimosa pudica*	6457.34	1896.56	8353.91	30.58	7.87	38.44
13	*Scindapsus aurieus*	35.64	13.16	48.80	1.61	0.56	2.18
14	*Thysanlaena maxima*	1064.96	522.24	1587.20	17.85	8.39	26.25

Sl. No. – serial number; TAGB, TBGB – total above- and below-ground biomass; TB – total biomass; TAGC, TBGC – total above- and below-ground carbon; TC – total carbon

DISCUSSION

Forests act as carbon reservoirs by storing large amounts of carbon in trees, undergrowth vegetation, forest floor and soil (Rotter, Danish 2002). Owning diversified forest ecosystems, Bangladesh forestry sector is acting as an important carbon sink. Hossain et al. (2008) mentioned that on an average,

Table 3. Soil organic carbon stock at different soil depths

Depth of soil (cm)	Bulk density (g·cm^{-3})	Organic carbon (%)	Organic carbon (t·ha^{-1}·depth^{-1})	Organic carbon (t·ha^{-1}·cm^{-1})
0–1	1.12 ± 0.046	1.12 ± 0.41	0.13 ± 0.01	0.13 ± 0.01
1–3	1.12 ± 0.046	1.02 ± 0.05	0.23 ± 0.02	0.11* ± 0.01
3–14	1.16 ± 0.062	0.85 ± 0.06	1.06* ± 0.09	0.09* ± 0.01
14–30	1.16 ± 0.062	0.72 ± 0.07	1.36 ± 0.14	0.09 ± 0.01
30–100	1.19 ± 0.078	0.69 ± 0.03	5.63 ± 0.81	0.08 ± 0.01
F	0.223	10.048	37.832	4.520
P	0.925	0.000	0.000	0.002

* the values in the same column are not significantly different at $P < 0.05$, n – 100

Table 4. Total carbon stock (t·ha^{-1}) in Tankawati forest of Bangladesh in 2009

Vegetation	TAGB	TBGB	TB	TAGC	TBGC	TBC	LBC	SOC	TC
Tree	182.48	27.37	209.85	96.13	14.47	110.94			
Shrubs	0.34	0.14	0.47	0.18	0.06	0.24			
Herbs and grass	0.32	0.20	0.53	0.17	0.08	0.26	4.21	168.15	283.80
Total	183.14	27.71	210.85	96.48	14.61	111.44			

TAGB, TBGB – total above- and below-ground biomass; TB – total biomass; TAGC, TBGC – total above- and below-ground carbon; TBC – total biomass carbon; LBC – litter fall biomass carbon; SOC – soil organic carbon; TC – total carbon

92 t·ha^{-1} carbon is stored by the existing tree tissues in the forests of Bangladesh. In our study, the carbon stock stored by tree tissues has been estimated to be 96.13 t·ha^{-1}. Comparing the aboveground carbon stock of forests in different Asian countries, our results were fairly similar to the natural forests of Thailand (98.76 t·ha^{-1}), Malaysia (100 t·ha^{-1}) and Philippines (86 t·ha^{-1}) (Pibumrung et al. 2008). It implies that remarkable payments for carbon stock can be demanded per ha forest cover. According to Islam (2003), out of the total forest cover of Bangladesh only 40% is under tree cover and the rest on 60% includes denuded lands covered by grassland, scrub land and encroachment areas. Lugo (1992) mentioned that the amount of biomass in undergrowth shrubs, vines, and herbaceous plants can be variable but it is generally about 3% or less of the total biomass of more mature forests. In the study area, whole undergrowth biomass carbon was found to amount to 3% of the total carbon. So, the undergrowth vegetation found the suitable environment for its growth and carbon stock in the forest. In the present study, litter biomass carbon was lowest, as per litter collection by the local poor people to meet their daily fuel need. Islam (2003) mentioned that litter carbon is the end-product of litter availability on the forest floor and high decomposition rate. Forest soils in Bangladesh stocked carbon at a rate of 115, 100 and 60 t·ha^{-1} in moist, seasonal and dry soils, respectively (Anonymous 1998). Shin et al. (2007) stated that due to the overextraction of forest resources and forest land encroachment soil carbon reduces fast. The national average soil organic carbon stock in India was 182.94 t·ha^{-1} (Jha et al. 2003). In our study, total soil organic carbon at five soil depths was found to be 168.15 t·ha^{-1}, which is close to the Indian national average, and expresses the excellent ability of forests of Bangladesh to stock organic carbon. In the present study, soil organic carbon was found highest in the top layer of soil, and this may be due to the rapid decomposition of forest litter in the favourable environment. However, Mendoza-Vega et al. 2003, Chowdhury et al. 2007 found that more soil organic carbon was stocked at the soil depth of 0–14 cm, so their reports also espouse our results.

CONCLUSIONS

The results of the study indicated that the forest of Bangladesh has a high carbon stock capacity if the forest area is managed sustainably. The study showed that *Dipterocarpus* spp., dominant tree species and highly valued timber species of Bangladesh, stocked the highest biomass carbon. Also, different undergrowth and forest soil were found a good reservoir of carbon stock in this forest. It is high time to confer emphasis not only trees but also undergrowth and soil to sequester more carbon from the atmosphere and to ascertain forests a more effective sink of carbon. Climate change mitigation through carbon sequestration by forests is the low-cost method and it will open a door for development activities because it is a very easy and simple way of receiving funds for carbon sequestration. In the study, the carbon stock estimation can be directed to researchers and administrators to analyse for global carbon credit, which can be helpful to improve the forest resources and environmental sectors like Bangladesh and other tropical countries with similar conditions.

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