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Contribution as a Carbon Sink

Technical Paper

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India's Forest and Tree Cover: Contribution as a Carbon Sink

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Abstract

India ranks 10th in the list of most forested nations in the world with 76.87 million ha of forest and tree cover. Like other forests of the world, our forests also provide critical ecosystem goods and services. However, the significant role of forests in carbon storage and sequestration has increased their importance manifold and brought them to the centre-stage of climate change mitigation strategies.

India's forest and tree cover accounts for about 23.4% of the total geographical area of the country. Over the past decades, national policies of India aimed at conservation and sustainable management of forests have transformed India's forests into a net sink of CO_2. From 1995 to 2005, carbon stocks stored in our forests have increased from 6244.78 to 6621.55 million tonnes (mt) registering an annual increment of 37.68 mt of carbon = 138.15 mt of CO_2eq. This annual removal by forests is enough to neutralise 9.31% of our total annual emissions of 2000. This amount of carbon sequestration will still be adequate to dent our emissions even when these will be on the increase due to our accelerated development process. Estimates show that the continued removals by the forests would still be able to offset 6.53% and 4.87% of our projected annual emissions in 2010 and 2020 respectively. It is estimated that emissions in 2010 and 2020 will respectively be 45% and 95% higher than those in 2000.

And, if over and above the current trend, the National Mission for a Green India as part of the 'National Action Plan on Climate Change' (NAPCC) becomes operational, the capability of the forestry sector to contribute in GHG removal will further enhance. Afforestation and reforestation of 6 million hectares of degraded forest land covered under the National Mission with participation of Joint Forest Management Committees (JFMCs) would be able to add another 18 mt of carbon = 66 mt of CO_2eq by 2020. Annual addition of 6 mt of biomass due to operationalization of the Mission will increase the annual emissions removal capability of the forests from 4.87% to 5.18% of the corresponding projected emissions in 2020. Even if half (3 mt) of the annual biomass increment (6 mt) is removed annually on a sustainable basis from 2025 onwards, the emission removal capability of forestry sector would still be able to offset every year 5.02% of the 2020 level emissions.

It is abundantly clear that forestry sector has significant emissions removal capability which can further be enhanced by operationalizing major afforestation and reforestation initiatives like National Mission for a Green India besides continued strengthening of the present protection regime of forests. Launching a programme to pro-

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vide LPG in hilly areas of Himalayan region and in central tribal belt offers another potential opportunity to further improve the carbon sequestration potential of our forests as this kind of fuel switching by the hilly and tribal communities would reduce pressure of fuelwood removal from forests.

Key words: Emissions Removal, Capability of Forests, GHG Emissions, Carbon Storage, Forest Carbon Stocks, Joint Forest Management Committees, Green India

Introduction

Forests provide a wide range of goods and services. Goods include timber, fuelwood, as well as food products (berries, mushrooms, etc.) and fodder. As regards important services, forests and trees play a role in the conservation of ecosystems, in maintaining quality of water, and in preventing or reducing the severity of floods, avalanches, erosion, and drought. Forests provide a wide range of economic and social benefits, such as employment, forest products, and protection of sites of cultural value (FAO, 2006).

Forests, like other ecosystems, are affected by climate change. The impacts due to climate change may be negative in some areas, and positive in others. However, forests also influence climate and the climate change process mainly by effecting the changes in the quantum of carbon dioxide in the atmosphere. They absorb CO_2 from atmosphere, and store carbon in wood, leaves, litter, roots and soil by acting as "carbon sinks". Carbon is released back into the atmosphere when forests are cleared or burned. Forests by acting as sinks are considered to moderate the global climate. Overall, the world's forest ecosystems are estimated to store more carbon than the entire atmosphere (FAO, 2006).

However, deforestation, mainly conversion of forests to agricultural land, is continuing at an alarmingly high rate. Forest area, which is about 30% (4 billion hectares) of the global total land area decreased worldwide by 0.22% per year in the period 1990-2000 and 0.18% per year between 2000 and 2005. However, the net loss of forest is slowing down as a result of the planting of new forests and of natural expansion of forests. Forests and trees are being planted for many purposes and at increasing rates, yet the plantations still account for only 5 percent of

total forest area (FAO, 2006). Quantifying the substantial roles of forests as carbon stores, as sources of carbon emissions and as carbon sinks has become one of the keys to understanding and modifying the global carbon cycle.

Worldwide numerous ecological studies have been conducted to assess carbon stocks based on carbon density of vegetation and soils (Atjay *et. al.,* 1979; Olson *et. al.,* 1983; Saugier and Roy, 2001). The results of these studies are not uniform and have wide variations and uncertainties probably due to aggregation of spatial and temporal heterogeneity and adaptation of different methodologies. IPCC (2000) estimated an average carbon stock of 86 tonnes per hectare in the vegetation of the world's forests for the mid-1990s. The corresponding carbon in biomass and dead wood in forests reported in FRA, 2005 amounts to 82 tonnes per hectare for the year 1990 and 81 tonnes per hectare for the year 2005. Each cubic metre of growing stock equals different amounts of biomass and carbon (in biomass) in different regions. Globally, each cubic metre of growing stock equals, on an average, 1 tonne of above-ground biomass, 1.3 tonnes of total biomass and 0.7 tonnes of carbon in biomass (FAO, 2006). The country reports of FAO indicate that global forest vegetation stores 283 Gt of carbon in its biomass, and an additional 38 Gt in dead wood, for a total of 321 Gt and IPCC (2000) assumed 359 Gt of carbon in these pools.

Total growing stock shows a slight overall downward tendency – mainly owing to a decrease in forest area. However, some regions also show significant positive trends in growing stock per hectare. For example, Europe shows an increase and Southeast Asia a decrease. It is estimated that the world's forests store 638 Gt of carbon in the ecosystem as a whole (to a soil depth of 30 cm). Thus forests contain more carbon than

the entire atmosphere. Roughly half of total carbon is found in forest biomass and dead wood combined and half in soils and litter combined (FAO, 2006).

India is a large developing country known for its diverse forest ecosystems and mega-biodiversity. It ranks 10th amongst the most forested nations of the world (FAO, 2006) with 23.4 percent (76.87 million ha) of its geographical area under forest and tree cover (FSI, 2008). With nearly 173,000 villages classified as forest fringe villages, there is obviously a large dependence of communities on forest resources. Thus, it is very important to assess the likely impacts of projected climate change on forests, to develop and implement adaptation strategies both for biodiversity conservation and protection and for safeguarding the livelihoods of forest dependent people, and to ensure production of round wood for industrial and commercial needs.

The forest carbon was assessed in different ways by different researchers. Earlier attempts for estimating forest carbon did not take into consideration soil carbon. The biomass carbon stock in India's forests was estimated at 7.94 MtC during 1880 and nearly half of that after a period of 100 years (Richards and Flint, 1994). The first available estimates for forest carbon stocks (biomass and soil) for the year 1986, are in the range of 8.58 to 9.57 GtC (Ravindranath, *et al.*, 1997; Haripriya, 2003; Chhabra and Dadhwal, 2004). As per FAO estimates (FAO, 2005), the total forest carbon stocks in India have increased over a period of 20 years (1986–2005) and amount to 10.01 GtC. The carbon stock projections for the period 2006–30 is projected to be increasing from 8.79 to 9.75 GtC (IISc, 2006) with forest cover becoming more or less stable, and new forest carbon accretions coming from the current initiatives of afforestation and reforestation programme (Ravindranath, *et al.*, 2008). Need-

less to say that the present state of forest carbon stocks owes its origin to the drive of plantation forestry in India started in the late 1950s and supplemented later by the social and farm forestry initiatives of the 1980s and early 1990s. All the same, the National Communication of the Government of India to the UNFCCC for 1994 has reported that the LULUCF sector is a marginal source of emissions with a figure of 14.29 mt (million tonnes) of CO_2. However, in the LULUCF sector 'changes in forest and other woody biomass stock' account for a net removal of 14.25 mt of CO_2 (NATCOM, 2004). Thus, for forests alone, the NATCOM presents a net sink of 14.25 mt CO_2eq. With the knowledge and the information that is now emerging, the role of forests and plantations in mitigation is becoming more and more important. NATCOM reports a comprehensive inventory of India's emissions from all energy, industrial processes, agriculture activities, land use, land use change and forestry and waste management practices to the United Nations Framework Convention on Climate Change (UNFCCC) for the base year 1994. It is a useful reference document to compare the contribution of different sectors in the national level emissions.

The compounded annual growth rate of CO_2eq emissions in India is 4.2 per cent. Some may consider this to be higher than the desired, but the absolute value of these emissions is still one-sixth that of the United States and lowest for the per capita GHG emissions (Rawat and Kishwan, 2008).

In India, CO_2 emissions from forest diversion or loss are largely offset by carbon uptake due to forest increment and afforestation. Many authors concluded that for the recent period, the Indian forests are nationally a small source with some regions acting as small sinks of carbon as well (Ravindranath, *et al.*1997; Haripriya, 2003;

Chhabra and Dadhwal, 2004; Ravindranath, *et al.,* 2008). The improved quantification of pools and fluxes related to the forest carbon cycle is important for understanding the contribution of India's forests to net carbon emissions as well as their potential for carbon sequestration in the context of the Kyoto Protocol (Chhabra and Dadhwal, 2004).

It was in this background that the country recognized the importance of pursuing the policies of conservation and expanding the areas of woodlots that besides goods and other services allowed the forests to sequester more and more carbon in biomass and the soil. This is happening not only in India, but in many other developing countries. To encourage conservation and expansion of forests world-wide, India internationally supported compensation for nations in return for the carbon services they are, and will be, providing by conserving, stabilizing and/or increasing their forest cover. The policy approach advocated by India in the context of the agenda item of "Reducing emissions from deforestation in developing countries" of the United Nations Framework Convention on Climate Change (UNFCCC), also known as REDD or REDD-plus was named "compensated conservation" (Kishwan, 2007). However, any future agreement on REDD/REDD-plus would require assessment and monitoring of forest carbon stocks of a country at regular intervals through application of scientifically acceptable methodologies.

Purpose of this study is to compute improved estimates for biomass, and therefrom biomass carbon in forests taking into account the inventory data for diversified forest types present in the country, and also by accounting for biomass in other vegetation on forest floor (other than trees). It may also be mentioned that most studies related to estimation of biomass have not

incorporated the biomass stored in the understory of the forest (Brown and Lugo, 1991; Manhas, *et al.*, 2006).

Methodology

Estimation of carbon stocks in forestry sector, present in biomass and soil, is based either on IPCC guidelines or through use of actual conversion and other factors starting from the growing stock (GS) data of forest inventories. Forest Survey of India is primary source of these data in the country. However, some other sources such as FAO, and research papers complement these inventories. The present study for the assessment of forest carbon stocks uses primary data for the soil carbon pool and secondary data of growing stock from various sources for estimating the biomass carbon (Brown and Lugo, 1984; Houghton, *et al.* 1985; Dadhwal and Nayak, 1993). Approach of the study being a combination of primary and secondary data with large number of samples for assessment of soil organic carbon (SOC) makes it more reliable for carbon pool estimates. Mathematically, assessment of forest carbon stocks in the study can be represented as:

$$C_{Carbon} = C_{Biomass} + C_{Soil}$$

Where,

C_{Carbon} = Total available carbon in the forest, i.e., in the vegetation and in soil

$C_{Biomass}$ = Total available carbon in the above and below ground biomass of all forest vegetation

C_{Soil} = Total available soil organic carbon (SOC) up to 30cm depth in the forest

Soil Organic Carbon (SOC) Pool -

For estimating SOC, the IPCC guidelines (IPCC, 1997) prescribe that only the upper 30 cm layer of soil, which contains the actively changing soil carbon pool in the forest, should be considered. For this purpose, the representative soil samples were collected from a pit of 30 cm wide, 30 cm deep and 50 cm in length. The samples contained thoroughly mixed soil with gravels removed, and were collected randomly from all forest types by digging a fresh rectangular pit in the forest and by clearing the top layer of grass, litter and humus in an area of 50 cm x 50 cm. However, no samples were taken from eroded land, or from near the trunk of trees, roads, houses and construction sites, etc. For estimating bulk density, two to three clods of about 2 to 3 cm size were picked from each pit from top to bottom using standard collectors. Soil samples were collected from a total of 571 sample points laid in different forest types covering the whole country. Forest types were used as strata for sampling and equal number of sample points were allocated to each stratum. The study covered a total of 571 samples in forest area and 101 additional samples in the nearby non-forest areas. But, for assessment of SOC in forests, 101 samples collected from non-forest areas were not taken into account. Additionally, 15 samples falling in alpine scrub were discarded as area of this forest type was not available. Soil organic carbon was estimated by standard Walkley and Black method and bulk density was estimated using standard Clod method. All measurements, observations and information required for each sample were systematically recorded. The bulk density (D) was calculated as under:

D = weight of soil (gm)/volume of core (cylinder) in cm^3

Soil organic carbon stock Q_i (Mg m^{-2}) in a soil layer or sampling level i with a depth of E_i (m) depends on the carbon content C_i (g C g^{-1}), bulk density D_i (Mg m^{-3}) and on the volume fraction of coarse elements G_i, given by the formula (Batjes, 1996):

$$Q_i = C_i D_i E_i (1 - G_i)$$

For the soil thickness z with k levels of departure, the total stock of carbon was obtained by adding the stocks for each of the k levels (Schwartz and Namri, 2002):

$$C_{soil} = Q_t = \sum_{i=1}^{k} Q_i = \sum_{i=1}^{k} C_i D_i E_i (1 - G_i)$$

Rock outcrop at a site affects the representative elementary volume and the regolith volume available for root growth. This attribute was eliminated by using a simple estimate of areal percentage (McDonald et al., 1990).

Biomass Carbon-

Biomass carbon can be disaggregated into above ground and below ground biomass. Change in forest carbon stocks during a time period is an indicator of the net emissions or removals of CO_2 in that period. Total biomass was calculated for the years 1995 and 2005, and linearly projected for the year 2015.

Assessment of biomass was based on the consideration that all lands, more than one hectare in area, with a tree canopy density of more than 10 per cent are defined as 'Forest'. The country's forest carbon estimate is based on the forest cover assessment of 1997 and 2005 by Forest Survey of India (FSI). Additionally, data for the year 2003 was also considered. The satellite data used for 1997 assessment related to the period from 1993 to 1995, and for 2005, pertained to 2003 to 2005. Therefore, we have safely pre-

sumed that these assessments are sufficiently and adequately representative, and thus can be used for forest carbon stock estimation for 1995 and 2005 (Saxena, et al., 2003). The total forest cover in India according to the State of Forest Report 2005 is 67.71 mha or 20.60% of the geographic area (FSI, 2008), and as per 1995 report, the forest cover is 63.34 mha covering 19.27% of geographic area of country (Manhas, et al., 2006).

The component-wise, i.e., growing stock separately for forest and tree cover of the country for the years 2003 and 2005 is respectively available in State of Forest Report 2003 (FSI, 2005) and State of Forest Report 2005 (FSI, 2008). However, for 1995, growing stock only for forest cover is available at the national level. Growing stock for the tree cover for 1995 at the country level was estimated based on the mean of the ratio between growing stock of tree cover and that of forest cover for the years 2003 and 2005 with the assumption that during the period of about a decade between 1993, and 2003-2005, the increment in growing stock of the tree cover and that of forest cover have followed a uniform pattern. As regards, state-wise break-up of data relating to the quantum of growing stock for forest cover, and that for tree cover, the same is not available for 2005, which makes it difficult to estimate state-wise figures for such data for 1995 also.

Suitable biomass increment values (expansion and conversion for calculating total tree above ground biomass) and the ratio of below and above ground biomass (for calculating total tree biomass above and below ground) as available in different studies covering a range of forest types of the country were used in the present study. The referred studies measured directly or indirectly the total biomass of the stand broken down into the individual components (Chhabra, et al., 2002; Kaul, et al., 2009). These compo-

nents were stemwood, branches, leaves and roots of the tree in a stand or even in a larger area depending on the study. The biomass of other vegetation on forest floor (understory) was estimated based on the ratio of total tree biomass to the total forest floor biomass excluding the tree component in the area. In general, other forest floor biomass accounts for less than 2 percent of total biomass of closed forest formations (Ogawa, et al., 1965; Rai, 1981; Brown and Lugo, 1984). However for this study, ratio was adopted based on the published records for different vegetation types and different localities, and also keeping in view its application and representation for the country level estimates (Singh and Singh, 1985; Rawat and Singh, 1988; Negi, 1984; Roy and Ravan, 1996). Mathematically, the above ground biomass of tree component is as follows:

$$GS_{Total} = GS_{Tree} + GS_{Other.Vegetaion}$$

GS_{Total} = Total growing stock in forest

GS_{Tree} = Growing stock of tree component

$GS_{Other.Vegetaion}$ = Growing stock of other vegetation on forest floor

$$GS_{Tree} = V_{Above.Ground} + V_{Below.Ground}$$

$V_{Above.Ground}$ = Above ground volume

$V_{Below.Ground}$ = Below ground volume

$$V_{Above.Ground} = GS_{Commercial} \times \text{Expansion factor}$$

$GS_{Commercial}$ = Growing stock of tree bole upto 10 cm diameter

Expansion factor = Adjusted mean biomass (volume) expansion factor for the country

$$V_{Below.Ground} = V_{Above.Ground} \times \text{Ratio}$$

Ratio = Adjusted mean ratio between below and above ground biomass (volume)

$$GS_{Other.Vegetaion} = GS_{Tree} \times R$$

R = Ratio of other forest floor biomass to growing stock of tree component

The biomass is estimated by taking into account the total growing stock of the forest including the above and below ground volume of all vegetation in the forest and multiplying it with a 'volume to mass' conversion factor. The conversion factor adopted in this study is influenced by the contents of studies of Brown, Gillespie and Lugo, 1991; Rajput, et al., 1996 and Kaul, et al., 2009.

$$B = GS_{Total} \times MD$$

B = Biomass (million tonnes)

GS_{Total} = Total forest growing stock (million m³)

MD = Mean wood density

Biomass material contains about 40% carbon by weight, with the hydrogen (6.7%) and oxygen (53.3%). The remaining proportions include nitrogen with a share of 0.3-3.8%, and sulfur 0.1-0.9%. The variability of approximately 9% depends on the nature of the biomass material (Bowen, 1979; Levine, 1996). Although most studies have used the carbon proportions between 40 to 50% depending on the requirements (IPCC, 1997; 2004; Andreae, 1991; 1993 Susott, et al., 1996; Ludwig, et al., 2003), the present study uses the conservative value of 40% carbon content keeping in view the fact that the study deals with mixed biomass comprising timber, fuelwood, leaves, twigs, roots, etc. The study also assumes the presence of an average moisture content of 20% mcdb (mois-

ture content on dry basis) in dry wood and other biomass. This has also been suggested by Leach and Gowen, 1987; Hall, *et al.*, 1994 for getting more realistic estimate considering that good amount of water still remains in wood even after proper drying (Ludwig, *et al.,* 2003). Conservative values of carbon content and mcdb have been adopted to have realistic estimates in view of the errors that are generally associated with use of such values and factors in computation of total growing stock, wood densities, expansion and conversion factor, etc. Mathematically, the biomass carbon can be estimated as follows:

$$C_{Biomass} = \text{Biomass} \times (1 - \text{mcdb}) \times \text{Proportion of Carbon Content}$$

Based on the carbon estimates for the year 2005 and 1995, the annual addition of carbon in India's forest was calculated. This increment was converted into the CO_2 equivalent for comparing and estimating the emissions offsetting capability of India's forest in relation to the national level GHG emissions. Figures for GHG emissions of the country were available in published records for the year 1990, 1994 and 2000 in Sharma, *et al.,* 2006, and for 2000, 2010 and 2020 in Shukla, 2006 with corresponding CO_2 equivalent value. Emissions removal or offsetting capability of forests was calculated as a percentage of these projected values. Increment in forest carbon stocks over a period of time is calculated as under:

Carbon Increment in m years (I_m) = C_{Carbon} in t^{th} year - C_{Carbon} in $(t-m)^{th}$ year

Based on above, the annual increment (I_A) in forest carbon stocks is

$$I_A = I_m/m$$

Result

The growing stock of the country for the year 2005 is 6,218 million cubic meter comprising 4,602 million cubic meter corresponding to the forest cover and 1,616 million cubic meter corresponding to the tree cover. Average growing stock in the recorded forest area per hectare is 59.79 cubic meter. However, in 2003, the growing stock under tree cover was 1,632 million cubic meter and for forest cover was 4,781 million cubic meter. The proportion of growing stock for tree cover as compared to that for forest cover is 35.12% and 34.14% in 2005 and 2003 respectively (FSI, 2005, 2008). The mean of these proportions (34.63 %) is utilized for estimating the growing stock under tree cover for the country in the year 1995, as the figure for this growing stock for 1995 is not available. In this year, the growing stock under forest cover was 4,339.55 million cubic meter (FSI, 1997; Manhas, *et. al.,* 2006), and the estimated growing stock under tree cover worked out on the basis of average proportion is 1,502.77 million cubic meter, making the total growing stock of 5,842.32 million cubic meter for both forest and tree cover. Following the description in methodology, the adjusted mean biomass expansion factor, ratio between below and above ground biomass, mean density, and ratio between other forest floor biomass to the tree biomass were estimated, and are presented below in Table 1 together with calculation for forest biomass carbon in the country's forests. The calculation uses conversion of commercial wood volume (growing stock) into total biomass using average adjusted wood density and expansion factors and ratios as also suggested by Brown, Gillespie and Lugo, 1991.

Soil organic carbon pool for different forest groups was estimated based on the primary data as described in methodology and reported in Table 2 for 1995 and 2003.

Table 1: Forest Biomass Carbon in India (million tonnes)

Item with symbolic description	Factor	1995	2005
Growing Stock of Country in Mm³ - GS		5842.320	6218.282
Mean Biomass Expansion Factor - EF	1.575		
Ratio (Below to Above Ground Biomass) - RBA	0.266		
Above Ground Biomass (Volume) - AGB = GS X EF		9201.654	9793.794
Below Ground Biomass (Volume) - BGB = AGB X RBA		2447.640	2605.149
Total Biomass (Volume) – TB = AGB + BGB		11649.294	12398.943
Mean Density - MD	0.7116		
Biomass in Mt = Growing Stock (Mm³) x Mean Density (MD)		8289.638	8823.088
Ratio (Other Forest Floor Biomass except tree to Tree Biomass)	0.015		
Total Forest Biomass in Mt (Trees + Shrubs + Herbs) - TFB		8413.982	8955.434
Dry Weight in Mt (80% of TFB) - DW		6731.186	7164.348
Carbon in Mt (40 % of DW)		2692.474	2865.739

Factors for various items were derived from mainly Kaul, *et.al.*, 2009; Ray and Ravan, 1996 and Singh and Singh, 1985.

Table 2: Soil Organic Carbon Pool Estimates (0 - 30 cm) in India's Forests (million tonnes)

Area in 000 ha

Forest Type (Group)	Area 1995	Area 2005	Mean Soil Carbon	Sample Number	SE	Total SOC 1995	Total SOC 2005
Himalayan dry temperate forest	31	32	36.198	24	5.56	1122.144	1158.343
Himalayan moist temperate forest	2230	2447	71.577	48	7.16	159616.937	175149.168
Littoral and swamp forest	383	481	71.062	70	12.20	27216.904	34181.021
Montane wet temperate forest	2583	2593	115.460	16	14.61	298233.293	299387.893
Sub alpine and alpine forest	2021	2067	74.071	12	12.18	149698.375	153105.661
Sub tropical broad leaved hill forest	260	303	86.611	20	14.97	22518.833	26243.102
Sub tropical dry evergreen forest	1223	1248	65.279	3	10.37	79836.780	81468.766
Sub tropical pine forest	4556	4743	50.270	12	8.08	229031.601	238432.151
Tropical dry deciduous forest	18233	19156	34.195	143	4.16	623475.447	655037.332
Tropical dry evergreen forest	134	165	52.398	10	11.64	7021.363	8645.709
Tropical moist deciduous forest	23091	24284	55.009	57	6.73	1270222.177	1335848.398
Tropical semi evergreen forest	2573	2946	54.625	40	5.71	140549.907	160925.000
Tropical thorn forest	1604	1827	20.375	61	5.75	32681.741	37225.399
Tropical wet evergreen forest	5040	5414	101.404	40	10.04	511078.124	549003.366
Total	63962	67706		556		**3552303.628**	**3755811.310**

The area under various forest types are from FSI reports (FSI, 1995 and FSI, 2008).

Based on the figures for biomass carbon and SOC in forests given in Table 1 and Table 2 above, the estimates of total forest carbon stocks comprising components of biomass carbon and SOC for 1995 and 2005 were computed, and are presented below in Table 3. Component-wise changes in the period from 1995-2005 were also worked out.

Table 3: Component-wise Carbon in India's Forests in 1995 and 2005 (million tonnes)

Carbon	1995	2005	Incremental Change
In Biomass	2692.474	2865.739	173.265
In Soil	3552.304	3755.811	203.507
Total	6244.778	6621.55	376.772

The analysis showed that there is improvement in forest carbon stocks on temporal basis from 1995 to 2005. The difference of 376.772 mt between figures of 1995 and 2005 shows the incremental carbon accumulation in India's forests during the period. On yearly basis, the addition of carbon was 37.677 mt ≈ 37.68 mt (say), which means an annual removal of 138.15 mt CO_2 eq. Annual accumulation of forest carbon stocks was compared with the trend of national GHG emissions as computed and reported by Shukla, 2006 and Sharma, *et al.*, 2006 to work out the proportion of national level emissions offset by forests in India. Proportion of emissions removed/offset by India's forestry sector in different years is reported below in Table 4.

Implementation of the National Mission for a Green India as part of the National Action Plan for Climate Change can further enhance the present mitigation potential of the forestry sector. Same methodology as has been used for calculating forest carbon stocks for forestry sector can be used for estimating the additional quantum of carbon sequestered by afforestation and reforestation of 6 million ha of degraded forest lands. Presuming a conservative dry biomass accumulation of 1 t ha^{-1} yr^{-1}, 18 million tonnes (mt) of carbon (in 45 mt of dry biomass) would get accumulated by 2020 when the plantation is done at the rate of 1 million ha per year, 2010 onwards. The figure would rise to 75 million tonnes of carbon in 2025. In 2020, when 6 mt of biomass = 2.4 mt of carbon or 8.8 mt of CO_2eq is sequestered every year; this will be able to additionally offset 0.31% of projected 2020 level emissions annually. The mission will have the effect of increasing the emissions removal capability of the country's forests from 4.87 to 5.18% annually of the 2020 emissions level. Even if half the biomass of 3 mt from the total annual incremental biomass is removed from 2025 onwards on a sustainable basis, the

Table 4: Total GHG Emissions (mt CO_2eq) from various sectors, and proportion thereof offset by forestry sector

Estimate Source/ Proportion	1990	1994	2000	2010	2020
Shukla, 2006	–	–	1454	2115	2839
Proportion of Emissions Removed by India's Forestry Sector (%)			9.50	6.53	4.87
Sharma *et. al.* 2006	987.885	1,228.539	1,484.622	–	–
Proportion of Emissions Removed by India's Forestry Sector (%)	13.98	11.25	9.31		

plantations of the mission would still be able to maintain the increased emissions removal capability of forestry sector at 5.02% of the 2020 level emissions.

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