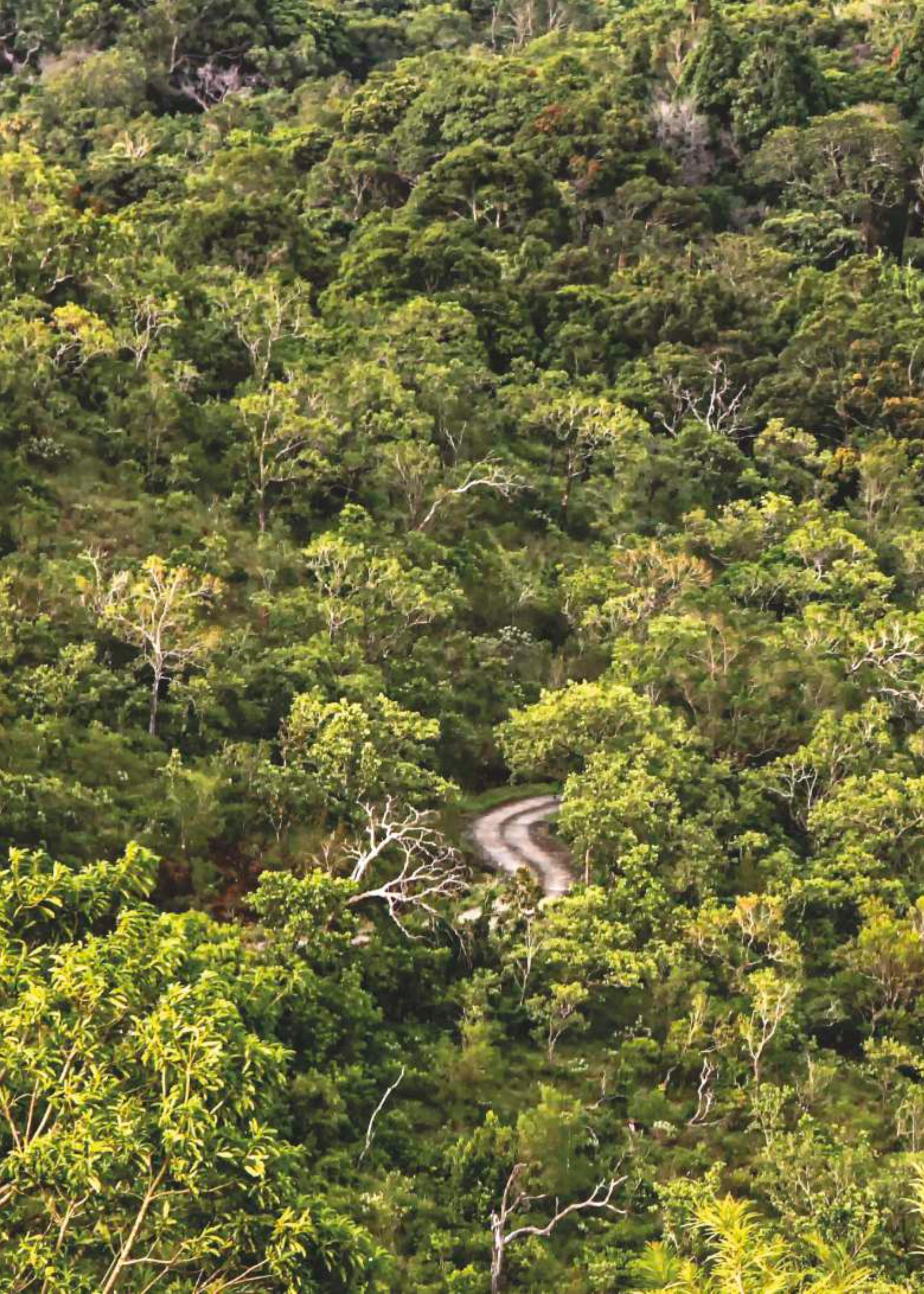


09

CARBON STOCK IN INDIAS FORESTS

Introduction 9.1

Carbon is the most abundant element and is essential for all known living systems. The carbon cycle comprises of a sequence of events, which enable life forms to exist and sustain on the earth. The carbon cycle can also be described in terms of sources and sinks. Sources are those parts of the cycle that add carbon to the atmosphere, and sinks are those parts that remove carbon from the atmosphere. When the sun's energy reaches the Earth's atmosphere, some of it is reflected back to space and the rest is absorbed and re-radiated by greenhouse gases. The carbon cycle's sources and sinks help in regulating the amount of greenhouse gases in the atmosphere which are essential for life on earth. The Greenhouse gases include water vapors, carbon dioxide, methane, nitrous oxide, ozone and some artificial chemicals such as chlorofluorocarbons (CFCs). The right amount of greenhouse gases in earth's surface keeps it warm enough for all forms of life to exist. Hypothetically, if there were no greenhouse gases in the earth's atmosphere, the average temperature on the earth's surface would become too low to support any floral/faunal life on the earth. On the other hand, more concentration of these on the earth would make it too warm to support life.

The key to keeping everything in balance is for the sources and sinks to have the same amount of CO_2. The most important sinks are the oceans, forests & soil on land. The forests and oceans each remove around one-fourth of the carbon that humans add to the atmosphere. During the last one and a half century, the increased human activities, particularly burning fossil fuels, agriculture and deforestation are increasing the concentrations of greenhouse gases. This is the enhanced greenhouse effect, which is contributing to warming of the Earth causing Climate Change.

Climate change has become a serious threat to the environment and the quality of life all over the world. Forests play very important role in mitigation and adaptation to climate change. Forests are considered as reservoir, sink and source of carbon. Forests sequester and store more carbon than any other terrestrial ecosystem and act as natural 'brakes' on climate change. Carbon sequestration by forests has attracted much interest globally as it is a relatively inexpensive means of mitigation of climate change. Varied topography and climate regimes, large geographical area, long coastline and oceanic islands have endowed India with a diversity of natural biomes from deserts to alpine meadows, tropical rain forests to temperate pine forests, mangroves to coral reefs and marshlands to high altitude lakes. The diversity of forests in India makes it resilient to climate change and also an efficient sink of carbon.

The parties to the United Nations Framework Convention on Climate Change (UNFCCC) have undertaken many policy measures, actions and programmes to address the issues of climate change mitigation and adaptation. India is also a Party to the Convention and therefore, is required to periodically submit greenhouse gas inventory for the country from all the sectors including Land Use, Land-Use Change and Forestry (LULUCF) as National Communication (NATCOM). Towards the fulfillment of reporting obligations under the UNFCCC, India has so far submitted two full NATCOMs and three Biennial Update Reports (BUR) to the UNFCCC:

a. Initial National Communication (INC) in June 2004, containing national GHG inventory of 1994 (1984 - 1994).

b. Second National Communication (SNC) in May 2012, containing national GHG inventory for the year 2004 (1994 - 2004).

c. First Biennial Update Report (BUR-1) in January 2016, containing national GHG inventory for the year 2010.

d. Second Biennial Update Report (BUR-2) in December 2018, containing national GHG inventory for the year 2014.

e. Third Biennial Update Report (BUR-3) in February 2021, containing national GHG inventory for the year 2016.

Apart from the international reporting, periodic forest carbon assessment helps in monitoring flow of carbon in different pools in the forests of the country and is an important indicator of ecosystem services from forests. India is committed at the highest level to meet its commitments under the Nationally Determined Contributions (NDC) made to the international community under the Paris Agreement (2015). According to the forestry target under NDC, India has committed to create additional carbon sink of 2.5 to 3.0 billion tonnes of CO_2 eq through additional forest and tree cover by 2030. The country is making concerted efforts to meet the Paris commitments and achieve the NDC target. Approximately 80 per cent of the country's terrestrial biodiversity exists in forests, and more than 300 million people have high dependency on the forest for their livelihood. Forests as a carbon sink have a prominent role in mitigating climate change. Various legislations and acts have been formulated by the Indian government for the conservation of forests and their resources.

As per the BUR-3, for the year 2016, India's total GHG emissions, excluding Land Use Land-Use Change and Forestry (LULUCF) were 2,838.89 million tonnes Co_2 eq and 2,531.07 million tonnes Co_2 eq with the inclusion of LULUCF. Carbon dioxide emissions accounted for 2,231 million tonnes (78.59 per cent), methane emissions for 409 million tonnes Co_2 eq (14.43 per cent) and nitrous oxide emissions for 145 million tonnes CO_2 eq (5.12 per cent). The LULUCF sector was a net sink of 307,820 Gg CO_2 eq in 2016, registering an increase in the net sink activity by 39 percent since 2000. Forest land, cropland and settlements categories were net sinks while grassland was a net source of CO_2. About 15 per cent of India's carbon dioxide emissions in 2016 were removed from the atmosphere by the LULUCF sector.

As per the Global Forest Resources Assessment 2020 published by the FAO, the total forest carbon stock (i.e. including all carbon pools) is estimated at 662 Gt (163 tonnes per ha), comprising 300 Gt in soil organic matter, 295 Gt in living biomass and 68.0 Gt in dead wood and litter. Soil organic matter constitutes the biggest pool, with 45.2 percent of the total carbon, followed by above-ground biomass, below-ground biomass, litter and dead wood. The report also mentions that globally, between 1990 and 2020 the global forest carbon stock decreased from 668 Gt to 662 Gt due to an overall decrease in forest area. There were considerable regional and sub-regional differences in the trend, however, for example, the carbon stock in forest biomass increased significantly in East Asia, Western and Central Asia, Europe and North America (where forest area increased) and decreased considerably in South America and Western and Central Africa.

Forest Carbon Estimation of India 9.2

FSI has been estimating carbon stock in the country's forests for various NATCOMs and providing valuable inputs to the MoEF&CC in preparation of GHG inventory of the country. In Initial National Communication (INC, also referred as NATCOM-I) process under which estimation of carbon stock was to be done for the period 1984-1994, FSI estimated forest carbon of only woody growing stock as data for the other parameters was not available. For reporting for INC, the growing stock (volume) data was first converted into biomass by using species wise specific gravity of the wood. Thereafter, biomass expansion factors were used to convert woody biomass into total above ground biomass which included all other components like small wood and foliage of trees, shrub, herbs etc. Similarly, below ground biomass was computed using default root-shoot ratio given in GPG 2003. The total biomass so obtained was then converted into carbon using conversion factor.

For the Second National Communication (SNC) to UNFCCC, FSI conducted 'Greenhouse gas inventory in Forest Land Remaining Forest Land & Land Converted into Forest Land for the period 1994 to 2004' under 'Land Use, Land-Use Change and Forestry (LULUCF)'. GHG fluxes in the LULUCF sector are generally estimated as net changes in carbon stocks over time. The increase in total carbon stocks over the time are equated with a net removal of CO_2 from the atmosphere and decreases in total carbon stocks (less transfer to other pools such as harvested wood products) are equated with net emissions of CO_2. FSI published a separate report on 'Carbon stock in India's Forests' in the year 2011. A separate chapter on carbon stock was given first time in ISFR 2011 highlighting the results of SNC. Since then, the information on total carbon stock and change with respect to previous assessment is a part of successive ISFRs.

With the launch of National Forest Inventory (NFI), FSI has been estimating growing stock in both forest and TOF since 2003. Subsequently suitable modifications were also made in the plot design to collect information required for calculation of the carbon stock in different carbon pools. The NFI design was changed in the year 2016 again by switching over from district based to grid-based design to meet the data needs at the national and international levels. In addition, the information on forest cover in different forest types is used for the estimation of carbon stock.

Methodology for Forest Carbon Estimation 9.3

FSI estimates the forest carbon stock by following a post sampling stratification approach in which data of sample plots of national forest inventory has been used along with forest cover and forest type layers. Sample plots of inventory are overlaid on different strata and biomass for each pool is determined.

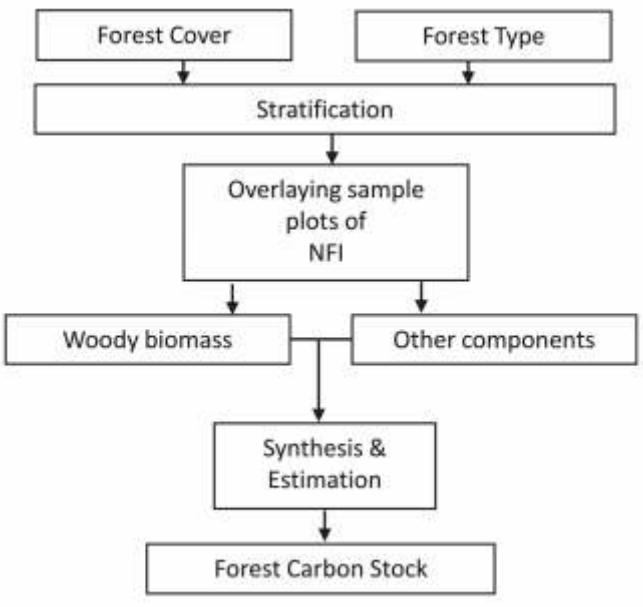
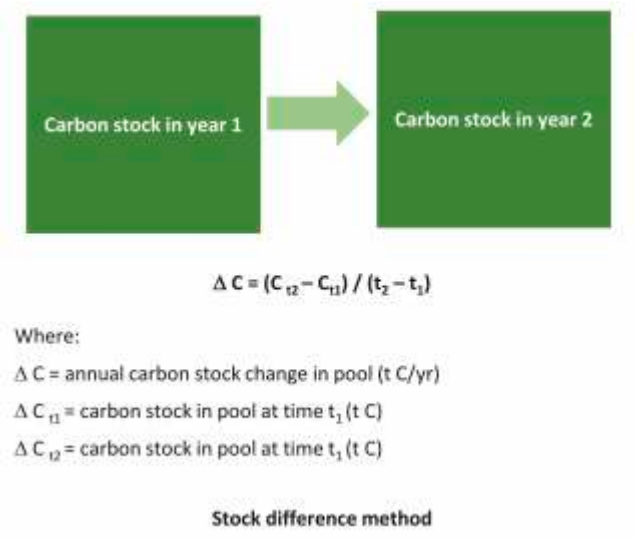


Figure 9.1 Schematic diagram showing methodology of forest carbon assessment

Method for calculating biomass for different pools is described in the following sub sections. Change in Forest Carbon between the current and previous assessment has been done following stock difference approach (GPG, 2003) as shown in Figure 9.2.

Figure 9.2
Stock difference methods for determining change in forest carbon stock



9.3.1 Stratification of Forest area

Stratification helps in improving the precision of the estimates by dividing a heterogeneous population into relatively homogeneous sub-populations based on certain stratification criteria. Since, carbon stored in the vegetation largely depends upon canopy density and forest type; these two layers have been used for stratification for assessment of forest carbon in the country.

9.3.2 Forest Type Mapping

Forest Type is a unit of vegetation, which possesses broad characteristics in physiognomy and structure sufficiently pronounced to permit its differentiation from other such units. Forest type characterizes forests in terms of floristic composition and conditions of plant growth. FSI had earlier mapped Forest Types of India, according to Champion & Seth classification (1968) on 1: 50,000 scale in 2011. The second exercise for refining the previous Forest Type map has been completed by FSI recently. Using the Forest Type maps, distribution of forest cover in different forest types has been determined for the country. Forest cover map has been superimposed with the forest type map for creating the stratification. Overlaying of forest cover layer with three canopy density classes and forest type with the 17 type groups including TOF & plantations - has resulted into 51 strata. Area statistics for each stratum has been generated using GIS.

Estimation of Biomass and Carbon in different pools 9.3.3

FSI has developed volume equations for forest and TOF species. Through a special study done for different forest types, biomass equations have also been developed for important species. Using forest type specific volume equations and Biomass Expansion Factors (BEF), biomass in different pools have been determined. Specific gravity and carbon content in biomass for different forest types/species as available in different literature including IPCC Guidelines (2006)[1] have been used in estimation of forest carbon. Methods for estimation of biomass/carbon in different pools are described in short in the following sub sections.

Above Ground Biomass (AGB) of trees having dbh ≥ 10 cm. 9.3.3.1

Forest inventory data collected at more than 23,500 sample plots in the last four years as per the new sampling design has been used for calculation of AGB of trees above dbh 10 cm. At each sample plot, all trees of diameter 10 cm and above were measured. The woody volume of trees for each sample plot was calculated using volume equations developed by FSI for various species. The volume equation provides above ground woody volume i.e. above ground volume, which includes volume of main stem measured upto 10 cm diameter and volume of all branches having diameter 5 cm or more. Data of specific gravity and percentage carbon content of most of the tree species have been obtained from different published literature. For some important species, percentage carbon content was ascertained by experimentation and for remaining an average of all other species was used. Standard formula were used to calculate biomass and carbon content of each tree.

For estimating volume of the bark, the double bark thickness of trees measured during forest inventory and volume equation of trees have been used. Using species-wise, dbh and bark thickness, bark volume equations were developed and were adjusted for 'bark void factor' which were utilized to estimate bark volume. With the help of the specific gravity of bark, the volume was converted into biomass. Using carbon content percent of wood, carbon stored in bark was estimated.

Above ground biomass of trees having dbh <10 cm 9.3.3.2

This information was initially derived by using biomass equations developed by FSI from a special study conducted during 2008 - 10 for Second National Communication to UNFCCC. These equations were developed for 20 important species in each of 14 physiographic zones. For each of such species, 3 trees of diameters 1- 9 cm (at 1.37 m. height) were felled. From the felled trees, separate biomass was calculated and recorded for wood, twigs and leaves in the prescribed format. Taking the dry biomass of wood/foliage as dependent variable and dbh as independent variable biomass equations were developed for each species. Using the plot level regeneration data from NFI i.e. recruits, un-established, established and all trees having dbh between 5 to 10 cm, biomass and carbon content at plot level is calculated.

[1] IPCC Guidelines for National Green House Inventories (2006), Intergovernmental Panel on Climate Change

9.3.3.3 Above Ground Biomass of shrubs, herbs, climbers, and biomass of dead organic matter (DOM: dead wood and litter)

For this purpose, the data of forest inventory conducted during 2002 - 2008 was analysed to ascertain the optimum number of plots required for each combination of forest type and forest density. It revealed that about 15 clusters of 2 sample plots for each combination, would suffice for estimating the biomass/carbon factors for these components if 15% permissible error is considered. This survey was conducted in the districts on randomly selected points which were already inventoried during 2002 - 2008 and for which forest type and density were known.

For the desired combinations of forest type and forest density, the exact geographical locations (latitude and longitude) of the optimum number of randomly selected sample plots were visited. Using this information, centre of sample point, three concentric plots of size 5m x 5m, 3m x 3m and 1m x 1m were laid out at a distance of 30 m away from the centre of sample point in North and South direction. In 5m x 5m plot, all dead wood above 5 cm diameter were collected, weighed and recorded. In 3m x 3m plot, all woody litter i.e. all branches below 5 cm diameter were collected, weighed and recorded. All shrubs & climbers in 3m x 3m plots were uprooted, weighed and recorded in the prescribed format. In 1m x 1m plot, all herbs were uprooted, weighed and recorded. Dry biomass was converted to carbon stock.

9.3.3.4 Above Ground Biomass of branches, foliage of trees having dbh ≥ 10 cm

This information was first derived by using biomass equations developed by FSI from a special study conducted during 2008 -10 for Second National Communication to UNFCCC. As described above, 20 important tree species in each physiographic zone were identified. For each such species other than palm like trees, in each of the diameter class, three normal trees were selected. Its diameter, height, crown length, crown width in two directions, blanks in canopy and shape of the crown were recorded.

For the purpose of biomass calculation, one normal tree of each diameter class of each species was selected. In the selected tree, partial destructive method was used to compute biomass of woody branches up to 5 cm dia, twigs and leaves. Biomass of all these parameters was separately recorded in the prescribed formats. Taking the dry biomass of small wood/foliage as dependent variable and dbh as independent variable biomass equations were developed for each species. Using the plot level data of NFI, species wise carbon content, the total biomass and carbon content at plot level was calculated.

9.3.3.5 Organic matter in soil and forest floor

While carrying out forest inventory, the data on forest floor (non-woody litter and humus) and soil carbon is also collected from each sample plot. For data collection on humus and soil carbon, two sub-plots of size 1m x 1m are laid out within the main plot. The forest floor from both the plots is first swept and material so collected is weighed and a portion of the same is kept for carbon analysis. Further, at the center of these two sub-plots, a pit of 30cm x 30cm x 30cm is dug and a composite sample of soil of 200gm is kept for organic carbon analysis. Samples of soil and humus are analysed from the standard soil labs and are used for the calculation.

Below ground biomass 9.3.3.6

This is the most difficult pool to measure and is generally not measured in forest inventory. It has been estimated using a relationship, root-to-shoot ratio which gives a relationship between above ground biomass (AGB) to the below ground biomass (BGB) which have been established by various researchers. GPG, 2003 also provides default values of root-to-shoot ratios for six major global forest types. FSI has selectively used these default values to arrive at the carbon estimates.

Synthesizing Data for National Carbon Estimation 9.3.4

The area under each strata has been determined using GIS. By aggregating biomass/carbon for each pool from each plot falling within a strata and dividing the same by area under that strata, 'carbon per ha' for each pool was determined for each strata. For each State/UT area under each strata was determined with the help of GIS. Multiplication of the strata area with the corresponding 'carbon per ha' value for each pool, the total carbon stock for each pool in the State has been calculated. Aggregation of the forest carbon stock of all the States/UTs has given the pool wise forest carbon stock and its total for the country.

Results 9.4

Forest Carbon Stock under different Carbon pools and change w.r.t previous assessment 9.4.1

The Forest Carbon Estimates at the national level under different carbon pools and change in respect to previous assessment has been given in table 9.1

(in million tonnes)

Component	Carbon Stock in forest in 2021	Carbon stock in forest in 2019	Net change in Carbon stock	Annual change in Carbon stock
Above Ground Biomass	2,319.9	2,256.5	63.4	31.7
Below Ground Biomass	718.9	700.8	18.1	9.1
Dead wood	47.7	35.8	11.9	6.0
Litter	107.3	127.9	-20.6	-10.3
Soil	4010.2	4,003.6	6.6	3.3
Total	**7,204.0**	**7,124.6**	**79.4**	**39.7**

Table 9.1 Forest Carbon Stock under different pools and changes wrt previous assessment

The carbon stock for 2021 has been estimated 7,204.0 million tonnes. There is an increase of 79.4 million tonnes of carbon stock as compared to the estimates of previous assessment. The annual increase of carbon stock is estimated 39.7 million tonnes which is 145.6 million tonnes of CO_2 equivalent. Soil organic carbon is the largest pool of forest carbon accounting for (55.67 %) followed by AGB (32.20 %), BGB (9.98 %), Litter (1.49 %) and dead wood (0.66%). On comparing the changes between present and previous assessment, maximum changes have been observed in AGB and dead wood.

Figure 9.3 Forest Carbon Stock in different pools (in million tonnes)

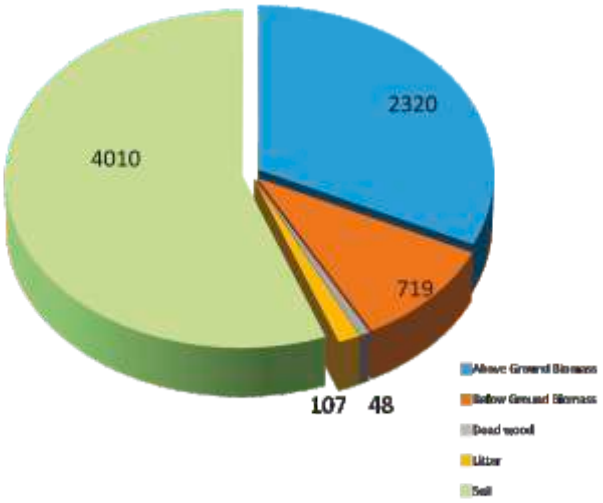
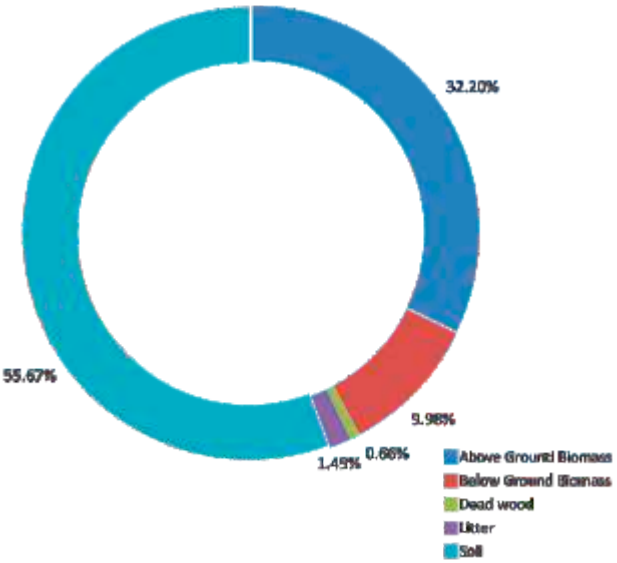


Figure 9.4 Forest Carbon Stock in different pools (%)



9.4.2 Forest Carbon Stock of State & UTs

Forest carbon stock in different carbon pools in States and UT's under different carbon pools are presented in table 9.2. The per hectare for each State/UT's under each pool has been given in parentheses.

(in '000 tonnes)

Table 9.2 Forest Carbon Stock in States & UTs in different carbon pools with stock in tonnes per ha given in parentheses

S. No.	State/ UT	Area sq km	AGB	BGB	Dead Wood	Litter	SOC	Total
1.	Andhra Pradesh	29,784	63,951 (21.47)	25,064 (8.42)	979 (0.33)	3,171 (1.06)	1,37,057 (46.02)	2,30,222 (77.30)
2.	Arunachal Pradesh	66,431	3,40,351 (51.23)	1,02,229 (15.39)	9,163 (1.38)	11,802 (1.78)	5,60,298 (84.34)	10,23,843 (154.12)
3.	Assam	28,312	87,070 (30.75)	21,495 (7.59)	1,875 (0.66)	4,890 (1.73)	1,56,042 (55.12)	2,71,372 (95.85)
4.	Bihar	7,381	14,743 (19.97)	5,249 (7.11)	231 (0.31)	785 (1.06)	35,873 (48.60)	56,881 (77.05)

(in '000 tonnes)

S. No	State/ UT	Area sq km	AGB	BGB	Dead Wood	Litter	SOC	Total
5.	Chhattisgarh	55,717	1,52,714 (27.41)	48,947 (8.78)	2,520 (0.45)	8,487 (1.52)	2,83,769 (50.93)	4,96,437 (89.09)
6.	Delhi	195	263 (13.49)	78 (3.99)	5 (0.24)	17 (0.87)	839 (43.03)	1,202 (61.62)
7.	Goa	2,244	8,863 (39.49)	2,606 (11.61)	232 (1.03)	448 (2.00)	13,095 (58.35)	25,244 (112.48)
8.	Gujarat	14,926	28,602 (19.16)	9,814 (6.58)	502 (0.34)	1,634 (1.09)	67,214 (45.03)	1,07,766 (72.20)
9.	Haryana	1,603	2,326 (14.50)	836 (5.22)	41 (0.26)	139 (0.87)	6,890 (42.97)	10,232 (63.82)
10.	Himachal Pradesh	15,443	1,14,269 (73.99)	31,880 (20.64)	2,657 (1.72)	3,328 (2.15)	1,05,937 (68.60)	2,58,071 (167.10)
11.	Jharkhand	23,721	51,017 (21.51)	20,819 (8.78)	774 (0.33)	2,536 (1.07)	1,09,665 (46.23)	1,84,811 (77.92)
12.	Karnataka	38,730	1,22,741 (31.69)	36,716 (9.48)	2,890 (0.75)	6,380 (1.65)	2,07,668 (53.62)	3,76,395 (97.19)
13.	Kerala	21,253	61,802 (29.08)	17,440 (8.21)	1,534 (0.72)	3,198 (1.50)	1,21,549 (57.19)	2,05,523 (96.70)
14.	Madhya Pradesh	77,493	1,71,587 (22.14)	67,160 (8.67)	2,676 (0.35)	8,653 (1.12)	3,59,174 (46.35)	6,09,250 (78.63)
15.	Maharashtra	50,798	1,37,831 (27.13)	42,353 (8.34)	2,316 (0.46)	7,928 (1.56)	2,61,178 (51.42)	4,51,606 (88.91)
16.	Manipur	16,598	47,590 (28.67)	14,101 (8.50)	880 (0.53)	2,652 (1.60)	1,11,708 (67.30)	1,76,931 (106.60)
17.	Meghalaya	17,046	55,241 (32.41)	15,820 (9.28)	1,238 (0.73)	3,075 (1.80)	1,08,014 (63.37)	1,83,388 (107.59)
18.	Mizoram	17,820	48,157 (27.02)	10,622 (5.96)	758 (0.43)	3,140 (1.76)	95,961 (53.85)	1,58,638 (89.02)
19.	Nagaland	12,251	39,339 (32.11)	10,618 (8.67)	854 (0.70)	2,006 (1.64)	82,115 (67.03)	1,34,932 (110.15)
20.	Odisha	52,156	1,31,015 (25.12)	40,441 (7.75)	2,252 (0.43)	7,671 (1.47)	2,63,451 (50.51)	4,44,830 (85.28)
21.	Punjab	1,847	3,420 (18.52)	1,284 (6.95)	56 (0.31)	175 (0.95)	8,623 (46.70)	13,558 (73.43)
22.	Rajasthan	16,655	26,714 (16.04)	10,803 (6.49)	462 (0.28)	1,476 (0.89)	71,319 (42.82)	1,10,774 (66.52)
23.	Sikkim	3,341	18,024 (53.95)	5,466 (16.36)	498 (1.49)	607 (1.82)	30,944 (92.62)	55,539 (166.24)
24.	Tamilnadu	26,419	60,459 (22.88)	20,671 (7.82)	1,198 (0.45)	3,102 (1.17)	1,29,183 (48.90)	2,14,613 (81.22)
25.	Telangana	21,214	44,413 (20.94)	18,415 (8.68)	675 (0.32)	2,169 (1.02)	96,314 (45.40)	1,61,986 (76.36)
26.	Tripura	7,722	24,349 (31.53)	5,358 (6.94)	477 (0.62)	1,486 (1.92)	43,304 (56.08)	74,974 (97.09)
27.	Uttar Pradesh	14,818	32,543 (21.96)	10,234 (6.91)	534 (0.36)	1,825 (1.23)	72,105 (48.66)	1,17,241 (79.12)
28.	Uttarakhand	24,305	1,59,674 (65.70)	42,893 (17.65)	3,561 (1.46)	5,184 (2.13)	1,66,847 (68.65)	3,78,159 (155.59)
29.	West Bengal	16,832	45,365 (26.95)	14,119 (8.39)	726 (0.43)	2,162 (1.28)	92,889 (55.19)	1,55,261 (92.24)

(in '000 tonnes)

S. No.	State/ UT	Area sq km	AGB	BGB	Dead Wood	Litter	SOC	Total
30.	Andaman Nicobar Islands	6,744	47,560 (70.52)	15,450 (22.91)	1,432 (2.12)	1,808 (2.68)	43,586 (64.63)	1,09,836 (162.86)
31.	Chandigarh	23	47 (20.49)	15 (6.62)	1 (0.30)	3 (1.17)	117 (51.27)	183 (79.85)
32.	Dadra and Nagar Haveli and Daman and Diu	228	558 (24.49)	129 (5.68)	11 (0.48)	38 (1.68)	1,244 (54.60)	1,980 (86.93)
33.	Jammu & Kashmir	21,387	1,63,897 (76.63)	45,864 (21.45)	3,386 (1.58)	4,951 (2.32)	1,52,772 (71.43)	3,70,870 (173.41)
34.	Ladakh	2,272	13,293 (58.50)	3,836 (16.88)	269 (1.18)	317 (1.39)	12,987 (57.16)	30,702 (135.11)
35.	Lakshadweep	27	46 (17.12)	10 (3.77)	1 (0.25)	3 (1.15)	150 (55.34)	210 (77.63)
36.	Puducherry	53	76 (14.25)	17 (3.25)	1 (0.24)	5 (0.96)	287 (53.76)	386 (72.46)
	Total	**7,13,789**	**23,19,910 (32.50)**	**7,18,852 (10.07)**	**47,665 (0.67)**	**1,07,251 (1.50)**	**40,10,168 (56.18)**	**72,03,846 (100.92)**

The above table shows that Arunachal Pradesh has maximum carbon stock of 1,023.84 million tonnes followed by Madhya Pradesh (609.25 million tonnes), Chhattisgarh (496.44 million tonnes) and Maharashtra (451.61 million tonnes). The per hectare carbon stock among different States/UTs indicates that Jammu & Kashmir is contributing maximum per hectare carbon stock of 173.41 tonnes/ha, followed by Himachal Pradesh (167.10 tonnes/ha), Sikkim (166.24 tonnes/ha) and Andaman & Nicobar Islands (162.86 tonnes/ha). At national level 32% of carbon stock is in AGB whereas about 56% in SOC.

9.4.3 Carbon Stock in different carbon pools under different forest types and density

Carbon stock in different carbon pools under different forest types and density is given in Table 9.3. The per hectare for each forest type and pool has been given in parentheses.

Table 9.3 Forest Type and Density wise Carbon Stock in different carbon pools with per ha stock in tonnes in parentheses

(in '000 tonnes)

Forest Type Stratum	Density	Area in sq km	AGB	BGB	Dead Wood	Litter	SOC	Total
Tropical Wet Evergreen Forests	VDF	9,147	81,708 (89.33)	30,230 (33.05)	2,753 (3.01)	3,211 (3.51)	66,524 (72.73)	1,84,426 (201.63)
	MDF	7,863	54,720 (69.59)	20,248 (25.75)	1,801 (2.29)	1,989 (2.53)	51,676 (65.72)	1,30,434 (165.88)
	OF	2,562	10,250 (40.01)	3,792 (14.80)	305 (1.19)	151 (0.59)	16,256 (63.45)	30,754 (120.04)
Tropical Semi-Evergreen Forests	VDF	8,520	50,693 (59.50)	11,152 (13.09)	1,772 (2.08)	1,534 (1.80)	48,051 (56.40)	1,13,202 (132.87)
	MDF	29,997	1,28,717 (42.91)	28,317 (9.44)	2,760 (0.92)	7,079 (2.36)	1,65,103 (55.04)	3,31,976 (110.67)
	OF	30,679	62,860 (20.49)	13,836 (4.51)	460 (0.15)	4,479 (1.46)	1,59,191 (51.89)	2,40,826 (78.50)
Tropical Moist Deciduous Forests	VDF	24,796	1,13,291 (45.69)	24,920 (10.05)	1,760 (0.71)	6,372 (2.57)	1,45,624 (58.73)	2,91,967 (117.75)
	MDF	65,377	2,17,248 (33.23)	47,791 (7.31)	4,446 (0.68)	15,298 (2.34)	3,79,384 (58.03)	6,64,167 (101.59)
	OF	41,632	92,298 (22.17)	20,316 (4.88)	1,749 (0.42)	6,370 (1.53)	2,25,812 (54.24)	3,46,545 (83.24)

(in '000' tonnes)

Forest Type Stratum	Density	Area in sq km	AGB	BGB	Dead Wood	Litter	SOC	Total
Littoral and Swamp Forests	VDF	1,558	13,644 (87.55)	5,048 (32.39)	92 (0.59)	466 (2.99)	9,764 (62.65)	29,014 (186.17)
	MDF	1,653	9,567 (57.88)	3,541 (21.42)	93 (0.56)	264 (1.60)	10,296 (62.29)	23,761 (143.75)
	OF	2,267	4,835 (21.33)	1,789 (7.89)	88 (0.39)	197 (0.87)	12,940 (57.08)	19,849 (87.56)
Tropical Dry Deciduous Forests	VDF	23,634	83,522 (35.34)	35,073 (14.84)	1,158 (0.49)	4,750 (2.01)	1,22,659 (51.90)	2,47,162 (104.58)
	MDF	1,25,840	3,56,504 (28.33)	1,49,749 (11.90)	4,279 (0.34)	12,836 (1.02)	6,11,455 (48.59)	11,34,823 (90.18)
	OF	1,31,074	1,67,119 (12.75)	70,124 (5.35)	3,670 (0.28)	11,534 (0.88)	5,42,383 (41.38)	7,94,830 (60.64)
Tropical Thorn Forests	VDF	165	412 (25.03)	172 (10.48)	30 (1.82)	18 (1.09)	750 (45.58)	1,382 (84.00)
	MDF	3,587	3,852 (10.74)	1,618 (4.51)	129 (0.36)	344 (0.96)	13,464 (37.54)	19,407 (54.11)
	OF	9,508	6,950 (7.31)	2,919 (3.07)	124 (0.13)	542 (0.57)	18,302 (19.25)	28,837 (30.33)
Tropical Dry Evergreen Forests	VDF	133	644 (48.57)	270 (20.38)	17 (1.28)	18 (1.35)	1,181 (89.02)	2,130 (160.60)
	MDF	420	1,644 (39.12)	691 (16.43)	21 (0.50)	46 (1.10)	1,524 (36.26)	3,926 (93.41)
	OF	282	475 (16.84)	200 (7.09)	2 (0.07)	25 (0.89)	991 (35.14)	1,693 (60.03)
Subtropical Broadleaved Hill Forests	VDF	7,288	49,406 (67.79)	20,749 (28.47)	794 (1.09)	1,348 (1.85)	71,089 (97.54)	1,43,386 (196.74)
	MDF	13,859	44,211 (31.90)	18,571 (13.40)	1,233 (0.89)	2,772 (2.00)	1,23,832 (89.35)	1,90,619 (137.54)
	OF	9,868	18,236 (18.48)	7,657 (7.76)	30 (0.03)	750 (0.76)	71,897 (72.86)	98,570 (99.89)
Subtropical Pine Forests	VDF	1,787	16,436 (91.98)	4,437 (24.83)	284 (1.59)	307 (1.72)	13,407 (75.03)	34,871 (195.15)
	MDF	9,077	48,516 (53.45)	13,098 (14.43)	1,253 (1.38)	1,489 (1.64)	62,848 (69.24)	1,27,204 (140.14)
	OF	6,937	22,892 (33.00)	6,181 (8.91)	333 (0.48)	992 (1.43)	46,886 (67.59)	77,284 (111.41)
Subtropical Dry Evergreen Forest	VDF	8	90 (106.25)	38 (45.00)	1 (1.25)	1 (1.25)	95 (112.50)	225 (266.25)
	MDF	60	532 (89.33)	223 (37.50)	2 (0.33)	4 (0.67)	397 (66.67)	1,158 (194.50)
	OF	105	515 (49.14)	217 (20.67)	2 (0.19)	3 (0.29)	578 (55.14)	1,315 (125.43)
Montane Wet Temperate Forests	VDF	8,599	50,614 (58.86)	13,664 (15.89)	1,789 (2.08)	1,703 (1.98)	1,11,358 (129.50)	1,79,128 (208.31)
	MDF	9,423	29,042 (30.82)	7,840 (8.32)	1,555 (1.65)	433 (0.46)	1,08,951 (115.62)	1,47,821 (156.87)
	OF	2,163	4,815 (22.26)	1,300 (6.01)	43 (0.20)	91 (0.42)	9,275 (42.88)	15,524 (71.77)
Himalayan Moist Temperate Forests	VDF	8,687	1,37,280 (158.03)	37,067 (42.67)	4,170 (4.80)	3,953 (4.55)	72,858 (83.87)	2,55,328 (293.92)
	MDF	13,534	1,37,248 (101.41)	37,056 (27.38)	2,815 (2.08)	3,262 (2.41)	1,08,637 (80.27)	2,89,018 (213.55)
	OF	6,506	43,508 (66.87)	11,744 (18.05)	768 (1.18)	1,217 (1.87)	45,135 (69.37)	1,02,372 (157.34)
Himalayan Dry Temperate Forests	VDF	1,227	20,409 (166.28)	5,919 (48.22)	242 (1.97)	1,105 (9.00)	12,968 (105.65)	40,643 (331.12)
	MDF	1,681	21,875 (130.17)	6,344 (37.75)	235 (1.40)	437 (2.60)	12,476 (74.24)	41,367 (246.16)
	OF	1,347	9,643 (71.59)	2,796 (20.76)	106 (0.79)	189 (1.40)	9,158 (67.99)	21,892 (162.53)

(in '000' tonnes)

Forest Type Stratum	Density	Area in sq km	AGB	BGB	Dead Wood	Litter	SOC	Total
Sub-Alpine Forests	VDF	2,785	32,208 (115.64)	9,339 (33.53)	443 (1.59)	735 (2.64)	32,322 (116.05)	75,047 (269.45)
	MDF	5,662	36,627 (64.69)	10,622 (18.76)	1,523 (2.69)	1,263 (2.23)	47,662 (84.18)	97,697 (172.55)
	OF	4,225	20,274 (47.99)	5,876 (13.91)	511 (1.21)	545 (1.29)	32,491 (76.91)	59,697 (141.31)
Moist Alpine Scrub	VDF	76	393 (51.45)	114 (14.87)	9 (1.18)	15 (1.97)	507 (66.32)	1,038 (135.79)
	MDF	279	781 (28.03)	227 (8.14)	10 (0.36)	23 (0.82)	1,582 (56.77)	2,623 (94.12)
	OF	297	271 (9.12)	79 (2.66)	6 (0.20)	19 (0.64)	1,598 (53.77)	1,973 (66.39)
Dry Alpine Scrub	VDF	194	1,908 (98.45)	553 (28.56)	23 (1.19)	46 (2.37)	1,171 (60.46)	3,701 (191.03)
	MDF	583	3,551 (60.87)	1,030 (17.65)	45 (0.77)	110 (1.89)	3,345 (57.34)	8,081 (138.52)
	OF	1,619	8,397 (51.88)	2,436 (15.05)	159 (0.98)	159 (0.98)	4,524 (27.95)	15,675 (96.84)
Plantation/TOF	VDF	1,174	4,749 (40.44)	1,045 (8.90)	129 (1.10)	93 (0.79)	7,278 (61.98)	13,294 (113.21)
	MDF	17,996	39,878 (22.16)	8,782 (4.88)	522 (0.29)	2,573 (1.43)	1,04,465 (58.05)	1,56,220 (86.81)
	OF	56,051	54,650 (9.75)	12,051 (2.15)	1,121 (0.20)	4,092 (0.73)	2,88,047 (51.39)	3,59,961 (64.22)
Total	**7,13,789**		**23,19,909 (32.50)**	**7,18,850 (10.07)**	**47,663 (0.67)**	**1,07,252 (1.50)**	**40,10,169 (56.18)**	**72,03,843 (100.92)**

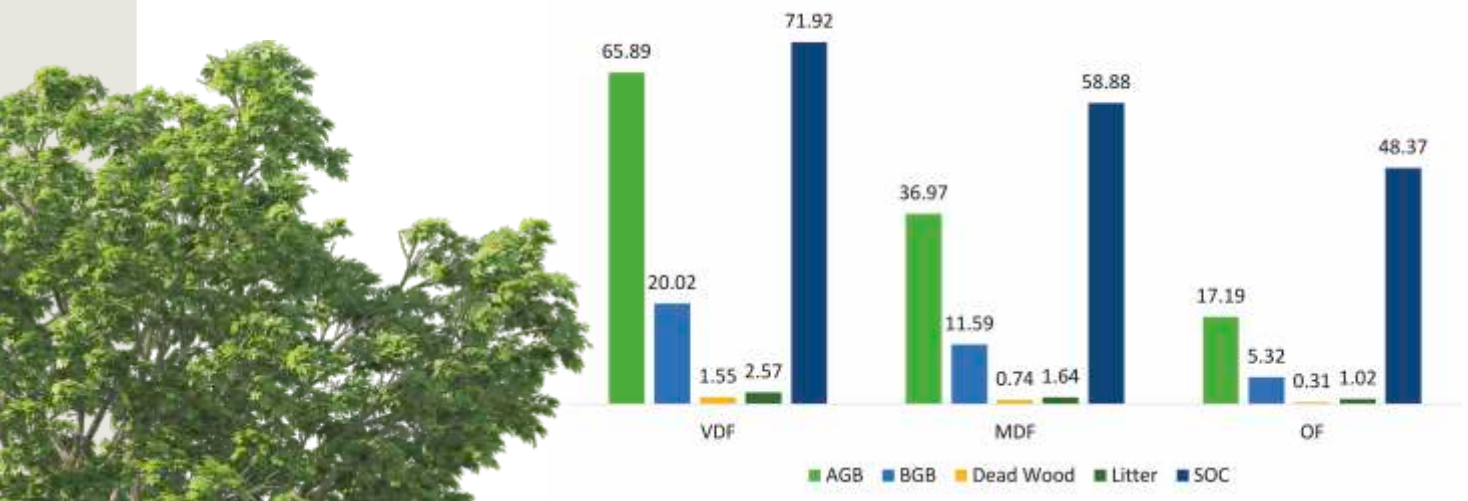


Figure 9.5
Density wise carbon stock per ha in tonnes in different pools

Carbon stock in different forest types under different pools 9.4.4

Carbon stock in different forest types under different pools is given in Table 9.4. The per hectare for each forest type and pool has been given in parentheses.

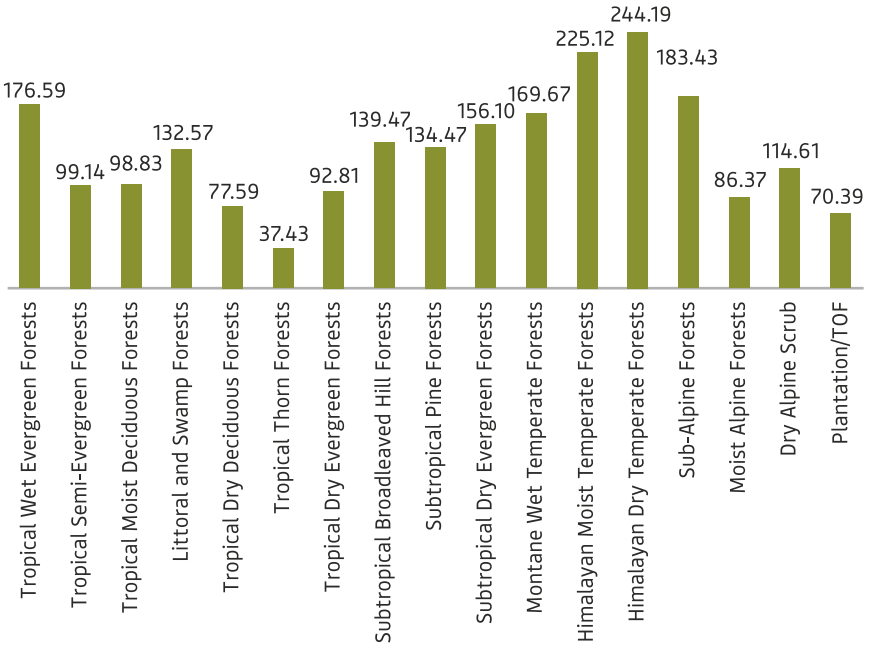
(in '000 tonnes)

Forest Type Stratum	Area in sq km	AGB	BGB	Dead Wood	Litter	SOC	Total
Tropical Wet Evergreen Forests	19,572	1,46,678 (74.94)	54,269 (27.73)	4,859 (2.48)	5,351 (2.73)	1,34,456 (68.70)	3,45,613 (176.58)
Tropical Semi-Evergreen Forests	69,195	2,42,270 (35.01)	53,306 (7.70)	4,992 (0.72)	13,092 (1.89)	3,72,346 (53.81)	6,86,006 (99.13)
Tropical Moist Deciduous Forests	1,31,805	4,22,838 (32.08)	93,027 (7.06)	7,955 (0.60)	28,040 (2.13)	7,50,821 (56.96)	13,02,681 (98.83)
Littoral and Swamp Forests	5,478	28,046 (51.20)	10,377 (18.94)	273 (0.50)	928 (1.69)	32,999 (60.24)	72,623 (132.57)
Tropical Dry Deciduous Forests	2,80,547	6,07,145 (21.64)	2,54,946 (9.09)	9,107 (0.32)	29,121 (1.04)	12,76,497 (45.50)	21,76,816 (77.59)
Tropical Thorn Forests	13,259	11,214 (8.46)	4,709 (3.55)	283 (0.21)	904 (0.68)	32,516 (24.52)	49,626 (37.42)
Tropical Dry Evergreen Forests	835	2,763 (33.09)	1,161 (13.90)	40 (0.48)	89 (1.07)	3,696 (44.26)	7,749 (92.80)
Subtropical Broadleaved Hill Forests	31,015	1,11,853 (36.06)	46,978 (15.15)	2,057 (0.66)	4,870 (1.57)	2,66,818 (86.03)	4,32,576 (139.47)
Subtropical Pine Forests	17,801	87,843 (49.35)	23,715 (13.32)	1,870 (1.05)	2,788 (1.57)	1,23,141 (69.18)	2,39,357 (134.47)
Subtropical Dry Evergreen Forest	173	1,137 (65.77)	478 (27.66)	5 (0.29)	8 (0.47)	1,070 (61.91)	2,698 (156.10)
Montane Wet Temperate Forests	20,185	84,471 (41.85)	22,804 (11.30)	3,387 (1.68)	2,227 (1.10)	2,29,584 (113.74)	3,42,473 (169.67)
Himalayan Moist Temperate Forests	28,727	3,18,037 (110.71)	85,867 (29.89)	7,753 (2.70)	8,431 (2.93)	2,26,630 (78.89)	6,46,718 (225.12)
Himalayan Dry Temperate Forests	4,255	51,927 (122.04)	15,059 (35.39)	583 (1.37)	1,730 (4.07)	34,601 (81.32)	1,03,900 (244.19)
Sub-Alpine Forests	12,672	89,109 (70.32)	25,837 (20.39)	2,477 (1.95)	2,543 (2.01)	1,12,476 (88.76)	2,32,442 (183.43)
Moist Alpine Scrub	652	1,445 (22.16)	420 (6.43)	25 (0.38)	57 (0.87)	3,687 (56.52)	5,634 (86.36)
Dry Alpine Scrub	2,396	13,856 (57.84)	4,019 (16.78)	227 (0.95)	315 (1.31)	9,041 (37.74)	27,458 (114.62)
Plantation/TOF	75,221	99,277 (13.20)	21,878 (2.91)	1,772 (0.24)	6,758 (0.90)	3,99,790 (53.15)	5,29,475 (70.40)
Total	**7,13,789**	**23,19,909 (32.50)**	**7,18,850 (10.07)**	**47,665 (0.67)**	**1,07,252 (1.50)**	**40,10,169 (56.18)**	**72,03,845 (100.92)**

Table 9.4 Forest Type wise Carbon Stock at the National level in different carbon pools with per ha stock given in tonnes in parenthesis

The Table 9.4 shows that the maximum carbon stock has been stored in Tropical Dry Deciduous Forest (2,177 million tonnes) followed by Tropical Moist Deciduous Forest (1,303 million tonnes) and Tropical Semi Evergreen Forest (686 million tonnes).

Figure 9.6
Forest Type wise carbon stock per ha in tonnes



9.5 Conclusion

Over the last 5 biennial assessments, the carbon stock of the country's forests has shown an increasing trend. The carbon stock has risen from 6,663 million tonnes in the 2011 assessment to 7,204.0 million tonnes in the present assessment showing an increase of 541 million tonnes between the period 2011 to 2021.