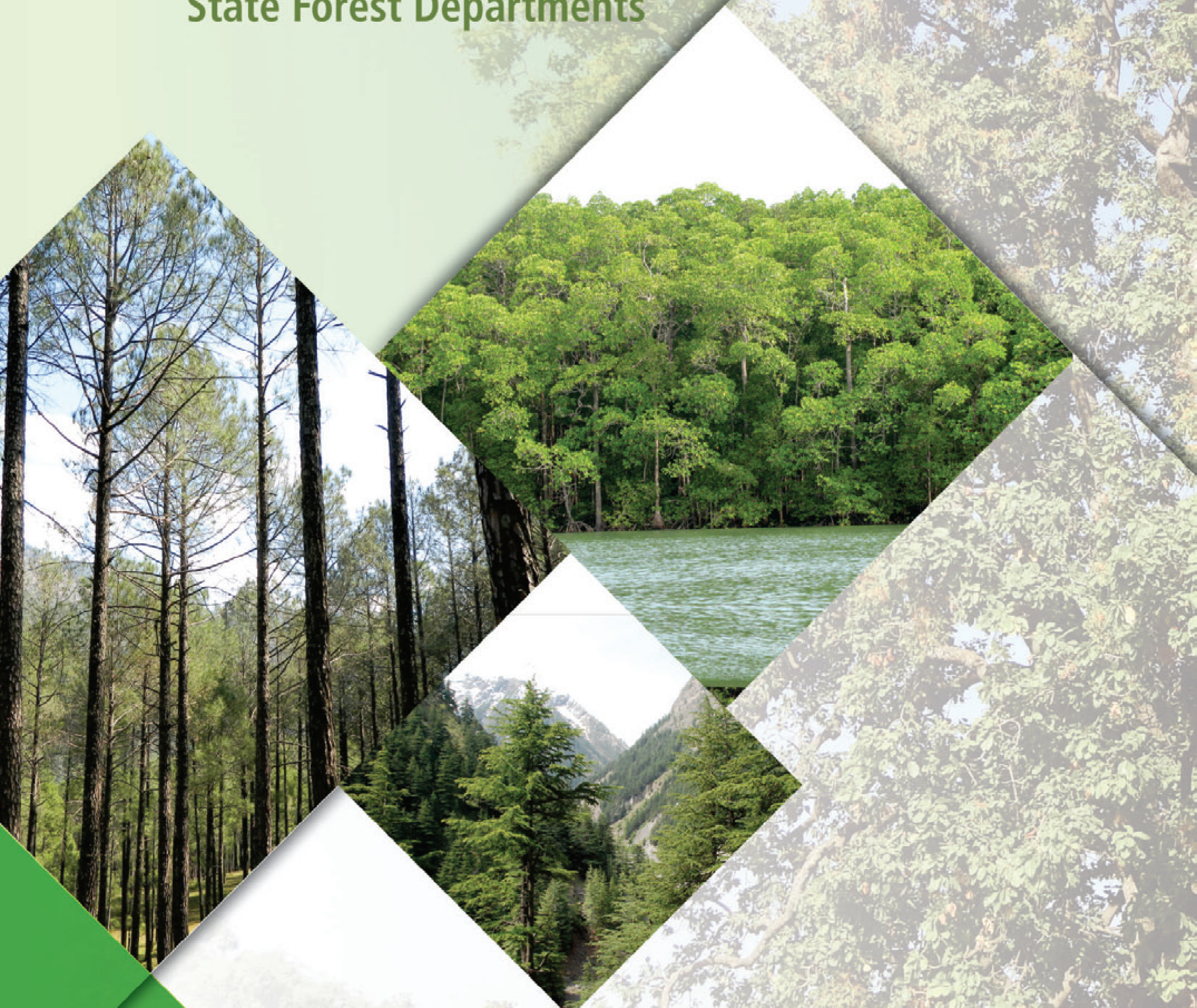
Resource Manual

Measurement of Forest Carbon Stocks for Capacity Building of State Forest Departments



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Resource Manual

Measurement of Forest Carbon Stocks for Capacity Building of State Forest Departments

2020

Indian Council of Forestry Research and Education

(An Autonomous Body of Ministry of Environment, Forest and Climate Change, Government of India)
P. O. New Forest, Dehradun - 248006 (INDIA)

The Resource Manual on **"Measurement of Forest Carbon Stocks"** is prepared under the World Bank funded Ecosystem Services Improvement Project being implemented by the Indian Council of Forestry Research and Education, Dehradun in the states of Chhattisgarh and Madhya Pradesh as a reference manual for Capacity Building of the State Forest Departments.

Published by
Biodiversity and Climate Change Division,
Indian Council of Forestry Research and
Education P.O. New Forest,
Dehradun - 248 006 (INDIA)

ISBN : 978-81-936157-8-2

Manual Preparation Team

Direction and Guidance
Sh. Anurag Bhardwaj
Director (International Cooperation) and Project Director, ESIP, ICFRE

Edited and Finalized by
Dr. R.S. Rawat
Scientist In-charge, BCC Division and Project Manager, ESIP, ICFRE
Dr. Sanjay Singh
Scientist 'D'& Technical Manager, ESIP, ICFRE
Dr. Shilpa Gautam
Scientist 'D' & Project Coordinator, ESIP, ICFRE

Prepared by
Dr. Md. Shahid
Carbon Sequestration Consultant, ESIP
Sh. V.R.S. Rawat
Policy-cum-Knowledge Management Consultant, ESIP

Page Layout & Type Setting
Sh. Umang Thapa
Establishment-cum-Secretarial Expert, ESIP

Citation
ICFRE (2020). Resource Manual: Measurement of Forest Carbon Stocks for Capacity Building of State Forest Departments. Indian Council of Forestry Research and Education, Dehradun (INDIA).

अरुण सिंह रावत, भा.व.से.
Arun Singh Rawat, IFS

महानिदेशक
भारतीय वानिकी अनुसंधान एवं शिक्षा परिषद्
डाकघर न्यूफॉरेस्ट, देहरादून–248006
(आई.एस.ओ. 9001:2008 प्रमाणित संस्था)
Director General
Indian Council of Forestry Research and Education
P.O. New Forest, Dehradun – 248006
(An ISO 9001:2008 Certified Organisation)

FOREWORD

Globally, burning of fossil fuel and deforestation emerged as principal anthropogenic sources of rising concentration of atmospheric carbon dioxide (CO_2). There are compelling scientific evidences that humans are altering the climate in ways that threaten our societies and the ecosystems. Forests are both source and sink of CO_2 due to which forests are an integral part of international agreements dealing with climate change. Forests are considered to provide a large mitigation opportunity at relatively low costs along with other significant ecosystem goods and services benefits. India is one of the few countries where forest and tree cover are increasing, and transforming forests into a net sink of CO_2. India has submitted its Nationally Determined Contribution (NDC) to United Nations Framework Convention on Climate Change (UNFCCC) under Paris Agreement and forestry target of NDC is to capture an additional 2.5 to 3 billion tonnes of CO_2 eq through additional forest and tree cover by 2030.

ICFRE is proactive in the field of forests and climate change and contributing significantly in climate change issues relevant in the forestry sector at national and international level. ICFRE has contributed to UN Climate Change negotiations for simplifying modalities for CDM A/R and policy approaches for REDD+. ICFRE has prepared National REDD+ Strategy on behalf of Ministry of Environment, Forest and Climate Change, Government of India. ICFRE also contributed to India's Initial and Second National Communications, BUR I, BUR II and BUR III to UNFCCC. ICFRE has also been actively engaged in capacity building programmes on forests and climate related issues for forest officers, scientists and technologists at national level.

The World Bank funded Ecosystem Services Improvement project (ESIP) supports the goals of the Green India Mission by demonstrating models for adaptation-based mitigation through sustainable land and ecosystem management and livelihood benefits. ESIP attempts to introduce new tool and technologies for better management of natural resources, including biodiversity and carbon stocks. As a Project Implementing Agency for ESIP, ICFRE is building the capacity of State Forest Departments and Joint Forest Management Committees of Chhattisgarh and Madhya Pradesh on forest carbon measurement and monitoring. I hope this resource manual on Measurement of Forest Carbon Stocks will be a guiding field manual for the foresters, scientists, researchers, trainees and students for measurement of forest carbon stocks. I congratulate the Project Director, Project Manager and entire team of ESIP for putting in their best efforts for conceptualizing and preparing this resource manual.

Date: 02/06/2020

(Arun Singh Rawat)

पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय, भारत सरकार की एक स्वायत परिषद्
An Autonomous Body of Ministry of Environment, Forest & Climate Change, Government of India

दूरभाष/Phone : 0135-2759382 (O)
EPABX : 0135-2224855, 2224333 (O)
ई–मेल/E-mail : dg@icfre.org
फैक्स/Fax : 0091-135-2755353

अनुराग भारद्वाज, भा.व.से.
Anurag Bhardwaj, IFS

निदेशक (अंतर्राष्ट्रीय सहयोग)
भारतीय वानिकी अनुसंधान एवं शिक्षा परिषद्
डाकघर न्यूफॉरेस्ट, देहरादून–248006
(आई.एस.ओ. 9001:2008 प्रमाणित संस्था)
Director (International Cooperation)
Indian Council of Forestry Research and Education
P.O. New Forest, Dehradun – 248006
(An ISO 9001:2008 Certified Organisation)

PREFACE

In the recent years, climate change is one of the global issues that have received tremendous attention of common man, scientists and policy planners. Global climate change is a threat having perceptible and tangible impacts upon human kind and nature. Scientists have documented climate induced changes in a number of physical and biological processes. The adverse effects are evident that world is experiencing more intense rainfall, floods and storms are more severe, heat waves are becoming more extreme, trees flower earlier in spring, glaciers are melting and the global mean sea level is rising.

The world governments are looking towards effective mitigation of climate change. Under the Paris Agreement, world governments have agreed to limit rise in global temperature by 1.5°C by the end of this century. A report of IPCC concludes that meeting a 1.5°C target is possible but would require "deep emissions reductions" and "rapid, far-reaching and unprecedented changes in all aspects of society." Forests are now an integral part of international protocols dealing with climate change mitigation. Achieving forestry target of capturing an additional 2.5 to 3 billion tonnes of additional CO_2 equivalent through additional forest and tree cover is a challenging task for India under its Nationally Determined Contributions commitment.

India is one of the fastest growing economies of the world. Its large and fast growing population requires forests for the valuable ecosystem goods and services they provide. ICFRE as an implementing agency of Ecosystem Services Improvement Project (ESIP) shall be attempting to upscale various Sustainable Land and Ecosystem Management best practices in the selected forest landscapes of Chhattisgarh and Madhya Pradesh and also building the capacities of State Forest Departments of Chhattisgarh and Madhya Pradesh on measurement and monitoring of forest carbon stocks.

Field foresters have limited exposure to the new tools and techniques for measurement of forest carbon stocks. The resource manual on 'Measurement of Forest Carbon Stocks' has been developed in such a manner that a field forester can easily make an assessment of forest carbon stored in forests. The manual covers all aspects of carbon assessment right from determining the sample size, laying out sample plots, measuring various variables and finally analysis of different carbon pools in a forest ecosystem. I am sure this manual will be useful for field foresters for measurement of forest carbon stocks. I congratulate the Project Manager, ESIP and all the team members of ESIP for developing this resource manual.

(Anurag Bhardwaj)
Project Director, ESIP

Date: 02/06/2020

C O N T E N T S

Acknowledgement

- Indian Council of Forestry Research and Education, Dehradun
- Ministry of Environment, Forest and Climate Change, Government of India
- The World Bank
- Forest Survey of India, Dehradun
- Sh. Arun Singh Rawat, Director General, ICFRE
- Dr. Suresh Gairola, Former Director General, ICFRE
- Sh. S.D. Sharma, Dy. Director General (Research) and Former Project Director, ESIP, ICFRE
- Mr. Andrew M Mitchell, Team Task Leader, Ecosystem Services Improvement Project, the World Bank
- Dr. Anupam Joshi, Co-Team Task Leader, Ecosystem Services Improvement Project, the World Bank
- All the consultants of ESIP-PIU, Indian Council of Forestry Research and Education
- All the researchers and staff of Biodiversity and Climate Change Division, Indian Council of Forestry Research and Education, Dehradun

1 FORESTS AND CLIMATE CHANGE

Climate Change

Intergovernmental Panel on Climate Change stated that "Human influence on the climate system is clear and recent anthropogenic emissions of greenhouse gases are the highest in history. Recent climate changes have had widespread impacts on human and natural systems" (IPCC, 2014). Earth's atmosphere is made up of various gases released by the natural processes and anthropogenic activities. The earth's atmosphere acts like a blanket of greenhouse gases viz. carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs) and sulfur hexafluoride, which traps the long wave terrestrial radiations released by the planet earth. This is a natural phenomenon and known as greenhouse effect. However, human activities have increased the concentration of greenhouse gases into the atmosphere which are responsible for the trapping of the outgoing long wave terrestrial radiations into the earth's atmosphere resulting, an increase in atmospheric temperature.

According to IPCC (2014), globally CO_2 emissions from fossil fuel combustion and industrial processes contributed about 78% of the total greenhouse gas (GHG) emission increase from 1970 to 2010, with a similar percentage contribution for the period 2000–2010. An estimated 23% of total anthropogenic greenhouse gas emissions (2007-2016) were derived from Agriculture, Forestry and Other Land Use (IPCC,2019). The IPCC report on the impacts of global warming of 1.5°C above pre-industrial levels (IPCC, 2018) has highlighted that average global earth's temperature has increased by about 1°C as compared to pre-industrial level due to anthropogenic activities. In line with increasing trends witnessed in global surface temperature, the average yearly temperature over India for the period 1901 to 2017 has shown significant rising trend of 0.66°C over 100 years. Extreme events like heat waves have risen in past 30 years (MoEF&CC, 2017).

Forests and Climate Change

The impact of climate change has alarmed the global communities and attracted the interest of scientific communities towards various mitigation and adaptation measures. Forest ecosystem plays a significant role in reducing the impact of climate change. Intrinsically forests and climate change are directly linked to each other. Forests are known as the sink as well as the source of carbon dioxide. Forest ecosystem during the process of photosynthesis, absorbs the carbon dioxide from the atmosphere and releases oxygen into the atmosphere. Role of forests has been increasingly recognized as most cost-effective option for climate change mitigation through carbon

captured in biomass and soils. Forests are considered to provide a large climate change mitigation opportunity at relatively lower costs along with other significant co-benefits. Global forests cover around 30% of earth's surface, spread over about 4 billion hectares of land mass. Forestry mitigation options including reduced deforestation, forest management, afforestation, and agro-forestry are estimated to contribute 0.2-13.8 $GtCO_2$ per year of economically viable abatement in 2030 (IPCC, 2014).

The overall contribution from agriculture, forestry and other land use (AFOLU) sector is around 23% of total anthropogenic greenhouse gas emissions for the period from 2007 to 2016 (IPCC, 2019). In forest ecosystem the carbon is stored in the growing stock (standing trees, herbs, shrubs etc.) and in the soil. The cutting down of trees and removal of vegetation from the forest ecosystem for fuel wood, timber, fodder etc. releases the stored carbon in the form of CO_2. Various anthropogenic activities like burning of fossil fuels, industrial as well as urban growth, deforestation and forest degradation are mainly responsible for increasing the concentration of CO_2 and other greenhouse gases into the atmosphere.

Carbon Services of India's Forests

India is a vast country with a rich biological diversity. Forest is the second-largest land use in India after agriculture. Roughly, 275 million rural people in India depend on forests for at least part of their subsistence and livelihood (World Bank, 2006). As per the India State of Forest Report 2019 (FSI, 2019), the forest cover of the country stood at 7,12,249 km^2, while it was 7,08,273 km^2 in 2017 (FSI, 2017), recording an increase of 3976 km^2 within two years. The total forest and tree cover of the country is 24.56% of its geographical area. The National Forest Policy of India envisages 33% of its geographical area under forest and tree cover.

With its focus on sustainable management of forests, afforestation and regulating diversion of forest lands for non-forest purposes, India has been successful in improving carbon stocks in its forests. In 2019, estimated total carbon stocks in forest was 7,124.6 million tonnes (FSI, 2019) while in 2017 it was 7082 million tonnes (FSI, 2017) which is a net increase of 42.6 million tonnes in country's carbon stocks within two years. Various national programmes and policies have converted India's forests into net sink of CO_2. The land use, land use change and forestry (LULUCF) sector was source of CO_2 in the year 1994 accounting for 1.16% of CO_2eq emissions when India submitted its first National Communication (NATCOM) to United Nations Framework Convention on Climate Change (UNFCCC) in 2000 (MoEF, 2004). In its second National Communication, LULUCF sector was a net sink of total national emissions (MoEF, 2012). India's first biennial update report to UNFCCC has reported that the LULUCF sector was a net carbon sink offsetting 252.5 million tonnes of CO_2 eq (MoEF&CC, 2015). LULUCF sector was a net sink of 301.19 million tonnes CO_2eq during 2014, registering an increase in the sink activity of the sector. Forests were net sinks and about 12% of India's GHG emissions were offset by the LULUCF sector. Thus, forestry sector in India is making a positive contribution to climate change mitigation (MoEF&CC, 2018).

Ful Filling International Commitments on Climate Change

Fulfilling emission reduction commitments under the United Nations Framework Convention on Climate Change (UNFCCC), Government of India launched National Action Plan on Climate Change (NAPCC) in 2008. Government of India is committed to achieve its Nationally Determined Contributions (NDCs) under the Paris Agreement.

India's National Action Plan on Climate Change

National Action Plan on Climate Change identifies several measures that simultaneously advance the country's development and climate change related objectives of adaptation and mitigation. The implementation of the NAPCC is designed to take place through eight National Missions, which form the core of the National Action Plan on Climate Change and incorporate multi-pronged, long-term and integrated strategies for achieving India's key goals in the context of climate change. National Mission for a Green India also known as Green India Mission (GIM) is one of the key missions under NAPCC dealing with mitigation and adaptation of climate change in the forestry sector (MoEF&CC, 2014).

National Mission for a Green India: The National Mission for a Green India (GIM) recognizes that climate change phenomena will seriously affect and alter the distribution, type and quality of forests of the country and the associated livelihoods of the people.

GIM puts the "greening" in the context of climate change adaptation and mitigation, meant to enhance ecosystem services like carbon sequestration and storage (in forests and other ecosystems), hydrological services and biodiversity; along with provisioning services like fuelwood, fodder, small timber and non-timber forest produce. GIM aims at responding to climate change by a combination of adaptation and mitigation measures, which would help in: (i) enhancing carbon sinks in sustainably managed forests and other ecosystems; (ii) adaptation of vulnerable species/ecosystems to the changing climate; and (iii) adaptation of forest dependent local communities in the face of climatic variability. The objectives of the GIM are as follows:

- Increased forest/tree cover on 5 million ha of forest/non-forest lands and improved quality of forest cover on another 5 million ha (a total of 10 million ha).
- Improved ecosystem services including biodiversity, hydrological services and carbon sequestration as a result of treatment of 10 million ha.
- Increased forest-based livelihood income for 3 million forest dependent households.
- Enhanced annual CO_2 sequestration of 50-60 million tonnes.

India's Nationally Determined Contribution for Forestry Sector

India is a signatory to the UNFCCC and its Paris Agreement. Under Paris Agreement India has committed to meet its Nationally Determined Contribution (NDC). The forestry sector goal of NDC is to create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030. To achieve this, India is determined to continue with its on-going interventions, enhance the existing policies and launch new initiatives in the priority areas *inter alia* full implementation of Green India Mission and other programmes of afforestation. Planned afforestation has been seen as a major mitigation strategy in the forestry sector. India is one of the few countries where forest and tree cover has increased in recent years transforming the country's forests into a net sink owing to national policies aimed at conservation and sustainable management of forests.

India's efforts to increase the forest and tree cover have been further augmented by policies like National REDD-plus Strategy (2018), National Agroforestry Policy (2014), Joint Forest Management Guidelines 1990; National Afforestation Programme, *Namami Gange* programme and afforestation along the river sides, Green Highways Mission and afforestation under Compensatory Afforestation Fund Management and Planning Authority Act.

2 FOREST CARBON STOCKS MEASUREMENT

Purposes of Carbon Measurement in Forest Ecosystem

Forests are both source and sink of carbon dioxide. A growing forest captures atmospheric carbon and this carbon is released into the atmosphere through activities like deforestation and forest degradation. The climate change mitigation benefit of forests is one of the ecosystem services rendered by forests which are fully measurable, reportable and verifiable. Measurement of forest carbon stocks is a vital part of Ecosystem Services Improvement Project (ESIP) implementation or even other forestry projects because CO_2 emission reductions and removals by implementing various forestry activities are estimated by measuring changes in the amount of forest carbon and credits are also issued on the basis of carbon accrued through these actions. Measurement can be defined as the continuous measurement and collection of data on anthropogenic forest-related greenhouse gas emissions by sources and removals by sinks. The measurement system must be transparent, consistent and accurate, and uncertainty should be minimized. The purpose of carbon measurement in forests is given below in nutshell:

(i) To estimate plot level forest carbon stocks at above ground and belowground carbon pools and develop a comprehensive picture of carbon stocks at project, regional or country level

(ii) To estimate future forest carbon stocks and emissions under a wide range of forest management and land use scenarios, allowing for a comparison of the emissions, or carbon storage,

(iii) To assess potential to monetize carbon sequestration under various domestic and international carbon trading mechanisms.

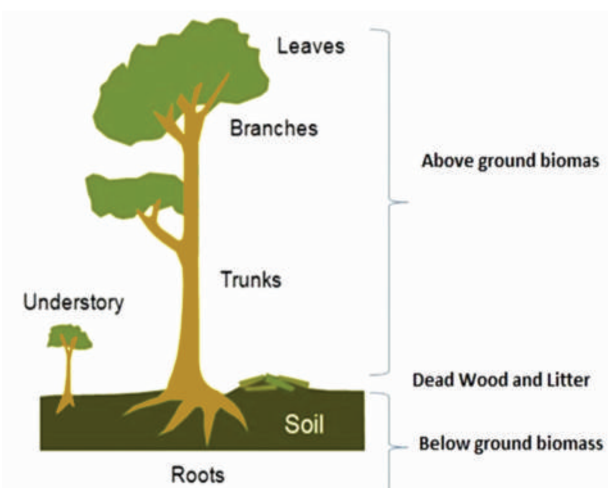


Fig. 1 : Various carbon pools in a forest ecosystem

Table 1: Definitions of terrestrial carbon pools

Pool		Description
Living Biomass	Above Ground Biomass	All living biomass above the soil including stem, stump, branches, bark, seeds and foliage.
	Below Ground Biomass	All living biomass of live roots. Fine roots of less than 2 mm diameter (suggested) are often excluded because these often cannot be distinguished empirically from soil organic matter or litter.
Dead Organic matter	Dead wood	Includes all non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Dead wood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter or any other diameter used by the country.
	Litter	Includes all non-living biomass with a diameter less than a minimum diameter chosen by the country [Forest Survey of India (FSI) has selected 5 cm diameter], lying dead, in various states of decomposition above the mineral or organic soil. This includes the litter, fulvic, and humic layers. Live fine roots (of less than the suggested diameter limit for below-ground biomass) are included in litter where they cannot be distinguished from it empirically.
Soil	Soil Organic Matter	Includes organic carbon in mineral and organic soils (including peat) to a specified depth chosen by the country (FSI as selected : 30 cm) and applied consistently through the time series. Live fine roots (of less than the suggested diameter limit for below-ground biomass) are included with soil organic matter where they cannot be distinguished from it empirically.

(Source: IPCC, 2003 and FSI, nd)

Carbon Pools

Carbon pool may be defined as a system that has the capacity to store or release carbon. For the estimation of carbon pools in a forested stand, IPCC (2003) identified five carbon pools. The detailed description of these carbon pools is given in Table 1 and also depicted in Figure 1.

Different Tiers of Estimation of Forest Carbon Stocks

The IPCC (2006) provides three general approaches for estimating emissions/removal of greenhouse gases, called "Tiers" ranging from 1 to 3, representing an increasing level of data requirement and analytical complexity.

Tier 1 methods are designed to be the simplest to use, for which equations and default parameter values (e.g., emission and stock change factors) are used. For Tier 1 there are often globally available sources of activity data estimates (e.g., deforestation rates, agricultural production statistics, global land cover maps, fertilizer use, livestock population data, etc.) though these data are usually spatially coarse.

Tier 2 can use the same methodological approach as Tier 1 but applies emission and stock change factors that are based on country or region-specific data, for the most important land-use or livestock categories. Higher temporal and spatial resolution and more disaggregated activity data are typically used in Tier 2 to correspond with country-defined coefficients for specific regions and specialized land-use or livestock categories.

Tier 3 higher order methods are used, including models and inventory measurement systems tailored to address national circumstances, repeated over time, and driven by high-resolution activity data and disaggregated at sub-national level. These higher order methods provide estimates of greater certainty than lower tiers. Such systems may include comprehensive field sampling repeated at regular time intervals and/or GIS-based systems of age, class/ production data, soil data, and land-use and management activity data, integrating several types of monitoring.

Despite differences in approach among the three Tiers, all tiers have common adherence to IPCC good practice concepts of transparency, completeness, consistency, comparability and accuracy, thereby, increasing accuracy of the estimation. This manual has been designed to follow the Tier 3 approach using GIS for estimation of forest carbon stocks.

Forest Cover Mapping in India

India is among the few countries which are regularly using satellite based remote sensing technology in detecting forest cover changes. The application of satellite remote sensing technology to assess the forest cover of the entire country in India began in early 1980s. The Forest Survey of India (FSI) is assessing the forest cover of the country on a two-year cycle. Over the years, there have been improvements both in the quality of remote sensing data and the accuracy of interpretation techniques. The 16th biennial cycle of forest inventory has been completed by using 23.5 m resolution images. The minimum mappable unit in respect of forest cover assessment is an area of 1 ha in extent and having tree canopy of 10% (FSI, 2019). Forest cover is classified by FSI in terms of canopy density as given in Table 2.

Table 2: Forest cover classified in terms of canopy density classes

S. No.	Class	Description
1	Very Dense Forest	All lands with tree canopy density of 70% and above
2	Moderately Dense Forest	All lands with tree canopy density of 40% and more but less than 70%
3	Open Forest	All lands with tree canopy density of 10% and more but less than 40%
4	Scrub	Degraded forest lands with canopy density of less than 10%
5	Non Forest	Lands not included in any of the above classes (including water)

(Source: FSI, 2017)

3 USE OF REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM IN MEASUREMENT OF FOREST CARBON STOCKS

Forests are essential natural resources which have huge contribution in regulating global carbon cycle. Therefore measurements of forest cover and change are important to understand the status of forest. It has potential to mitigate climate change and stabilize the atmospheric carbon dioxide into various carbon pools via carbon sequestration. Quantification of various attributes of forest stands such as volume, aboveground biomass, soil carbon, etc. are important to assess at different intervals. There are conventional and unconventional methods to quantify carbon stocks from forests. Conventional methods include intensive field inventory which are costly, time and labour consuming. Unconventional method includes application of remote sensing and geographical information system (GIS) in forest carbon stocks measurement. It is an efficient and economical way for the quantification and regular monitoring of the forest carbon stocks having wide coverage.

Remote sensing technique is designed to collect and retrieve large amount of data without any physical contact with the object. The data collected could be about various aspects of the object or phenomenon. It relies upon technical instruments to collect data over large areas which reduce the manual works, allows retrieval of data of inaccessible areas and collect large amounts of data over a large area in a relatively short period. GIS is a computer based tool for mapping and analyzing features and events on earth. GIS technology integrates common database operations such as query and statistical analysis and interprets the huge data sets on natural resources into more meaningful information in various forms that can guide in decision making process. This requires software to handle the whole geographical and spatial data for further analysis. The function of the remote sensing and GIS based software is to collect, process, analyse, and understand raw geospatial data/ images and extract meaningful information. The software belongs to two categories based upon its purchasing value.

Paid remote sensing and GIS softwares : These are commercial software and the companies provide licensed versions after requisite payment for example ERDAS IMAGINE, ENVI, Arc-GIS, Manifold GIS, ECognition, TerrSet etc.

Open source remote sensing and GIS softwares : Open source remote sensing softwares are freely available in public domain for public use. Some of the open source softwares such as Quantum GIS (QGIS) which is one of the most powerful open source GIS software where satellite imagery can be directly downloaded in the plug-in and also provides tools for pre and post-processing of imagery. Others are MODIS Sentinel Toolbox (s-1 tbx), SAGA GIS: System for Automated Geoscientific Analyses (ideal for most remote sensing needs because of its rich library grid, imagery and terrain processing modules), ORFEO (Optical and Radar Federated Earth Observation), GRASS GIS (Geographic Resources Analysis Support System-GIS), PolSARPro, Whitebox GAT (Geospatial Analysis Tool), ILWIS (Integrated Land and Water Information System), E-fot, OSSIM (Open Source Software Image Map) etc.

Stratification of Forest for Carbon Stocks Measurement

For accuracy, the prior requirement for carbon stock measurement is to achieve homogeneity conditions of forest which can resonate with the satellite imagery and further statistics can be applied on it. This brings the importance of forest canopy density and forest type together for stratification especially in natural forest. For plantations, the type of species planted and its age becomes the factor for homogenization. Currently, IRS-Resouresat-2 and LISS III sensors are used for forest cover mapping. Latest tools and geo informatics techniques provide technical acuity for analysis of forest carbons stocks by intersecting both the forest type and forest canopy density as layers. This brings an increment in accuracy when applied with the field inventory attributed as sample plots in different homogenous blocks of forests. One such example is given for ESIP areas of Budhni Forest Range in Madhya Pradesh in Figure 2 showing forest type and density map.

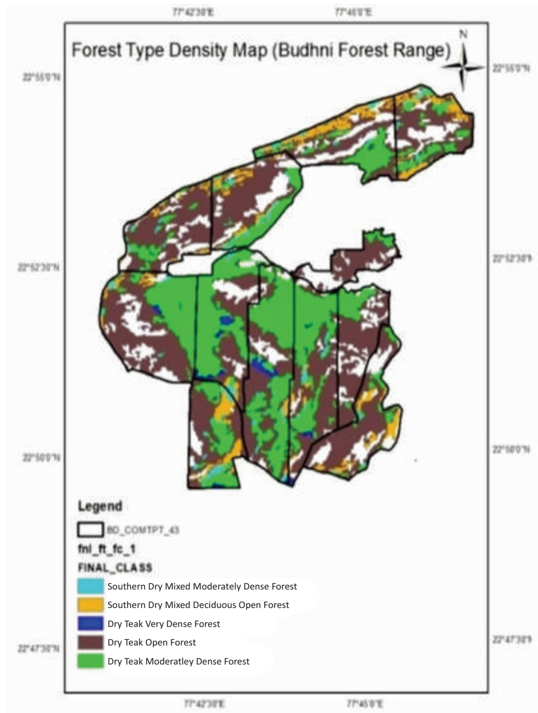


Fig. 2 : Forest type and density map of Budhni Forest Range, MP

Sample Size Determination

To reach to a good precision and acceptable accuracy for estimation of forest carbon stocks, there is a strong necessity to have population representativeness in the samples during sampling. Number of sample plots and size of plots plays a crucial role for representing the area and for extrapolation of the data. Knowledge of local conditions which influence the variability in forest area is the key element that should be focused upon for achieving the accuracy. To remove the bias and avoid a sampling error, random points are useful for the sample size determination. In Arc-GIS system, an important tool such as 'create random tool' helps in generating random points within the study area. Further, the latitude and longitude of the sample points can be generated in a separate file through following steps:

Open attribute table of feature class

↓

For latitude, add field within the attribute table with type double and then click ok. Perform these steps for longitude too

↓

Highlight the field, right click on the header and calculate geometry

↓

Ensure property lists Y coordinate of Point and click ok then list X coordinate of Point for latitude and longitude field

To illustrate this, sample plots laid down in ESIP areas of Budhni Forest Range (Figure 3). Attributes of sample plots marked as red dots is fiven in Figure 4.

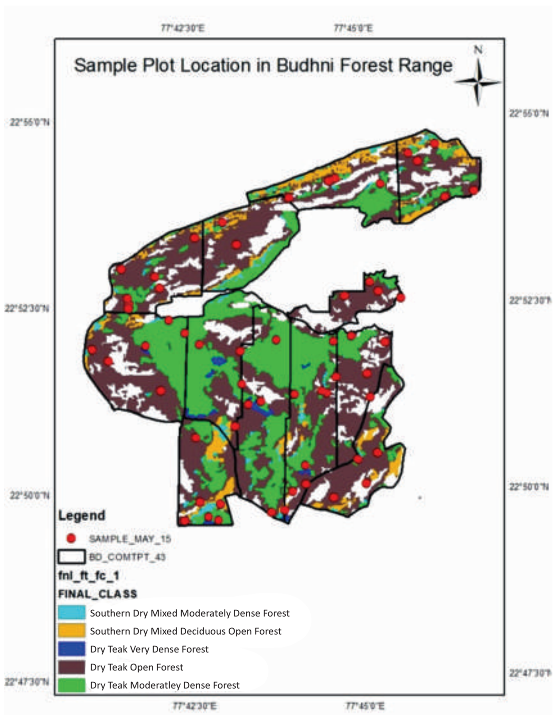


Fig. 3 : Allocation of Sample Plots in Budhni Forest Range

Table

SAMPLE_MAY_15

FID	Shape *	CID	Class	COMP_NU	RS_COMP	Lat	Long	Plot_Nu
0	Point	0	Dry Teak Open Forest	654	2	77.7785	22.89967	1
1	Point	0	Dry Teak Open Forest	654	2	77.76494	22.90647	2
2	Point	0	Dry Teak Open Forest	653	4	77.73334	22.89882	3
3	Point	0	Dry Teak Open Forest	653	4	77.74320	22.90232	4
4	Point	0	Dry Teak Open Forest	654	2	77.77138	22.89835	5
5	Point	1	Dry Teak MDF	654	2	77.76268	22.90833	6
6	Point	1	Dry Teak MDF	653	4	77.74478	22.90282	7
7	Point	1	Dry Teak MDF	653	4	77.75570	22.90143	8
8	Point	3	Southern Dry OF	654	2	77.76917	22.91027	9
9	Point	3	Southern Dry OF	652	5	77.71713	22.89356	10
10	Point	0	Dry Teak Open Forest	645	8	77.75469	22.87753	11
11	Point	0	Dry Teak Open Forest	645	8	77.74648	22.87659	12
12	Point	0	Dry Teak Open Forest	651	3	77.69402	22.87564	13
13	Point	0	Dry Teak Open Forest	652	5	77.72047	22.88842	14
14	Point	0	Dry Teak Open Forest	651	3	77.70044	22.88160	15
15	Point	0	Dry Teak Open Forest	645	8	77.76023	22.87595	16
16	Point	0	Dry Teak Open Forest	651	3	77.71020	22.89016	17
17	Point	0	Dry Teak Open Forest	651	3	77.70151	22.87909	18
18	Point	1	Dry Teak MDF	645	8	77.75276	22.87969	19
19	Point	1	Dry Teak MDF	650	6	77.70356	22.87192	20
20	Point	1	Dry Teak MDF	651	3	77.69375	22.87689	21
21	Point	4	Southern Dry MDF	651	3	77.69384	22.87454	22
22	Point	4	Southern Dry MDF	651	3	77.69217	22.88341	23
23	Point	0	Dry Teak Open Forest	646	9	77.75168	22.85919	24
24	Point	0	Dry Teak Open Forest	650	6	77.68869	22.86291	25
25	Point	0	Dry Teak Open Forest	647	10	77.74399	22.85866	26
26	Point	0	Dry Teak Open Forest	650	6	77.68481	22.86552	27
27	Point	0	Dry Teak Open Forest	648	11	77.72113	22.85737	28
28	Point	0	Dry Teak Open Forest	649	7	77.72094	22.86467	29
29	Point	0	Dry Teak Open Forest	650	6	77.70137	22.85620	30
30	Point	0	Dry Teak Open Forest	646	9	77.75620	22.86623	31
31	Point	0	Dry Teak Open Forest	661	1	77.75241	22.85391	32
32	Point	0	Dry Teak Open Forest	649	7	77.71927	22.84792	33
33	Point	0	Dry Teak Open Forest	648	11	77.72565	22.85337	34
34	Point	0	Dry Teak Open Forest	647	10	77.74165	22.85504	35
35	Point	1	Dry Teak MDF	647	10	77.73394	22.85484	36
36	Point	1	Dry Teak MDF	650	6	77.70743	22.86894	37
37	Point	1	Dry Teak MDF	647	10	77.74353	22.86653	38
38	Point	1	Dry Teak MDF	646	9	77.74791	22.86762	39
39	Point	1	Dry Teak MDF	649	7	77.71094	22.86641	40
40	Point	1	Dry Teak MDF	648	11	77.72972	22.86709	41
41	Point	2	Dry Teak VDF	648	11	77.72267	22.85283	42
42	Point	2	Dry Teak VDF	650	6	77.69781	22.86629	43
43	Point	4	Southern Dry MDF	647	10	77.74062	22.85545	44
44	Point	0	Dry Teak Open Forest	644	12	77.70660	22.82705	45
45	Point	0	Dry Teak Open Forest	661	1	77.74298	22.83163	46
46	Point	0	Dry Teak Open Forest	661	1	77.74894	22.84007	47
47	Point	0	Dry Teak Open Forest	644	12	77.70974	22.84557	48
48	Point	0	Dry Teak Open Forest	661	1	77.75379	22.84144	49
49	Point	0	Dry Teak Open Forest	647	10	77.73630	22.83476	50
50	Point	0	Dry Teak Open Forest	647	10	77.73097	22.82895	51
51	Point	0	Dry Teak Open Forest	647	10	77.73296	22.83311	52
52	Point	1	Dry Teak MDF	644	12	77.71483	22.82699	53
53	Point	1	Dry Teak MDF	648	11	77.72784	22.82870	54
54	Point	1	Dry Teak MDF	644	12	77.71536	22.83069	55

Fig. 4 : X and Y Coordinates of the sample plots in an attribute table presented in ARCGIS software

Variety of data sources and statistical methods can be used to improve the accuracy and predictive quality. Schematic representation of forest carbon measurement methodology is given in following flow chart :

Forest type map | Forest canopy density map

↓

Stratification to get homogenous blocks of forest stand to get forest type

↓

Using command from ARCGIS software 'Generate random points' in each stratum inside the forest boundary and create latitude and longitude of sample plots

↓

Locate the sample plots on field using the help of latitude and longitude generated in the software and laid down the sample plot in each stratum

↓

Measurements of five carbon pools on the sample plots for forest carbon stock assessment

Extrapolation of Forest Biomass at Higher Geographical Area

With the help of remote sensing, the field data can be presented for the larger area with efficient cost and time induced. It also helps in various future projections based on the extrapolated data without direct observation. Quality assurance/ quality control depends on many factors which includes sincerity during plotting for the biomass estimation which helps in reducing the error. Many methods like parametric and non parametric algorithms which include regression models, weighted regression and machine learning techniques can be incorporated for extrapolation of forest biomass for the larger area. Examples of machine learning techniques are random forest, support vector machine, random learning, artificial neural network etc. which increases the complexity to produce the desired results.

Advanced Techniques in Remote Sensing for Forest Carbon Stocks Measurement

The necessity for accuracy in forest carbon stocks measurement in forests in varied climate especially in cloud prone areas demands use of advanced techniques in remote sensing and GIS. This help in bringing the judicious use of resources for strengthening of the data and reducing the error. Advanced techniques like LiDAR, RADAR and geostatistics can be useful for forest carbon stocks measurement. Geostatistics is an evolutionary method that helps in analyzing and further predicting values at unsampled places that vary in space from both more and less sparse sample data. Geostatistics is helpful at regional level which helps in constructing the biomass database. LIDAR and RADAR, provide high quality 3D image and can be useful for mapping forest canopy height, biomass and biomass change, forest cover change and monitoring in the time effective manner. Application of integrated approach of remote sensing and field inventory will be useful for measurement of forest carbon stocks.

(Contributed by Dr. Gurveen Arora, Research Associate, BCC Division, ICFRE)

4 SAMPLING DESIGN AND ALLOCATION OF SAMPLE PLOTS

Sampling Design

Sampling is the most important step for the estimation of forest carbon stocks. Appropriate sampling for the carbon stocks estimation can provide reliable estimates at a reasonable cost with limited man power. Sampling includes the number, size and shape of the plots to be required to measure the forest carbon stocks. Sampling a small portion of the entire population enables conclusions to be drawn about an entire population. Sampling theory provides the means for collecting information from the sample plots to the whole project area or even to a regional and national level (IPCC, 2003). Thus, measurements of forest carbon stocks of sample plots can be extrapolated to per hectare or for the whole project area. Sampling methods include simple random sampling, stratified random sampling and systematic sampling. Standard sampling theory relies on random selection of a sample from the population so that each unit of the population has an equal probability of being included in the sample.

Simple Random Sampling: Simple random sampling involves measurement of sampling units (such as a tree or plot) allocated randomly across the forest area in such a way that every sampling unit in the forest has the same probability of being sampled. Sample plots are laid out randomly to avoid bias in locating the plots. Random sampling ensures that each sample plot in the area has an equal probability of being chosen. A simple random sample is meant to be an unbiased representation of population. Sample plot location has no impact on the position of other sample plots. Generally, simple random sampling is not adopted for the assessment of forest carbon stock as it considers the population as homogenous. The project area is considered as one unit and the heterogeneity of forest type, forest cover soil, topography is not considered.

Systematic Sampling: Systematic sampling involves measuring plots at fixed spaced intervals in the project area. After the sample size calculation, systematic sampling may be followed depending on the time and resources. The systematic sampling may be based on the system of grids of latitude and longitude or distance, say 1 km × 1 km. The size of grid can be ascertained using area of the concerned division and optimum sample size and sample grids be selected. It may be all grids of 25″ × 25″ (approximately one plot per 0.56 km^2, assuming that at the centre of country on an average 2.5′ × 2.5′ covers an area of 20 km^2) or alternate grids of 25″ × 25″ size (approximately one plot per 1.11 km^2) or all grids of 50″ × 50″ size (approximately one plot per 2.22 km^2) or alternate grids of 50″ × 50″ size (approximately one plot per 4.44 km^2), all grids of 1.25′ × 1.25′ size (approximately one plot per 5 km^2) and so on (MoEF&CC, 2014). This method is simple, regular spacing and systematic layout provides easy pattern for travels and fieldwork. In other method, the project area converted into grids of appropriate size. The grids size could be of 100 m × 100 m, 200 m × 200 m, 300 m × 300 m, 400 m × 400 m, 500 m × 500 m. Grid size of any dimension may be selected depending on the resource's availability. For example, 200 grids with a total project area of 40 ha. Plot numbers may be marked on the grid map of project area.

- Calculate the sampling interval "k" by using the following equation :

  $k = N/n$

  where,

  k = sampling interval of grids or plots = 200/5 =40,

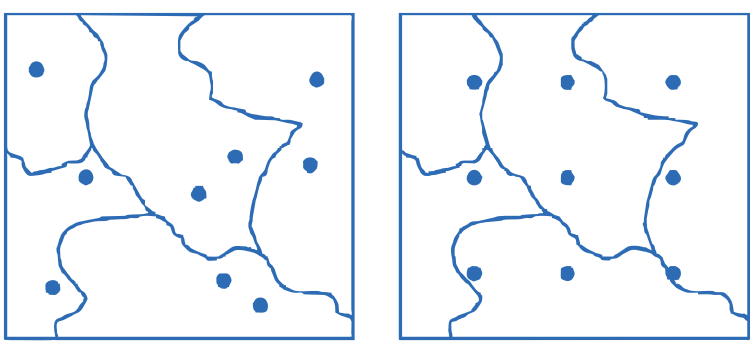
  N = total number of grids representing a given strata (200) and

  n = number of sample plots to be selected.

- Select a random number smaller than k (smaller than 40 in this example), say 25.
- Select and mark the first grid based on the random number.
- The first sampling grid number is 25.
- The second sampling grid = sampling interval k (40) + first sampling grid (25) = 65.
- The third sampling grid = sampling interval k (40) + second sampling grid (65) = 105.
- The procedure repeated for the remaining number of sample plots.

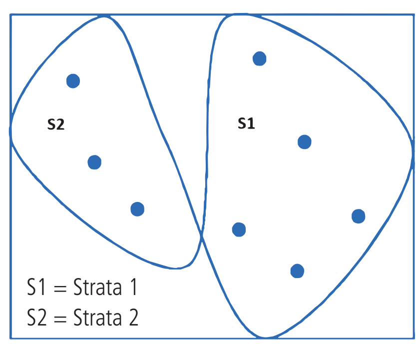
Stratified Random Sampling: Stratified sampling involves defining a forest stratification system, and then establishing a target number of plots within each defined stratum (allocated on either a random or systematic basis). 'Stratification' is the process of grouping a forest into areas with similar characteristics. This process is intended to improve the efficiency of the sampling program, as variation within a stratum is minimized, making it more likely that the measurements taken in the sub-sample are representative of the entire stratum.

This provides a better (more precise) estimate of the average forest carbon stocks for the stratum generated with the least amount of effort and cost.



Random Sampling   Systematic Sampling

Fig. 5 : Layout for Random Sampling and Systematic Sampling



Stratified Sampling

Fig. 6 : Layout for Stratified Sampling

Literature review should be conducted for the quality assurance and sampling design. Sources that may be consulted include peer-reviewed research articles/ reports on the project area or similar area. National level reports having similar kind of forest may also be consulted before deciding the sampling design. Information regarding the range, standard deviations, standard errors and coefficient of variation of carbon stocks in project area or area similar to project area is useful to determine the number of sampling plots.

Sample size depends on the required precision and the anticipated variance in the specific forest strata. At least 10% extra plots may be laid for more reliable estimate of carbon density.

Stratification

It is useful to stratify the project area into strata that form relatively homogenous units. The IPCC (2006) recommends stratifying by climate, soil, ecological zone and management practices. In general, stratification also decreases the costs of measurement because it typically diminishes the sampling efforts while maintaining the same level of confidence. Potential stratification options include:

- Land use (for example forest, plantation, etc)
- Type of vegetation or species (if several)
- Slope (for example: steep, flat)
- Drainage (for example: flooded, dry)
- Age of vegetation
- Proximity to settlement
- Management Practice: Natural or plantation

In India, Forest Survey of India (FSI) has prepared forest density map and forest types map of India. These forest density map and forest types map could be used to stratify the project area into forest type density stratum. Intersect tool in ArcGIS or other GIS softwares can be used to produce the forest type and density maps of the sampling area.

Determination of Number of Permanent Sample Plot

The level of precision required for a forest carbon inventory has a direct effect on inventory for forest carbon stock assessment. Once the level of precision has been decided upon, sample size can be determined for each stratum in the project area. Volume or the aboveground biomass can be used to estimate the variance and further to estimate the sample size. Study of 10-15 sample plots in the project area are usually enough to evaluate variance. For preparation of forest inventory for carbon estimation normally sampling can be done at an intensity of 90/10 (90% confidence level and 10% precision). Confidence level amounts to uncertainty one can tolerate. Precision level is the margin of error one can tolerate.

For example, for the estimation of the variance, mean (M) is assumed as 60.41 t/ha and standard deviation as ± 24.81 and further can be worked out as follows:

Coefficient of Variation (CV) = Standard deviation/Mean × 100

Mean (M) = 60.41 t/ha

Standard Deviation (SD) = ± 24.81

CV = 24.81/60.41 × 100
= 41.06

Use the value of variance in the following equation (MoEF&CC, 2014) :

Sample Size (N) = $(1.64 \times CV/AE)^2$
(at 90% confidence interval with 10% allowable error)

Where,

CV = Coefficient of Variation as calculated above

AE = Allowable error (e.g. 10%, 5%)

1.64 = Student's t-value at 90 % confidence interval

N = $(1.64 \times 41.06/10)^2$

Where Sample Size (N) is the number of sample plot

required to estimate the forest carbon stocks in given area.

N= 45

This means 45 plots are required to be laid in the project area.

Allocation of Sample Plot in Each Stratum

Once the sample size is calculated, the allocation of sample size to different strata is required. This is done using following formula:

A = Area of Strata/Total Area × Sample Size

where,
A = number of sample plots allocated to stratum

For example : In a Forest Range, total forest area is 9296.30 ha and having six forest types. Forest types wise area is given in the following table:

Stratum	Forest Strata	Area (ha)
S1	Dry Teak Open Forest	3091.90
S2	Dry Teak Moderately Dense Forest	537.46
S3	Dry Teak Very Dense Forest	253.08
S4	Southern Dry Mixed Deciduous Moderately Dense Forest	3874.30
S5	Southern Dry Mixed Deciduous Open Forest	1469.00
S6	Southern Dry Mixed Deciduous Very Dense Forest	70.67
	Total	**9296.30**

Allocation of sample plots to be laid in each stratum is calculated by using the above mentioned formula. Forest type/strata wise allocation of sample plots will be as follows:

Stratum	Forest Strata	Calculation	No. of Sample Plots
S1	Dry Teak Open Forest	A1 = 3091.90/9296.30x45	15
S2	Dry Teak Moderately Dense Forest	A2 = 537.46/9296.30x45	3
S3	Dry Teak Very Dense Forest	A3 = 253.08/9293.30x45	1
S4	Southern Dry Mixed Deciduous Moderately Dense Forest	A4 = 3874.30/9296.30x45	19
S5	Southern Dry Mixed Deciduous Open Forest	A5 = 1469/9296.30x45	7
S6	Southern Dry Mixed Deciduous Very Dense Forest	A6 = 70.67/9296.30x45	0

It is further advised that to increase 10% sample size to give adequate coverage to the under represented class. Here A3 and A6 allocation of sample size shows 1 and 0 sample plot respectively. It is advisable to allocate at least 03 sample plots in each stratum for sound statistical analysis.

5 LAYING OUT OF SAMPLE PLOTS IN THE FIELD AND COLLECTION OF DATA

Location of Sample Plots

Randomization of sample plots in a stratum: "ArcGIS" Software or other GIS softwares may be used to locate the sample plot randomly in random manner in each stratum. ArcGIS is a Geographic Information System (GIS) for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database. Service "Create Random Points" function of ArcGIS randomly places a specified number of points within an extent window or inside the features of a polygon, line, or point feature class.

Sample Plot Layout

Permanent sample plots are generally considered as statistically more efficient in estimating changes in forest carbon stocks compared to temporary sample plots because typically there is high covariance between observations taken at successive sampling events in temporary plots. Permanent sample plots should be established for the assessment and monitoring of carbon stocks in the forest. Carbon monitoring requires both size and number of sample plots to be decided. Plot size has the impact on the cost of carbon inventory and monitoring. Larger the plots, lower the variability between two samples. National Working Plan Code-2014 may be followed for the sample plot design and layout methods. National Working Plan Code-2014 is following the square sample plot design and the same is adopted for collection of the data on forest carbon stocks.

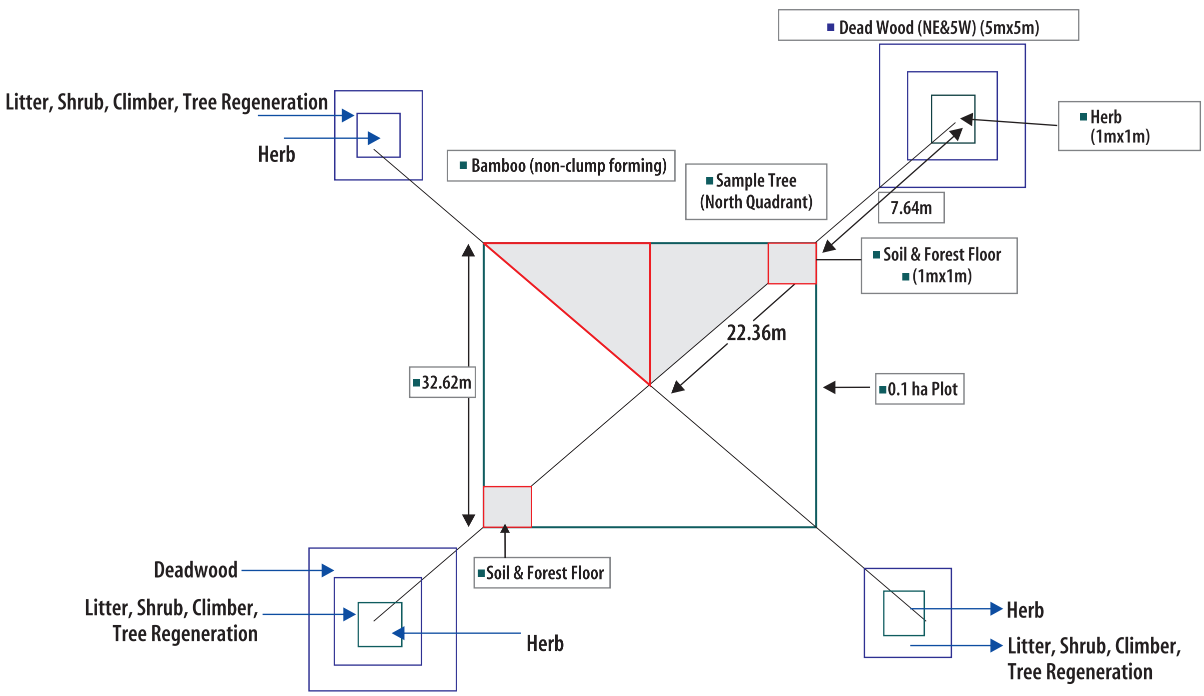
After reaching the predetermined sampling plot location, a square plot of 0.1 ha (31.62 m × 31.62 m) would be laid out by measuring 22.36 m horizontal distance i.e. half of the diagonal in all the four directions at 45°in north-east, at 135°in south-east, at 225° in the south west, and at 315°in north-west corners of the plot from true north. Care should be taken for laying out the proper dimensions of the plot. Then subplots of size 3 m × 3 m and 1 m × 1 m would be laid out at 30 m from the center of the main plot of 0.1 ha in all the four directions for the collection of samples for shrubs, climber and regeneration and herbs/grasses respectively (Figure 7). Along with, the quadrats of size 1 m × 1 m, 3 m × 3 m and 5 m × 5 m would be laid at North East (NE) and South West (SW) direction. In 5 m × 5 m plot, all the dead wood above 5 cm diameter would be collected, weighed and recorded. In 3 m × 3 m, all woody litter that is branches below 5 cm diameter, leaf litter, dried fruits litter would be collected weighed and recorded. All shrubs and climbers in 3 m × 3 m plot should be cut at ground level, weighed and recorded. In 1 m ×1 m plot, all the herbs/grasses would be collected, weighed and recorded. For estimation of soil organic carbon, forest floor should be swept and a pit of 30 cm × 30 cm × 30 cm would be dug at the center of 1 m x 1 m plot at NE and SW corner of the main 0.1 ha plot. A composite sample of soil (mixture of soil from various depths 0-10 cm, 10-20 cm and 20-30 cm) weighing 200 gm should be collected for soil organic carbon analysis. The soil sample should be kept in a polythene bag and tightly closed and properly labeled for further laboratory analysis.

Circular Cluster Sample Plot Design

Now, Forest Survey of India has shifted from single square plot to cluster of circular plots for national forest inventory as mentioned in India State of Forest Report 2019. A brief about circular cluster sample plot design is also described in this section for the knowledge of users. However, development of this manual is based on square plot sample design as prescribed in the Working Plan Code – 2014.

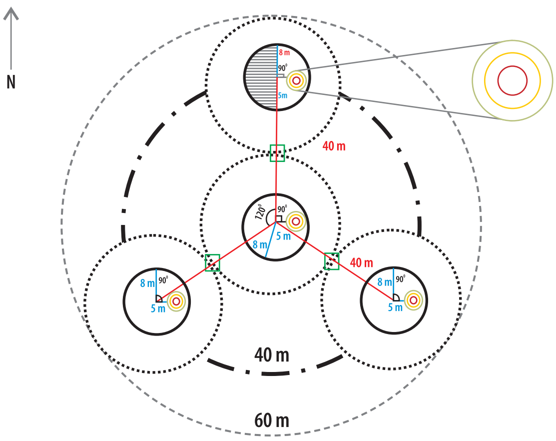
Circular sample plot design is the cluster of four circular sub-plots each with radius of 8 m in a fixed pattern. The central sub-plot 1 is laid out at the point with assigned latitude and longitude. Other three sub-plots 2, 3 and 4 are to be located at a distance 40 m in north, 120 degree and 240 degree from north respectively. Sample plot design given in Figure 8 can be laid out as per following steps:

- Cluster of four sub-plots of 8 metre radius each from the centre of sub-plot 1 at azimuth at 360 degree, 120 degree and 240 degree at a



(Source: MoEF&CC, 2014)

Fig. 7 : Sample Plot Layout : Configuration of main plot and attached sub-plots



	Sub plot	8.0 m radius
	Annular plot	20 m radius
	Lichens plot	40 m radius
	Description plot	60 m radius
	Hub vegetation plot	0.6 m radius
	Shrub re-generation litter plot	1.7 m radius
	Deadwood plot	2.8 m radius
	Soil and forest floor sample plot	1m x 1m at mid point between subplots
	Non-Clump forming bamboo plot	Half of the Sub-plot no 2

Source: FSI, 2019

Fig. 8 : New National Forest Inventory Sample Plot Layout

distance of 40 metre.

- Three 1 m x 1m plot for soil and forest floor with centre at a distance of 20 metre from the centre of sub-plot-1 in the direction of sub-plot 2, 3 and 4.
- Two circular plots for herbs (0.6 m radius), shrub, climber and regeneration and woody litter (1.7 m radius) in all four sub-plots at a distance of 5 metre from the centre towards east.
- A circular plot of 2.8 metre for stump & dead wood collection will be laid out in all four sub-plots at a distance of 5 metre from the centre towards east.
- Set of herbs, shrubs-climbers-regeneration-woody litter and stump, dead wood circular plots is concentric.

Equipment Required

Field sampling kit should be prepared well in advance before proceeding to the field for sampling. The following equipments and items are required for laying the sample plots in the forest for carbon measurement:

Equipment/Items	Purpose
Nylon Rope (04) of the length 31.62 m (or more) for all the four side of the plot.	Marking of the plot
Clinometer/Hagaalti-meter/ Ravi multimeter	Tree height measurement
Compass	Direction checking
Global Positioning System (GPS)	Locating the sample plot
Camera	Clicking photograph of the sample plot/ prominent features
Aluminium Tags	Marking on the trees
Hammer	Marking
Field Maps (Stratified Forest Maps)	Locating the sample plot
Electronic Weighing Balance	Weigh the sample collected
Measuring Tape (50 m)	Laying sample plot
Iron Pole/Wooden stick	Marking boundary
Polybags/Paper bags	Collection of samples
Rubber Bands	Packing the samples
Nails	Tagging
Permanent Marker	Marking
Secateurs	Cutting
Khurpi/Kudal	Digging
Core Sampler	Collection of soil sample for bulk density estimation
Batteries for GPS	Power backup
Paint and Brush	Marking on the trees
Spade/Shovel	Digging soil

Constitution of Field Team

Field team for data collection from sample plots require at least one experienced/ trained person and four assistants to layout the plots and collect required data and samples. Human resource should be properly trained before field sampling, if required a hands on training to the staff/ field team can be provided on the first day. Proper division of work helps in the efficient coordination between the team members and reduces the cost and time of carbon measurement.

Field Background Information

Before going for field sampling, information regarding the field location should be collected that will help in locating sample plots and other locality features. Field maps should be prepared with the help of Geographic Information System. Project area, project boundary, nearby settlements, roads, river, forest types, forest cover, and other land use features should be properly marked on the field maps. Base camp should be established in the project area. Interaction with the local communities can help in collecting information about the project area and ground truthing. Local labour can also be hired for easy movement in the forest and nearby locations.

Tree Measurements

Measurement from individual tree to forest stand for estimation of tree volume and biomass is important for assessment of biomass carbon. In tree and forest measurement some variables are not measured directly like volume of wood, biomass etc. It is difficult to measure some parameters or it cannot be measured directly at all, indirect methods/models are applied to approximate or estimate the parameter of interest. These methods often involve measuring parts of the body (e.g., tree trunk), or parts which can be measured with desired accuracy. Then mathematical models/ procedures are used to convert the known measurements of the parts to estimate the parameter of interest (e.g. tree biomass carbon in the present case).

Tree Circumference at Breast Height (CBH) Measurements : For aboveground biomass all trees having diameter of 10 cm and above or circumference at breast height of 30 cm and above are enumerated. Species and diameter class wise information obtained from the sample plot of 0.1 ha is recorded carefully in the data collection form (Annex-V). Borderline trees i.e. the stem of the trees touching the north and west borderline of the plot should be enumerated. However, the stem of the trees touching the east and south borderline of the plot should be treated as "out trees" and information about out trees should not be recorded in the Data Collection Form. Trees below 10 cm diameter at breast height over bark will be enumerated as sapling. One should be clear that the enumeration in the plot should be started from the North-east corner and should proceed in clockwise direction. The same procedure should be followed for all the sample plots. The height of the trees in all the sample plots should be measured.

Circumference of the tree (circumference at breast height, CBH) is measured at 1.37 m or 4.5 feet from the ground. The circumference may be measured by wrapping measuring tape firmly around the stem, perpendicular to axis. The point must be marked for repeated measurements for assessing the growth rate to ensure that the same position will be measured on each occasion.

Following precautions are to be observed while measuring tree CBH:

(i) On sloping ground measurements should be taken from the uphill side of the stem.

(ii) For leaning trees (on level ground), the point will be on the under-side of the tree parallel to the axis of the stem.

(iii) Trees forked below breast height should be treated as a double stem i.e. two separate trees.

(iv) Trees forked above breast height should be treated as a single stem and measured according to the position of the tree on ground or hills.

(v) Trees forking at breast height or slightly above are measured at the point of minimum diameter below the fork.

(vi) Coppice crops should be measured from ground level, not from the stool level.

Besides above, following precautions should also be taken for proper and accurate measurements.

(i) The loose mounds of soil and litter should be displaced and cleared.

(ii) The vines, moss, loose bark and other loose material at breast height should be removed.

(iii) The breast height should be fixed by using a fixed height stick of 1.37 m.

(iv) Measure at right angles to the stem axis. Keep tapes taut.

(v) Special attention should be placed for buttressing and fluting situations to ensure standardization and comparability of records. Normally, measurement is made above the buttress/fluting. Where this extends well up the bole, an arbitrary height is specified, e.g. 3 m above ground (Figure 9).

Diameter at breast height (DBH) of tree can be calculated from CBH by using following formula:

DBH = CBH/π

Where,

DBH = Diameter at breast height

CBH = Circumferance at breast height

π = pie (value of π = 3.14)

Tree Height Measurement: Height of a tree is an important characteristic for measuring the total amount of wood contained in tree. It is the vertical

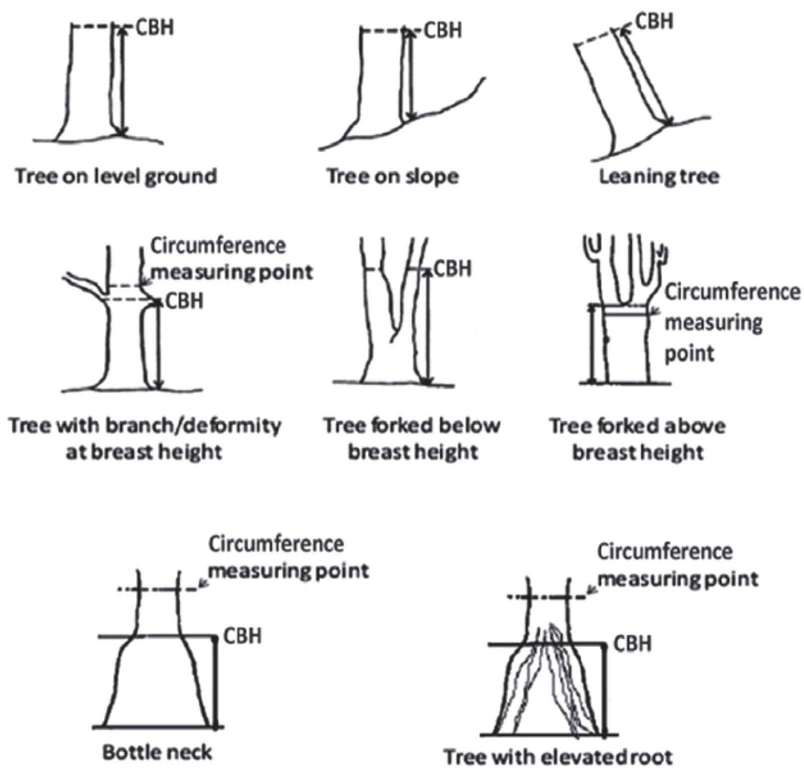


Fig. 9 : Tree CBH measurement under different situations at 1.37 m

distance from ground level to the highest given point on the tree known as tree top. Identifying actual tree top and the fact that the tree top may not be directly over the base of the tree are main sources of error for tree height measurements. Therefore, the concept of merchantable tree heights is adopted with the view of utilization perspective. It is the height of the tree (or the length of trunk) up to which a particular product may be obtained. The height can be measured by specially designed instruments specifically for tree-height measurements such as clinometers, altimeters or hypsometers. Height can also be measured through ocular estimate, non-instrumental, (shadow method, single pole method).

Measuring tree parameters

(i) Walk around the tree and find the best location to view the top of the tree
(ii) Stand far enough from the tree so that the top of the tree is less than 90 degrees above the line of sight
(iii) Always stand up-slope of the tree. Standing down-slope of the tree should only take place when no other option exists
(iv) Measure height of all the trees
(v) Follow the instructions provided by the manufacturer of the instruments
(vi) Place chalk mark on the tree to indicate that the tree has been measured
(vii) All trees should be tagged with the placement of an aluminum numbered tag and nail
(viii) Record species name with the local name and the associated CBH and height into the format
(ix) When all of the trees in the plot have been measured, there should be a check to see that all of the trees have been measured

Shrub Sampling

Four quadrats of 3 m × 3 m should be laid at 30 m from the center of the main plot (0.1 ha). The sample of every shrub should be collected and data from all the quadrats should be recorded in the data collection form.

Procedure

(i) Cut all the shrubs from the plot from ground level
(ii) Fresh weight of the harvested shrubs from the shrub plot should be measured using a portable weighing machine
(iii) Collect the 200 gm fresh sample and pack in the poly bags to be carried to the laboratory for further analysis of dry weight

Tree Regeneration/Sapling

In 3 m × 3 m plot, CBH all the saplings having CBH <10 cm should be measured. Biomass equations developed by FSI to estimate the biomass of the tree having a diameter <10 cm should be used to calculate the carbon stocks in saplings.

Herb Sampling

Sampling of the herbs is done by laying out of 1m ×1 m plot using destructive sampling.

Procedure

Species name and number of each herb should be recorded in the format.

(i) Harvest all the herbs in the plot of 1m ×1m
(ii) Fresh weight of the harvested herbs/grasses should be recorded through portable electronic weighing machine
(iii) A small sample of known quantity should be properly packed and brought to the laboratory for further dry weight estimation

Litter Sampling

Litter sample should be collected from 3 m × 3 m plot from all four corners.

Procedure

(i) Collect all the litter in the sample plot after enumeration of regeneration, shrubs, herbs etc. Litter contains all dead plant material that includes fallen leaves (fresh, dry, semi or partially decomposed leaves), fruit, flower, twigs, bark etc.

(ii) Record the fresh weight of the total litter collected.

(iii) Take the 200 gm sample of the litter.

(iv) Sample should be properly marked and packed for laboratory analysis for determination of dry weight.

Dead wood sampling

All dead wood above 5 cm diameter should be recorded in 5 m × 5 m plot.

Soil Sampling

For collecting data on soil organic carbon, forest floor should be swept and a pit of 30 cm × 30 cm × 30 cm should be dug at the center of 1 m × 1 m plot at NE and SW corner of the main 0.1 ha plot. A composite sample of soil weighing 200 gm should be kept for soil organic carbon using Walkley and Black (1934) method. The soil sample will be kept in a polythene bag and tightly closed and properly labeled.

Concept of Bulk Density of Soil: Bulk density of the soil is defined as the dry weight of soil per unit volume of the soil. It is required to convert between volume and weight of the soil. Information on bulk density is required for determining soil organic carbon content per unit area. Collection of soil sample for bulk density estimation is done in 1 m × 1 m plot. A core sampler of known volume (bulk density core sampler) is inserted in soil between 0-10 cm depth with the help of hammer, up to the top of the core. Remove the core carefully so that soil inside the core may not drop down. Collect the entire soil in a polythene bag and proper label should be fixed on the sample. Repeat this exercise again in the soil 10-20 cm and 20-30 cm depth and samples should be kept in polythene bags with proper labelling for further laboratory analysis.

6 FOREST CARBON STOCKS ESTIMATION

Estimation of Tree Biomass

Biomass is defined as the total amount of living organic matter (above ground and below ground) in trees. It is generally expressed on oven-dry weight basis. Carbon is one of the most abundant chemical elements on earth and is present in all living beings. It is also a naturally occurring component of earth's atmosphere. Denoted by the symbol C, carbon is found in large quantities in the leaves, branches, stems and roots of trees. In addition to about 50% of water, the biomass of a live tree contains approximately 25% carbon and remaining 25% is made up of varying amounts of other elements including nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg) and other trace elements. However, on oven dry weight basis, the approximate amount of carbon will be 50% of biomass.

More recently there has been increasing interest in measurement of the weight that is the biomass of tree. Role of forest has been increasingly recognized as most cost-effective option for climate change mitigation through carbon captured in biomass and soils. Furthermore, it is not just stem which are of interest but the whole living biomass components of the tree (bole, bark, branches, twigs, roots and leaves). Biomass can be measured directly or through estimation functions.

Biomass by Direct Measurement: Direct measurement of biomass involves felling, dissecting and weighing different components of tree. Stratified tree technique method is normally used for biomass estimation by harvesting the sample trees, for which temporary sample plots of different sizes are laid out according to the size of the area in the forest. The diameter at breast height (DBH) and height of all the standing trees in the sample plots covering the entire diameter range of each plot are recorded and correlation (diameter & height) is established by having regression coefficient (R^2) values. The whole diameter range is divided into three or four diameter classes. One mean tree from each diameter class is harvested.

All the tree components (leaves, twigs, branches, bark, bole) including roots are separated immediately after felling and their fresh weights are recorded in the field. The representative samples of each tree component (100 or 200 gm each of leaves, twigs, branches, bark, fruits) are taken for oven dry weight estimation in laboratory.

The bole portion of the sample trees is cut into 2 m long sections (billets) for convenience of weighing.

Approximately 5 cm broad discs are removed from the base of each billet for estimation of fresh and dry weights of bark and wood (under bark) and also for the estimation of volume (over bark and under bark) of the main bole (upto a diameter limit of 5 cm over bark). The average diameter of the two successive discs are taken to calculate the volume (over bark and under bark) of each section and finally the volume of each section is added up to get the volume of main bole (over bark and under bark).

The root systems of all the sample trees are completely excavated excluding their fine rootlets. All possible care is to be taken to remove the soil particles sticking to the roots and fresh weight taken immediately to prevent the weight loss. Representative root samples are also taken for its dry weight estimation. The oven dry weight of each component thus obtained is summed up which is the oven dry weight of the sample tree. The stand biomass (t ha^{-1}) was obtained by multiplying the dry weights of the sample trees by the number of trees in respective diameter classes followed by summation of biomass in each diameter class.

Biomass Estimation Functions

Given the difficulty associated with direct measurement of tree biomass, allometric functions allow tree biomass estimation from simply measured characteristics standing trees. Allometry is the relation between the size of an organism and the size of any of its parts. Allometric equation is usually expressed in power-law form or logarithmic form and is widely used in many biological disciplines to describe systematic changes in morphogenesis, physiology, adaptation and evolution. Once an allometric equation has been developed, the biomass can be estimated in a forest stand using just the simple measurements of diameter. The general form of allometric equations is usually written as,

$y = b \times a$

or, in natural logarithmic (ln) terms,

$\ln y = \ln b + a \ln x$

Where, b is a constant (called the "allometric coefficient"), and a is the allometric exponent.

These equations should be avoided outside the specified diameter range, otherwise the estimates may tend to be over estimated.

If local allometric equations are available, the biomass can be assessed easily by using them. If such equations are not available, then it is better to develop site-specific allometric equations by collecting data from individual trees. Allometric equations for estimation of biomass have been developed for most Indian tree species and are available in literature.

Estimation of Carbon in Different Pools

1) Above ground Biomass

Aboveground biomass includes live tree biomass and non-tree biomass comprising of herbs and shrubs.

a) Live Tree Biomass: The biomass of tree is usually estimated using volumetric equation. For most of the tree species Forest Survey of India has given volumetric equation (FSI, 1996). Volumetric equations relate biomass with the tree height and/or diameter at breast height (DBH) measured 1.37 m above the ground.

Tree Carbon Stock Estimation

$C = [V \times D \times BEF] \times (1+R) \times CF$

Where,

V = merchantable volume, m^3ha^{-1}, tree volume of a stand are normally available in forest inventory and growing stock data

D = basic wood density, tonnes dry matter m^{-3}, merchantable volume (Species wise information on basic wood density is available in literature)

BEF = biomass expansion factor for conversion of merchantable volume to above ground tree biomass, dimension less. Biomass expansion factor is defined as: the ratio of total aboveground oven-dry biomass density of trees with a minimum dbh of 10 cm or more to the oven-dry biomass density of the inventoried volume

R = root-to-shoot ratio (dimension less)

CF = carbon fraction of dry matter (default = 0.47)

Biomass expansion factors are not available for majority of Indian tree species. FSI has developed equation to estimate the biomass of small wood and foliage of trees having DBH 10 cm or more as well as for DBH less than 10 cm. FSI method of calculating biomass of small wood and foliage having DBH 10 cm or more and also for the sapling having DBH less than 10 cm can be used.

Biomass Estimation

i) Estimate the volume of each tree in the sample plot using volumetric equation (FSI, 1996, see Annex I)

ii) Obtain basic wood density/specific gravity for all the tree species encountered in the sampling plot from the literature (Annex III)

iii) Multiply the volume of each tree with the respective wood density to obtain the dry weight of each tree

iv) Use the Biomass equation for estimation of biomass of small wood and foliage of trees having DBH 10 cm or more and also for DBH less than 10 cm (Annex II)

v) Sum the weight of all the trees of all tree species for all the sample plots

vi) Extrapolate the weight of each species from the total sample area (sum of all the plots) to per hectare value (tonnes of biomass per hectare for each species).

vii) Sum the biomass of each species to obtain the total biomass of all the trees in tonnes per hectare.

viii) Carbon is 47% of the biomass (IPCC, 2006).

b) Shrub Biomass: Samples brought to the laboratory are oven dried until reaching constant weight. Biomass of the shrubs is extrapolated per hectare basis after calculation as follows:

$$\text{Shrub Biomass} = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} \times \text{Actual fresh weight}$$

c) Herb Biomass: Samples brought to the laboratory are oven dried until reaching constant weight. Biomass of the herbs is extrapolated per hectare basis after calculation as follows:

$$\text{Herb Biomass} = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} \times \text{Actual fresh weight}$$

2) Belowground Biomass

Belowground biomass (BGB), commonly known as root biomass estimated by using a default root-to-shoot ratio value of 0.28 given by IPCC, 2006. This means that belowground biomass is 28% of the aboveground biomass.

3) Litter Biomass

Samples brought to the laboratory are oven dried until reaching constant weight. Biomass of the litter is extrapolated per hectare basis after calculation as follows:

$$\text{Litter Biomass} = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} \times \text{Actual fresh weight}$$

4) Dead Wood Biomass

Samples brought to the laboratory are oven dried at 70-85°C until reaching constant weight. Biomass of the dead wood is extrapolated per hectare basis after calculation as follows:

$$\text{Dead Wood Biomass} = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} \times \text{Actual fresh weight}$$

Soil Organic Carbon

IPCC (2006) recommends soil organic carbon in the upper 30 cm of soil. This zone is intended to cover the actively changing soil carbon pools. Analysis of soil samples can be done by utilizing the services of state forest research institutes, research institutes of ICFRE, state or central agricultural universities and ICAR institutes and NABL accredited soil testing laboratories etc.

Bulk Density of Soil: The bulk density of the soil sample can be determined by Core Sampler Method described by Wilde *et al.*,1964. Soil samples would be dried in oven at 105°C and measure the weight of sample. Bulk density of soil is calculated as:

$$\text{Bulk Density} = \frac{\text{Weight of soil (gm)}}{\text{Volume of core (cylinder) in cm}^3}$$

Estimating Percent Course Fragment in the Soil: Percent coarse fragment (>2 mm size) in soils is estimated to work out the correct soil weight. After taking the weight of the sample dried for bulk density, the same sample is put in the 2 mm sieve, and run the water over it. Soil particles less than 2 mm will go away with water. Take out the fraction from the sieve and dry it and weigh it. Calculate the percentage of the coarse fragment.

Preparation of the Sample for Soil Organic Carbon Estimation: Open the polythene bag and spread the samples on a brown paper sheet in the laboratory. Let the sample air dry at room temperature in the laboratory. Avoid direct sun drying or oven drying. After drying the samples, grind it and sieve it through 2 mm sieve. This sieved sample is used for soil organic carbon estimation.

Laboratory Analysis of Soil Samples: Soil organic carbon percentage is estimated by standard Walkley and Black (1934) method. The organic matter (humus) in the soil gets oxidized by chromic acid (potassium dichromate plus concentrated sulphuric acid) utilizing the heat of dilution of sulphuric acid. The untreated chromate is determined by back titration with ferrous ammonium sulphate (redox titration). Following reagents are required for laboratory analysis:

(i) 1N potassium dichromate (49.04g of AR grade, $K_2Cr_20_7$ per liter of solution)

(ii) 0.5N (approx.) ferrous ammonium sulphate (196 g of the hydrated crystalline salt per litre containing 20 ml of concentrated sulphuric acid). This solution is relatively more stable and convenient to work than that of ferrous sulphate.

(iii) Diphenylamine indicator: 0.5 g diphenylamine dissolved in a mixture of 20 ml of water and 100 ml of concentrated sulphuric acid

(iv) Concentrated sulphuric acid (sp. gr 1.84) containing 1.25 percent silver sulphate (in case of soils free from chloride use of silver sulphate can be avoided)

(v) Ortho-phosphoric acid (~5%) and sodium fluoride (chemically pure).

Procedure: The soil is ground completely and passed through 2 mm sieve and 1.00 g is placed at the bottom of a dry 500 ml conical flask (Corning Pyrex). 10 ml of IN $K_2Cr_20_7$ is pipetted in and swirled a little. The flask is kept on asbestos sheet. Then 20 ml of sulphuric acid (H_2S0_4) (containing 1.25 % Ag_2SO_4) is run in and swirled again two or three times. The flask is allowed to stand for 30 minutes and thereafter 200 ml of distilled water is added. Add 10 ml of ortho-phosphoric acid (H_3P0_4), 0.5 g sodium fluoride and 1 ml of diphenylamine indicator. The contents are titrated with ferrous ammonium sulphate solution till the colour flashes from blue-violet to green. A combination of H_3P0_4 and sodium fluoride (NaF) is found to give a sharper end point. Simultaneously a blank is run without soil. If more than 7 ml of the dichromate solution is consumed the determination must be repeated with a smaller quantity (0.25-0.5g) of soil.

Calculation: Organic carbon calculated as per following formula:

$$\text{Organic carbon (\%)} = 10\ \frac{B-T}{B} \times 0.003 \times \frac{100}{\text{Weight of soil}}$$

Where,

B = Volume (in ml) of ferrous ammonium sulphate solution required for blank titration

T = Volume of ferrous ammonium sulphate needed for soil sample

Soil Carbon Stock Calculations: Soil stoniness and land use should be recorded. Soil samples should be analyzed for required parameters *viz* bulk density and organic carbon. Soil organic carbon stock Qi (Mg m^{-2}) in a soil layer or sampling level i with a depth of Ei (m) depends on the carbon content Ci (g C g^{-1}), bulk density Di (Mg m^{-3}) and on the volume fraction of coarse elements Gi, given by the formula (Batjes, 1996):

Qi=CiDiEi (1-Gi)

Total Forest Carbon Stocks

(i) Carbon contents for trees, shrubs, herbs, dead wood, litter and soil are calculated at plot level.

(ii) The carbon contents for the different components (trees, shrubs, herbs, dead wood, litter and soil) within plots are summed up to get carbon stock per plot in tonne C/ha.

(iii) The plot level results are then extrapolated on per hectare basis. This is carbon density or carbon stock per unit area, or tonnes of carbon per hectare).

(iv) The carbon stocks per unit area are then multiplied by the area of the stratum (e.g. forest type/density) to produce an estimate of the total carbon stock of the stratum.

Carbon contents of different strata are summed to produce the total carbon stock of the project area (Annex - IV). The following equation was used to calculate the total forest carbon stock:

Total Forest
Carbon Stocks = ABGC+BGBC+LTC+DW+SOC

Where,

ABGC = Aboveground biomass carbon (composed of aboveground tree biomass, sapling biomass, herb biomass and shrub biomass)

BGBC = Belowground biomass carbon

LTC = Litter carbon

DWC = Deadwood carbon

SOC = Soil organic carbon

Quality Assurance/ Quality Control (QA/QC)

Following points should be taken in consideration for maintaining the QA/QC plan for measurement of forest carbon stocks:

- During all data collection in the field, the field members responsible for recording must check all measurements. This is to ensure that the proper number should be recorded on the data sheet.
- After data is collected at each plot and before the field members leave the plot, the team leader should double check to make sure that all data are to correctly filled.
- At the end of each day all data sheets must be checked by team leader to ensure that all the relevant information are collected. If for some reason there is some information that seems odd or is missing, mistakes can be corrected the following day.
- Samples should be properly labelled so that there must not be any confusion during handling and testing of the samples.
- Soil samples should be collected from surface layers (0-30 cm), and should be mixed thoroughly to prepare homogenous soil, and 200 gm of soil sample should be taken for analysis.
- Sampling should be done before monsoon (rainy season) and early fall period of the year. The samples should be representative of the landscape.
- Plant residue, roots, debris, etc. from soil sample should be removed.
- Collected soil sample (approximately 200 gm) should be kept in labeled bags in cool and dark places.

- Soil samples should be air dried in dark/ shadow place and not to be exposed direct sun). Later, samples should be crushed with wooden hammer, and passed through 10-mesh (2 mm) sieve for analysis.
- Analytical Grade (AR) regent should be used for organic carbon estimation to maintain the quality.
- 30 percent soil samples should be planned to be repeated in the same laboratory to confirm the standardization and procedure.
- 10 percent of soil samples should be cross checked for their soil organic carbon in other soil laboratory to assure its accuracy 2 to 5% variability.
- To ensure that data is entered correctly, the person entering data (whether during fieldwork or after a return to the office) should recheck all the data entered and compare it with the original hard copy data sheet before entering another sheet.
- After data entry into computer, a random check should be conducted. Sheets should be selected randomly for re-checks and compared with data entered. Ten percent of all data sheets should be checked for consistency and accuracy in data entry.

REFERENCES

Batjes, N.H. (1996). Total carbon and nitrogen in the soils of the world. European Journal of Soil Science, 47:151-163.

FSI (1996). Volume Equations for Forests of India, Nepal and Bhutan. Forest Survey of India, Ministry of Environment and Forest, Dehradun.

FSI (nd). Carbon Stock in India's Forests. Forest Survey of India, Ministry of Environment and Forest Dehradun.

FSI (2017). State of Forest Report 2017. Forest Survey of India, Ministry of Environment, Forest and Climate Change, Dehradun.

FSI (2019). State of Forest Report 2019. Forest Survey of India, Ministry of Environment, Forest and Climate Change, Dehradun.

IPCC (2003). Good Practice Guidance for Land Use, Land- Use Change and Forestry. Institute for Global Environmental Strategies (IGES), Japan.

IPCC (2006). IPCC Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme. [(H.S. Engleston, L. Bundia, K. Miwa, T. Nagra and K. Tanabe, (eds.)] IPCC-IGES, Japan.

IPCC (2014). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.

IPCC (2018). Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte, V., P. Zhai, H.O. Portner, D. Roberts, J. Skea, P.R. Shukla, A. Pirani, W. Moufouma Okia, C. Pean, R. Pidcock, S. Connors, J.B.R. Matthews, Y. Chen, X. Zhou, M.I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, and T. Waterfield (eds.)].

IPCC (2019). An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. Summary for Policy Makers. https://www.ipcc.ch/site/assets/ uploads /2019/08/4.-SPM_Approved_ Microsite_ FINAL.pdf.

MoEF (2004). India's Initial Communication to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India.

MoEF (2012). India's Second National Communication to the United Nations Framework Convention on Climate Change. Ministry of Environment Forest and Climate Change, Government of India.

MoEF&CC (2014). National Working Plan Code-2014 (for Sustainable Management of Forests), Published by Forest Research Institute, Dehradun, on behalf of Ministry of Environment, Forest and Climate Change, Government of India.

MoEF&CC (2015). India: First Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India

MoEF&CC (2017). Extreme Changes in Climate. Press Information Bureau, Government of India. Download from: http://pib.nic.in/newsite/ erelcontent. aspx?relid=159973

MoEF&CC (2018). India: Second Biennial Update Report to the United Nations Framework Convention on Climate Change. Ministry of Environment, Forest and Climate Change, Government of India.

Rajput, S.S., Shukla, N.K., Gupta, V.K.and Jain, J.D.(1996). Timber Mechanics: Strength, Classification and Grading of Timber. Indian Council of Forestry Research and Education, Dehradun.

Walkley, A. and Black, I.A. (1934). An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science,* 37: 29-37.

Wilde, S.A., Voigt, G.K. and Iyer, J.G. (1964). Soil and Plant Analysis for Tree Culture. Oxford Publishing House, Calcutta, India.

GLOSSARY

ArcGIS

ArcGIS is an architecture geographic information system (GIS) for working with maps and geographic information. It is used for creating and using maps, compiling geographic data, analyzing mapped information, sharing and discovering geographic information, using maps and geographic information in a range of applications, and managing geographic information in a database.

Biomass density

Amount of vegetation biomass per unit area. Therefore, when using the term "biomass" it refers to the vegetation biomass density, that is mass per unit area of live or dead plant material. Unit of measure is g/m^2 or t /ha or multiples.

Biomass

Biomass is defined as mass of live or dead organic matter. It includes the total mass of living organisms in a given area or volume; recently dead plant material is often included as dead biomass. The quantity of biomass is expressed on oven dry weight basis.

Bulk Density

Bulk Density is a property of soils and other masses of particulate material. It's the weight of the particles of the soil divided by the total volume.

Carbon dioxide equivalent (CO_2 eq)

To convert carbon in to CO_2, the tones of carbon are multiplied by the ratio of the molecular weight of carbon dioxide to the atomic weight of carbon (44/12).

Carbon pool

A system which has the capacity to accumulate or release carbon.

Carbon sequestration

The removal of carbon from the atmosphere and long-term storage in sinks.

Carbon sink

It is a carbon reservoir that absorbs more carbon than release. Forests can act as sink through the process of tree growth and resultant biological carbon sequestration. Activities like afforestation & reforestation (AR), sustainable forest management (SFM), conservation and enhancement of forests acts as carbon sinks.

Carbon source

It is a carbon pool from which more carbon flows out

than flows in forests can often represent a net source of carbon due to the processes of decay, combustion and respiration. Activities like deforestation, forest fire and forest degradation acts as sources of carbon.

Carbon stock

The mass of carbon contained in a carbon pool.

Carbon

It is the term used for the C stored in terrestrial ecosystems, as living or dead plant biomass (aboveground and belowground) and in the soil as soil organic carbon.

Coarse fragment

Coarse fragment means a rock fragment contained within the soil which is greater than two millimeters in equivalent spherical diameter or which is retained on a two millimeter sieve.

Coefficient of variation

The coefficient of variation (CV) is a statistical measure of the dispersion of data points in a data series around the mean. The coefficient of variation represents the ratio of the standard deviation to the mean, and it is a useful statistic for comparing the degree of variation from one data series to another, even if the means are drastically different from one another.

Composite sample

A composite sample is made by thoroughly mixing several grab samples. The whole composite may be measured or random samples from the composites may be withdrawn and measured.

Confidence level

Confidence level indicates the probability, with which the estimation of the location of a statistical parameter (e.g. an arithmetic mean) in a sample survey is also true for the population.

Net emission reduction

Indicates the expected amount of emissions reductions in terms of carbon dioxide equivalent (CO_2 eq) that will be generated by the project activities for a certain period.

Sample size

Sample size is a count of the individual samples/ observations or number of sample plots.

Sampling

Sampling is a process used in statistical analysis in which a predetermined number of observations are taken from a larger population.

Standard deviation

The standard deviation (SD) is a statistic that measures the dispersion of a dataset relative to its mean and is calculated as the square root of the variance.

Standard error

A measure of the statistical accuracy of an estimate, equal to the standard deviation of the theoretical distribution of a large population of such estimates.

Variance

Variance is the expectation of the squared deviation of a random variable from its mean.

Wood density

Wood density is the ratio of the wood mass to the wood volume at a certain moisture content.

Annex I PHYSIOGRAPHIC ZONE WISE VOLUME EQUATIONS

(Source: FSI. nd. Carbon Stock in India's Forests. Forest Survey of India, Dehradun)

Western Himalayas

S.No.	Species Name	Volume Equation
1	*Abies densa*	$\sqrt{V} = -0.084305 + 3.060072 D$
2	*Abies pindrow*	$V = 0.293884 - 3.441808 D + 15.922114 D^2$
3	*Picea smithiana*	$\sqrt{} = 0.20050 + 4.58840 D -1.42603 \sqrt{D}$
4	*Acacia catechu*	$V = 0.02384 - 0.72161 D + 7.46888 D^2$
5	*Acer* sp.	$\sqrt{V} =-0.10851 + 3.04250 D$
6	*Lyonia ovalifolia*	$V = 0.03468 - 0.56878 D + 4.72282 D^2$
7	*Mallotus philippinensis*	$V = 0.14749-2.87503 D + 19.61977 D^2-19.11630 D^3$
8	*Pinus wallichiana*	$V/D^2 = 0.213315/D^2 + 12.631292 - 2.519227/D$
9	*Pinus roxburghii*	$\sqrt{V} = 0.05131 + 3.9859 D -1.0245 \sqrt{D}$
10	*Quercus floribunda*	$V/D^2 = 0.0988/D^2 -1.5547/D + 10.1631$
11	*Quercus incana*	$\sqrt{V} = 0.240157 + 3.820069 D -1.394520 \sqrt{D}$
12	*Quercus semecarpifolia*	$V/D2 = 0.0988/D^2 -1.5547/D + 10.1631$
13	*Rhododendron arboreum*	$V = 0.06007 - 0.21874 \sqrt{D} + 3.63428 D^2$
14	*Shorea robusta*	$V/D^2 =0.1919/D^2 - 2.7070/D + 11.7563$
15	*Taxus baccata*	$V = 0.04430 - 0.84266 D + 6.36239 D^2 + 2.27556 D^3$
16	*Tectona grandis*	$V/D = 0.00341/D-0.65623 + 7.881 D$

Eastern Himalayas

S.No.	Species Name	Volume Equation
1	*Alnus nepalensis*	$V/D^2 = 0.06674/D^2 - 0.02039/D + 0.001559$ (dia D is in cm)
2	*Castanopsis indica*	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
3	*Castanopsis* sp.	$V = 0.05331 - 0.87098 D + 6.52533 D^2 + 1.74231 D^3$
4	*Cinnamomum* sp.	$V = 0.10970 - 0.88666 D + 6.09700 D^2 -1.62672 D^3$
5	*Ficus* sp.	$\sqrt{V} = 0.03629 + 3.95389 D - 0.84421 \sqrt{D}$
6	*Macaranga* sp.	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
7	*Machilus* sp.	$V/D^2 = 4.84009-0.02402/D^2$

8	*Michelia* sp.	$V = 0.23057 - 3.51494 D + 17.62619 D^2$
9	*Quercus* sp.	$V/D^2 = 5.09470 + 0.00563/D^2$
10	*Symplocos lucida*	$V = -0.03754 + 0.000587 D^2$ (dia D is in cm)
11	*Terminalia myriocarpa*	$V = -0.096981 + 0.001065 D^2$ (dia D is in cm)

North-Eastern Ranges

S.No.	Species Name	Volume Equation
1	*Albizzia* sp.	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
2	*Bauhinia* sp.	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
3	*Callicarpa arborea*	$\sqrt{V} = -0.04506 + 2.33446 D$
4	*Castanopsis hystrix* Syn. *C. tribuloides*	$\sqrt{V} = 0.34640 + 3.99269 D - 1.64666 \sqrt{D}$
5	*Castanopsis* sp.	$V = 0.05331 - 0.87098 D + 6.52533 D^2 + 1.74231 D^3$
6	*Dysoxylum gotadhora* Syn. *D. binectariferum*	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
7	*Eugenia* sp.	$V = -0.02792 + 0.92933 D - 5.56465 D^2 + 25.77488 D^3$
8	*Ficus* sp.	$\sqrt{V} = 0.03629 + 3.95389 D - 0.84421 \sqrt{D}$
9	*Gmelina arborea*	$V = 0.01156 + 0.21230 D + 5.10448 D^2$
10	*Macaranga* sp.	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
11	*Schima wallichii*	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
12	*Stereospermum tetragonum* Syn. *S. personatum*	$\sqrt{V} = 0.49746 + 5.98454 D - 2.84986 \sqrt{D}$
13	*Syzygium cumini*	$\sqrt{V} = -0.05923 + 2.33654 D$
14	*Tectona grandis*	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
	Equation for rest of species	$V = 0.15958 - 1.57976 D + 8.25014 D^2 - 0.48518 D^3$

Northern Plain

S.No.	Species Name	Volume Equation
1	*Acacia catechu*	$V/D^2 = 0.16609/D^2 - 2.78851/D + 17.22127 - 11.60248 D$
2	*Aegle marmelos*	$V/D^2 = 0.16609/D^2 - 2.78851/D + 17.22127 - 11.60248 D$
3	*Bombax ceiba*	$V/D^2 = 0.18573/D^2 - 2.85418/D + 15.03576$
4	*Butea monosperma*	$\sqrt{V} = -0.24276 + 2.95525 D$
5	*Dalbergia sissoo*	$V/D^2 = 0.00331/D^2 + 0.000636$ (dia D is in cm)
6	*Diospyros melanoxylon*	$V = 0.024814 - 0.578532 D + 6.11017 D^2$
7	*Diospyros* sp.	$V/D = 0.06206/D - 1.43609 + 9.778164 D$
8	*Ehretia laevis*	$V/D^2 = 0.16609/D^2 - 2.78851/D + 17.22127 - 11.60248 D$
9	*Eucalyptus* sp.	$V = 0.02894 - 0.89284 D + 8.72416 D^2$
10	*Holarrhena pubescens* Syn. *H. antidysenterica*	$V = 0.17994 - 2.78776 D + 14.44961 D^2$
11	*Lagerstroemia parviflora*	$V = 0.10529 - 1.68829 D + 10.29573 D^2$
12	*Mallotus philippinensis*	$V = 0.14749 - 2.87503 D + 19.61977 D^2 - 19.11630 D^3$
13	*Shorea robusta*	$\sqrt{V} = 0.16306 + 4.8991 D - 1.57402$ “D
14	*Syzygium cumini*	$V = 0.08481 - 1.81774 D + 12.63047 D^2 - 6.69555 D^3$
15	*Tectona grandis*	$V = 0.08847 - 1.46936 D + 11.98979 D^2 + 1.970560 D^3$
16	*Terminalia tomentosa*	$V/D^2 = 0.18149/D^2 - 2.85865/D + 18.60799$
17	*Mallotus polycorpus* Syn. *Trewia nudiflora*	$W = -0.45312 - 0.41426 D + 2.10913 \sqrt{D}$
18	*Zizyphus mauritiana*	$V = 0.027354 + 4.663714 D^2$

Eastern Plain

S.No.	Species Name	Volume Equation
1	*Amoora* sp.	$\sqrt{V} = 0.00905 + 3.7648 D - 0.64993 \sqrt{D}$
2	*Aglaia spectabilis* Syn. *Amoora wallichii*	$\sqrt{V} = 0.00905 + 3.7648 D - 0.64993 \sqrt{D}$

3	*Careya arborea*	$\sqrt{V} = -0.07109 + 2.99732\ D - 0.26953 \sqrt{D}$
4	*Castanopsis* sp.	$V = 0.05331 - 0.87098\ D + 6.52533\ D^2 + 1.74231\ D^3$
5	*Dillenia pentagyna*	$\sqrt{V} = 0.31202 + 4.75915\ D - 1.83940 \sqrt{D}$
6	*Lagerstroemia parviflora*	$V = 0.11740 - 1.58941\ D + 9.76464\ D^2$
7	*Lagerstroemia speciosa*	$V = 0.11740 - 1.58941\ D + 9.76464\ D^2$
8	*Schima wallichii*	$V = 0.27609 - 3.68443\ D + 15.86687\ D^2$
9	*Shorea robusta*	$V/D2 = 0.00389/D^2 - 0.27516/D + 6.90733$
10	*Tectona grandis*	$\sqrt{V} = -0.07109 + 2.99732\ D - 0.26953 \sqrt{D}$
11	*Terminalia bellirica*	$V = 0.26454 - 3.05249\ D + 12.35740\ D^2$
12	*Terminalia tomentosa*	$V/D^2 = 0.022389/D^2 - 0.84158/D + 9.4721$
13	*Mallotus polycarpa* Syn. *Trewia nudiflora*	V = 0.0549-0.0131 D +0.001 D2 (diaDincm)
14	*Wrightia arborea* Syn. *W. tomentosa*	$\sqrt{V} = 0.23229 + 4.41646\ D - 1.55989 \sqrt{D}$

Western Plain

S.No.	Species Name	Volume Equation
1	*Acacia catechu*	$V = -0.02471 + 0.16897\ D + 1.12083\ D^2 + 2.9328\ D^3$
2	*Acacia ferruginea*	$\sqrt{V} = -0.00142 + 2.61911\ D - 0.54703 \sqrt{D}$
3	*Acacia lenticularis*	$\sqrt{V} = -0.00142 + 2.61911\ D - 0.54703 \sqrt{D}$
4	*Acacia* sp.	$\sqrt{V} = -0.00142 + 2.61911\ D - 0.54703 \sqrt{D}$
5	*Anogeissus pendula*	$V/D^2 = 0.00085/D^2 - 0.35165/D + 4.77386 - 0.90585\ D$
6	*Bauhinia* sp.	$\sqrt{V} = -0.07109 + 2.99732\ D - 0.26953 \sqrt{D}$
7	*Boswellia serrata*	$\sqrt{V} = -0.11629 + 2.4254\ D$
8	*Butea monosperma*	$\sqrt{V} = -0.24276 + 2.95525\ D$
9	*Diospyros melanoxylon*	$V = 0.15581 - 2.2075\ D + 9.17559\ D^2$
10	*Lannea coromandelica*	$V = -0.00146 - 0.39953\ D + 5.33895\ D^2$
11	*Manilkara zapota* Syn. *M. achras*	$V = 0.0245 - 0.00497\ D + 0.000719\ D^2$ (dia D is in cm)
12	*Wrightia tinctoria*	$V = 0.028917 + 7.777047\ D^3$
	Equation for rest of species	$V = 0.081467 - 1.063661\ D + 6.452918\ D^2$

Central Highlands

S.No.	Species Name	Volume Equation
1	*Acacia catechu*	$V = -0.02471 + 0.16897\ D + 1.12083\ D^2 + 2.9328\ D^3$
2	*Acacia lenticularis/ Leucaena leucocephala*	$\sqrt{V} = -0.00142 + 2.61911\ D - 0.54703 \sqrt{D}$
3	*Aegle marmelos*	$V/D^2 = 0.16609/D^2 - 2.78851/D + 17.22127 - 11.60248\ D$
4	*Anogeissus latifoiia*	$\sqrt{V} = -0.20236 + 3.13059\ D$
5	*Anogeissus pendula*	$V/D^2 = 0.00085/D^2 - 0.35165/D + 4.77386 - 0.90585\ D$
6	*Boswellia serrata*	$\sqrt{V} = -0.1503 + 2.79425\ D$
7	*Buchanania cochinchinensis* Syn. *B.lanzan*	$V = 0.031 - 0.64087\ D + 6.04066\ D^2$
8	*Butea monosperma*	$\sqrt{V} = -0.24276 + 2.95525\ D$
9	*Chloroxylon swietenia*	$V = -0.003156 + 2.043969\ D^2$
10	*Diospyros melanoxylon*	$V = 0.15581 - 2.2075\ D + 9.17559\ D^2$
11	*Lagerstroemia parviflora*	$V = 0.10529 - 1.68829\ D + 10.29573\ D^2$
12	*Lannea coromandelica*	$V/D^2 = 0.14004/D^2 - 2.35990/D + 11.90726$
13	*Madhuca longifolia*	$V = 0.063632 + 5.355486\ D^3$
14	*Miliusa tomentosa*	$\sqrt{V} = 0.66382 + 7.03093\ D - 3.68133 \sqrt{D}$
15	*Mitragyna parviflora*	$V/D^2 = 0.099768/D^2 - 1.744274/D + 10.086934$
16	*Tectona grandis*	$\sqrt{V} = -0.405890 + 1.98158\ D + 0.987373 \sqrt{D}$
17	*Terminalia crenulata / T. tomentosa*	$\sqrt{V} = -0.203947 + 3.159215\ D$
18	*Wrightia tinctoria*	$\sqrt{V} = 0.050294 + 3.115497\ D - 0.687813 \sqrt{D}$
19	*Ziziphus xylopyrus*	$V = 0.027354 + 4.663714\ D^2$
	Equation for rest of species	$\sqrt{V} = -0.153973 + 2.724109\ D$

North Deccan

S.No.	Species Name	Volume Equation
1	*Acacia catechu*	$V = 0.04235 - 0.74240 D + 7.26875 D^2$
2	*Aegle marmelos*	$V = 0.119- 1.768 D + 9.258 D^2$
3	*Anogeissus latifolia*	$V =-0.061856 + 7.952136 D^2$
4	*Bauhinia dicvaricata* Syn. *B. retusa/ B. variegata*	$V = -0.0236 + 0.3078 D + 1.2361 D^2$
5	*Buchanania cochincinensis* Syn. *B. latifolia/ B. lanzan*	$V = -0.00767 + 0.2654 D + 1.0383 D^2 + 7.527 D^3$
6	*Butea monosperma* Syn.*Butea frondosa*	$V = -0.032-0.0619 D + 7.208 D^2$
7	*Chloroxylon swietenia*	$V = 0.0242 - 0.6689 D + 5.2777 D^2$
8	*Cleistanthus collinus*	$\sqrt{V} = -0.07324 + 2.187427 D$
9	*Diospyros melanoxylon*	$V/D = 0.033867/D - 0.975148 D + 8.255412 D$
10	*Gardenia resinifera* Syn. *G.turgida* Syn.*G .lucida/ G. latifolia*	$V = 0.078- 1.188 D + 6.751 D^2$
11	*Lagerstroemia parviflora*	$V/D^2 = 0.06466/D^2 - 1.371984/D + 9.629971$
12	*Lannea coromandelica*	$V = 0.093318 - 1.531417 D + 9.011590 D^2$
13	*Madhuca latifolia*	$V = 0.074069 - 1.230020 D + 7.726902 D^2$
14	*Memecylon edule*	$V = 0.103- 1.709 D + 9.692 D^2$
15	*Miliusa tomentosa* Syn. *Saccopetalum tomentosum*	$\sqrt{V} = 0.66382 + 7.03093 D - 3.68133 \sqrt{D}$
16	*Syzygium cumini*	$V = 0.2736 - 3.377 D + 12.959 D^2$
17	*Tectona grandis*	$\sqrt{V} = -0.106720 + 2.562418 D$
18	*Terminalia crenulata/ T. tomentosa*	$V/D^2 = 0.048532/D^2 - 1.05615/D + 8.204564$
19	*Wrightia tinctoria*	$V = -0.009510 + 4.149345 D^2$
20	*Ziziphus xylopyrus*	$V = -0.0257 + 0.2313 D + 1.4794 D^2$

East Deccan

S.No.	Species Name	Volume Equation
1	*Anogeissus latifolia*	$V/D^2 = -0.02958/D^2 + 8.05003$
2	*Boswellia serrata*	$V = 0.36432 - 1.32768 \sqrt{D} + 9.48471 D^2$
3	*Bridelia retusa* Syn. *B. Squamosa*	$\sqrt{V} = 0.1162 + 4.12711 D- 1.085085 \sqrt{D}$
4	*Buchanania cochincinensis* Syn. *B. latifolia/ B. lanzan*	$V = 0.031 - 0.64087 D + 6.04066 D^2$
5	*Butea monosperma* Syn. *Butea frondosa*	$W = -0.24276 + 2.95525 D$
6	*Chloroxylon swietenia*	$V =-0.003156 + 2.043969 D^2$
7	*Cleistanthus collinus*	$V = 0.030925 - 0.567037 D + 5.709471 D^2$
8	*Dalbergia lanceolaria* Syn. *D. paniculata*	$\sqrt{V} = 0.76896 + 7.31777 D - 4.01953 \sqrt{D}$
9	*Diospyros melanoxylon*	$V = 0.12401 - 2.00966 D + 10.87747 D^2$
10	*Diospyros species*	$V = 0.12401 - 2.00966 D + 10.87747 D^2$
11	*Phyllanthus emblica* Syn. *Emblica officinalis*	$V = -0.022635 + 4.889163 D^2$
12	*Lagerstroemia parviflora*	$V = 0.06913 - 1.37605 D + 11.89119 D^2$
13	*Lannea coromandelica* Syn. *Lannea grandis*	$V = 0.057424 - 1.153088 D + 8.542648 D^2$
14	*Madhuca longifolia*	$V = -0.00092 - 0.55547 D + 7.34460 D^2$
15	*Pterocarpus marsupium*	$V/D^2 = -0.04659/D^2 + 8.06901$
16	*Shorea robusta*	$V = 0.05823 - 1.22994 D + 10.51982 D^2$
17	*Tectona grandis*	$V/D^2 = 0.045181/D^2 - 0.91863/D + 8.18261 + 1.95661 D$
18	*Terminalia crenulata / T. tomentosa*	$V = 0.05061 - 1.11994 D + 8.77839 D^2$
19	*Ziziphus xylopyrus*	$V = 0.027354 + 4.663714 D^2$
	Equation for rest of species	$V/D = 0.088074/D - 1.449236 + 8.760534 D$

South Deccan

S.No.	Species Name	Volume Equation
1	*Acacia auriculiformis*	$\sqrt{V} = -0.00142 + 2.61911 D - 0.54703$ “D
2	*Albizia amara*	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953$ “D
3	*Anogeissus latifolia*	$V = 0.289 - 2.653 D + 11.771 D^2$
4	*Chloroxylon swietenia*	$V = -0.0532 D + 3.2378 D^2$
5	*Dalbergia lanceolaria* Syn. *D. paniculata*	$V = 0.18945 - 2.46215 D + 10.54462 D^2$
6	*Eucalyptus* species	$V = 0.02894 - 0.89284 D + 8.72416 D^2$
7	*Hardwickia binata*	$V = 0.063632 + 5.355486 D^3$
8	*Lagerstroemia parviflora*	$V = 0.066188 - 1.334512 D + 9.403257 D^2$
9	*Lannea coromandelica* Syn. *Lannea grandis*	$V = 0.091153 - 1.66153 D + 10.24624 D^2$
10	*Tectona grandis*	$V = -0.2414 + 2.8458 D - 5.5816 D^2 + 14.816 D^3$
11	*Terminalia crenulata / T. tomentosa*	$V = 0.051812 - 1.076790 D + 7.991280 D^2$
12	*Terminalia paniculata*	$V = 0.13100 - 1.87132 D + 9.47861 D^2$
13	*Wrightia tinctoria*	$\sqrt{V} = 0.050294 + 3.115497 D - 0.687813 \sqrt{D}$
	Equation for rest of species	$V = 0.088183 - 1.490948 D + 8.984266 D^2$

Western Ghats

S.No.	Species Name	Volume Equation
1	*Acacia mearnsii*	$\sqrt{V} = -0.143393 + 3.040067 D$
2	*Acacia melanoxylon*	$\sqrt{V} = -0.00142 + 2.61911 D - 0.54703 \sqrt{D}$
3	*Acrocarpus fraxinifolius*	$V/D^2 = -0.0941/D^2 + 0.00097$ (dia D is in cm)
4	*Anogeissus latifolia*	$V = 0.030502 - 1.105937 D + 12.261268 D^2$
5	*Aporosa cardiosperma* Syn. *A. lindleyana*	$V = 0.1009 - 1.4613 D + 8.0557 D^2$
6	*Artocarpus heterophyllus* Syn. *Artocarpus integrifolia*	$V = 0.076 - 1.319 D + 11.370 D^2$
7	*Durio ceylanicus* Syn. *Cullenia excelsa*	$V = 16.792 D^{2.7168}$
8	*Holarrhena pubescens* Syn. *H. antidysenterica*	$V = 0.17994 - 2.78776 D + 14.44961 D^2$
9	*Lagerstroemia lanceolata/ L. microcarpa*	$V = 0.23839 - 2.48071 D + 10.14106 D^2$
10	*Macaranga peltata*	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
11	*Myristica malabarica*	$V/D^2 = 0.00085/D^2 - 0.35165/D + 4.77386 - 0.90585 D$
12	*Olea dioica*	$V = -0.03001 + 5.75523 D^2$
13	*Palaquium ellipticum*	$V = -0.0929 + 0.0122 D + 0.0001 D^2 + 0.00002 D^3$ (dia D is in cm)
14	*Pinus patula*	$\sqrt{V} = -0.200251 + 2.927166 D$
15	*Schleichera trijuga / S. oleosa*	$V/D^2 = 0.016042/D^2 - 0.49647/D + 6.2214$
16	*Syzygium cumini* Syn. *S. jambolanum* Syn. *Eugenia jambolana*	$\sqrt{V} = 0.30706 + 5.12731 D - 2.09870 \sqrt{D}$
17	*Tectona grandis*	$\sqrt{V} = -0.405890 + 1.98158 D + 0.987373 \sqrt{D}$
18	*Terminalia crenulata/ T. tomentosa*	$\sqrt{V} = -0.203947 + 3.159215 D$
19	*Terminalia paniculata*	$V = 0.13100 - 1.87132 D + 9.47861 D^2$
20	*Xylia xylocarpa*	$\sqrt{V} = 0.01631 + 2.20921 D$

Eastern Ghats

S.No.	Species Name	Volume Equation
1	*Albizia amara*	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
2	*Albizzia* sp.	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
3	*Anogeisus latifolia*	$V = 0.13928 - 2.87067 D + 20.22404 D^2 - 13.80572 D^3$
4	*Bridelia retusa*	$V/D = 0.035142/D - 0.839708 + 8.157614 D$
5	*Buchanania cochinchinensis* Syn. *B. latifolia* Syn. *B. lanzan*	$\log_e V = 2.2491 + 2.5206 \log_e D$

6	*Chloroxylon swietenia*	$V =-0.003156 + 2.043969 D^2$
7	*Cleistanthus collinus*	$\sqrt{V} = 0.12956 + 3.7819 D- 1.04671 \sqrt{D}$
8	*Diospyros melanoxylon*	$\sqrt{V} = 0.06728 + 4.06351 D - 0.99816 \sqrt{D}$
9	*Grewia tilifolia*	$\log_e V = 2.2491 + 2.5206 \log_e D$
10	*Lannea coromandelica*	$V = 0.057424 - 1.153088 D + 8.542648 D^2$
11	*Pterocarpus marsupium*	$\sqrt{V} = -0.16276 + 2.82002 D + 0.04034 \sqrt{D}$
12	*Semecarpus anacardium*	$\sqrt{V} = 0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
13	*Shorea robusta*	$\sqrt{V} = 0.19994 + 4.57179 D- 1.56823 \sqrt{D}$
14	*Syzygium cumini*	$\sqrt{V} = 0.30706 + 5.12731 D - 2.09870 \sqrt{D}$
15	*Tectona grandis*	$V/D^2 = 0.12591/D^2 - 2.45212/D + 16.52336 - 7.57135 D$
16	*Terminaiia crenulata/T. tomentosa*	$V = 0.05061 - 1.11994 D + 8.77839 D^2$
17	*Xylia xylocarpa*	$V = 0.098- 1.52 D + 8.963 D^2$

West Coast

S.No.	Species Name	Volume Equation
1	*Acacia catechu*	$V = -0.048108 + 5.873169 D^2$
2	*Anogeissus latifolia*	$\sqrt{V} = -0.357373 + 2.430449 D + 0.794626 \sqrt{V}$
3	*Bombax ceiba*	$V/D^2 = 0.136196/D^2 - 2.07674/D + 10.1566$
4	*Boswellia serrata*	$\sqrt{V} = -0.188655 + 3.021335 D$
5	*Bridelia retusa*	$V/D = 0.035142/D - 0.839708 + 8.157614 D$
6	*Butea monosperma* Syn. *Butea frondosa*	$V/D^2 = 0.136196/D^2 - 2.07674/D + 10.1566$
7	*Careya arborea*	$\sqrt{V} = -0.23738 + 2.33289 D + 0.48512 \sqrt{D}$
8	*Dalbergia latifolia*	$\sqrt{V} = -0.144504 + 2.943115 D$
9	*Garuga pinnata*	$V/D = 0.077965/D - 1.481043 + 9.797028 D$
10	*Grewia tilifolia*	$V = 0.018620 + 13.916741 D^3$
11	*Lagerstroemia lanceolata* Syn. *L. microcarpa*	$V = 0.177-1.817 D + 9.285 D^2$
12	*Lannea coromandelica* Syn. *Lannea grandis*	$\sqrt{V} = 0.404153 + 5.555051 D - 2.545525 \sqrt{D}$
13	*Macaranga peltata*	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
14	*Schleichera trijuga/ S.oleosa*	$V/D^2 = 0.016042/D2 - 0.49647/D + 6.2214$
15	*Tectona grandis*	$\sqrt{V} = -0.405890 + 1.98158 D + 0.987373 \sqrt{D}$
16	*Terminalia bellirica*	$V = 10.988 D^{2.6676}$
17	*Terminalia crenulata / T. tomentosa*	$\sqrt{V} = -0.203947 + 3.159215 D$
18	*Terminalia paniculata*	$V = 0.13100 - 1.87132 D + 9.47861 D^2$
19	*Wrightia tinctoria*	$\sqrt{V} = 0.050294 + 3.115497 D - 0.687813 \sqrt{D}$
20	*Xylia xylocarpa*	$\sqrt{V} = 0.01631 + 2.20921 D$

East Coast

S.No.	Species Name	Volume Equation
1	*Albizia amara*	$\sqrt{V} = -0.07109 + 2.99732 D - 0.26953 \sqrt{D}$
2	*Anogeissus latifolia*	$V = 0.289 - 2.653 D + 11.771 D^2$
3	*Boswellia serrata*	$V = 0.36432 - 1.32768 \text{“}D + 9.48471 D^2$
4	*Diospyros species*	$\sqrt{V} = 0.06728 + 4.06351 D - 0.99816 \sqrt{D}$
5	*Grewia tilifolia*	$\log_e V = 2.2491 + 2.5206 \log_e D$
6	*Lannea coromandelica* Syn. *Lannea grandis*	$V = 0.057424 - 1.153088 D + 8.542648 D^2$
7	*Pterocarpus marsupium*	$\sqrt{V} = -0.16276 + 2.82002 D + 0.04034 \sqrt{D}$
8	*Shorea robusta*	$\sqrt{V} = 0.19994 + 4.57179 D - 1.56823 \sqrt{D}$
9	*Tectona grandis*	$V = 0.023613 - 0.531006 D + 6.731036 D^2$
10	*Terminalia crenulata / T. tomentosa*	$V = 0.05061 - 1.11994 D + 8.77839 D^2$
11	*Wrightia tinctoria*	$V = -0.009510 + 4.149345 D^2$
	Equation for rest of species	$V/D = 0.088074/D - 1.449236 + 8.760534 D$

Annex II

PHYSIOGRAPHIC ZONE WISE BIOMASS EQUATIONS

(Source: FSI. Nd. Carbon stock in India's Forests. Forest Survey of India, Dehradun)

BE1 : Biomass equation used to estimate biomass of small wood of trees having DBH 10 cm or more
BE2 : Biomass equation used to estimate biomass of foliage of trees having DBH 10 cm or more
BE3 : Biomass equation used to estimate biomass of small wood of trees having DBH less than 10 cm
BE4 : Biomass equation used to estimate biomass of foliage of trees having DBH less than 10 cm
D : Diameter at breast height in meter; D_1: diameter at breast height in cm; unit of biomass is kg

Western Himalayas

S.No.	Species Name	Biomass Equation
1	*Pinus roxburghii*	$BE_1 = 608.6848\ D^2 - 82.2998\ D + 19.9426$ $BE_2 = 26.2180\ D^2 + 1.6287\ D + 0.8936$ $BE_3 = -0.0443\ D_1^2 + 1.6656\ D_1 - 1.7908$ $BE_4 = 0.0023\ D_1^2 + 0.1103\ D_1 - 0.0527$
2	*Quercus incana*	$BE_1 = 185.5939\ \log_e D + 442.2679$ $BE_2 = 21.6921\ \log_e D + 52.8184$ $BE_3 = 0.2861\ D_1^2 - 0.1181\ D_1 + 0.0455$ $BE_4 = 0.0024\ D_1^3 + 0.0075\ D_1^2 - 0.0543\ D_1 + 0.0868$
3	*Rhododendron arboreum*	$BE_1 = -262.1187\ D^2 + 419.5980\ D - 19.2402$ $BE_2 = 6.5974\ \log_e D + 17.4170$ $BE_3 = 0.0776\ D_1^2 + 0.4770\ D_1 + 0.1780$ $BE_4 = 0.0172\ D_1^2 + 0.0488\ D_1 - 0.0212$
4	*Quercus semecarpifolia*	$BE_1 = -46.1643\ D^2 + 323.0309\ D - 23.3726$ $BE_2 = -4.5071\ D^2 + 46.8789\ D - 3.3746$ $BE_3 = 0.0776\ D_1^2 + 0.4770\ D_1 + 0.1780$ $BE_4 = 0.0177\ D_1^2 + 0.0423\ D_1 - 0.0023$
5	*Lyonia ovalifolia*	$BE_1 = 413.6936\ D^2 + 163.3936\ D - 6.2066$ $BE_2 = 15.4757\ D^2 + 16.9044\ D - 0.7621$ $BE_3 = 0.2511\ D_1^2 - 0.5647\ D_1 + 0.8784$ $BE_4 = 0.0046\ D_1^3 - 0.0492\ D_1^2 + 0.1761\ D_1 - 0.1050$

6	*Cedrus deodara*	$BE_1 = -49.9504\ D^2 + 143.3015\ D + 10.5851$ $BE_2 = 1.7605\ \log_e D + 5.5882$ $BE_3 = 0.0787\ D_1^3 - 1.0246\ D_1^2 + 4.7307\ D_1 - 1.7967$ $BE_4 = 0.0072\ D_1^3 - 0.1118\ D_1^2 + 0.5714\ D_1 - 0.2522$
7	*Abies pindrow*	$BE_3 = -0.0491\ D_1^2 + 2.7026\ D_1 - 2.8253$ $BE_4 = -0.0022\ D_1^3 + 0.0260\ D_1^2 + 0.1971\ D_1 - 0.0809$
8	*Shorea robusta*	$BE_1 = -56.4459\ D_2 + 140.2030\ D + 6.1908$ $BE_2 = -3.4159\ D_2 + 18.1330\ D + 0.2431$ $BE_3 = 0.1094\ D_1^2 + 0.7826\ D_1 - 0.8099$ $BE_4 = 0.0204\ D_1^2 + 0.0470\ D_1 - 0.0245$
9	*Mallotus philippinensis*	$BE_1 = -0.3399\ D^2 + 63.3702\ D + 4.6962$ $BE_2 = -1.5869\ D^2 + 6.5544\ D + 0.4646$ $BE_3 = 0.0844\ D_1^2 + 0.8311\ D_1 - 0.1602$ $BE_4 = 0.0003\ D_1^3 + 0.0082\ D_1^2 + 0.0685\ D_1 - 0.0181$
10	*Tectona grandis*	$BE_1 = -218.7650\ D^2 + 252.6165\ D - 6.4059$ $BE_2 = -19.8692\ D^2 + 21.2077\ D - 0.5973$ $BE_3 = 0.1189\ D_1^2 + 0.1503\ D_1 + 0.5695$ $BE_4 = 0.0103\ D_1^2 - 0.0272\ D_1 + 0.1544$
11	*Acacia catechu*	$BE_1 = 412.4293\ D^2 - 101.8017\ D + 21.9977$ $BE_2 = 5.0812\ D^2 + 1.7792\ D + 0.3749$ $BE_3 = 0.1995\ D_1^2 - 0.3849\ D_1 + 1.6476$ $BE_4 = 0.0493\ D_1 + 0.0429$
12	*Machilus* sp.	$BE_1 = 11.3342\ D^2 + 117.6158\ D + 2.3917$ $BE_2 = -8.1106\ D^2 + 13.5748\ D + 0.4823$ $BE_3 = -0.0367\ D_1^3 + 0.5986\ D_1^2 - 0.8331\ D_1 + 0.5136$ $BE_4 = 0.0079\ D_1^2 + 0.1270\ D_1 - 0.1368$
13	*Myrica esculenta* Syn. *M. nagi*	$BE_1 = -19.9850\ D^2 + 89.8844\ D + 4.6474$ $BE_2 = -3.0448\ D^2 + 7.8240\ D + 0.3483$ $BE_3 = -0.0032\ D_1^3 + 0.0844\ D_1^2 + 0.8019\ D_1 - 0.0739$ $BE_4 = -0.0014\ D_1^3 + 0.0331\ D_1^2 - 0.0898\ D_1 + 0.0719$

Eastern Himalayas

S.No.	Species Name	Biomass Equation
1	*Quercus* sp.	$BE_1 = 69.2347\ D^2 + 135.6707\ D - 1.4147$ $BE_2 = 0.8100\ D^2 + 8.7234\ D + 0.1811$ $BE_3 = 0.1810\ D_1^2 - 0.4654\ D_1 + 1.6797$ $BE_4 = 0.0024\ D_1^2 + 0.0991\ D_1 + 0.0344$
2	*Rhododendron* sp.	$BE_1 = -17.6343\ D_2 + 237.1436\ D - 8.9400$ $BE_2 = -4.7666\ D_2 + 12.3843\ D - 0.5536$ $BE_3 = 0.1635\ D_1^2 - 0.3656\ D_1 + 1.4922$ $BE_4 = -0.0022\ D_1^2 + 0.0874\ D_1 - 0.0154$
3	*Macaranga* sp.	$BE_1 = -255.0664\ D^2 + 507.2459\ D - 43.8670$ $BE_2 = -8.5948\ D^2 + 15.9095\ D - 0.6507$ $BE_3 = 0.1277\ D_1^2 - 0.3029\ D_1 + 0.8538$ $BE_4 = 0.0025\ D_1^2 + 0.0314\ D_1 + 0.1583$
4	*Alnus nepalensis*	$BE_1 = -458.2088\ D^2 + 893.8913\ D - 66.9783$ $BE_2 = -10.0112\ D^2 + 18.4510\ D - 1.0379$ $BE_3 = 0.1785\ D_1^2 - 0.5265\ D_1 + 1.9236$ $BE_4 = 0.0085\ D_1^2 - 0.0182\ D_1 + 0.1152$

5	*Rhododendron arboreum*	$BE_1 = 112.6006\ D^2 + 135.5182\ D - 2.3433$ $BE_2 = 11.2386\ D^2 + 3.0581\ D + 0.1432$ $BE_3 = 0.1194\ D_1^2 + 0.0907\ D_1 + 0.9907$ $BE_4 = 0.0018\ D_1^2 + 0.0516\ D_1 + 0.0361$
6	*Michelia* sp.	$BE_3 = 0.1699\ D_1^2 - 0.2576\ D_1 + 0.9618$ $BE_4 = -0.0026\ D_1^2 + 0.1016\ D_1 - 0.0145$
7	*Ficus* sp.	$BE_1 = 328.6517\ D^2 + 41.5013\ D + 5.8245$ $BE_2 = 43.8976\ D^2 + 1.7589\ D + 0.3012$ $BE_3 = 0.1420\ D_1^2 - 0.2210\ D_1 + 1.2739$ $BE_4 = 0.0128\ D_1^2 - 0.0368\ D_1 + 0.1336$
8	*Terminalia* sp.	$BE_1 = 138.5098\ D^2 + 230.1472\ D - 12.1090$ $BE_2 = 5.1039\ D^2 + 8.0168\ D - 0.3351$ $BE_3 = 0.2029\ D_1^2 - 0.4475\ D_1 + 0.2983$ $BE_4 = 0.0085\ D_1^2 - 0.0165\ D_1 + 0.0270$
9	*Machilus* sp.	$BE_1 = 84.3775\ D^2 + 94.3260\ D + 4.1137$ $BE_2 = -3.4948\ D^2 + 12.2233\ D + 0.5985$ $BE_3 = 0.0503\ D_1^2 + 1.3645\ D_1 - 1.3642$ $BE_4 = 0.0122\ D_1^2 + 0.0941\ D_1 - 0.0972$
10	*Eurya japonica*	$BE_1 = 328.6517\ D^2 + 41.5013\ D + 5.8245$ $BE_2 = 47.6984\ D^2 + 0.8919\ D + 0.1988$ $BE_3 = 0.101\ D_1^2 + 0.222\ D_1 + 0.604$ $BE_4 = -0.004\ D_1^2 + 0.123\ D_1 + 0.139$

North - Eastern Ranges

S.No.	Species Name	Biomass Equation
1	*Schima wallichii*	$BE_1 = 1000.7174\ D^2 - 208.9540\ D + 30.8140$ $BE_2 = 78.8815\ D^2 - 13.3130\ D + 1.6297$ $BE_3 = 0.293\ D_1^2 - 1.098\ D_1 + 1.290$ $BE_4 = 0.0060\ D_1^2 + 0.0551\ D_1 + 0.0619$
2	*Macaranga* sp.	$BE_1 = 295.2237\ D^2 + 329.7146\ D - 21.1529$ $BE_2 = -6.5259\ D^2 + 22.0047\ D - 0.8689$ $BE_3 = 0.2135\ D_1^2 - 0.5857\ D_1 + 0.6587$ $BE_4 = 0.0167\ D_1^2 - 0.0088\ D_1 + 0.1192$
3	*Shorea robusta*	$BE_1 = 239.3148\ D^2 - 3.3963\ D + 21.0528$ $BE_2 = 21.7716\ D^2 + 3.7241\ D + 0.5622$ $BE_3 = 0.4006\ D_1^2 - 1.5864\ D_1 + 2.3434$ $BE_4 = 0.0130\ D_1^2 - 0.0264\ D_1 + 0.2234$
4	*Syzygium cumini*	$BE_1 = 133.7182\ D^2 + 199.3136\ D - 9.3632$ $BE_2 = 10.8365\ D^2 + 2.7031\ D + 1.2267$ $BE_3 = 0.0847\ D_1^2 + 0.4512\ D_1 - 0.3127$ $BE_4 = 0.0089\ D_1^2 - 0.0260\ D_1 + 0.0249$
5	*Careya arborea*	$BE_1 = 340.5659\ D^2 + 91.1216\ D + 3.3365$ $BE_2 = 18.1285\ D^2 + 4.8505\ D + 0.1776$ $BE_3 = 0.1089\ D_1^2 + 0.5761\ D_1 + 0.2813$ $BE_4 = -0.0024\ D_1^2 + 0.1238\ D_1 - 0.0092$
6	*Tectona grandis*	$BE_1 = -235.2067\ D^2 + 454.1317\ D - 29.7996$ $BE_2 = -9.3264\ D^2 + 18.3483\ D - 0.8165$ $BE_3 = 0.1775\ D_1^2 - 0.0216\ D_1 + 0.6538$ $BE_4 = 0.0099\ D_1^2 + 0.0007\ D_1 + 0.0188$

7	*Bauhinia sp.*	$BE_1 = -40.1501\ D^2 + 109.6091\ D + 3.7405$ $BE_2 = -2.8341\ D^2 + 7.7369\ D + 0.2640$ $BE_3 = 0.1139\ D_1^2 + 0.1204\ D, + 0.3863$ $BE_4 = 0.0046\ D_1^2 + 0.0798\ D_1 - 0.0373$
8	*Toona ciliata* Syn. *Cedrela toona*	$BE_1 = 650.9882\ D^2 - 142.8644\ D + 25.0843$ $BE_2 = 24.2705\ D^2 - 1.1020\ D + 0.7574$
9	*Ficus* sp.	$BE_1 = 481.1172\ D^2 + 39.3014\ D + 5.8236$ $BE_2 = 42.6242\ D^2 + 1.7079\ D + 0.2924$ $BE_3 = 0.141\ D_1^2 - 0.180\ D_1 + 0.410$ $BE_4 = 0.010\ D_1^2 + 0.026\ D_1 + 0.011$
10	*Holarrhena pubescens* Syn. *H. antidysenterica*	$BE_4 = 0.0134\ D_1^2 - 0.0042\ D_1 + 0.0014$

Northern Plain

S.No.	Species Name	Biomass Equation
1	*Shorea robusta*	$BE_1 = 25.5451\ D^2 + 201.6606\ D - 13.1829$ $BE_2 = 9.1786\ D^2 + 11.0520\ D - 0.8946$ $BE_3 = -0.0766\ D_1^2 + 1.5811\ D_1 - 1.0110$ $BE_4 = -0.0060\ D_1^2 + 0.1003\ D_1 + 0.0134$
2	*Mallotus philippinensis*	$BE_1 = 131.2114\ D^2 - 20.6129\ D + 12.2762$ $BE_2 = 6.9373\ D^2 - 1.0890\ D + 0.5986$ $BE_3 = 0.0746\ D_1^2 + 0.6614\ D_1 + 0.2329$ $BE_4 = 0.0041\ D_1^2 + 0.0024\ D_1 + 0.0519$
3	*Tectona grandis*	$BE_1 = -172.2384\ D^2 + 234.5179\ D - 5.5074$ $BE_2 = -17.8148\ D^2 + 24.5465\ D - 0.6081$ $BE_3 = 0.048\ D_1^2 + 0.812\ D_1 - 0.351$ $BE_4 = 0.0095\ D_1^2 - 0.0266\ D_1 + 0.1383$
4	*Acacia catechu*	$BE_1 = -40.0134\ D^2 + 178.4533\ D - 4.2859$ $BE_2 = 10.8820\ D + 0.0076$ $BE_3 = 0.0642\ D_1^2 + 1.4964\ D_1 - 0.7879$ $BE_4 = 0.0114\ D_1^2 - 0.0090\ D_1 + 0.0917$
5	*Eucalyptus* sp.	$BE_1 = 33.6773\ D^2 + 101.4271\ D - 2.2653$ $BE_2 = 16.6353\ D^2 + 18.3505\ D - 1.1172$ $BE_3 = 0.2870\ D_1^2 - 1.1264\ D_1 + 1.2830$ $BE_4 = 0.0122\ D_1^2 + 0.0347\ D_1 - 0.0213$
6	*Syzygium cumini*	$BE_1 = 148.1069\ D^2 + 306.2417\ D - 20.7654$ $BE_2 = -4.0782\ D^2 + 8.9461\ D + 0.0084$ $BE_3 = 0.0873\ D_1^2 - 0.0444\ D_1 + 0.4975$ $BE_4 = 0.0060\ D_1^2 + 0.0176\ D_1 - 0.0035$
7	*Dalbergia sissoo*	$BE_1 = 7.2757\ D^2 + 53.1018\ D + 12.3640$ $BE_2 = -4.6845\ D^2 + 14.7263\ D - 0.0240$ $BE_3 = 0.1418\ D_1^2 + 0.7801\ D_1 - 0.3749$ $BE_4 = 0.0035\ D_1^2 + 0.1600\ D_1 - 0.0726$
8	*Mallotus polycarpus* Syn. *Trewia nudiflora*	$BE_1 = 96.5047\ D^2 + 13.8015\ D + 7.1858$ $BE_2 = 11.9851\ D^2 + 0.4885\ D + 0.4786$ $BE_3 = -0.0023\ D_1^2 + 0.9608\ D_1 - 0.4878$ $BE_4 = -0.0034\ D_1^2 + 0.0899\ D_1 - 0.0439$

9	*Holarrhena antidysenterica*	$BE_1 = -184.5679\ D^2 + 168.5082\ D - 10.0526$ $BE_2 = 2.5585\ D^2 + 3.9530\ D - 0.0693$ $BE_3 = 0.066\ D_1^2 - 0.179\ D_1 + 0.458$ $BE_4 = 0.0007\ D_1^2 + 0.0065\ D_1 + 0.0083$
10	*Diospyros melanoxylon*	$BE_1 = -6.8624\ D^2 + 88.2043\ D + 11.2256$ $BE_2 = 4.6996\ D^2 + 13.7476\ D + 1.0999$ $BE_3 = 0.1977\ D_1^2 + 0.2373\ D_1 + 0.4882$ $BE_4 = 0.0245\ D_1^2 - 0.0023\ D_1 + 0.0097$
11	*Bombax ceiba*	$BE_1 = 142.4990\ D^2 + 15.7340\ D + 11.7480$ $BE_2 = 4.1172\ D^2 + 0.8835\ D + 0.2329$ $BE_3 = 0.1772\ D_1^2 - 0.2771\ D_1 + 0.7359$ $BE_4 = -0.0009\ D_1^2 + 0.0399\ D_1 + 0.0226$
12	*Butea monosperma* Syn. *Butea frondosa*	$BE_1 = -22.7925\ D^2 + 53.4590\ D - 1.4797$ $BE_2 = -2.0225\ D^2 + 5.2640\ D + 0.1399$ $BE_3 = 0.0093\ D_1^2 + 0.3026\ D_1 + 0.2964$ $BE_4 = -0.0039\ D_1^2 + 0.1019\ D_1 + 0.0318$

Eastern Plain

S.No.	Species Name	Biomass Equation
1	*Shorea robusta*	$BE_1 = -136.4916\ D^2 + 321.3854\ D - 15.6215$ $BE_2 = 20.7480\ D^2 + 0.9479\ D + 0.4223$ $BE_3 = 0.0770\ D_1^2 + 0.8211\ D_1 - 0.4931$ $BE_4 = 0.0037\ D_1^2 + 0.0199\ D_1 + 0.0438$
2	*Lagerstroemia speciosa* Syn. *Lagerstroemia flos-reginae*	$BE_1 = 282.0677\ D^2 + 122.5817\ D - 1.6765$ $BE_2 = 4.3637\ D^2 + 10.5371\ D - 0.2504$ $BE_3 = 0.1708\ D_1^2 + 0.2991\ D_1 - 0.0735$ $BE_4 = 0.0154\ D_1^2 - 0.0430\ D_1 + 0.0677$
3	*Aglaia spectabilis* Syn. *Amoora wallichii*	$BE_1 = 1536.3332\ D^2 - 381.4076\ D + 39.6576$ $BE_2 = 43.9892\ D^2 - 7.6717\ D + 0.9609$ $BE_3 = 0.1708\ D_1^2 + 0.2991\ D_1 - 0.0735$ $BE_4 = 0.0154\ D_1^2 - 0.0430\ D_1 + 0.0677$
4	*Schima wallichii*	$BE_1 = 845.4033\ D^2 - 151.7822\ D + 22.8579$ $BE_2 = 29.1497\ D^2 - 3.6565\ D + 0.9238$ $BE_3 = 0.1270\ D_1^2 + 0.5903\ D_1 + 0.1752$ $BE_4 = 0.0068\ D_1^2 + 0.0347\ D_1 + 0.0934$
5	*Careya arborea*	$BE_1 = 371.7445\ D^2 + 99.4637\ D + 3.6420$ $BE_2 = 15.2099\ D^2 + 4.0695\ D + 0.1490$ $BE_3 = 0.1089\ D_1^2 + 0.5761\ D_1 + 0.2813$ $BE_4 = -0.0024\ D_1^2 + 0.1238\ D_1 - 0.0092$

Western Plain

S.No.	Species Name	Biomass Equation
1	*Anogeissus pendula*	$BE_1 = 128.0517\ D^2 + 0.5828\ D + 9.3216$ $BE_2 = 4.3925\ D^2 + 0.2702\ D + 0.2610$ $BE_3 = 0.1337\ D_1^2 + 0.2955\ D_1 - 0.0497$ $BE_4 = 0.0045\ D_1^2 - 0.0118\ D_1 + 0.0117$

2	*Wrightia tinctoria*	$BE_1 = 33.4482\ D^2 + 31.7569\ D + 4.2284$ $BE_2 = 2.5576\ D^2 + 2.4283\ D + 0.3233$ $BE_3 = 0.1047\ D_1^2 + 0.3438\ D_1 - 0.1780$ $BE_4 = 0.0098\ D_1^2 - 0.0394\ D_1 + 0.0496$
3	*Boswellia serrata*	$BE_1 = -6.5495\ D^2 + 51.2405\ D + 2.7240$ $BE_2 = 0.4262\ D^2 + 4.9770\ D + 0.2160$ $BE_3 = 0.1826\ D_1^2 - 0.3714\ D_1 + 0.4298$ $BE_4 = 0.0062\ D_1^2 + 0.0331\ D_1 + 0.0154$
4	*Lannea coromandelica* Syn. *Lannea grandis*	$BE_1 = -62.5969\ D^2 + 161.9918\ D - 11.4549$ $BE_2 = -4.5518\ D^2 + 12.0968\ D - 0.7425$ $BE_3 = -0.0103\ D_1^2 + 0.7183\ D_1 - 0.2651$ $BE_4 = -0.0042\ D_1^2 + 0.0895\ D_1 + 0.0302$
5	*Butea monosperma* Syn. *Butea frondosa*	$BE_1 = 34.3335\ D^2 - 7.3049\ D + 6.2960$ $BE_2 = 13.7310\ D^2 - 2.7107\ D + 1.3816$ $BE_3 = 0.0705\ D_1^2 + 0.0149\ D_1 + 0.6722$ $BE_4 = 0.0059\ D_1^2 + 0.0714\ D_1 + 0.0245$
6	*Acacia lenticularis/ Leucaena leucocephala*	$BE_1 = 192.6516\ D^2 - 41.3427\ D + 12.0217$ $BE_2 = 6.2026\ D^2 - 1.2040\ D + 0.3180$ $BE_3 = 0.061\ D_1^2 + 1.089\ D_1 - 0.433$ $BE_4 = 0.0207\ D_1 - 0.0075$
7	*Prosopis juliflora*	$BE_1 = -39.6165\ D^2 + 107.8593\ D + 3.0089$ $BE_2 = -2.8724\ D^2 + 4.2047\ D + 0.1598$ $BE_3 = 0.1142\ D_1^2 + 0.8472\ D_1 - 1.0051$ $BE_4 = 0.0070\ D_1^2 - 0.0239\ D_1 + 0.0297$
8	*Anogeissus latifolia*	$BE_1 = -222.4935\ D^2 + 246.0476\ D - 15.0305$ $BE_2 = -3.3058\ D^2 + 14.4901\ D -1.1089$ $BE_3 = 0.0292\ D_1^2 + 1.0467\ D_1 - 0.9345$ $BE_4 = 0.0001\ D_1^2 + 0.0265\ D_1 - 0.0114$
9	*Prosopis cineraria*	$BE_1 = 374.8853\ D^2 - 102.6065\ D + 19.8870$ $BE_2 = 9.2529\ D^2 - 2.6345\ D + 0.4375$ $BE_3 = 0.0724\ D_1^2 + 1.1342\ D_1 - 0.9111$ $BE_4 = 0.0053\ D_1^2 - 0.0112\ D_1 + 0.0115$
10	*Acacia species*	$BE_1 = -67.6663\ D^2 + 113.1102\ D + 4.3385$ $BE_2 = -8.2494\ D^2 + 12.7608\ D - 0.7229$ $BE_3 = 0.1080\ D_1^2 + 0.4211\ D_1 - 0.2382$ $BE_4 = 0.0073\ D_1^2 - 0.0240\ D_1 + 0.0267$
11	*Diospyros melanoxylon*	$BE_1 = -75.7877\ D^2 + 118.0755\ D - 0.4650$ $BE_2 = -7.2382\ D^2 + 14.2527\ D - 0.0318$ $BE_3 = 0.1480\ D_1^2 - 0.2759\ D_1 + 1.3843$ $BE_4 = 0.0181\ D_1^2 - 0.0604\ D_1 + 0.1507$
12	*Bauhinia* sp.	$BE_1 = -58.2370\ D^2 + 62.9259\ D + 1.9694$ $BE_2 = -7.3222\ D^2 + 7.9117\ D + 0.2476$ $BE_3 = 0.0393\ D_1^2 + 0.5534\ D_1 - 0.2755$ $BE_4 = 0.0063\ D_1^2 + 0.0240\ D_1 + 0.0637$
13	*Holoptelea integrifolia*	$BE_3 = 0.0617\ D_1^2 + 0.6450\ D_1 - 0.5946$ $BE_4 = 0.0058\ D_1^2 + 0.0177\ D_1 + 0.0234$
14	*Salvadora oleoides*	$BE_1 = -37.9134\ D^2 + 59.4648\ D + 1.2415$ $BE_2 = -13.8490\ D^2 + 20.2648\ D - 0.9427$ $BE_3 = 0.0882\ D_1^2 + 0.3256\ D_1 - 0.2153$ $BE_4 = -0.0066\ D_1^2 + 0.1889\ D_1 - 0.0883$

15	*Acacia catechu*	$BE_1 = 862.9319\ D^2 - 170.7552\ D + 21.2422$ $BE_2 = 32.5724\ D^2 - 6.4454\ D + 0.8018$ $BE_3 = 0.0345\ D_1^2 + 1.1686\ D_1 + 0.1762$ $BE_4 = 0.0068\ D_1^2 - 0.0193\ D_1 + 0.0323$
16	*Holarrhena pubescens* Syn. *H. antidysenterica*	$BE_1 = -176.0015\ D^2 + 165.7520\ D - 6.7282$ $BE_2 = -8.7809\ D^2 + 8.2695\ D - 0.3357$ $BE_3 = 0.0180\ D_1^2 + 0.7709\ D_1 - 0.6103$ $BE_4 = 0.0054\ D_1^2 + 0.0031\ D_1 + 0.0326$

Central Highlands

S.No.	Species Name	Biomass Equation
1	*Acacia catechu*	$BE_1 = 461.0594\ D^2 + 127.4788\ D - 8.6248$ $BE_2 = 14.1668\ D^2 + 8.6870\ D - 0.4187$ $BE_3 = 0.0111\ D_1^2 + 1.7348\ D_1 - 0.8604$ $BE_4 = 0.0078\ D_1^2 + 0.0060\ D_1 + 0.0809$
2	*Anogeissus pendula*	$BE_1 = -256.5319\ D^2 + 327.3360\ D - 19.9557$ $BE_2 = -24.9712\ D^2 + 27.0362\ D - 1.6791$ $BE_3 = -0.0413\ D_1^2 + 1.6164\ D_1 - 0.8311$ $BE_4 = 0.0612 D_1 + 0.0148$
3	*Boswellia serrata*	$BE_1 = 120.4804\ D^2 + 162.6570\ D - 9.0293$ $BE_2 = 5.0517\ D^2 + 8.6131\ D - 0.2364$ $BE_3 = 0.1294\ D_1^2 - 0.0842\ D_1 + 0.1589$ $BE_4 = 0.0037\ D_1^2 + 0.0198\ D_1 + 0.0092$
4	*Lannea coromandelica* Syn. *Lannea grandis*	$BE_1 = 37.5026\ D^2 + 235.1910\ D - 16.6356$ $BE_2 = -4.6969\ D^2 + 29.3272\ D - 1.8890$ $BE_3 = 0.0252\ D_1^2 + 0.5893\ D_1 - 0.0258$ $BE_4 = 0.0036\ D_1^2 + 0.0276\ D_1 + 0.0877$
5	*Butea monosperma* Syn. *Butea frondosa*	$BE_1 = 221.3745\ D^2 - 43.7095\ D + 5.1897$ $BE_2 = 20.3847\ D^2 - 2.5894\ D + 0.8161$ $BE_3 = 0.0716\ D_1^2 - 0.2408\ D_1 + 0.7970$ $BE_4 = 0.0070\ D_1^2 - 0.0174\ D_1 + 0.0790$
6	*Diospyros melanoxylon*	$BE_1 = 409.0799\ D^2 - 108.5871\ D + 14.2917$ $BE_2 = 29.9753\ D^2 - 6.1664\ D + 0.9315$ $BE_3 = 0.0764\ D_1^2 - 0.2359\ D_1 + 0.4756$ $BE_4 = 0.0068\ D_1^2 + 0.0021\ D_1 + 0.0124$
7	*Anogeissus latifolia*	$BE_1 = -185.9612\ D^2 + 363.4651\ D - 23.7470$ $BE_2 = -8.7736\ D^2 + 18.6843\ D - 1.2968$ $BE_3 = 0.0506\ D_1^2 + 0.6227\ D_1 - 0.3709$ $BE_4 = 0.0030\ D_1^2 + 0.0121\ D_1 + 0.0401$
8	*Terminalia crenulata/ T. tomentosa*	$BE_1 = 412.9096\ D^2 + 218.7041\ D - 21.1708$ $BE_2 = 27.3545\ D^2 + 9.4647\ D - 0.9363$ $BE_3 = 0.1189\ D_1^2 - 0.1393\ D_1 + 0.5844$ $BE_4 = 0.0028\ D_1^2 - 0.0009\ D_1 + 0.0261$
9	*Mitragyna parvifolia*	$BE_1 = -70.9902\ D^2 + 315.1673\ D - 25.4308$ $BE_2 = -4.7461\ D^2 + 20.5859\ D - 1.6376$ $BE_3 = 0.0524\ D_1^2 + 0.1302\ D_1 - 0.0629$ $BE_4 = 0.0050\ D_1^2 - 0.0093\ D_1 + 0.0334$

10	*Wrightia tinctoria*	$BE_1 = 243.9454\ D^2 + 177.3004\ D - 16.2788$ $BE_2 = 0.5403\ D^2 + 5.9345\ D - 0.3329$ $BE_3 = 0.0132\ D_1^2 + 0.7130\ D_1 - 0.4479$ $BE_4 = -0.0014\ D_1^2 + 0.0265\ D_1 + 0.0104$
11	*Ziziphus xylopyrus*	$BE_3 = 0.0511\ D_1^2 + 0.5596\ D_1 - 0.1862$ $BE_4 = -0.0017\ D_1^2 + 0.0328\ D_1 - 0.0021$
12	*Aegle marmelos*	$BE_1 = -316.8777\ D^2 + 401.7510\ D - 28.8949$ $BE_2 = -26.68\ D^2 + 33.47\ D - 2.394$ $BE_3 = 0.1395\ D_1^2 - 0.1710\ D_1 + 0.6693$ $BE_4 = 0.0090\ D_1^2 - 0.0048\ D_1 + 0.0680$
13	*Acacia lenticularis/ Leucaena leucocephala*	$BE_1 = 290.6110\ D^2 + 78.7053\ D - 6.0127$ $BE_2 = 6.5580\ D^2 + 4.6176\ D - 0.3076$ $BE_3 = 0.0891\ D_1^2 + 0.2386\ D_1 + 0.1853$ $BE_4 = -0.0012\ D_1^2 + 0.0353\ D_1 - 0.0078$
14	*Madhuca longifolia* Syn. *M. latifolia*	$BE_1 = 215.7248\ D^2 + 189.7812\ D - 8.4775$ $BE_2 = 14.6794\ D^2 + 3.5935\ D - 0.1774$ $BE_3 = 0.0471\ D_1^2 + 0.3412\ D_1 + 0.1263$ $BE_4 = 0.0028\ D_1^2 - 0.0074\ D_1 + 0.0863$
15	*Miliusa tomentosa* Syn. *Saccopetalum tomentosum*	$BE_3 = 0.0305\ D_1^2 + 0.9146\ D_1 - 0.7580$ $BE_4 = 0.0078\ D_1^2 - 0.0227\ D_1 + 0.0692$
16	*Flacourtia indica* Syn. *Flacourtia ramontchi*	$BE1 = 564.5753\ D^2 - 11.5172\ D + 4.8052$ $BE_2 = 28.1133\ D^2 - 0.5735\ D + 0.2393$ $BE_3 = -0.0386\ D_1^2 + 1.3890\ D_1 - 0.2761$ $BE_4 = -0.0029\ D_1^2 + 0.0835\ D_1 + 0.0256$

North Deccan

S.No.	Species Name	Biomass Equation
1	*Tectona grandis*	$BE_1 = 724.8313\ D^{1.8139}$ $BE_2 = -5.7898\ D^2 + 16.1859\ D - 0.8153$ $BE_3 = 0.1701\ D_1^2 - 0.5602\ D_1 + 1.3209$ $BE_4 = 0.0080\ D_1^2 + 0.0186\ D_1 + 0.0245$
2	*Terminalia crenulata/ T. tomentosa*	$BE_1 = -893.2875\ D^3 + 1888.8940\ D^2 - 463.5333\ D + 54.7484$ $BE_2 = 20.0615\ D^2 + 1.5684\ D + 0.4141$ $BE_3 = 0.1545\ D_1^2 + 0.0612\ D_1 + 0.5004$ $BE_4 = 0.0061\ D_1^2 - 0.0027\ D_1 + 0.0550$
3	*Chloroxylon swietenia*	$BE_1 = 884.6576\ D^2 + 395.8155\ D - 38.2331$ $BE_2 = 13.0100\ D - 0.3999$ $BE_3 = 0.1990\ D_1^2 - 0.3570\ D_1 + 0.5943$ $BE_4 = 0.0118\ D_1^2 - 0.0027\ D_1 + 0.0401$
4	*Anogeissus pendula*	$BE_1 = 1299.4268\ D^3 - 1653.6151\ D^2 + 1320.6808\ D - 110.1954$ $BE_2 = -3.8043\ D^2 + 10.7862\ D - 0.3515$ $BE_3 = -0.0650\ D_1^2 + 2.1152\ D_1 - 1.1784$ $BE_4 = -0.0079\ D_1^2 + 0.1908\ D_1 - 0.0179$
5	*Butea monosperma* Syn. *Butea frondosa*	$BE_1 = 287.6540\ D^2 + 67.0071\ D - 1.9463$ $BE_2 = 4.6446\ D^2 + 3.8577\ D + 0.2056$ $BE_3 = 0.8883\ D_1 - 0.0294$ $BE_4 = 0.0040\ D_1^2 + 0.0373\ D_1 + 0.1501$

6	*Lannea coromandelica* Syn. *Lannea grandis*	$BE_1 = 84.0382\ D^2 + 262.3237\ D - 20.4447$ $BE_2 = 1.611\ D^2 + 18.47\ D - 0.894$ $BE_3 = 0.011\ D_1^3 - 0.068\ D_1^2 + 0.351\ D_1 + 0.296$ $BE_4 = 0.007\ D_1^2 + 0.006\ D_1 + 0.192$
7	*Diospyros* sp.	$BE_1 = 479.3323\ D^2 + 25.4894\ D + 8.4235$ $BE_2 = 6.7291\ D^2 + 6.0102\ D + 0.2414$ $BE_3 = 0.0307\ D_1^2 + 0.7393\ D_1 - 0.2260$ $BE_4 = 0.0033\ D_1^2 + 0.0669\ D_1 - 0.0027$
8	*Lagerstroemia parviflora*	$BE_1 = 243.9685\ D^2 + 163.6429\ D - 12.3582$ $BE_2 = -35.4845\ D^3 + 44.3745\ D^2 - 1.2717\ D + 0.2303$ $BE_3 = 0.0326\ D_1^2 + 0.4611\ D_1 + 0.3191$ $BE_4 = 0.0074\ D_1^2 - 0.0222\ D_1 + 0.0456$
9	*Buchanania cochincinensis* Syn. *B. latifolia*	$BE_1 = 225.0254\ D^2 + 81.1387\ D - 3.3972$ $BE_2 = 25.4746\ D^2 - 0.6373\ D + 0.6366$ $BE_3 = 0.0888\ D_1^2 + 0.0680\ D_1 + 0.5616$ $BE_4 = 0.0108\ D_1^2 - 0.0187\ D_1 + 0.1278$
10	*Madhuca longifolia* Syn. *M. latifolia*	$BE_1 = 199.2222\ D^2 + 263.1915\ D - 9.9139$ $BE_2 = 6.1590\ D - 0.3077$ $BE_3 = 0.1405\ D_1^2 - 0.0649\ D_1 + 0.7852$ $BE_4 = 0.0015\ D_1^2 + 0.0042\ D_1 + 0.0175$
11	*Acacia catechu*	$BE_1 = 412.9191\ D^2 - 2.7602\ D + 11.2512$ $BE_2 = 7.0246\ D^2 - 1.8951\ D + 0.5892$ $BE_3 = 0.1995\ D_1^2 - 0.3849\ D_1 + 1.6476$ $BE_4 = -0.0007\ D_1^2 + 0.0562\ D_1 + 0.0312$
12	*Gardenia resinifera* Syn. *Gardenia turgida*	$BE_1 = 167.8008\ D^2 + 212.0485\ D - 10.6145$ $BE_2 = 3.9604\ D^2 + 2.5419\ D + 0.4212$ $BE_3 = 0.1779\ D_1^2 - 0.5745\ D_1 + 1.6701$ $BE_4 = 0.0119\ D_1^2 - 0.0425\ D_1 + 0.1287$
13	*Wrightia tinctoria*	$BE_1 = 703.4801\ D^2 - 128.9582\ D + 13.6679$ $BE_2 = -4.0215\ D^2 + 4.6618\ D - 0.2465$ $BE_3 = 0.0232\ D_1^2 + 0.5686\ D_1 - 0.2292$ $BE_4 = 0.0006\ D_1^2 + 0.0111\ D_1 + 0.0151$
14	*Cleistanthus collinus*	$BE_1 = 267.9289\ D^2 + 203.8644\ D - 13.2061$ $BE_2 = 4.1925\ D^2 + 0.6047\ D + 0.1422$ $BE_3 = 0.0895\ D_1^2 + 0.3236\ D_1 + 0.5934$ $BE_4 = 0.0006\ D_1^2 + 0.0129\ D_1 - 0.0064$
15	*Syzygium cumini*	$BE_1 = 252.1925\ D^2 + 138.7321\ D - 10.9596$ $BE_2 = 10.9963\ D^2 - 1.6709\ D + 0.6265$ $BE_3 = 0.5933\ D_1 - 0.0378$ $BE_4 = 0.0095\ D_1^2 - 0.0349\ D_1 + 0.0480$
16	*Ziziphus xylopyrus*	$BE_1 = 625.9479\ D^2 - 132.8810\ D + 16.6826$ $BE_2 = 1.4667\ D^2 + 0.4772\ D + 0.0650$ $BE_3 = 0.0564\ D_1^2 + 0.5274\ D_1 - 0.3069$ $BE_4 = -0.0005\ D_1^2 + 0.0207\ D_1 + 0.0120$
17	*Aegle marmelos*	$BE_1 = 604.8017\ D^2 + 0.0041\ D + 1.7251$ $BE_2 = 43.2013\ D^2 - 11.9883\ D + 1.0009$ $BE_3 = 0.0940\ D_1^2 + 0.0813\ D_1 + 0.1856$ $BE_4 = 0.0081\ D_1^2 - 0.0021\ D_1 + 0.0102$

18	*Bauhinia dicvaricata* Syn. *B. retusa / B. variegata*	$BE_1 = 57.2611\ D^2 + 205.3085\ D - 15.5737$ $BE_2 = 1.6214\ \log_e D + 3.9181$ $BE_3 = 0.0508\ D_1^2 + 0.3060\ D_1 + 0.2747$ $BE_4 = 0.0083\ D_1^2 - 0.0012\ D_1 + 0.0113$

East Deccan

S.No.	Species Name	Biomass Equation
1	*Shorea robusta*	$BE_1 = 96.1525\ D^2 + 141.9383\ D - 7.6058$ $BE_2 = 17.2383\ D^2 + 4.2380\ D - 0.1970$ $BE_3 = -0.0561\ D_1^2 + 1.3533\ D_1 - 0.6625$ $BE_4 = 0.0001\ D_1^3 - 0.0085\ D_1^2 + 0.1150\ D_1 - 0.0198$
2	*Terminalia crenulata/ T. tomentosa*	$BE_1 = 487.5527\ D^2 + 151.9905\ D - 10.5122$ $BE_2 = 20.6898\ D^2 + 0.6700\ D + 0.7183$ $BE_3 = 0.2261\ D_1^2 - 0.2118\ D_1 + 0.4479$ $BE_4 = 0.0231\ D_1^2 - 0.0128\ D_1 + 0.0067$
3	*Buchanania cochincinensis* Syn. *B. latifolia Syn. B. lanzan*	$BE_1 = 371.3904\ D^2 - 24.8493\ D + 11.8891$ $BE_2 = 11.5126\ D^2 + 11.7616\ D - 0.4661$ $BE_3 = 0.1774\ D_1^2 + 0.0497\ D_1 + 0.2405$ $BE_4 = 0.0167\ D_1^2 - 0.0533\ D_1 + 0.1272$
4	*Lagerstroemia parviflora*	$BE_1 = 282.0677\ D^2 + 122.5817\ D - 1.6765$ $BE_2 = 4.4738\ D^2 + 10.3883\ D - 0.2022$ $BE_3 = 0.3060\ D_1^2 - 0.8760\ D_1 + 1.8367$ $BE_4 = 0.0057\ D_1^2 + 0.0473\ D_1 + 0.0448$
5	*Diospyros melanoxylon*	$BE_1 = 454.7209\ D^2 + 91.0511\ D - 0.7796$ $BE_2 = 6.0086\ D^2 + 14.4343\ D - 0.6523$ $BE_3 = 0.2289\ D_1^2 - 0.5895\ D_1 + 1.2901$ $BE_4 = 0.0054\ D_1^2 - 0.0027\ D_1 + 0.0586$
6	*Lannea coromandelica* Syn. *Lannea grandis*	$BE_1 = 480.8026\ D^3 + 776.5053\ D^2 - 12.8368\ D + 3.2642$ $BE_2 = 24.8730\ D^3 - 34.3265\ D^2 + 32.9611\ D - 2.2382$ $BE_3 = 0.1437\ D_1^2 - 0.0925\ D, + 0.2315$ $BE_4 = 0.0041\ D_1^2 + 0.0476\ D_1 + 0.0538$
7	*Anogeissus latifolia*	$BE_1 = 617.5004\ D^2 + 213.1245\ D - 10.7193$ $BE_2 = 2.6012\ D^2 + 4.6100\ D + 0.4850$ $BE_3 = 0.0093\ D_1^2 + 2.0713\ D_1 - 1.3562$ $BE_4 = 0.0055\ D_1^2 + 0.0538\ D_1 - 0.0308$
8	*Madhuca longifolia* Syn. *M. latifolia*	$BE_1 = 363.8918\ D^2 + 21.7241\ D + 12.4076$ $BE_2 = -0.5623\ D^2 + 5.9581\ D - 0.3769$ $BE_3 = 0.1643\ D_1^2 - 0.1839\ D_1 + 0.8660$ $BE_4 = 0.0015\ D_1^2 + 0.0042\ D_1 + 0.0175$
9	*Chloroxylon swietenia*	$BE_1 = 975.0536\ D^2 + 304.3150\ D - 28.7845$ $BE_2 = 1.1759\ D^2 + 12.2568\ D - 0.5698$ $BE_3 = 0.2140\ D_1^2 - 0.3769\ D_1 + 0.6000$ $BE_4 = 0.0104\ D_1^2 - 0.0135\ D_1 + 0.0148$
10	*Tectona grandis*	$BE_1 = 400.7901\ D^2 + 154.6186\ D - 10.3648$ $BE_2 = 0.8874\ D^2 + 7.7946\ D + 0.2524$ $BE_3 = 0.0236\ D_1^3 - 0.0907\ D_1^2 + 0.1486\ D_1 + 0.7882$ $BE_4 = 0.0121\ D_1^2 - 0.0132\ D_1 + 0.0450$
11	*Butea monosperma* Syn. *Butea frondosa*	$BE_1 = 370.0886\ D^2 - 109.6483\ D + 17.2888$ $BE_2 = 60.7797\ D^2 - 17.5339\ D + 2.3183$ $BE_3 = 0.0863\ D_1^2 - 0.0040\ D_1 + 0.5788$ $BE_4 = 0.0033\ D_1^2 + 0.0519\ D_1 + 0.1722$

South Deccan

S.No.	Species Name	Biomass Equation
1	*Tectona grandis*	$BE_1 = 539.6789\ D^2 - 91.0556\ D + 27.1753$ $BE_2 = 25.3092\ D^2 + 0.7069\ D + 0.5550$ $BE_3 = 0.2044\ D_1^2 + 1.0601\ D_1 - 1.2801$ $BE_4 = 0.0080\ D_1^2 + 0.0186\ D_1 + 0.0267$
2	*Anogeissus latifolia*	$BE_1 = 527.5528\ D^2 + 190.9378\ D - 6.3153$ $BE_2 = 1.8701\ D^2 + 2.0075\ D - 0.0042$ $BE_3 = 0.1675\ D_1^2 + 0.5589\ D_1 + 0.7879$ $BE_4 = 0.0025\ D_1^2 + 0.0046\ D_1 + 0.0086$
3	*Terminalia crenulata/ T. tomentosa*	$BE_1 = 810.6925\ D^2 - 139.3736\ D + 36.0631$ $BE_2 = 5.5404\ D^2 + 2.6344\ D + 0.0470$ $BE_3 = 0.2952\ D_1^2 - 0.5102\ D_1 + 1.4387$ $BE_4 = 0.0021\ D_1^2 - 0.0009\ D_1 + 0.0157$
4	*Albizia amara*	$BE_1 = -31.5487\ D^2 + 88.5829\ D + 1.3364$ $BE_2 = -0.6411\ D^2 + 2.7919\ D + 0.0396$ $BE_3 = 0.0363\ D_1^2 + 1.4877\ D_1 - 0.7142$ $BE_4 = 0.0012\ D^2 + 0.0209\ D_1 + 0.0161$
5	*Chloroxylon swietenia*	$BE_1 = 488.0505\ D^2 + 33.6399\ D + 15.4392$ $BE_2 = 14.1500\ D^2 - 0.9931\ D + 0.4151$ $BE_3 = 0.3823\ D_1^2 - 1.2603\ D_1 + 1.8184$ $BE_4 = 0.0043\ D_1^2 - 0.0183\ D_1 + 0.0393$
6	*Dalbergia lanceolaria* Syn. *D. paniculata*	$BE_1 = -102.7024\ D^2 + 293.0061\ D - 11.0535$ $BE_2 = -9.9474\ D^2 + 15.0404\ D - 0.1593$ $BE_3 = 0.2463\ D_1^2 - 0.3225\ D_1 + 0.5993$ $BE_4 = 0.0072\ D_1^2 + 0.0776\ D_1 - 0.0471$
7	*Eucalyptus* sp.	$BE_1 = 1992.5579\ D^2 - 569.1502\ D + 58.6038$ $BE_2 = 108.9443\ D^2 - 30.6000\ D + 3.4514$ $BE_3 = 0.1846\ D_1^2 + 0.6850\ D_1 - 0.6812$ $BE_4 = 0.0169\ D_1^2 + 0.0038\ D_1 + 0.0106$
8	*Butea monosperma* Syn. *Butea frondosa*	$BE_1 = -112.9531\ D^2 + 137.3176\ D - 6.7571$ $BE_2 = -21.0604\ D^2 + 28.5709\ D - 1.8295$ $BE_3 = 0.0459\ D_1^2 + 0.4265\ D_1 - 0.4595$ $BE_4 = 0.0011\ D_1^2 + 0.0548\ D_1 - 0.0031$
9	*Lagerstroemia lanceolata* Syn. *L. microcarpa*	$BE_1 = 100.9008\ D^2 + 84.8999\ D + 4.2891$ $BE_2 = 8.7374\ D^2 + 6.2665\ D - 0.4480$ $BE_3 = 0.1927\ D_1^2 + 0.4646\ D_1 + 0.1709$ $BE_4 = 0.0026\ D_1^2 + 0.0024\ D_1 + 0.0440$
10	*Hardwickia binata*	$BE_1 = 111.0238\ D^2 + 88.3600\ D + 5.3628$ $BE_2 = -2.4828\ D^2 + 13.0998\ D - 0.2666$ $BE_3 = 0.2426\ D_1^2 + 0.1704\ D_1 - 0.2384$ $BE_4 = 0.0128\ D_1^2 + 0.0298\ D_1 - 0.0483$
11	*Wrightia tinctoria*	$BE_1 = 844.1903\ D^2 - 209.0971\ D + 22.2997$ $BE_2 = 32.1939\ D^2 - 5.8653\ D + 0.8683$ $BE_3 = 0.1241\ D_1^2 + 0.3036\ D_1 - 0.2649$ $BE_4 = 0.0054\ D_1^2 + 0.0148\ D_1 - 0.0268$
12	*Syzygium cumini*	$BE_1 = 855.3180\ D^2 - 242.6737\ D + 46.4286$ $BE_2 = 53.5761\ D^2 - 11.0837\ D + 2.0611$ $BE_3 = 0.1650\ D_1^2 + 1.5328\ D_1 - 1.9294$ $BE_4 = 0.0108\ D_1^2 + 0.0597\ D_1 - 0.0420$

Western Ghats

S.No.	Species Name	Biomass Equation
1	*Tectona grandis*	$BE_1 = 426.4085\ D^2 - 65.3303\ D + 30.9354$ $BE_2 = 4.0598\ D^2 + 1.0953\ D + 0.3664$ $BE_3 = 0.3533\ D_1^2 + 0.1121\ D_1 - 0.3794$ $BE_4 = 0.0015\ D_1^2 + 0.0013\ D_1 + 0.0066$
2	*Anogeissus latifolia*	$BE_1 = 1983.9425\ D^3 - 1588.1130\ D^2 + 533.6380\ D - 23.3952$ $BE_2 = 6.6210\ D^2 - 1.2689\ D + 0.4737$ $BE_3 = 0.3349\ D_1^2 - 0.3465\ D_1 + 1.9953$ $BE_4 = 0.0012\ D_1^2 + 0.0045\ D_1 + 0.0504$
3	*Terminalia crenulata/ T. tomentosa*	$BE_1 = 1815.5165 - 1348.7147\ D^2 + 594.0835\ D - 29.0793$ $BE_2 = 44.8486\ D^2 - 8.7590\ D + 1.2305$ $BE_3 = 0.4186\ D_1^2 - 1.3886\ D_1 + 2.4775$ $BE_4 = 0.0105\ D_1^2 - 0.0363\ D_1 + 0.1030$
4	*Holarrhena pubescens* Syn. *H. antidysenterica*	$BE_1 = 140.3103\ D^2 + 199.3693\ D - 8.2801$ $BE_2 = 6.6914\ D^2 + 11.6819\ D - 0.7106$ $BE_3 = 0.1875\ D_1^2 + 0.4663\ D_1 + 1.2023$ $BE_4 = 0.0656\ D_1 - 0.0051$
5	*Terminalia paniculata*	$BE_1 = 362.5509\ D^2 + 278.3135\ D - 17.7837$ $BE_2 = 8.1731\ D^2 + 10.4816\ D - 0.7031$ $BE_3 = 0.2724\ D_1^2 - 0.0125\ D_1 - 0.0558$ $BE_4 = 0.0064\ D_1^2 - 0.0052\ D_1 + 0.0306$
6	*Macaranga peltata*	$BE_1 = -351.6206\ D^2 + 698.1528\ D - 49.8923$ $BE_2 = -17.3870\ D^2 + 43.6160\ D - 3.0387$ $BE_3 = 0.2502\ D_1^2 + 0.1864\ D_1 - 0.4365$ $BE_4 = 0.0208\ D_1^2 - 0.0584\ D_1 + 0.0589$
7	*Syzygium cumini*	$BE_1 = 1720.1630\ D^2 - 423.8031\ D + 49.9381$ $BE_2 = 30.1113\ D^3 + 47.5624\ D^2 - 12.5773\ D + 2.7618$ $BE_3 = 0.4284\ D_1^2 - 1.4660\ D_1 + 2.4189$ $BE_4 = 0.0222\ D_1^2 - 0.0127\ D_1 + 0.0632$
8	*Schleichera trijuga/ S.oleosa*	$BE_1 = -23.7715\ D^2 + 374.0009\ D - 11.3382$ $BE_2 = 13.2675\ D^2 + 10.6145\ D + 0.7554$ $BE_3 = 0.5121\ D_1^2 - 1.2087\ D_1 + 1.9627$ $BE_4 = 0.0058\ D_1^2 + 0.1484\ D_1 + 0.0070$
9	*Myristica malabarica*	$BE_1 = 368.3320\ D^2 + 159.3366\ D + 7.8771$ $BE_2 = 16.2036\ D^2 + 5.4228\ D + 1.5594$ $BE_3 = 0.3164\ D_1^2 + 0.3275\ D_1 + 0.2305$ $BE_4 = 0.0340\ D_1^2 - 0.1066\ D_1 + 0.2631$
10	*Artocarpus heterophyllus* Syn. *Artocarpus integrifolia*	$BE_1 = -187.2610\ D^2 + 496.1925\ D - 31.2311$ $BE_2 = -4.7945\ D^2 + 26.9481\ D - 1.5618$ $BE_3 = 0.3121\ D_1^2 - 0.7693\ D_1 + 1.1439$ $BE_4 = 0.0197\ D_1^2 - 0.0557\ D_1 + 0.1090$
11	*Pinus patula*	$BE_1 = 593.5119\ D^2 + 67.7435\ D + 6.1820$ $BE_2 = 91.3057\ D^2 - 13.2752\ D + 2.3799$ $BE_3 = 0.3316\ D_1^2 + 0.5356\ D_1 - 0.2299$ $BE_4 = 0.0117\ D_1^2 + 0.1553\ D_1 - 0.0117$
12	*Lagerstroemia lanceolata* Syn. *L. microcarpa*	$BE_1 = -123.7223\ D^2 + 290.7752\ D - 13.5650$ $BE_2 = -2.7947\ D^2 + 7.1714\ D - 0.3286$ $BE_3 = 0.2400\ D_1^2 - 0.1514\ D_1 + 0.7339$ $BE_4 = 0.0041\ D_1^2 - 0.0095\ D_1 + 0.0495$

13	*Olea dioica*	$BE_1 = 362.7717\ D^2 + 210.9870\ D - 12.1988$ $BE_2 = 23.3807\ D^2 + 3.2779\ D + 0.2784$ $BE_3 = 0.1892\ D_1^2 + 0.4478\ D_1 - 0.0970$ $BE_4 = 0.0037\ D_1^2 + 0.0383\ D_1 + 0.0399$
14	*Aporosa cardiosperma* Syn. *A. lindleyana*	$BE_1 = 530.3446\ D^2 - 110.2824\ D + 24.3668$ $BE_2 = 35.9394\ D^2 - 2.9608\ D + 0.8623$ $BE_3 = 0.2798\ D_1^2 + 0.0430\ D_1 + 0.0606$ $BE_4 = 0.0107\ D_1^2 + 0.0178\ D_1 - 0.0003$
15	*Palaquim ellipticum*	$BE_1 = 775.1896\ D^2 + 125.0958\ D - 6.8587$ $BE_2 = 110.1075\ D^2 - 30.0260\ D + 2.9517$ $BE_3 = 0.0466\ D_1^3 - 0.3060\ D_1^2 + 1.4217\ D_1 - 0.3071$ $BE_4 = 0.0020\ D_1^3 - 0.0205\ D_1^2 + 0.0923\ D_1 + 0.0019$
16	*Xylia xylocarpa*	$BE_1 = 568.7019\ D^2 - 55.8345\ D + 21.9233$ $BE_2 = 41.5004\ D^2 - 8.6750\ D + 1.3020$ $BE_3 = 0.2545\ D_1^2 + 0.2466\ D_1 + 0.0771$ $BE_4 = 0.0093\ D_1^2 - 0.0287\ D_1 + 0.0676$
17	*Acrocarpus fraxinifolius*	$BE_1 = 461.9579\ D^2 - 2.3924\ D + 13.4012$ $BE_2 = 6.3026\ D^2 + 7.7195\ D + 0.1565$

Eastern Ghats

S.No.	Species Name	Biomass Equation
1	*Anogeissus latifolia*	$BE_1 = -121.0216\ D^2 + 500.9042\ D - 28.9668$ $BE_2 = -5.4172\ D^2 + 25.3317\ D - 1.9576$ $BE_3 = 0.3864\ D_1^2 - 0.1017\ D_1 + 0.6930$ $BE_4 = 0.0119\ D_1^2 - 0.0244\ D_1 + 0.0553$
2	*Pterocarpus marsupium*	$BE_1 = 110.8192\ D^2 + 214.1240\ D + 3.5771$ $BE_2 = 4.2573\ D^2 + 1.6800\ D + 0.9568$ $BE_3 = 0.4878\ D_1^2 - 0.9367\ D_1 + 0.5848$ $BE_4 = 0.0143\ D_1^2 - 0.0025\ D_1 + 0.0594$
3	*Xylia xylocarpa*	$BE_1 = -496.1913\ D^3 + 1071.5492\ D^2 - 165.4776\ D + 23.4904$ $BE_2 = 14.0701\ D^2 + 3.9727\ D + 0.3602$ $BE_3 = 0.1199\ D_1^2 + 1.2698\ D_1 - 0.1217$ $BE_4 = 0.0048\ D_1^2 + 0.0336\ D_1 + 0.1327$
4	*Lannea coromandelica* Syn. *Lannea grandis*	$BE_1 = 271.6220\ D^2 - 40.3564\ D + 19.9687$ $BE_2 = 11.1041\ D^2 - 1.5074\ D + 0.6238$ $BE_3 = 0.2214\ D_1^2 - 0.3856\ D_1 + 1.0501$ $BE_4 = 0.0083\ D_1^2 - 0.0262\ D_1 + 0.0415$
5	*Albizia amara*	$BE_1 = -386.5990\ D^3 + 671.8284\ D^2 - 31.9297\ D + 13.2123$ $BE_2 = 9.0211\ D^2 + 0.9626\ D + 0.6121$ $BE_3 = 0.2472\ D_1^2 - 0.4306\ D_1 + 1.1724$ $BE_4 = 0.0103\ D_1^2 - 0.0305\ D_1 + 0.0394$
6	*Terminalia crenulata/ T. tomentosa*	$BE_1 = -40.7829\ D^2 + 287.6667\ D - 6.1942$ $BE_2 = 5.9678\ D^2 + 12.1631\ D - 0.0384$ $BE_3 = 0.2815\ D_1^2 + 0.1622\ D_1 - 0.3747$ $BE_4 = 0.0084\ D_1^2 + 0.0047\ D_1 + 0.0684$
7	*Syzygium cumini*	$BE_1 = 986.1005\ D^2 - 92.1288\ D + 33.8089$ $BE_2 = 11.5552\ D^2 + 17.0550\ D - 0.7249$ $BE_3 = 0.4195\ D_1^2 - 1.3629\ D_1 + 2.2772$ $BE_4 = 0.0120\ D_1^2 + 0.0650\ D_1 - 0.0304$

8	*Protium caudatum*	$BE_1 = -62.6698 D^2 + 247.9972 D + 0.1338$ $BE_2 = 11.8728 D^2 - 2.2968 D + 1.2622$ $BE_3 = 0.3017 D_1^2 - 0.2789 D_1 + 1.2292$ $BE_4 = 0.0050 D_1^2 + 0.0070 D_1 + 0.1057$
9	*Tectona grandis*	$BE_1 = -169.7104 D^2 + 395.4129 D - 20.4598$ $BE_2 = -1.0487 D^2 + 5.7623 D + 0.0875$ $BE_3 = 0.3080 D_1^2 - 0.2848 D_1 + 1.2549$ $BE_4 = 0.0439 D_1 + 0.0603$
10	*Buchanania cochincinensis* Syn. *B. latifolia* Syn. *B. lanzan*	$BE_1 = 514.5816 D^2 - 110.3860 D + 19.3994$ $BE_2 = 26.1420 D^2 - 1.3736 D + 0.1491$ $BE_3 = 0.1721 D_1^2 - 0.1164 D_1 + 1.0897$ $BE_4 = 0.0029 D_1^2 - 0.0005 D_1 + 0.0924$
11	*Semecarpus anacardium*	$BE_1 = 238.3735 D^2 + 154.6146 D + 0.4939$ $BE_2 = -145.9652 D^3 + 152.4208 D^2 - 20.6768 D + 1.1954$ $BE_3 = 0.4337 D_1^2 - 1.7265 D_1 + 2.9325$ $BE_4 = 0.0015 D_1^2 + 0.0480 D_1 + 0.0867$
12	*Memecylon angustifolium*	$BE_1 = 1066.9594 D^2 + 17.0450 D + 8.6471$ $BE_2 = 115.6513 D^2 - 21.8666 D + 2.4348$ $BE_3 = 0.2995 D_1^2 - 0.6521 D_1 + 1.0513$ $BE_4 = 0.0095 D_1^2 + 0.0629 D_1 - 0.0146$
13	*Eucalyptus globulus*	$BE_1 = 557.4072 D^2 - 32.8449 D + 7.5162$ $BE_2 = 40.1676 D^2 - 10.4524 D + 1.5134$ $BE_3 = 0.0473 D_1^2 + 1.4532 D_1 - 0.9075$ $BE_4 = 0.0064 D_1^2 + 0.0264 D_1 + 0.0089$
14	*Grewia tilifolia*	$BE_1 = 1,088.6600 D^2 - 295.8026 D + 31.3839$ $BE_2 = 31.8648 D^2 - 5.8728 D + 0.9027$ $BE_3 = 0.1080 D_1^2 + 0.0197 D_1 + 0.3650$ $BE_4 = 0.0027 D_1^2 + 0.0187 D_1 + 0.0524$
15	*Albizia* sp.	$BE_1 = -0.5537 D^2 + 311.6459 D - 17.5544$ $BE_2 = 13.3705 D^2 + 3.3486 D - 0.0903$ $BE_3 = 0.2918 D_1^2 - 0.3776 D_1 + 0.3181$ $BE_4 = 0.0012 D_1^2 + 0.0382 D_1 + 0.0381$
16	*Chloroxylon swietenia*	$BE_1 = -37.7511 D^2 + 567.6453 D - 32.7446$ $BE_2 = -30.8783 D^2 + 33.6090 D - 1.5800$ $BE_3 = 0.4783 D_1^2 - 1.7953 D_1 + 2.8131$ $BE_4 = 0.0254 D_1^2 - 0.0856 D_1 + 0.1643$
17	*Diospyros melanoxylon*	$BE_1 = 363.4903 D^2 + 63.6002 D + 18.6796$ $BE_2 = 10.6620 D^2 + 1.9007 D + 0.6227$ $BE_3 = 0.4217 D_1^2 - 0.8802 D_1 + 1.7676$ $BE_4 = 0.0118 D_1^2 - 0.0391 D_1 + 0.0988$

West Coast

S.No.	Species Name	Biomass Equation
1	*Terminalia crenulata/ T. tomentosa*	$BE_1 = 129.4544 D^2 + 279.1008 D - 15.8988$ $BE_2 = 3.7497 D^2 + 10.4516 D - 0.4220$ $BE_3 = 0.2705 D_1^2 - 0.5967 D_1 + 0.3978$ $BE_4 = 0.0095 D_1^2 - 0.0183 D_1 + 0.0300$
2	*Tectona grandis*	$BE_1 = -210.8047 D^2 + 363.7074 D - 30.9608$ $BE_2 = -12.3596 D^2 + 19.0225 D - 1.4386$ $BE_3 = 0.0199 D_1^2 + 0.4817 D_1 - 0.0768$ $BE_4 = 0.0024 D_1^2 + 0.0092 D_1 + 0.0005$

3	*Terminalia paniculata*	$BE_1 = 89.4351\ D^2 + 144.8093\ D + 3.4972$ $BE_2 = 1.0052\ D^2 + 5.8501\ D - 0.2071$ $BE_3 = 0.2006\ D_1^2 + 0.0929\ D_1 - 0.1476$ $BE_4 = 0.0036\ D_1^2 + 0.0151\ D_1 - 0.0085$
4	*Anogeissus latifolia*	$BE_1 = 203.6969\ D^2 + 181.8029\ D - 4.7474$ $BE_2 = 19.0048\ D^2 + 2.7890\ D + 0.1024$ $BE_3 = 0.1883\ D_1^2 + 1.2756\ D_1 - 0.8306$ $BE_4 = 0.0127\ D_1^2 - 0.0328\ D_1 + 0.0646$
5	*Lannea coromandelica* Syn. *Lannea grandis*	$BE_1 = 506.4382\ D^2 - 52.4468\ D + 3.0437$ $BE_2 = 7.7513\ D^2 + 0.3448\ D + 0.1622$ $BE_3 = 0.0941\ D_1^2 - 0.2675\ D_1 + 0.8115$ $BE_4 = 0.0020\ D_1^2 + 0.0278\ D_1 + 0.0088$
6	*Wrightia tinctoria*	$BE_1 = 25.0382\ D^2 + 14.3874\ D + 3.4237$ $BE_2 = 2.5184\ D^2 + 1.4471\ D + 0.3444$ $BE_3 = 0.0188\ D_1^2 + 0.3085\ D_1 - 0.2230$ $BE_4 = 0.0034\ D_1^2 + 0.0226\ D_1 - 0.0197$
7	*Bombax ceiba*	$BE_1 = 199.7191\ D^2 + 40.5382\ D + 2.7931$ $BE_2 = 5.1029\ D^2 + 1.0464\ D + 0.0809$ $BE_3 = 0.0694\ D_1^2 + 0.5091\ D_1 - 0.1759$ $BE_4 = 0.0004\ D_1^2 + 0.0318\ D_1 + 0.0309$
8	*Terminalia bellirica*	$BE_1 = 266.6358\ D^2 + 290.2640\ D - 23.9759$ $BE_2 = 5.2817\ D^2 + 7.7464\ D - 0.0264$ $BE_3 = 0.1241\ D_1^2 + 0.7381\ D_1 - 0.8244$ $BE_4 = 0.0021\ D_1^2 + 0.0313\ D_1 - 0.0278$
9	*Xylia xylocarpa*	$BE_1 = 339.0974\ D^2 + 152.6241\ D - 7.9297$ $BE_2 = 11.2178\ D^2 + 3.3692\ D + 0.2132$ $BE_3 = 0.1214\ D_1^2 + 0.3886\ D_1 + 1.4836$ $BE_4 = 0.0046\ D_1^2 + 0.0077\ D_1 + 0.1764$
10	*Careya arborea*	$BE_1 = 458.3502\ D^2 - 89.9168\ D + 10.8998$ $BE_2 = 36.5716\ D^2 - 7.1744\ D + 0.8697$ $BE_3 = 0.0434\ D_1^2 + 0.8321\ D_1 - 0.8767$ $BE_4 = 0.0140\ D_1^2 - 0.0328\ D_1 + 0.0291$
11	*Bridelia retusa* Syn. *B. squamosa*	$BE_1 = 274.2959\ D^2 - 15.3477\ D + 6.6623$ $BE_2 = 4.3652\ D^2 + 5.8977\ D + 0.0525$ $BE_3 = 0.7561\ D_1 + 0.0612$ $BE_4 = 0.0081\ D_1^2 - 0.0285\ D_1 + 0.0630$
12	*Boswellia serrata*	$BE_1 = -645.0798\ D^3 + 1113.3680\ D^2 - 259.1198\ D + 27.2892$ $BE_2 = -34.4889\ D^3 + 59.3882\ D^2 - 14.6827\ D + 1.5184$ $BE_3 = 0.1294\ D_1^2 - 0.0842\ D_1 + 0.1589$ $BE_4 = 0.0037\ D_1^2 + 0.0198\ D_1 + 0.0092$
13	*Acacia catechu*	$BE_3 = 0.1804\ D_1^2 - 0.1351\ D_1 + 0.0823$ $BE_4 = 0.0077\ D_1^2 - 0.0163\ D_1 + 0.0109$

East Coast

S.No.	Species Name	Biomass Equation
1	*Anogeissus latifolia*	$BE_1 = 674.1855\ D^2 - 110.5556\ D + 29.0428$ $BE_2 = 33.2586\ D^3 - 19.0005\ D^2 + 8.5843\ D + 0.1585$ $BE_3 = 0.3659\ D_1^2 - 0.4339\ D_1 + 2.8980$ $BE_4 = 0.0109\ D_1^2 - 0.0210\ D_1 + 0.0506$

2	*Chloroxylon swietenia*	$BE_1 = 765.2303\ D^2 + 168.2262\ D - 3.0852$ $BE_2 = 8.9006\ D^2 + 9.2803\ D + 0.2925$ $BE_3 = 0.3048\ D_1^2 + 0.0510\ D_1 + 1.3016$ $BE_4 = 0.0192\ D_1^2 - 0.0604\ D_1 + 0.1462$
3	*Hardwickia binata*	$BE_1 = 77.1275\ D^2 + 151.8085\ D - 3.8947$ $BE_2 = 16.5442\ D^2 + 2.5420\ D + 0.2356$ $BE_3 = 0.2191\ D_1^2 - 0.4328\ D_1 + 1.0074$ $BE_4 = 0.0135\ D_1^2 - 0.0276\ D_1 + 0.0517$
4	*Lannea coromandelica* Syn. *Lannea grandis*	$BE_1 = 432.2980\ D^2 - 76.6868\ D + 19.1344$ $BE_2 = 14.5699\ D^2 - 2.4830\ D + 0.7867$ $BE_3 = 0.3170\ D_1^2 - 0.9568\ D_1 + 1.4400$ $BE_4 = 0.0098\ D_1^2 - 0.0331\ D_1 + 0.0500$
5	*Terminalia crenulata/ T. tomentosa*	$BE_1 = 53.1260\ D^2 + 168.7540\ D - 4.2270$ $BE_2 = 8.2135\ D^2 + 10.4334\ D - 0.2935$ $BE_3 = 0.3285\ D_1^2 - 0.8470\ D_1 + 1.5459$ $BE_4 = 0.0056\ D_1^2 + 0.0240\ D_1 + 0.0470$
6	*Albizia amara*	$BE_3 = 0.1924\ D_1^2 + 0.8919\ D_1 - 1.3365$ $BE_4 = 0.0117\ D_1^2 - 0.0395\ D_1 + 0.0487$
7	*Boswellia serrata*	$BE_1 = 131.8646\ D^2 + 151.2382\ D - 6.7430$ $BE_2 = 5.7979\ D^2 + 7.9756\ D - 0.1766$ $BE_3 = 0.1619\ D_1^2 + 0.0616\ D_1 + 0.1171$ $BE_4 = 0.0102\ D_1^2 - 0.0267\ D_1 + 0.0624$
8	*Pterocarpus marsupium*	$BE_1 = 36.2830\ D^2 + 180.2650\ D + 6.6087$ $BE_2 = 2.3214\ D^2 + 3.1932\ D + 0.6980$ $BE_3 = 0.4378\ D_1^2 - 1.2914\ D_1 + 1.6650$ $BE_4 = 0.0047\ D_1^2 + 0.0659\ D_1 - 0.0257$
9	*Ziziphus xylopyrus*	$BE_1 = 700.8008\ D^2 - 165.1396\ D + 18.5104$ $BE_2 = 9.8070\ D^2 - 1.2673\ D + 0.2926$ $BE_3 = 0.0610\ D_1^2 + 0.7082\ D_1 + 0.0818$ $BE_4 = 0.0049\ D_1^2 - 0.0135\ D_1 + 0.0390$
10	*Dalbergia lanceolaria* Syn. *D. paniculata*	$BE_1 = 843.0770\ D^2 - 201.6857\ D + 31.5918$ $BE_2 = 18.1052\ D^2 + 1.8575\ D + 0.3899$ $BE_3 = 0.2468\ D_1^2 - 0.3282\ D_1 + 0.6072$ $BE_4 = 0.0091\ D_1^2 + 0.0517\ D_1 - 0.0079$
11	*Grewia* sp.	$BE_1 = 431.9626\ D^2 + 42.0418\ D + 5.3807$ $BE_2 = 23.9226\ D^2 - 1.6761\ D + 0.4293$ $BE_3 = 0.2228\ D_1^2 - 0.2016\ D_1 + 0.7210$ $BE_4 = 0.0039\ D_1^2 + 0.0185\ D_1 + 0.0143$
12	*Dolichandrone falcata*	$BE_3 = 0.2869\ D_1^2 - 0.7273\ D_1 + 1.1723$
13	*Grewia tilifolia*	$BE_1 = 774.4589\ D^2 - 116.1260\ D + 18.3122$ $BE_2 = 36.5148\ D^2 - 7.4833\ D + 0.8974$ $BE_3 = 0.1224\ D_1^2 + 0.5551\ D_1 - 0.5487$ $BE_4 = 0.0021\ D_1^2 + 0.0203\ D_1 + 0.0515$
14	*Tectona grandis*	$BE_1 = 621.9517\ D^2 - 154.0887\ D + 25.0716$ $BE_2 = 9.0619\ D^2 - 1.0880\ D + 0.5854$ $BE_3 = 0.3555\ D_1^2 - 1.1680\ D_1 + 1.8808$ $BE_4 = 0.0017\ D_1^2 + 0.0248\ D_1 + 0.0803$
15	*Sterculia urens*	$BE_1 = -48.6227\ D^2 + 94.6488\ D - 0.0630$ $BE_2 = -0.0177\ D^2 + 4.8882\ D - 0.0948$ $BE_3 = 0.1480\ D_1^2 + 0.0066\ D_1 + 0.5951$ $BE_4 = 0.0010\ D_1^2 + 0.0366\ D_1 - 0.0128$

16	*Diospyros* sp.	$BE_1 = 164.0576\ D^2 + 98.0941\ D + 1.3802$ $BE_2 = 7.4373\ D^2 + 3.4612\ D - 0.0140$ $BE_3 = 0.1460\ D_1^2 + 0.1213\ D_1 + 0.8565$ $BE_4 = 0.0060\ D_1^2 - 0.0218\ D_1 + 0.0310$
17	*Wrightia tinctoria*	$BE_1 = 111.7943\ D^2 + 0.7670\ D + 4.4363$ $BE_2 = 8.5389\ D^2 + 0.8670\ D + 0.3686$ $BE_3 = 0.0539\ D_1^2 + 0.1154\ D_1 + 0.4646$ $BE_4 = 0.0048\ D_1^2 + 0.0126\ D_1 - 0.0080$
18	*Acacia sundra*	$BE_1 = -46.9981\ D^2 + 148.5105\ D + 1.1821$ $BE_2 = -1.0538\ D^2 + 4.4842\ D + 0.0021$ $BE_3 = 0.1821\ D_1^2 + 0.2052\ D_1 + 1.7224$ $BE_4 = 0.0081\ D_1^2 - 0.0249\ D_1 + 0.0269$

Annex III SPECIFIC GRAVITY OF MAJOR SPECIES

Both density and specific gravity describe mass and may be used to compare different substances. Density is a property of matter and can be defined as the ratio of mass to a unit volume of matter. It's typically expressed in units of grams per cubic centimeter, kilograms per cubic meter, or pounds per cubic inch.

Specific gravity is the density of a substance divided by the density of water. Since (at standard temperature and pressure) water has a density of 1 $gram/cm^3$, and since all of the units cancel, specific gravity is usually very close to the same value as density (but without any units). Information on specific gravity for most of the Indian tree species is available in literature. Therefore, Specific gravity has been used in place of Wood Density

Species	Specific Gravity (i.e. wt. oven dry/vol. green)
Acacia catechu	0.875
Acacia leucophloea	0.660
Aegle marmelos	0.754
Anogeissus latifolia	0.799
Azadirachta indica	0.693
Bauhinia malabarica	0.670
Bridelia retusa	0.499
Buchanania cochinchinensis	0.458
Butea monosperma	0.465
Casearia tomentosa	0.620
Cassia fistula	0.746
Chloroxylon swietenia	0.771
Dalbergia latifolia	0.750
Dalbergia paniculata	0.640
Diospyros melanoxylon	0.678
Gardenia latifolia	0.635
Grewia tilifolia	0.679
Haldina cordifolia	0.597
Lagerstroemia parviflora	0.620

Species	Specific Gravity (i.e. wt. oven dry/vol. green)
Lannea coromandelica	0.513
Madhuca longifolia	0.740
Ougenia oojeinensis	0.704
Phyllanthus emblica	0.800
Pterocarpus marsupium	0.649
Saccopetalum tomentosum	0.615
Semecarpus anacardium	0.640
Schleichera oleosa	0.841
Soymida febrifuga	0.963
Syzygium cumini	0.647
Tamarindus indica	0.750
Tectona grandis	0.563
Terminalia bellirica	0.628
Terminalia chebula	0.642
Terminalia tomentosa	0.730

Source: Rajput et al., 1996

Annex IV EXAMPLE OF DATA ANALYSIS

Tree Analysis

Tree ID	Local Name	Botanical Name	CBH (cm)	Height (m)	D (cm)	D (m)	Sqrt D	D^2	D^3	Sqrt V	V/D^2	V (m^3)	V (m^3/ha)	WD	Bole Biomass (BB)(t/ha)	BE1 (Kg)	BE2 (Kg)	B (Kg)	B (t)	AGB (BB+B) (t/ha)
1	Mahua	*Madhuca longifolia*	120	15	38.22	0.38	0.62	0.15	0.06			0.6	5.99	0.74	4.44	119.8	2.05	121.81	0.12	4.56
2	Lendia	*Lagerstroemia parviflora*	32	8	10.19	0.1	0.32	0.01	0			0.03	0.33	0.62	0.2	6.85	0.52	7.38	0.01	0.21
3	Char	*Buchanania cochinchinensis*	88	12	28.03	0.28	0.53	0.08	0.02			0.33	3.26	0.46	1.49	37.02	2.46	39.48	0.04	1.53
4	Kari	*Saccopetalum tomentosum*	60	10	19.11	0.19	0.44	0.04	0.01	0.4		0.16	1.58	0.62	0.97	25.69	1.34	27.03	0.03	1
5	Kari	*Saccopetalum tomentosum*	52	10	16.56	0.17	0.41	0.03	0	0.33		0.11	1.09	0.62	0.67	18.65	1.07	19.72	0.02	0.69
6	Lendia	*Lagerstroemia parviflora*	32	8	10.19	0.1	0.32	0.01	0			0.03	0.33	0.62	0.2	6.85	0.52	7.38	0.01	0.21
7	Dudhai	*Wrigh tiatinctoria*	55	8	17.52	0.18	0.42	0.03	0.01	0.31		0.09	0.95	0.75	0.71	12.66	0.45	13.11	0.01	0.73
8	Dudhai	*Wrightia tinctoria*	40	8	12.74	0.13	0.36	0.02	0	0.2		0.04	0.41	0.75	0.31	8.66	0.28	8.94	0.01	0.31
9	Saja	*Terminalia tomentosa*	130	20	41.4	0.41	0.64	0.17	0.07			1.58	15.8	0.73	11.53	123.2	4.5	127.72	0.13	11.66
10	Mahua	*Madhucalongifolia*	92	10	29.3	0.29	0.54	0.09	0.03			0.33	3.29	0.74	2.43	84.3	1.5	85.8	0.09	2.52
11	Char	*Buchanania cochinchinensis*	102	12	32.48	0.32	0.57	0.11	0.03			0.46	4.6	0.46	2.11	46.7	3.12	49.82	0.05	2.16
12	Kosam	*Schleicheraoleosa*	136	13	43.31	0.43	0.66	0.19	0.08			1.75	17.53	0.84	14.74	133.5	4.73	138.25	0.14	14.88
13	Mahua	*Madhuca longifolia*	100	12	31.85	0.32	0.56	0.1	0.03			0.4	3.99	0.74	2.95	94.11	1.65	95.76	0.1	3.05
14	Saja	*Terminalia tomentosa*	42	10	13.38	0.13	0.37	0.02	0			0.1	0.99	0.73	0.73	24.4	0.98	25.39	0.03	0.75
15	Lendia	*Lagerstroemia parviflora*	56	10	17.83	0.18	0.42	0.03	0.01			0.13	1.25	0.62	0.78	24.59	1.21	25.8	0.03	0.8
16	Lendia	*Lagerstroemia parviflora*	32	11	10.19	0.1	0.32	0.01	0			0.03	0.33	0.62	0.2	6.85	0.52	7.38	0.01	0.21
17	Char	*Buchanania cochinchinensis*	68	10	21.66	0.22	0.47	0.05	0.01			0.18	1.76	0.46	0.8	24.73	1.69	26.42	0.03	0.83
18	Char	*Buchanania cochinchinensis*	52	10	16.56	0.17	0.41	0.03	0			0.09	0.91	0.46	0.41	16.21	1.23	17.44	0.02	0.43
19	Mahua	*Madhuca longifolia*	48	6	15.29	0.15	0.39	0.02	0			0.05	0.5	0.74	0.37	34.97	0.63	35.61	0.04	0.41
20	Mahua	*Madhuca longifolia*	52	8	16.56	0.17	0.41	0.03	0			0.07	0.68	0.74	0.5	39.14	0.71	39.85	0.04	0.54
21	Mahua	*Madhuca longifolia*	48	10	15.29	0.15	0.39	0.02	0			0.05	0.5	0.74	0.37	34.97	0.63	35.61	0.04	0.41
22	Kari	*Saccopetalum tomentosum*	32	10	10.19	0.1	0.32	0.01	0	0.21		0.04	0.42	0.62	0.26	4.61	0.47	5.08	0.01	0.26
23	Mahua	*Madhuca longifolia*	32	10	10.19	0.1	0.32	0.01	0		3.95	0.04	0.41	0.74	0.3	18.98	0.32	19.3	0.02	0.32
24	Mahua	*Madhuca longifolia*	52	10	16.56	0.17	0.41	0.03	0			0.07	0.68	0.74	0.5	39.14	0.71	39.85	0.04	0.54
25	Mahua	*Madhuca longifolia*	34	10	10.83	0.11	0.33	0.01	0		4.01	0.05	0.47	0.74	0.35	20.92	0.36	21.28	0.02	0.37
26	Mahua	*Madhuca longifolia*	38	10	12.1	0.12	0.35	0.01	0			0.01	0.11	0.74	0.08	24.86	0.44	25.29	0.03	0.11
27	Mahua	*Madhuca longifolia*	66	11	21.02	0.21	0.46	0.04	0.01			0.14	1.43	0.74	1.05	54.21	0.99	55.2	0.06	1.11
28	Ghiriya	*Chloroxylon swietenia*	96	10	30.57	0.31	0.55	0.09	0.03		7.05	0.66	6.59	0.77	5.08	165.5	3.58	169.05	0.17	5.25
29	Kari	*Saccopetalum tomentosum*	46	10	14.65	0.15	0.38	0.02	0	0.28		0.08	0.81	0.62	0.5	13.9	0.88	14.78	0.01	0.51
30	Ghiriya	*Chloroxylonswietenia*	48	10	15.29	0.15	0.39	0.02	0		4.87	0.11	1.14	0.77	0.88	42.95	1.59	44.54	0.04	0.92
31	Ghiriya	*Chloroxylon swietenia*	34	8	10.83	0.11	0.33	0.01	0		4.01	0.05	0.47	0.77	0.36	15	1.01	16.01	0.02	0.38
32	Ghiriya	*Chloroxylon swietenia*	85	10	27.07	0.27	0.52	0.07	0.02		6.72	0.49	4.93	0.77	3.8	133.7	3.12	136.86	0.14	3.93
33	Ghiriya	*Chloroxylon swietenia*	32	10	10.19	0.1	0.32	0.01	0		3.95	0.04	0.41	0.77	0.32	11.29	0.93	12.22	0.01	0.33
34	Lendia	*Lagerstroemia parviflora*	32	10	10.19	0.1	0.32	0.01	0			0.03	0.33	0.62	0.2	6.85	0.52	7.38	0.01	0.21
35	Bija	*Pterocarpus marsupium*	54	10	17.2	0.17	0.41	0.03	0.01	0.49		0.24	2.44	0.65	1.58	20.33	1.14	21.47	0.02	1.61
36	Ghiriya	*Chloroxylon swietenia*	35	10	11.15	0.11	0.33	0.01	0		4.05	0.05	0.5	0.77	0.39	16.88	1.05	17.93	0.02	0.41
37	Ghiriya	*Chloroxylon swietenia*	32	4	10.19	0.1	0.32	0.01	0		3.95	0.04	0.41	0.77	0.32	11.29	0.93	12.22	0.01	0.33
38	Ghiriya	*Chloroxylon swietenia*	58	10	18.47	0.18	0.43	0.03	0.01		5.5	0.19	1.88	0.77	1.45	65.06	2	67.07	0.07	1.52
39	Baheda	*Terminalia bellirica*	50	10	15.92	0.16	0.4	0.03	0	0.4		0.16	1.56	0.63	0.98	25.23	1.17	26.4	0.03	1.01
40	Ghiriya	*Chloroxylon swietenia*	32	10	10.19	0.1	0.32	0.01	0		3.95	0.04	0.41	0.77	0.32	11.29	0.93	12.22	0.01	0.33
41	Mohan	*Lannea coromandelica*	54	10	17.2	0.17	0.41	0.03	0.01		5.42	0.16	1.6	0.51	0.82	27.15	2.33	29.48	0.03	0.85
																				68.18

Sapling Analysis

Tree ID	Local Name	Botanical Name	CBH (cm)	Height (m)	D^1 (cm)	D^1 (cm)	D_1^3 (cm)	BE3 (Kg)	BE4 (Kg)	B=BE3+BE4 (Kg)	B (t/ha)
1	Ghirya	*Chloroxylon swietenia*	26.00	4.00	8.28	68.56		11.28	0.83	12.11	0.01
2	Kari	*Saccopetalum tomentosum*	26.00	6.00	8.28	68.56		15.99	0.70	16.69	0.02
3	Ghirya	*Chloroxylon swietenia*	11.00	4.00	3.50	12.27		1.79	0.18	1.96	0.00
4	Ghirya	*Chloroxylon swietenia*	10.00	3.00	3.18	10.14		1.48	0.15	1.63	0.00
5	Lendia	*Lagerstroemia parviflora*	20.00	4.00	6.37	40.57		4.58	0.20	4.78	0.00
6	Saaj	*Terminalia tomentosa*	26.00	3.00	8.28	68.56		11.60	0.45	12.05	0.01
7	Saaj	*Terminalia tomentosa*	16.00	3.00	5.10	25.96		4.82	0.20	5.02	0.01
8	Lendia	*Lagerstroemia parviflora*	20.00	5.00	6.37	40.57		4.58	0.20	4.78	0.00
9	Ghirya	*Chloroxylon swietenia*	19.00	4.00	6.05	36.61		5.72	0.46	6.18	0.01
10	Ghirya	*Chloroxylon swietenia*	18.00	6.00	5.73	32.86		5.09	0.41	5.50	0.01
11	Ghirya	*Chloroxylon swietenia*	26.00	6.00	8.28	68.56		11.28	0.83	12.11	0.01
12	Ghirya	*Chloroxylon swietenia*	26.00	4.00	8.28	68.56		11.28	0.83	12.11	0.01
13	Ghirya	*Chloroxylon swietenia*	18.00	8.00	5.73	32.86		5.09	0.41	5.50	0.01
14	Lendia	*Lagerstroemia parviflora*	14.00	3.00	4.46	19.88		3.02	0.09	3.12	0.00
15	Lendia	*Lagerstroemia parviflora*	26.00	4.00	8.28	68.56		6.37	0.37	6.74	0.01
16	Ghirya	*Chloroxylon swietenia*	12.00	6.00	3.82	14.61		2.14	0.20	2.34	0.00
17	Saaj	*Terminalia tomentosa*	18.00	3.00	5.73	32.86		5.93	0.24	6.17	0.01
18	Saaj	*Terminalia tomentosa*	28.00	4.00	8.92	79.52		13.33	0.52	13.85	0.01
19	Kari	*Saccopetalum tomentosum*	14.00	6.00	4.46	19.88		7.16	0.27	7.43	0.01
20	Tendu	*Diospyros melanoxylon*	26.00	5.00	8.28	68.56		8.00	0.78	8.78	0.01
21	Ghirya	*Chloroxylon swietenia*	14.00	6.00	4.46	19.88		2.96	0.26	3.22	0.00
22	Ghirya	*Chloroxylon swietenia*	10.00	3.00	3.18	10.14		1.48	0.15	1.63	0.00
23	Ghirya	*Chloroxylon swietenia*	16.00	5.00	5.10	25.96		3.94	0.33	4.27	0.00
24	Ghirya	*Chloroxylon swietenia*	10.00	3.00	3.18	10.14		1.48	0.15	1.63	0.00
25	Ghirya	*Chloroxylon swietenia*	10.00	3.00	3.18	10.14		1.48	0.15	1.63	0.00
26	Ghirya	*Chloroxylon swietenia*	16.00	5.00	5.10	25.96		3.94	0.33	4.27	0.00
27	Ghirya	*Chloroxylon swietenia*	18.00	4.00	5.73	32.86		5.09	0.41	5.50	0.01
28	Lendia	*Lagerstroemia parviflora*	10.00	3.00	3.18	10.14		2.12	0.05	2.17	0.00
29	Lendia	*Lagerstroemia parviflora*	16.00	3.00	5.10	25.96		3.52	0.12	3.64	0.00
30	Ghirya	*Chloroxylon swietenia*	24.00	6.00	7.64	58.42		9.49	0.71	10.20	0.01
31	Moyem	*Lannea coromandelica*	18.00	4.00	5.73	32.86	188.38	2.15	0.46	2.60	0.00
32	Dudhai	*Wrightia tinctoria*	18.00	4.00	5.73	32.86		3.79	0.10	3.89	0.00
33	Ghirya	*Chloroxylon swietenia*	14.00	3.00	4.46	19.88		2.96	0.26	3.22	0.00
34	Ghirya	*Chloroxylon swietenia*	15.00	3.00	4.78	22.82		3.43	0.30	3.73	0.00
35	Tendu	*Diospyros melanoxylon*	22.00	3.00	7.01	49.09		6.46	0.63	7.09	0.01
36	Ghirya	*Chloroxylon swietenia*	10.00	3.00	3.18	10.14		1.48	0.15	1.63	0.00
37	Ghirya	*Chloroxylon swietenia*	20.00	4.00	6.37	40.57		6.39	0.50	6.90	0.01
38	Kari	*Saccopetalum tomentosum*	26.00	8.00	8.28	68.56		15.99	0.70	16.69	0.02
											0.23

Herb Biomass

Plot No.	Sample No.	Actual Fresh Weight (g)	Dry Weight (g)	Total Biomass (t/ha)	Average Herb Biomass (t/ha)
1	H1	80	25.2	0.2520	0.2810
	H2	88	31.8	0.3180	
	H3	60	26.2	0.2620	
	H4	90	29.2	0.2920	

Shrub Biomass

Plot No.	Sample No.	Actual Fresh Weight (g)	Sample Fresh Weight (g)	Dry Weight (g)	Biomass (g/m^2)	Total Biomass (t/ha)	Average Shrub Biomass (t/ha)
1	S1	980	100	40.6	397.88	3.98	2.36
	S2	300	100	25	75.00	0.75	

Aboveground Biomass (AGB) = Tree Biomass + Sapling Biomass + Shrub Biomass + Herb Biomass

AGB (t/ha) = 68.18 +0.23+2.36+0.2810 = 71.05 (t/ha)

Below ground Biomass (BGB)

Below ground biomass = Above ground biomass x Root-Shoot ratio

= 71.05 × 0.28 = 19.89 (t/ha)

Litter Biomass (LB)

Plot No.	Sample No.	Actual Fresh Weight (g)	Sample Fresh Weight (g)	Sample Dry Weight (g)	Biomass (g/m^2)	Total Biomass (t/ha)	Average Litter Biomass (t/ha)
1	L1	760	100	81.4	618.64	6.19	3.40
	L2	240	100	93.2	223.68	2.24	
	L3	190	100	94.6	179.74	1.80	
	L4	340	100	99.4	337.96	3.38	

Dead Wood (DWB)

Plot No.	Sample No.	Actual Fresh Weight (g)	Sample Fresh Weight (g)	Sample Dry Weight (g)	Biomass (g/m^2)	Total Biomass (t/ha)	Average Litter Biomass (t/ha)
1	L21	450	100	91.4	411.30	4.11	4.23
	L22	280	100	97	271.60	2.72	
	L23	760	100	92.6	703.76	7.04	
	L24	340	100	90.2	306.68	3.07	

Total Biomass (TB) = AGB+BGB+LB+DWB

= 71.05+19.89+3.40+4.23 = 98.57 (t/ha)

Vegetation Carbon = TB × 0.47

= 98.57 × 0.47 = 46.33 (t/ha)

Soil Organic Carbon

The amount of organic carbon to 30 cm depth in soil with a carbon value of 1.5 % and bulk density of 1.3g/cm3 is :

15 (g C/kg soil) x 1 300 000 (kg soil/ha) = 58.5 t/ha or

1.5 x 1.3 x 30 = 58.5 t/ha

Adjusting for gravel content

If there is gravel in the soil sample, laboratory results will need to be adjusted as this is taken out before carbon analyses. So if SOC was 1.5% but soil had 25% gravel (by volume) then: 1.5 - (1.5 x 0.25) = 1.1% SOC

Total Carbon = Vegetation Carbon + Soil Organic Carbon

= 46.33 + 58.5= 104.83 (t/ha)

Annex V FIELD DATA COLLECTION FORM FOR FOREST CARBON STOCKS MEASUREMENT

General Information

Plot Number:	Date:
Compartment:	GPS Reading
Forest Range:	
Slope:	Latitude:
Aspect:	Longitude:

A. Trees **Plot Size:** 31.62 m X 31.62 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	CBH (cm)	Height (m)	Remark
1				
2				
3				
4				
5				

B. (a) Saplings : North-West Corner **Plot Size :** 3 m X 3 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	CBH (cm)	Height (m)
1			
2			
3			
4			
5			

B. (b) Saplings : North-East Corner **Plot Size :** 3 m X 3 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	CBH (cm)	Height (m)
1			
2			
3			
4			
5			

B. (c) Saplings : South-East Corner **Plot Size :** 3 m X 3 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	CBH (cm)	Height (m)
1			
2			
3			
4			
5			

B. (d) Saplings : South-West Corner **Plot Size :** 3 m X 3 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	CBH (cm)	Height (m)
1			
2			
3			
4			
5			

C. (a) Shrubs : North-West Corner **Plot Size :** 3 m X 3 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	Fresh Weight (gm)	Sample Fresh Weight (gm)	Sample Code
1				
2				
3				
4				
5				

C. (b) Shrubs : North-East Corner **Plot Size :** 3 m X 3 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	Fresh Weight (gm)	Sample Fresh Weight (gm)	Sample Code
1				
2				
3				
4				
5				

C. (c) Shrubs : South-East Corner

Plot Size : 3 m X 3 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	Fresh Weight (gm)	Sample Fresh Weight (gm)	Sample Code
1				
2				
3				
4				
5				

C. (d) Shrubs : South-West Corner

Plot Size : 3 m X 3 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	Fresh Weight (gm)	Sample Fresh Weight (gm)	Sample Code
1				
2				
3				
4				
5				

D. (a) Herbs : North-West Corner

Plot Size : 1 m X 1 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	Fresh Weight (gm)	Sample Fresh Weight (gm)	Sample Code
1				
2				
3				
4				
5				

D. (b) Herbs : North-East Corner

Plot Size : 1 m X 1 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	Fresh Weight (gm)	Sample Fresh Weight (gm)	Sample Code
1				
2				
3				
4				
5				

D. (c) Herbs : South-East Corner

Plot Size : 1 m X 1 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	Fresh Weight (gm)	Sample Fresh Weight (gm)	Sample Code
1				
2				
3				
4				
5				

D. (d) Herbs : South-West Corner **Plot Size :** 1 m X 1 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	Fresh Weight (gm)	Sample Fresh Weight (gm)	Sample Code
1				
2				
3				
4				
5				

E. Litter **Plot Size :** 3m X 3m

a. North West Corner
   Fresh Weight (gm) = ...
   Sample Fresh Weight (gm) = ...

b. North East Corner
   Fresh Weight (gm) = ...
   Sample Fresh Weight (gm) = ...

c. South East Corner
   Fresh Weight (gm) = ...
   Sample Fresh Weight (gm) = ...

d. South West Corner
   Fresh Weight (gm) = ...
   Sample Fresh Weight (gm) = ...

G. Soil Sample

a. Soil Sample for Bulk Density Sample: Tick below after sample collection :

0-10 cm	10-20 cm	20-30 cm

b. Soil Sample for Soil Organic Carbon :
   North East Corner: Sample Code ....
   South West Corner: Sample Code ....

H. (a) Dead Wood: North-East Corner **Plot Size :** 5 m X 5 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	CBH (cm)	Height (m)
1			
2			
3			
4			
5			

H. (b) Dead Wood: South-West Corner **Plot Size :** 5 m X 5 m

S.No.	Species Name (Hindi/English/Local/Scientific Name)	CBH (cm)	Height (m)
1			
2			
3			
4			
5			

Design & Print
Saraswati Press # 7055053333

Published by :

Biodiversity and Climate Change Division
Indian Council of Forestry Research and Education
P.O. New Forest, Dehradun – 248 006
Web : www.icfre.gov.in

978-81-936157-8-2