Resource Manual

Training Programme for the Staff of Madhya Pradesh Forest Department on

Measurement of Forest Carbon Stocks

under

Ecosystem Services Improvement Project

17-18 June 2019

Indian Council of Forestry Research and Education
P.O. New Forest, Dehradun - 248006

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The background material in this manual is prepared under the Ecosystem Services Improvement Project (ESIP) being implemented by the Indian Council of Forestry Research and Education (ICFRE), Dehra Dun as a reference manual for participants of the two days training programme for Officers of Madhya Pradesh Forest Department on "Forest Carbon Stocks Measurement" from 17-18 June 2019 at Hoshangabad, Madhya Pradesh organized by ESIP, PIU of the Indian Council of Forestry Research and Education, Dehra Dun.

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Definition of some important terms

Carbon pool: A system which has the capacity to accumulate or release carbon. Examples of carbon pools are forest biomass, wood products, soils and atmosphere.

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.

Carbon sequestration: The removal of carbon from the atmosphere and long term storage in sinks, such as marine or terrestrial ecosystems.

Carbon stock: The mass of carbon contained in a carbon pool.

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/m2 or tonnes /ha or multiples.

Carbon: 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.

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 sink: is a carbon pool from which more carbon flows in than out: 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: 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.

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 on a certain period of time.

1. Climate Change and Forests

1.1 Climate Change

Intergovernmental Panel on Climate Change (2014) 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". 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 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 is responsible for the trapping of the outgoing long wave terrestrial radiations into the earth 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 GHG emission increase from 1970 to 2010, with a similar percentage contribution for the period 2000–2010. Various anthropogenic activities have increased GHGs concentration by 10 $GtCO_2eq$ between 2000 and 2010 e.g. energy supply (47%), industry (30%), transport (11%) and buildings (3%) sectors. The recent IPCC report (IPCC, 2018) has highlighted that average global earth's temperature has increased by about 1^0C 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 0.66^0C over 100 years. Extreme events like heat waves have risen in past 30 years (MoEF&CC, 2017).

1.2 Forests and Climate Change

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

The fifth assessment report of IPCC (AR5) estimate that, annual greenhouse gas emission flux from land use and land-use change and forestry activities accounted for approximately 4.3-5.5 $GtCO_2eq$/yr or about 9-11% of total anthropogenic greenhouse gas emissions (IPCC, 2014).

The overall contribution from agriculture, forestry and other land use (AFOLU) sector is around one quarter of the global anthropogenic greenhouse gas emissions. 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 $GtCO_2$/yr of economically viable abatement in 2030. (IPCC, 2014).

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 fuelwood, 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 etc. are mainly responsible for increasing the concentration of CO_2 and other harmful greenhouse gases into the atmosphere (Figure.1.1).

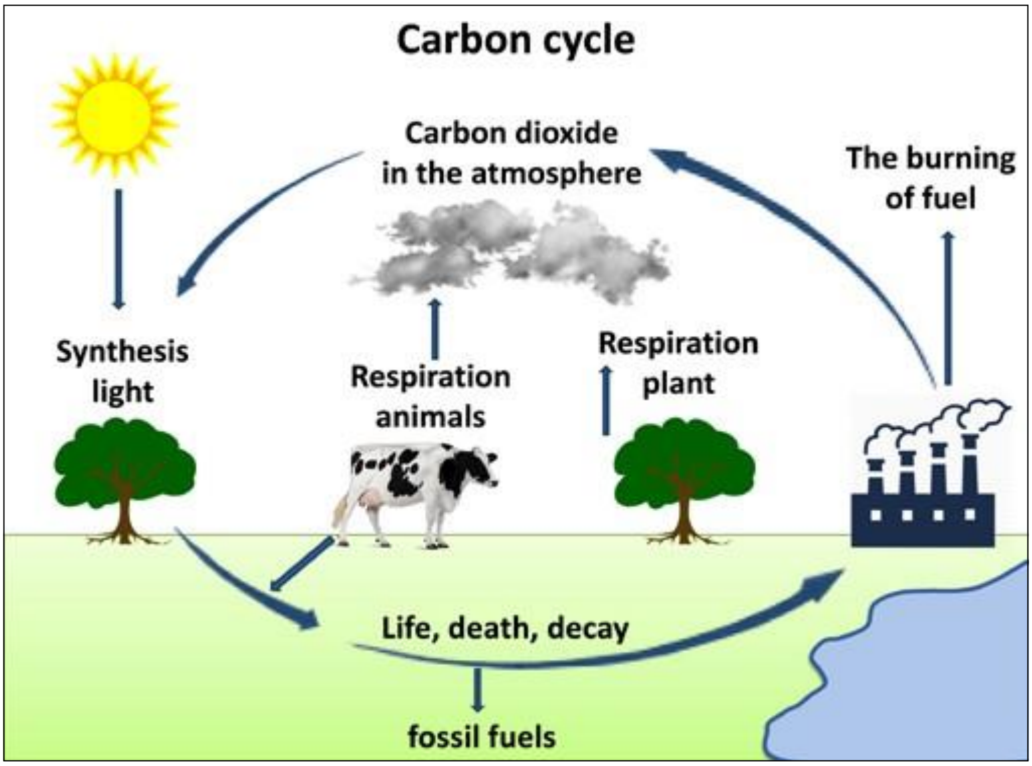

Figure 1.1: Global Carbon Cycle: Atmospheric source and sinks of carbon

1.3 Fulfilling International Commitments on Climate Change

Fulfilling their emission-limitation commitments under the UNFCCC and Paris Agreement on climate Change, Government of India, launched India's National Action Plan on Climate Change (NAPCC) in 2008. Government of India in its Nationally determined contributions (NDC) to UNFCCC under Paris Agreement also committed 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.

1.3.1 India's National Action Plan on Climate Change:

India's National Action Plan on Climate Change (NAPCC) identifies a number of 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 and incorporate multi-pronged, long-term and integrated strategies for achieving India's key goals in the context of climate change. The eight National Missions under NAPCC are given in the Box 1. National Mission for a Green India also called 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).

Box 1: Various Missions under India's National Action Plan on climate Change

India's National Action Plan on Climate Change

Mission	Objectives	Responsible Entity
JLN National solar Mission	•100,000 MW of solar power by 2020	Ministry of New & Renewable Energy
National Mission for Enhanced Energy Efficiency	•10,000 MW of EE saving by 2020 •5% saving/anum-100 mt CO2 miti/a	Ministry of Power
National Mission for Sustainable Habitat	•EE in residential and commercial buildings, public transport, Solid waste management	Ministry of Urban Development
National Water Mission	•Water conservation, river basin management	Ministry of Water Resources
National Mission for Sustaining the Himalayan Ecosystem	•Conservation and adaptation practices, glacial monitoring	Ministry of Science & Technology
National Mission for a Green India	•5 m hectares of afforestation over degraded forest lands by 12th Plan	Ministry of Env Forests & CC
National Missions for Sustainable Agriculture	•Drought proofing, risk management, agricultural research	Ministry of Agriculture
National Mission on Strategic knowledge for CC	•Vulnerability assessment, Research & observation, data management	Ministry of Science & Technology

National Mission for a Green India (GIM): The National Mission for a Green India (also referred to as Green India Mission or GIM) recognizes that climate change phenomena will seriously affect and alter the distribution, type and quality of natural resources of the country and the associated livelihoods of the people. GIM acknowledges the influences that the forestry sector has on environmental amelioration through climate mitigation, food security, water security, biodiversity conservation and livelihood security of forest dependent communities (NAEB, nd).

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 fuel, fodder, small timber and NTFP.

The Green India Mission 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.

1.3.2 India's Nationally Determined contribution (NDC) for Forestry sector

India is signatory to the United Nations Framework Convention on Climate Change (UNFCCC) and its Paris Agreement. Under Paris Agreement India is committed to meet its nationally determined contribution (NDC). The Indian NDC beside other sectors commits 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 the above contributions, 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. The highlights of forestry contribution to India's INDC are as follows:

Planned Afforestation has been seen as a major mitigation strategy in forestry sector. India is one of the few countries where forest and tree cover has increased in recent years transforming country's forests into a net sink owing to national policies aimed at conservation and sustainable management of forests. Government of India's long term goal is to bring 33% of its geographical area under forest cover eventually.

These efforts have been further augmented by policies like National Agro-forestry Policy (NAP), National REDD-Plus Strategy, Joint Forest Management; National Afforestation Programme, *NamamiGange* programme and afforestation along the river sides, Green Highways (Plantation & Maintenance) Policy and proposed devolution CAMPA funds to the states.

2. Carbon Accounting in Forest Ecosystems

2.1 Purposes of Carbon Accounting in Forest ecosystems

Forests are both source and sink of carbon. A growing forest captures atmospheric carbon and this carbon is released into atmosphere through activities like deforestation and forest degradation. The climate change mitigation benefit of forests is one of the ecosystem service rendered by forests which is fully measurable, reportable and verifiable (MRVable). Measurement of forest carbon is a vital part of Ecosystem Services Improvement Project (ESIP) implementation 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 accounting for forestry projects is given below in nutshell:

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

(ii) to calculate the average carbon stock for various land uses systems;

(iii) to estimate 'future 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.

(iv) to assess potential to monetise carbon sequestration under various domestic and international carbon trading mechanisms.

2.2 Carbon Pools: For the estimation of carbon pools in a forested stand, IPCC (2003) identified following five carbon pools. The detailed description of these carbon pools is given in table 2.1 and also depicted in figure 2.1 .

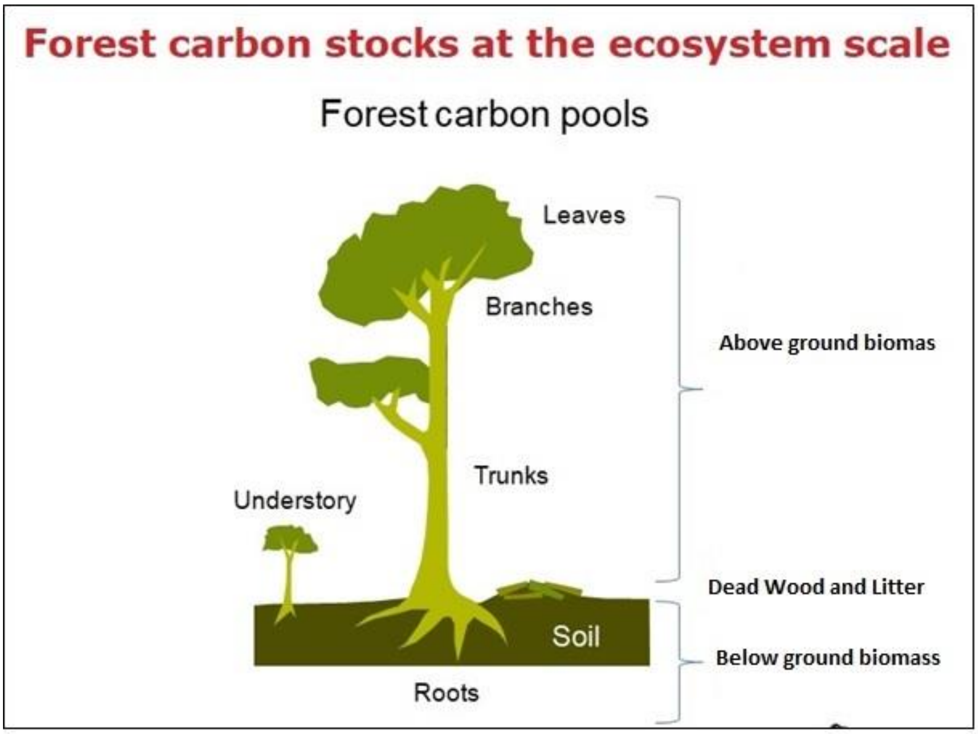

Figure 2.1 Various carbon pools in a forested ecosystem

Table 2.1: Definitions of terrestrial carbon pools (IPCC GPG, 2003)

Pool		**Description**
Living Biomass	Above Ground Biomass	All living biomass above the soil including stem, stump, branches, bark, seeds, and foliage. Note: In cases where forest understorey is a relatively small component of the above ground biomass carbon pool, it is acceptable for the methodologies and associated data used in some tiers to exclude it, provided the tiers are used in a consistent manner throughout the inventory time series.
	Below Ground Biomass	All living biomass of live roots. Fine roots of less than (suggested) 2 mm diameter 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 (for example 10 cm), 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 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.
Note: *National circumstances may necessitate slight modifications to the pool definitions used here. Where modified definitions are used, it is good practice to report upon them clearly, to ensure that modified definitions are used consistently over time, and to demonstrate that pools are neither omitted nor double counted.*		

At national level relative percentage proportion of carbon stocks in different pools is given in Table 2.2

Table 2.2 Relative percentage proportion of carbon in different pools in India and Madhya Pradesh

Carbon Pool	National	Madhya Pradesh
1. Aboveground biomass	32	38
2. Belowground biomass	10	15
3. Litter	1	1
4. Dead Wood	Negligible	Negligible
5. Soil Organic carbon	56	46

(Source: FSI, nd)

2.3 Different Tiers of Estimation

The IPCC (2006) also provides three general approaches for estimating emissions/removal of greenhouse gases, called “Tiers” ranging from 1 to 3, representing 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.), although 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, soils 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, therefore, increasing accuracy of the estimation.

2.4 Forest Cover Mapping in India

India is among the few countries to regularly use 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) has since been 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 15th biennial cycle has been completed in 2017 at 23.5 m resolution. The minimum mappable unit in respect of forest cover assessment is an area of 1 ha in extent and having tree canopy of 10% and above with a minimum mapping unit of 1 ha with adequate level of confidence (FSI, 2017). Forest cover is classified by FSI in terms of canopy density as given in following table (Table 2.3):

Table 2.3: Forest cover classified in terms of canopy density classes

Sl. No.	Class	Description
1	Very Dense Forest (VDF)	All lands with tree canopy density of 70% and above
2	Moderately Dense Forest (MDF)	All lands with tree canopy density of 40% and more but less than 70%
3	Open Forest (OF)	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)

Forest Survey of India (FSI) has also completed mapping of the Forest Types of India on 1:50,000 scale down to >200 sub group types described by Champion and Seth (1968). However, in its Forest type mapping FSI could identify and locate only 178 sub group type of forests including plantations. (FSI, 2012)

3: Sampling Design and Allocation of Sample Plots

3.1 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 limited cost and man power. Sampling includes the number, size and shape of the plots required to measure the 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 scaling up information from the sample plots to the whole project area or even to a regional and national level (IPCC 2003). Thus, measurements of carbon stocks of sample plots can be extrapolated to per hectare 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.

Review literature 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, or 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 to reliably estimate the increase in carbon density.

3.2 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 monitoring because it typically diminishes the sampling efforts necessary, while maintaining the same level of confidence.

Potential stratification options include:

- Land use (for example, forest, plantation, agroforestry etc);
- Vegetation species (if several);
- Slope (for example, steep, flat);
- Drainage (for example, flooded, dry);
- Age of vegetation;
- Proximity to settlement.

In India, FSI has prepared Forest Cover map and Forest Type map of India. These Forest Cover maps and Forest Type maps have been used to stratify the project area into Forest Type and density stratum. Intersect tool in Arc GIS may be used to produce the Forest Type and Density maps.

3.3 Calculation 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. 10-15 plots in the project area are usually enough to evaluate variance. For forestry inventory for carbon estimation normally a sampling intensity of 90/10(90 % confidence level and 10% precision) is followed. Confidence level amounts to uncertainty one can tolerate. Precision level is the margin of error one can tolerate. For example, estimation of the standard deviation and mean aboveground biomass or volume (t/ha) of the pilot sample plots can be worked out as follows:

Variance (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 equation 1
Sample Size (N) = $(1.64*CV/AE)^2$ Eq. 1. (at 90% confidence interval with 10% allowable error)
Where,
CV= Coefficient of Variance as calculated above
AE = Allowable error (e.g. 10%, 5%)
N = $(1.64 * 41.06/10)^2$
N= 45
Sample Size (N) = 45.
This means 45 plots are required to be laid in the project area.

3.4 Allocation of Sample Plot in Each Stratum.

Once the sample size is calculated, allocation of sample size to different strata is required. This is done using following formula:
A = Area of Strata/Total Area × Sample Size
For example .

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**

For Stratum 1
A1 = 3091.90/9296.30*45
A1 = 15
For Stratum 2
A2 = 537.46/9296.30*45
A2 = 3
For Stratum 3
A3 = 253.08/9293.30*45
A3 = 1
For Stratum 4
A4 = 3874.30/9296.30*45
A4 = 19
For Stratum 5
A5 = 1469/9296.30*45
A5 = 7
For Stratum 6
A6 = 70.67/9296.30*45
A6 = 0
It is further advised that to increase 10 % sample size to give adequate coverage to the underrepresented 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.

4. Laying out of field plot and Field data collection

4.1 Location of Sample Plots

Randomization of sample plots in a stratum: Arc GIS Software may be used to locate the sample plot in random manner in each stratum.

4.2 Sample Plot Layout: Permanent sample plots are generally regarded as statistically more efficient in estimating changes in forest carbon stocks compared to temporary 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 project area. Carbon monitoring requires both size and number of sample plots 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 circumstances may also be considered for assessment of carbon stocks. National Working Plan Code – 2014 may be followed for the sample plot design and layout methods.

After reaching the predetermined sampling plot location, a square plot of 0.1 ha (31.62 m × 31.62 m) should 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 31.5°in north-west corners of the plot from true north. Care should be taken for lying out the proper dimensions of the plot. Then nested subplots of size 3 m × 3 m and 1 m × 1 m will 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. Along with the nested quadrat of size 3 m × 3 m and 1 × 1 m, 5 × 5 m quadrats should be laid at NE and SW direction. In 5 × 5 m plot, all the dead wood above 5 cm diameter would be collected, weighed and recorded. In 3 m × 3m, all woody litter, that is branches below 5 cm be collected weighed and recorded. All shrubs and climbers in 3 m × 3m plot would be up-rooted, weighed and recorded. In 1m ×1m plot, all the herbs/grasses including leaf litter would be collected, weighed and recorded. For estimation of soil organic carbon, forest floor would be swept and a pit of 30×30×30 cm would be dug at the center of 1m× 1 m plot at NE and SW corner of the main 0.1 ha plot. A composite sample of soil weighing 200gm would be kept for Soil Organic Carbon analysis. The soil sample will be kept in a polythene bag and tightly closed and properly labelled.

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 ion bulk density is required for determination of soil organic carbon content per unit area. Collection of soil sample for bulk density estimation is done in 1m × 1m 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 and 20-30 cm depth.

Bulk Density of Soil: information on bulk density is required for determination of soil organic carbon content per unit area. Collection of soil sample for bulk density estimation is done in 1m × 1m 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 and 20-30 cm depth.

Scheme of laying out of a sample plot of 0.1 ha is given in figure 4.1

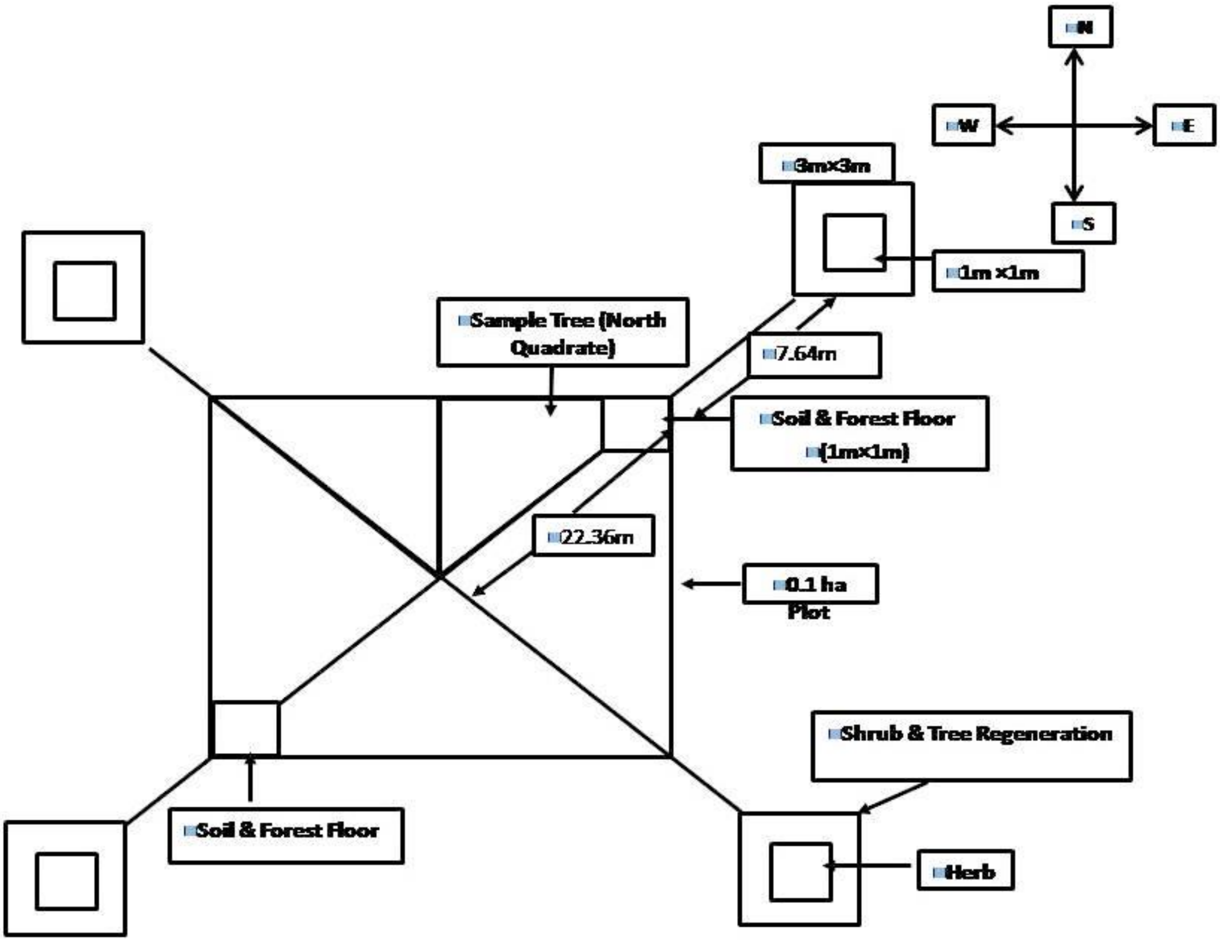

Figure 4.1 Sample Plot Layout

4.3 Equipment Required: Field Sampling Kit should be prepared well in advance before proceeding to the field for measurements. The following equipments and items are required for laying the sample plots in the forest for carbon monitoring:

1. Nylon – Rope (04) of the length 31.62 m (or more) for all the four side of the plot.	2. Stapler Pins	3. Field Maps
4. Clinometer/hagaaltimer/ Ravi multimeter for height measurement	5. Electronic Weighing Balance	6. Secateurs
7. Compass	8. Measuring Tape (50 m)	9. Khurpi/Kudal
10. Global Positioning System (GPS)	11. Iron Pole/Wooden stick	12. Khukri/Machete
13. Camera	14. Polybags/Paper Bags	15. Core Sampler
16. Aluminum Tags	17. Rubber Bands	18. Batteries
19. Hammer	20. Nails	21. Torch
22. Stapler	23. Rucksack	24. Paint and Brush
25. First Aid Kit	26. Permanent Marker	27. Data Recording Sheets
28. Toposheet	29. Spade	30. Axe

4.4 Field Team: Field tours for data collection from sample plots require at least one experienced/trained person and four assistants to layout the plots. Human resource should be properly trained before going to the field or first day can be given to layout the sample plot and proper division of work help in the efficient coordination between the team members and reduce the cost of the carbon inventory.

4.5 Field Background: Before going to the field studies, information regarding the field location should be collected that will help in locating sample plots. Field maps should be prepared with the help Geographic Information System. Project area, project boundary, nearby settlements, roads, river, forest types, forest cover, and other land use features should be properly embarked 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 the easy movement in the forest and nearby locations.

4.6 Tree Measurements

Forest measurement from individual tree to stand of trees and measurement and estimation of tree volume and biomass is important for assessment of biomass carbon in a forested stand. In tree and forest measurement some variables are not measured directly like volume of wood that is harvested from a large area. If 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 make an estimate of the parameter of interest (e.g., tree biomass carbon in the present case).

Procedure

(i) Mark the center of the plot and record the GPS location.
(ii) Mark all the four corners of plot with the ranging pole/wooden stick
(iii) Assign the unique code to the permanent plot.
(iv) Record the species name.
(v) Paint all the trees with yellow/red color at 1.37 m height.
(vi) Take photographs of the plot

Tree CBH Measurements

For aboveground biomass all tress having diameter of 10 cm and above (≥10 cm) or CBH (≥30 cm)will be enumerated. Species and diameter class wise information obtained from the sample plot of 0.1 ha is recorded carefully in the plot description form (Annexure VI). Border line trees i.e. the stem of the trees touch the north and west border line of the plot will be enumerated. However, the stem of the trees touches the east and south border line of the plot will be treated as “out trees” and information about out tress will not be recorded in the plot description form. Trees below 10cm 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 will be proceed in clockwise direction. The same procedure should be followed for all the sample plots. The height of the trees in the all the sample plots should be measured.

Circumference of the tree (Circumference at breast height, CBH) is measured at 1.37 m 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 growth rate to ensure that the same position will be measured in each occasion.

Following precautions are to be observed while measuring tree CBH

(i) On slopping 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 tree.
(iv) Trees forked above breast height should be treated as a single stem and measured according to the position of 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 stool level.

Besides this, following precautions should also be ensured for proper 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 (bh) stick.
(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 4.2)

Tree Height Measurement

(i) The height of tree is important characteristics for measuring the total amount of wood contained in tree. It is the vertical distance from ground level to the highest given point on the tree known as tip of the tree. 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. Height can be measured through ocular estimate, non-instrumental, (shadow method, single pole method). The height can be measured by specially designed instruments specifically for tree-height measurements such as clinometers, altimeters or hypsometers.

Measuring tree parameters:

(i) Walk around the tree and find the best location to view the top of the tree.
(ii) Stand far enough away 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 tree
(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 DBH 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.

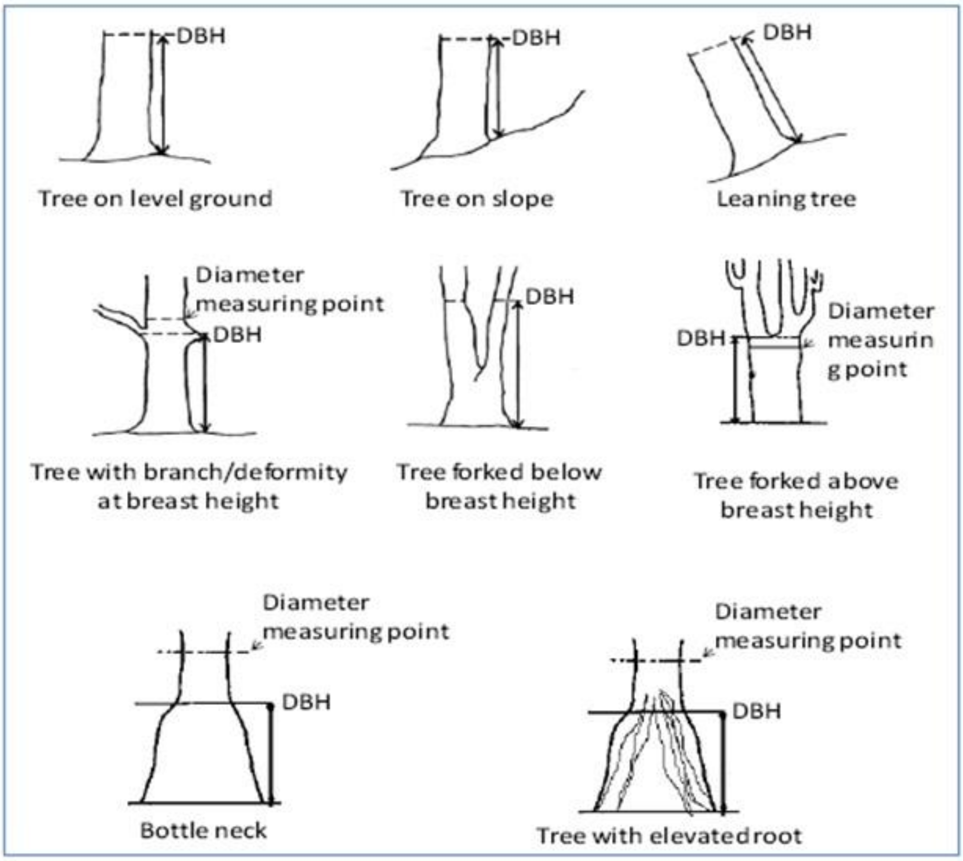

Fig 4.2: Tree CBH measurement under different situations

4.7 Shrub Sampling: 4 quadrats of 3m × 3m should be laid at 30 m form 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 plot description 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 portable weighing machine.
(iii) Collect the 200 gmfresh sample and pack in the polybags to be carried to the laboratory for further analysis of dry weight.

4.8 Tree Regeneration/Sapling: In3m × 3m plot, CBH all the trees having CBH <10 cm should be measured. Biomass equations have been developed by FSI to estimate the biomass of the tree having diameter <10 cm.

4.9 Herb Sampling: Sampling of the herbs is done by lying 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 herb plot of 1m ×1 m.
(ii) Fresh weight of the harvested herbs/grasses should be recorded through portable weighing machine.
(iii) A small Sample of known quantity should be properly packed and brought to the laboratory for further dry weight estimation.

4.10 Litter Sampling: Litter sampling should be conducted by laying 3m ×3 m plot

Procedure:

(i) Lay out a plot of 3m × 3 m.
(ii) Collect all the litter in the sample plot. Litter contains all deal plan material that includes fallen leaves (fresh, dry, semi or partially decomposed leaves), fruit, flower, twigs, bark etc.
(iii) Record the fresh weight of the total litter collected.
(iv) Take the 200gm sample of the litter
(v) Sample should be properly marked and packed for laboratory analysis for determination of dry weight.

4.11 Dead wood: All dead wood above 5 cm diameter should be collected, weighed and recorded. A sample of known quantity should be kept for laboratory analysis.

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

Soil Sample Collection for Bulk Density: Collection of soil sample for bulk density estimation is done in 1m × 1m plot. Insert the bulk density core sampler (of known volume) in 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 labeled should be fixed on the sample. Repeat this exercise again in the soil 10-20 and 20-30 cm depth.

5. Forest Carbon Stock Estimation

5.1 Estimation of Tree Biomass

Biomass is defined as the total amount of living organic matter (aboveground and below ground) in trees. It is generally expressed on oven-dry basis per unit area. More recently there has been increasingly 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 and leaves. Biomass can be measured directly or through estimation functions.

5.1.1 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 a temporary sample plots of different sizes are laid out according to the size of the area in the forest. The DBH and height of all the standing trees in the sample plots covering the entire diameter range of each plot is recorded and correlation (diameter & height) was 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 recorded in the field. The representative samples of each tree component (100 or 200 g each of leaves, twigs, branches, bark, fruit) are taken for oven dry weight estimation in laboratory.

The bole portion of the sample trees is cut into 2m 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 5cm 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 sample 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 tree in respective diameter classes followed by summation of biomass in each diameter class.

5.2 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 in logarithmic form and are 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 equation's is usually written as,

$y = bx^a$

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 be tend to overestimated.

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.

5.3 Estimation of Carbon in different pools:

1) **Aboveground 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 have given volumetric equation (FSI, 2009). 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, m3 ha-1 Tree volume of a stand are normally available in forest inventory and growing stock data.

D basic wood density, tonnesd.m. m-3 merchantable volume (Species wise information on Basic wood density are available in literature.

BEF biomass expansion factor for conversion of merchantable volume to aboveground tree biomass, dimensionless. 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 (dimensionless)

CF carbon fraction of dry matter (default = 0.047)

BEF is not available for majority of Indian tree species. FSI has developed equation for 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 is used.

Biomass Estimation

i) Estimate the volume of each tree in the sample plot using volumetric equation (FSI, 1996, Annexure I)
ii) Obtain basic wood density for all the tree species encountered in the sampling plot from the literature (Annexure 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).

Shrub Biomass: Samples brought to the laboratory are oven dried at 70-85°C until reaching constant weight. Biomass of the shrubs is extrapolated per hectares basis after calculating as follows:

$$\textbf{Biomass} = \frac{\textbf{Dry Weight of sample}}{\textbf{Fresh Weight of sample}} \times \textbf{Actual Fresh Weight}$$

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

$$\textbf{Biomass} = \frac{\textbf{Dry Weight of sample}}{\textbf{Fresh Weight of sample}} \times \textbf{Actual Fresh Weight}$$

2) Belowground Biomass: Relationship exist between biomass in shoot and roots for a tree. In the absence of default value of the Root-Shoot Ratio of the tree species, IPCC (2003) default factors will be used for the estimation of Belowground Biomass.

3) Litter Biomass: Samples brought to the laboratory are oven dried at 70-85°C until reaching constant weight. Biomass of the herb is extrapolated per hectares basis after calculation as follows:

$$\textbf{Biomass} = \frac{\textbf{Dry Weight of sample}}{\textbf{Fresh Weight of sample}} \times \textbf{Actual Fresh Weight}$$

4)Dead Wood Biomass: Samples brought to the laboratory are oven dried at 70-85°C until reaching constant weight. Biomass of the herb is extrapolated per hectares basis after calculation as follows:

$$\textbf{Biomass} = \frac{\textbf{Dry Weight of sample}}{\textbf{Fresh Weight of sample}} \times \textbf{Actual Fresh Weight}$$

5.4 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. Facility for estimation of soil organic carbon may not be available with Sate Forest Departments. Forest Department may get the samples analyzed from their state Forest Research Institutes, research Institutes under ICFRE/State or central Agricultural Universities and ICAR institutes Accredited soil testing laboratories etc.

Estimating percent course fragment in the soil:

Percent coarse fragment (> 2mm size) in soils is estimated to work out the correct soil weight. After taking the weight of the sample dried for bulk density, this 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 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.

Analysis of the sample for soil organic carbon:

Soil organic carbon percentage is estimated by standard Walkley & Black (1934) method.(AnnexureIV)

Soil carbon stock calculations:

Soil stoniness and land use are recorded. Soil samples are analysed for required parameters 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):

$$Qi = CiDiEi(1 - Gi)$$

5.5 Total Carbon Stock:

(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 MgC/ha.
(iii) The plot level results are then extrapolated on per hectare basis. This is carbon density or Carbon stock per unit area, say 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.
(v) Carbon contents of different strata are summed to produce the total carbon stock of the project area (Annexure V)
(vi) Multiply the carbon stocks by 3.67 (or 44/12) to convert the carbon stocks into CO_2 equivalent. Climate Change mitigation benefit of forestry projects are accounted in terms of carbon dioxide equivalent

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Volume Equations

Central Highlands

S. No	Species	Volume Equation
1	*Acacia catechu*	$V = -0.02471 + 0.16897 D + 1.12083 D^2 + 2.9328 D^3$
2	*Acacia lenticularis/leucophloea*	$\sqrt{V} = -0.00142 + 2.61911 D – 0.54703 \sqrt{D}$
3	*Aegle marmelos*	$V/D^2 = 0.16609/D^2 – 2.78851/D + 17.22127 – 11060248 D$
4	*Anogeissus latifolia*	$\sqrt{V} = -0.20236 + 3.13059 D$
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 latifolia/lanzan*	$V = 0.031 -0.64087 D + 6.04066 D^2$
8	*Butea monosperma (old) Butea frondosa*	$\sqrt{V} = -0.24276 + 2.95525 D$
9	*Chloroxylon swietenia*	$V = -0.003156 + 2.95525 D^2$
10	*Diospyros melanoxylon*	$V = 0.15581 – 2.2075 D + 9.17559 D^2$
11	*Flacourtia indica (old) Flacourtia ramontchi*	$\sqrt{V} = -0.153973 + 2.724109 D$
12	*Lagerstroemia parviflora*	$V = 0.10529 – 1.68829 D + 10.29573 D^2$
13	*Lannea coromandelica/lannea grandis*	$V/D^2 = 0.14004/D2 – 2.35990/D + 11.90726$
14	*Madhuca latifolia/ M. indica (old)/ Bassia latifolia*	$V = 0.063632 + 5.355486 D^3$
15	*Miliusa tometosum (old) Saccopetalum tomenmntosum*	$\sqrt{V} = 0.66382 + 7.03093 D – 3.68133 \sqrt{D}$
16	*Mitragyna parviflora/ Stephegyne parviflora*	$V/D2 = 0.099768/D^2 – 1.744274/D + 10.086934$
17	*Tectona grandis*	$\sqrt{V} = -0.405890 + 1.98158 D + 0.987373 \sqrt{D}$
18	*Terminalia crenulata/tomentosa*	$\sqrt{V} = -0.203947 + 3.159215 D$
19	*Wrightia tinctoria*	$\sqrt{V} = 0.050294 + 3.115497 D - 0.687813 \sqrt{D}$
20	*Zizyphus xylopyrus*	$V = 0.027354 + 4.663714 D^2$

North Deccan

S. No	Species	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 retusa/variegata*	$V = -0.0236 + 0.3078 D + 1.2361 D^2$
5	*Buchanania latifolia/lanzan*	$V = -0.00767 + 0.2654 D + 1.0383 D^2 + 7.527 D^3$
6	*Butea monosperma (old) 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 (old) Gardenia turgida/Lucida/latifolia*	$V = 0.078 – 1.188 D + 65.751 D^2$
11	*Lagerstroemia parviflora*	$V/D^2 = 0.06466/D^2 – 1.371984/D + 9.629971$

12	*Lannea coromandelica/Lannea grandis*	$V = 0.093318 – 1.531417 D + 9.011590 D^2$
13	*Madhuca latifolia/ M. indica (old)/ Bassia 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 tometosum (old) Saccopetalum tomenmntosum*	$\sqrt{V} = 0.66382 + 7.03093 D – 3.68133 \sqrt{D}$
16	*Syzygium cumini/jambolanum (old) Eugenia jambolana*	$V = 0.2736 – 3.377 D + 12.959 D^2$
17	*Tectona grandis*	$\sqrt{V} = -0.106720 + 20562418 D$
18	*Terminalia crenulate/tomentosa*	$V/D2 = 0.048532/D^2 – 1.05615/D + 8.204564$
19	*Wrightia tinctoria*	$V = - 0.009510 + 4.149345 D^2$
20	*Zizyphus xylopyrus*	$V = -0.0257 + 0.2313 D + 1.474 D^2$

Rest of species' Volume Equation is used

(Source: FSI,nd)

Biomass Equations

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

Central Highland

S.No.	Species Name	Equation
1	*Acacia catechu*	$BE_1 = 461.0594\ D^2 + 127.4788D - 8.6248$
		$BE2 = 14.1668\ D^2 + 8.6870D - 0.4187$
		$BE3 = 0.0111\ D_1^2 + 1.7348D_1 - 0.8604$
		$BE4 = 0.0078\ D_1^2 + 0.0060D_1 + 0.0809$
2	*Anogeissus pendula*	$BE1 = -0.256.5319\ D^2 + 327.3360\ D – 19.9557$
		$BE2 = -24.9712\ D^2 + 27.0362\ D – 1.6791$
		$BE3 = -0.0413\ D_1^2 + 1.6164D_1 – 0.8311$
		$BE4 = 0.0612\ D_1 + 0.0148$
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*	$BE_1 = 37.5026\ D^2 + 235.1910\ D – 16.6356$
		$BE_2 = -4.6969\ D^2 +29.3272\ D -1.8890$
		$BE_3 = 0.0252\ D_1^2 + 0.5896\ D_1 - 0.0258$
		$BE_4 = 0.0036\ D_1^2 + 0.0276\ D_1 + 0.0877$
5	*Butea monosperma*	$BE_1 = 221.3745\ D^2 - 43.7095\ D + 5.1897$
		$BE_2 = 20.3847\ D^2 +2.5894\ D + 0.8161$
		$BE_3 = 0.0716\ D_1^2 -0.2408\ D_1 + 0.7970$
		$BE_4 = 0.0070\ D_1^2 -0.0174\ D_1 + 0.0790$
6	*Diospyros melanoxylon*	$BE_1 = 409.0799\ D^2 – 108.5871\ D + 14.2917$
		$BE_2 = 29.9753\ D^2 – 6.1664\ D + 0.9315$
		$BE_3 = 0.0764\ D_1^2 – 0.2359\ D_1 + 0.4756$
		$BE_4 = 0.0068\ D_1^2 +0.0021D_1 + 0.4756$
7	*Anogeissus latifolia*	$BE_1 = -18.9612\ D^2 + 363.4651\ D – 23.7470$
		$BE_2 = -8.7736\ D^2 + 18.6843\ D – 1.2968$
		$BE_3 = 0.0506\ D_1^2 + 0.6227\ D_1 – 0.3709$
		$BE_4 = 0.0030\ D_1^2 + 0.0121\ D_1 + 0.0401$
8	*Terminalia 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 parviflora*	$BE_1 = -70.9902\ D^2 + 315.1673\ D – 25.4308$
		$BE_2 = -4.7461\ D^2 + 20.5859\ D – 1.6376$
		$BE_3 = 0.0524\ D_1^2 + 0.1302\ D_1 – 0.0629$
		$BE_4 = 0.0050\ D_1^2 – 0.0093\ D_1 + 0.0334$
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	*Zizyphus 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*	$BE_1 = -316.8777\ D^2 + 78.7053\ D – 6.0127$
		$BE_2 = 6.5580\ D^2 + 4.6176\ D - 0.3076$

		$BE_3 = 0.0891\ D_1^2 + 0.2386\ D_1 + 0.1853$
		$BE_4 = -0.0012\ D_1^2 + 0.0353\ D_1 – 0.0078$
13	*Acacia lenticularis/leucopholea*	$BE_1 = 290.6110\ D^2 + 78.7053\ D -6.0127$
		$BE_2 = 6.5580\ D^2 + 4.6176\ D – 0.3076$
		$BE_3 = 0.0891\ D_1^2 + 0.2386\ D_1 + 0.1853$
		$BE_4 = -0.0012\ D_1^2 + 0.0353\ D_1 – 0.0078$
14	*Madhuca 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 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*	$BE_1 = 564.\ 5753\ D^2 -11.5172\ D + 4.8052$
		$BE_2 = 28.1133\ D^2 - 0.5735\ D + 0.2393$
		$BE_3 = -0.0386\ D_1^2 – 1.3890\ D_1 – 0.2761$
		$BE_4 = -0.0029\ D_1^2 + 0.0835\ D_1 + 0.0256$

North Deccan

S.No.	**Species Name**	**Equation**
1	*Tectona grandis*	$BE_1 = 724.8313\ D^{1.8139}$
		$BE_2 = -5.7898\ D^2 + 16.1859\ D – 0.8153$
		$BE_3 = 0.1701\ D_1^2 – 0.5602\ D1 + 1.3209$
		$BE_4 = 0.0080\ D_1^2 + 0.0186\ D1 +0.0245$
2	*Terminalia tomentosa*	$BE_1 = -893.2875\ D^3 + 1888.8940\ D^2 – 463.\ 5333\ D +54.7484$
		$BE_2 = 20.\ 0615\ D^2 +1.5684\ D + 0.4141$
		$BE_3 = 0.1545\ D_1^2 + 0.0612\ D1 + 0.5004$
		$BE_4 = 0.0061\ D_1^2 + 0.0027\ D1 + 0.0550$
3	*Chloroxylon swietenia*	$BE_1 = 884.6576\ D^2 + 395.8155\ D – 38.2331$
		$BE_2 = 13.0100\ D – 0.3999$
		$BE_3 = 0.1990\ D_1^2 – 0.3570\ D_1 + 0.5943$
		$BE_4 = 0.0118\ D_1^2 – 0.0027\ D1 + 0.0401$
4	*Anogeissus pendula*	$BE_1 = 1299.4268\ D^3 – 1653\ D^2 + 1320.6808\ D – 110.1954$
		$BE_2 = -3.8043D^2 +10.7862\ D - 0.3515$
		$BE_3 = -0.0650\ D_1^2 + 2.1152\ D_1 – 1.1784$
		$BE_4 = -0.0079\ D_1^2 + 0.1908\ D1 - 0.0179$
5	*Butea monosperma*	$BE_1 = 287.6540\ D^2 + 67.0071\ D - 1.9463$
		$BE_2 = 4.6446\ D^2 + 3.8577\ D + 0.2056$
		$BE_3 = 0.8883\ D_1 – 0.0294$
		$BE_4 = 0.0040\ D_1^2 +0.0373\ D_1 + 0.1501$
6	*Lannea coromandelica*	$BE_1 = 84.0382\ D^2 + 262.3237\ D – 20.4447$
		$BE_2 = 1.611\ D^2 + 18.47\ D – 0.894$
		$BE_3 = 0.011\ D_1^3 – 0.068\ D_1^2 + 0.351\ D_1 + 0.296$
		$BE_4 = 0.007\ D_1^2 + 0.006\ D_1 + 0.192$
7	Diospyros species	$BE_1 = 479.3323\ D^2 + 25.\ 4894\ D +8.4235$
		$BE_2 = 6.7291\ D^2 + 6.0102\ D + 0.2414$
		$BE_3 = 0.0307\ D_1^2 + 0.7393D_1 – 0.2260$
		$BE_4 = 0.0033\ D_1^2 + 0.0669\ D_1 – 0.0027$
8	*Lagerstroemia parviflora*	$BE_1 = 243.9685\ D^2 + 163.\ 6429\ D - 12.3582$
		$BE_2 = -35.4845D^3 + 44.3745\ D^2 -1.2717\ D + 0.2303$

		$BE_3 = 0.0326\ D_1^2 + 0.4611\ D1 + 0.3191$
		$BE_4 = 0.0074\ D_1^2 – 0.0222\ D_1 + 0.0456$
9	Buchnania latifolia/lanzan	$BE_1 = 225.0254\ D^2 +81.1387\ D – 3.3972$
		$BE_2 = 25.4746\ D^2 – 0.6373\ D + 0.6366$
		$BE_3 = 0.0888\ D_1^2 + 0.0680\ D_1 + 0.5616$
		$BE_4 = 0.0108\ D_1^2 – 0.0187\ D_1 + 0.1278$
10	Madhuca latifolia	$BE_1 = 199.2222\ D^2 + 263.1915 – 9.9139$
		$BE_2 = 6.1590\ D – 0.3077$
		$BE_3 = 0.1405\ D_1^2 – 0.0649\ D_1 + 0.7852$
		$BE_4 = 0.0015\ D_1^2 + 0.0042\ D_1 + 0.0175$
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/turgida	$BE_1 = 167.8008\ D^2 + 212.0485\ D – 10.6145$
		$BE_2 = 3.9604\ D^2 + 2.5419\ D + 0.4212$
		$BE_3 = 0.1779\ D1 – 0.5745\ D_1 + 1.671$
		$BE_4 = 0.0119\ D_1^2 - 0.0425\ D_1 + 0.1287$
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*	$BE_1 = 252.1925\ D^2 + 138.7321\ D – 10.9596$
		$BE_2 = 10.9963\ D^2 – 1.6709\ D + 0.6265$
		$BE_3 = 0.5933\ D1 - 0.0378$
		$BE_4 = 0.0095\ D_1^2 -0.0349\ D_1 + 0.0480$
16	*Zizyphus 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*	$BE_1 = 604.8017\ D^2 + 0.0041\ D + 1.7251$
		$BE_2 = 43.2013\ D2 – 11.9883\ D + 1.0009$
		$BE_3 = 0.0940\ D_1^2 + 0.0813\ D_1 + 0.1856$
		$BE_4 = 0.0081\ D_1^2 – 0.0021\ D_1 + 0.0102$
18	*Bauhinia retusa/variegata*	$BE_1 = 57.2611\ D^2 + 205.3085\ D – 15.\ 5737$
		$BE_2 = 1.6214\ \log_e D + 3.9181$
		$BE_3 = 0.0508\ D_1^2 + 0.3060\ D_1 + 0.2747$
		$BE_4 = 0.0083\ D_1^2 – 0.0012 D_1 + 0.0113$
19	Miscellaneous Species	BE_1=631.2*(D^2) + 51.49*D - 7.191
		BE_2=12.77*(D^2) + 6.048*D - 0.282
		BE_3=0.064*(D^2) + 1.496*D - 0.787
		BE_4=0.008*(D^2) + 0.01*D + 0.068

(Source: FSI,nd)

Specific Gravity of Major Species

Wood Density and Specific Gravity

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/cm3, 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	0.67
Bridelia retusa	0.499
Buchanania cochinchinensis	0.458
Butea monosperma	0.465
Casearia tomentosa	0.62
Cassia fistula	0.746
Chloroxylon swietenia	0.771
Dalbergia latifolia	0.750
Dalbergia paniculata	0.64
Diospyros melanoxylon	0.678
Gardenia latifolia	0.635
Grewia tilifolia	0.679
Haldina cordifolia	0.597
Lagerstroemia parviflora	0.620
Lannea coromandelica	0.513
Madhuca longifolia	0.74
Ougenia oojeinensis	0.704
Phyllanthus emblica	0.80
Pterocarpus marsupium	0.649
Saccopetalum tomentosum	0.615
Semecarpus anacardium	0.64
Schleichera oleosa	0.841
Soymida febrifuga	0.963
Syzygium cumini	0.647
Tamarindus indica	0.75
Tectona grandis	0.563
Terminalia bellirica	0.628
Terminalia chebula	0.642
Terminalia tomentosa	0.73

Source: Rajput et al. 1985

Walkley and Black Method for Soil Organic Carbon

Estimation of Organic Carbon: The organic matter (humus) in the soil gets oxidized by chromic acid (potassium dichromate plus conc. Sulphuric acid) utilizing the heat of dilution of sulphuric acid. The untreated chromate is determined by back titration with ferrous ammonium sulphate (redox titration).

Reagents:

(i) 1N potassium dichromate (49.04g of AR grade, $K_2Cr_2O_7$ per liter of solution)

(ii) 0.5N (approx.) ferrous ammonium sulphate (196g of the hydrated crystalline salt per litre containing 20 ml of conc. H_2SO_4). This solution is relatively more stable and convenient to work than that of ferrous sulphate.

(iii) Diphenylamine indicator: 0.5g diphenylamine dissolved in a mixture of 20 ml of water and 100 ml of Conc. H_2SO_4

(iv) Concentrated sulphuric acid (sp.gr 1.84) containing 1.25 per cent silver sulphate (in case of soils free from chloride use of Ag_2SO_4 can be avoided)

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

Procedure:

The soil is ground and completely passed through 0.2 mm sieve and 1.00 g is placed at the bottom of a dry 500 ml conical flask (Corning Pyrex). 10 ml of IN $K_2Cr_2O_7$ is pipetted in and swirled a little. The flask is kept on asbestos sheet. Then 20 ml of H_2SO_4 (containing 1.25 % Ag_2SO4) 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, 0.5g 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 H3P04 and 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 (%) = (10(B-T)/B*0.003*(100/wt. of soil)

Where B=volume (in ml) of ferrous ammonium sulphate solution required for blank titration; and T=volume of ferrous ammonium sulphate needed for soil sample.

Annexure V

Data Analysis Example

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	BE1 (Kg)	BE2 (Kg)	B (Kg)	B (t)	AGB (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	*Wrightia tinctoria*	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	*Madhuca longifolia*	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	Schleichera oleosa	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	*Chloroxylon swietenia*	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)

Belowground Biomass (BGB)

Belowground biomass = Aboveground 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 1.3 g/cm^3 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)

कार्बन स्टॉक आंकलन हेतु डाटा संग्रह फ़ार्म

सामान्य सूचनाः

प्लॉट संख्याः	दिनांकः
कम्पार्टमेंट संख्याः	जीपीएस रीडिंग (लैट/लांग/समुद्र तल से ऊंचाई):
वन रेंजः	
ऐस्पेक्टः	लॉपिंग/चरान/आग आदिः
ढालान	

A. वृक्ष (Trees): प्लॉट आकार : 31.62 m x 31.62 m

क्रम संख्या	प्रजाति नाम (हिन्दी/अंग्रेज़ी/स्थानीय भाषा/वैज्ञानिक नाम)	परिधि (सेंमी.में)	ऊँचाई (मी.में)	टिप्पणी
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B. (a) किशोर वृक्ष (Saplings): प्लॉट आकार : 3 m x 3 m

क्रम संख्या	प्रजाति नाम (हिन्दी/अंग्रेज़ी/स्थानीय भाषा/वैज्ञानिक नाम)	परिधि (सेंमी.में)	ऊँचाई (मी.में)
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B (b) किशोर वृक्ष (Saplings): प्लॉट आकार : 3 m x 3 m

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	परिधि (सेंमी.में)	ऊँचाई (मी.में)
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B (c) किशोर वृक्ष (Saplings):   प्लॉट आकार : 3 m x 3 m

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	परिधि (सेंमी.में)	ऊँचाई (मी.में)
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B (d) किशोर वृक्ष (Saplings): प्लॉट आकार : 3 m x 3 m

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	परिधि (सेंमी.में)	ऊँचाई (मी.में)
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C. (a) झाड़ियाँ

प्लॉट आकार : **3 m x 3 m**

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	प्रजाति संख्या	कुल ताज़ा वज़न	सैम्पल ताज़ा वजन	सैम्पल कोड
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(b) झाड़ियाँ

प्लॉट आकार : **3 m x 3 m**

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	प्रजाति संख्या	कुल ताज़ा वज़न	सैम्पल ताज़ा वजन	सैम्पल कोड
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C (c) झाड़ियाँ

प्लॉट आकार : **3 m x 3 m**

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	प्रजाति संख्या	कुल ताज़ा वज़न	सैम्पल ताज़ा वजन	सैम्पल कोड
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C (d) झाड़ियाँ

प्लॉट आकार : **3 m x 3 m**

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	प्रजाति संख्या	कुल ताज़ा वज़न	सैम्पल ताज़ा वजन	सैम्पल कोड
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D. हर्ब्स (Herbs):

a. उत्तर–पश्चिम कोना: प्लॉट आकार : **1 m x 1 m**

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	कुल ताज़ा वज़न	सैम्पल ताज़ा वजन	सैम्पल कोड
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b. उत्तर–पूर्व कोना: प्लॉट आकार : **1 m x 1 m**

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	कुल ताज़ा वज़न	सैम्पल ताज़ा वजन	सैम्पल कोड
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c. दक्षिण–पूर्व कोना:   प्लॉट आकार : **1 m x 1 m**

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	प्रजाति संख्या	कुल ताज़ा वज़न	सैम्पल ताज़ा वजन	सैम्पल कोड
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d. दक्षिण–पश्चिम कोना:   प्लॉट आकार : **1 m x 1 m**

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	प्रजाति संख्या	कुल ताज़ा वज़न	सैम्पल ताज़ा वजन	सैम्पल कोड
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E. परोपजीवी / लता / समकक्ष पौधे:   प्लॉट आकार : 3 m x 3 m

क्रम संख्या	प्रजाति नाम (हिन्दी / अंग्रेज़ी / स्थानीय भाषा / वैज्ञानिक नाम)	पौधों की संख्या	सैम्पल ताज़ा वजन	सैम्पल कोड
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F. गिरे हुए पत्ते, टहनियां, फल, फूल व बीज के सैम्पल का संग्रह (प्लॉट आकार : 3 m x 3 m):

a. उत्तर–पष्चिम कोना:

ताज़ा वजन (ग्राम में) = ______________________

सैम्पल ताज़ा वजन (ग्राम में) = ______________________

b. उत्तर–पूर्व कोना

ताज़ा वजन (ग्राम में) = ______________________

सैम्पल ताज़ा वजन (ग्राम में) = ______________________

c. दक्षिण–पूर्व कोना

ताज़ा वजन (ग्राम में) = ______________________

सैम्पल ताज़ा वजन (ग्राम में) = ______________________

d. दक्षिण–पश्चिम कोना

ताज़ा वजन (ग्राम में) = ______________________

सैम्पल ताज़ा वजन (ग्राम में) = ______________________

G मिट्टी के सैम्पल

(a) Bulk Density: 0–10 सेंमि0, 10–20 सेंमि0, तथा 20–30 सेंमि0 की गहराई से मिट्टी के सैम्पल को इकट्ठा करने के लिए, कोरर का प्रयोग करें। हर कोर के सैम्पल को एक अलग पारदर्शी पॉलीथीन बैग में भर लें। एक स्थाई मार्कर पेन से उस बैग पर सैम्पल का नंबर डाल लें (उदाहरण के लिए, 1BDa जहां '1' प्लॉट नंबर है , 0–10 सेंमि0 के लिए, '1BDb' 10 से 20 सेंमि0 के लिए तथा '1BDc', 20–30 सेंमि0 के लिए). Tick below after sample collection:

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

(b) **मिट्टी के सैम्पल का संग्रहः** 30 सेंमि0 के गड्डा खोदें, मिट्टी को मिलाएं तथा 200 ग्राम सैम्पल को एक पारदर्शी पॉलीथीन बैग में भर लें। एक स्थाई मार्कर पेन से उस बैग पर सैम्पल का नंबर डाल लें (उदाहरण के लिए, 1a, जहां '1' प्लॉट नंबर है, और 'a' 0–30 सेंमि0 का मिट्टी का कॉलम है).

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