CHAPTER 4
MATERIALS AND METHODS

4.1: INTRODUCTION:

Preparation of a base-line terrestrial carbon inventory, for carbon mitigation as well as forest conservation and greenhouse gas inventory projects, requires estimation of stocks of carbon pools in biomass and in soil. There are five carbon pools, and measurement, monitoring and projection of changes in stocks of carbon in all the five carbon pools may be desirable. However, further stocks of some of the carbon pools may not change or change only marginally during the period selected for monitoring or projection. IPCC (2003, 2006) has defined five carbon pools (Table 4.1) for greenhouse gas inventory, including live biomass (above ground, below ground) and Non-living biomass (dead organic carbon, soil organic carbon).

4.2: SEGMENTS OF CARBON POOLS:

Biomass and soil carbon are the two major carbon pools. Biomass is defined as the total quantity of live and inert or dead organic matter, above and below the ground, expressed in tonnes of dry matter per unit area, such as a hectare. Soil carbon is carbon held in soil as organic matter in stable structures such as charcoal. Biomass is eventually gets converted to carbon by multiplying it with a carbon fraction of dry matter. The exact value of the fraction varies within a small range for different species and components of plants, and is usually about 0.5 (IPCC 2006).

\[
\text{Biomass carbon} = \text{(aboveground biomass carbon + belowground biomass carbon + dead organic matter carbon + Soil carbon)}
\]

4.3: PROJECT BOUNDARY:

The project boundary was defined as the geographically marked area dedicated to the project activity. Both study areas i.e. Pune University Campus and Pardisan forest were mapped with GPS for precise and accurate plotting and descriptive GIS maps of both study areas were prepared.
Table 4.1: Definition of carbon pools according to IPCC (2006).

<table>
<thead>
<tr>
<th>Pool</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Above-ground Biomass (AGB)</strong></td>
<td>All biomass of living vegetation, both woody and herbaceous, above the soil including stems, stumps, branches, bark, seeds and foliage.</td>
</tr>
<tr>
<td><strong>Below-ground Biomass (BGB)</strong></td>
<td>All biomass of live roots. Fine roots of less than 2 mm diameter (the suggested minimum) are often excluded because these often cannot be distinguished empirically from soil organic matter.</td>
</tr>
<tr>
<td><strong>Deadwood</strong></td>
<td>All non-living woody biomass not contained in the litter, either standing, lying on the ground, or in the soil. Deadwood includes wood lying on the surface, dead roots, and stumps larger than or equal to 10 cm in diameter.</td>
</tr>
<tr>
<td><strong>Litter</strong></td>
<td>All non-living biomass with a size greater than the limit for soil organic matter (the suggested minimum is 2 mm) and less than the minimum diameter chosen for deadwood (e.g. 10 cm) lying dead and in various states of decomposition above or within the mineral organic soil. This includes the litter layer as usually defined in soil typologies. Live fine roots above the mineral or organic soil (of less than the suggested minimum for below-ground biomass) are included whenever they cannot be empirically distinguished from the litter.</td>
</tr>
<tr>
<td><strong>Soil organic Carbon (SOC)</strong></td>
<td>Organic carbon in mineral soils to a specified depth chosen and applied consistently through a time series. Live and dead fine roots within the soil (of less than the suggested minimum for belowground biomass) are included wherever they cannot be empirically distinguished from the soil organic matter.</td>
</tr>
</tbody>
</table>
4.4: SCALE OF THE PROJECT:

Project size determines the methods to be used for carbon inventory. Carbon stock changes in small-scale projects could be monitored using field measurements whereas large-scale projects may require adoption of remote sensing and modeling techniques. Small-scale projects are likely to be more homogeneous with respect to soil, topography and species dominance (Sanz et al., 2005). Pune University Campus (Pune city) and Pardisan Forest (Kerman city) were both considered as urban hot spots within the cities of Pune and Kerman, respectively. Campus of Pune University (Fig. 3.1) having 64.59 hectare (Study area No. 1) and Pardisan forest (Study area No. 2) includes 73.41 (Fig. 3.2) hectares, respectively. Field measurement and GIS approach were selected as the dominant methods in both study area.

4.5: SAMPLING DESIGN AND PHYSICAL MEASUREMENT:

Carbon inventory methods suggested by Ravindranath and Ostwald (2008) were used for measuring the above and belowground biomass and estimation of carbon pool. All the terrestrial carbon pools were measured step by step (Fig. 4.1). Random sampling was used to collect different variables since it was the most versatile, and scientific method for estimating above ground biomass. To apply simple random sampling technique, project area was alienated into large equal sized grids. In this method, the sample plots were laid out randomly to avoid the bias in locating the plots. Random sampling ensures that each point or grid in inventory area has an equal chance of being included in sample. Randomization made it possible to obtain unbiased estimates of variability as well as the mean per unit area.

**Fig. 4.1: Stepwise physical field measurements.**
4.6: THE GPS APPROACH:

The Global Positioning System (GPS) was used to estimate land areas as well as making border by walking along the boundary of both study areas. GPS was used extensively in all research stages and all map digitization was done based on GPS points recorded in the plots of both study areas. The method was based on a single unit, handheld GPS (GARMIN Make), which gives an accuracy of ±10 m. This accuracy is adequate for most land area estimations (Greenhouse, 2002). Along with GPS, the other field work devices used for field measurement are shown in Fig. 4.2. A comparative account of GPS approach and physical measurements are illustrated in Table 4.2.

Fig. 4.2: Field work devices.

4.7: CARBON POOLS ESTIMATION:

Selection of the most scientific and economically accepted technique for any type of carbon mitigation project, whether a natural or man-made forest, is of great importance. Plot method as the most accepted and proved method for carbon inventory
was selected. In addition GIS (Arc view 9.2) as a complimentary tool was used for higher accuracy and better interpretation of different carbon pools in the study areas.

### Table 4.2: Advantages vs. Disadvantages of physical and GIS approach

<table>
<thead>
<tr>
<th>Field work</th>
<th>Merits</th>
<th>Demerits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical</strong></td>
<td>➢ Provides ground knowledge of the project area to the project managers</td>
<td>➢ High cost, particularly for large areas</td>
</tr>
<tr>
<td><strong>Measurement</strong></td>
<td>➢ Easy to adopt and local staff could be trained to implement the method</td>
<td>➢ Difficult if there are multiple land units far apart</td>
</tr>
<tr>
<td></td>
<td>➢ Suitable for projects covering small geographical areas</td>
<td>➢ Not suitable for large sized projects</td>
</tr>
<tr>
<td></td>
<td>➢ Suitable for project proposal development phase</td>
<td></td>
</tr>
<tr>
<td><strong>GPS</strong></td>
<td>➢ Supplies data even while on the move, that is, the data are not restricted to a few fixed locations</td>
<td>➢ In dense forests or mountainous regions, signals from the satellites can be obstructed, lowering the accuracy of data</td>
</tr>
<tr>
<td></td>
<td>➢ Adequate accuracy (± 10 m)</td>
<td>➢ Difficult if there are multiple land units that are far apart</td>
</tr>
<tr>
<td></td>
<td>➢ Compatible with GIS</td>
<td></td>
</tr>
<tr>
<td></td>
<td>➢ Suitable for projects covering a small geographical area</td>
<td></td>
</tr>
<tr>
<td></td>
<td>➢ Suitable particularly for project proposal development phase</td>
<td></td>
</tr>
</tbody>
</table>

### 4.8: PLOT METHOD:

The principle of the plot method is to estimate the volume or weight of tree and non-tree biomass in a set of sample plots using the measured values of various indicator parameters such as DBH and height of tree. The plot method is extensively used in forest
inventory programmes and by project managers and evaluators for estimating and monitoring the carbon stock changes. It is also used for estimating biomass changes in cropland as well as grassland projects. The method is described in reports, manuals and books Special Report of Intergovernmental Panel on Climate Change on Land Use Land-Use Change and Forestry (Watson et al., 2000); Winrock Carbon Monitoring Guideline (MacDicken, 1997); FAO (Brown, 1997); Revised IPCC 1996 Guidelines (IPCC, 1996); IPCC Good Practice Guidance (IPCC, 2003); (Vine and Sathaye, 1999); CIFOR Methods (Hairiah et al., 2001); GHG Inventory Guidelines 2006 (IPCC, 2006) and Forest Inventory (Kangas and Maltamo, 2006).

4.9: MEASURED PARAMETERS FOR ESTIMATING THE ABOVE-GROUND BIOMASS POOL:

The goal of measurement and monitoring was to estimate the stocks of above-ground biomass on per hectare basis as well as for the total project area. The most commonly used parameters were as follows:

(i) Plant Form and Name of the Species:

It was the first parameter recorded for the plant form, namely tree, shrub, herb, followed by the name of the species. Tree species differ in shape, size, rate of growth and wood density. It is also important to estimate the density of trees (number per unit area) of each species in the sample plots. Biomass for tree species was estimated as weight or volume per tree, which was extrapolated to per hectare based on the density and distribution of each species.

(ii) Diameter or girth at breast height:

Diameter or girth at breast height is usually measured in terms of diameter or girth at breast height (DBH or GBH), and is one of the most important parameters and represents the volume or weight of a tree, which can be converted to biomass per unit area (tonnes/hectare or tonnes/hectare/year). The diameter and height can be used for estimating the volume by simple equations; DBH values can also be used in allometric functions to estimate volume or biomass per tree or per hectare. The breast height in DBH was recorded at 130 cm above the ground (Fig. 4.3 and 4.4).
Studies on above and below ground biomass of selected plant species and its relevance to carbon sequestration.

Fig. 4.3: Measurement of DBH.

Fig. 4.4: GBH of different shapes and forms of trees (Ravindranath & Ostwald, 2008)
(iii) Height of Trees:

Next to DBH, height was the most important parameter for the volume or weight of a tree. Measuring the height of tall trees, especially those with overlapping canopies, required instruments and could introduce errors. It was measured in meters. Trees taller than 5 m were measured using a graduated height-stick by holding the stick against the side of the tree. Abney-level was also used for measuring the height of trees but it was not suitable for dense vegetation where visibility was limited. The parameters recorded for estimation of aboveground biomass are presented on Table 4.3.

Table 4.3: Recorded Parameters for AGB.

<table>
<thead>
<tr>
<th>Carbon pool</th>
<th>Parameters to be recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above-ground biomass of trees</td>
<td>➢ Plant Form</td>
</tr>
<tr>
<td></td>
<td>➢ Name of the species</td>
</tr>
<tr>
<td></td>
<td>➢ GBH (cm)</td>
</tr>
<tr>
<td></td>
<td>➢ Height (m)</td>
</tr>
<tr>
<td></td>
<td>➢ Origin: regenerated or planted</td>
</tr>
<tr>
<td></td>
<td>➢ Status: dead or living</td>
</tr>
</tbody>
</table>

4.10: ACCURACY AND PRECISION:

Field sampling involves two common statistical concepts, namely accuracy and precision (IPCC 2003, Pearson et al., 2005b). Accuracy is a measure of how close the sample measurements are to actual values. Precision is a measure of how well a value is defined. In the case of carbon inventory, precision shows how closely the results from different sampling points or plots are grouped (Fig. 4.5).

Fig. 4.5: Accuracy and Precision (Rawindranath and Ostwald, 2008).
Accuracy and precision reflect how well the measurements estimate the true value of tree variables such as diameter, height and area covered by a stand of tree. An unbiased estimate will depend on repeated measurements being similar (Precise) and averaging close to the true value (Pearson et al., 2005b).

Fig. 4.6: Accuracy and precision in Pardisan forest plot distribution.
4.11: SHAPE OF PLOTS:

Square plots of 25×25m were the most commonly adopted shape for plots for estimating biomass in most vegetation types including forests, plantations and grassland (Fig. 4.7). The table 4.4 shows the selection of the plot size according to the DBH (diameter at breast height).

![Fig. 4.7: Standard Plot of 25×25 m²](image)

Table 4.4: Plot selection (Ravindranath & Ostwald, 2008)

<table>
<thead>
<tr>
<th>Stem diameter (DBH, cm)</th>
<th>Square plot (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 5</td>
<td>2×2</td>
</tr>
<tr>
<td>5–20</td>
<td>7×7</td>
</tr>
<tr>
<td>21–50</td>
<td>25×25</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>35×35</td>
</tr>
</tbody>
</table>

4.12: CALCULATION OF AGB:

Based on field survey and data collection such as height and DBH, calculation of biomass and eventually volume of sequestration were done. These values were used to estimate the volume of the trees, which eventually converted into weight using wood
density. Sequestration was accepted as half of the core biomass of the plant. Method used involves the following steps:

**Step 1:** The height and DBH of all the trees in the sample plots were measured.

**Step 2:** All the recorded data including height and dbh were tabulated.

**Step 3:** Volume of each tree in the sample plot was calculated using the following formulae.

\[ V = \pi \times r^2 \times H \]

Where: 
- \( V \) = volume of the tree in cubic centimeters or cubic meters
- \( r \) = radius of the tree at 130 cm above the ground = DBH/2
- \( H \) = height of the tree in centimeters or meters.

**Step 4:** Wood density values were obtained for each of the tree species from [http://www.worldagroforestrycentre.org/sea/Products/AFDbases/WD/](http://www.worldagroforestrycentre.org/sea/Products/AFDbases/WD/), or in case density was not available, 0.6 was accepted as wood density (Ravindranath & Ostwald, 2008).

**Step 5:** Dry weight of any tree was calculated from multiplying the volume of the tree with the respective wood density and convert the weight from grams to kilograms or tonnes.

(Weight of tree (in g) = volume of the tree (in cm\(^3\)) \times wood density (g/cm\(^3\))

**Step 6:** The weight of all trees of each species were summed in the selected sample plots (in kilograms or tonnes for each species).

**Step 7:** In the next step the results were extrapolated from 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).

**Step 8:** And in the final step the biomass of each species was summed to obtain the total biomass of all the trees in tonnes per hectare (dry matter).

Table 4.5 exhibits a sample worksheet for calculating the terrestrial carbon sequestration for each sample plots. In this worksheet, species name, number of individuals, GBH (cm), bole height (m), tree height (m), radius (m), wood density (m\(^3\)), wood volume (m\(^3\)), biomass (kg), and sequestered carbon (tonnes) have been mentioned.
Table 4.5: A sample worksheet for calculations of AGB for each plot.

<table>
<thead>
<tr>
<th>Species Name</th>
<th>No. of Individuals</th>
<th>GBH (cm)</th>
<th>Bole Height (m)</th>
<th>Tree Height (m)</th>
<th>Radius (m)</th>
<th>Wood Volume (m³)</th>
<th>Wood Density (kg/m³)</th>
<th>Biomass (kg)</th>
<th>Sequestrated Carbon (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total Carbon Sequestered =
4.13: BELOW-GROUND BIOMASS (BGB):

The below ground biomass in both study areas was calculated based on the relationship between shoot and roots for a tree of a given species. According to the importance of both study areas as urban hot spots and to avoid destructive methods, the below ground biomass was obtained from multiplying above ground biomass in 0.26 as an indirect method to obtain the value of below-ground biomass. A comparative review by Cairns *et al.* (1997) includes more than 160 studies covering native tropical, temperate and boreal forests that reported both below-ground biomass and above-ground biomass. The below-ground (root) biomass to average above-ground (shoot) biomass ratio developed based on these studies was 0.26 with a range of 0.18–0.30. The ratios did not vary significantly with latitude (tropical, temperate or boreal), soil texture (fine, medium or coarse) or tree type (angiosperms or gymnosperms). Based on these studies, the ratio developed for average above-ground (shoot) biomass vs. below-ground (root) biomass was 1: 0.26 (aboveground : belowground).

4.14: HERBS AND LITTER BIOMASS ESTIMATION:

Herbaceous biomass estimation was performed using the quadrates of 1m x 1m size. The quadrates were divided into four parts (¼ each). Herbs were harvested from two corners (Fig. 4.8) of this quadrate to avoid over harvesting in the study area; and it was extrapolated. End of monsoon (rainy season) was selected as the most proper time for sampling. Species name and fresh weight of standing herb biomass were recorded initially. The following steps were adopted for estimation herbs and litter sequestration:

**Step 1:** Name of the species was recorded.

**Step 2:** The fresh weight of the herb biomass was measured and recorded.

**Step 3:** The harvested sample of fresh herb biomass was weighted and dried to a constant weight to loose all the tissue moisture in oven. Samples were ovened for 48 hrs at 70-80°C and the dry mass was weighted (Mac Dicken, 1997).
Fig. 4.8: Herbaceous biomass sampling and collection in 1×1 meter plot

4.15: ESTIMATION OF SOIL ORGANIC CARBON (SOC):

Stocks of organic carbon in soil vary with land-use systems. The share of soil organic carbon in the total carbon stock may vary from 50% to 84% in forests to 97% in grasslands (Bolin and Sukumar, 2000). The concentration of organic carbon in soil is highest in the topsoil. Soil carbon dynamics is normally restricted to the top 15–45 cm, which is the zone of maximum microbial activity. Soil organic carbon is normally estimated to a depth of 0–30 cm since most of it is present in the top layers and root activity is also concentrated in this horizon.

During this study soil samples were collected from 15 and 30 cm in both study areas and were analyzed by Walkley-Black (1934, 1947) method as the most accepted method for SOC evaluation. Besides this, the GIS maps were prepared for both study areas according to the recorded lab data.

Wet digestion or titrimetric determination method, which is also cost-effective procedure is the most common method used in the field that involved a rapid titration procedure to estimate the organic carbon content of soil (Kalara and Maynard, 1991). Organic matter was oxidized with a mixture of K₂Cr₂O₇ and H₂SO₄. Unused K₂Cr₂O₇ was back-titrated with ferrous ammonium sulphate (FAS). Organic carbon in the soil is
oxidized to CO$_2$. The percentage of soil organic carbon was calculated using following formula:

$$\text{% of organic carbon in the soil} = \frac{[(X−Y)/2 \times 0.003 \times 100]}{S}$$

Where:
- $S =$ Weight of the sample in gram
- $X =$ Volume of FAS used in blank in grams
- $Y =$ Volume of FAS used to oxidize SOC in grams
- $N =$ Normality of FAS
- $(X−Y)/2 =$ Volume of 1 N K$_2$Cr$_2$O$_7$ used for the oxidation of carbon
- 1 ml of 1 N K$_2$Cr$_2$O$_7 =$ 0.003 g SOC

4.16: MEASUREMENT OF BULK DENSITY PARAMETERS:

Soil bulk density was defined as the oven-dry weight of soil per unit of its bulk volume. Bulk density is considered to have relatively low spatial variability (the coefficient of variation is less than 10%) but values were required for converting soil organic matter content to tonnes of soil organic carbon per unit area (tC/ha) (Baruah and Barthakur, 1997). Soil Bulk density was determined by samples which were taken by driving a metal corer into the soil at the desired depths of 15 and 30 cm. The samples were then oven dried and weighed.

$$\text{Bulk density (g/cc)} = \frac{(W_2-W_1)}{V}$$

Where
- $W_1 =$ (empty container),
- $W_2 =$ (Soil + container) and
- $V =$ volume of container.

4.17: GIS Application in Carbon Sequestration Assessment:

The application of GIS comes from a database management system that is designed to store and manipulate data (Lillesand et al. 2004). Apart from its application for remote sensing data, GIS also offers the possibility of integrating further analysis of other types of information including data on soil types and population of a certain area in
terms of different types of projects (Ostwald, 2002). In the present study GIS was used as a complimentary technique along with field measurements to obtain more accurate and precise calculation and interpretation of different layers including above and below ground biomass, soil organic carbon, leaf and litter, herb biomass distribution and eventually it was used as a worthy technique for indicating dominant species in the study area and marking hot spots of the project as an important step in any terrestrial carbon inventory project at the baseline stage. Arc view 9.2, as a recent software of Geographic Information System (GIS) was used. Above and below ground values along with other important parameters of all plots were entered in the software to show the concentration of carbon pools in both study areas. GIS based map shows the location and value of above and below ground carbon sequestration for each plot in the study area. Green color indicated the high concentration and shifting toward red indicated lower CO₂ presence in the carbon pool.

4.19: INVERSE DISTANCE WEIGHTING (IDW):

Inverse distance weighting (Watson and Philip, 1985; Colin, 2004) is a method for multivariate interpolation, a process of assigning values to unknown points by using values from usually scattered set of known points. Here, the value at the unknown point is a weighted sum of the values of known points. IDW is an interpolation technique in which interpolated estimates are made based on values at nearby locations weighted only by distance from the interpolation location. IDW does not make assumptions about spatial relationships except the basic assumption that nearby points ought to be more closely related than distant points to the value at the interpolate location. This technique determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. IDW allows the user to control the significance of known points upon the interpolated values, based upon their distance from the output point.