Chapter 3

Materials and Methods
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3.1 Study Area

Asola-Bhatti Wildlife Sanctuary (ABWLS), a protected area located in the south-eastern part of the southern Delhi ridge, India; lies between latitude 28°24′00″ to 28°30′00″N and longitude 77°12′00″ to 77°17′00″E (Plate 3.1) covering an area of about 32.71 km$^2$ and the entire sanctuary bio-geographically represents one of the oldest mountain system in India. Out of 542 Wildlife sanctuaries in India, the ABWLS is the only area, which represents north-eastern flat-topped hill form of country’s oldest hill ranges- the Aravalli-a highly eroded remnant of Precambrian uplift. Bhatti area of the sanctuary has undergone massive open cast mining of feldspar (for preparation of high grade pottery) and subsequently for red sand stone or morrum (building material). Mining was stopped and Asola Wildlife Sanctuary (4707 acres) was carved in 1986 under section 18 of Wildlife (Protection) Act 1972 from the community-land of three villages namely Asola, Shurpur and Maidangarhi. Subsequently in 1991 another notification was issued to declare Bhatti (2167 acres) as a part of Wildlife Sanctuary. Therefore, the administration undertook extensive seeding and planting of the area with several tree species, of which *Prosopis juliflora* and *Acacia* sps. have been successful.

The site is heterogeneous with intermixing of hard stable rocks and red sand mounds prone to erosion. This landscape has undergone drastic transformations due to mining, replacement of natural forest with commercial plantations of exotic species and urbanization. As a result, natural habitats have fragmented and degraded causing local extinction of several species. A major disturbance factor in the area is livestock grazing and fodder collection. Despite its ecological importance as home to a large number of threatened and charismatic species of flora and fauna this area has been neglected in terms of ecological studies and biodiversity assessments.

The climate of ABWLS is typically continental which is characterized by cold winter months and hot, dry summer months (Fig 3.1). Cool, oceanic air penetrates the area only during the monsoon months i.e., July to September). The annual precipitation is about 711 mm falling majorly during the monsoon months (July – September). Thar Desert in west and Gangetic plains in east also have their impacts on climate of ABWLS.
Plate 3.1: Location Map of Asola-Bhatti Wildlife Sanctuary (ABWLS)
3.2 Sampling Procedures

A total of six sites representing various categories of natural forests, secondary forests and plantations in relation to regeneration and disturbance regimes were selected for research (Fig 3.2) including (i) Mixed Natural Forest (MNF) constituting mixed natural forest free from anthropogenic pressure (Plate 3.2) and; (ii), *Anogeissus* natural forest (ANF) an *Anogeissus pendula* dominated natural forest patch which remained protected due to socio-religious tradition of considering the area as sacred groove (Plate 3.3). (iii) Naturally regenerated secondary forest in mining pits (SFMP), undisturbed from human interference which was under isolation period of more than 20 to 28 years (Plate 3.4); (iv) Naturally regenerated secondary forest on mine spoils of Sanctuary (SFMS) dominated by *Prosopis juliflora* (Plate 3.5); (v) Mixed Plantations site (MP) is a cluster plantation site in which mixed species such as *Dalbergia sissoo*, *Holoptelea integrifolia*, *Cassia fistula*, *Ficus religiosa*, *Azadirachta indica* etc were planted under a project on eco-rehabilitation of about 2,100 acres of degraded forests and abandoned mine pits of bhatti mines area by 132 Infantry Batallion (TA) ECO Rajput (Eco-Task Force - ETF) in the year 2003-2004 (Plate 3.6); and (vi) Barren land site (BL) was devoid of natural vegetation with heavily eroded top soil (Plate 3.7). Among the sites selected, the two study sites under consideration represent extreme ecological conditions; one being the highly degraded (BL) and the other relatively well protected (MNF). The site characteristics are summarised in Table 3.1.
Fig 3.2: Flow chart depicting the study site characterisation

<table>
<thead>
<tr>
<th>Study Sites</th>
<th>Forest Type</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Altitude (m asl)</th>
<th>Terrain</th>
<th>Vegetation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MNF</td>
<td>Mixed natural forests</td>
<td>28°28'50&quot;</td>
<td>77°12'45&quot;</td>
<td>237</td>
<td>Bouldry</td>
<td>Moderately dense thorn forest</td>
</tr>
<tr>
<td>ANF</td>
<td><em>Anogeissus</em> Natural Forest</td>
<td>28°25'05&quot;</td>
<td>77°12'55&quot;</td>
<td>288</td>
<td>Undulating, bouldry and rocky</td>
<td><em>Anogeissus pendula</em> dominated moderately dense thorn forest</td>
</tr>
<tr>
<td>SFMP</td>
<td>Naturally Vegetated Secondary Forest in Mining Pits</td>
<td>28°25'22&quot;</td>
<td>77°13'87&quot;</td>
<td>152</td>
<td>Slope towards North West</td>
<td><em>Prosopis juliflora</em> dominated Moderately dense thorn forest</td>
</tr>
<tr>
<td>SFMS</td>
<td>Naturally Vegetated Secondary Forest on Mine Spoils</td>
<td>28°29'25&quot;</td>
<td>77°14'25&quot;</td>
<td>236</td>
<td>Plain surface, Hard soil</td>
<td>Open scrub forest</td>
</tr>
<tr>
<td>MP</td>
<td>Mixed Plantation</td>
<td>28°29'10&quot;</td>
<td>77°13'06&quot;</td>
<td>239</td>
<td>Slope towards South-eastern side</td>
<td>Plantation scrub</td>
</tr>
<tr>
<td>BL</td>
<td>Barren land</td>
<td>28°25'25&quot;</td>
<td>77°14'25&quot;</td>
<td>280</td>
<td>Undulating Terrain</td>
<td>No vegetation</td>
</tr>
</tbody>
</table>
Plate 3.2: A general view of Mixed Natural Forests (MNF) site in ABWLS
Plate 3.3: A general view of Anogeissus Natural Forests (ANF) site in ABWLS
Plate 3.4: A general view of Naturally Vegetated Secondary Forests in Mining Pits (SFMP) site in ABWLS
Plate 3.5: A general view of Naturally Vegetated Secondary Forests on Mine Spoils (SFMS) site in ABWLS
Plate 3.6: A general view of Mixed Plantations (MP) site in ABWLS
Plate 3.7: A general view of Barren Land (BL) site in ABWLS
3.3 Methods

3.3.1 Land Use Land Cover Trajectory

A variety of remote sensing change detection methodologies have been developed and evaluated over the past twenty years (Rogan et al., 2002; Woodcock and Ozdogan, 2004; Healey et al., 2005). The purpose of this sub objective was to provide an indicative picture of regeneration in the study area over a period of two decades and to provide a case study using existing remote sensing change detection methods that benefiting Sanctuary resource management and monitoring. Fig 3.3 demonstrated the methodology flow chart for Land Use Land Cover Classification in Asola-Bhatti Wildlife Sanctuary.

Satellite data was used for a speedy and reliable method to determine land-use/ land-cover change (LUCC) in the study area. Landsat data with a resolution of 30 m, four points of time was used. Since supervised classification necessitates creating numerous training sets, data was collected using a hand held Global Positioning System (GPS).

3.3.1.1 Data Acquisition/ Preparation

- **Satellite Data**

Landsat remote sensing data was used as the primary data source for derivation of generalized land-cover information. Landsat satellites provide multispectral data from the early 1970s to the present. Given that the purpose of this study was to provide a general landscape characterization and change analysis instead of detailed vegetation and resource mapping, the spatial resolution of Landsat data was appropriate. Data availability and cost were also a consideration. A significant amount of Landsat data was available at no cost from on-line open resources. As the intent of this objective was to indicate the general trends of land-cover change and landscape context, the difference in spatial resolution between MSS and TM/ ETM+ images was not a concern as long as we obtained areas of land-cover types. Landsat data that represented the best match in time frame and, if possible, were close to the anniversary of image acquisition was searched in order to reduce seasonal effects. Four scenes of Landsat images, 1992 (TM data), 1999 and 2006 (ETM+ data) and 2013(OLI data) were acquired and processed.
Fig 3.3: Flow chart of methodology for land use land cover classification of ABWLS

All images were projected into Universal Transverse Mercator (UTM) map coordinates and, when necessary, conducted geometric rectification with ortho-rectified Landsat TM, ETM+ and OLI images as the base.

- **Collateral Data Collection**

  Topographic maps of scale 1:50000 of the study area were procured from Survey of India (Fig 3.4). These maps were digitized by table digitization and were used to extract only the area of interest (AOI) from whole map.
Fig 3.4: Topographic map demarked with Asola-Bhatti Wildlife Sanctuary boundary (scale-1:50000)
Table 3.2: Hardware and software used for determining the land use land cover change in ABWLS

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Type</th>
<th>Particulars</th>
<th>Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Hardware</td>
<td>P4 with Intel core two duo processor</td>
<td>Data storage and processing</td>
</tr>
<tr>
<td>2.</td>
<td>Hardware</td>
<td>GARMIN eTrex Venture HC Global Positioning System (GPS)</td>
<td>To complement the results of classification</td>
</tr>
<tr>
<td>3.</td>
<td>Software</td>
<td>ERDAS Imagine 9.1</td>
<td>Image processing and data analysis. Development of land use /land cover classes and subsequently for the change detection analysis of the study area.</td>
</tr>
<tr>
<td>4.</td>
<td>Software</td>
<td>Arc GIS 9.3</td>
<td>Map composition, spatial analysis and data base creation, display and processing of the data.</td>
</tr>
<tr>
<td>6.</td>
<td>Software</td>
<td>Microsoft Word 2007</td>
<td>Documentation</td>
</tr>
<tr>
<td>7.</td>
<td>Software</td>
<td>Microsoft Excel 2007</td>
<td>Field data analysis</td>
</tr>
</tbody>
</table>

This map was also used as ground truthing information in classifying the satellite image during supervised classification.

Varieties of software were employed in the present study following the different requirements of the work. The ERDAS (Earth Resources Data Analysis System) Imagine version 9.1 and ArcGIS 9.3 was employed for database development, spatial data analysis, producing thematic maps and extracted spectral reflectance. Microsoft Excel was used for statistical analysis.

3.3.1.2 Geo-referencing

Geo-referencing of Survey of India toposheet no 53 H/3/NE was done to extract the boundaries of the study area. After undergoing registration process, image to image registration of Landsat TM, ETM+ and OLI was carried out to make the image unified to a same coordinate system UTM/43N/WGS84 datum. To reduce the spectrum loss of satellite images, the nearest neighbour re-sampling method (Jing, 2008) has been applied.
3.3.1.3 Image Enhancement (Haze Removal)

Image enhancement was used to increase the detail of the image by assigning the image maximum and minimum brightness values to maximum and minimum display values and it was done on pixel values and this made visual interpretation easier by increasing the visual discrimination between features in a scene and assists the human analyst: False colour composite (FCC), spatial re-sampling, etc.

3.3.1.4 Thematic Map Preparation

- **Land Use/ Land Cover Change Detection**
  Satellite data of four years were mosaiced and the area of interest (AOI) was delineated. Visual interpretation of satellite imagery and reconnaissance survey of the area was carried out for obtaining patterns of vegetation and other land cover features during June 2012 to June 2014.

- **Image Classification (Maximum Likelihood Method)**
  Supervised classification was performed to classify the image into different land use changes as supervised classification has high accuracy to that of unsupervised classification since, the user can train the classes according to wish. The base map and further four mentioned year’s maps for change detection were hence prepared by supervised classification. Maximum likelihood classifier is generally used for supervised classification (Lillesand *et al.*, 2004). Data of the different land use land cover classes obtained from the field study (GPS location) were used as training sample for supervised classification. The maximum likelihood classifier (MLC) which is a widely used classification algorithm was used for the classification. MLC calculates for each class the probability each cell belonging to a particular class depending on its attribute values; with the cell being assigned to the class with the highest probability. Land cover was classified into the following seven classes (Table 3.3).
Table 3.3: Image interpretation key for different forest and land cover mapping

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Class</th>
<th>Tone, Texture and Pattern</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Barren land</td>
<td>White, Rocky or sandy areas with sparse vegetation or no vegetation</td>
</tr>
<tr>
<td>2.</td>
<td>Settlements</td>
<td>Cyan, Regularised</td>
</tr>
<tr>
<td>3.</td>
<td>Rock outcrops</td>
<td>Cyan, Rough</td>
</tr>
<tr>
<td>4.</td>
<td>Forests</td>
<td>Dark red to reddish green; rough texture, but in dry season the areas take up greenish shade with no evidence of foliage</td>
</tr>
<tr>
<td>5.</td>
<td>Forests plantation</td>
<td>Reddish white</td>
</tr>
<tr>
<td>6.</td>
<td>Scrub</td>
<td>Whitish green; Mottled; Scattered stunted vegetation with exposed ground surface</td>
</tr>
<tr>
<td>7.</td>
<td>Water body</td>
<td>Greenish blue; Checkered pattern, smooth texture</td>
</tr>
</tbody>
</table>

This classification was used to prepare Land Use Land Cover map of ABWLS. Training data collected from field study was used for the classification of 2013 (OLI) satellite image whereas for the classification of 1992 (TM), 1999 (ETM) and 2006 (ETM) image, digital topographic map was used. All satellite imageeriyas were rectified with the help of Survey of India topographical map (of 1:50,000 scale) and a common coordinate system was used for the study sites. These datasets were analyzed using Erdas Imagine 9.1 (ERDAS Inc., Atlanta, GA, USA) and ArcGIS 9.3 (ESRI, Redlands, CA, USA) was used to analyze landscape metrics.

The satellite imageries were classified and different land use and land cover categories were delineated on the basis of tone, texture, color etc. Based on the reconnaissance survey of the ground details and signatures, an interpretation key was developed to enable information extraction from the image. The classified maps of four time periods were produced. Independently classified images were then compared with each other to determine the changes of land use land cover types. The field observations provided essential independent reference data for identifying LULC types within the images as well as for accuracy assessment.

- **Ground Truthing**

The ground reference points were measured during the field visit to the study areas in the period from October 2012 to February 2014. They were selected based on pre-classified maps for the imagery. The coordinates for each reference point were recorded...
using hand-held GARMIN eTrex Venture HC Global Positioning System (GPS). Information on land use and cover was recorded too.

- **Accuracy Assessment (stratified random assessment)**

  Based on the 30-meter resolution of the Land sat data used to create map, it is important to keep in mind that the map will be most accurate for viewing geographic patterns over larger areas. Visual interpretation of satellite imagery and reconnaissance survey of the area has been carried out for obtaining patterns of vegetation and other land cover features during June 2012 to June 2014. Accuracy assessment was done through field verification method.

- **Land Use/Land Cover Maps**

  To determine the rate of land use land cover change, the period of two decades 1992-2013 was divided into three sub-periods with a subsequent gap of 7 years and the land use land cover changes of these three sub-periods were compared. The first sub-period was from 1992-1999 the second sub-period was from 1999-2006 and the third period from 2006-2013. The comparative analysis in land use and land cover change focused on the three sub-periods. The spatial distribution of the average (annual) rate of land use land cover change between two periods was computed by a slight modified formula used by Long *et al.* (2007):

  \[
  \Delta = \left[ \frac{(A_1 - A_2)}{A_1} \right] \times 100 \left/ \left( T_1 - T_2 \right) \right. 
  \]

  Where:

  - \( \Delta \): Average annual rate of change (%)
  - \( A_1 \): Amount of land cover land use type in time 1 (\( T_1 \))
  - \( A_2 \): Amount of land cover land use type in time 2 (\( T_2 \))

  **3.3.1.5 Vegetation/ Forest Change Detection (NDVI)**

  Vegetation Index (VI) is commonly used for evaluating vegetation condition. To explore the effects land-use/land-cover change (LUCC) on vegetation health in the Asola-Bhatti Wildlife Sanctuary, a proxy for the vegetation health namely the Normalized Difference Vegetation Index (NDVI) was used. The NDVI is a widely used
vegetation index and several studies have used it. NDVI was derived from the Landsat imageries using the ERDAS Imagine software (ERDAS Inc., Atlanta, GA, USA).

\[
\text{NDVI} = \frac{\text{NIR} - \text{RED}}{\text{NIR} + \text{RED}}
\]

Because of the availability of remote sensing data, the 1992 Landsat TM, 1999 and 2006 Landsat ETM+ images and 2013 Landsat OLI images were used to analyse vegetation conditions over the study period. The NDVI was calculated using Bands 3 and 4 of Landsat 5 (TM) and 7 (ETM+) and Bands 4 and 5 of Landsat 8 (OLI) as red and near-infrared bands, respectively. The resulting NDVI images were then compared and thresholds were used to categorize the vegetation change. The high NDVI means better vegetation conditions. Where NDVI is less than or equal to zero (NDVI ≤ 0), the land cover types are most likely bare ground without vegetation such as rocky outcrops and water bodies. Moreover, the area of human-induced categorical change was also considered.

### 3.3.2 Vegetation Composition and Plant Diversity Patterns

The vegetation analysis was done during the study period 2012 and 2013 in ABWLS. Six study sites including (i) mixed natural forests (MNF); (ii) *Anogeissus* natural forest (ANF); (iii) Naturally vegetated secondary forest in mining pits (SFMP); (iv) Naturally vegetated secondary forests on mine spoils (SFMS); (v) Mixed plantations (MP) and (vi) Barren Land (BL) were selected for vegetation analysis. The size of the quadrat used in this study was decided based on the species area curve method following Mishra (1968) and the running mean method (Kershaw, 1973). At each site 10 quadrats (10 m x 10 m) were laid for sampling the tree stratum, 3m x 3m quadrats were used to quantify shrubs and 1m x 1m quadrats for herbs and grasses. In each quadrat the individual trees were enumerated and for each tree diameter at breast height (DBH) i.e., at 1.37 m from the ground were recorded. Collar diameter in case of herbs and grasses with the help of tree calliper and electronic digital calliper was recorded. In case of grasses and sedges, each erect shoot was considered to be a plant tiller and the enumeration was done by laying 1m x 1m quadrats at random, further subdivided into 10cm x 10cm segments. Four such segments selected at random were analysed from
each quadrat by counting the tillers individually as per method used by Singh and Yadava (1974).

3.3.2.1 Floristic Composition of Vegetation

The principle of sampling was to collect field data based on vegetation type strata i.e. trees, shrubs and herbs, to bring out vegetation type and macro-habitat specific relative species abundance information along with other ecologically important variables. Hence sampling was aimed to address the basic issues related to composition, structure and function through appropriate distribution and intensity across spatial and temporal gradients at the landscape level. The sampling of tree layer vegetation was undertaken in rainy, winter and summer seasons. For ground floor vegetation, based on the field phenology, sampling was undertaken during rainy, winter and summer seasons in order to cover maximum number of occurrence.

3.3.2.2 Analysis of Vegetation Structure

Phytosociology is the study of the characteristics, classification, relationships and distribution of plant communities. The quantitative vegetation characteristics were studied in terms of plant density, abundance, frequency and basal area.

The density, basal area and Importance Value Index of the trees and shrubs were calculated following Phillips (1959) and Misra (1968) as follows:

\[
\text{Density} = \frac{\text{No. of individuals of a species in all quadrats}}{\text{Total number of quadrats studied}}
\]

Density is expressed as the number of individuals per unit area

\[
\text{Frequency} (%) = \frac{\text{No. of quadrats in which species occur}}{\text{Total number of quadrats studied}} \times 100
\]

\[
\text{Relative Density} (%) = \frac{\text{Density of one species}}{\text{Sum of densities of all the species}} \times 100
\]

\[
\text{Relative Frequency} (%) = \frac{\text{Frequency of one species}}{\text{Sum of Frequency of all the species}} \times 100
\]
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Relative Dominance (\%) = \frac{\text{Total basal cover of a species}}{\text{Sum of Basal cover of all the species}} \times 100

where,

\[
\text{Basal Cover} = \frac{(Cbh)^2}{4\pi}
\]

Importance Value Index (IVI) following Curtis and McIntosh (1951) were calculated as:

Important Value Index (IVI) = \text{Relative density (\%) + Relative frequency (\%) + Relative basal area (\%)}

3.3.2.3 Analysis of Species Diversity Indices

The dominance – diversity curves (Magurran 1988) of species of each site were plotted using log values of importance value index (IVI) and species sequence. Shannon-Weaver index (Shannon-Weaver, 1963) for species diversity was computed from the importance value index of various plant species.

Diversity index was calculated following Shannon and Weaver (1963) as follows:

\[
H' = \sum_{i=1}^{s} p_i \ln p_i
\]

where \(p_i\) is the proportion of individuals of \(i^{th}\) species and total number of individuals of all species.

The concentration of dominance was calculated following Simpson (1949) as follows:

\[
Cd = \sum_{i=1}^{s} (p_i)^2
\]

where \(p_i\) is the proportion of individuals of \(i^{th}\) species and total number of individuals of all species.

The species evenness or equitibility was calculated following Pielou (1975) as follows:

\[
J' = \frac{H'}{H_{max}}
\]
where $H'$ is the Shannon diversity index and $H_{\text{max}}$ is the Shannon maximum diversity index, which was calculated as follows:

$$H_{\text{max}} = \ln(S)$$

where $S$ = the total number of species in the forest site.

Species richness index ($d$) indicating the mean number of species per sample (Margalef 1958) was calculated as $d = S/\sqrt{N}$, where, $S$ = number of species, $N$ = number of individuals of all species.

### 3.3.3 Analysis of Physico-chemical Properties of Soil

#### 3.3.3.1 Soil Sampling

Soil samples were collected randomly from three experimental plots marked with in 20m x 20m sampling plots at all the six sites seasonally across the study period from 2011 to 2014. The soil samples were collected by using soil corer from 0 to 10 cm, 10 to 20 cm and 20 to 30 cm soil layers. The soil samples from the same study site and same layer were mixed thoroughly, air dried and passed through a 2mm mesh sieve to remove the stone pieces and large root particles. The samples were collected in marked polythene bags and tightly closed to prevent any air exchange. Some samples were procured for immediate moisture content and bulk density measurement, while others were air dried at room temperature for further determining various physico-chemical parameters of soil.

#### 3.3.3.2 Percent Moisture Content

The procedure outlined by Schlichting and Blume (1966) was followed for the estimation of gravimetric water content of the soil sampled. 20 gm of soil sample was placed in a crucible and dried to a constant weight at 105°C for 3 hrs. The dried samples were placed in a dessicator and reweighed. The percent moisture content was determined by:

$$\% \text{ Moisture Content} = \left[ \frac{\text{[(Fresh weight - Dry weight)]}}{\text{Fresh weight}} \right] \times 100$$
3.3.3.3 Soil Bulk Density

The bulk density (g cm\(^{-3}\)) was studied by using a soil corer (3.5 cm internal diameter). The soil sampler was used to take fresh soil sample at a depth of 0-10, 10-20 and 20-30 cm from each plot. The bulk density was determined on weight and volume ratio of the oven dried at 105°C.

\[
\text{Bulk Density} = \frac{\text{Dry soil weight}}{\text{Volume}}
\]

3.3.3.4 Soil Texture

Soil texture with regard to each experimental site was determined by the hydrometer method (Boyucos, 1962). A 50 g of air-dried soil was weighed into a measuring cylinder and 50 ml of calgon (sodium hexamethaphosphate) added. The suspension was shaken and allowed to stand. Corrected hydrometer readings at 40 seconds and 5 hours were taken.

\[
\begin{align*}
\% \text{ sand} &= 100 - [(A/W) \times 100] \\
\% \text{ clay} &= 100 \times (B/W) \\
\% \text{ silt} &= 100 - (\% \text{ sand} + \% \text{ clay})
\end{align*}
\]

where A = corrected hydrometer reading at 40 seconds; B = corrected hydrometer reading at 5 hours; W = weight of dry soil

The textural class was determined from the textural triangle (ternary) diagrams for the representation of particle shape were then plotted following the method recommended by Benn and Ballantyne (1993) and first proposed by Sneed and Folk (1958).

3.3.3.5 Soil pH

Soil suspension was used for determination of pH. The ratio of soil to water is a subject of controversy and ranges from a sticky point to 1:5 ratio (Allen et al., 1974). In the present investigation, 1:2 (w/v) ratio of soil to water was used. The freshly collected samples were sieved through 2 mm sieve. An equivalent of 10g of fresh soil sample was suspended in 20 ml deionised double distilled water and stirred for 30 minutes in
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New Brunswick G 24 Environmental Incubator Shaker maintained at 145 rpm and at 30°C. the suspension was allowed to stand till the suspended soil particles settled down at the bottom. The pH of the soil suspension was measured using electronic pH meter.

3.3.3.6 Soil Organic Carbon

Soil organic carbon was determined by rapid dichromate oxidation technique (Walkley and Black, 1934). The organic matters in the soil were oxidized by chromic acid (Potassium dichromate plus conc. H₂SO₄) utilizing the heat of dilution of H₂SO₄. The un-reacted dichromate was determined by back titration with ferrous ammonium sulphate.

3.3.4 Estimation of Biomass and Net Primary Productivity

3.3.4.1 Estimation of Plant Biomass

Biomass of trees for all the experimental sites was estimated by dimension analysis of sampled trees following two methods. First, by using volumetric regression equations between diameter and using specific gravity, compiled and published by Forest Survey of India (FSI, 1996); and second, by using site specific biomass equations developed for the forests of Aravallies following Singh, (2014).

Ten experimental/ treatment plots of 10 x 10m were demarcated within each forest sites except site II for recording observation on growth parameters of trees. Trees were marked and their circumference was measured at 1.37 m height above the ground during October 2011. The measurements of CBH were recorded during the month of October in the years 2011 to 2013.


Wood volume of individual trees was estimated using species specific volumetric equations using DBH (diameter at breast height) of the trees. The volume was multiplied by species specific gravity to obtain above ground biomass (AGB). The species specific volumetric equations and specific gravity were published and compiled by Forest Survey of India (FSI, 1996). The mean biomass of various trees was added to find the total biomass for each site. Volumetric regression equations and specific
gravity values used for biomass estimation of trees species (FSI, 1996) are given in Appendix Table A19.

Below ground biomass (BGB) was computed by using regression equation of Cairns et al., (1997) for tropical trees for each forest site, as follows:

\[ \text{BGB} = \exp \{-1.0587 + 0.8836 \times \ln (\text{AGB})\} \]

From tree density and the mean biomass of trees, total AGB and total BGB were computed.

- **Method II – Site Specific Biomass Equation (Singh, 2014)**

The regression equation showing the relationship between growth and weight of trees were computed following Singh (2014) to determine the biomass of tree components, above ground and below ground. The regression equations used for different tree components are as follows:

- Above-ground biomass (kg) = \(0.181494261 \times D^{2.058650773}\)
- Below-ground biomass (kg) = \(0.084773863 \times D^{2.028825779}\)

\(D\): diameter at breast height in case of tree (>3.0cm diameter)

From tree density and the mean biomass of trees, total AGB and total BGB were computed.

### 3.3.4.2 Estimation of Net Primary Productivity

Above-ground net primary productivity (ANP) of trees was calculated on the basis of sum of increment in the biomass of non-photosynthetic parts over a time period of one year and the annual litter production during the same period (Olson, 1975). The below-ground net primary productivity (BNP) of trees was calculated as the sum of increment in below-ground biomass over a time period of one year. The annual litter production was added to the biomass increment to obtain net primary productivity.

### 3.3.4.3 Estimation of Litter Fall Production

Litter fall was quantified by litter trap measurements (Proctor, 1983). Ten litter traps of 1m x 1m with nylon netting, 50 cm high above ground were installed on each forest site
except site II. Litter fall was collected at seasonal intervals from the traps for one year (October, 2012-September, 2013). The litter samples were taken to the laboratory and separated into leaf litter and twig litter. The litter samples were oven dried to a constant dry weight at 80°C and weighed to obtain dry weight.

3.3.5 Estimation of Carbon Pool and Carbon Flux

3.3.5.1 Carbon in Vegetation and Litter

The above-ground, below-ground biomass and litter fall carbon stock was calculated by assuming that the carbon constitutes between 45 to 50 percent of dry matter and it can be estimated (C = 0.475 x Biomass) by taking a fraction of biomass (Brown and Lugo 1982, Ravindranath et al., 1997). Carbon flux was calculated as the difference between the carbon stocks sequestered by vegetation per year. Estimated C stocks in tree components were converted to CO₂ equivalents (C x 3.67) for calculating CO₂ assimilation by biomass.

3.3.5.2 Soil Carbon Stock

Soil carbon stock was estimated from bulk density, soil depth and carbon concentration in soil of the respective soil depth using the following equation:

\[
\text{Soil Carbon Stock (Mg C ha}^{-1}\text{)} = \frac{\% \text{ Carbon} \times \text{Bulk Density (Mg m}^{-3}\text{)} \times \text{Depth (m)} \times 104 \text{ m}^2\text{ha}^{-1}}{100}
\]

3.3.5.3 Total Carbon Stocks in Study Sites

The soil organic carbon stocks and vegetation carbon stocks were summed up to estimate the total carbon stocks of the respective forest system. The carbon stocks of all the study sites were summed up to determine the carbon stocks of the forest system.

3.3.6 Analysis of Cross Linkages between REDD+ and Carbon Sequestered

3.3.6.1 Change Detection

Post-classification comparison (change detection) of the imagery was applied to determine the changes in land use and land cover that had occurred in the study areas A
and B and demonstrating the net degradation taken place over time. All the imageries were classified independently. Post-classification is most common approach used for monitoring land use land cover change since it provides more useful information on initial and final land covers types in a complete matrix of change direction. In the change detection application, the magnitude, rate and nature of the land use land cover change and conversion and change map were derived as well.

3.3.6.2 Analysis of Forest Dependency and Extraction Pressure through Socioeconomic Survey of Villages

Eight villages were selected as study sites Satberi, Sahurpur, Asola, Bhatti, Chandanhula, Maidangari, Rajpur Khurd and Sangam Vihar in order to assess local knowledge and their dependency on ABWLS. Data collection was carried out from Jan 2012 to January 2013 among the study villages situated adjacent or within a diameter of 3km from sanctuary (Table 3.4).

<table>
<thead>
<tr>
<th>Study Villages</th>
<th>Number of Households</th>
<th>Total Population</th>
<th>Distance from Sanctuary</th>
</tr>
</thead>
<tbody>
<tr>
<td>SangamVihar</td>
<td>20160</td>
<td>106285</td>
<td>Adjacent to ABWLS</td>
</tr>
<tr>
<td>Sahurpur</td>
<td>578</td>
<td>3090</td>
<td>Adjacent to ABWLS</td>
</tr>
<tr>
<td>Bhatti</td>
<td>3727</td>
<td>18864</td>
<td>Adjacent to ABWLS</td>
</tr>
<tr>
<td>RajpurKhurd</td>
<td>2388</td>
<td>11161</td>
<td>0.5 km away from ABWLS</td>
</tr>
<tr>
<td>Satberi</td>
<td>1218</td>
<td>6076</td>
<td>1 km away from ABWLS</td>
</tr>
<tr>
<td>Maidangari</td>
<td>2289</td>
<td>11111</td>
<td>2 km away from ABWLS</td>
</tr>
<tr>
<td>Asola</td>
<td>2502</td>
<td>11111</td>
<td>3 km away from ABWLS</td>
</tr>
<tr>
<td>Chandanhula</td>
<td>1184</td>
<td>6780</td>
<td>3 km away from ABWLS</td>
</tr>
</tbody>
</table>

Both Satberi and Sahurpur are located adjacent to the ABWLS and is 1 km away from the Sanctuary. The livestock in this region consisted of cows, buffaloes, goats, camels, pig and sheep. Bhatti village is located within the vicinity of the ABWLS in which two unauthorized colony Sanjay colony and Balbir Nagar were established since
These colonies were settled at the time of active mining. Most of the residents were migrants and belong to other part of the state. The livestock in this region consisted of mules and donkeys for transporting the mined material. Sangam Vihar was an unauthorized colony along the north-western boundary and Maidangari was approximately 2km to the ABWLS, whereas Chandanhula was 3km and Rajpurkhurd was 0.5 km away from the Sanctuary.

For each of eight village’s population size, sex, age distribution, number of households, education level, type of employment, data were obtained from Directorate of Economics and Statistics and Office of Chief Registrar, Government of National Capital Territory of Delhi (GNCTD) in respect of National Census done by Govt. of India in 2011. This data was then crossed check against information provided by local health centres, village council offices government schools and village administrative offices.

Distance of the study villages from ABWLS boundary was obtained from forest department and ranged from 0.03 to 3.5 km. Interview was carried out among a total of 157 people (86 men and 81 women) in the eight focal villages namely Satberi, Sahurpur, Asola, Bhatti, Chandanhula, Maidangari, RajpurKhurd and SangamVihar; each respondent representing a different household. Table 3.5 summarises the interviewed population in eight villages located adjacent and around ABWLS. For each village, an attempt was made to interview statistically so that at least 1% of population above the age of 20 years will got selected under different age groups and types. Interviews were conducted conditional upon the individual’s willingness to fully participate and if at any point during the interview the individual express reservation, the interview was terminated. The interview contain a series of closed and open ended questions relating to the household demographic and residency, land use pattern, carbon benefits, household behaviour causing deforestation and forest degradation and their conservation attitude towards the sanctuary (Questionnaire Appendix Table A20). Respondents were also asked about their attitudes towards conservation and protection of the forest in ABWLS and the forest department which administers the protected area. Mean extraction pressure for each village was co-related with the no of household in
that village as an indicator of village size and household were the basic units involved in resource extraction.

**Table 3.5:** Description of the interviewed population in eight villages located adjacent and around ABWLS (HH = households)

<table>
<thead>
<tr>
<th>Study Village</th>
<th>Total HH</th>
<th>Sampled HH</th>
<th>Total Population</th>
<th>Total Respondent</th>
<th>Age Category</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>M F</td>
<td>M F M F M F M F M F</td>
<td></td>
</tr>
<tr>
<td>Sangam Vihar(187)</td>
<td>9811</td>
<td>9</td>
<td>28860 24571</td>
<td>5 4 1 1 2 1 2 2</td>
<td></td>
</tr>
<tr>
<td>Sangam Vihar(188)</td>
<td>10349</td>
<td>10</td>
<td>29029 23879</td>
<td>5 5 1 1 2 2 2 2</td>
<td></td>
</tr>
<tr>
<td>Sahurpur</td>
<td>578</td>
<td>6</td>
<td>1712 1378</td>
<td>3 3 1 1 1 1 1 1</td>
<td></td>
</tr>
<tr>
<td>Bhatti</td>
<td>3727</td>
<td>38</td>
<td>10114 7750</td>
<td>19 19 7 7 6 6 7 7</td>
<td></td>
</tr>
<tr>
<td>Rajpur Khurd</td>
<td>2388</td>
<td>24</td>
<td>6049 5112</td>
<td>11 11 3 3 3 3 5 5</td>
<td></td>
</tr>
<tr>
<td>Satberi</td>
<td>1218</td>
<td>12</td>
<td>3448 2628</td>
<td>6 6 2 2 2 2 2 2</td>
<td></td>
</tr>
<tr>
<td>Maidangarhi</td>
<td>2289</td>
<td>22</td>
<td>5915 5196</td>
<td>12 12 4 4 4 4 4 4</td>
<td></td>
</tr>
<tr>
<td>Asola</td>
<td>2502</td>
<td>25</td>
<td>7160 6115</td>
<td>13 12 4 4 5 4 4 4</td>
<td></td>
</tr>
<tr>
<td>Chandanhula</td>
<td>1184</td>
<td>15</td>
<td>3723 3057</td>
<td>9 6 3 2 3 2 3 2</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>34046</strong></td>
<td><strong>161</strong></td>
<td><strong>96010 79686</strong></td>
<td><strong>83 78 26 25 28 25 30 29</strong></td>
<td></td>
</tr>
</tbody>
</table>

Eight villages were selected as study sites Satberi, Sahurpur, Asola, Bhatti, Chandanhula, Maidangari, Rajpur Khurd and Sangam Vihar in order to assess local knowledge and their dependency on ABWLS. Both Satberi and Sahurpur are located adjacent to the ABWLS and is 1 km away from the Sanctuary. The livestock in this region consisted of cow, buffaloes, goats, camels, pig and sheep. Bhatti lies within the vicinity of the ABWLS in which two unauthorized colony Sanjay colony and Balbir Nagar were established since 1975. These colonies were settled at the time of active mining. Most of the residents were migrants and belong to other part of the state. The livestock in this region consisted of mules and donkeys for transporting the mined material. Sangam Vihar was an unauthorized colony along the north-western boundary and Maidangari was approximately 2km to the ABWLS, whereas Chandanhula was 3km and Rajpur Khurd was 0.5 km away from the Sanctuary. The livestock in this region consist of cow, buffaloes and goats, camels, pig and sheep.
3.3.6.3 Valuing Carbon Stocks under REDD+ Mechanism

The estimated CO$_2$ equivalents were used to calculate the value of carbon sequestration by forest ecosystems using a gross valuation method based on the rate of US$6 per tonne of CO$_2$ which indicated the cost of avoiding future global warming by the fixing of carbon (EPCO, 2013).

3.4 Statistical Analysis

The results of the experimental protocols were analysed statistically through one-way Analysis of Variance (ANOVA) using SPSS 16.0.