# Ecosystem Services Improvement Project: Baseline Report of Forest Carbon Stocks of Project Areas of Madhya Pradesh

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# Ecosystem Services Improvement Project: Baseline Report of Forest Carbon Stocks of Project Areas of Madhya Pradesh

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## FOREWORD

Climate change is a threat having perceptible and tangible impacts upon human kind and natural resources. The role of forests in climate change mitigation is well known. Forests are now an integral part of international protocols dealing with climate change. Responding to global call for nationally appropriate mitigation actions, the Government of India released its National Action Plan for Climate Change (NAPCC) with eight National Missions. Green India Mission is one of the flagship missions under NAPCC.

The World Bank supported Ecosystem Services Improvement Project (ESIP) is supporting the Green India Mission (GIM) in states of Madhya Pradesh and Chhattisgarh. ESIP is supporting the goals of GIM by demonstrating models for adaptation-based mitigation through sustainable land and ecosystem management. New tools and technologies for better management of natural resources, including biodiversity and carbon assets and the use of advanced monitoring systems are being introduced under ESIP, which have been widely usedand are considered a necessity in the forestry sector. The pilots in Chhattisgarh and Madhya Pradesh will help demonstrate the potential for nationwide scaling up of the ESIP and will directly support India's Nationally Determined Contributions.

ICFRE as one of the project implementing unit for the ESIP and implementing sub-component on Forest carbon stocks measurement, monitoring and capacity building besides the component on Scaling up Sustainable Land and Ecosystem Management best practices in selected landscapes of Chhattisgarh and Madhya Pradesh. The baseline survey was conducted to assess the outcomes and impacts of the ESIP activities in the forests of selected landscape of Madhya Pradesh.

I have great pleasure in presenting this 'Baseline Report of Forest Carbon Stocks of Project Areas of Madhya Pradesh'. I am hopeful that the findings of this report will serve as a framework for assessing impacts of the project and will be a guiding document for effective implementation of ESIP activities in the state of Madhya Pradesh.

I compliment all the team members of ESIP-PIU, ICFRE for bringing out this baseline report of forest carbon stocks for project areas of Madhya Pradesh.

Date: 02/06/2020

(Arun Singh Rawat)

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We are hopeful that the Baseline Report of Forest Carbon Stocks of Ecosystem Services Improvement Project Areas of Madhya Pradesh will be a benchmark document to monitor the forest carbon stocks assessment over a period of time.

Report Preparation Team

# Contents

## Abbreviations Used

| | |
|---|---|
| AFOLU | Agriculture, Forestry and Other Land Use |
| AGB | Above Ground Biomass |
| BD | Bulk Density |
| BGB | Belowground Biomass |
| C | Carbon |
| CBH | Circumference at Breast Height |
| CF | Coarse Fragments |
| cm | Centimeter |
| $Co_2$ | Carbon Dioxide |
| cum | Cubic metre |
| $^0C$ | Degree Celsius |
| DBH | Diameter at Breast Height |
| ESIP | Ecosystem Services Improvement Project |
| FSI | Forest Survey of India |
| GIM | Green India Mission |
| GHG | Greenhouse Gases |
| ha | Hectare |
| ICFRE | Indian Council of Forestry Research and Education |
| IPCC | Intergovernmental Panel on Climate Change |
| JFMCs | Joint Forest Management Committees |
| LULUCF | Land Use, Land Use Change and Forestry |
| M | million |
| m | Meter |
| Mg | Megagram |
| mg | Milligram |
| ml | Milliliter |
| mm | Millimeter |
| MoEFCC | Ministry of Environment, Forest and Climate Change |
| NAPCC | National Action Plan for Climate Change |
| N | Normal Solution |
| NaF | Sodium Fluoride |
| OC | Organic Carbon |
| NWFP | Non-wood Forest Product |
| SLEM | Sustainable Land and Ecosystem Management |
| SOC | Soil Organic Carbon |
| Sp. Gr. | Specific Gravity |
| Sq km | Square Kilometre |
| t | Tonne |
| UNFCCC | United Nations Framework Convention on Climate Change |

# Executive Summary

Ecosystem Services Improvement Project (ESIP) is being implemented in the state of Madhya Pradesh. The State Forest Department of Madhya Pradesh has selected Budhni Forest Range (Sehore Forest Division), Bhaura Forest Range (North Betul Forest Division), and Sukhtawa, Itarsi and Banapura Forest Ranges (Hoshangabad Forest Division) for implementation of project activities under ESIP. Estimated forest covers of Budhni Forest Range, Bhaura Forest Range and areas under Banapura, Itarsi and Sukhtawa Forest Ranges estimated to be 4079.92 ha, 6640.16 ha and9296.30 ha, respectively. Forests store significant amount of carbon in its biomass, litter, dead wood and soil, and it has major role in climate change adaptation and mitigation. Baseline of the forest carbon stocks in the project area will act as a benchmark for the activities to be carried out by Madhya Pradesh State Forest Department under ESIP for the enhancement of forest carbon stocks in the project area.

Five carbon pools viz., aboveground biomass, belowground biomass, litter, deadwood, soil organic matter were considered for measurement of forest carbon stocks. Stratified random sampling was followed using forest density maps and forest type maps prepared by Forest Survey of India to stratify the project area into forest type density stratum. Intersect tool in GIS software was used to produce the Forest Type and Density maps of the project areas. Sample plot design and layout method prescribed in the National Working Plan Code – 2014 were followed for measurement of forest carbon stocks. A total of 155 permanent sample plots were laid out to generate data on baseline forest carbon stocks of ESIP area. The baseline total forest carbon stocks for the year 2019 have been estimated to be 11,72,639.59 tonnes for the ESIP areas of Madhya Pradesh. Areas under Banapura, Itarsi and Sukhtawa Forest Ranges have the maximum carbon stocks (5,56,996.94 tonnes) followed by Bhaura Forest Range (3,78,629.12 tonnes) and Budhni Forest Range (2,37,013.53 tonnes), respectively. Forest areas under ESIP havethe potential to sequester more carbon as maximum trees are young, which can build biomass in the subsequent years and therefore can store the carbon in biomass.

Baseline data on forest carbon stocks of the ESIP areas of Madhya Pradesh revealed that average carbon stocks density for Bhaura Forest Range has been estimated to be 57.59 t/ha with the aboveground biomass contribution of 26.35 t/ha. The average carbon stocks density for BudhniForest Range has been estimated to be 59.80 t/ha with aboveground biomass contribution of 22.94 t/ha. Average carbon stocks density for the areas under Banapura, Itarsi and Sukhtawa Forest Ranges has been estimated to be 62.24 t/ha with aboveground biomass contribution of 26.45 t/ha. Soil organic carbon contribution ranged from 23.77 t/ha in Bhaura Forest Range to 29.65 t/ha in Budhni Forest Range.

Various anthropogenic activities in the project areas like collection of fuelwood, fodder and NWFPs, grazing and fire were recorded and are causing forest degradation and eventually responsible for the loss of carbon stocks. The drivers of forest degradation need to be addressed with the implementation of feasible and site-specific intervention packages/ demonstrative models as pilots in the project areas under ESIP for conservation of forests and enhancement of forest carbon stocks.

# 1. Introduction

Intergovernmental Panel on Climate Change (IPCC) stated that "human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history" (IPCC, 2014a). Earth's atmosphere is made up of various gases released by natural processes and anthropogenic activities. The earth's atmosphere acts like a blanket of greenhouse gases (GHG) which traps the long wave terrestrial outgoing radiations emitted by the planet earth. This is a natural process that warms the earth's surface and known as the greenhouse effect. However, anthropogenic activities have increased the concentration of greenhouse gases in the atmosphere which is further trapping the outgoing long wave terrestrial radiations into the earth's atmosphere and ultimately increasing the earth's temperature.

According to IPCC (2014b), globally carbon dioxide emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission which increased from 1970 to 2010, with a similar percentage contribution for the period from 2000 to 2010. Agriculture, forestry and other land use (AFOLU) sector contributed 23% of total anthropogenic GHG emissions for the period from 2007 to 2016 (IPCC, 2019). The IPCC special report on Global Warming of 1.5$^{0}$C above pre-industrial levels (IPCC, 2018) highlighted that the average global earth's temperature has been increased by about 1$^{0}$C as compared to the 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 a significant rising trend of 0.66$^{0}$C.

The impact of climate change has alarmed human beings across the globe and attracted the attention of scientific communities towards developing suitable climate change mitigation and adaptation measures. Intrinsically forest and climate change are directly linked to each other and forests play a significant role in mitigating climate change. Forests are considered to provide a large climate change mitigation opportunity at relatively lower costs along with other significant co-benefits. Forests are known as the sink as well as the source of carbon. The role of forests has been increasingly recognized as cost-effective option for climate change mitigation through carbon capture and storage in the biomass and soil. The felling of trees and removal of vegetation from the forests for collection of fuelwood, timber, fodder etc. releases the stored carbon in the form of carbon dioxide. Various anthropogenic activities like burning of fossil fuels, industrialization, urbanization, deforestation and forest degradation are mainly responsible for increasing the concentration of carbon dioxide and other greenhouse gases into the atmosphere.

IPCC's Special Reports on 'Global Warming of 1.5$^{0}$C' and 'Climate Change and Land' (IPCC, 2018 and 2019) bring a very strong message on the importance of land restoration for climate change mitigation and adaptation. IPCC Special Report on Global warming of 1.5$^{0}$C above pre industrial level and related global GHG pathways (IPCC, 2018) stated that global warming at 1.5$^{0}$C can be limited through unprecedented transformational changes in all spheres of the society. Carbon dioxide removal measures related to AFOLU can have important positive effect on land, bio diversity and restoration of natural ecosystems. Restoration of degraded forest lands has been considered as one of the key activities that can be taken with carbon dioxide removal measures for providing climate change mitigation and adaptation opportunity (IPCC, 2019).

Forests sequester and store more carbon than any other terrestrial ecosystem. The main carbon pools in forest ecosystems are the living biomass of trees and understorey vegetation, dead mass of litter and woody debris, and soil organic matter. Knowledge of the aboveground living biomass density is useful in determining the amount of carbon stored through photosynthesis in the forest stands. Soil carbon is an important determinant of site fertility due to its role in maintaining soil physical and chemical properties (Reeves, 1997).

Forest is the second-largest land use in India after agriculture and it is estimated that about 275 million rural people in India are dependent on the forests for their subsistence and livelihood (World Bank, 2006). About 200,000 villages are categorized as forest fringe villages and local communities of the forest fringe villages are directly or indirectly depending on the forests for fuelwood, fodder and non-timber forest products, and forest also serve as a safety net for local communities in the lean agricultural season. Thus, it is, essential to assess the likely impacts of projected climate change on forests, and to develop and implement suitable climate change mitigation and adaptation strategies in the forest ecosystem to ensure continued flow of ecosystem goods and services.

The forest cover of the country is 7,12,249 sq km as per the India State of Forest Report 2019 (FSI, 2019) which was 7,08,273 sq km as per the 2017 assessment (FSI, 2017), recording an increase of 3976 sq km within two years. The total forest and tree cover of the country is 8,07,276 sq km which is 24.56% of its geographical area. India has been successful in enhancing carbon stocks in its forests through sustainable management of forests, afforestation and regulating diversion of forest lands for non-forestry purposes. As per the India State of Forest Report 2019, total carbon stocks in the forests are estimated to be 7,124.6 million tonnes with an increase of 42.6 million tonnes over the previous assessment of 2017 (FSI, 2019). Various national programmes and policies have converted India's forest into net sink of carbon. As per India's initial National Communi-cation to United Nations Framework Convention on Climate Change (UNFCCC), the land use, land use change and forestry (LULUCF) sector was a source of carbon and accounting for 1.16% of total national greenhouse gas emissions (MoEF, 2004). In its second National Communication to UNFCCC, LULUCF sector was a net sink of carbon and offset 17% of total national greenhouse gas emissions (MoEF, 2012). India's first biennial update report to UNFCCC has reported that the LULUCF sector was a net carbon sink and offsetting 252.5 million tonnes of carbon dioxide equivalent, and the contribution of forestry sector offset was about 12% of India's total GHG emission (MoEFCC, 2015).

The central Indian highlands (including districts in the states of Madhya Pradesh and Chhattisgarh) are part of the 39 percent forest grids of India identified and mapped as 'vulnerable to climate change'. These grids also face threats of degra-dation due to unsustainable land-use practices (MoEF, 2012). In 2011, the Government of India has initiated the National Mission for a Green India, commonly referred to as the Green India Mission (GIM) under its National Action Plan on Climate Change. GIM aims to improve the forest cover by integrating the issues of forest quality and ecosystem services. It aims at protecting, restoring and enhancing the diminishing forest cover, and responding to climate change by a combination of adaptation and mitigation measures.

The World Bank funded Ecosystem Services Improvement Project (ESIP) aims to support the goals of the GIM by demonstrating models for adaptation based mitigation measures through sustainable land and ecosystem management (SLEM) practices and also to provide livelihood benefits to the local communities. By piloting SLEM approaches in the States of Madhya Pradesh and Chhattisgarh, ESIP will help in demonstrating the potential for nation-wide scaling-up of GIM. ESIP, in many ways, brings a new and novel approach to address some of the challenges in management of land and ecosystems. It will introduce new tools and technologies for better management of the natural resources, including bio diversity and carbon stocks. Implementation of the ESIP activities will support in sequestration of additional carbon of about 10% in the forest areas of Madhya Pradesh and Chhattisgarh over the baseline (World Bank, 2017). It also presents a good opportunity to improve the carbon sequestration potential of the entire target area of GIM through scaling up of successful demonstrative pilots.

Indian Council of Forestry Research and Education (ICFRE) is also implementing the sub-component on forest carbon stocks measuring, monitoring and capacity-building besides the component on scaling up of Sustainable Land and Ecosystem Management practices under ESIP. Generation of baseline report on forest carbon stocks of the project areas is one of the activities under the project. The purpose of baseline report of forest carbon stocks is to assess the outcomes and impacts of the intervention of ESIP activities mainly related to forest quality improvement.

## 2. Overview of Forests and Carbon Stocks in Madhya Pradesh

As per India State of Forest Report 2019, Madhya Pradesh is one of the forest-rich states and is ranked first in terms of the recorded forest area. The recorded forest area in the State is 94,689 sq km of which 61,886 sq km is reserved forests, 31,098 sq km is protected forests and 1,705 sq km is unclassed forests (FSI, 2019).The forest cover of Madhya Pradesh is 77,482.49 sq km which is 25.14% of its geographical area and is further categorized as 6,675.02 sq km under very dense forest (2.17% of the total geographical area), 34,341.40 sq km area under moderately dense forest (11.14% of the total geographical area) and 36465.07 sq km under open forest (11.83% of the total geographical area). Scrubs represent the 6002 sq km area of the state. Tree cover in Madhya Pradesh has been estimated to be 8,339 sq km which is 2.71% of its geographical area. Total growing stock in the state is estimated to be 449.01 cum which comprises 342.62 cum in recorded forest area and 106.39 cum in the tree outside the forests (FSI, 2019).

As per the Champion and Seth (1968) classification of Forest Types of India the forests in Madhya Pradesh belong to five Forest Type Groups viz. Group 3: Tropical Moist Deciduous Forests, Group 4: Littoral & Swamp Forests, Group 5: Tropical Dry Deciduous Forests, Group 6: Tropical Thorn Forests, and Group 8: Subtropical Broadleaved Hill Forests, which are further divided into 21 Forest Sub-group Types (FSI, 2019).

**Group 3: Tropical Moist Deciduous Forests:** Moist deciduous forests are a class of forests which shed leaves in winter months to overcome the low temperature and again become flushed by January-February. In other words, they remain leafless for about a month and during the rest of the year they are evergreen in nature and it is difficult to distinguish them from semi-evergreen and evergreen forest types. This is the second largest group of Forest Type in India comprising of 19.73% of India's forests (FSI, 2011). These types of forests are found in the areas where rainfall is moderately high and the length of dry period extends up to three to four months. The type is distributed throughout the country covering both Southern and Northern states with similar species composition except *sal* dominating in the north and teak in the south due to differences in the frost tolerance capacity of teak and *sal.*

The species composition in the moist forest type is distinctly different from evergreen and semi-evergreen forest types. Champion and Seth (1968) have classified this type into three major sub-groups, *i.e.,*Andamans Moist Deciduous Forests (3A), South Indian Moist Deciduous Forest (3B) and North Indian Moist Deciduous Forests (3C). Tropical Moist Deciduous Forests also constitute the second-largest group of forest types in Madhya Pradesh accounting for about 8% of the total forest cover of the state (Table 2.1).

**Table 2.1** Percentageof subgroup types of Group 3. Tropical Moist Deciduous Forests

| S. No. | Forest subgroup type | % of Forest Cover |
|---|---|---|
| 1. | 3B/C1c Slightly Moist Teak Forest | 2.28 |
| 2. | 3B/C2 Southern Moist Mixed Deciduous Forest | 2.29 |
| 3. | 3C/DS1 Moist Sal Savannah | 0.04 |
| 4. | 3C/C2e (i) Moist Peninsular High Level Sal | 3.25 |

(Source: FSI, 2019)

**Group 4. Littoral and Swamp Forests:** Under this forest type group, type 4E/RS1 (Riparian fringing forest) has been recorded from the state of Madhya Pradesh(FSI, 2019). Champion and Seth (1968) described that these forests consist of few species of large trees typically forming a rather narrow fringe along the water courses sometimes spreading out along the bigger rivers. These trees may be evergreen or deciduous but were usually sub-evergreen found along the banks of most of the streams in the hilly tracts. They stand widely spaced with smaller trees and shrubs between and often much coarse grass. Examples are *Bischofia javanica, Terminalia arjuna, T. myriocarpa* and *Lagerstroemia speciosa* etc. Champion and Seth (1968) reported representative floristic form Central India, Assam and Mysore. However, as per India State of Forest Report 2019 this group occupies about 0.02% of the forest cover in Madhya Pradesh (FSI, 2019).

**Group 5. Tropical Dry Deciduous Forests:** Tropical dry deciduous forests are the largest forest type of India covering more than 40% of the total forest area of the country. It is distributed throughout India's tropical climate adjacent to the moist deciduous forests and spread towards the low rainfall areas of 600 to 1000 mm. The type is characterized by the occurrence of deciduous species which have the ability to survive the prolonged dry period. These types are also surrounded by unbroken human habitations and thus subjected to very intense anthropogenic pressures. The type is very unique from the point of wild life as the large expanse of these landscapes is an ideal habitat for the herbivores and the carnivores. The open type of the vegetation allow good grass to regenerate during the monsoon time which naturally supports herbivore population including ungulates and the elephant population along with carnivores and other wildlife population. More than 90% of the forest cover of Madhya Pradesh belongs to this type group and represented by 14 subgroup types (Table 2.2).

**Table 2.2** Percentage of sub-group types of Group 5. Tropical Dry Deciduous Forests

| S. No. | Forest subgroup types | % of Forest Cover |
|---|---|---|
| 1 | 5/1S2 Khair-Sissu Forest | 1.67 |
| 2 | 5/E1/DS1 *Anogeissuspendula* Scrub | 0.39 |
| 3 | 5/DS1 Dry Deciduous Scrub | 8.10 |
| 4 | 5/DS2 Dry Savannah Forest | - |
| 5 | 5/DS4 (Dry Grass Land) | 0.01 |
| 6 | 5/E1 *Anogeissus pendula* Forest | 3.43 |
| 7 | 5/E2 *Boswellia* Forest | 0.49 |
| 8 | 5/E5 *Butea* Forest | 0.24 |
| 9 | 5/E9 Dry Bamboo Brake | 0.90 |
| 10 | 5A/C1a Very Dry Teak Forest | 0.86 |
| 11 | 5A/C1b Dry Teak Forest | 26.40 |
| 12 | 5A/C3 Southern Dry Mixed Deciduous Forest | 24.55 |
| 13 | 5B/C1c Dry Peninsular Sal Forest | 5.10 |
| 14 | 5B/C2 Northern Dry Mixed Deciduous Forest | 18.55 |

(Source: FSI, 2019)

**Group 6. Tropical Thorn Forests:** These formations are open thorny forests found distributed in the low rainfall areas of Peninsular and Central India. The most predominant species is *Acacia* along with many other thorny species. The limited moisture and prolonged dry period have influenced the formation of this type. Champion and Seth (1968), further divided this forest group into Southern (6A) and Northern (6B) subgroup types. As per the India State of Forest Report 2019, this forest group in Madhya Pradesh is represented by 6B/C2 Ravine thorn forest(FSI, 2019) and covering about 0.23% forest cover of the state.

**Group 8. Subtropical Broad leaved Hill Forest:** As per the India State of Forest Report 2019 this forest group in Madhya Pradesh is represented by subgroup type 8A/C3 Central Indian Subtropical Hill Forest.

**Forests and Carbon Stocks :** Forests are the major store of atmospheric carbon and contribute in mitigating the climate change. Large quantities of carbon are stored in the forest vegetation on account of sequestration and storage through photosynthesis. Several studies have established the fact that carbon sequestration by trees could provide relatively low-cost net emission reductions of greenhouse gases (Adams *et al*., 1993; Richards *et al*., 1993; Dixon *et al*., 1994; Parks and Hardie, 1995; Plantinga and Birdsey, 1995; Callaway and Mc Card, 1996). Forests merit attention due to their important role in the global carbon flux. They store large quantities of carbon in vegetation ecosystem and exchange carbon with the atmosphere through photosynthesis and respiration, and act as sources of atmospheric carbon if they are disturbed by some human activities or natural causes (Haripriya, 2003).

Biomass is an important parameter to assess the atmospheric carbon that is sequestrated by trees. In recent times, biomass-related studies have become significant due to climate change. Terrestrial ecosystems of India are extensively studied for biomass and productivity estimations using ecological methods. Most of the studies have been performed in a small area only, using conventional ground-based methods. Satellite remote sensing is a proven tool to estimate biomass at local and global level. Roy and Ravan (1996) have estimated patch level biomass in Madhav National Park, Shivpuri District, Madhya Pradesh by extrapolating values from plot to stratum, using satellite remote sensing technology. There is a need to perform extensive studies for biomass estimation to understand the role of forest in carbon cycling. Creation of reliable biomass data requires region-specific allometric equations to estimate the biomass, the values of which can be further extrapolated to the local and regional levels using appropriate satellite driven geospatial modeling techniques.

Soil organic matter contains the largest terrestrial reservoir of carbon in the biological global carbon cycle and plays a major role in the control of carbon dioxide levels in the atmosphere (Follett *et al*., 2007). Soils and vegetation represent potential sinks for carbon and several authors have suggested afforestation as a possible means of mitigating global climate change (Rosenberg *et al*., 1999; Rosenzweig and Hillet, 2000 and Ramachandran *et al*., 2007). There is a major potential for increasing soil organic carbon through restoration of degraded soils and widespread adoption of soil conservation practices (Lal and Kimble, 1997; Lal and Bruce, 1999). Soils store 2.5 to 3.0 times as much carbon that stored in plants (Post *et al.,* 1990; Davidson *et al*., 2000).

**Carbon Stocks in Forest of Madhya Pradesh:** Salunkhe *et al.* (–2014) estimated carbon stock in tropical deciduous forests of Madhya Pradesh and reported that the carbon stock ranged from 1.89 to 25.6 t/ha in the forests of Damoh, Katni, Raisen and Sagar. They concluded that tropical deciduous forests in Madhya Pradesh have strong potential for carbon sequestration. Salunkhe *et al.* (2016) in another estimate of carbon stock in tropical deciduous forests of Madhya Pradesh reported carbon stocks of 25-54 Mg/ha in the mixed non-teak forest, 13-42 Mg/ha in the dry mixed non-teak forest, 33-53 Mg/ha in teak-dominated forest and 16-24 Mg/ha dry teak forest. Hirankhede *et al.* (2017) estimated the carbon density for tropical forests of Madhya Pradesh and reported that carbon density ranged between 3.0 to 33.21 t/ha in mixed forest, 5.17 to 67.78 t/ha in the teak forest and 36.10 to 102.39 t/ha in sal forest. Rahangdale *et al*. (2019) estimated above-ground biomass carbon in the range of 4.02 t/ha to 86.48 t/ha in the tropical deciduous forests of Madhya Pradesh.

The total forest carbon stocks including the tree outside the forests in the State of Madhya Pradesh are estimated to be 588.73 million tonnes which is 8.26% of total forest carbon stocks of the country. Pool wise forest carbon in Madhya Pradesh as per India State of Forest Report 2019 is given in Table 2.3 and carbon density is given in Table 2.4.Total forest carbon stocks of Madhya Pradesh as per India State of Forest Report 2017 was 689.66 million tonnes. The India State of Forest Report 2019 has registered a decline of about 15% from the previous assessment of 2017 despite increase in forest cover and growing stock of the state. The decline in carbon stock reported in the assessments of 2019, is because of change in sampling methodology for growing stock estimation adopted by FSI for the first tine from District based sampling to grid based sampling.

**Table 2.3:** Forest carbon stocks in different carbon pools of Madhya Pradesh

| **Forest carbon stocks in different carbon pools (in milliontonnes)** | | | | | |
|---|---|---|---|---|---|
| Above Ground Biomass | Below Ground Biomass | Dead wood | Litter | Soil Organic Carbon | **Total** |
| 165.07 | 64.63 | 1.53 | 8.16 | 349.34 | **588.73** |

(Source: FSI, 2019)

**Table 2.4:** Carbon density in forests of Madhya Pradesh

| Carbon Pool | Year wise Carbon density (t/ha) | | |
|---|---|---|---|
| | **2011** | **2017** | **2019** |
| Above Ground Biomass | 34.25 | 34.37 | 21.30 |
| Below Ground Biomass | 13.08 | 13.11 | 8.34 |
| Dead Wood | 0.20 | 0.21 | 0.20 |
| Litter | 0.92 | 1.00 | 1.05 |
| Soil Organic Carbon | 41.34 | 41.17 | 45.09 |
| **Total** | **89.79** | **89.86** | **75.98** |

Source: FSI (2011, 2017 &2019)

Average proportion of forest carbon stocks in different carbon pools for the state of Madhya Pradesh as per India State of the Forest Report 2019 is given in Table 2.5.

**Table 2.5:** Average proportion of forest carbon stocks in different pools

| Carbon Pool | National Average (tonne/ha) | Average in State of Madhya Pradesh (tonne/ha) |
|---|---|---|
| Aboveground biomass | 31.68 | 21.30 |
| Belowground biomass | 9.84 | 8.34 |
| Litter | 1.80 | 1.05 |
| Dead Wood | 0.50 | 0.20 |
| Soil Organic carbon | 56.21 | 45.09 |
| **Total** | **100.03** | **75.98** |

(Source: FSI, 2019)

# 3. ESIP Project Areas in Madhya Pradesh and Methodology for Forest Carbon Measurement

**3.1 ESIP Project Areas:** The state of Madhya Pradesh has selected two L1 level landscapes (Satpura-Narmada and Vindhya Plateau) which comprise of three L2 level landscapes in Betul, Hoshangabad and Sehore Forest Divisions spreading over an area of 20,618.47 ha (Fig 3.1).

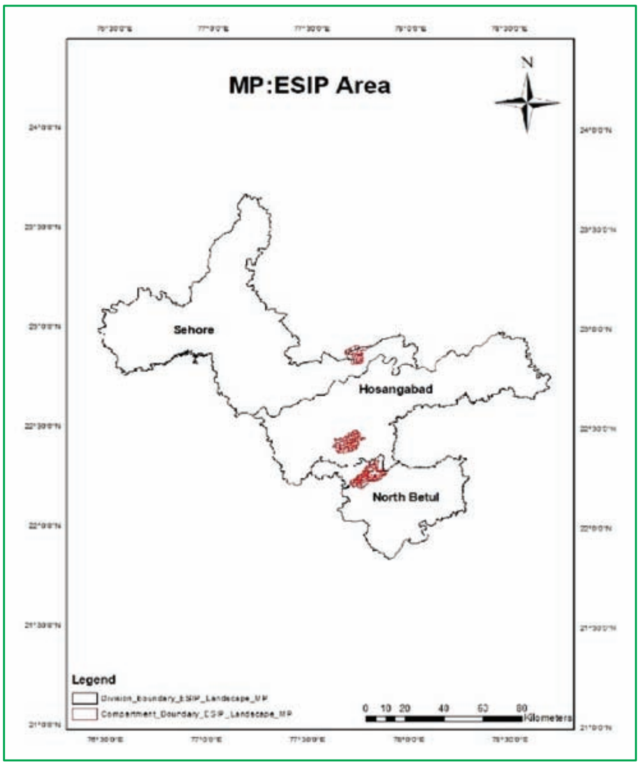



Figure 3.1: Location of Forest Ranges in ESIP areas of Madhya Pradesh

**Sehore:** Sehore stands in the foot hills of Vindhyanchal range in the middle of Malwa region. The district extends between 22°31' to 22°40' N latitude and 76°22' to 78°08' E longitude. The large extent of the district is part of Malwa plateau. The altitude of the district varies from 282 to 666 m above mean sea level. Sehore is a part of Central Highlands physiographic zone of India. Sehore district has 6,578 sq km geographical area in which 23.90 sq km is covered by very dense forest while 614.85 sq km is under moderately dense forest and 719.15 sq km is covered by open forest. Budhni Forest Range in Sehore Forest Division is selected for the implementation of the ESIP activities.

**Betul:** The Betul district is located in Satpura hill range, the terrain is hilly with small hillocks spread all over. The district extends between 21°22' to 22°24' N latitude and 77°10' to 78°33' E longitude. The altitude ranges from353 to 1078 m above mean sea level. Betul is a part of North Deccan physiographic zone of India. Betul district has 10,043 sq km geographical area of which 230.34 sq km is covered by very dense forest while 1,938.14 sq km is under moderately dense forest and 1,495.22 sq km is under by open forest. Betul has 36.48% of its geographical area under forest cover. Bhaura Forest Range in North Betul Forest Division is selected for the implementation of the ESIP activities.

**Hoshangabad**:Hoshangabad lies in the Narmada River valley. The district extended between 22°44'N latitude to 77°72' E longitude. The average rainfall of the district is 134 cm and temperature varies from minimum average of 19°C to maximum average of 40°C. Soils of the area are characterized by black grey, red and yellow colour, often mixed with red and black alluvium and ferruginous red ravel or lateritic soil. Hoshangabad falls under the North Deccan physiographic zone of India. Banapura, Itarsi and Sukhtawa Forest Ranges in Hoshangabad Forest Division are selected for the implementation of the ESIP activities. Hoshangabaddistrict has 6,703 sq km geographical area in which 271.89 sq kmis covered by very dense forest while 1,370.32 sq kmbymoderately dense forest and 663.85 sq km is covered by open forest. Dry Teak and Southern Dry Mixed Deciduous Forest are the major Forest Types present in Banapura, Itarsi and Sukhtawa Ranges of Hoshangabad Forest Division.

**3.2 Methodology for Forest Carbon Measurement**

Forests are both source and sink of carbon dioxide. 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 services rendered by forests which are fully measurable, reportable and verifiable. Measurement of forest carbon is a vital part of Ecosystem Services Improvement Project implementation because carbon dioxide emission reductions and removals by implementing various project activities like assisted natural regeneration, plantation etc. will help to enhance the forest carbon stock. Measurement of forest carbon stocks in the project area will act as a benchmark for the activities carried out by state forest department for the enhancement of forest carbon stocks in the project area. The measurement system must be transparent, consistent, and accurate, and uncertainty should be minimized. Methodological approach followed for measurement of forest carbon stocks is depicted in Figure 3.2.

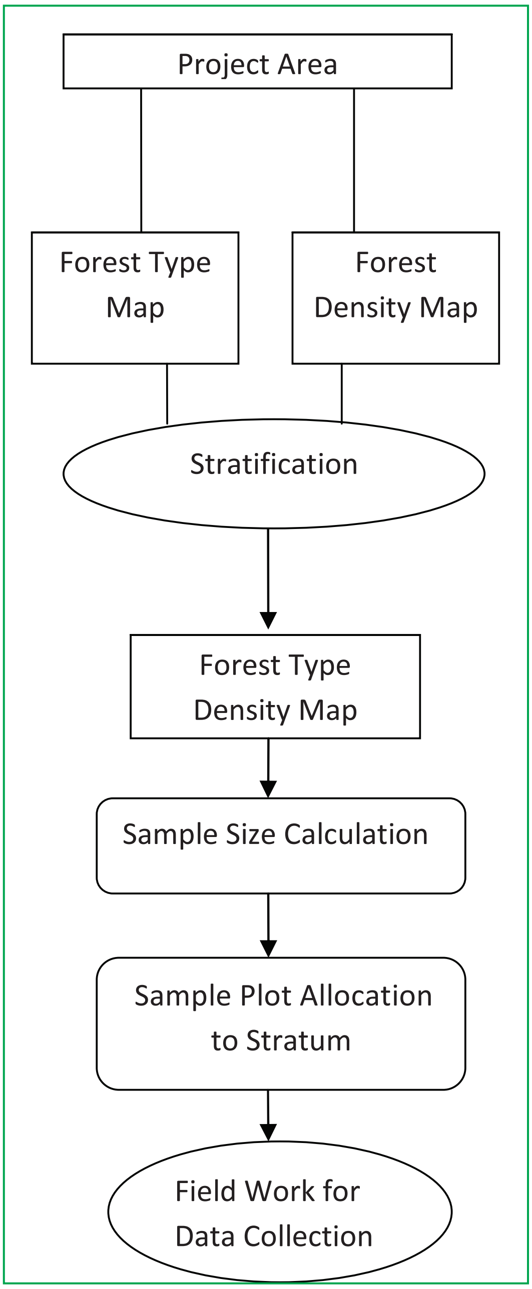



Fig 3.2: Methodology adopted for Forest Carbon Stock Assessment in ESIP area

**Carbon Pools:** Carbon pool may be defined as system that has the capacity to store or release carbon. IPCC (2003) identified five carbon pools for viz., aboveground biomass, belowground biomass, litter, deadwood, soil organic matter for the estimation of carbon pools in a forested stand.All the carbon pools were considered for measurement of forest carbon stocks under the project area.

**Sampling:** Stratified random sampling was followed using forest density maps and forest type maps prepared by Forest Survey of India to stratify the project area into forest type density stratum. Intersect tool in GIS software was used to produce the Forest Type and Density maps of the sampling area.GIS software used to create, manage, share and analyze spatial data.

**Sample Size**: Pilot study may be needed to find out the variability in forest carbon stocks and to find out the appropriate number of permanent sample plots to be laid out for measurement of forest carbon stocks. Accordingly, pilot study was conducted by laying out of sample plots in Banapura, Itarsi and Sukhtawa Forest Ranges (36 sample plots), Bhaura Forest Range (21 sample plots) and Budhni Forest Range (15 sample plots) to calculate the sample size using variability analysis. Sample plots calculated for ESIP areas of Madhya Pradesh on the basis of variability analysis are given in Table 3.1. Formula used for calculation of the number of permanent sample plot:

Sample Size (N) = $(1.64 \times CV/AE)^2$

where,

CV= Coefficient of Variation

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

1.64 = Student's t-value at 90%

confidence interval Coefficient of

Variation (CV) = Standard deviation/

Mean × 100

The number of sample plots calculated to be laid out for forest carbon stocks measurement in Budhni Forest Range, Bhaura Forest Range and areas under Banapura, Itarsi and Sukhtawa Forest Ranges are given in Table 3.1. Initially, it was planned to laid out more number of sample plots than the calculated ones i.e. 59 sample plots in Budhni Forest Range, 59 sample plots in Bhaura Forest Range and 52 sample plots in the areas under Banapura, Itarsi and Sukhtawa Forest Ranges to give wide representation to all the forest types density class of the ESIP areas. However, due to frequent movement of leopards in the forests during the time of field surveys and inaccessibility, some sample points could not be surveyed. Forest types and density class wise details of sample plots laid out for measurement of forest carbon stocks in the ESIP areas of Madhya Pradesh are given in Table 3.2, 3.3 and 3.4.

**Table3.1:** Sample plots calculated for measurement of forest carbon stocks in ESIP areas in Madhya Pradesh

| Forest Range | No. of Sample Plots laid outfor pilot study | Mean Carbon density(t/ha) | Standard Deviation | Coefficient of Variation | Sample Size |
|---|---|---|---|---|---|
| Budhni Forest Range | 15 | 45.76 | ±20.94 | 45.76 | **56** |
| Bhaura Forest Range | 21 | 56.57 | ±23.98 | 42.39 | **48** |
| Banapura, Itarsi and Sukhtawa Forest Ranges | 36 | 60.2 | ±24.80 | 41.20 | **45** |

**Table 3.2:** Number of Sample plots laid out in the Budhni Forest Range (ESIP areas) of Madhya Pradesh for measurement of forest carbon stocks

| Forest Type Density Class | Area (ha) | Sample Plots |
|---|---|---|
| Dry Teak Open Forest | 2381.79 | 29 |
| Dry Teak Moderately Dense Forest | 1264.53 | 24 |
| Dry Teak Very Dense Forest | 35.67 | 1 |
| Southern Dry Mixed Deciduous Open Forest | 284.16 | 3 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 113.77 | 2 |
| **Total** | **4079.92** | **59** |

**Table 3.3:** Number of Sample plots laid out in the Bhaura Forest Range (ESIP areas) of Madhya Pradesh for measurement of forest carbon stocks

| Forest Type Density Class | Area (ha) | Sample Plots |
|---|---|---|
| Dry Teak Open Forest | 1863.57 | 9 |
| Dry Teak Moderately Dense Forest | 2249.39 | 19 |
| Dry Teak Very Dense Forest | 213 | 2 |
| Southern Dry Mixed Deciduous Open Forest | 1149.17 | 5 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 1122.74 | 8 |
| Southern Dry Mixed Deciduous Very Dense Forest | 42.29 | 1 |
| Scrub | - | 1 |
| **Total** | **6640.16** | **45** |

**Table 3.4:** Number of Sample plots laid out in the Banapura, Itarsi, and Sukhtawa Forest Ranges (ESIP areas) of Madhya Pradesh for measurement of forest carbon stocks

| Forest Type Density Class | Area (ha) | Sample Plots |
|---|---|---|
| Dry Teak Open Forest | 537.46 | 2 |
| Dry Teak Moderately Dense Forest | 3091.89 | 16 |
| Dry Teak Very Dense Forest | 253.08 | 1 |
| Southern Dry Mixed Deciduous Open Forest | 1468.95 | 5 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 3874.25 | 27 |
| Southern Dry Mixed Deciduous Very Dense Forest | 70.67 | - |
| **Total** | **9296.30** | **51** |

**Randomization of sample plots in a stratum**: GIS Software was used to place the sample plots in randomly in each stratum.'Create Random Points' function of GIS software randomly places specified number of points within an extent window or inside the features of a polygon, line, or point feature class.

**Layout of Sample Plot:** Permanent sample plots are generally considered as statistically more efficient in estimating changes in forest carbon stocks compared to temporary sample plots because typically there is high covariance between observations taken at successive sampling events in temporary plots. Permanent sample plots should be established for the assessment and monitoring of carbon stocks in the forest. Carbon monitoring requires both the size and number of sample plots to be determined. Plot size has an impact on the cost of carbon inventory and monitoring. Sample plot design and layout methods prescribed in the National Working Plan Code – 2014 was followed for measurement of forest carbon stocks. The sample plot layout given in National Working Plan Code-2014 (MoEFCC, 2014) is similar to the sample plot design prescribed by Forest Survey of India for preparation of National Forest Inventory.

After reaching the predetermined sampling plot location, a square plot of 0.1 ha (31.62 m × 31.62 m) was 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 was taken for lying out the proper dimensions of the plot. Then subplots of size 3 m × 3 m and 1 m × 1 m were 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 (Figure3.3). Along with the quadrat of size 3 m × 3 m and 1 m × 1 m, 5 m × 5 m quadrats were laid out at North-East (NE) and South-West (SW) direction.

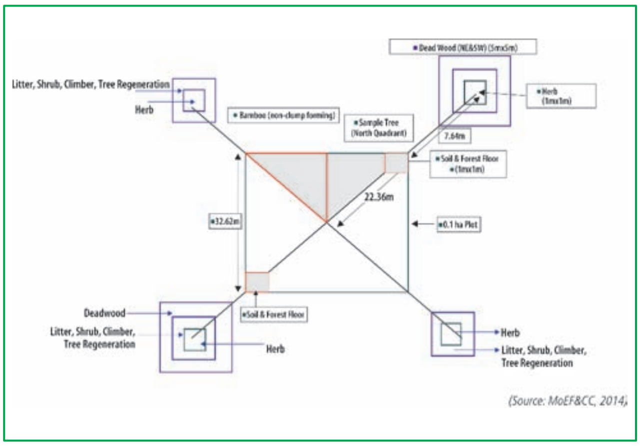



Figure 3.3: Sample Plot Layout: Configuration of main plot and attached sub-plots

In 5m × 5 m plot, all the dead wood above 5 cm diameter were collected, weighed and recorded. In 3 m × 3 m, all woody litter with branches below 5 cm were collected weighed and recorded. All shrubs and climbers in 3 m × 3m plot were up-rooted, weighed and recorded. In 1 m × 1 m plot, all the herbs/grasses including leaf litter were collected, weighed and recorded. For estimation of soil organic carbon, forest floor was swept, and a pit of 30 × 30 × 30 cm were dug out 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 (mixture of soil from various depths 0-10 cm, 10-20 cm and 20-30 cm) weighing about 200 gm was collected for laboratory analysis of soil organic carbon. The soil samples were kept in a properly labeled zipped polythene bag and tightly closed and properly labeled. Necessary plot data for the assessment of forest carbon stocks were collected from the sample plots of ESIP areas in a format given in Annex I.

### 3.3 Forest Carbon Stocks Calculation

**Aboveground Biomass**: All the trees having a diameter of 10 cm and above are enumerated in 0.1 ha plot. The height and diameter at breast height (1.37 m above the ground) of all trees with circumference at breast height (CBH) ≥30 cm were measured. Diameter and height of all trees within the sample plot were used to estimate the standing volume in each forest type. The species-specific volume equations were used to compute the volume of trees (Annex II). General volume equation is used for the species whose specific volume equationsare not available. The estimated volume of each tree in the sample plot was multiplied by its specific gravity (Annex III) to derive the individual bole biomass.

**Aboveground Biomass of Branches, Foliage of Trees having DBH≥10 cm**: Biomass equations developed by Forest Survey of India were used to calculate the total biomass and carbon content at plot level and extrapolated on hectare basis (FSI, nd).

**Aboveground Sapling Biomass:** Biomass equations developed by Forest Survey of India for trees having DBH<10 cm were used to estimate the biomass and converted into carbon stock per hectare basis (Annex IV).

**Shrubs and Herbs Carbon Density:** Destructive sampling approach was adopted for the estimation of shrubs and herbs biomass. Shrubs and herbs were harvested at ground level from their respective sampling quadrats, packed in bags and fresh weight was measured at the time of sampling in the field. The samples were oven dried at 72°C in the laboratory till constant dry weight. Carbon stock in each layer was estimated by multiplying the biomass value with 0.47 (IPCC, 2006) and later extrapolated on hectare basis.

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

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

**Soil Organic Carbon:** The soil organic carbon (SOC)was estimated by taking the average value of two composite soil samples taken at a depth of 30cm (IPCC, 2006). Composite soil sample was prepared by mixing the homogeneous soils of all three layers (0-10 cm, 10-20 and 20-30 cm) to determine the concentration of organic carbon. Altogether, five soil samples (three samples at three different depths i.e., 0-10, 10-20 and 20-30 cm and two composite samples) from each plot were collected for laboratory analysis. Finally, two levels of estimation were done to calculate the soil organic carbon. First, soil bulk density was calculated for three samples (0–10cm,10–20cm and20–30cm)from each plot the naveraged, and the organic carbon content (%) was calculated from the two composite soil samples as per Walkley and Black (1934) method. The soil organic carbon was calculated using the following equation (Pearson*etal*., 2007):

$$SOC = p \times D \times \%C$$

where:

SOC= Soil organic carbon stock per unit area [$t\ ha^{-1}$]

p = Soil bulk density [$gcm^{-3}$]

D = the total depth at which the sample was taken [cm]

%C = Carbon concentration[%]

**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 onbulk density is required for determination of soil organic carbon content per unit area. Collection of soil sample for bulk density estimation was done in 1 m × 1 m plot. A core sampler of known volume (bulk density core sampler) was inserted in soil between 0-10 cm depth with the help of a hammer, up to the top of the core. Core was carefully removed so that soil inside the core may not drop down. Soil sample was collected in a polythene bag, and proper label was fixed on the sample. The exercise was repeated in the plot for collectionof soil samples at the depth of 10-20 cm and 20-30 cm and samples kept in polythene bags with proper labeling for further laboratory analysis.The bulk density of the soil sample was determined by Core Sampler Method described by Wilde *et al.,*1964.Soil samples were dried in oven at 105$^{0}$C and weight of the soil was measured. Bulk density of soil was calculated as:

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

**Laboratory analysis of Soil Samples:** Laboratory analysis of soil samples for determination of soil organic carbon was done as per the methods given by Walkley and Black, 1934. The organic matter (humus) in the soil gets oxidized by chromic acid (potassium dichromate plus concentrated sulphuric acid) utilizing the heat of dilution of sulphuric acid. The untreated chromate is determined by back titration with ferrous ammonium sulphate (redox titration). Following reagents are required for laboratory analysis:

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

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

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

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

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

**Procedure:** The soil is ground completely and passed through 2 mm sieve and 1.00 g is placed at the bottom of a dry 500 ml conical flask (Corning Pyrex). 10 ml of IN $K_2Cr_2O_7$ is pipette in and swirled a little. The flask is kept on asbestos sheet. Then 20 ml of sulphuric acid ($H_2SO_4$) (containing 1.25 % $Ag_2SO_4$) is run in and swirled again two or three times. The flask is allowed to stand for 30 minutes and thereafter 200 ml of distilled water is added. Add 10 ml of ortho phosphoric acid ($H_3PO_4$), 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 $H_3PO_4$ and sodium fluoride(NaF) is found to give a sharper end point. Simultaneously a blank is run without soil. If more than 7 ml of the dichromate solution is consumed the determination must be repeated with a smaller quantity (0.25-0.5g) of soil.

**Calculation:** Organic carbon calculated as per following formula:

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

where

B= Volume of ferrous ammonium sulphate solution required for blank titration

T= Volume of ferrous ammonium sulphate needed for soil sample

Soil stoniness and land use were also recorded from the sample plots. 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):

**Litter biomass:** Litter collected at ground level from the 3 m × 3 m quadrats were packed in bags and fresh weight was measured at the time of sampling in the field. The samples were oven dried at 72$^0$C in the

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

laboratory till constant dry weight. Carbon stock was estimated by multiplying the biomass value with 0.47 (IPCC, 2006).

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

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

Carbon stock was estimated by multiplying the biomass value with 0.47 (IPCC, 2006).

**Total Forest Carbon Stock:** The carbon values for each forest carbon pool were summed to estimate total forest carbon stocks. The following equation was used to calculate the total forest carbon stock:

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

where,

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

BGBC = Belowground biomass carbon

LTC = Litter carbon

DWC = Deadwood carbon

SOC = Soil organic carbon

# 4.Result and Discussion

## 4.1 Assessment of Forest Carbon Stocks

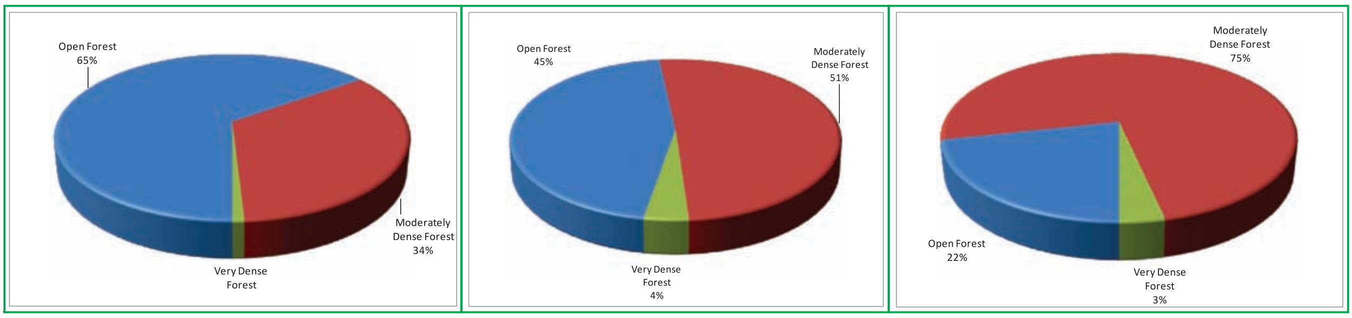
The objective of ESIP component on investments for improving forest quality in selected landscapes is to improve the quality and productivity of the existing forests so as to ensure sustained flows of ecosystem services and carbon sequestration. Implementation of ESIP activities envisage to increase the carbon sequestration potential of the forests under project areas and will help in sequestering additional carbon of about 10 percent over baseline. The activities will also provide means to improve the carbon sequestration in the entire target area of GIM through implementation of successful demonstrative pilotswhich will further help in achieving India's forestry goal of Nationally Determined Contribution under Paris Agreement. ESIP also envisages bringing a new and novel approach to address some of the challenges in management of ecosystems and land, and introduce new tools and technologies for better management as well as assessment of forest carbon stocks under the project component on strengthening capacity of government institutions in forestry and land management programmes. Generation of baseline report of forest carbon stocks of the project areas has paramount importance for making realistic assessments of the forest carbon stocks due to project interventions. The measurement system for forest carbon stocks must be transparent, consistent, accurate, and having minimum uncertainty.

## 4.2 Stratification

The stratification of the project area was done with the help of GIS software. The stratification was done on the basis of forest type groups and forest cover under the project area. The details of forest covers of ESIP areas under the Budhni Forest Range, Bhaura Forest Range, and Banapura, Itarsi and Sukhtawa Forest Ranges are given in Table 4.1 and Figure 4.1.

**Table 4.1:** Forest Cover in ESIP Areas of Madhya Pradesh

| Forest Range | Forest Density Class | Area (ha) |
|---|---|---|
| Budhni Forest Range | Open Forest | 2665.95 |
| | Moderately Dense Forest | 1378.30 |
| | Very Dense Forest | 35.67 |
| | **Total** | **4079.92** |
| Bhaura Forest Range | Open Forest | 3012.74 |
| | Moderately Dense Forest | 3372.13 |
| | Very Dense Forest | 255.29 |
| | **Total** | **6640.16** |
| Banapura, Itarsi and Sukhtawa Forest Range | Open Forest | 2006.41 |
| | Moderately Dense Forest | 6966.14 |
| | Very Dense Forest | 323.75 |
| | **Total** | **9296.30** |




Budhni Forest Range | Bhaura Forest Range | Banapura, Itarsi and Sukhtawa Forest Ranges

**Figure 4.1**: Forest Cover of ESIP Areas inBudhni Forest Range, Banapura, Itarsi and Sukhtawa Forest Ranges and Bhaura Forest Range of Madhya Pradesh

Forest cover, forest type, stratified and sample plots location maps of ESIP areas under the Budhni Forest Range, Bhaura Forest Range and Banapura, Itarsi and Sukhtawa Forest Ranges are given in Figure 4.2 to 4.13.

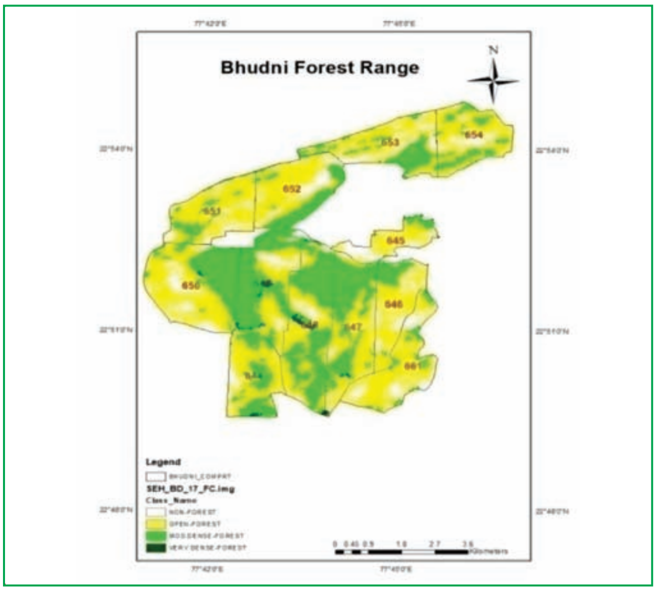



**Figure 4.2:** Forest Cover Map of Budhni Forest Range

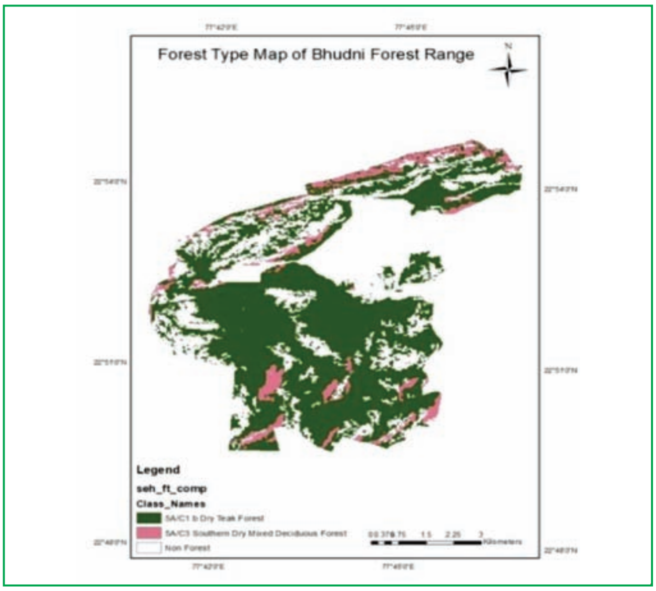



**Figure 4.3:** Forest Type Map of Budhni Forest Range

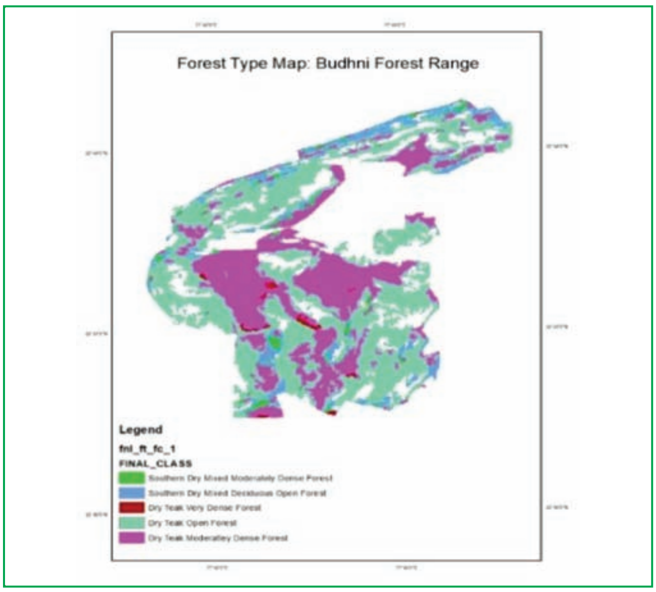



**Figure 4.4:** Stratified Map of Budhni Forest Range

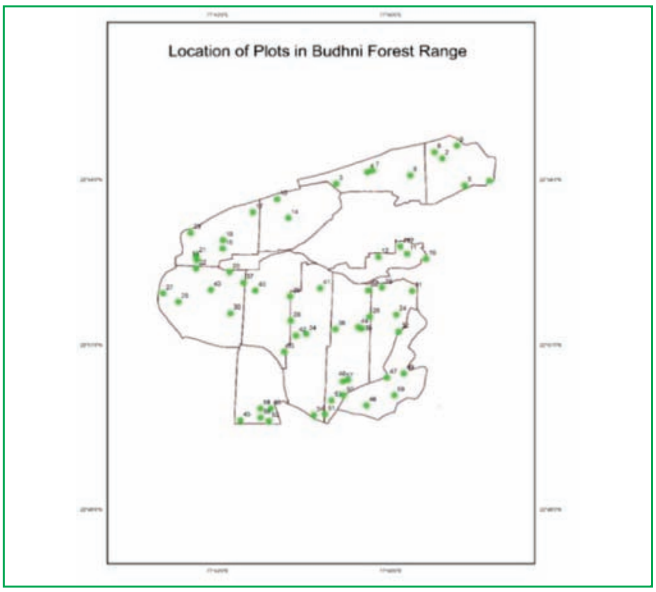



**Figure 4.5:** Location of Sample Plots in Budhni Forest Range

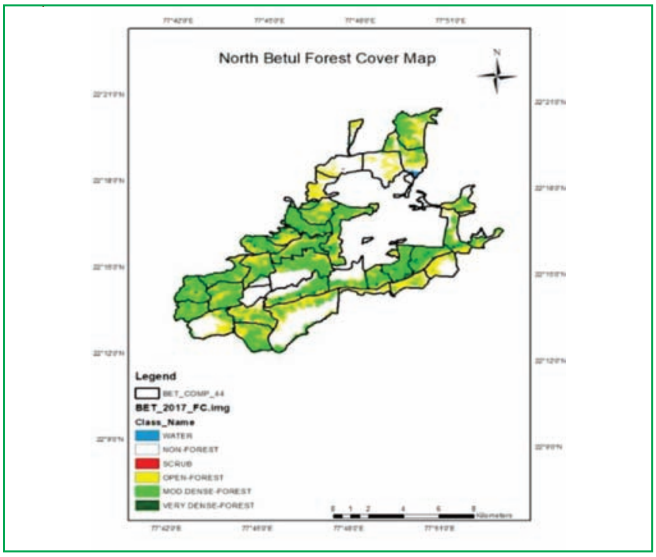



**Figure4.6:** Forest Cover Map of Bhaura Forest Range

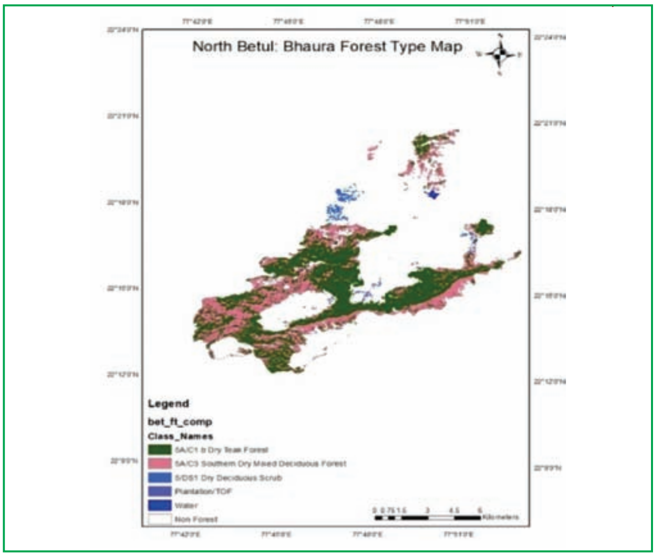



**Figure 4.7:**Forest Type Map of Bhaura Forest Range

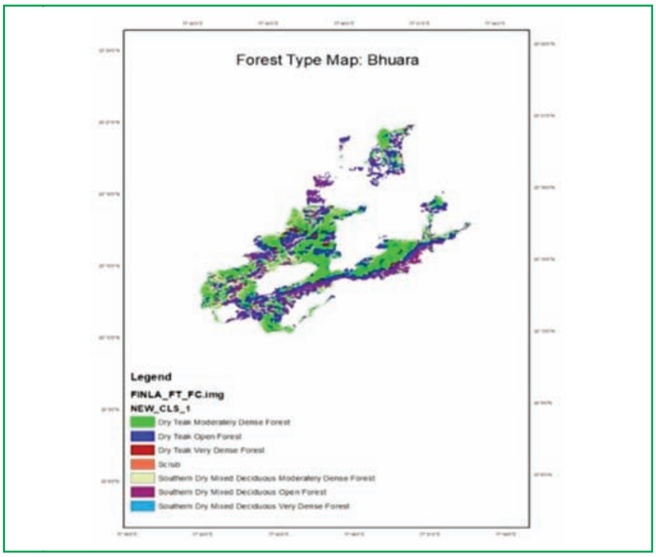



**Figure 4.8:** Stratified Map of Bhaura Forest Range

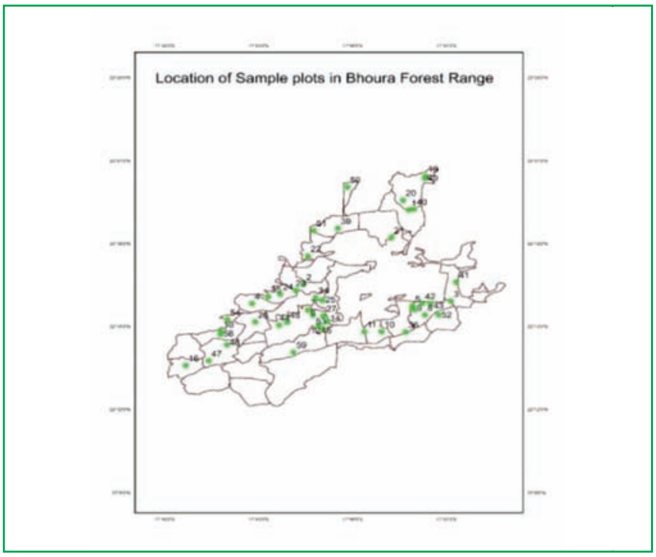



**Figure 4.9:** Location of Sample Plots in Bhaura Forest Range

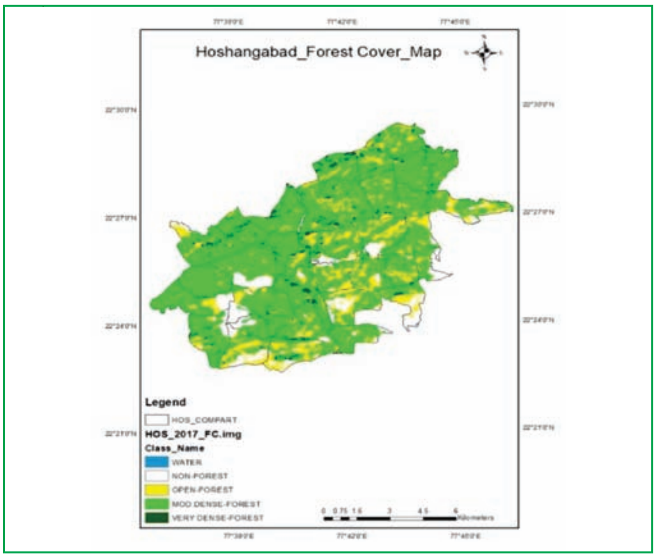



**Figure 4.10:** Forest Cover Map of Banapura, Itarsi and Sukhtawa Forest Ranges

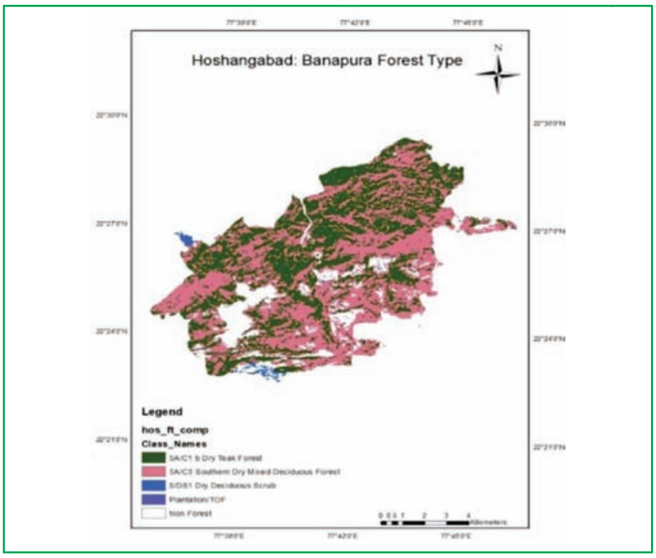



**Figure 4.11:** Forest Type Map of Banapura, Itarsi and Sukhtawa Forest Ranges

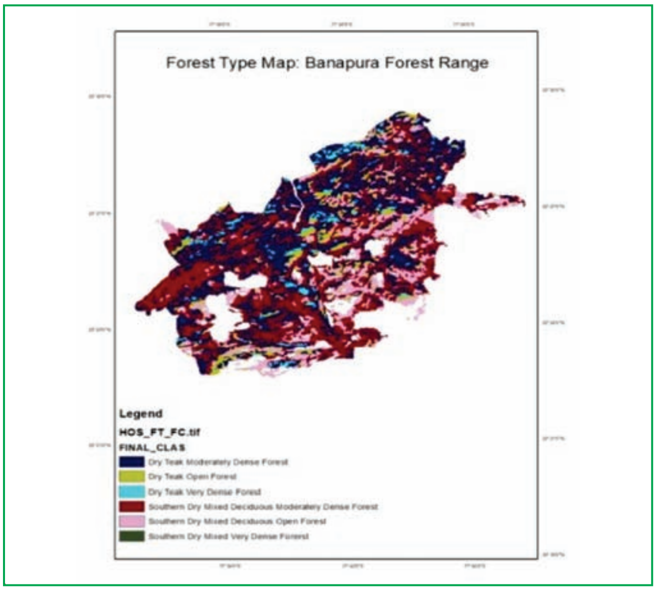



**Figure 4.12:**Stratified Map of Banapura, Itarsi and Sukhtawa Forest Ranges

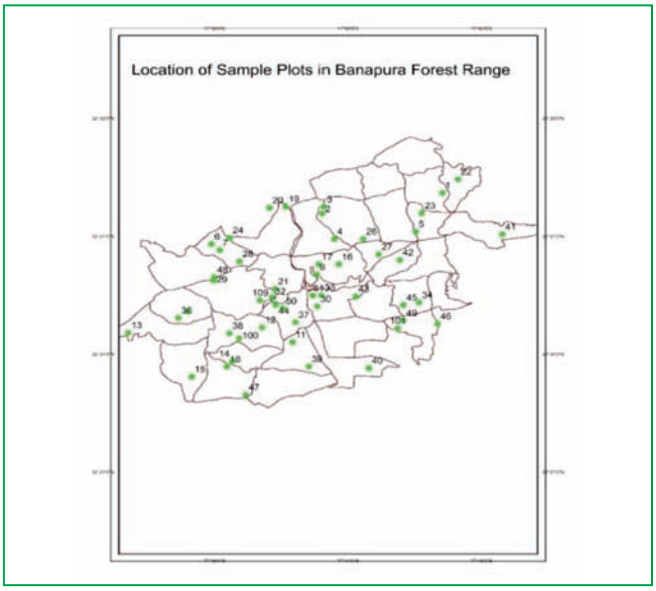



**Figure 4.13:**Location of Sample Plots in Banapura, Itarsi and Sukhtawa Forest Ranges

### 4.3 Forest Carbon Stocks in ESIP Areas

The total forest carbon stocks in ESIP areas of Madhya Pradesh for the year 2019 is estimated to be 11,72,639.19 tonnes. ESIP areas of Banapura, Itarsi and Sukhtawa Forest Ranges has the maximum carbon stocks (5,56,996.94 tonnes) followed by Bhaura Forest Range (3,78,629.12 tonnes) and Budhni Forest Range (2,37,013.53 tonnes), respectively (Figure 4.14).

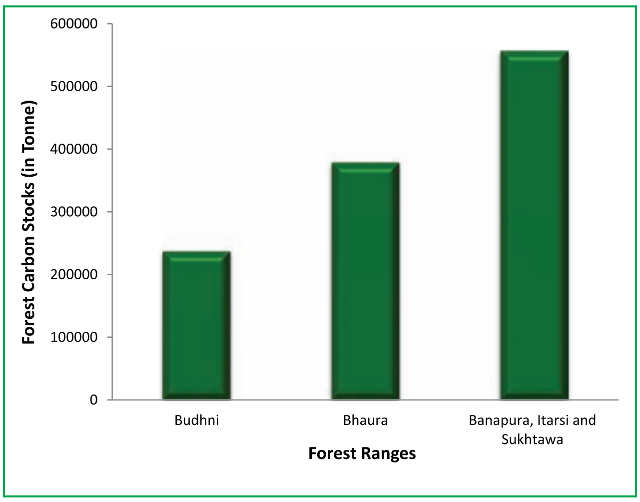



**Figure 4.14:** Forest Carbon Stocks in ESIP Areas of Madhya Pradesh

Forest type density stratification class wise forest carbon stocks in ESIP Areas of Madhya Pradesh is given in the Table 4.2.

Baseline data on forest carbon stocks of the ESIP areas of Madhya Pradesh revealed that average carbon stocks density varied from 57.59 t/ha in Bhaura Forest Range to 62.24 t/ha in the ESIP areas of Banapura, Itarsi and Sukhtawa Forest Range of Madhya Pradesh. Average carbon stocks density for Budhni Forest Range has been estimated to be 59.82 t/ha with the aboveground biomass contribution of 22.94 t/ha. Average carbon stocks density for Bhaura Forest Range has been estimated to be 57.59 t/ha with aboveground biomass contribution of 26.35 t/ha. Average carbon stocks density for the areas under Banapura, Itarsi and Sukhtawa Forest Range has been estimated to be 62.24t/ha with aboveground biomass contribution of 26.45 t/ha. Soil organic carbon contribution ranged from 23.77 t/ha in Bhaura Forest Range to 29.65 t/ha in Budhni Forest Range (Table 4.3). Sample plots wise data of forest carbon stocks are annexed as Annex V, VI and VII, respectively.

***Forest Carbon Stocks in Budhni Forest Range:*** 59 permanent sample plots were laid out to estimate the carbon stocks in Budhni Forest Range of Sehore Forest Division. The carbon stock density for Budhni Forest Range ranged from 5.80 t/ha to 118.84 t/ha. Average carbon stock density for Budhni Forest Range has been estimated to be 59.82 t/ha. Aboveground biomass contribution in carbon stock density is recorded to be 38.35% while the contribution of belowground biomass is recorded to be 10.73%. Soil organic carbon has the maximum contribution of 49.57% in the carbon stock density (Figure 4.15).

**Table 4.2:** Forest Carbon Stocks in ESIP Areas of Madhya Pradesh according to Forest Type Density Stratification

| Forest Type Density Stratification Class | Carbon Stock (in Tonnes) | | |
|---|---|---|---|
| | Budhni Forest Range | Bhaura Forest Range | Banapura, Itarsi and Sukhtawa Forest Ranges |
| Dry Teak Open Forest | 126997.04 | 90681.3 | 27378.21 |
| Dry Teak Moderately Dense Forest | 86089.20 | 128170 | 189440.1 |
| Dry Teak Very Dense Forest | 2139.84 | 12560.6 | 21253.66 |
| Southern Dry Mixed Deciduous Open Forest | 13506.12 | 64790.2 | 72096.07 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 8281.32 | 78816.3 | 246828.5 |
| Southern Dry Mixed Deciduous Very Dense Forest | - | 3610.72 | - |
| **Total** | **237013.53** | **378629.12** | **556996.54** |

**Table 4.3:** Carbon pool wise carbon stock density in project areas

| Forest Ranges | Carbon Pool (t/ha) | | | | | Total Carbon Stock Density (t/ha) |
|---|---|---|---|---|---|---|
| | AGB | BGB | Litter | Dead wood | Soil Organic Carbon | |
| Budhni Forest Range | 22.94 | 6.42 | 0.78 | 0.026 | 29.65 | 59.82 |
| Bhaura Forest Range | 26.35 | 7.38 | 0.09 | 0.0 | 23.77 | 57.59 |
| Banapura, Itarsi and Sukhtawa Forest Ranges | 26.45 | 7.41 | 0.09 | 0.0 | 28.29 | 62.24 |

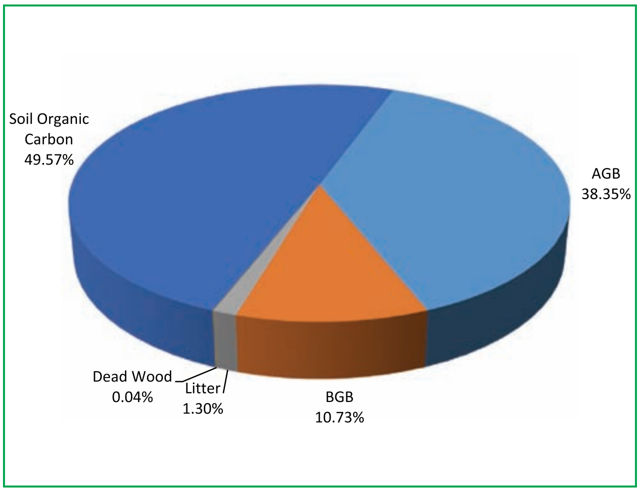



**Figure 4.15:**Contribution of various carbon pools in carbon stock density in Budhni Forest Range

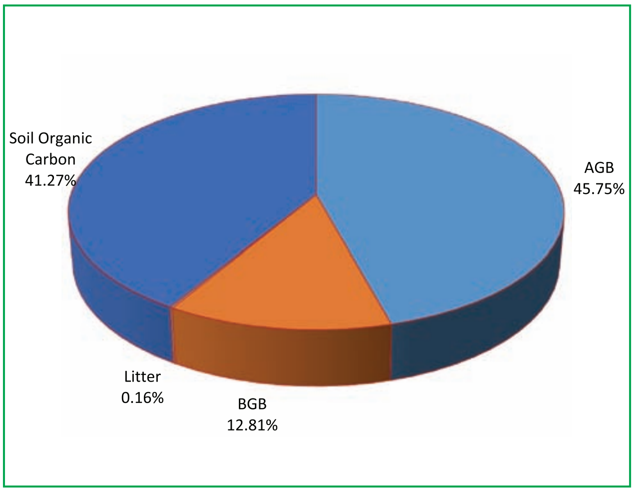



**Figure 4.16:** Contribution of various carbon pools in carbon stock densityin Bhaura Forest Range

In Budhni Forest Range, Dry Teak Moderately Dense Forest contributes 68.08 t/ha of the carbon stock while Dry Teak Open Forest contributes 53.32 t/ha of the carbon stock. Southern Dry Mixed Deciduous Open Dense Forest, Southern Dry Mixed Deciduous Moderately Forest and Dry Teak Very Dense Forest have 47.53, 72.79 and 59.99 t/ha of carbon stock, respectively (Table 4.3).

***Forest Carbon Stocks in Bhaura Forest Range:*** 45 sample plots were laid out to estimate the carbon stocks in Bhaura Forest Range of North Betul Forest Division. The carbon stock density for Bhaura Forest Range ranged from 24.14 t/ha to 107.44 t/ha. Average carbon stock density for Bhaura Forest Range has been estimated to be 57.59 t/ha. Aboveground biomass contribution in carbon stock density is recorded to be 45.75% while the contribution of belowground biomass is recoded to be 12.81%. Soil organic carbon contributes maximum of 41.27% in the carbon stocks (Fig 4.16).

In Bhaura Forest Range, Dry Teak Open Forest contributes 48.66 t/ha of the carbon stock while Dry Teak Open Moderately Dense contributes 56.98 t/ha of the carbon stock. Dry Teak Very Dense Forest has 58.97 t/ha carbon stock density. Southern Dry Mixed Deciduous Open Forest Dense Forest, Southern Dry Mixed Deciduous Moderately Dense Forest and Southern Dry Mixed Deciduous Very Dense Forest have 56.38, 70.20 and 85.38 t/ha of carbon stock density respectively (Table 4.4).

**Table 4.3:**Forest type and density wise carbon stock in Budhni Forest Range

| Class | Carbon stock (t/ha) |
|---|---|
| Dry Teak Open Forest | 53.32 |
| Dry Teak Moderately Dense Forest | 68.08 |
| Dry Teak Very Dense Forest | 59.99 |
| Southern Dry Mixed Deciduous Open Forest | 47.53 |
| Southern Dry Mixed Moderately Dense Forest | 72.79 |

**Table 4.4:** Forest type and density wise carbon stock in Bhaura Forest Range

| Class | Carbon Stocks (t/ha) |
|---|---|
| Dry Teak Open Forest | 48.66 |
| Dry Teak Moderately Dense Forest | 56.98 |
| Dry Teak Very Dense Forest | 58.97 |
| Southern Dry Mixed Deciduous Open Forest | 56.38 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 70.20 |
| Southern Dry Mixed Deciduous Very Dense Forest | 85.38 |
| Scrub | 24.14 |

***Forest Carbon Stocks in Banapura, Itarsi and Sukhtawa Forest Range:*** 51 sample plots were laid out to estimate the carbon stocks in ESIP areas of Banapura, Itarsi and Sukhtawa Forest Ranges of Hoshangabad Forest Division. The carbon stock density in Banapura, Itarsi and Sukhtawa Forest Ranges varied from 27.12 t/ha to 110.81 t/ha. Average carbon stock density for ESIP areas ofBanapura, Itarsi and Sukhtawa Forest Range has been estimated to be 62.24 t/ha. Aboveground biomass contribution in carbon stock density is recoded to be 42.50% while the contribution of belowground biomass is 11.91%. Soil organic carbon contributes maximum of 45.45% in the carbon stock (Fig 4.17).

In Bhaura Forest Range, Dry Teak Open Forest contributes 48.66 t/ha of the carbon stock while Dry Teak Open Moderately Dense contributes 56.98 t/ha of the carbon stock. Dry Teak Very Dense Forest has 58.97 t/ha carbon stock density. Southern Dry Mixed Deciduous Open Forest Dense Forest, Southern Dry Mixed Deciduous Moderately Dense Forest and Southern Dry Mixed Deciduous Very Dense Forest have 56.38, 70.20 and 85.38 t/ha of carbon stock density respectively (Table 4.4).

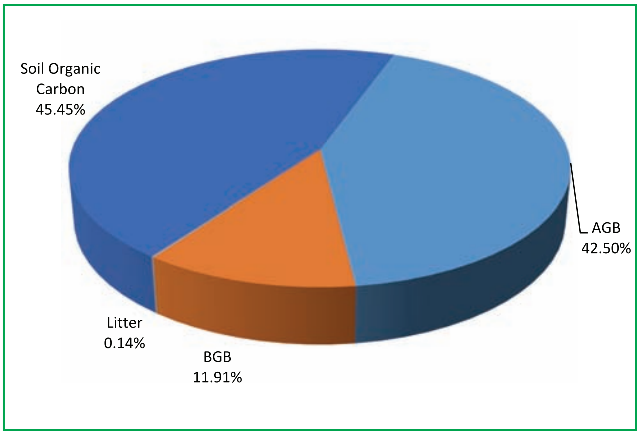



**Figure 4.17:** Contribution of various carbon pools in carbon stock density in Banapura, Itarsi and Sukhtawa Forest Ranges

In ESIP areas of Banapura, Itarsi and Sukhtawa Forest Ranges, Dry Teak Open Forest contributes 50.94 t/ha of the carbon stock while in Dry Teak Moderately Dense Forest 62.63 t/ha of the carbon stock is present (Table 4.5). Dry Teak Very Dense Forest has 83.98 t/ha carbon stock density. Southern Dry Mixed Deciduous Open Forest and Southern Dry Mixed Deciduous Moderately Dense Forest have 49.08 and 63.71 t/ha carbon stock density respectively.

About 41 tree species i.e. *Acacia catechu* (Khair), *Acacia leucophloea* (Rinjha), *Aegle marmelos* (Bel), *Albizia odoratissima* (Kala siris), *Anogeissus acuminata* (Dhou), *Anogeissus latifolia* (Dhavda), *Azadirachta indica* (Neem), *Bauhinia malabarica* (Astra), *Bridelia retusa* (Kasai), *Buchanania cochinchinensis* (Char), *Butea monosperma* (Palash), *Careya arborea* (Kumbhi), *Casearia graveolens* (Gilchi), *Cassia fistula* (Amaltas), *Chloroxylon swietenia* (Ghirya), *Dalbergialanceolaria* subsp. *paniculata* (Fasi), *Diospyros melanoxylon* (Tendu), *Elaeodendron glaucum* (Vajarvattu), *Erythrina variegata* (Gadha-palash), *Ficus benghalensis* (Bargad), *Flacourtia indica* (Kakai), *Gardenia latifolia* (Papda), *Grewia tiliifolia* (Dhaman), *Haldina cordifolia* (Haldu), *Holoptelea integrifolia* (Chil-bil), *Hymenodictylon excelsum* (Bhowr-sal), *Lagerstroemia parviflora*(Lendia), *Lannea coromandelica* (Moyan), *Madhuca longifolia* (Mahuwa), *Mitragyna parvifolia* (Kalam), *Phyllanthus emblica* (Aola), *Saccopetalum tomentosum* (Kari), *Schleichera oleosa* (Kusum), *Semecarpus anacardium* (Bhilwa), *Soymida febrifuga* (Rohini), *Tectona grandis* (Sagon), *Terminalia bellirica* (Baheda), *Terminalia chebula* (Harra), *Terminalia tomentosa* (Saj) and *Wrightia tinctoria* (Dudhai) were recorded as a major tree species of ESIP areas of Banapura, Itarsi and Sukhtawa Forest Ranges.

**Table 4.5:** Forest carbon stocks of ESIP areas of Banapura, Itarsi and Sukhtawa Forest Ranges

| Forest Type Stratum | C stock (t/ha) |
|---|---|
| Dry Teak Open Forest | 50.94 |
| Dry Teak Moderately Dense Forest | 61.27 |
| Dry Teak Very Dense Forest | 83.98 |
| Southern Dry Mixed Deciduous Open Forest | 49.08 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 63.71 |

About 38 tree species i.e. *Acacia leucophloea* (Rinjha), *Aegle marmelos* (Bel), *Anogeissus latifolia* (Dhavda), *Azadirachta indica* (Neem), *Balanites aegyptiaca* (Hingan), *Bauhinia malabarica* (Astra), *Boswellia serrata* (Salai), *Buchanania cochinchinensis* (Char), *Butea monosperma* (Palash), *Careya arborea* (Kumbhi), *Casearia graveolens* (Gilchi), *Cassia fistula* (Amaltas), *Chloroxylon swietenia* (Ghirya), *Dalbergia lanceolaria* subsp. *paniculata* (Fasi), *Desmodium oojeinense* (Tinsa), *Diospyros melanoxylon* (Tendu), *Elaeodendron glaucum* (Vajarvattu), *Ficus benghalensis* (Bargad), *Flacourtia indica* (Kakai), *Gardenia latifolia* (Papda), *Garuga pinnata* (Kekhar), *Grewia tiliifolia* (Dhaman), *Haldina cordifolia* (Haldu), *Lagerstroemia parviflora* (Lendia), *Lannea coromandelica* (Moyan), *Madhuca longifolia* (Mahuwa), *Mitragyna parvifolia* (Kalam), *Phyllanthus emblica* (Aola), *Saccopetalum tomentosum* (Kari), *Schleichera oleosa* (Kusum), *Soymida febrifuga* (Rohini), *Syzygium cumini* (Jamun), *Tamarindus indica* (Imli), *Tectonagrandis* (Sagon), *Terminalia bellirica*

(Baheda), *Terminalia chebula* (Harra), *Terminalia tomentosa* (Saj), and *Wrightia tinctorial* (Dudhai) were recorded as a major tree species of Bhaura Forest Range.

About 37 tree species i.e. *Acacia catechu* (Khair), *Acacia leucophloea* (Rhinja), *Aegle marmelos* (Bel), *Anogeissus latifolia* (Dhavda), *Azadirachta indica* (Neem), *Bauhinia retusa* (Sehra), *Bombax ceiba* (Semal), *Bridelia retusa* (Kasai), *Buchanania cochinchinensis* (Char), *Butea monosperma* (Palash), *Carey aarborea* (Kumbhi), *Cassia fistula* (Amaltas), *Chloroxylon swietenia* (Ghirya), *Dalbergia lanceolaria* subsp. *paniculata* (Fasi), *Desmodium oojeinense* (Girjan), *Diospyros melanoxylon* (Tendu), *Elaeodendron glaucum* (Vajarvattu), *Ficus religiosa* (Peepal*), Gardenia latifolia* (Papda), *Grewia tiliifolia* (Dhaman), *Haldina cordifolia* (Haldu), *Lagerstroemia parviflora* (Lendia), *Lannea coromandelica* (Moyan), *Madhuca longifolia* (Mahuwa), *Mitragyna parvifolia* (Kaim), *Phyllanthus emblica* (Aola), *Pterocarpus marsupium* (Beeja-sal), *Saccopetalum tomentosum* (Kari), *Schleichera oleosa* (Kusum), *Soymida febrifuga* (Rohini), *Tectona grandis* (Sagon), *Terminalia arjuna* (Arjun), *Terminalia bellirica* (Baheda), *Terminalia tomentosa* (Saj), *Wrightia tinctorial* (Dudhai) and *Zizyphus xylopyra* (Gator/Ber) were recorded as a major tree species of Budhni Forest Range.

**4.5 Discussion**

The role of forests in general and tropical dry deciduous forest in particular in sequestering atmospheric carbon has gained considerable importance and is in debate in the recent years. More than 40% of global gross primary production in the forest ecosystem has been accounted by tropical and subtropical forests (Beer *et al*., 2010). Tropical forest ecosystem is one of the biodiversity rich terrestrial ecosystems, which stores approximately half of the world living terrestrial carbon and its significant proportion fixed in the form of above ground biomass, thus they play an important role in global carbon cycle and regulating the climate (Shi and Singh, 2002). Baishya *et al.* (2009) suggested that tropical forests are more effective in carbon sequestration than other forests. Tropical forests are considered as having great carbon sequestration potential and therefore now gaining attention for mitigation of climate change (Hunter et al., 2013). ICFRE (2013) reported that tropical moist deciduous forests store the maximum amount of soil organic carbon than the other forests. Soil organic carbon is the amount of carbon present in the organic matter and includes all the plant residues, living roots, biological organism, and decomposing, decomposed or burnt material of varying sizes. The amount of soil organic carbon has direct relation with the productivity, species richness as well as health of vegetation.

Haripriya (2000) reported that above ground biomass carbon ranged from 48.30 Mg/ha to 97.30 Mg/ha in tropical deciduous forests of India. The carbon storage in the present study is much similar to in range as compared to the estimates made in different tropical forests (Atjay *et al*., 1979; Brown *et al*., 1989; Brown *et al*., 1996; Swamy, 1998; FSI, 2019). Comparative assessment of the data suggests that these values are similar to those of carbon and biomass density recorded from other forests of India.

In Madhya Pradesh, forests are surrounded by large numbers of villages and most of the tribal populations depend upon forests for their livelihood security (Pande, 2005). Aboveground biomass and carbon stocks varied with the degree of anthropogenic pressure in tropical dry deciduous forests in Madhya Pradesh. Several studies indicated that the rural populations of forest fringe villages solely depend upon forest biomass for meeting their livelihood security such as fuel wood, fodder, non-timber forest products etc. and degrade the forest quality through its over exploitation (Sagar *et al*., 2003, Pande, 2005; Ramacharitra, 2006, Salunkhe *et al*., 2014; Salunkhe *et al*., 2016). Human intervention, land use changes and other activities, released carbon from forests in to the atmosphere (Haripriya, 2003; Bhat and Ravindranath, 2011). Similar types of pressure on the forests under the ESIP areas of Madhya Pradesh have been observed during the field surveys which are reasons for comparatively less forest carbon stocks. Poor regeneration of tree species due to heavy grazing, repeated forest fires and invasion of obnoxious weeds were also observed during the field surveys.ICFRE has conducted the socio-economic studies in the ESIP areas and reported that fuel woodis being used as a primary source of energy for cooking and on an average 20 kg of fuel wood has been collected per day per households from forest in the project areas. Besides the collection of fuel wood and fodder, other forest produces are also being collected by the local communities of the project areas for their sustenance and livelihoods in the project areas (ICFRE, 2019).

## 5. Conclusion

This study provides baseline data on forest carbon stocks in the ESIP areas of Madhya Pradesh. A total of 155 permanent sample plots were laid out to assess the baseline of forest carbon stocks in ESIP area. It can be concluded that the forest in ESIP area, can sequester more carbon in the future as maximum trees are young, which means a greater tendency to build biomass, and therefore carbon storage. The carbon stock density of areas under Banapura, Itarsi and Sukhtawa Forest Ranges (62.24 t/ha) was higher than the Budhni Forest Range (59.82 t/ha) and Bhaura Forest Range (57.59 t/ha). The report also provides relevant information on carbon stocks in different forest types of ESIP area of Madhya Pradesh. The results of the baseline study will be a benchmark for evaluating the ESIP project interventions in terms of enhanced carbon storage in project areas over a period of time by implementing better silvi cultural interventions. The results of the baseline study will also help the State Forest Department of Madhya Pradesh to initiate appropriate forest management practices for enhancement of forest carbon stocks in the project areas under ESIP as successful demonstrative models which can be latter on scaled up in other parts of the state. It can be stated that dependency of local communities on forest produce is one of the factors of forest degradation. There is a need to sensitize the local communities on issue of forest degradation and their role in sustainable management of the forests. Generation of this baseline report on forest carbon stocks will be helpful in making realistic assessments of the forest carbon stocks of the ESIP areas of Madhya Pradesh.

## 6. Way Forward

Baseline study conducted in the ESIP areas of Madhya Pradesh provide information about the baseline carbon stocks in different forest types and forest covers, as well as it shows variations of carbon stocks in different carbon pool like aboveground biomass, belowground biomass, litter, deadwood and soil organic carbon pool. The sample plot laid out in the project areas will be used to monitor the forest carbon stocks. The results will act as baseline information on carbon stocks of the project areas and will be helpful to determine the changes in the forest carbon stocks over a period of time due to successful implementation of project activities and will also be further helpful in designing the climate change mitigation and adaptation programmes. Various anthropogenic activities in the project areas like collection of fuelwood, fodder and NWFPs, grazing and forest fire are causing forest degradation and responsible for loss of carbon stocks. The drivers of forest degradation need to be addressed with implementation of feasible interventions. National REDD+ Strategy also advocates identifying and addressing the drivers of deforestation and forest degradation (MoEFCC, 2018).The state of Madhya Pradesh is well known for involvement of the Joint Forest Management Committees (JFMCs) in the forest management. Therefore, capacity building of local communities especially the members of JFMCs on various aspects of forest conservation and sustainable harvesting of NWFP scan play an important role in enhancing the forest carbon stocks and improving the livelihoods of the local communities.


Field surveys for measurement of forest carbon stocks

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Annex - I

## Form for Data Collection for Forest Carbon Stock Assessment

General Information:

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

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

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

**B.** (a) Saplings: Plot Size: 3 m X 3 m

North West Corner

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

(b) Saplings: Plot Size: 3 m X 3 m

North East Corner

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

(c) Saplings Plot Size: 3 m X 3 m

South-East Corner

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

(d) Saplings: Plot Size: 3 m X 3 m

South-West Corner

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

**C.** (a) Shrubs: Plot Size: 3 m X 3 m

North West Corner

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

(b) Shrubs: Plot Size: 3 m X 3 m

North-East Corner

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

(c) Shrubs: Plot Size: 3 m X 3 m

South-East Corner

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

(d) Shrubs: Plot Size: 3 m X 3 m

South-West Corner

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

(a) Herbs: Plot Size: 1 m X 1 m

North West Corner

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

(b) Herbs:

North East Corner Plot Size: 1 m X 1 m

| S.No. | Species Name (Hindi/English/Local/Scientific Name) | Fresh Weight (gm) | Sample Fresh Weight (gm) | Sample Code |
|---|---|---|---|---|
| 1 | | | | |
| 2 | | | | |

| | | | | |
|---|---|---|---|---|
| 3 | | | | |
| 4 | | | | |
| 5 | | | | |

(c) Herbs:

South East Corner Plot Size: 1 m X 1 m

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

(d) Herbs:

South West Corner Plot Size: 1 m X 1 m

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

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

a. North West Corner

Fresh Weight (gm) = ____________________

Sample Fresh Weight (gm) = ____________________

b. North East Corner

Fresh Weight (gm) = ____________________

Sample Fresh Weight (gm) = ____________________

c. South East Corner

Fresh Weight (gm) = ____________________

Sample Fresh Weight (gm) = ____________________

d. South West Corner

Fresh Weight (gm) = ____________________

Sample Fresh Weight (gm) = ____________________

## G. Soil Sample

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

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

(b) Soil Sample for Soil Organic Carbon:

North East Corner: Sample Code__________

South West Corner: Sample Code__________

**H (a) Dead wood** **Plot Size: 5 m X 5 m**

North East Corner

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

**H (b) (Dead wood)** Plot Size: 5 m X 1 m

South West Corner

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

**Volume Equations**

(Used for tree species)

**Central Highlands**

| S. No. | Species | Local Name | Volume Equation |
|---|---|---|---|
| 1 | *Acacia catechu* | Khair | $V = -0.02471 + 0.16897\ D + 1.12083\ D^2 + 2.9328\ D^3$ |
| 2 | *Acacia lenticularis/ Leucaena leucophloea* | Rinjha | $\sqrt{V} = -0.00142 + 2.61911\ D – 0.54703\ \sqrt{D}$ |
| 3 | *Aegle marmelos* | Bel | $V/D^2 = 0.16609/D^2 - 2.78851/D + 17.22127-11.60248\ D$ |
| 4 | *Anogeissu slatifolia* | Dhawda | $\sqrt{V} = -0.20236 + 3.13059\ D$ |
| 5 | *Anogeissus pendula* | | $V/D^2 = 0.00085/D^2 – 0.35165/D + 4.77386 – 0.90585\ D$ |
| 6 | *Boswellia serrata* | Salai | $\sqrt{V} = -0.1503 + 2.79425\ D$ |
| 7 | *Buchanania cochinensis* Syn. *B. latifolia* Syn. *B. lanzan* | Char | $V = 0.031 -0.64087\ D + 6.04066\ D^2$ |
| 8 | *Butea monosperma* Syn. *Butea frondosa* | Palash | $\sqrt{V} = -0.24276 + 2.95525\ D$ |
| 9 | *Chloroxylon swietenia* | Ghirya | $V = -0.003156 + 2.043969\ D^2$ |
| 10 | *Diospyros melanoxylon* | Tendu | $V = 0.15581 – 2.2075\ D + 9.17559\ D^2$ |
| 11 | *Flacourtia indica* | Kakai | $\sqrt{V} = -0.153973 + 2.724109\ D$ |
| 12 | *Lagerstroemia parviflora* | Lendia | $V = 0.10529 – 1.68829\ D + 10.29573\ D^2$ |
| 13 | *Lannea coromandelica/ Lannea grandis* | Moyan | $V/D^2 = 0.14004/D^2 – 2.35990/D + 11.90726$ |
| 14 | *Madhuca latifolia* Syn. *M. indica* | Mahuwa | $V = 0.063632 + 5.355486\ D^3$ |
| 15 | *Miliusa tomentosum/ Saccopetalum tomentosum* | Kari | $\sqrt{V} = 0.66382 + 7.03093\ D – 3.68133\ \sqrt{D}$ |
| 16 | *Mitragyna parviflora/ Stephegyne parviflora* | Kem | $V/D^2 = 0.099768/D^2 – 1.744274/D + 10.086934$ |
| 17 | *Tectona grandis* | Sagon | $\sqrt{V} = -0.405890 + 1.98158\ D + 0.987373\ \sqrt{D}$ |
| 18 | *Terminalia crenulata / T. Tomentosa* | Saj | $\sqrt{V} = -0.203947 + 3.159215\ D$ |
| 19 | *Wrightia tinctoria* | Dudhai | $\sqrt{V} = 0.050294 + 3.115497\ D - 0.687813\ \sqrt{D}$ |
| 20 | Zizyphus xylopyrus | Ber | $V = 0.027354 + 4.663714\ D^2$ |
| 21 | General Equation* | | $V/D^2 = 0.0697/D^2-1.4597/D+11.79933-2.35397D$ |

**North Deccan**

| S. No. | Species | Local Name | Volume Equation |
|---|---|---|---|
| 1 | *Acacia catechu* | Khair | $V = 0.04235 – 0.74240 D + 7.26875 D^2$ |
| 2 | *Aegle marmelos* | Bel | $V = 0.119 – 1.768 D + 9.258 D^2$ |
| 3 | *Anogeissus latifolia* | Dhawda | $V = - 0.061856 +7.952136 D^2$ |
| 4 | *Bauhinia retusa/ B. variegata* | Kachnar | $V = -0.0236 +0.3078 D + 1.2361 D^2$ |
| 5 | *Buchanania cochinensis* | Char | $V = -0.00767 + 0.2654 D + 1.0383 D^2 + 7.527 D^3$ |
| 6 | *Butea monosperma* Syn. *Butea frondosa* | Palash | $V = -0.032 – 0.0619 D + 7.208 D^2$ |
| 7 | *Chloroxylon swietenia* | Ghirya | $V = 0.0242 – 0.6689 D + 5.2777 D^2$ |
| 8 | *Cleistanthus collinus* | | $\sqrt{V} = - 0.07324 + 2.187427 D$ |
| 9 | *Diospyros melanoxylon* | Tendu | $V/D = 0.033867/D – 0.975148 D + 8.255412 D$ |
| 10 | *Gardenia resinifera* Syn. | Papda | $V = 0.078 – 1.188 D + 6.751 D^2$ |
| 11 | *Lagerstroemia parviflora* | Lendia | $V/D^2 = 0.06466/D^2 – 1.371984/D + 9.629971$ |
| 12 | *Lannea coromandelica* | Moyan | $V = 0.093318 – 1.531417 D + 9.011590 D^2$ |
| 13 | *Madhuca latifolia* | Mahuwa | $V = 0.074069 - 1.230020 D + 7.726902 D^2$ |
| 14 | *Memecylon edule* | kaayam | $V = 0.103 – 1.709 D + 9.692 D^2$ |
| 15 | *Miliusa tomentosum/ Saccopetalum tomentosum* | Kari | $\sqrt{V} = 0.66382 + 7.03093 D – 3.68133 \sqrt{D}$ |
| 16 | *Syzygium cumini/ Eugenia jambolana* | Jamun | $V = 0.2736 – 3.377 D + 12.959 D^2$ |
| 17 | *Tectona grandis* | Sagon | $\sqrt{V} = -0.106720 + 2.562418 D$ |
| 18 | *Terminalia crenulata/tomentosa* | Saj | $V/D^2 = 0.048532/D^2 – 1.05615/D + 8.204564$ |
| 19 | *Wrightia tinctoria* | Dudhai | $V = - 0.009510 + 4.149345 D^2$ |
| 20 | *Zizyphus xylopyrus* | Ber | $V = -0.0257 + 0.2313 D + 1.474 D^2$ |
| 21 | General Equation* | | $V/D^2 = 0.0697/D^2-1.4597/D+11.79933-2.35397D$ |

*For other species General Equation is used (Source: FSI, 1996).

(Source: FSI,nd)

## Specific Gravity of Major Species

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

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

| Name of the Species | Specific Gravity (wt. oven dry/vol. green) |
|---|---|
| *Acacia catechu* | 0.875 |
| *Acacia leucophloea* | 0.660 |
| *Aegle marmelos* | 0.754 |
| *Anogeissus latifolia* | 0.799 |
| *Azadirachta indica* | 0.693 |
| *Bauhinia malabarica* | 0.670 |
| *Bridelia retusa* | 0.499 |
| *Buchanania cochinchinensis* | 0.458 |
| *Butea monosperma* | 0.465 |
| *Casearia tomentosa* | 0.620 |
| *Cassia fistula* | 0.746 |
| *Chloroxylon swietenia* | 0.771 |
| *Dalbergia latifolia* | 0.750 |
| *Dalbergia paniculata* | 0.640 |
| *Diospyros melanoxylon* | 0.678 |
| *Gardenia latifolia* | 0.635 |
| *Grewia tilifolia* | 0.679 |
| *Haldina cordifolia* | 0.597 |
| *Lagerstroemia parviflora* | 0.620 |
| *Lannea coromandelica* | 0.513 |
| *Madhuca longifolia* | 0.740 |
| *Ougenia oojeinensis* | 0.704 |
| *Phyllanthus emblica* | 0.800 |
| *Pterocarpus marsupium* | 0.649 |
| *Saccopetalum tomentosum* | 0.615 |
| *Semecarpus anacardium* | 0.640 |
| *Schleichera oleosa* | 0.841 |
| *Soymida febrifuga* | 0.963 |
| *Syzygium cumini* | 0.647 |
| *Tamarindus indica* | 0.750 |
| *Tectona grandis* | 0.563 |
| *Terminalia bellirica* | 0.628 |
| *Terminalia chebula* | 0.642 |
| *Terminalia tomentosa* | 0.730 |

Annex - IV

## 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

D: diameter at breast height in meter; $D_1$: diameter at breast height in cm; unit of biomass is Kg.

**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* | $BE_1 = -185.9612\ D^2 + 363.4651\ D – 23.7470$ |
| | | $BE_2 = -8.7736\ D^2 + 18.6843\ D – 1.2968$ |
| | | $BE_3 = 0.0506\ D_1^2 + 0.6227\ D_1 – 0.3709$ |
| | | $BE_4 = 0.0030\ D_1^2 + 0.0121\ D_1 + 0.0401$ |
| 8 | *Terminalia 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* | $BE_1 = -316.8777 D^2 + 401.7510 D – 28.8949$ |
| | | $BE_2 = 26.68 D^2 + 33.47 D – 2.394$ |
| | | $BE_3 = 0.1395 D_1^2 + 0.1710 D_1 + 0..6693$ |
| | | $BE_4 = 0.0090 D_1^2 + 0.0048 D_1 +0.0680$ |
| 13 | *Acacia lenticularis/ leucophlea* | $BE_1 = 290.6110 D^2 + 78.7053 D -6.0127$ |
| | | $BE_2 = 6.5580 D^2 + 4.6176 D – 0.3076$ |
| | | $BE_3 = 0.0891 D_1^2 + 0.2386 D_1 + 0.1853$ |
| | | $BE_4 = -0.0012 D_1^2 + 0.0353 D_1 – 0.0078$ |
| 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* | $BE_1 = 724.8313 D^{1.8139}$ |
| | | $BE_2 = -5.7898 D^2 + 16.1859 D – 0.8153$ |
| | | $BE_3 = 0.1701 D_1^2 – 0.5602 D_1 + 1.3209$ |
| | | $BE_4 = 0.0080 D_1^2 + 0.0186 D_1 +0.0245$ |
| 2 | *Terminalia tomentosa* | $BE_1 = -893.2875 D^3 + 1888.8940 D^2 – 463. 5333D +54.7484$ |
| | | $BE_2 = 20. 0615 D^2 +1.5684 D + 0.4141$ |
| | | $BE_3 = 0.1545 D_1^2 + 0.0612 D_1 + 0.5004$ |
| | | $BE_4 = 0.0061 D_1^2 + 0.0027 D_1 + 0.0550$ |
| 3 | *Chloroxylon swietenia* | $BE_1 = 884.6576 D^2 + 395.8155 D – 38.2331$ |
| | | $BE_2 = 13.0100 D – 0.3999$ |
| | | $BE_3 = 0.1990 D_1^2 – 0.3570 D_1 + 0.5943$ |
| | | $BE_4 = 0.0118 D_1^2 – 0.0027 D_1 + 0.0401$ |
| 4 | *Anogeissus pendula* | $BE_1 = 1299.4268 D^3 – 1653.6151 D^2 + 1320.6808 D – 110.1954$ |
| | | $BE_2 = -3.8043D^2 +10.7862 D - 0.3515$ |
| | | $BE_3 = -0.0650 D_1^2 + 2.1152 D_1 – 1.1784$ |
| | | $BE_4 = -0.0079 D_1^2 + 0.1908 D_1 - 0.0179$ |
| 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* | $BE_1 = 243.9685\ D^2 + 163.\ 6429\ D - 12.3582$ |
| | | $BE_2 = -35.4845D^3 + 44.3745\ D^2 -1.2717\ D + 0.2303$ |
| | | $BE_3 = 0.0326\ D_1^2 + 0.4611\ D_1 + 0.3191$ |
| | | $BE_4 = 0.0074\ D_1^2 –0.0222\ D_1 + 0.0456$ |
| 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* | $BE_1 = 167.8008\ D^2 + 212.0485\ D – 10.6145$ |
| | | $BE_2 = 3.9604\ D^2 + 2.5419\ D + 0.4212$ |
| | | $BE_3 = 0.1779\ D_1 – 0.5745\ D_1 + 1.6701$ |
| | | $BE_4 = 0.0119\ D_1^2 - 0.0425\ D_1 + 0.1287$ |
| 13 | *Wrightia tinctoria* | $BE_1 = 703.4801\ D^2 – 128.9582\ D + 13.6679$ |
| | | $BE_2 = -4.0215\ D^2 + 4.6618\ D - 0.2465$ |
| | | $BE_3 = 0.0232\ D_1^2 +0.5686\ D_1 – 0.2292$ |
| | | $BE_4 = 0.0006\ D_1^2 + 0.0111D_1 + 0.0151$ |
| 14 | *Cleistanthus collinus* | $BE_1 = 267.9289\ D^2 + 203.8644\ D – 13.2061$ |
| | | $BE_2 = 4.1925\ D^2 + 0.6047\ D + 0.1422$ |
| | | $BE_3 = 0.0895\ D_1^2 + 0.3236\ D_1 + 0.5934$ |
| | | $BE_4 = 0.0006\ D_1^2 + 0.0129\ D_1 – 0.0064$ |
| 15 | *Syzygium cumini* | $BE_1 = 252.1925\ D^2 + 138.7321\ D – 10.9596$ |
| | | $BE_2 = 10.9963\ D^2 – 1.6709\ D + 0.6265$ |
| | | $BE_3 = 0.5933\ D_1 - 0.0378$ |
| | | $BE_4 = 0.0095\ D_1^2 -0.0349\ D_1 + 0.0480$ |
| 16 | *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* | $BE_1 = 604.8017\ D^2 + 0.0041\ D + 1.7251$ |
| | | $BE_2 = 43.2013\ D^2 – 11.9883\ D + 1.0009$ |
| | | $BE_3 = 0.0940\ D_1^2 + 0.0813\ D_1 + 0.1856$ |
| | | $BE_4 = 0.0081\ D_1^2 –0.0021\ D_1 + 0.0102$ |
| 18 | *Bauhinia retusa/variegata* | $BE_1 = 57.2611\ D^2 + 205.3085\ D – 15.\ 5737$ |
| | | $BE_2 = 1.6214\ \log_e D + 3.9181$ |
| | | $BE_3 = 0.0508\ D_1^2 + 0.3060\ D_1 + 0.2747$ |
| | | $BE_4 = 0.0083\ D_1^2 – 0.0012D_1 + 0.0113$ |
| 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 |

## Annex - V

Sample Plots Wise Forest Carbon Stocks in Budhni Forest Range

| Class | Plot No. | Longitude | Latitude | Carbon Pool | | | | | Total Carbon (t/ha) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | AGB (t/ha) | BGB (t/ha) | Litter (t/ha) | Deadwood (t/ha) | Soil (t/ha) | |
| Dry Teak Open Forest | 1 | E 77°46'42.708" | N 22°53'58.884" | 15.50 | 4.34 | 1.03 | 0.00 | 37.5 | 58.40 |
| Dry Teak Open Forest | 2 | E 77°45'53.712" | N 22°54'23.292" | 10.60 | 2.97 | 0.21 | 0.00 | 23.8 | 37.60 |
| Dry Teak Open Forest | 3 | E 77°44'3.3" | N 22°53'55.752" | 11.76 | 3.29 | 0.47 | 0.00 | 19.3 | 34.86 |
| Dry Teak Open Forest | 4 | E 77°44'35.592" | N 22°54'8.388" | 4.35 | 1.22 | 0.23 | 0.00 | 0.0 | 5.80 |
| Dry Teak Open Forest | 5 | E 77°46'17.004" | N 22°53'53.916" | 18.73 | 5.24 | 1.60 | 0.00 | 10.1 | 35.72 |
| Dry Teak Moderately Dense Forest | 6 | E 77°45'45.504" | N 22°54'30.312" | 29.05 | 8.13 | 1.63 | 0.00 | 28.2 | 67.05 |
| Dry Teak Moderately Dense Forest | 7 | E 77°44'41.208" | N 22°54'10.116" | 5.07 | 1.42 | 0.17 | 0.00 | 35.7 | 42.41 |
| Dry Teak Moderately Dense Forest | 8 | E 77°45'20.412" | N 22°54'4.896" | 33.70 | 9.44 | 0.51 | 0.00 | 45.3 | 88.94 |
| Southern Dry Mixed Deciduous Open Forest | 9 | E 77°46'8.904" | N 22°54'37.512" | 5.40 | 1.51 | 0.90 | 0.003 | 41.1 | 48.91 |
| Southern Dry Mixed Deciduous Open Forest | 10 | E 77°43'1.956" | N 22°53'38.868" | 6.25 | 1.75 | 0.66 | 0.16 | 21.4 | 30.25 |
| Dry Teak Open Forest | 11 | E 77°45'17.1" | N 22°52'39.108" | 13.53 | 3.79 | 0.47 | 0.00 | 16.8 | 34.63 |
| Dry Teak Open Forest | 12 | E 77°44'47.4" | N 22°52'35.688" | 5.54 | 1.55 | 0.26 | 0.00 | 28.7 | 36.01 |
| Dry Teak Open Forest | 13 | E 77°41'38.508" | N 22°52'32.304" | 22.94 | 6.42 | 0.30 | 0.00 | 43.2 | 72.89 |
| Dry Teak Open Forest | 14 | E 77°43'13.584" | N 22°53'18.096" | 18.08 | 5.06 | 0.52 | 0.00 | 61.8 | 85.50 |
| Dry Teak Open Forest | 15 | E 77°42'5.184" | N 22°52'44.688" | 32.01 | 8.96 | 0.19 | 0.00 | 44.2 | 85.37 |
| Dry Teak Open Forest | 16 | E 77°45'36.792" | N 22°52'33.492" | 36.20 | 10.13 | 0.49 | 0.00 | 2.2 | 49.01 |
| Dry Teak Open Forest | 17 | E 77°42'36.756" | N 22°53'24.612" | 44.49 | 12.46 | 0.36 | 0.00 | 32.8 | 90.09 |
| Dry Teak Moderately Dense Forest | 18 | E 77°42'5.616" | N 22°52'53.904" | 27.20 | 7.62 | 0.70 | 0.00 | 42.4 | 77.89 |
| Dry Teak Moderately Dense Forest | 19 | E 77°45'9.9" | N 22°52'46.884" | 15.93 | 4.46 | 0.31 | 0.00 | 31.6 | 52.34 |
| Dry Teak Moderately Dense Forest | 20 | E 77°42'12.6" | N 22°52'18.912" | 14.96 | 4.19 | 1.10 | 0.02 | 17.1 | 37.36 |
| Dry Teak Moderately Dense Forest | 21 | E 77°41'37.608" | N 22°52'36.516" | 28.24 | 7.91 | 1.01 | 0.00 | 15.5 | 52.67 |
| Dry Teak Moderately Dense Forest | 22 | E 77°41'37.716" | N 22°52'23.016" | 23.27 | 6.51 | 1.32 | 0.00 | 31.0 | 62.10 |
| Dry Teak Open Forest | 23 | E 77°41'31.884" | N 22°53'1.896" | 14.40 | 4.03 | 0.53 | 0.00 | 56.4 | 75.38 |
| Dry Teak Open Forest | 24 | E 77°45'5.904" | N 22°51'33.084" | 43.44 | 12.16 | 0.49 | 0.00 | 48.1 | 104.19 |
| Dry Teak Open Forest | 25 | E 77°41'19.212" | N 22°51'46.512" | 17.59 | 4.92 | 1.26 | 0.00 | 23.9 | 47.68 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Dry Teak Open Forest | 26 | E 77°44'38.292" | N 22°51'31.104" | 16.40 | 4.59 | 2.01 | 0.00 | 9.1 | 32.14 |
| Dry Teak Moderately Dense Forest | 27 | E 77°41'3.3" | N 22°51'55.8" | 20.10 | 5.63 | 1.36 | 0.00 | 37.9 | 65.00 |
| Dry Teak Open Forest | 28 | E 77°43'15.996" | N 22°51'26.496" | 5.41 | 1.51 | 0.54 | 0.00 | 39.1 | 46.53 |
| Dry Teak Open Forest | 29 | E 77°43'15.384" | N 22°51'52.416" | 22.70 | 6.36 | 0.32 | 0.00 | 31.2 | 60.60 |
| Dry Teak Moderately Dense Forest | 30 | E 77°42'13.392" | N 22°51'34.488" | 38.00 | 10.64 | 0.37 | 0.00 | 31.7 | 80.71 |
| Dry Teak Open Forest | 31 | E 77°45'22.392" | N 22°51'58.392" | 18.81 | 5.27 | 0.40 | 0.00 | 0.0 | 24.49 |
| Dry Teak Open Forest | 32 | E 77°45'8.316" | N 22°51'14.616" | 17.80 | 4.99 | 0.86 | 0.00 | 16.8 | 40.43 |
| Dry Teak Open Forest | 33 | E 77°43'9.3" | N 22°50'52.512" | 9.67 | 2.71 | 0.22 | 0.00 | 38.9 | 51.54 |
| Dry Teak Moderately Dense Forest | 34 | E 77°43'32.196" | N 22°51'11.988" | 15.35 | 4.30 | 0.51 | 0.00 | 19.1 | 39.26 |
| Dry Teak Open Forest | 35 | E 77°44'29.904" | N 22°51'18" | 30.59 | 8.57 | 0.78 | 0.00 | 10.8 | 50.70 |
| Dry Teak Moderately Dense Forest | 36 | E 77°44'2.508" | N 22°51'17.388" | 19.44 | 5.44 | 0.76 | 0.00 | 40.7 | 66.38 |
| Dry Teak Moderately Dense Forest | 37 | E 77°42'26.892" | N 22°52'7.608" | 40.39 | 11.31 | 2.25 | 0.00 | 44.1 | 98.04 |
| Dry Teak Moderately Dense Forest | 38 | E 77°44'36.708" | N 22°51'58.896" | 24.45 | 6.85 | 1.31 | 0.00 | 21.7 | 54.36 |
| Dry Teak Moderately Dense Forest | 39 | E 77°44'51" | N 22°52'1.992" | 57.49 | 16.10 | 1.22 | 0.02 | 44.0 | 118.84 |
| Dry Teak Moderately Dense Forest | 40 | E 77°42'39.312" | N 22°51'58.896" | 26.95 | 7.55 | 1.69 | 0.00 | 9.0 | 45.18 |
| Dry Teak Moderately Dense Forest | 41 | E 77°43'46.884" | N 22°52'1.416" | 39.86 | 11.16 | 1.59 | 0.00 | 28.8 | 81.45 |
| Dry Teak Very Dense Forest | 42 | E 77°43'21.684" | N 22°51'10.188" | 10.60 | 2.97 | 0.29 | 0.00 | 46.13 | 59.99 |
| Dry Teak Moderately Dense Forest | 43 | E 77°41'53.088" | N 22°51'59.508" | 37.58 | 10.52 | 1.51 | 0.00 | 55.8 | 105.45 |
| Southern Dry Mixed Moderately Dense Forest | 44 | E 77°44'26.088" | N 22°51'19.584" | 36.81 | 10.31 | 0.67 | 0.01 | 23.3 | 71.12 |
| Dry Teak Open Forest | 45 | E 77°42'23.616" | N 22°49'37.488" | 19.61 | 5.49 | 0.59 | 0.00 | 42.5 | 68.16 |
| Dry Teak Open Forest | 46 | E 77°44'34.728" | N 22°49'53.904" | 16.29 | 4.56 | 0.25 | 0.00 | 12.2 | 33.35 |
| Dry Teak Open Forest | 47 | E 77°44'56.112" | N 22°50'24.288" | 15.42 | 4.32 | 0.58 | 0.00 | 27.2 | 47.50 |
| Dry Teak Moderately Dense Forest | 48 | E 77°44'15.612" | N 22°50'21.912" | 13.51 | 3.78 | 0.23 | 0.00 | 23.9 | 41.45 |
| Dry Teak Open Forest | 49 | E 77°45'13.5" | N 22°50'29.004" | 25.03 | 7.01 | 0.36 | 0.00 | 11.7 | 44.14 |
| Dry Teak Open Forest | 50 | E 77°44'10.716" | N 22°50'5.1" | 19.99 | 5.60 | 1.50 | 0.02 | 31.4 | 58.49 |
| Dry Teak Open Forest | 51 | E 77°43'51.6" | N 22°49'44.184" | 24.57 | 6.88 | 0.53 | 0.01 | 59.5 | 91.52 |
| Dry Teak Open Forest | 52 | E 77°43'58.404" | N 22°49'59.484" | 27.45 | 7.68 | 0.50 | 0.00 | 7.8 | 43.47 |
| Dry Teak Moderately | 53 | E 77°42'53.388" | N 22°49'37.092" | 28.59 | 8.00 | 0.78 | 0.00 | 8.7 | 46.09 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Dense Forest | | | | | | | | | | |
| Dry Teak Moderately Dense Forest | 54 | E 77°43'40.188" | N 22°49'43.284" | 45.12 | 12.63 | 1.34 | 0.00 | 46.6 | 105.68 |
| Dry Teak Moderately Dense Forest | 55 | E 77°42'55.404" | N 22°49'50.484" | 36.38 | 10.19 | 0.65 | 0.002 | 10.6 | 57.77 |
| Dry Teak Moderately Dense Forest | 56 | E 77°42'44.604" | N 22°49'40.512" | 23.59 | 6.60 | 0.98 | 0.01 | 39.8 | 71.02 |
| Dry Teak Moderately Dense Forest | 57 | E 77°44'10.284" | N 22°50'20.112" | 23.63 | 6.62 | 1.14 | - | 45.2 | 76.56 |
| Southern Dry Mixed Moderately Dense Forest | 58 | E 77°42'44.496" | N 22°49'50.592" | 33.89 | 9.49 | 0.85 | 0.002 | 30.2 | 74.47 |
| Southern Dry Mixed Deciduous Open Forest | 59 | E 77°45'3.816" | N 22°50'4.992" | 13.90 | 3.89 | 0.39 | 0.00 | 45.2 | 63.42 |

## Sample Plots Wise Forest Carbon Stocks in Bhaura Forest Range

| Class | Plot No. | Longitude | Latitude | Carbon Pools | | | | | Total Carbon (t/ha) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | AGB (t/ha) | BGB (t/ha) | Litter (t/ha) | Deadwood (t/ha) | Soil (t/ha) | |
| Dry Teak Moderately Dense Forest | 1 | E 77°49'47.172" | N 22°19'13.224" | 26.06 | 7.30 | 0.21 | 0.00 | 12.42 | 45.98 |
| Dry Teak Moderately Dense Forest | 2 | E 77°46'25.5" | N 22°16'31.8" | 11.96 | 3.35 | 0.17 | 0.00 | 12.42 | 27.90 |
| Dry Teak Moderately Dense Forest | 3 | E 77°51'8.208" | N 22°15'55.512" | 14.46 | 4.05 | 0.18 | 0.00 | 30.06 | 48.75 |
| Dry Teak Moderately Dense Forest | 4 | E 77°44'46.968" | N 22°15'50.004" | 16.67 | 4.67 | 0.00 | 0.00 | 13.48 | 34.83 |
| Dry Teak Moderately Dense Forest | 5 | E 77°49'54.228" | N 22°15'44.856" | 16.35 | 4.58 | 0.37 | 0.00 | 26.04 | 47.34 |
| Dry Teak Moderately Dense Forest | 6 | E 77°46'33.996" | N 22°15'35.892" | 30.01 | 8.40 | 0.00 | 0.00 | 23.18 | 61.59 |
| Dry Teak Moderately Dense Forest | 7 | E 77°46'34.104" | N 22°15'35.964" | 21.30 | 5.96 | 0.00 | 0.00 | 18.52 | 45.78 |
| Dry Teak Moderately Dense Forest | 8 | E 77°50'17.772" | N 22°15'25.128" | 36.85 | 10.32 | 0.40 | 0.00 | 25.68 | 73.25 |
| Dry Teak Moderately Dense Forest | 9 | E 77°49'57.54" | N 22°15'36.648" | 60.14 | 16.84 | 0.12 | 0.00 | 30.34 | 107.44 |
| Dry Teak Moderately Dense Forest | 10 | E 77°48'55.008" | N 22°14'48.984" | 8.48 | 2.38 | 0.00 | 0.00 | 33.95 | 44.81 |
| Dry Teak Moderately Dense Forest | 11 | E 77°48'21.996" | N 22°14'48.984" | 16.35 | 4.58 | 0.17 | 0.00 | 28.13 | 49.23 |
| Dry Teak Moderately Dense Forest | 12 | E 77°47'3.588" | N 22°14'54.492" | 29.13 | 8.16 | 0.12 | 0.00 | 34.41 | 71.82 |
| Dry Teak Moderately Dense Forest | 13 | E 77°43'47.244" | N 22°14'49.668" | 18.24 | 5.11 | 0.05 | 0.00 | 35.36 | 58.75 |
| Dry Teak Moderately Dense Forest | 14 | E 77°47'11.004" | N 22°15'10.404" | 27.02 | 7.57 | 0.04 | 0.00 | 30.76 | 65.39 |
| Dry Teak Moderately Dense Forest | 15 | E 77°46'54.516" | N 22°15'2.484" | 41.02 | 11.49 | 0.10 | 0.00 | 22.57 | 75.18 |
| Dry Teak Open Forest | 16 | E 77°46'11.496" | N 22°16'18.768" | 29.84 | 8.35 | 0.00 | 0.00 | 22.22 | 60.42 |
| Dry Teak Moderately Dense Forest | 17* | E 77°44'55.70" | N 22°12'16.02" | - | - | - | - | - | - |
| Dry Teak Moderately Dense Forest | 18* | E 77°44'41.86" | N 22°12'21.87" | - | - | - | - | - | - |
| Dry Teak Open Forest | 19 | E 77°45'41.148" | N 22°16'10.668" | 35.38 | 9.91 | 0.00 | 0.00 | 16.26 | 61.54 |
| Dry Teak Open Forest | 20 | E 77°47'2.076" | N 22°15'57.24" | 36.43 | 10.20 | 0.00 | 0.00 | 11.94 | 58.58 |
| Dry Teak Open Forest | 21 | E 77°46'33.96" | N 22°17'33.396" | 4.65 | 1.30 | 0.08 | 0.00 | 21.66 | 27.69 |
| Dry Teak Open Forest | 22 | E 77°44'53.088" | N 22°15'9.9" | 12.77 | 3.58 | 0.00 | 0.00 | 26.17 | 42.52 |

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|---|---|---|---|---|---|---|---|---|---|
| Dry Teak Moderately Dense Forest | 23 | E 77°42'39.996" | N 22°13'35.292" | 19.82 | 5.55 | 0.13 | 0.00 | 21.15 | 46.66 |
| Dry Teak Open Forest | 24 | E 77°47'3.516" | N 22°15'23.616" | 35.13 | 9.84 | 0.00 | 0.00 | 7.80 | 52.76 |
| Dry Teak Open Forest | 25 | E 77°46'48.684" | N 22°16'3.108" | 21.10 | 5.91 | 0.00 | 0.00 | 8.30 | 35.30 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 26 | E 77°50'13.164" | N 22°15'50.22" | 39.29 | 11.00 | 0.17 | 0.00 | 21.00 | 71.47 |
| Dry Teak Open Forest | 27 | E 77°45'17.964" | N 22°16'4.908" | 16.86 | 4.72 | 0.00 | 0.00 | 22.56 | 44.14 |
| Dry Teak Open Forest | 28* | E 77°48'11.69" | N 22°14'19.78" | - | - | - | - | - | - |
| Dry Teak Open Forest | 29* | E 77°46'40.18" | N 22°13'55.21" | - | - | - | - | - | - |
| Dry Teak Open Forest | 30* | E 77°43'55.95" | N 22°13'18.17" | - | - | - | - | - | - |
| Dry Teak Open Forest | 31* | E 77°44'39.90" | N 22°13'36.38" | - | - | - | - | - | - |
| Dry Teak Open Forest | 32* | E 77°45'02.85" | N 22°12'49.55" | - | - | - | - | - | - |
| Dry Teak Open Forest | 33* | E 77°43'53.31" | N 22°12'57.13" | - | - | - | - | - | - |
| Dry Teak Moderately Dense Forest | 34 | E 77°50'18.564" | N 22°20'27.024" | 43.13 | 12.08 | 0.00 | 0.00 | 28.14 | 83.34 |
| Dry Teak Very Dense Forest | 35 | E 77°47'31.416" | N 22°18'33.588" | 9.88 | 2.77 | 0.00 | 0.00 | 30.17 | 42.83 |
| Dry Teak Very Dense Forest | 36 | E 77°49'57.144" | N 22°19'15.42" | 23.33 | 6.53 | 0.00 | 0.00 | 45.24 | 75.11 |
| Dry Teak Very Dense Forest | 37* | E 77°43'35.86" | N 22°13'19.01" | - | - | - | - | - | - |
| Dry Teak Very Dense Forest | 38* | E 77°44'42.20" | N 22°12'07.69" | - | - | - | - | - | - |
| Scrub | 39 | E 77°51'18.144" | N 22°16'36.552" | 6.84 | 1.91 | 0.17 | 0.00 | 15.22 | 24.14 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 40 | E 77°50'29.076" | N 22°15'50.076" | 35.73 | 10.01 | 0.34 | 0.00 | 23.13 | 69.20 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 41 | E 77°45'38.736" | N 22°15'2.952" | 57.89 | 16.21 | 0.00 | 0.00 | 19.57 | 93.67 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 42 | E 77°45'54.144" | N 22°15'9.324" | 18.42 | 5.16 | 0.00 | 0.00 | 23.37 | 46.95 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 43 | E 77°43'58.836" | N 22°14'20.436" | 22.13 | 6.20 | 0.00 | 0.00 | 28.33 | 56.66 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 44 | E 77°43'23.988" | N 22°13'45.444" | 32.19 | 9.01 | 0.00 | 0.00 | 15.17 | 56.37 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 45 | E 77°50'18.096" | N 22°20'22.56" | 66.59 | 18.65 | 0.27 | 0.00 | 20.10 | 105.61 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 46 | E 77°47'49.596" | N 22°20'3.3" | 30.39 | 8.51 | 0.02 | 0.00 | 22.76 | 61.69 |
| Dry Teak Moderately Dense Forest | 47 | E 77°49'36.264" | N 22°19'34.896" | 19.64 | 5.50 | 0.08 | 0.00 | 29.84 | 55.05 |

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|---|---|---|---|---|---|---|---|---|---|
| Southern Dry Moderately Dense Forest | 48* | E 77°45'47.00" | N 22°13'32.60" | - | - | - | - | - | - |
| Southern Dry Mixed Deciduous Open Forest | 49 | E 77°46'45.012" | N 22°18'29.016" | 24.63 | 6.90 | 0.18 | 0.00 | 28.66 | 60.36 |
| Southern Dry Mixed Deciduous Open Forest | 50 | E 77°50'44.448" | N 22°15'25.524" | 13.07 | 3.66 | 0.34 | 0.00 | 20.40 | 37.47 |
| Southern Dry Mixed Deciduous Open Forest | 51 | E 77°46'43.824" | N 22°15'24.516" | 33.95 | 9.51 | 0.00 | 0.00 | 21.85 | 65.31 |
| Southern Dry Mixed Deciduous Open Forest | 52 | E 77°43'59.844" | N 22°15'14.832" | 22.31 | 6.25 | 0.22 | 0.00 | 28.53 | 57.31 |
| Dry Teak Open Forest | 53 | E 77°49'41.016" | N 22°14'48.012" | 23.37 | 6.54 | 0.00 | 0.00 | 25.14 | 55.04 |
| Southern Dry Mixed Deciduous Open Forest | 54 | E 77°43'46.812" | N 22°14'43.404" | 34.07 | 9.54 | 0.07 | 0.00 | 17.79 | 61.46 |
| Southern Dry Open Forest | 55* | E 77°48'57.65" | N 22°14'23.10" | - | - | - | - | - | - |
| Southern Dry Open Forest | 56* | E 77°44'22.91" | N 22°12'58.21" | - | - | - | - | - | - |
| Southern Dry Open Forest | 57* | E 77°45'24.65" | N 22°13'01.59" | - | - | - | - | - | - |
| Southern Dry Mixed Deciduous Very Dense Forest | 58 | E 77°46'6.492" | N 22°14'4.596" | 29.54 | 8.27 | 0.07 | 0.00 | 47.49 | 85.38 |
| Dry Teak Moderately Dense Forest | 59 | E 77°49'13.908" | N 22°18'13.932" | 13.30 | 3.72 | 0.08 | 0.00 | 22.36 | 39.45 |

** Sample points could not be located due to frequent movement of leopards in the forests during the time of field surveys*

**Sample Plots Wise Forest Carbon Stocks in ESIP areas of Banapura, Itarsi and Sukhtawa Forest Ranges**

| Class | Plot No. | Longitude | Latitude | Carbon Pool | | | | | Total Carbon (t/ha) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | AGB (t/ha) | BGB (t/ha) | Litter (t/ha) | Deadwood (t/ha) | Soil (t/ha) | |
| Dry Teak Moderately Dense Forest | 1 | E 77°44'7.116" | N 22°28'6.42" | 27.02 | 7.56 | 0.00 | 0.00 | 27.9 | 62.47 |
| Dry Teak Moderately Dense Forest | 2 | E 77°41'24.72" | N 22°27'34.596" | 21.45 | 6.01 | 0.04 | 0.00 | 18.5 | 46.04 |
| Dry Teak Moderately Dense Forest | 3 | E 77°41'27.168" | N 22°27'45.144" | 12.40 | 3.47 | 0.04 | 0.00 | 27.2 | 43.14 |
| Dry Teak Moderately Dense Forest | 4 | E 77°41'41.388" | N 22°26'55.968" | 22.77 | 6.38 | 0.06 | 0.00 | 14.4 | 43.56 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 5 | E 77°43'31.08" | N 22°27'7.2" | 17.11 | 4.79 | 0.11 | 0.00 | 10.1 | 32.16 |
| Dry Teak Moderately Dense Forest | 6 | E 77°38'55.716" | N 22°26'48.192" | 14.10 | 3.95 | 0.17 | 0.00 | 12.2 | 30.46 |
| Dry Teak Moderately Dense Forest | 7 | E 77°39'6.804" | N 22°26'39.012" | 31.91 | 8.94 | 0.12 | 0.00 | 34.3 | 75.31 |
| Dry Teak Moderately Dense Forest | 8 | E 77°41'17.7" | N 22°26'1.752" | 38.30 | 10.72 | 0.04 | 0.00 | 16.7 | 65.80 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 9 | E 77°40'1.164" | N 22°25'22.008" | 25.77 | 7.22 | 0.01 | 0.00 | 41.1 | 74.09 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 10 | E 77°40'1.056" | N 22°25'22.368" | 42.09 | 11.78 | 0.07 | 0.00 | 21.4 | 75.38 |
| Dry Teak Moderately Dense Forest | 11 | E 77°40'45.192" | N 22°24'18.504" | 37.81 | 10.59 | 0.10 | 0.00 | 23.8 | 72.31 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 12 | E 77°40'3.72" | N 22°24'40.896" | 31.76 | 8.89 | 0.10 | 0.00 | 28.7 | 69.42 |
| Dry Teak Moderately Dense Forest | 13 | E 77°37'3.108" | N 22°24'32.688" | 36.35 | 10.18 | 0.00 | 0.00 | 24.4 | 70.89 |
| Dry Teak Moderately Dense Forest | 14 | E 77°39'23.688" | N 22°23'49.416" | 23.59 | 6.60 | 0.05 | 0.00 | 80.6 | 110.81 |
| Dry Teak Moderately Dense Forest | 15 | E 77°38'28.788" | N 22°23'25.584" | 37.22 | 10.42 | 0.10 | 0.00 | 21.9 | 69.61 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 16 | E 77°41'47.256" | N 22°26'17.376" | 24.80 | 6.94 | 0.22 | 0.00 | 2.2 | 34.15 |
| Dry Teak Open Forest | 17 | E 77°41'20.328" | N 22°26'17.412" | 9.25 | 2.59 | 0.04 | 0.00 | 15.2 | 27.12 |
| Dry Teak Open Forest | 18 | E 77°39'16.308" | N 22°23'40.848" | 43.93 | 12.30 | 0.05 | 0.00 | 18.5 | 74.75 |
| Dry Teak Moderately Dense Forest | 19 | E 77°40'35.508" | N 22°27'45.396" | 34.61 | 9.69 | 0.00 | 0.00 | 16.5 | 60.77 |
| Dry Teak Very Dense Forest | 20 | E 77°40'13.908" | N 22°27'43.596" | 19.97 | 5.59 | 0.00 | 0.00 | 58.4 | 83.98 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 21 | E 77°40'21.288" | N 22°25'39.396" | 10.88 | 3.05 | 0.00 | 0.00 | 25.5 | 39.41 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 22 | E 77°44'28.14" | N 22°28'27.3" | 18.98 | 5.31 | 0.03 | 0.00 | 46.7 | 71.03 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 23 | E 77°43'39.036" | N 22°27'35.28" | 20.14 | 5.64 | 0.30 | 0.00 | 56.4 | 82.50 |

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|---|---|---|---|---|---|---|---|---|---|
| Southern Dry Mixed Deciduous Moderately Dense Forest | 24 | E 77°39'20.196" | N 22°26'57.804" | 25.01 | 7.00 | 0.00 | 0.00 | 48.1 | 80.11 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 25* | E 77°42'20.06" | N 22°27'18.00" | - | - | - | - | - | - |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 26 | E 77°42'20.088" | N 22°26'56.112" | 29.57 | 8.28 | 0.05 | 0.00 | 9.1 | 47.04 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 27 | E 77°42'40.86" | N 22°26'32.352" | 25.45 | 7.13 | 0.08 | 0.00 | 44.1 | 76.75 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 28 | E 77°39'33.516" | N 22°26'21.588" | 21.75 | 6.09 | 0.10 | 0.00 | 39.1 | 67.01 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 29 | E 77°38'58.2" | N 22°25'52.5" | 25.02 | 7.01 | 0.05 | 0.00 | 31.2 | 63.30 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 30 | E 77°41'18.312" | N 22°25'12.9" | 30.01 | 8.40 | 0.20 | 0.00 | 54.0 | 92.64 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 31 | E 77°41'12.264" | N 22°25'29.388" | 17.62 | 4.93 | 0.10 | 0.00 | 20.9 | 43.59 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 32 | E 77°40'17.22" | N 22°25'26.976" | 12.98 | 3.64 | 0.10 | 0.00 | 16.8 | 33.50 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 33 | E 77°41'23.784" | N 22°25'30.072" | 37.20 | 10.42 | 0.02 | 0.00 | 38.9 | 86.58 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 34 | E 77°43'35.4" | N 22°25'18.948" | 22.22 | 6.22 | 0.14 | 0.00 | 20.4 | 48.99 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 35 | E 77°38'22.992" | N 22°25'5.088" | 27.02 | 7.56 | 0.10 | 0.00 | 10.8 | 45.44 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 36 | E 77°38'10.788" | N 22°24'55.404" | 17.87 | 5.00 | 0.10 | 0.00 | 66.4 | 89.34 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 37 | E 77°40'48.864" | N 22°24'48.816" | 9.94 | 2.78 | 0.10 | 0.00 | 62.1 | 74.92 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 38 | E 77°39'19.8" | N 22°24'32.004" | 23.92 | 6.70 | 0.09 | 0.00 | 32.0 | 62.68 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 39 | E 77°41'6.936" | N 22°23'41.1" | 43.57 | 12.20 | 0.10 | 0.00 | 44.0 | 99.89 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 40 | E 77°42'27.9" | N 22°23'38.796" | 39.85 | 11.16 | 0.00 | 0.00 | 13.8 | 64.76 |
| Southern Dry Mixed Deciduous Open | 41 | E 77°45'28.008" | N 22°27'3.168" | 17.15 | 4.80 | 0.04 | 0.00 | 23.98 | 45.98 |

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|---|---|---|---|---|---|---|---|---|---|
| Forest | | | | | | | | | |
| Southern Dry Mixed Deciduous Open Forest | 42 | E 77°43'9.552" | N 22°26'23.928" | 17.42 | 4.88 | 0.11 | 0.00 | 20.49 | 42.90 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 43 | E 77°42'9.9" | N 22°25'28.092" | 29.50 | 8.26 | 0.03 | 0.00 | 47.3 | 85.13 |
| Dry Teak Moderately Dense Forest | 44 | E 77°40'22.08" | N 22°25'15.456" | 31.34 | 8.78 | 0.08 | 0.00 | 11.5 | 51.68 |
| Southern Dry Mixed Deciduous Open Forest | 45 | E 77°43'14.376" | N 22°25'15.06" | 11.42 | 3.20 | 0.19 | 0.00 | 36.33 | 51.14 |
| Southern Dry Mixed Deciduous Open Forest | 46 | E 77°44'0.348" | N 22°24'46.44" | 34.17 | 9.57 | 0.00 | 0.00 | 15.32 | 59.06 |
| Southern Dry Mixed Deciduous Open Forest | 47 | E 77°39'41.724" | N 22°22'57.936" | 26.12 | 7.31 | 0.10 | 0.00 | 12.77 | 46.30 |
| Dry Teak Moderately Dense Forest | 48 | E 77°38'59.208" | N 22°25'57.504" | 51.91 | 14.53 | 0.13 | 0.00 | 22.5 | 89.11 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 49 | E 77°43'14.304" | N 22°24'51.408" | 28.22 | 7.90 | 0.37 | 0.00 | 11.7 | 48.22 |
| Dry Teak Moderately Dense Forest | 50 | E 77°40'31.944" | N 22°25'10.236" | 32.96 | 9.23 | 0.09 | 0.00 | 25.8 | 68.09 |
| Dry Teak Moderately Dense Forest | 51 | E 77°39'32.976" | N 22°24'24.012" | 22.64 | 6.34 | 0.00 | 0.00 | 13.0 | 41.98 |
| Southern Dry Mixed Deciduous Moderately Dense Forest | 52 | E 77°43'6.816" | N 22°24'39.492" | 35.06 | 9.82 | 0.28 | 0.00 | 7.8 | 52.99 |

**Sample point could not be surveyed due to inaccessibility*

**Indian Council of Forestry Research and Education**

(An Autonomous Body of Ministry of Environment, Forest and Climate Change, Government of India)

**P. O. New Forest, Dehradun – 248006 (INDIA)**