Ecosystem Services Improvement Project: Baseline Report of Forest Carbon Stocks of Project Areas of Chhattisgarh

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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)

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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 integral part of international protocols dealing with climate change. Responding to global call for nationally appropriate mitigation actions, Government of India released its National Action Plan on Climate Change (NAPCC) with eight National Missions. National Mission for a Green India is one of the flagship missions under NAPCC.

The World Bank funded Ecosystem Services Improvement Project (ESIP) is supporting Green India Mission (GIM) in the 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 become wide use and are considered 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 also support in achieving India's forestry goal of Nationally Determined Contribution under the Paris Agreement.

ICFRE as one of the project implementing agencies for 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 forest carbon stocks of selected landscape of Chhattisgarh.

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

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

Date: 05 /08/2020

(Arun Singh Rawat)

Acknowledgment

Report Preparation Team

Contents

Abbreviations Used

AFOLU	Agriculture, Forestry and Other Land Use
AGB	Aboveground 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
^{0}C	Degree Celsius
DBH	Diameter at Breast Height
ESIP	Ecosystem Services Improvement Project
FSI	Forest Survey of India
Gt	Giga tonne
GIM	Green India Mission
GHG	Greenhouse Gas
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 on Climate Change
N	Normal Solution
NATCOM	National Communication
OC	Organic Carbon
NWFP	Non-wood Forest Product
SLEM	Sustainable Land and Ecosystem Management
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
Sp. Gr.	Specific Gravity
sq km	square kilometre
t	Tonne
UNFCCC	United Nations Framework Convention on Climate Change
WB	Walkley and Black

Executive Summary

Ecosystem Services Improvement Project (ESIP) is being implemented in the states of Chhattisgarh and Madhya Pradesh. The State Forest Department of Chhattisgarh has selected Raghunathnagar Forest Range (Balrampur Forest Division), Pali Forest Range (Katghora Forest Division), Marwahi Forest Range (Marwahi Forest Division) and Pandariya West Forest Range (Kawardha Forest Division) for implementation of project activities under ESIP. Forest covers of Raghunathnagar Forest Range, Pali Forest Range, Marwahi Forest Range and Pandariya West Forest Range are estimated to be 2264.60 ha, 4019.39 ha, 5900.47 ha and 6596.05 ha, respectively. Forests store significant amount of carbon in its biomass, litter, dead woods and soil, and have major role in climate change mitigation. The purpose for generation of baseline report on forest carbon stocks of the ESIP areas of Chhattisgarh is to assess the outcomes and impacts of implementation of project components on strengthen capacity of government institutions in forestry and land management programs, and investments for improving forest quality. Baseline of the forest carbon stocks of the project area will act as a benchmark for the activities to be carried out by Chhattisgarh 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 and organic matter were considered for measurement of forest carbon stocks. Stratified random sampling was followed using forest density maps and forest type maps of Forest Survey of India (FSI) to stratify the project area into forest type density stratum. Intersect tool in Arc-GIS software was used to produce forest type and density maps of the project areas. Sample plot design and layout methods prescribed in National Working Plan Code – 2014 was 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 areas under ESIP. The total forest carbon stocks for the year 2019 have been estimated to be 12,23,310.56 tonnes for the ESIP areas of Chhattisgarh. Pandariya West Forest Range has the maximum carbon stocks (4,86,749.60 tonnes) followed by Pali Forest Range (3,48,362.24 tonnes) and Marwahi Forest Range (2,61,660.33 tonnes), respectively. Minimum forest carbon stocks estimated for Raghunathnagar Forest Range (1,26,538.39 tonnes). Forest areas under ESIP have potential to sequester more carbon as most of the trees are young, which can build biomass in the subsequent years and therefore store more carbon in biomass.

Baseline data on forest carbon stocks of ESIP areas of Chhattisgarh revealed that average carbon stocks density for Raghunathnagar Forest Range has been estimated to be 60.07 t/ha with the aboveground biomass contribution of 22.50 t/ha. Average carbon stocks density for Pali Forest Range has been estimated to be 96.73 t/ha with aboveground biomass contribution of 49.32 t/ha. Average carbon stocks density for Pandariya West Forest Range has been estimated to be 80.91 t/ha with aboveground biomass contribution of 37.26 t/ha. Average carbon stocks density for Marwahi Forest Range has been estimated to be 58.73 t/ha with aboveground biomass contribution of 23.61 t/ha. Soil organic carbon contribution ranged from 28.46 t/ha in Marwahi Forest Range to 33.38 t/ha in Pandariya Forest Range.

Various anthropogenic activities in the project areas like collection of fuelwood, fodder and Non-wood forest products (NWFPs), grazing and forest fire were causing forest degradation and eventually responsible for loss of carbon stocks. The drivers of forest degradation need to be addressed with implementation of feasible and site specific interventions 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, 2014 a). Earth's atmosphere is made up of various gases released by the natural processes and anthropogenic activities. The earth's atmosphere acts like a blanket of greenhouse gases (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 into the atmosphere which are further trapping the outgoing long wave terrestrial radiations into the earth atmosphere and ultimately increasing the earth's temperature.

According to IPCC (2014 b), 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 is contributing 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°C' highlighted that average global temperature has increased by about 1°C as compared to pre-industrial level due to anthropogenic activities (IPCC, 2018). In line with increasing trends witnessed in global surface temperature, the average yearly temperature over India for the period from 1901 to 2017 has shown a significant rising trend of 0.66°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 the 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. Role of forests has been increasingly recognized as cost-effective option for climate change mitigation through carbon capture and storage in the biomass and in the soil. The felling of trees and removal of vegetation from the forests for collection of fuelwood, timber, fodder etc. release 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°C' and 'Climate Change and Land' (IPCC, 2018 and 2019) brings very strong message on importance of land restoration for climate change mitigation and adaptation. IPCC Special report on Global warming of 1.5°C above preindustrial level and related GHG pathways (IPCC, 2018) stated that global warming at 1.5°C can be limited through unprecedented transformational changes in all spheres of the society. Carbon dioxide removal measure(s) related to AFOLU can have important positive effect on land, biodiversity 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 understory vegetation, and 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 2,00,000 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 the 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 2019 assessment (FSI, 2019) which was 7,08,273 sq km as per 2017 assessment (FSI, 2017), recording an increase of 3,976 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 is 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 forests into net sink of carbon. As per India's initial National Communication to United Nations Framework Convention on Climate Change (UNFCCC), the land-use, land-use change and forestry (LULUCF) sector was source of carbon and accounted for 1.16% of total national greenhouse gas emissions (MoEF, 2004). As per India's Second National Communication to United Nations Framework Convention on Climate Change (UNFCCC), LULUCF sector was a net sink of carbon and offset about 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 contribution of forestry sector offset was about 12% of India's total GHG emission (MoEFCC, 2015). India's second Biennial Update Report to UNFCCC has also reported that forestry sector offset about 12% of total GHG emissions (MOEFCC, 2018 a).

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 degradation 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) and also to provide livelihood benefits to the local communities. By piloting SLEM approaches in the States of Chhattisgarh and Madhya Pradesh, 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 biodiversity and carbon stocks. Implementation of the ESIP activities will support in sequestration of additional carbon of about 10% in the forest areas of Chhattisgarh and Madhya Pradesh 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 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 for generation 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.
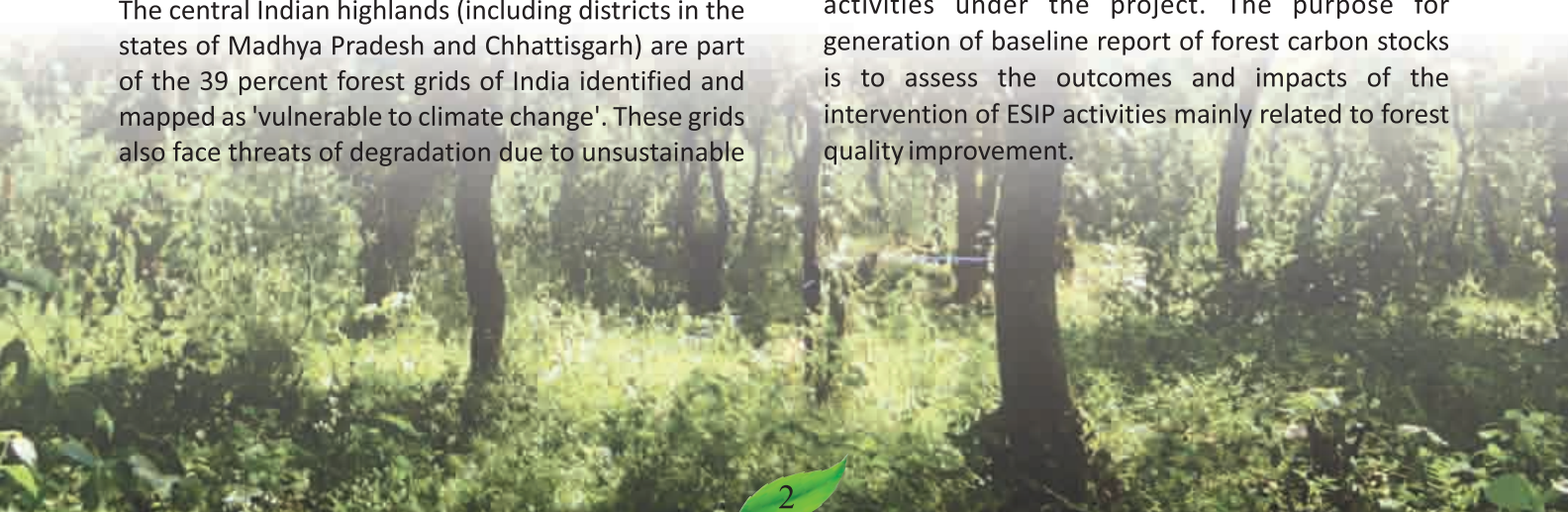
Chhattisgarh was carved out of Madhya Pradesh on 01 November, 2000 with 16 districts. Chhattisgarh is the 10th largest state in India with an area of 1,35,191 sq km, which is 4.1% of the geographical area of the country. Chhattisgarh is the 16th largest state in terms of population which is approximately equal to 2,08,00,000. Chhattisgarh borders the states of Madhya Pradesh in the northwest, Maharashtra in the west, Andhra Pradesh in the south, Odisha in the east, Jharkhand in the northeast, Telangana in the south and Uttar Pradesh in the north (Fig 2.1).

Chhattisgarh extends from 17°46' & 24°06' N latitude and 80°15' & 84°51'E longitude. There are four major river systems in the state viz. Mahanadi, Godavari, Narmada and Wainganga. Mahanadi, Indravati, Hasdev, Sivanath, Arpa and Eeb are major rivers in the state. The climate of Chhattisgarh is tropical. It is hot and humid because of its proximity to the Tropic of Cancer and its dependence on the monsoons for rains.

Summer temperature in Chhattisgarh generally reaches up to 49°C. The monsoon season is from late June to September. Chhattisgarh receives an average of 1,292 mm of rainfall and winters are pleasant with low temperatures and less humidity.

Forests of Chhattisgarh are divided into two major categories, namely Tropical Humid Deciduous Forests and Tropical Dry Deciduous Forests. Sal (*Shorea robusta*) and teak (*Tectona grandis*) are the main tree species. In addition, other canopy species are Bija (*Pterocarpus marsupium*), Saja (*Terminalia tomentosa*), Dhavdha (*Anogeissus latifolia*), Mahua (*Madhuca indica*), Tendu (*Diospyros melanoxylon*). Mid-Canopy species are Anwala (*Embilica officinalis*), Karra (*Cleistanthus collinus*) and bamboo (*Dendrocalamus strictus*) etc. Forests of the state are very important for ecological security as well as for providing livelihood to the local communities of forest fringe villages.
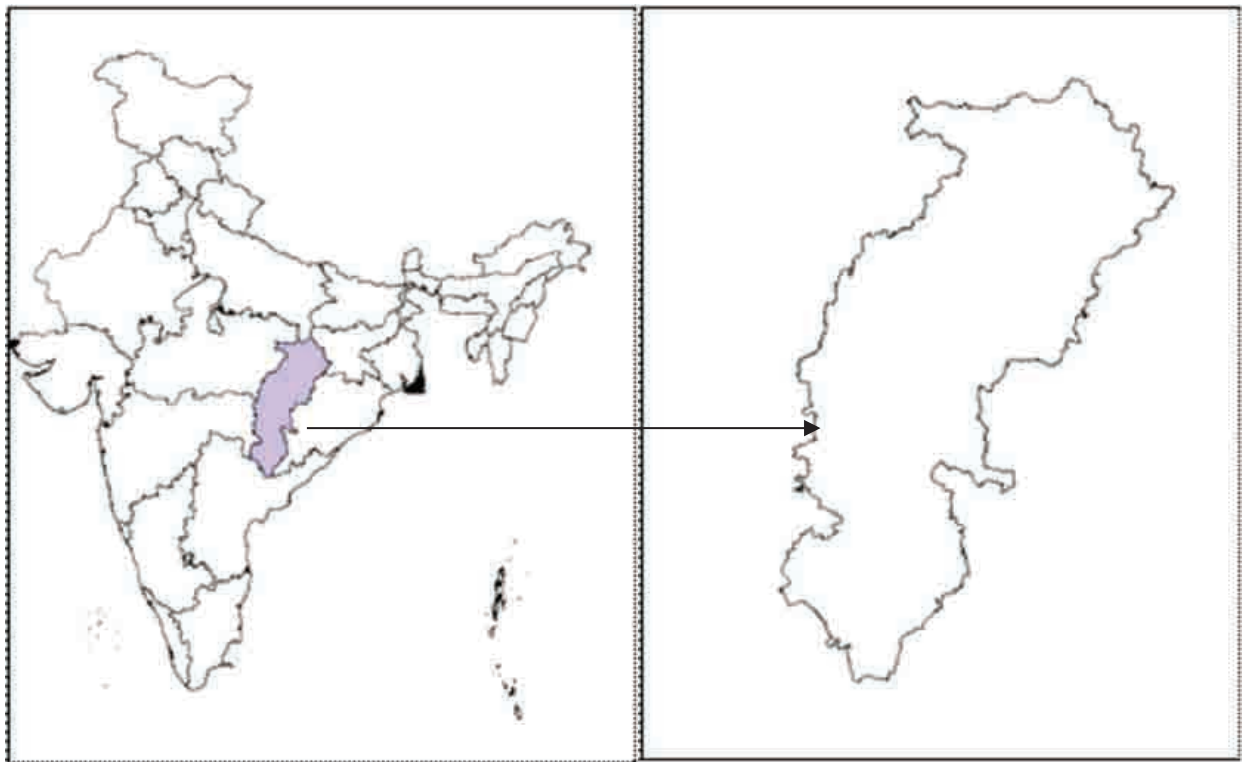
Fig 2.1: Location of Chhattisgarh in India

The state is full of mineral resources like coal, iron, bauxite, lime, corundum, diamond, gold, tin etc. which are mainly found in forest areas. About 50 percent of the villages are situated within 5 km radius of forests, where the inhabitants are mainly tribal, and dependent on the forests for their livelihoods. In addition, a large number of non-tribal and landless communities are also depending on the forests for their livelihoods. There are more than 7,887 Joint Forest management Committees (JFMCs) managing an area of about 33,19,000 hectares through involvement of about 11,17,000 families (cgforest.gov.in).

Forests in Chhattisgarh

Recorded Forest Area in the State is 59,772 sq km of which 25,786 sq km is under Reserved Forest, 24,034 sq km is under Protected Forest and 9,952 sq km is under Unclassed Forest. In Chhattisgarh, during the period from 1st January 2015 to 5th February 2019, a total of 3,793.05 hectares of forest land was diverted for various non-forestry purposes under the Forest (Conservation) Act, 1980 (FSI, 2019).

Based on the interpretation of IRS Resourcesat-2 LISS III satellite data of the period November 2017 to January 2018, the forest cover in the state was 55,610.57 sq km which is 41.14% of the state's geographical area. In terms of forest canopy density classes, the state has 7,067.72 sq km under Very Dense Forest (VDF), 32,197.56 sq km under Moderately Dense Forest (MDF) and 16,345.29 sq km under Open Forest (OF) (Table 2.1). Forest Cover in the State has increased by 63.57 sq km as compared to the previous assessment of 2017 (FSI, 2019)

Table 2.1: Forest Cover of Chhattisgarh

Class	Area (sq. km)	% GA of State
Very Dense Forest	7,067.72	5.23
Moderately Dense Forest	32,197.56	23.82
Open Forest	16,345.29	12.09
Total	55,610.57	41.14
Scrub	609.52	0.45

Forest Types in Chhattisgarh

As per the Champion and Seth classification of Forest Types of India (1968), the forests in Chhattisgarh belong to two Forest Type Groups viz. Group 3: Tropical Moist Deciduous Forests, and Group 5: Tropical Dry Deciduous Forests, which are further divided into 12 Forest Types (FSI, 2019). Percentage of forest cover under different forest types of Chhattisgarh estimated by Forest survey of India (FSI) is presented in the Table 2.2.

Table 2.2: Percentage area under different forest types of Chhattisgarh

S.No.	Forest Type	% of Forest cover
1.	3B/C1c Slightly Moist Teak Forest	6.47
2.	3B/C2 Southern Moist Mixed Deciduous Forest	15.68
3.	3C/C2e (i) Moist Peninsular High Level Sal Forest	1.48
4.	3C/C2e (ii) Moist Peninsular Low Level Sal Forest	16.64
5.	3/E1 *Terminalia tomentosa* Forest	0.02
6.	5A/C1b Dry Teak Forest	0.43
7.	5A/C3 Southern Dry Mixed Deciduous Forest	27.37
8.	5B/C1c Dry Peninsular Sal Forest	15.27
9.	5B/C2 Northern Dry Mixed Deciduous Forest	13.16
10.	5B/DS1 Dry Deciduous Scrub	0.98
11.	5/E9 Dry Bamboo Brakes	1.49
12.	Plantation/ TOF	1.01

Slightly Moist Teak Forest (3B/C1c): This forest type is characterized by rainfall between 1200 to 1600 mm, moderately deep loamy soils with medium to high percentage (20-60%) of Teak. This forest type is mainly found throughout the peninsula in the districts of Dantewada, Bastar, Raipur, Kawardha and Bilaspur wherever the rainfall exceeds 1300 mm. Main associates of this forest type are *Tectona grandis, Terminalia tomentosa, Haldina cordifolia, Albizzia odoratissima, Salmalia malabarica, Dalbergia paniculata* and *Diospyros melanoxylon.*

Southern Moist Mixed Deciduous Forest (3B/C2): These forests spread over the ridges and lower slopes having elevation of 100 m to 400 m above msl where the soil is generally rich. The top canopy remains leafless between March and May. The moist mixed deciduous forests have a closed canopy with tall and cylindrical trees. Trees tend to attain height of 30 m and more. The understorey is well defined and the forest floor is full of vegetal growth. This forest type is found in Sarguja, Jashpur, Korba, Bilaspur, Raigarh, Durg, Rajnandgaon, Dantewada and Kawardha districts.

Moist Peninsular High Level Sal Forest (3C/C2e(i)): Sal is the predominant species in this type with its associates like *Syzygium cumini, Pterocarpus marsupium, Terminalia tomentosa* and *Bauhinia* spp., and the type occurs upto the top of hills**.** Undergrowth is abundant with the presence of climbers.

Moist Peninsular Low Level Sal Forest (3C/c2e(ii)): This forest type has a fairly wide distribution and occurs in several valleys on their gentle and sheltered slopes usually on the northern aspects in the districts of Sarguja, Jashpur, Korba, Bilaspur, Bastar, Mahasamund, Dhamtari, Kawardha and Dantewada. The soil varies from alluvial clay loam to clay on the slopes and it is moist, deep and well-drained. Sal is pure and well-stocked with trees upto 40 m. The main associates of Sal are *Buchanania lanzan, Diospyros melanoxylon, Terminalia tomentosa, Lagerstroemia parviflora, Caeseria graveolens, Cassia fistula* and *Anogeissus latifolia*. Shrubs include *Moghania chappar, Indigofera pulchella, Randia spinosa, Croton oblongifolia* etc.

Terminalia tomentosa Forest (3/E1): This type is typically a closed forest of good height and development with a lower storey tree canopy of smaller trees and a shrubby growth which has little grass except in water logged openings. As the name suggests, *Terminalia tomentosa* is the main species with other associates such as *Terminalia bellirica,*

Terminalia arjuna, Salmalia malabarica etc. This forest type is mainly found in Raipur district.

Dry Teak Forest (5A/C1b): Dry Teak Forest are associated with *Anogeissus latifolia, Diospyros melanoxylon, Cassia fistula* and *Boswellia serrata.* In the lower canopy, species like *Nyctanthes arbortristis, Woodfordia fruticosa, Grewia hirsuta*, *Holarrhena antidysenterica* etc*.* are present*.*

Southern Dry Mixed Deciduous Forest (5A/C3): This type of forest is attributed to relatively low rainfall and lower altitude i.e., 300 m - 400 m above msl. The canopy is open allowing good percentage of grass and herbs to grow. Bamboos occur as under growth and become bushy. The forest floor is thickly covered with dry twigs and leaves. Forest fires are common due to high degree of biotic pressure. Due to repeated forest fires in the past, the forests have degraded and thus a few fire-hardy species like *Chloroxylon swietenia*, *Cleistanthus collinus*, *Phoenix acaulis* etc. are growing in these areas. This type occurs in Dantewada, Bastar, Raipur, Dhamtari, Kawardha, Durg, Bilaspur and Raigarh districts.

Dry Peninsular Sal Forest (5B/C1c): Sal is the dominant species of this forest type in Korya, Sarguja, Jashpur, Korba, Janjgir-Champa, and Raigarh districts and comprises of more than 50% of the forests. The associated species of Sal are *Terminalia tomentosa, Haldina cordifolia, Diospyros melanoxylon, Boswellia serrata, Lannea coromandelica* and *Mitragyna parviflora.* Most common shrubs of these forests are *Nyctanthes arbor-tristis, Carissa opaca, Woodfordia fruticosa* and *Casearia tomentosa.*

Northern Dry Mixed Deciduous Forest (5B/C2): This forest type extensively occurs on steep slopes and in upper valleys where the soil is scanty mainly in the districts of Korya, Sarguja, Korba and Janjgir-Champa. Dried lands are covered with this type of forest with low frequency of sal. Major components of this forest type are *Terminalia tomentosa, Haldina cordifolia, Mitragyna parviflora, Lagerstroemia parviflora, Cleistanthus collinus, Pterocarpus marsupium* and *Soymida febrifuga.*

Dry Deciduous Scrub (5/DS1): This forest types represent degradational stages of the sal and miscellaneous forest. The only species left in these areas in addition to heavily lopped Sal trees are *Acacia catechu*, *Carissa opaca*, etc. This forest type exists throughout the state of Chhattisgarh.

Dry Bamboo Brakes (5/E9): Dense but relatively low brakes of *Dendrocalamus strictus* occur in some parts

of the state. Often thorny shrub grows between the dense patches of bamboo where grazing is common. Biotic factors influence the occurrence of these brakes but apparently soil conditions also play a significant role.

Forests and Carbon Stocks

Forests, like other ecosystems, are affected by climate change. The impacts due to climate change may be negative in some areas and positive in others. However, forests also influence climate and climate change process mainly affecting the changes in the quantum of carbon dioxide in the atmosphere. They absorb carbon dioxide from atmosphere, and store carbon in wood, leaves, litter, roots and soil by acting as 'carbon sinks'. Carbon is released back into the atmosphere when forests are cleared or burned. Forests by acting as sinks are considered to mitigate the global climate. Overall, the world's forest ecosystems are estimated to store more carbon than the entire atmosphere.

Carbon exists in various forms in ocean, terrestrial biosphere and atmosphere. Due to various human activities such as fuel combustion and deforestation, carbon dioxide concentration in the atmosphere increased, which is responsible for global warming and climate change (Dixon *et* al., 1994). Terrestrial ecosystem plays a key role in climate change as they may act as a source or sink for carbon dioxide.

Mature and particularly old forests contain large store of carbon that gets locked up in the live and dead wood for long period of time. This carbon is released into atmosphere due to deforestation thereby acting as a source for carbon emission. On the other hand plant sequesters carbon through photosynthesis, which is the elemental base for carbon accumulation, growth, and biomass production of plants. Photosynthetic responses to rising global mean temperature of terrestrial plants can potentially alter ecosystem carbon balance and cycling.

Estimation of above-ground biomass (AGB) is an essential aspect of studies of carbon stocks and carbon sequestration. Estimating AGB is a useful measure for comparing structural and functional attributes of forest ecosystems across wide range of environmental conditions.

Pawar *et al.* (2014) estimated that the total above ground biomass was between 111.20 t/ha and 199.42 t/ha, whereas total below ground biomass varied from 16.49 to 28.29 t/ha, respectively. The total carbon storage ranged from 55.12 to 98.54 t/ha and found

higher under least disturbed site and lowest under medium disturbed site in the Korba district of Chhattisgarh. It has least proportion in small girth class and maximum storage under the higher girth class of trees. It is evident that disturbances have significant impact on density, vegetation diversity, biomass accumulation and carbon storage pattern. Jhariya *et al.,* (2014) have estimated the total biomass of the Bhoramdeo Wildlife Sanctuary of Chhattisgarh which was ranging from 101.43 to 192.36 t/ha. Reddy *et al.* (2015) reported that the dense forest has high phytomass and the maximum carbon storage. Aboveground phytomass and carbon density in open forests were comparatively very low. The mean carbon stock value of above ground phytomass of dense forests and open forests has been estimated as 46.08 t/ha and 23.63 t/ha in 2010 respectively in Central India. Bijalwan *et al.* (2010) characterized the land use, biomass and carbon status of dry tropical forest in Raipur district of Chhattisgarh using satellite remote sensing data and GIS techniques for the year 2001-2002. The standing volume, aboveground biomass and carbon storage varied from 35.59 to 64.32 m^3/ha, 45.94 to 78.32 t/ha, and 22.97 to 33.27 t/ha, respectively among different forest types. The highest standing volume, aboveground biomass and carbon storage per hectare were found in the mixed forest and lowest in degraded forest.

Comparative analysis of soil organic carbon storage under different land use and land cover in Achanakmar, Chhattisgarh was conducted by Iqbal and Tiwari (2017) and estimated the soil carbon sequestration potential in four land uses (forestland, grassland, agricultural land and wasteland) and five land covers. The highest soil carbon storage potential was found in forest land (118.14 t/ha) followed by grassland (95.54 t/ha), agricultural land (75.70 t/ha) and least in the wasteland (57.05 t/ha). Among the different land covers, maximum soil carbon storage potential was found in the soils under mixed land cover (118.18 t/ha) followed by teak (76.64 t/ha), bamboo (67.21 t/ha), sal (64.28 t/ha) and least under soils of open and scrub (48.72 t/ ha) land cover.

The total carbon stock of forests in the state of Chhattisgarh including the tree outside forest was estimated to be 480.25 million tonnes which is 6.74% of total forest carbon stocks of the country. Pool wise forest carbon in Chhattisgarh is given in Table 2.3 and carbon density is given in Table 2.4. The India State of Forest Report 2019 has registered a decline in forest carbon stocks 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 time from District based sampling to grid based sampling (FSI, 2019).

Table 2.3: Forest carbon stocks in different carbon pools of Chhattisgarh

Total forest carbon stocks (in million tonnes)					
Above Ground Biomass	Below Ground Biomass	Dead wood	Litter	Soil Organic Carbon	Total
145.912	46.908	1.858	9.969	275.603	480.25

(Source: FSI, 2019)

Table 2.4: Carbon density of forests of Chhattisgarh

Carbon Pool	Year wise Carbon density (tonne/ha)		
	2011	2017	2019
Above Ground Biomass	36.46	37.21	26.24
Below Ground Biomass	12.11	12.27	8.44
Dead Wood	0.43	0.47	0.33
Litter	1.15	1.37	1.79
Soil Organic Carbon	56.25	49.67	49.56
Total	106.40	100.99	86.36

Source: FSI (2011), FSI (2017), FSI (2019)

Average proportion of forest carbon stocks in different carbon pools for the state of Chhattisgarh as per the India State of 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 Chhattisgarh (tonne/ha)
Aboveground biomass	31.68	26.24
Belowground biomass	9.84	8.44
Litter	1.80	0.33
Dead Wood	0.50	1.79
Soil Organic carbon	56.21	49.56
Total	100.03	86.36

Source: FSI (2019)
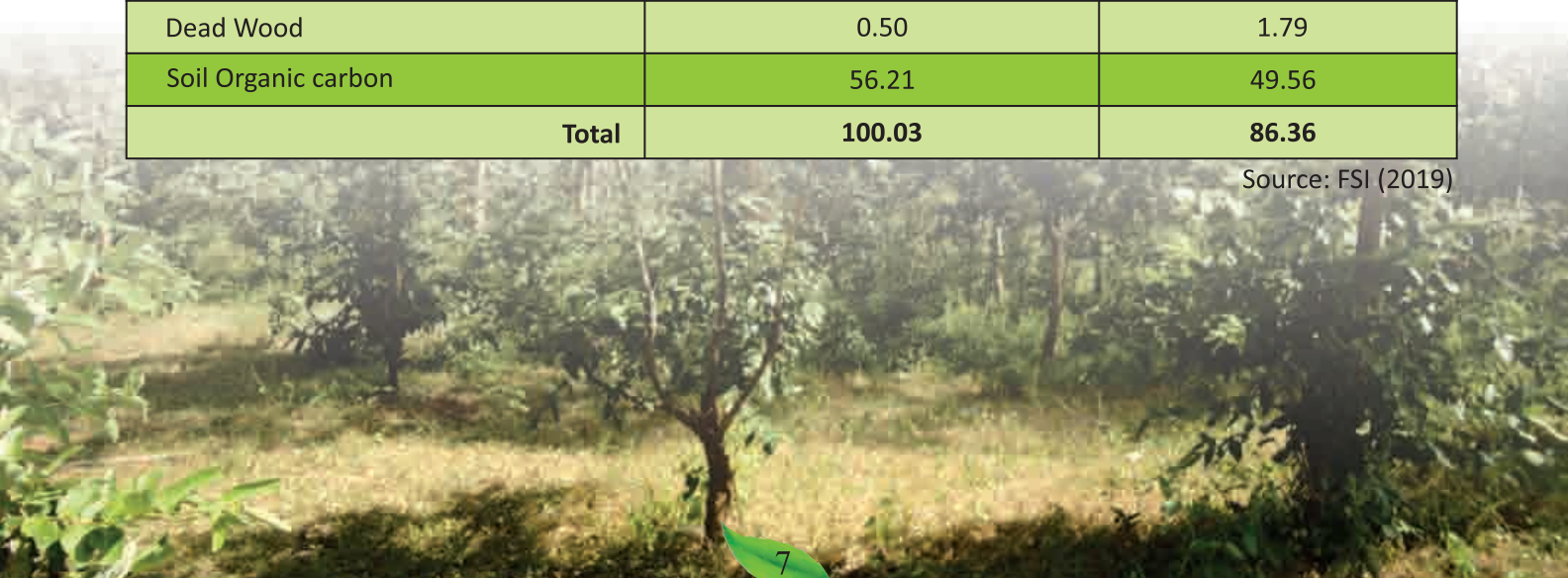
3.1 Ecosystem Services Improvement Project Area: The State Forest Department of Chhattisgarh has selected four Forest Ranges in four Forest Divisions of Chhattisgarh for the implementation of project activities under Ecosystem Services Improvement Project (Fig 3.1) which fall under Bilaspur, Balrampur, Kabirdham and Korba districts of Chhattisgarh.

Bilaspur: Bilaspur district is situated between 21.47° to 23.8° N and 81.14° to 83.15°E. The total population of the district is around 19,61,922. The type of climate of Bilaspur district is sub-tropical, semi-arid, continental and monsoon. Thus, it has hot summers, cool winters and short rainy seasons. Bilaspur district has 8,272 sq km geographical area of which 395 sq km is covered by very dense forest while 1,539.19 sq km is under moderately dense forest and 522.70 sq km is covered by open forest. Bilaspur has 29.70% of its geographical area under forest cover. Marwahi Forest Range in Marwahi Forest Division is selected for the implementation of the ESIP activities. Recently, Gaurela-Pendra-Marwahi is carved from Bilaspur district therefore ESIP area is now in Gaurela-Pendra-Marwahi district of Chhattisgarh.

Balrampur: The District Balrampur - Ramanujganj is located in the northern part of Chhattisgarh. The hilly and thickly forested terrains of the Satpuda hill ranges cover a large part of the district. Balrampur is a part of the Northern Hills agro-climatic region of Chhattisgarh. The climate of the district is characterized by a hot summer and well distributed rainfall (average 125 cm) during the monsoon season. Pahadi Korwas, Gonds, Khairwars, Kanwars and Pandos are the major tribal groups residing in the district and major population is dependent on forest for their livelihood sustenance. Raghunathnagar Forest Range in Balrampur Forest Division is selected for the implementation of the ESIP activities.

Kabirdham: District Kabirdham is located on the southern bank of river Sakari. Kabirdham has 36.57 % of its geographical area under forest cover. Kabirdham district has geographical area of 4,235 sq km of which 79.09 sq km is covered by very dense forest while 1,083.84 sq km is under moderately dense forest and 385.79 sq km is covered by open forest. Pandariya West Forest Range in Kawardha Forest Division is selected for the implementation of the ESIP activities.

Korba: Korba is blessed with lush green forest cover, where a sizable number of tribal population is found. Korba District falls under the hot temperate climate zone and hence the district experiences very hot and dry weather. The average rainfall in the district is 1506.7 mm and normal rainfall is 1287.6 mm. The main river which is flowing through Korba district is the Hasdeo river which start from Pathar in the Valley of Chhota Nagpur. This district is rich in forest wealth. Pali Forest Range in Katghora Forest Division is selected for the implementation of ESIP activities.

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 and soil organic matter for the estimation
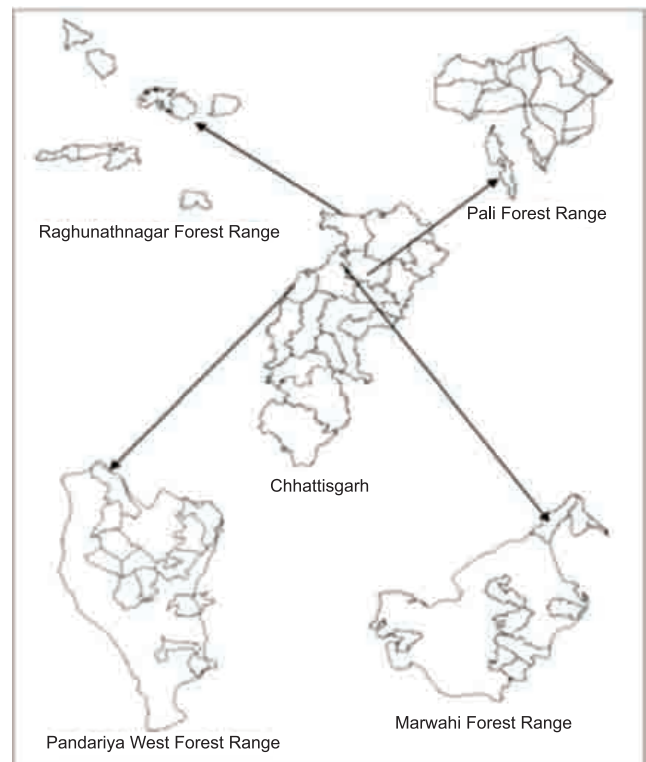
Figure 3.1: Location of project area in Chhattisgarh

of carbon stocks in a forested stand. All the carbon pools were considered for measurement of forest carbon stocks.

Sampling: Stratified random sampling was followed using forest density maps and forest types maps prepared by Forest Survey of India to stratify the project area into forest type density stratum. Intersect

tool in ArcGIS was used to produce the forest type and density maps of the sampling area. ArcGIS is Geographic Information System software used to create, manage, share and analyze spatial data.

Sample Size: Pilot study is 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 plot in Raghunathnagar Forest Range (16 sample plots), Pali Forest Range (30 sample plots), Marwahi Forest Range (28 sample plots) and Pandariya West Forest Range (17 sample plots) to calculate the sample size using variability analysis.

Sample plots calculated for ESIP areas of Chhattisgarh on the basis of variability analysis are given in Table 3.1. Forest types and density class wise details of sample plots laid out in the ESIP areas of Chhattisgarh are given in Table 3.2, 3.3, 3.4 and 3.5.

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 $\times 100$

Table 3.1: Sample plots calculated for measurement of forest carbon stocks in ESIP areas of Chhattisgarh

Forest Range	No. of Sample Plots laid out for pilot study	Mean Carbon density (t/ha)	Standard Deviation	Coefficient of Variation	Sample Size
Raghunathnagar Forest Range	16	69.7	25.6	36.7	38
Pali Forest Range	30	111.11	28.6	25.7	34
Marwahi Forest Range	28	64.21	24.65	38	47
Pandariya West Forest Range	17	64.3	25.5	39.6	42

Table 3.2: Forest type density class wise number of sample plots to be laid out in the Raghunathnagar Forest Range (ESIP areas) of Chhattisgarh for measurement of forest carbon stocks

Forest Type Density Class	Area (ha)	Sample Plots
Dry Bamboo Brake Moderately Dense Forest	194.22	3
Dry Bamboo Brake Open Forest	152.75	3
Dry Peninsular Sal Moderately Dense Forest	506.99	9
Dry Peninsular Sal Open Forest	432.51	7
Northern Dry Mixed Deciduous Moderately Dense Forest	410.45	7
Northern Dry Mixed Deciduous Open Forest	365.40	6
Scrub	31.44	3

Number of sample plots to be laid out were 38. However, actually 35 sample plots were laid out in the field due to issue of Human-Wildlife Conflict

Table 3.3: Forest type density class wise number of sample to be laid out planned in the Pali Forest Range (ESIP areas) of Chhattisgarh for measurement of forest carbon stocks

Forest Type Density Class	Area (ha)	Sample Plots
Dry Bamboo Brake Moderately Dense Forest	853.00	4
Dry Bamboo Brake Open Forest	138.01	3
Dry Bamboo Brake Very Dense Forest	147.63	3
Moist Peninsular Low Level Sal Moderately Dense Forest	1188.58	5
Moist Peninsular Low Level Sal Open Forest	22.12	3
Moist Peninsular Low Level Sal Very Dense Forest	819.82	4
Northern Dry Mixed Deciduous Moderately Dense Forest	455.90	3
Northern Dry Mixed Deciduous Open Forest	78.16	3
Northern Dry Mixed Deciduous Very Dense Forest	203.90	3
Southern Dry Mixed Deciduous Moderately Dense Forest	29.72	3

Number of sample plots to be laid out were 34. However, actually 33 sample plots were laid out in the field due to inaccessibility.

Table 3.4: Forest type density class wise number of sample to be laid out planned in the Marwahi Forest Range (ESIP areas) of Chhattisgarh for measurement of forest carbon stocks

Forest Type Density Class	Area (ha)	Sample Plots
Moist Peninsular Low Level Sal Moderately Dense Forest	1308.20	9
Moist Peninsular Low Level Sal Open Forest	138.18	3
Southern Moist Mixed Deciduous Moderately Dense Forest	398.64	3
Southern Moist Mixed Deciduous Open Forest	117.56	3
Southern Dry Mixed Deciduous Moderately Dense Forest	1676.20	11
Southern Dry Mixed Deciduous Open Forest	2247.30	15
Scrub	144.51	3

Number of sample plots to be laid out were 47. However, actually 45 sample plots were laid out in the field due to inaccessibility.

Table 3.5: Forest type density class wise number of sample to be laid out planned in the Pandariya West Forest Ranges (ESIP areas) of Chhattisgarh for measurement of forest carbon stocks

Forest Type Density Class	Area (ha)	Sample Plots
Moist Peninsular Low Level Sal Moderately Dense Forest	2063.40	15
Moist Peninsular Low Level Sal Open Forest	887.21	6
Southern Dry Mixed Deciduous Moderately Dense Forest	1384.40	10
Southern Dry Mixed Deciduous Open Forest	1592.40	11
Scrub	28.05	3

Number of sample plots to be laid out were 45. However, actually 42 sample plots were laid out in the field due to heavy rains.

Randomization of sample plots in a stratum: ArcGIS Software was used to place the sample plot randomly in each stratum. 'Create Random Points' function of ArcGIS randomly places a specified number of points within an extent window or inside the features of a polygon, line, or point feature class.
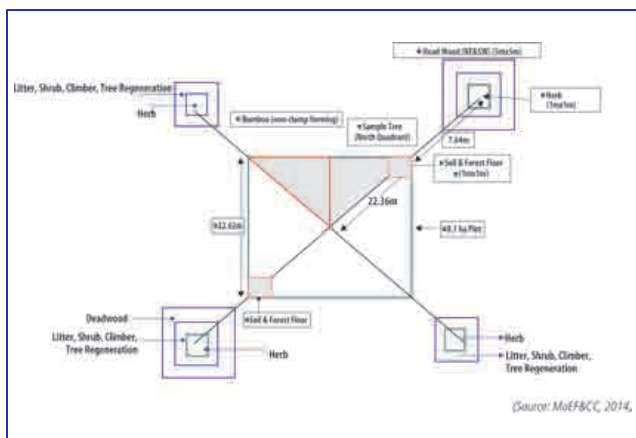
Figure 3.2: Sample Plot Layout: Configuration of main plot and attached sub-plots

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. Larger the plots, lower the variability between two samples. 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 315°in north-west corners of the plot from true north. Care was taken for laying out the proper dimensions of the plot. Then sub-plots 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, climbes, regeneration and herbs/grasses respectively (Figure 3.2). 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. In 5 m × 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 × 3 m 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 1 m × 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 sample was kept in a 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 annexed as 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 equation is not available (FSI, 1996). The estimated volume of each tree in the sample plot was multiplied by its wood density (Annex III) to derive the individual bole biomass (Rajput *et al.*, 1996).

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 is 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

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

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.

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 30 cm (IPCC, 2006). Composite soil sample was prepared by mixing the homogeneous soils of all three layers (0-10 cm, 10-20 cm and 20-30 cm) to determine the concentration of organic carbon. Altogether, five soil samples (three samples at three depths 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 (0–10 cm, 10–20 cm and 20–30 cm) from each plot then averaged, 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 *et al*., 2007):

$$SOC = p \text{ X } D \text{ X } \%C.$$

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 on bulk 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 collection of soil samples at the depth of 10-20 cm and 20-30 cm, soil 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:

Bulk Density= Weight of soil (gm)/ 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 (49.04 g of AR grade, $K_2Cr_2O_7$ per liter of solution)

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

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

(iv) Concentrated sulphuric acid (sp.gr 1.84) containing 1.25 per cent 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 and completely passed through 0.2 mm sieve and 1.00 g is placed at the bottom of a dry 500 ml conical flask (Corning Pyrex). 10 ml of IN $K_2Cr_2O_7$ is pipetted in and swirled a little. The flask is kept on asbestos sheet. Then 20 ml of 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), 0.5 g sodium fluoride and 1 ml of diphenylamine indicator. The contents are titrated with ferrous ammonium sulphate solution till the colour flashes from blue-violet to green. A combination of H_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 (0.25-0.5 g) of soil.

Calculation: Organic carbon calculated as per following formula:

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

Where

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

T = Volume of ferrous ammonium sulphate needed for soil sample

Soil stoniness and land use were also recorded from the sample plots. Soil samples analyzed for required parameters viz. bulk density and organic carbon. Soil organic carbon stock Q_i (Mg m^{-2}) in a soil layer or sampling level i with a depth of E_i (m) depends on the carbon content C_i (g C g^{-1}), bulk density D_i (Mg m^{-3}) and on the volume fraction of coarse elements G_i, given by the formula (Batjes, 1996):

$$Q_i = C_i D_i E_i (1 - G_i)$$

Litter Biomass: Litter collected at ground level from the 3 m × 3 m 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. Biomass of the litter was extrapolated per hectare basis after calculation as follows:

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

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

Dead Wood Biomass: All dead wood above 5 cm diameter was collected, weighed and recorded in 5 m × 5 m plot. A sample of known quantity was brought to the laboratory and oven dried at 70-85°C till constant weight. Biomass of the deadwood is extrapolated per hectare basis after calculation as follows:

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

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

Total Forest Carbon Stocks: 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 = AGBC + BGBC + LTC + DWC + SOC

Where,

AGBC = 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

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 flow 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 pilots which will further help in achieving India's forestry goal of Nationally Determined Contribution under the Paris Agreement. ESIP also envisages bringing a new and novel approach to address some of the challenges in management of ecosystems 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.

Stratification: The stratification of the project area was done with the help of ArcGIS 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 Raghunathnagar Forest Range, Pali Forest Range, Marwahi Forest Range and Pandariya West Forest Range are given in Table 4.1 and Figure 4.1.

Table 4.1: Forest Cover in ESIP Areas of Chhattisgarh

Forest Range	Forest Density Class	Area (ha)
Raghunathnagar Forest Range	Open Forest	1065.66
	Moderately Dense Forest	1198.94
	Very Dense Forest	-
	Total	**2,264.60**
Pali Forest Range	Open Forest	259.37
	Moderately Dense Forest	2,572.88
	Very Dense Forest	1,187.14
	Total	**4,019.39**
Marwahi Forest Range	Open Forest	2,252.44
	Moderately Dense Forest	3648.03
	Very Dense Forest	-
	Total	**5,900.47**
Pandariya West Forest Range	Open Forest	2,829.31
	Moderately Dense Forest	3,764.56
	Very Dense Forest	2.18
	Total	**6,596.05**
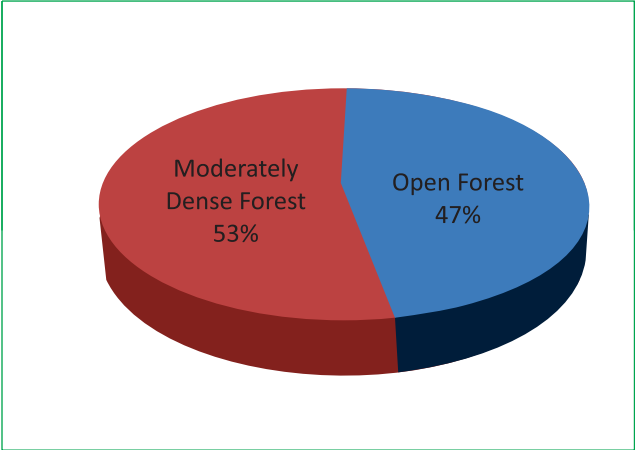
Raghunathnagar Forest Range
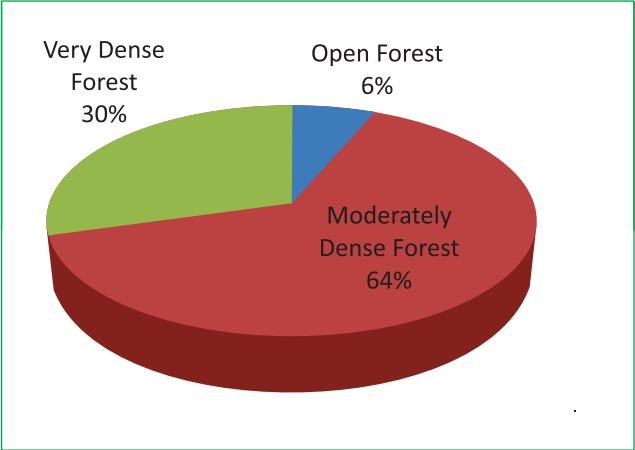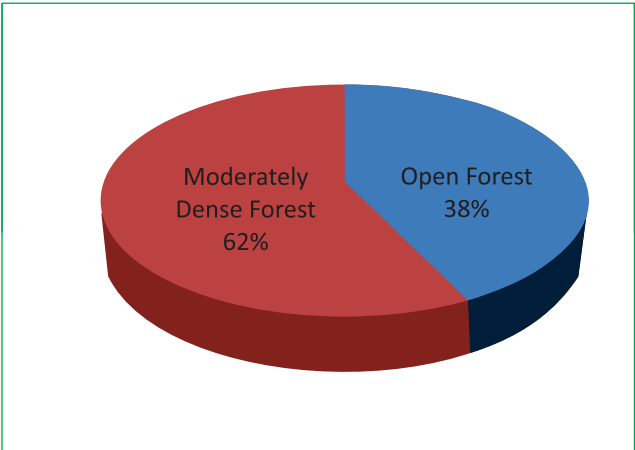
Pali Forest Range

Marwahi Forest Range
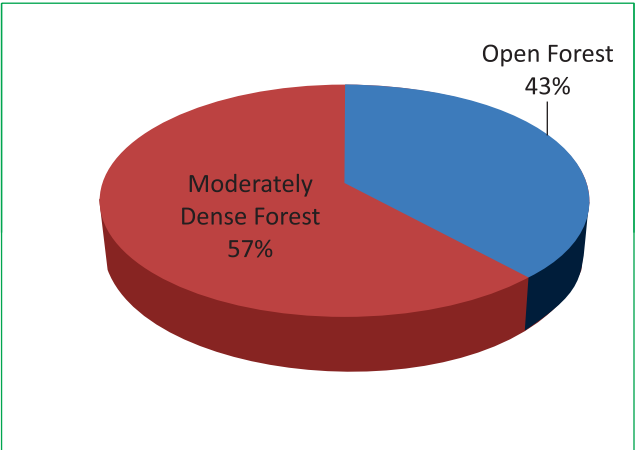
Pandariya West Forest Range

Figure 4.1 Forest Cover of ESIP Areas in Raghunathnagar, Pali, Marwahi and Pandariya West Forest Ranges of Chhattisgarh

Forest cover, forest type, stratified and sample plots location maps of ESIP areas under the Raghunathnagar Forest Range, Pandariya West Forest Range, Marwahi Forest Range and Pali Forest Range are given in Figure 4.2 to 4.17.
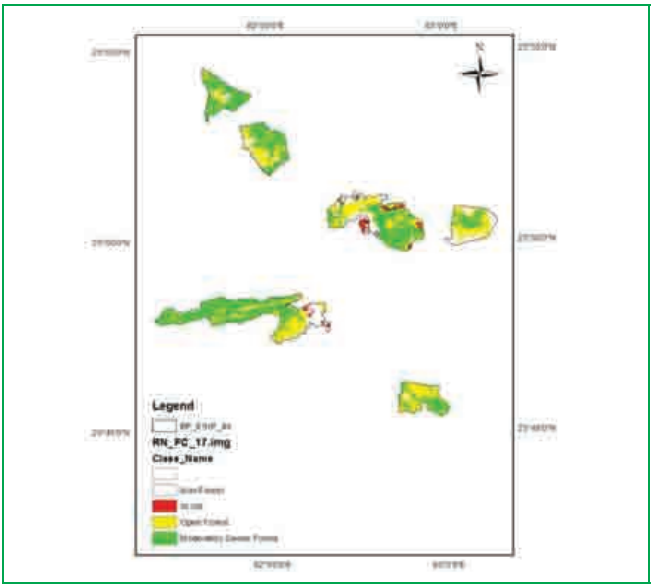
Figure 4.2: Forest Cover Map of Raghunathnagar Forest Range
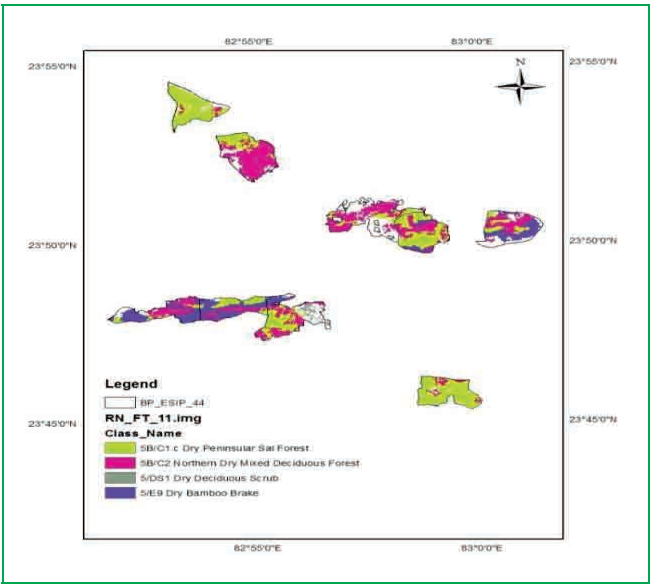
Figure 4.3: Forest Type Map of Raghunathnagar Forest Range
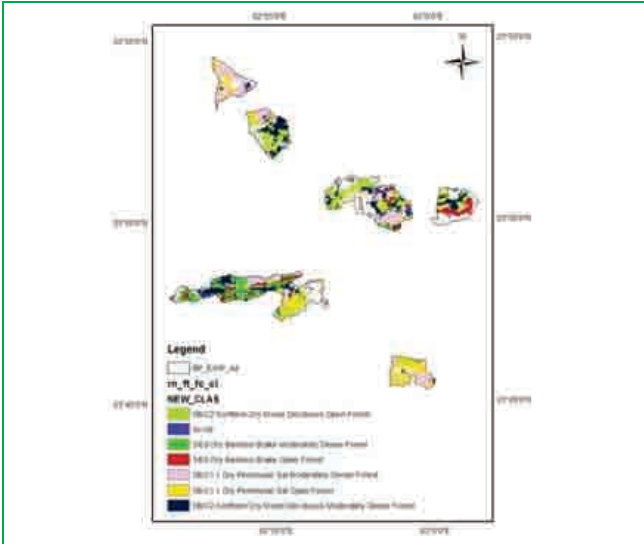
Figure 4.4: Stratified Map of Raghunathnagar Forest Range
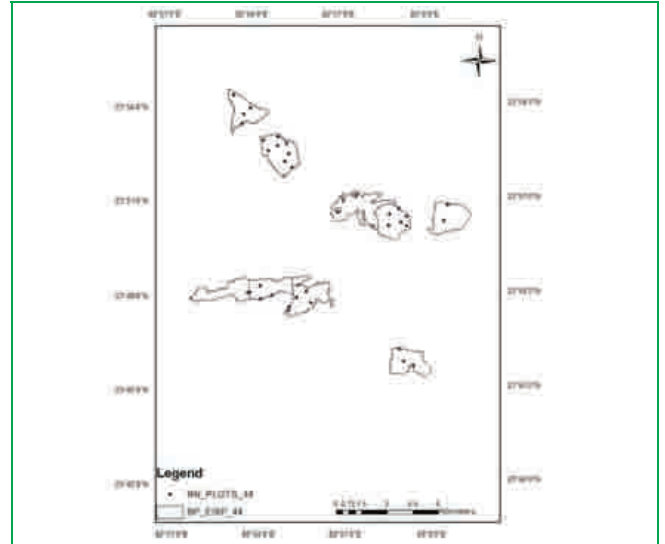
Figure 4.5: Location of Sample Plots in Raghunathnagar Forest Range
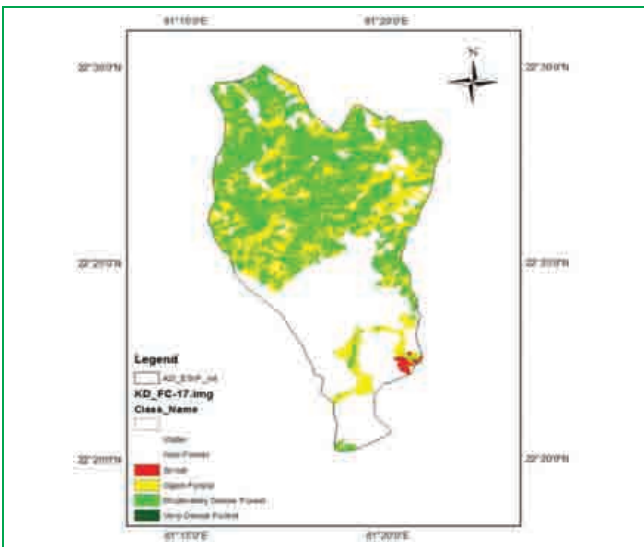
Figure 4.6: Forest Cover Map of Pandariya West Forest Range
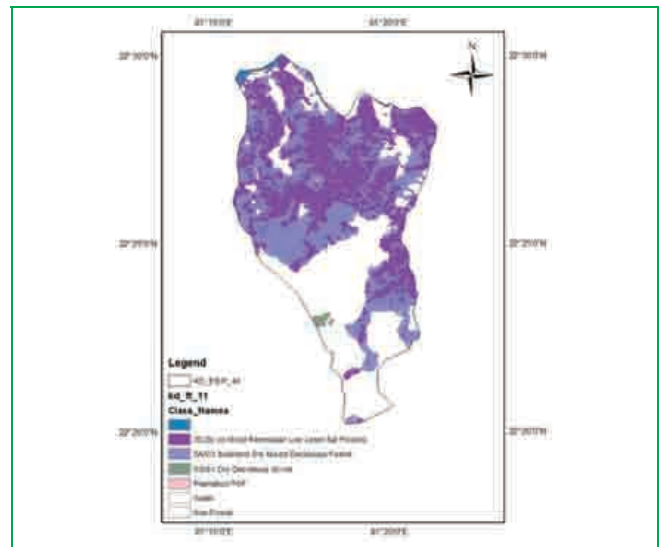
Figure 4.7: Forest Type Map of Pandariya West Forest Range
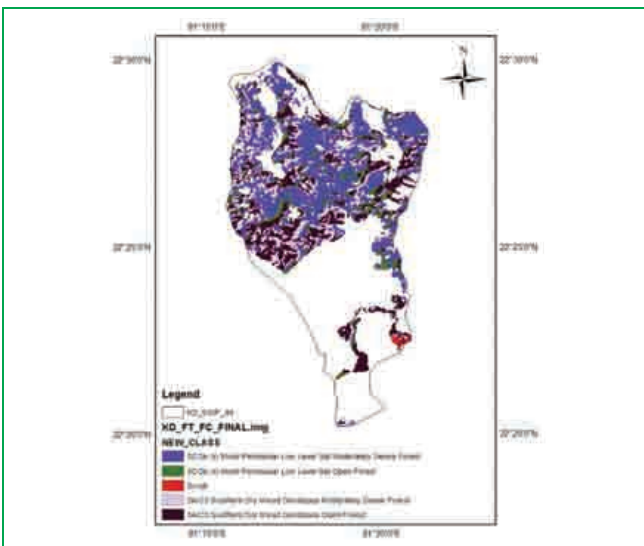
Figure 4.8: Stratified Map of Pandariya West Forest Range
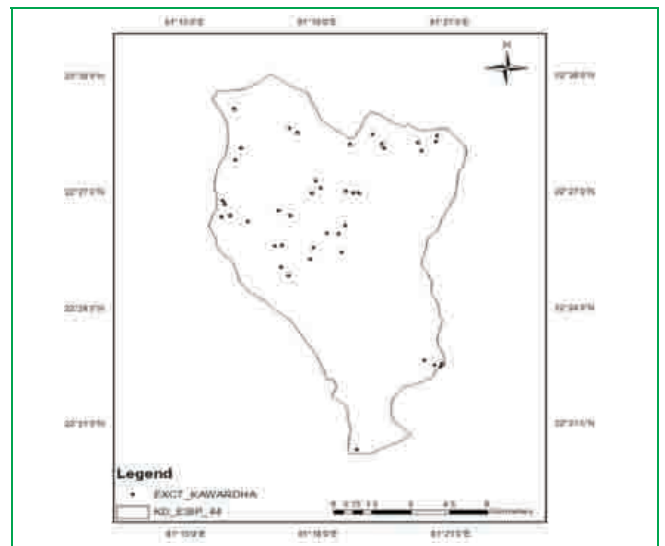
Figure 4.9: Location of Sample Plots in Pandariya West Forest Range

Figure 4.10: Forest Cover Map of Marwahi Forest Range

Figure 4.11: Forest Type Map of Marwahi Forest Range

Figure 4.12: Stratified Map of Marwahi Forest Range

Figure 4.13: Location of Sample Plots in Marwahi Forest Range

Figure 4.14: Forest Cover Map of Pali Forest Range

Figure 4.15: Forest Type Map of Pali Forest Range
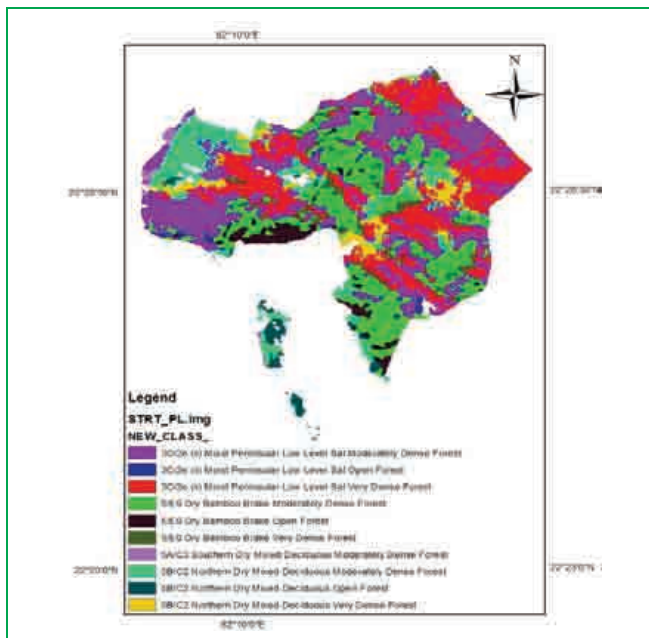
Figure 4.16: Stratified Map of Pali Forest Range
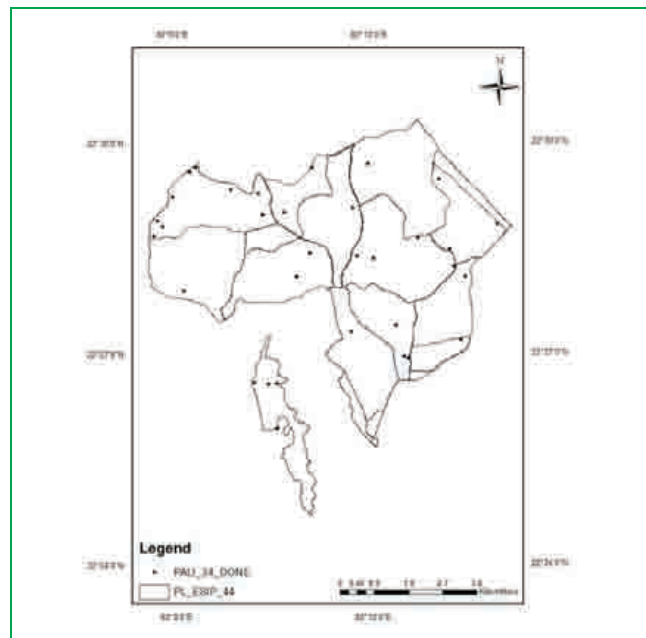
Figure 4.17: Location of Sample Plots in Pali Forest Range

4.3 Forest Carbon Stocks in ESIP Areas

The baseline forest carbon stocks for the year 2019 have been estimated to be 12,23,310.56 tonnes for the ESIP areas of Chhattisgarh. Pandariya West Forest Range has the maximum carbon stocks (4,86,749.60 tonnes) followed by Pali Forest Range (3,48,362.24 tonnes) and Marwahi Forest Range (2,61,660.33 tonnes). A minimum carbon stock (1,26,538.39 tonnes) is estimated in Raghunathnagar Forest Range (Table 4.2 and Figure 4.18).

Table 4.2: Forest Carbon Stocks in ESIP Areas of Chhattisgarh

Forest Type Density Class	Carbon Stock (in Tonnes)				Total Carbon Stocks (Tonnes)
	Raghunathnagar Forest Range	Pali Forest Range	Marwahi Forest Range	Pandariya West Forest Range	
Dry Bamboo Brake Very Dense Forest	0.00	15777.22	0.00	0.00	15777.22
Dry Bamboo Brake Moderately Dense Forest	14284.88	88217.26	0.00	0.00	102502.14
Dry Bamboo Brake Open Forest	6380.37	13733.38	0.00	0.00	20113.74
Dry Peninsular Sal Moderately Dense Forest	35215.53	0.00	0.00	0.00	35215.53
Dry Peninsular Sal Open Forest	21115.14	0.00	0.00	0.00	21115.14
Northern Dry Mixed Deciduous Very Dense Forest	0.00	22327.05	0.00	0.00	22327.05
Northern Dry Mixed Deciduous Moderately Dense Forest	28193.81	0.00	0.00	0.00	28193.81
Northern Dry Mixed Deciduous Open Forest	20279.70	3810.30	0.00	0.00	24090.00
Moist Peninsular Low Level Sal Very Dense Forest	0.00	84621.82	0.00	0.00	84621.82
Moist Peninsular Low Level Sal Moderately Dense Forest	0.00	117716.96	81814.83	198416.54	397948.34
Moist Peninsular Low Level Sal Open Forest	0.00	2055.83	8397.20	69087.04	79540.07
Southern Moist Mixed Deciduous Open Forest	0.00	0.00	6533.98	0.00	6533.98
Southern Moist Mixed Deciduous Moderately Dense Forest	0.00	102.42	25692.35	111790.30	137585.07
Southern Dry Mixed Deciduous Moderately Forest	0.00	0.00	132687.99	0.00	132687.99
Southern Dry Mixed Deciduous Open Forest	0	0	6533.98	107407.38	113941.36
Scrub	1068.96	0	0	48.34	1117.30
Total	**126538.39**	**348362.24**	**261660.33**	**486749.60**	**1223310.56**

Baseline data on forest carbon stocks of the ESIP areas of Chhattisgarh revealed that average carbon stocks
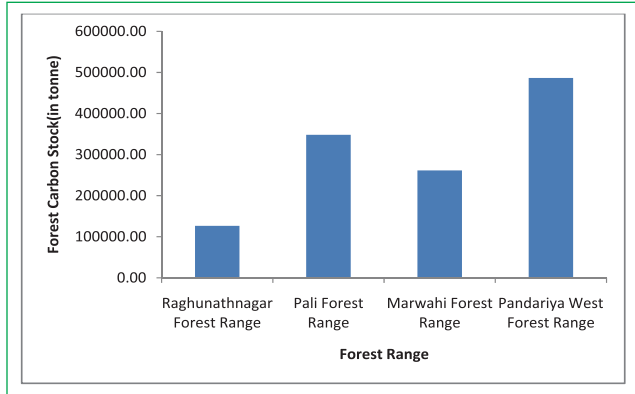
Figure 4.18: Forest Carbon Stocks in ESIP Areas of Chhattisgarh

density varied from 58.73 t/ha in Marwahi Forest Range to 96.73 t/ha Pali Forest Range in the ESIP areas

of Chhattisgarh. Average carbon stocks density for Raghunathnagar Forest Range has been estimated to be 60.07 t/ha with the aboveground biomass contribution of 22.50 t/ha. Average carbon stocks density for Pali Forest Range has been estimated to be 96.73 t/ha with aboveground biomass contribution of 49.32 t/ha. Average carbon stocks density for the areas under Pandariya West Forest Range has been estimated to be 80.91 t/ha with aboveground biomass contribution of 37.26 t/ha. Average carbon stocks density for the areas under Marwahi Forest Range has been estimated to be 58.73 t/ha with aboveground biomass contribution of 23.61 t/ha. Soil organic carbon contribution ranged from 28.46 t/ha in Marwahi Forest Range to 33.38 t/ha in Pandariya West Forest Range (Table 4.3). Sample plots wise data of forest carbon stocks are annexed as Annex V, VI, VII and VIII, respectively

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

Forest Ranges	Carbon Pool					Average Carbon Stock (t/ha)
	AGB (t/ha)	BGB (t/ha)	Litter (t/ha)	Dead wood (t/ha)	Soil Organic Carbon (t/ha)	
Raghunathnagar Forest Range	22.50	6.30	0.18	0.0	31.08	60.07
Pali Forest Range	49.32	13.81	0.15	0.0	33.23	96.73
Marwahi Forest Range	23.61	6.61	0.05	0.0	28.46	58.73
Pandariya West Forest Range	37.26	10.47	0.049	0.0	33.38	80.91

Forest Carbon Stocks in Raghunathnagar Forest Range: 35 permanent sample plots were laid out to estimate the carbon stocks in Raghunathnagar Forest Range of Balrampur Forest Division. The carbon stock density for Raghunathnagar Forest Range ranged from 34.00 t/ha to 110.73 t/ha. Average carbon stock density for Raghunathnagar Forest Range has been estimated to be 60.07 t/ha. Aboveground biomass contribution in carbon stock density is recorded to be 37% while the contribution of belowground biomass is recorded to be 11%. Soil organic carbon has the maximum contribution of 52% in the carbon stock density (Figure 4.19).

In Raghunathnagar Forest Range, Dry Bamboo Brake Moderately Dense Forest contributes 73.55 t/ha of the carbon stock while Dry Bamboo Brake Open Forest contributes 41.77 t/ha of the carbon stock. Dry Peninsular Sal Moderately Dense Forest and Dry Peninsular Sal Open Forest and have 69.46, and 48.82

t/ha of carbon stock, respectively. In Northern Dry Mixed Deciduous Moderately Dense Forest 68.69 t/ha carbon stock is present while 34 t/ha carbon stock is stocked by Scrub (Table 4.4).
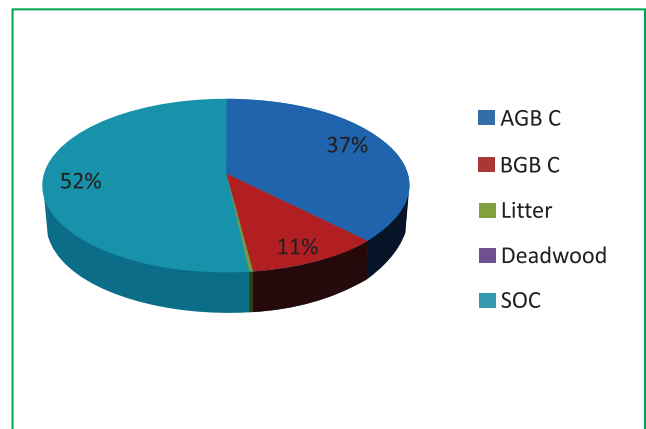
Figure 4.19: Contribution of various carbon pools in carbon stock density in Raghunathnagar Forest Range

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

Forest Type Density Class	Carbon Stock (t/ha)
Dry Bamboo Brake Moderately Dense Forest	73.55
Dry Bamboo Brake Open Forest	41.77
Dry Peninsular Sal Moderately Dense Forest	69.46
Dry Peninsular Sal Open Forest	48.82
Northern Dry Mixed Deciduous Moderately Dense Forest	68.69
Northern Dry Mixed Deciduous Open Forest	55.50
Scrub	34.00

Forest Carbon Stocks in Pali Forest Range: 33 permanent sample plots were laid out to estimate the carbon stocks in Pali Forest Range of Kathghora Forest Division. The carbon stock density for Pali Forest Range
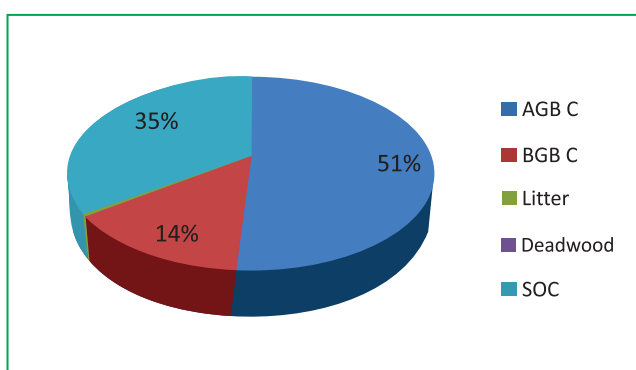
Figure 4.20: Contribution of various carbon pools in carbon stock density in Pali Forest Range

ranged from 44.07 t/ha to 140.02 t/ha. Average carbon stock density for Pali Forest Range has been estimated to be 96.73 t/ha. Aboveground biomass

contribution in carbon stock density is recorded to be 51% while the contribution of belowground biomass is recorded to be 14%. Soil organic carbon has the maximum contribution of 35% in the carbon stock density (Figure 4.20).

In Pali Forest Range, Dry Bamboo Brake Moderately Dense Forest contributes 103.42 t/ha of the carbon stock while Dry Bamboo Brake Open Forest contributes 99.51 t/ha of the carbon stock. Dry Bamboo Brake Very Dense Forest has 106.87 t/ha carbon stock. Moist Peninsular Low Level Sal Open Forest, Moist Peninsular Low Level Sal Moderately Dense Forest and Moist Peninsular Low Level Sal Very Dense Forest have 99.04, 92.94 and 103.22 t/ha of carbon stock respectively. Northern Dry Mixed Deciduous Very Dense Forest and Northern Dry Mixed Deciduous Moderately Dense Forest have 109.50 and 48.75 t/ha of carbon stock, respectively. In Southern Dry Mixed Deciduous Moderately Dense Forest 102.42 t/ha carbon stock is present (Table 4.5).

Table 4.5: Forest type and density wise carbon stock in Pali Forest Range

Forest Type Density Class	Carbon Stock (t/ha)
Dry Bamboo Brake Very Dense Forest	106.87
Dry Bamboo Brake Moderately Dense Forest	103.42
Dry Bamboo Brake Open Forest	99.51
Moist Peninsular Low Level Sal Very Dense Forest	103.22
Moist Peninsular Low Level Sal Moderately Dense Forest	99.04
Moist Peninsular Low Level Sal Open Forest	92.94
Northern Dry Mixed Deciduous Very Dense Forest	109.50
Northern Dry Mixed Deciduous Open Forest	48.75
Southern Dry Mixed Deciduous Moderately Dense Forest	102.42

Forest Carbon Stocks in Marwahi Forest Range: 45 permanent sample plots were laid out to estimate the carbon stocks in Marwahi Forest Range of Marwahi Forest Division. The carbon stock density for Marwahi Forest Range ranged from 23.89 t/ha to 90.92 t/ha. Average carbon stock density for Marwahi Forest

Range has been estimated to be 58.73 t/ha. Above ground biomass contribution in carbon stock density is recorded to be 40% while the contribution of belowground biomass is recorded to be 11%. Soil organic carbon has the maximum contribution of 49 % in the carbon stock density (Figure 4.21).
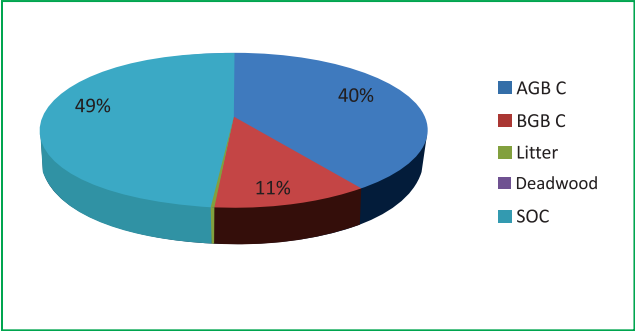
Figure 4.21: Contribution of various carbon pools in carbon stock density in Marwahi Forest Range

In Marwahi Forest Range, Moist Peninsular Low Level Sal Moderately Dense Forest contributes 62.54 t/ha of the carbon stock while Moist Peninsular Low Level Sal Open Forest contributes 60.77 t/ha of the carbon stock. Southern Moist Mixed Deciduous Moderately Dense Forest, Southern Moist Mixed Deciduous Open Forest have 64.45 and 55.58 t/ha carbon stock, respectively. Southern Dry Mixed Deciduous Moderately Dense Forest has 79.16 t/ha carbon stock while Southern Dry Mixed Deciduous Open Forest has 35.71 t/ha carbon (Table 4.6).

Table 4.6: Forest type and density wise carbon stock in Marwahi Forest Range

Forest Type Density Class	Carbon Stock (t/ha)
Moist Peninsular Low Level Sal Moderately Dense Forest	62.54
Moist Peninsular Low Level Sal Open Forest	60.77
Southern Moist Mixed Deciduous Moderately Dense Forest	64.45
Southern Moist Mixed Deciduous Open Forest	55.58
Southern Dry Mixed Deciduous Moderately Dense Forest	79.16
Southern Dry Mixed Deciduous Open Forest	35.71
Scrub	32.67

Forest Carbon Stocks in Pandariya West Forest Range: 42 permanent sample plots were laid out to estimate the carbon stocks in Pandariya West Forest Range of Kawardha Forest Division. The carbon stock density for Pandariya West Forest Range ranged from 36.30 t/ha to 144.10 t/ha. Average carbon stock density for Pandariya West Forest Range has been estimated to be 80.91 t/ha. Aboveground biomass contribution in carbon stock density is recorded to be 46% while the contribution of belowground biomass is recorded to be 13%. Soil organic carbon has the maximum contribution of 41% in the carbon stock density (Figure 4.22).

In Pandariya West Forest Range, Moist Peninsular Low Level Sal Moderately Dense Forest contributes 96.16 t/ha of the carbon stock while
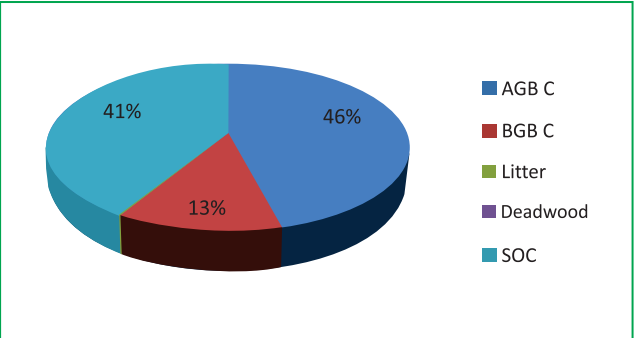
Figure 4.22: Contribution of various carbon pools in carbon stock density in Pandariya West Forest Range

Moist Peninsular Low Level Sal Open Forest contributes 77.87 t/ha of the carbon stock. Southern Moist Mixed Deciduous Moderately Dense Forest and Southern Moist Mixed Deciduous Open Forest have 80.75 and 67.45 t/ha carbon stock, respectively (Table 4.7).

Table 4.7: Forest type and density wise carbon stock in Pandariya West Forest Range

Forest Type Density Class	Carbon Stock (t/ha)
Moist Peninsular Low Level Sal Moderately Dense Forest	96.16
Moist Peninsular Low Level Sal Open Forest	77.87
Southern Dry Mixed Deciduous Moderately Dense Forest	80.75
Southern Dry Mixed Deciduous Open Forest	67.45
Scrub	48.34

4.4 Discussion

Forests sequester atmospheric carbon and therefore, play a vital role in energy and mass exchange on earth and sustenance of the life on the planet earth (Dadhwal *et al.,* 2009). The increasing carbon dioxide (CO_2) concentration in the atmosphere has become one of the major global environmental issues in recent years because increasing CO_2 concentration causes warming. Forest areas can behave as a source of atmospheric carbon when they get disturbed by human or natural causes, and an atmospheric carbon sink during the regrowth after disturbance, hence they can be managed to alter the magnitude and direction of their carbon fluxes (Brown *et al.*, 1996). Sheikh *et al.* (2011) estimated that in East Deccan carbon stock stored in biomass showed increasing trend from 373.07, 395.90, 425.62 Mt for the years 2003, 2005 and 2007 respectively. Dry tropical forests of Chhattisgarh had total carbon stocks of 78,170.72 tonne in mixed forest, 81,656.91 tonne in Teak forest, 7,833.23 tonne in degraded forest and 7,470.45 tonne in Sal mixed forest (Bijalwan *et al.,* 2010). Thakur (2014) reported total carbon storage in different forest types varied from 6.96 to 47.75 Mg C/ha in Barnowpara Sanctuary, Raipur, Chhattisgarh. Baishya *et al*. (2009) suggested that tropical forests are more effective in carbon sequestration than other forests. Tropical forests are considered as having high 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 carbon in the soil. Climate also plays a vital role in biomass development of trees. Tree growth is actually controlled by a complicated mix of climate-related factors. The variation in biomass and carbon stocks in the ESIP areas may be due to the various plant community structures, species contribution, and composition of forest and level of degradation. The forests of the project areas are extremely under anthropogenic disturbances, because the rural people are depending on these forests for their daily needs i.e. fuel wood, fodder, non-wood forest produces etc.

Diversion of forest land to villagers for agricultural practices under Forest Right Act, 2006 and developmental activities are also associated in the variation of forest carbon stocks. Poor regeneration of tree species due to heavy grazing, repeated forest fire and invasion of obnoxious weeds like *Lantana camara* etc. were also observed during the field surveys which are also associated for loss of forest carbon stocks. Ahmad *et al.,* 2019 has felt the adequate policy intervention for control of forest fire. Singh and Madguni (2017) studied the rate of deforestation at district level in the state of Chhattisgarh between 1989 and 2015 using biannual forest cover data produce by Forest Survey of India. Over the two decades, the forest of Chhattisgarh faced various levels of deforestation and forest degradation due to various anthropogenic causes, industrialization and mining. Local community residing near the forest fringes could be helpful in implementation of various activities for restoration of degraded forests and enhancing forest carbon stocks. The well-established natural forests in ESIP areas need full protection for retaining the soil fertility and productivity.

Activities like water conservation, agri-horticulture promotion, fodder cultivation and fire management by the local community can support the growth of forest by reducing the anthropogenic pressure on forests. Human development strategies covering their settlement needs should be synchronized with the conservation status of the forests of Chhattisgarh. ICFRE has conducted the socio-economic studies in the ESIP areas and reported that fuel wood has been used as a primary source of energy for cooking and on an average 20 Kg of fuel wood is being collected per day per households from forest in the project areas. Besides the fuel woods, fodder and other forest produces have also been collected by the local communities of the project areas for their sustenance and livelihoods in the project areas (ICFRE, 2020). Therefore, silvicultural management practices need to be implemented to conserve these forests against various drivers of forest degradation, so the carbon pools of these forests can be conserved and enhanced.
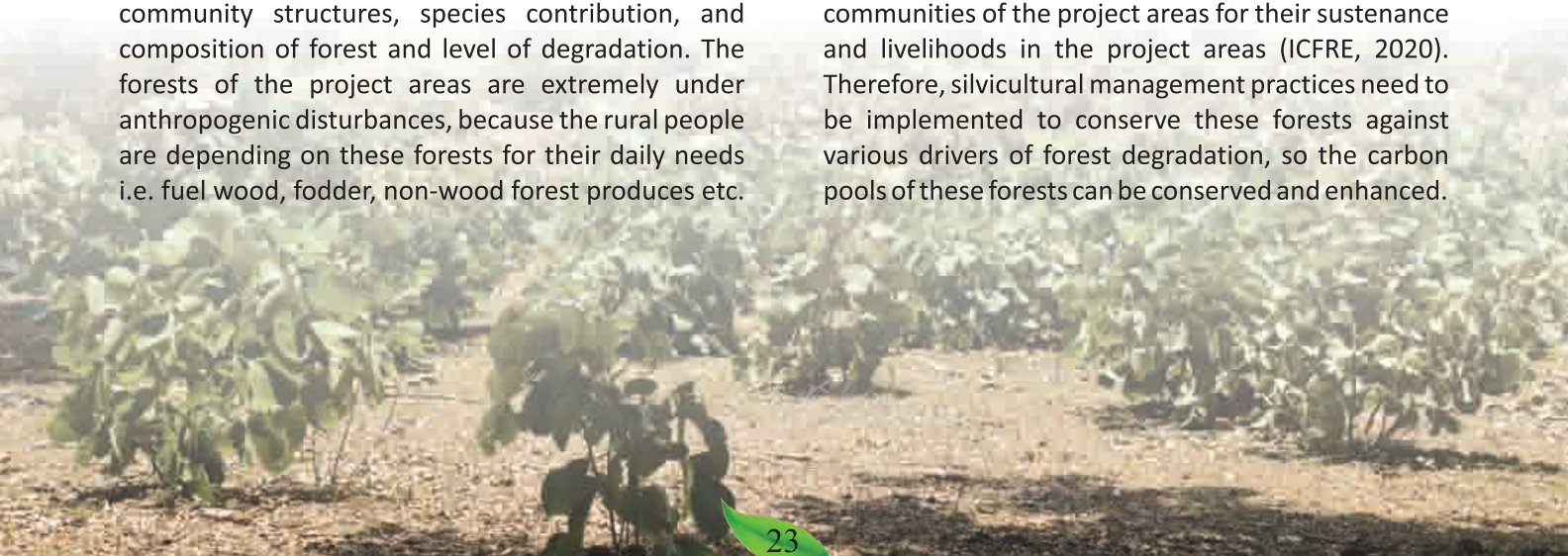
5. Conclusion

Forest ecosystems have structure, composition and function as the important attributes. Variations in these attributes are observed due to climate, topography, soil and anthropogenic factors. These factors along with forest succession causes local and landscape level variations in forest carbon stocks. A total of 155 permanent sample plots were laid to assess the baseline forest carbon stocks in ESIP areas of Chhattisgarh. 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 Pali Forest Range was maximum while the minimum carbon stock density is estimated in Marwahi Forest Range. The heterogeneous carbon stock in different types in different forest ranges can be attributed to the difference in tree density, basal area, and species diversity as well as various anthropogenic pressures. The report also provides relevant information on carbon stocks in different forest types of ESIP area in Chhattisgarh. The results of the baseline study will be benchmark for evaluating the ESIP project interventions in terms of enhanced carbon storage in project areas. The results of the baseline study will also help the State Forest Department of Chhattisgarh to initiate appropriate forest management practices for enhancement of forest carbon stocks in the areas under the Ecosystem Services Improvement Project as successful demonstrative models which can be 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 for forest degradation. There is a need to sensitize the local communities on issue of forest degradation and their role in sustainable management of forests. Generation of this baseline report on forest carbon stocks will be helpful in making realistic assessments of the forest carbon stocks of ESIP areas in Chhattisgarh.

6. Way Forward

Baseline study conducted in the ESIP areas of Chhattisgarh 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. The sample plot laid in the project area will be used to monitor the forest carbon stock in the project areas. 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, which will also be 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 fire are causing forest degradation and eventually 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 b).
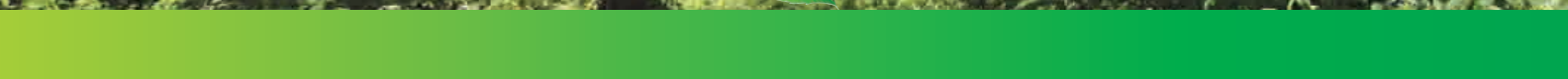
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Form for Data Collection for Forest Carbon Stock Assessment

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				

S.No.				
3		34		
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)

East Deccan

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

* For these species, Rest of species's Volume Equation is used.

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
Ougeinia oojeinensis	0.704
Phyllanthus emblica	0.800
Pterocarpus marsupium	0.649
Saccopetalum tomentosum	0.615
Semecarpus anacardium	0.640
Schleichera oleosa	0.841
Soymida febrifuga	0.963
Syzygium cumini	0.647
Tamarindus indica	0.750
Tectona grandis	0.563
Terminalia bellirica	0.628
Terminalia chebula	0.642
Terminalia tomentosa	0.730

Source: Rajput *et al.,* 1996

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

S. No.	Species Name	Biomass Equation
1	*Shorea robusta*	$BE_1 = 96.1525\ D^2 + 141.9383\ D - 7.6058$
	Shorea robusta	$BE_2 = 17.2383\ D^2 + 4.2380\ D - 0.1970$
	Shorea robusta	$Be_3 = -0.0561\ D_1^2 + 1.3533\ D_1 - 0.6625$
	Shorea robusta	$BE_4 = 0.0001\ D_1^3 - 0.0085\ D_1^2 + 0.1150\ D_1 - 0.0198$
2	*Terminalia crenulata/T. tomentosa*	$BE_1 = 487.5527\ D^2 + 151.9905\ D - 10.5122$
	Terminalia crenulata/T. tomentosa	$BE_2 = 20.6898\ D^2 + 0.6700\ D + 0.7183$
	Terminalia crenulata/T. tomentosa	$BE_3 = 0.2261\ D_1^2 - 0.2118\ D_1 + 0.4479$
	Terminalia crenulata/T. tomentosa	$BE_4 = 0.0231\ D_1^2 - 0.0128\ D_1 + 0.0067$
3	*Buchanania latifolia/ B. lanzan*	$BE_1 = 371.3904\ D^2 - 24.8493\ D + 11.8891$
	Buchanania latifolia/lanzan	$BE_2 = 11.5126\ D^2 + 11.7616\ D - 0.4661$
	Buchanania latifolia/lanzan	$BE_3 = 0.1774\ D_1^2 + 0.0497\ D_1 + 0.2405$
	Buchanania latifolia/lanzan	$BE_4 = 0.0167\ D_1^2 - 0.0533\ D_1 + 0.1272$
4	*Lagerstroemia parviflora*	$BE_1 = 282.0677\ D^2 + 122.5817\ D - 1.6765$
	Lagerstroemia parviflora	$BE_2 = 4.4738\ D^2 + 10.3883\ D - 0.2022$
	Lagerstroemia parviflora	$BE_3 = 0.3060\ D_1^2 - 0.8760\ D_1 + 1.8367$
	Lagerstroemia parviflora	$BE_4 = 0.0057\ D_1^2 + 0.0473\ D_1 + 0.0448$
5	*Diospyros melanoxylon*	$BE_1 = 454.7209\ D^2 + 91.0511\ D - 0.7796$
	Diospyros melanoxylon	$BE_2 = 6.0086\ D^2 + 14.4343\ D - 0.6523$
	Diospyros melanoxylon	$BE_3 = 0.2289\ D_1^2 - 0.5895\ D_1 + 1.2901$
	Diospyros melanoxylon	$BE_4 = 0.0054\ D_1^2 - 0.0027\ D_1 + 0.0586$
6	*Lannea coromandelica/Lannea grandis*	$BE_1 = 480.8026\ D^3 + 776.5053\ D^2 - 12.8368\ D + 3.2642$
	Lannea coromandelica/Lannea grandis	$BE_2 = 24.8730\ D^3 - 34.3265\ D^2 + 32.9611\ D - 2.2382$
	Lannea coromandelica/Lannea grandis	$BE_3 = 0.1437\ D_1^2 - 0.0925\ D_1 + 0.2315$
	Lannea coromandelica/ Lannea grandis	$BE_4 = 0.0041\ D_1^2 + 0.0476\ D_1 + 0.0538$
7	*Anogeissus latifolia*	$BE_1 = 617.5004\ D^2 + 213.1245\ D - 10.7193$
	Anogeissus latifolia	$BE_2 = 2.6012\ D^2 + 4.6100\ D + 0.4850$
	Anogeissus latifolia	$BE_3 = 0.0093\ D_1^2 + 2.0713\ D_1 - 1.3562$
	Anogeissus latifolia	$BE_4 = 0.0055\ D_1^2 + 0.0538\ D_1 - 0.0308$
8	*Madhuca latifolia* Syn. *M. indica*	$BE_1 = 363.8918\ D^2 + 21.7241\ D + 12.4076$
	Madhuca latifolia Syn. *M. indica*	$BE_2 = -0.5623\ D^2 + 5.9581\ D - 0.3769$
	Madhuca latifolia Syn. *M. indica*	$BE_3 = 0.1643\ D_1^2 - 0.1839\ D_1 + 0.8660$
	Madhuca latifolia Syn. *M. indica*	$BE_4 = 0.0015\ D_1^2 + 0.0042\ D_1 + 0.0175$
9	*Chloroxylon swietenia*	$BE_1 = 975.0536\ D^2 + 304.3150\ D - 28.7845$
	Chloroxylon swietenia	$BE_2 = 1.1759\ D^2 + 12.2568\ D - 0.5698$
	Chloroxylon swietenia	$BE_3 = 0.2140\ D_1^2 - 0.3769\ D_1 + 0.6000$
	Chloroxylon swietenia	$BE_4 = 0.0104\ D_1^2 - 0.0135\ D_1 + 0.0148$
10	*Tectona grandis*	$BE_1 = 400.7901\ D^2 + 154.6186\ D - 10.3648$
	Tectona grandis	$BE_2 = 0.8874\ D^2 + 7.7946\ D + 0.2524$

S. No.	Species Name	Biomass Equation
	Tectona grandis	$BE_3 = 0.0236\ D_1^3 - 0.0907\ D_1^2 + 0.1486\ D_1 + 0.7882$
	Tectona grandis	$BE_4 = 0.0121\ D_1^2 - 0.0132\ D_1 + 0.0450$
11	*Butea monosperma* Syn. *Butea frondosa*	$BE_1 = 370.0886\ D^2 - 109.6483\ D + 17.2888$
	Butea monosperma Syn. *Butea frondosa*	$BE_2 = 60.7797\ D^2 - 17.5339\ D + 2.3183$
	Butea monosperma Syn. *Butea frondosa*	$BE_3 = 0.0863\ D_1^2 - 0.0040\ D_1 + 0.5788$
	Butea monosperma Syn. *Butea frondosa*	$BE_4 = 0.0033\ D_1^2 + 0.0519\ D_1 + 0.1722$

(Source: FSI, nd)

Forest Carbon Stocks in Raghunathnagar 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)	
5/E9 Dry Bamboo Brake Moderately Dense Forest	1	82.89700	23.80151	51.25	14.35	0.04	0	45.09	110.73
5/E9 Dry Bamboo Brake Moderately Dense Forest	2	82.90956	23.79951	16.25	4.55	0.50	0	29.60	50.90
5/E9 Dry Bamboo Brake Moderately Dense Forest	3	82.89553	23.80120	27.22	7.62	0.04	0	35.46	70.35
5/E9 Dry Bamboo Brake Moderately Dense Forest	6	83.01164	23.84590	21.95	6.14	0.15	0	33.19	61.43
5/E9 Dry Bamboo Brake Open Forest	4	82.97797	23.84125	14.98	4.19	0.27	0	22.58	42.02
5/E9 Dry Bamboo Brake Open Forest	5	83.00895	23.83764	13.83	3.87	0.04	0	23.79	41.53
5B/C1 c Dry Peninsular Sal Moderately Dense Forest	7	82.89870	23.89857	12.46	3.49	0.09	0	28.74	44.78
5B/C1 c Dry Peninsular Sal Moderately Dense Forest	8	82.89378	23.89047	57.03	15.97	0.22	0	22.88	96.11
5B/C1 c Dry Peninsular Sal Moderately Dense Forest	9*	82.979021	23.845089	-	-	-	-	-	-
5B/C1 c Dry Peninsular Sal Moderately Dense Forest	10	82.91388	23.87835	23.41	6.56	0.04	0	19.13	49.14
5B/C1 c Dry Peninsular Sal Moderately Dense Forest	11	82.91443	23.88312	40.93	11.46	0.77	0	32.40	85.56
5B/C1 c Dry Peninsular Sal Moderately Dense Forest	12	82.91937	23.87955	15.86	4.44	0.69	0	48.49	69.48
5B/C1 c Dry Peninsular Sal Moderately Dense Forest	13	82.90298	23.80450	39.22	10.98	0.04	0	35.53	85.77
5B/C1 c Dry Peninsular Sal Moderately Dense Forest	14	82.98483	23.76345	15.25	4.27	0.07	0	54.37	73.97
5B/C1 c Dry Peninsular Sal Moderately Dense Forest	15	82.97743	23.83516	21.70	6.08	0.05	0	23.04	50.86
5B/C1 c Dry Peninsular Sal Open Forest	16	82.98245	23.77010	8.61	2.41	0.05	0	35.81	46.87
5B/C1 c Dry Peninsular Sal Open Forest	17	82.92374	23.79820	24.95	6.99	0.11	0	23.68	55.73
5B/C1 c Dry Peninsular Sal Open Forest	18	82.99034	23.76096	21.05	5.89	0.05	0	32.32	59.31
5B/C1 c Dry Peninsular Sal Open Forest	19	82.90589	23.88144	23.50	6.58	0.84	0	19.67	50.59
5B/C1 c Dry Peninsular Sal Open Forest	20	82.89493	23.89527	28.82	8.07	0.10	0	24.37	61.35
5B/C1 c Dry Peninsular Sal Open Forest	21	82.88905	23.90553	23.80	6.66	0.31	0	10.77	41.54

5B/C1 c Dry Peninsular Sal Open Forest	22	82.98310	23.84400	14.16	3.96	0.06	0	17.76	35.94
5B/C1 c Dry Peninsular Sal Open Forest	23	82.91941	23.79316	15.09	4.23	0.10	0	19.84	39.25
5B/C2 Northern Dry Mixed Deciduous Moderately Dense Forest	24	82.90295	23.79775	23.90	6.69	0.17	0	41.95	72.72
5B/C2 Northern Dry Mixed Deciduous Moderately Dense Forest	25	82.98429	23.83685	18.61	5.21	0.13	0	50.54	74.49
5B/C2 Northern Dry Mixed Deciduous Moderately Dense Forest	26	82.98773	23.83492	25.26	7.07	0.65	0	35.30	68.28
5B/C2 Northern Dry Mixed Deciduous Moderately Dense Forest	27	82.99034	23.76096	17.73	4.97	0.04	0	36.16	58.89
5B/C2 Northern Dry Mixed Deciduous ModeratelyDense Forest	28	82.92231	23.86667	22.42	6.28	0.04	0	42.93	71.68
5B/C2 Northern Dry Mixed Deciduous Moderately Dense Forest	29	82.92948	23.80133	19.23	5.38	0.04	0	41.43	66.08
5B/C2 Northern Dry Mixed Deciduous Open Forest	30	82.91874	23.79111	20.38	5.71	0.08	0	35.01	61.18
5B/C2 Northern Dry Mixed Deciduous Open Forest	31	82.91809	23.87015	28.09	7.87	0.16	0	36.92	73.04
5B/C2 Northern Dry Mixed Deciduous Open Forest	32	82.90878	23.87577	17.77	4.98	0.02	0	26.11	48.88
5B/C2 Northern Dry Mixed Deciduous Open Forest	33	82.94829	23.84286	24.30	6.80	0.06	0	28.38	59.54
5B/C2 Northern Dry Mixed Deciduous Open Forest	34	82.92056	23.87417	8.70	2.44	0.05	0	26.53	37.71
5B/C2 Northern Dry Mixed Deciduous Open Forest	35	82.93192	23.79537	18.57	5.20	0.01	0	28.88	52.67
Scrub	36	82.98786	23.83981	11.36	3.18	0.37	0	19.08	34.00
Scrub	37*	82.970712	23.844760	-	-	-	0	-	-
Scrub	38*	82.971343	23.846888		-	-	-	-	-

Sample points could not be laid out in the field due to issue of human-wildlife conflict during the field surveys

Forest Carbon Stocks in Pali 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)	
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	1	82.17256	22.48290	64.84	18.15	0.13	0	33.49	116.81
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	2	82.17797	22.48346	59.81	16.75	0.08	0	16.62	93.36
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	3	82.14577	22.48161	66.99	18.76	0.03	0	30.25	114.27
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	4	82.19953	22.49488	57.34	16.05	0.13	0	30.21	103.92
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	5	82.15560	22.49426	54.43	15.24	0.07	0	27.40	97.23
3C/2e (ii) Moist Peninsular Low Level Sal Open Forest	6	82.20844	22.44930	33.72	9.44	0.69	0	27.06	71.94
3C/2e (ii) Moist Peninsular Low Level Sal Open Forest	7	82.15239	22.46508	65.93	18.46	0.08	0	19.62	104.21
3C/2e (ii) Moist Peninsular Low Level Sal Open Forest	8	82.20940	22.44870	59.62	16.69	0.87	0	24.19	102.67
3C/2e (ii) Moist Peninsular Low Level Sal Very Dense Forest	9	82.21769	22.49105	40.39	11.31	0.05	0	49.13	100.94
3C/2e (ii) Moist Peninsular Low Level Sal Very Dense Forest	10	82.22130	22.47044	38.58	10.80	0.05	0	46.50	96.02
3C/2e (ii) Moist Peninsular Low Level Sal Very Dense Forest	11	82.20640	22.45660	57.96	16.23	0.15	0	36.85	111.40
3C/2e (ii) Moist Peninsular Low Level Sal Very Dense Forest	12	82.23250	22.48045	52.62	14.73	0.08	0	36.96	104.52
5/E9 Dry Bamboo Brake Moderately Dense Forest	13	82.22420	22.46800	46.76	13.09	0.33	0	29.36	90.03
5/E9 Dry Bamboo Brake Moderately Dense Forest	14	82.18517	22.49400	67.00	18.76	0.20	0	29.47	115.72
5/E9 Dry Bamboo Brake Moderately Dense Forest	15	82.19500	22.45520	52.43	14.68	0.17	0	48.72	116.25
5/E9 Dry Bamboo Brake Moderately Dense Forest	16	82.19563	22.48444	57.35	16.06	0.18	0	42.14	116.01
5/E9 Dry Bamboo Brake Open Forest	18	82.17015	22.44320	46.77	13.09	0.00	0	38.4	98.26
5/E9 Dry Bamboo Brake Open Forest	17	82.18456	22.47372	54.30	15.21	0.18	0	30.798	100.75
5/E9 Dry Bamboo Brake Open Forest	19*	82.200122	22.431152	-	-	-	-	-	-
5/E9 Dry Bamboo Brake Moderately Dense Forest	20	82.22290	22.45300	45.63	12.78	0.16	0	34.27	93.07
5/E9 Dry Bamboo Brake Very Dense Forest	21	82.18114	22.46830	54.92	15.38	0.09	0	36.34	106.87

5/E9 Dry Bamboo Brake Moderately Dense Forest	22	82.20082	22.47244	43.34	12.14	0.11	0	33.71	89.45
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	23	82.14699	22.48021	30.32	8.49	0.09	0	29.58	68.62
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	24	82.15395	22.49327	55.41	15.52	0.07	0	34.14	105.24
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	25	82.14957	22.48730	70.41	19.71	0.06	0	49.74	140.02
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	26	82.16437	22.48893	43.83	12.27	0.14	0	41.80	98.24
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	27	82.21227	22.47729	63.10	17.67	0.09	0	46.38	127.37
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	28	82.14468	22.47807	43.86	12.28	0.18	0	18.43	75.01
5B/C2 Northern Dry Mixed Deciduous Open Forest	29	82.17370	22.44270	8.88	2.49	0.12	0	35.43	47.11
5B/C2 Northern Dry Mixed Deciduous Open Forest	30	82.17580	22.43230	20.70	5.80	0.09	0	28.37	55.09
5B/C2 Northern Dry Mixed Deciduous Open Forest	31	82.17600	22.44290	7.07	1.98	0.14	0	34.65	44.07
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	32	82.19667	22.47306	55.39	15.51	0.08	0	26.01	97.11
5B/C2 Northern Dry Mixed Deciduous Very Dense Forest	33	82.17144	22.48800	53.32	14.93	0.09	0	52.64	121.11
5B/C2 Northern Dry Mixed Deciduous Very Dense Forest	34	82.22014	22.47456	54.49	15.26	0.03	0	28.05	97.89

Sample points could not laid out in the field due to inaccessibility

Forest Carbon Stocks in Marwahi 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)	
3B/C2 Southern Moist Mixed Deciduous Moderately Dense Forest	1	82.13248	22.90245	38.27	10.72	0.04	0	42.07	91.09
3B/C2 Southern Moist Mixed Deciduous Moderately Dense Forest	2	82.04989	22.89598	14.81	4.15	0.04	0	47.32	66.32
3B/C2 Southern Moist Mixed Deciduous Moderately Dense Forest	3	82.12888	22.87449	30.84	8.63	0.05	0	40.55	80.06
3C/2e(ii) Moist Peninsular Low Level Sal Moderately Dense Forest	4	82.16450	22.91916	14.93	4.18	0.04	0	28.53	47.68
3C/2e(ii) Moist Peninsular Low Level Sal Moderately Dense Forest	5	82.13220	22.88327	32.57	9.12	0.08	0	34.34	76.10
3C/2e(ii) Moist Peninsular Low Level Sal Moderately Dense Forest	6	82.13160	22.87781	35.93	10.06	0.07	0	39.56	85.62
3C/2e(ii) Moist Peninsular Low Level Sal Moderately Dense Fores	7	82.06824	22.89194	15.96	4.47	0.05	0	21.62	42.09
3C/2e(ii) Moist Peninsular Low Level Sal Moderately Dense Forest	8	82.15181	22.96492	36.96	10.35	0.07	0	26.85	74.22
3C/2e(ii) Moist Peninsular Low Level Sal Moderately Dense Forest	9	82.16282	22.92079	20.56	5.76	0.05	0	30.00	56.37
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	10	82.03069	22.88938	8.96	2.51	0.07	0	26.77	38.31
3C/2e(ii) Moist Peninsular Low Level Sal Moderately Dense Forest	11	82.13459	22.87378	25.92	7.26	0.05	0	29.73	62.96
3C/2e(ii) Moist Peninsular Low Level Sal Moderately Dense Forest	12	82.06038	22.87944	33.00	9.24	0.06	0	27.90	70.20
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	13	82.11251	22.93004	34.18	9.57	0.05	0	26.67	70.47
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	14	82.12994	22.89201	30.50	8.54	0.04	0	41.00	80.08
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	15	82.15382	22.86846	25.86	7.24	0.05	0	53.43	86.58
5A/C3 Southern Dry Mixed Deciduous Open Forest	16	82.13248	22.873572	32.47	9.09	0.06	0	49.30	90.92
5A/C3 Southern Dry Mixed Deciduous Open Forest	17	82.11810	2.84494	9.62	2.69	0.06	0	27.27	39.64
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	18	82.13075	22.91112	30.28	8.48	0.00	0	17.29	56.05
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	19	82.14040	22.86180	22.70	6.36	0.04	0	36.66	65.76
3C/2e(ii) Moist Peninsula Low Level Sal Moderately Dense Forest	20	82.13273	22.88539	23.92	6.70	0.03	0	16.97	47.62
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	21	82.05117	22.89911	21.93	6.14	0.04	0	30.65	58.76

5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	22	82.12477	22.88729	32.12	8.99	0.09	0	36.19	77.40
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	23	82.04235	22.90583	18.82	5.27	0.04	0	24.81	48.94
3B/C2 Southern Moist Mixed Deciduous Open Forest	24	82.16927	22.91676	8.99	2.52	0.02	0	23.08	34.61
5A/C3 Southern Dry Mixed Deciduous Open Forest	25	82.11647	22.93099	19.10	5.35	0.05	0	26.55	51.05
3B/C2 Southern Moist Mixed Deciduous Open Forest	26	82.04146	22.88441	9.28	2.60	0.04	0	24.90	36.81
3C/2e(ii) Moist Peninsular Low Level Sal Open Forest	27	82.16548	22.89463	22.44	6.28	0.02	0	21.50	50.25
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	28	82.07126	22.88448	27.41	7.67	0.06	0	18.04	53.18
5A/C3 Southern Dry Mixed Deciduous Open Forest	29	82.17861	22.95917	25.48	7.14	0.08	0	20.18	52.88
5A/C3 Southern Dry Mixed Deciduous Open Forest	30	82.12595	22.84465	28.36	7.94	0.05	0	42.16	78.52
5A/C3 Southern Dry Mixed Deciduous Open Forest	31	82.132931	22.873609	-	-	-	0	-	-
5A/C3 Southern Dry Mixed Deciduous Open Forest	32	82.03855	22.90772	20.36	5.70	0.05	0	21.37	47.49
A/C3 Southern Dry Mixed Deciduous Open Forest	33	82.12474	22.85259	21.63	6.06	0.05	0	16.15	43.88
5A/C3 Southern Dry Mixed Deciduous Open Forest	34	82.12416	22.86413	28.88	8.09	0.05	0	12.77	49.78
5A/C3 Southern Dry Mixed Deciduous Open Forest	35	82.12650	22.84943	33.29	9.32	0.06	0	20.05	62.71
Southern Dry Mixed Deciduous Open Forest	36	82.116878	22.855281	-	-	-	0	-	-
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	37	82.12407	22.92319	33.09	9.27	0.03	0	16.32	58.72
5A/C3 Southern Dry Mixed Deciduous Open Forest	38	82.05534	22.90348	12.72	3.56	0.06	0	22.46	38.80
5A/C3 Southern Dry Mixed Deciduous Open Forest	39	82.03476	22.89046	20.66	5.79	0.04	0	24.93	51.42
5A/C3 Southern Dry Mixed Deciduous Open Forest	40	82.13474	22.86225	6.29	1.76	0.04	0	20.99	29.08
5A/C3 Southern Dry Mixed Deciduous Open Forest	41	82.13703	22.87190	44.37	12.42	0.04	0	25.60	82.44
3C/2e(ii) Moist Peninsular Low Level Sal Open Forest	42	82.11230	22.84573	36.79	10.30	0.04	0	24.16	71.28
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	43	82.14064	22.89380	36.60	10.25	0.04	0	32.21	79.10
5A/C3 Southern Dry Mixed Deciduous Open Forest	44	82.13512	22.86057	25.92	7.26	0.06	0	26.27	59.50
Scrub	45	82.12840	22.85642	1.23	0.34	0.00	0	22.32	23.89
Scrub	46	82.16833	22.97220	1.35	0.38	0.03	0	37.54	39.29
Scrub	47	82.18281	22.90553	7.06	1.98	0.02	0	25.78	34.84

Forest Carbon Stocks in Pandariya West 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)	
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	1	81.27360	22.43697	39.55	11.07	0.09	0	48.14	98.85
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	2	81.32429	22.47027	46.59	13.05	0.05	0	46.15	105.83
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	3	81.32524	22.46872	58.40	16.35	0.04	0	29.35	104.14
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	4	81.34462	22.47141	79.79	22.34	0.07	0	39.67	141.87
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	5	81.31361	22.44938	50.22	14.06	0.06	0	39.06	103.41
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	6*	81.322541	22.472501	-	-		-	-	-
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	7	81.26369	22.43925	54.57	15.28	0.06	0	34.02	103.93
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	8	81.26913	22.46367	37.25	10.43	0.05	0	24.08	71.81
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	9	81.32083	22.47460	54.47	15.25	0.03	0	29.45	99.20
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	10	81.28970	22.43956	24.65	6.90	0.03	0	55.05	86.64
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	11	81.33933	22.46732	22.34	6.26	0.08	0	45.11	73.78
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	12	81.34513	22.47405	55.08	15.42	0.06	0	43.03	113.59
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	13	81.28524	22.44166	30.65	8.58	0.04	0	39.00	78.28
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	14	81.31084	22.45010	18.05	5.05	0.03	0	50.86	74.00
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	15	81.31035	22.43524	35.46	9.93	0.03	0	31.98	77.39
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	16	81.26506	22.44455	22.25	6.23	0.03	0	33.39	61.89
3C/2e (ii) Moist Peninsular Low Level Sal Open Forest	17	81.29843	22.42564	22.58	6.32	0.03	0	14.99	43.93
3C/2e (ii) Moist Peninsular Low Level Sal Open Forest	18	81.31550	22.44937	36.42	10.20	0.05	0	21.82	68.50
3C/2e (ii) Moist Peninsular Low Level Sal Open Forest	19	81.30341	22.43180	47.84	13.40	0.03	0	43.43	104.70
3C/2e (ii) Moist Peninsular Low Level Sal Open Forest	20	81.28650	22.42667	40.42	11.32	0.05	0	27.61	79.40
3C/2e (ii) Moist Peninsular Low Level Sal Open Forest	21	81.28405	22.42639	63.12	17.67	0.04	0	28.21	109.04

Forest Type								
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	22	81.26413	22.44619	44.84	12.55	0.08	0	29.65	87.12
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	23	81.30114	22.45150	32.36	9.06	0.04	0	47.63	89.09
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	24	81.34011	22.37728	10.10	2.83	0.05	0	32.12	45.09
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	25	81.29740	22.42064	86.26	24.15	0.03	0	19.82	130.28
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	26	81.29952	22.45462	30.70	8.60	0.07	0	12.52	51.89
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	27	81.341529	22.441339	-	-	-	-	-	-
5A/C3 Southern Dry Mixed Deciduous Open Forest	28	81.28954	22.47738	44.70	12.52	0.04	0	46.69	103.95
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	29	81.33803	22.47107	51.80	14.50	0.07	0	11.94	78.30
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	30	81.27110	22.46886	69.29	19.40	0.05	0	17.72	106.46
5A/C3 Southern Dry Mixed Deciduous Open Forest	31	81.28919	22.41390	28.24	7.91	0.03	0	44.59	80.77
5A/C3 Southern Dry Mixed Deciduous Open Forest	32	81.28622	22.41727	10.60	2.97	0.04	0	27.60	41.21
3C/2e (ii) Moist Peninsular Low Level Sal Open Forest	33	81.29781	22.44928	35.36	9.90	0.03	0	43.32	88.61
5A/C3 Southern Dry Mixed Deciduous Open Forest	34	81.321683	22.372250	-	-	-	0	-	-
3C/2e (ii) Moist Peninsular Low Level Sal Open Forest	35	81.31239	22.47032	8.85	2.48	0.04	0	39.56	50.94
5A/C3 Southern Dry Mixed Deciduous Open Forest	36	81.28519	22.50001	51.35	14.38	0.19	0	45.04	110.96
5A/C3 Southern Dry Mixed Deciduous Open Forest	37	81.31471	22.33872	23.74	6.65	0.00	0	14.92	45.30
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	38	81.29244	22.47532	16.29	4.56	0.04	0	49.44	70.33
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	39	81.30790	22.43159	18.48	5.18	0.03	0	17.56	41.25
5A/C3 Southern Dry Mixed Deciduous Open Forest	40	81.26707	22.43959	22.84	6.40	0.06	0	24.34	53.63
Scrub	41	81.34403	22.37531	6.11	1.71	0.06	0	34.49	42.36
5A/C3 Southern Dry Mixed Deciduous Open Forest	42	81.34630	22.37458	3.23	0.90	0.05	0	32.11	36.30
Scrub	43	81.34678	22.37604	13.71	3.842	0.04	0	36.73	54.32
3C/2e (ii) Moist Peninsular Low Level Sal Moderately Dense Forest	44	81.26871	22.48560	84.49	3.66	0.04	0	35.91	144.10
5A/C3 Southern Dry Mixed Deciduous Moderately Dense Forest	45	81.30917	22.42389	31.86	8.92	0.03	0	14.04	54.85

*_Sample plots could not laid out in the field due to heavy rains_

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