Ecosystem Services Improvement Project: Assessment of Forest Carbon Stock of Project Areas of Madhya Pradesh and 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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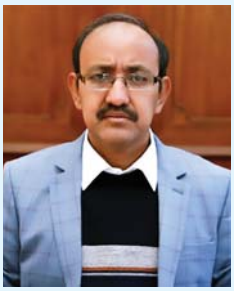
Foreword



The impact of climate change has alarmed the global communities and attracted the interest of scientific communities towards various mitigation and adaptation measures. Forest ecosystem plays a significant role in climate change mitigation and adaptation. Forests and climate change are directly linked to each other and forests are known as a sink or source of carbon dioxide. Role of forests have been increasingly recognized as most cost-effective option for climate change mitigation through carbon capture and storage in biomass and soils. Forests are considered to provide a large climate change mitigation opportunity at relatively lower costs along with other significant co-benefits. Forests are now integral part of international protocols and agreements dealing with climate change issues.

The World Bank funded Ecosystem Services Improvement Project (ESIP) supported the goals of Green India Mission (GIM) by demonstrating models for adaptation-based mitigation through sustainable land and ecosystem management. New tools, techniques and practices for better management and monitoring of forests, including biodiversity and carbon stock were introduced under ESIP which are considered necessity in the forest sector. The tools, techniques and practices introduced in the states of Madhya Pradesh and Chhattisgarh under ESIP are helpful in demonstrating its potential for scaling up across the country for sustainable management of forests.

ICFRE implemented a sub-component on 'Forest Carbon Stock Measurement, Monitoring and Capacity Building' besides the component on 'Scaling up of Sustainable Land and Ecosystem Management Practices' in selected landscapes of Madhya Pradesh and Chhattisgarh. The assessment of forest carbon stock was conducted to assess the outcomes and impacts of the ESIP activities in the forests.

I have great pleasure in presenting this report on 'Ecosystem Services Improvement Project: Assessment of Forest Carbon Stock of Project Areas of Madhya Pradesh and Chhattisgarh. I am hopeful that the findings of this report will serve as a framework for assessing the impact of project activities and will be a guiding document for scaling up of sustainable forest management practices in entire GIM landscapes of Madhya Pradesh and Chhattisgarh for improving the forest health and enhancement of forest carbon stock.

I compliment the entire team of ESIP of ICFRE for bringing out this assessment report on forest carbon stock of ESIP areas of Madhya Pradesh and Chhattisgarh.

Dated: 28/07/2022

(Arun Singh Rawat)

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I am grateful to the Ministry of Environment, Forest and Climate Change, Government of India and the World Bank for providing necessary guidance and support for measurement and monitoring of the forest carbon stock in the selected landscapes of Madhya Pradesh and Chhattisgarh under Ecosystem Services Improvement Project (ESIP).

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Various kinds of logistic support and active participation provided by the officers and field staff of North Betul, Sehore and Hoshangabad Forest Divisions of State Forest Department of Madhya Pradesh, and Marwahi, Katghora, Kawardha and Balrampur Forest Divisions of Forest and Climate Change Department of Chhattisgarh from time to time for conducting the field surveys are also gratefully acknowledged.

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Dr. R. S. Rawat, Project Manager, ESIP
on behalf of 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
^0C	Degree Centigrade
DBH	Diameter at Breast Height
ESIP	Ecosystem Services Improvement Project
FSI	Forest Survey of India
Gt	Giga tonne
GIM	Green India Mission
GHG	Greenhouse gases
ha	Hectare
ICFRE	Indian Council of Forestry Research and Education
IPCC	Intergovernmental Panel on Climate Change
JFMCs	Joint Forest Management Committees
LULUCF	Land Use, Land-Use Change and Forestry
M	Million
m	Meter
Mg	Megagram
mg	Milligram
ml	Milliliter
mm	Millimeter
MoEFCC	Ministry of Environment, Forest and Climate Change
NAPCC	National Action Plan for Climate Change
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 Kilometer
t	Tonne
UNFCCC	United Nations Framework Convention on Climate Change

Executive Summary

The World Bank funded Ecosystem Services Improvement Project (ESIP) was implemented in the selected landscapes of Madhya Pradesh and Chhattisgarh from 2018-19 to 2022-23. Madhya Pradesh State Forest Department selected Budhni Forest Range (Sehore Forest Division), Bhaura Forest Range (North Betul Forest Division), and Sukhtawa, Itarsi and Banapura Forest Ranges (Hoshangabad Forest Division) for implementation of project activities under ESIP. Chhattisgarh State Forest and Climate Change Department selected Marwahi Forest Range (Marwahi Forest Division), Pali Forest Range (Katghora Forest Division), Pandariya West Forest Range (Kwardha Forest Division) and Raghunathnagar Forest Range (Balrampur Forest Division) for implementation of project activities under ESIP.

Field surveys for preparation of the baseline reports of the forest carbon stock of the project areas of Madhya Pradesh and Chhattisgarh under ESIP were conducted during the year 2018-19. As per the baseline report of forest carbon stock of project areas of Madhya Pradesh, total forest carbon stock was estimated to be 11,72,639.19 tonnes with an average carbon stock density of 59.88 t/ha. Total baseline forest carbon stock for the project areas of Chhattisgarh was estimated to be 12,23,310.56 tonnes with an average carbon stock density of 74.11 t/ha.

A total of 2975 ha forest areas were brought under the enrichment plantations by Madhya Pradesh State Forest Department and 3218 ha forest areas were brought under the enrichment plantations by Chhattisgarh State Forest and Climate Change Department under ESIP for improvement of the forest health and enhancement of forest carbon stock in the project areas. Assisted natural regeneration activities and forest protection activities have also been done in the project areas of Madhya Pradesh and Chhattisgarh under ESIP by the State Forest Departments. As per the Result Framework Indicators Document of ESIP, an increment of 10% over the baseline forest carbon stock has to be achieved at the end of the project period through successful implementation of activities/ interventions under the project. Accordingly, field surveys were conducted in the ESIP areas of Madhya Pradesh and Chhattisgarh during the year 2022-23 for assessment of the impact of project interventions/ activities on the forest carbon stock in the project areas under ESIP.

The data of forest carbon stock assessment of the project areas of Madhya Pradesh revealed that total forest carbon stock was estimated to be 1308715.47 tonnes with the average carbon density of 66.59 t/ha in the year 2022-23 over the baseline total forest carbon stock of 1172639.19 tonnes in the year 2018-19. The total forest carbon stock in project areas of Chhattisgarh was estimated to be 1342860.20 tonnes with the average carbon density of 79.58 t/ha in the year 2022-23 over the baseline total forest carbon stock of 1223310.56 tonnes in the year 2018-19.

The current assessment reveals that the forest carbon stock in the ESIP areas of the Madhya Pradesh increased by about 11.25% and forest carbon stock in the ESIP areas of Chhattisgarh increased by 7.51% over the baseline forest carbon stock. It can be concluded that an increment of 9.38% had been estimated in the total forest carbon stock of project areas

of Madhya Pradesh and Chhattisgarh over the baseline forest carbon stock under ESIP.

The average forest carbon density for the ESIP areas of Madhya Pradesh (66.71 t/ha) and Chhattisgarh (79.32 t/ha) was lower than the state average of Madhya Pradesh (78.63 t/ha) and Chhattisgarh (89.09 t/ha). The probable reasons for lower average carbon density in the project areas of Madhya Pradesh and Chhattisgarh were due to the facts that project areas chosen for implementation of the project intervention/ activities under ESIP were fallen in the central Indian highlands which are part of the 39 percent forest grids of India identified and mapped as 'vulnerable to climate change'. Project areas were also under degradation due to unsustainable land use practices. Forest carbon assessment done by the Forest Survey of India covered forest as well as trees outside forests of the states as a whole whereas the assessment of the forest carbon stock of project areas of Madhya Pradesh and Chhattisgarh under ESIP covered only the forest areas.

New tools/ technologies and practices for better management and monitoring of forest carbon stock were introduced under ESIP. The data on forest carbon stock assessment clearly depicted that implementation of the project activities in the selected landscapes of Madhya Pradesh and Chhattisgarh were effective in improving the forest health and forest carbon stock. The practices implemented in the states of Madhya Pradesh and Chhattisgarh under ESIP were helpful in demonstrating its potential for scaling up across the country and support in achieving the forestry sector target of Nationally Determined Contributions under the Paris Agreement and Land Degradation Neutrality Target.

Introduction

1

Globally, forests are considered to provide a large climate change mitigation opportunity at relatively lower costs along with significant co-benefits. Forests and climate change are very intricately linked with each other and forests can be source or sink of carbon. Global forests cover about 30% of earth's surface, spread over 4 billion hectares of land mass. According to FAO (2020), 420 million ha of forests have been lost worldwide through deforestation since 1990, but the rate of forest loss has declined significantly. In the recent five-year period (2015–2020), the annual rate of deforestation was estimated to be 10 million ha which was 12 million ha in 2010–2015. Deforestation results in immediate release of the carbon which was originally stored in the trees as a biomass.

Increasing concentration of atmospheric greenhouse gases has created a global issue of climate change. According to the Sixth Assessment Report of the Inter-Governmental Panel on Climate Change, annual greenhouse gases flux from agriculture, forestry and other land use activities accounted for approximately 22% of total anthropogenic greenhouse gas emissions (IPCC, 2023). When forest is cleared or degraded, their stored carbon is released into the atmosphere as carbon dioxide. Forests serve as a reservoir of biodiversity and harbouring diverse floral and faunal species. Forests provide wide range of ecosystem services at local, regional and global scales (Ojea *et al.,* 2016). Forest ecosystem helps in continuous removal of carbon from the atmosphere and its storage in vegetation and soils. Carbon sequestration and storage are important climate-related functions of forests (Hicks *et al.,* 2014). Forests sequester approximately 47% of terrestrial carbon and are considered as an important global carbon sink (Dixon *et al.,* 1994; Ali and Yan, 2017). Forests play a significant role in climate change mitigation with its sustained ability to absorb carbon dioxide from the atmosphere and store it in the form of biomass (Diaz *et al.,* 2009). Forests sequester and store more carbon than any other terrestrial ecosystem and are an important 'natural brake' on climate change.

The persistence and resilience of forest carbon stock as well as the sustained ability of forests to absorb carbon dioxide from the atmosphere are the significant role that forests can play in climate change mitigation (Diaz et al., 2009). Soil carbon is an important determinant of site fertility due to its role in maintaining soil physical and chemical properties (Reeves, 1997). Land-use and soil-management practices can significantly influence soil organic carbon dynamics and carbon flux from the soil (Batjes, 1996; Post and Kwon, 2000). The scale and impact of land degradation and desertification are severe in the country and 29.77% of the total geographical area of the country experienced land degradation (SAC, 2021).

The forest cover of the country is 7,13,789 sq km as per 2021 assessment (FSI, 2021) which was 7,12,249 sq km as per 2019 assessment (FSI, 2019), recording an increase of 1,540 sq km within two years. The total forest and tree cover of the country is 8,09,537 sq km which is 24.62% of its geographical area. India has been successful in enhancing forest carbon stock through sustainable management of forests. As per the India State of Forest Report 2021, total forest carbon stock was estimated to be 7,204 million tonnes with an increase

of 79.4 million tonnes over the previous assessment of 2019 (FSI, 2021). The land use, land-use change and forestry (LULUCF) sector is the only sector that consistently absorbs carbon dioxide in the country, making it one of the most relevant for its mitigation potential. As per the Third Biennial Update report of India, LULUCF sector was a net sink of carbon and offset 15% of total national greenhouse gas emissions (MoEFCC, 2021). The Government of India has executed the National Mission for a Green India, commonly referred to as the Green India Mission (GIM) under its National Action Plan on Climate Change which 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 mitigation and adaptation measures.

The central Indian highlands 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). The World Bank funded Ecosystem Services Improvement Project (ESIP) was implemented in the selected landscapes of Madhya Pradesh and Chhattisgarh. ESIP envisaged 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 of the project areas. ESIP also envisaged to support in the sequestration of additional carbon of about 10% in the forest areas of Madhya Pradesh and Chhattisgarh over the baseline through implementation of the project interventions/ activities (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 of ESIP.

Indian Council of Forestry Research and Education implemented the sub-component on forest carbon stock measuring, monitoring and capacity-building besides the component on scaling up of sustainable land and ecosystem management practices in the selected landscapes of Madhya Pradesh and Chhattisgarh of ESIP as a Project Implementing Agency. The purpose for bringing out this report on assessment of forest carbon stock is to assess the impacts of the project interventions/ activities on sequestration and storage of additional carbon over the baseline carbon stock.

Overview of Forests and Carbon Stock of Madhya Pradesh and Chhattisgarh

2

Overview of Forests of Madhya Pradesh : As per India State of Forest Report 2021, Madhya Pradesh is one of the forest rich states and is ranked first in terms of the recorded forest area. Forest cover of Madhya Pradesh is 77492.60 sq km which is 25.14% of the its geographical area which is further categorized as 6,664.95 sq km under very dense forest (2.16% of the total geographical area), 34,209.02 sq km area under moderately dense forest (11.10% of the total geographical area) and 36,618.63 sq km under open forest (11.88% of the total geographical area) (Table 2.1). Tree cover in Madhya Pradesh has been estimated to be 8,054 sq km which is 2.61% of its geographical area. Total growing stock in the state was estimated to be 492.49 cum which comprises of 374.44 cum in recorded forest area and 118.05 cum in tree outside the forests (FSI, 2021). The state of Madhya Pradesh has registered increment of 10.11 sq km forest cover compared to the previous assessment of 2019.

Table-2.1: Forest Cover of Madhya Pradesh

Class	Area (sq km)	% of GA of State
Very Dense Forest	6, 664.95	2.16
Moderately Dense Forest	34,209.02	11.10
Open Forest	36,618.63	11.88
Total	**77,492.60**	**25.14**
Scrub	5,456.55	1.77

(Source: FSI, 2021)

Overview of Forest Carbon Stock of Madhya Pradesh: Total forest carbon stock of Madhya Pradesh including the tree outside the forests patches was 609.25 million tonnes which was 8.46% of total forest carbon stock of the country (FSI, 2021). As per the India State of Forest Report 2021, pool wise breakup of forest carbon stock of Madhya Pradesh is given in Table 2.2 and pool wise carbon density of Madhya Pradesh are given in Table 2.3.

Table-2.2: Forest carbon stock (in '000 tonnes) in Madhya Pradesh

Above Ground Biomass	Below Ground Biomass	Dead wood	Litter	Soil Organic Carbon	Total
1,71,587	67,160	2,676	8,356	3,59,174	6,09,250

(Source: FSI, 2021)

Table-2.3: Carbon density (t/ha) of forests of Madhya Pradesh

Carbon Pool	2019	2021
Above Ground Biomass	21.30	22.14
Below Ground Biomass	8.34	8.67
Dead Wood	0.20	0.35
Litter	1.05	1.12
Soil Organic Carbon	45.09	46.35
Total	**75.98**	**78.63**

(Source: FSI, 2019 and 2021)

Average forest carbon density in different carbon pools for the state of Madhya Pradesh is given in Table 2.4.

Table-2.4: Average forest carbon density in different carbon pools of Madhya Pradesh

Carbon Pool	National Average (t/ha)	Average in Madhya Pradesh (t/ha)
Aboveground biomass	32.50	22.14
Belowground biomass	10.07	8.67
Litter	1.50	1.12
Dead Wood	0.67	0.35
Soil Organic carbon	56.18	46.35
Total	**100.92**	**78.63**

(Source: FSI, 2021)

Overview of Forests of Chhattisgarh: Forests of the state are very important for ecological security as well as for providing livelihood to

the local communities of forest fringe villages. Recorded Forest Area of 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. As per India State of Forest Report 2021, the forest cover in the state was 55,716.60 sq km which is 41.21% of the state's geographical area. In terms of forest canopy density classes, the state has 7,068.21 sq km under Very Dense Forest, 32,278.59 sq km under Moderately Dense Forest and 16,369.80 sq km under Open Forest (Table 2.5). Forest Cover in the State has increased by 106.03 sq km as compared to the previous assessment of 2019 (FSI, 2021). Tree cover in Chhattisgarh has been estimated to be 5,3,55 sq km which is 3.96% of its geographical area. Total growing stock in the state was estimated to be 506.94 cum which comprises of 389.64 cum in recorded forest area and 117.30 cum in tree outside the forests (FSI, 2021).

Table-2.5: Forest Cover of Chhattisgarh

Class	Area (sq. km)	% of GA of State
Very Dense Forest	7,068.21	5.23
Moderately Dense Forest	32,278.59	23.87
Open Forest	16,369.80	12.11
Total	**55,716.60**	**41.21**
Scrub	615.26	0.45

(Source: FSI, 2021)

Overview of Forest Carbon Stock of Chhattisgarh: The total carbon stock of forests in the state of Chhattisgarh including the tree outside forest was estimated to be 496.44 million tonnes which is 6.89% of total forest carbon stock of the country (FSI, 2021). As per the India State of Forest Report 2021, pool wise forest carbon stock of Chhattisgarh is given in Table 2.6 and carbon density is given in Table 2.7.

Table-2.6: Forest carbon stock (in '000 tonnes) in different carbon pools of Chhattisgarh

Above Ground Biomass	Below Ground Biomass	Dead wood	Litter	Soil Organic Carbon	Total
1,52,714	48,947	2,520	8,487	2,83,769	4,96,437

(Source: FSI, 2021)

Table-2.7: Carbon density (t/ha) of forests of Chhattisgarh

Carbon Pool	2019	2021
Above Ground Biomass	26.24	27.41
Below Ground Biomass	8.44	8.78
Dead Wood	0.33	0.45
Litter	1.79	1.52
Soil Organic Carbon	49.56	50.93
Total	**86.36**	**89.09**

Source: FSI (2021)

Average forest carbon density in different carbon pools for the state of Chhattisgarh is given in Table 2.8.

Table-2.8: Average forest carbon density in different carbon pools of Chhattisgarh

Carbon Pool	National Average (t/ha)	Average in State of Chhattisgarh (t/ha)
Aboveground biomass	32.50	27.41
Belowground biomass	10.07	8.78
Dead Wood	0.67	0.45
Litter	1.50	1.52
Soil Organic carbon	56.18	50.93
Total	**100.92**	**89.09**

(Source: FSI, 2021)

Project Areas and Methodology for Forest Carbon Assessment

3

Project Areas of Madhya Pradesh

The Madhya Pradesh State Forest Department selected two L1 level landscapes (Satpura-Narmada and Vindhya Plateau) which comprise of three L2 level landscapes in Betul, Hoshangabad and Sehore Forest Divisions for implementation of the project activities under ESIP.

Hoshangabad: Hoshangabad (Narmadapuram) has 6,703 sq km geographical area in which 271.64 sq km is covered by very dense forest while 1,366.15 sq km is moderately dense forest and 783.41 sq km is covered by open forest. Banapura, Itarsi and Sukhtawa Forest Ranges in Hoshangabad Forest Division were selected for the implementation of the project activities under ESIP. Dry Teak and Southern Dry Mixed Deciduous Forests are the major forest type present in Banapura, Itarsi and Sukhtawa Forest Ranges of Hoshangabad Forest Division

Sehore: Sehore has 6,578 sq km geographical area in which 20.70 sq km is covered by very dense forest while 614.84 sq km is under moderately dense forest and 714.61 sq km is covered by open forest. Budhni Forest Range in Sehore Forest Division was selected for the implementation of the project activities under ESIP. Dry Teak and Southern Dry Mixed Deciduous Forest are Forest Type present in Budhni Forest Range of Sehore Forest Division.

Betul: Betul district has 10,043 sq km geographical area in which 230.11 sq km is covered by very dense forest while 1,922.32 sq km is under moderately dense forest and 1,510.36 sq km is under open forest. Bhaura Forest Range in North Betul Forest Division was selected for the implementation of the project activities under ESIP. Dry Teak and Southern Dry Mixed Deciduous Forest are Forest Type present in Bhaura Forest Range of North Betul Forest Division.

Project Areas of Chhattisgarh

The State Forest Department of Chhattisgarh initially selected four Forest Divisions viz. Marwahi, Balrampur, Kawardha and Katghora for implementation of the project activities under ESIP which fall under Gourela-Pendra-Marwahi, Balrampur, Kabirdham and Korba districts of Chhattisgarh. Kanker Forest Division was also selected in the later stage for implementation of the project activities under ESIP. Project areas under Kanker Forest Division was not considered for the assessment of forest carbon stock as baseline data of forest carbon stock were not available.

Gourela-Pendra-Marwahi: Gaurela-Pendra-Marwahi district is carved from Bilaspur district. Marwahi Forest Range in Marwahi Forest Division was selected for the implementation of the project activities under ESIP.

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. Raghunathnagar Forest Range in Balrampur Forest Division was selected for the implementation of the project activities under ESIP.

Kabirdham: Kabirdham has 36.55 % of its geographical area under forest cover. Kabirdham district has geographical area of 4,235 sq km of which 80.61 sq km is covered by very dense forest while 1,077.87 sq km is under moderately dense forest and 389.40 sq km is covered by open forest. Pandariya West Forest Range in Kawardha Forest Division was selected for the implementation of the project activities under ESIP.

Korba: Korba is blessed with lush green forest cover, where a sizable number of tribal populations is found. Pali Forest Range in Katghora Forest Division was selected for the implementation of the project activities under ESIP.

Methodology Used for Forest Carbon Assessment

Forests are both source and sink of carbon dioxide. A growing forest captures atmospheric carbon and this carbon is released into atmosphere through activities like deforestation and forest degradation. Measurement of forest carbon stock is a vital part of Ecosystem Services Improvement Project because carbon dioxide emission reductions and removals by implementing various project activities like assisted natural regeneration, plantation etc. help to enhance the forest carbon stock. The purpose of forest carbon stock assessment in the ESIP areas of Madhya Pradesh and Chhattisgarh was to know the impact of project activities on the forest carbon stock.

Carbon Pools: Five carbon pools viz., aboveground biomass, belowground biomass, litter, deadwood and soil organic matter were considered for measurement of forest carbon stock.

Sample Size: Sample size determination was conducted using the plantation year and baseline forest carbon stock. Accordingly, sample plot in Banapura, Itarsi and Sukhtawa Forest Ranges (45 sample plots), Bhaura Forest Range (36 sample plots) and Budhni Forest Range (33 sample plots) were calculated using variability analysis. Sample plots laying out and forest carbon stock measurement were done as per the standard procedures and methods given in the Resource Manual on Measurement of Forest Carbon stock for Capacity Building of State Forest Departments (ICFRE, 2020 a). Overall 114 sample plots including 39 permanent samples plots were laid out to estimate the changes in carbon stock in ESIP areas of Madhya Pradesh, and 112 sample plots including 33 permanent samples plots were laid out to estimate the changes in carbon stock in ESIP areas of Chhattisgarh. Sample plots laid out in the ESIP areas of Madhya Pradesh and Chhattisgarh are given in Table 3.1 and 3.2.

Table-3.1: Sample plots laid out in the project areas of Madhya Pradesh

Forest Range	Number of sample plots laid out	
	2019	2022
Budhni Forest Range	59	33
Bhaura Forest Range	45	36
Banapura, Itarsi and Sukhtawa Forest Range	51	45

Table-3.2: Sample Plots laid out laid out in the project areas of Chhattisgarh

Forest Range	Number of sample plots laid out	
	2019	2022
Marwahi Forest Range	45	34
Pali Forest Range	33	27
Pandariya West Forest Range	42	28
Raghunathnagar Forest Range	35	23

Aboveground Biomass: All the trees having diameter of 10 cm and above are enumerated in 0.1 ha plot. The height and diameter (1.37 m above the ground) of all trees (with circumference at breast height ≥30 cm) were measured. Diameter and height of all trees within the sample plot were used to estimate the standing volume. The species-specific volume equations were used to compute the volume of trees (FSI, 1996; FSI, nd). General volume equation is used for the species whose specific volume equation is not available. The estimated volume of each tree in sample plot was multiplied by its wood density (Rajput *et al* 1996) to drive the individual bole biomass.

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

Aboveground Sapling Biomass: Biomass equation for trees having DBH<10 cm was used to estimate the biomass and converted into carbon stock per hectare basis.

Shrubs and Herb 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. The samples were oven dried at 72°C in 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.

Belowground Biomass: Belowground biomass, commonly known as root biomass was estimated using a default root-to-shoot ratio value (0.28) (IPCC, 2006).

Soil Organic Carbon Density: The soil organic carbon 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 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 (Walkley and Black, 1934). The soil organic carbon was calculated by following Pearson *et al.,* 2007.

Bulk Density of Soil: Information on bulk density is required for determination of soil organic carbon content per unit area. Collection of soil sample for bulk density estimation 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 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. Exercise was repeated again in the soil 10-20 cm and 20-30 cm depth and samples kept in polythene bags with proper labeling for further laboratory analysis.

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. The samples were oven dried at 72°C in laboratory till constant dry weight. Carbon stock in each layer was estimated by multiplying the biomass value with 0.47 (IPCC, 2006).

The carbon values for each forest carbon pool were summed to estimate total forest carbon stock.

Result and Discussion

4

Assessment of Forest Carbon Stock

Implementation of ESIP activities envisaged to increase the carbon sequestration potential of the forests in the selected landscapes of Madhya Pradesh and Chhattisgarh and help in sequestering additional carbon of about 10 percent over the baseline stock. Madhya Pradesh State Forest Department and Chhattisgarh State Forest and Climate Change Department had done the enrichment plantations, fencing and assisted natural regeneration activities in the forest areas for improvement of forest health and enhancement of forest carbon stock under ESIP. The details of forest cover of ESIP areas under the Budhni Forest Range, Bhaura Forest Range, and Banapura, Itarsi and Sukhtawa Forest Ranges of Madhya Pradesh are given in Table 4.1. Details of plantations done by Madhya Pradesh State Forest Department in the project areas under ESIP are given in Table 4.2.

Table-4.1: Forest Cover in ESIP Areas of Madhya Pradesh in year 2019

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

(Source: ICFRE, 2020 b)

Table-4.2: Plantation done in the project areas of Madhya Pradesh under ESIP

Forest Range	Plantation (ha)
Budhni Forest Range	550
Bhaura Forest Range	1025
Banapura, Itarsi and Sukhtawa Forest Ranges	1400
Total	**2975**

The details of forest cover of ESIP areas under the Marwahi Forest Range, Pali Forest Range, Pandariya West Forest Range and Raghunathnagar Forest Ranges of Chhattisgarh are given in Table 4.3. Detail of plantation work done by Chhattisgarh Forest Department in the project areas under ESIP are given in Table 4.4.

Table-4.3: Forest Cover in ESIP Areas of Chhattisgarh in the year 2019

Forest Range	Forest Density Class	Area (ha)
Raghunathnagar Forest Range	Open Forest	1065.66
	Moderately Dense Forest	1198.94
	Very Dense Forest	-
Total		**2264.60**

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**

(Source: ICFRE, 2020 c)

Table-4.4: Plantation done in the project areas of Chhattisgarh under ESIP

Forest Range	Plantation (ha)
Raghunathnagar Forest Range	575
Pali Forest Range	750
Marwahi Forest Range	1173
Pandariya West Forest Range	720
Total	**3218**

Major tree species planted by Madhya Pradesh State Forest Department in the project areas are *Phyllanthus emblica*, *Terminalia arjuna*, *Terminalia bellirica*, *Pongamia pinnata*, *Syzygium cumini*, *Tectona grandis*, *Azadirachta indica*, *Madhuca longifolia*, *Tamarindus indica*, *Schleichera oleosa*, *Bridelia retusa*, *Bauhinia variegata*, *Ficus religiosa* and *Dalbergia sissoo*.

Major tree species planted by Chhattisgarh State Forest and Climate Change Department in the project areas are *Phyllanthus emblica*, *Aegle marmelos*, *Terminalia arjuna*, *Terminalia bellirica*, *Pongamia pinnata*, *Syzygium cumini*, *Tectona grandis*, *Azadirachta indica*, *Madhuca longifolia*, *Tamarindus indica*, *Schleichera oleosa*, *Ficus religiosa*, *Shorea robusta*, *Gmelina arborea*, *Mitragyna parvifolia*, *Cassia fistula*, *Cleistanthus collinus*, *Dalbergia sissoo*, *Zizyphus mauritiana*, *Neolamarckia cadamba*, *Albizia lebbeck* and *Saccopetalum tomentosum*.

Forest Carbon Stock in Project Areas of Madhya Pradesh

The total forest carbon stock in project areas of Madhya Pradesh for the year of 2022-23 has been estimated to be 1302477.11 tonnes over the baseline total forest carbon stock of 1172639.19 tonnes in the year 2018-19 (Table 4.5). It means total forest carbon stock have increased by 11.25% over the baseline forest carbon stock.

Table-4.5: Total forest carbon stock of project areas of Madhya Pradesh

Forest Range	Total forest carbon stock in 2018-19 (in Tonnes)	Total forest carbon stock in 2022-23 (in Tonnes)
Budhni Forest Range	237013.53	262445.08
Bhaura Forest Range	378629.12	429062.52
Banapura, Itarsi and Sukhtawa Forest Ranges	556996.54	610969.50
Total	**1172639.19**	**1302477.10**

The data of the assessment study revealed that average carbon stock density for Banapura, Itarsi and Sukhtawa Forest Ranges, Budhni Forest Range and Bhaura Forest Range was estimated to be 68.27 t/ha, 66.24 t/ha and 65.26 t/ha, respectively. Soil organic carbon contribution ranged from 28.53 t/ha in Banapura, Itarsi and Sukhtawa Forest Ranges to 34.89 t/ha in Budhni Forest Range (Table 4.6).

Table-4.6: Carbon pool wise carbon stock density in project areas of Madhya Pradesh

Forest Ranges	Carbon stock density (t/ha) in 2022-23					
	AGB	BGB	Litter	Deadwood	Soil	Total
Budhni Forest Range	24.42	6.84	0.10	-	34.89	**66.24**
Bhaura Forest Range	28.05	7.85	0.10	-	29.26	**65.26**
Banapura, Itarsi and Sukhtawa Forest Ranges	30.94	8.66	0.14	-	28.53	**68.27**

Forest Carbon Stock in Budhni Forest Range: The carbon stock density for Budhni Forest Range ranged from 30.26 t/ha to 133.73 t/ha. Average carbon stock density was estimated to be 66.24 t/ha. Aboveground biomass (AGB) contribution in carbon stock density was 37% while the contribution of belowground biomass (BGB) was 10%. Soil organic carbon (SOC) has the maximum contribution of 53% in the carbon stock density (Fig. 4.1).

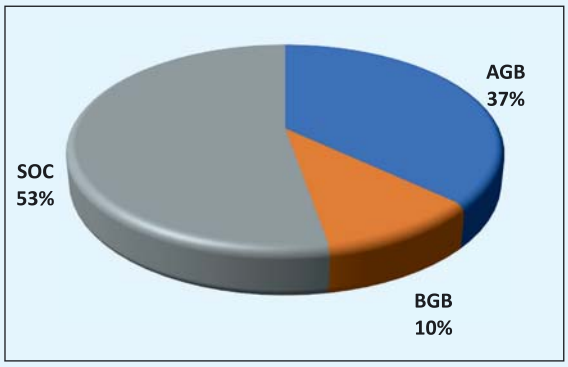

Fig.4.1.: Carbon stock contribution of various carbon pools in Budhni Forest Range

Forest Carbon Stock in Bhaura Forest Range: The carbon stock density for Bhaura Forest Range ranged from 44.04 t/ha to 98.61 t/ha. Average carbon stock density has been estimated to be 65.26 t/ha. Aboveground biomass (AGB) contribution in carbon stock density was recorded to be 43% while the contribution of belowground biomass (BGB) was 12%. Soil organic carbon (SOC) contributes maximum of 45% in the carbon stock (Fig. 4.2).

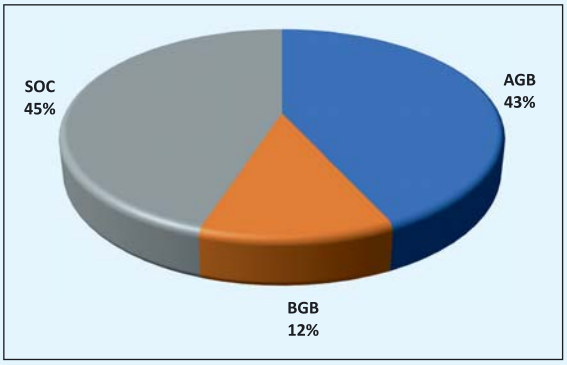

Fig.4.2.: Carbon stock contribution of various carbon pools in Bhaura Forest Range

Forest Carbon Stock in Banapura, Itarsi and Sukhtawa Forest Ranges: Average carbon stock density for Banapura, Itarsi and Sukhtawa Forest Ranges has been estimated to be 68.27 t/ha. Aboveground biomass (AGB) contribution in carbon stock density was recorded to be 45% while the contribution of belowground biomass (BGB) was recorded to be 13%. Soil organic carbon (SOC) has the contribution of 42% in the carbon stock density (Fig. 4.3).

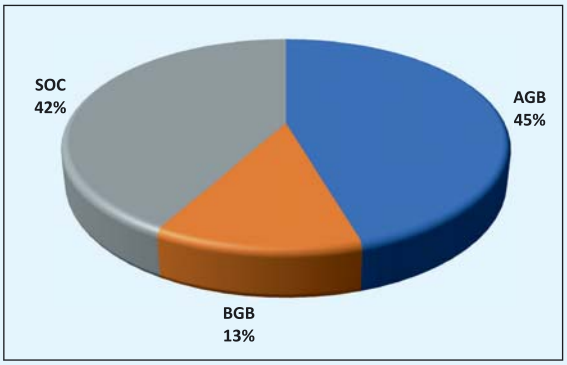

Fig.4.3.: Carbon stock contribution of various carbon pools in Banapura, Itarsi and Sukhtawa Forest Ranges

Changes in Forest Carbon Stock: Total forest carbon stock was estimated and increased by 11.25% in the project areas of Madhya Pradesh over the baseline forest carbon stock. Total forest carbon stock was estimated to be increased by 13.32% in Bhaura Forest Range, 10.73% in Budhni Forest Range while total carbon stock was estimated to be increased by 9.69% in Banapura, Itarsi and Sukhtawa Forest Ranges (Table 4.7).

Table-4.7: Incremental changes in the total forest carbon stock in project areas of Madhya Pradesh

Forest Ranges	Total forest carbon stock (in Tonnes)		
	2018-19	2022-23	% Increment
Budhni Forest Range	237013.53	262445.08	10.73
Bhaura Forest Range	378629.12	429062.52	13.32
Banapura, Itarsi and Sukhtawa Forest Ranges	556996.54	610969.50	9.69

The average carbon stock density in Budhni, Bhaura and Banapura, Itarsi & Sukhtawa Forest Ranges were 59.82 tC/ha, 57.59 tC/ha and 62.24 tC/ha, respectively in 2018-19. This increased to 66.24 tC/ha, 65.26 tC/ha and 68.27 tC/ha in Budhni, Bhaura and Banapura, Itarsi, Sukhtawa Forest Ranges respectively in 2022-23. The aboveground components and soil have maximum share of the total forest carbon stock, whereas deadwood contribution was negligible. Incremetal changes in carbon stock density in project areas of Madhya Pradesh is given in the Table 4.8.

Table-4.8: Incremental changes in carbon stock density in project areas of Madhya Pradesh

Forest Ranges	Average carbon stock density (t/ha)		
	2018-19	2022-23	% Increment
Budhni Forest Range	59.82	66.24	10.73
Bhaura Forest Range	57.59	65.26	13.32
Banapura, Itarsi and Sukhtawa Forest Ranges	62.24	68.27	9.69
Average	**59.88**	**66.59**	**11.25**

Forest Carbon Stock in Project Areas of Chhattisgarh

The total forest carbon stock in project areas of Chhattisgarh for the year of 2022-23 was estimated to be 1312014.46 tonnes (Table 4.9) over the baseline total forest carbon stock of 1223310.56 tonnes for the year 2018-19. It means total forest carbon stock has been increased by 7.51% over the baseline forest carbon stock.

Table-4.9: Total forest carbon stock of project areas of Chhattisgarh

Forest Ranges	Total forest carbon stock in 2018-19 (in Tonnes)	Total forest carbon stock in 2022-23 (in Tonnes)
Raghunathnagar Forest Range	126538.39	136572.88
Pali Forest Range	348362.24	373200.47
Marwahi Forest Range	261660.33	283901.46
Pandariya West Forest Range	486749.60	518339.65
Total	**1223310.56**	**1312014.46**

Average carbon stock density for Raghunathnagar Forest Range was estimated to be 64.83 t/ha with aboveground biomass (AGB) carbon contribution of 26.01 t/ha while 7.28 t/ha is contributed by belowground biomass (BGB) carbon. Average carbon stock density for Pali Forest Range has been estimated to be 103.63 t/ha with the aboveground biomass (AGB) carbon contribution of 54.35 t/ha. Average carbon stock density for Marwahi Forest Range been estimated to be 63.72 t/ha with aboveground biomass (AGB) carbon contribution of 25.91 t/ha. Soil organic carbon contribution ranged from 30.46 t/ha in Marwahi Forest Range to 35.25 t/ha in Pandariya West Forest Range (Table 4.10).

Table-4.10: Carbon pool wise carbon stock density in project areas of Chhattisgarh

	Carbon Stock Density (t/ha) in 2022-23					
Forest Ranges	**AGB**	**BGB**	**Litter**	**Deadwood**	**Soil**	**Total**
Raghunathnagar Forest Range	26.01	7.28	0.09	-	31.45	64.83
Pali Forest Range	54.35	15.22	0.15	-	33.91	103.63
Marwahi Forest Range	25.91	7.25	0.10		30.46	63.72
Pandariya West Forest Range	39.67	11.11	0.14	-	35.25	86.16

Forest Carbon Stock in Raghunathnagar Forest Range: Average carbon stock density for Raghunathnagar Forest Range has been estimated to be 64.83 t/ha. Aboveground biomass (AGB) contribution in carbon stock density was recorded to be 40% while the contribution of belowground biomass (BGB) was recorded to be 11%. Soil organic carbon (SOC) contribution was estimated to be 49% in the carbon stock density (Fig. 4.4).

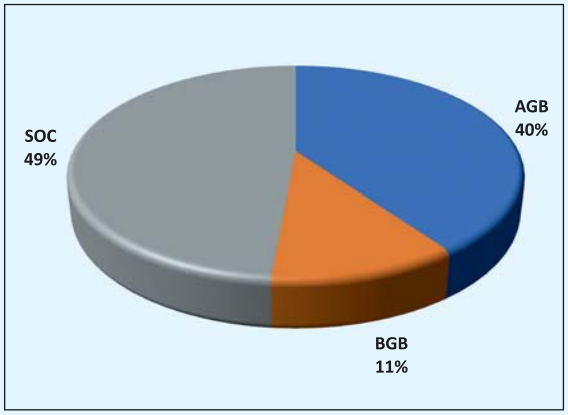

Fig.4.4.: Carbon stock contribution of various carbon pools in Raghunathnagar Forest Range

Forest Carbon Stock in Marwahi Forest Range: Average carbon stock density for Marwahi Forest Range has been estimated to be 63.72 t/ha. Aboveground biomass (AGB) contribution in carbon stock density was recorded to be 41% while the contribution of belowground biomass (BGB) was 11%. Soil organic carbon contributes maximum of 48% in the carbon stock (Fig. 4.6).

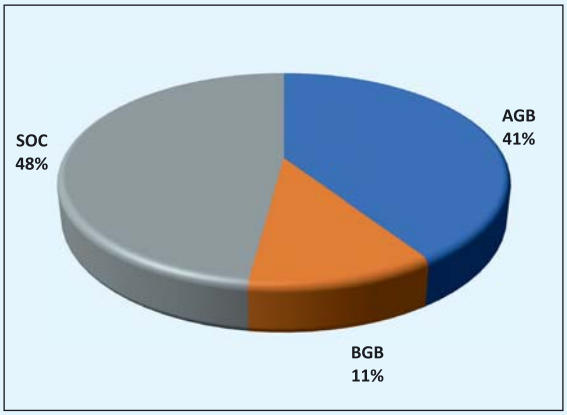

Fig.4.6.: Carbon stock contribution of various carbon pools in Marwahi Forest Range

Forest Carbon Stock in Pali Forest Range: Average carbon stock density for Pali Forest Range was estimated to be 103.63 t/ha. Aboveground biomass (AGB) contribution in carbon stock density was 52% while the contribution of belowground biomass (BGB) in carbon stock was recorded to be 15%. Maximum contribution of 33% in the carbon stock density was estimated for soil organic carbon pool (Fig 4.5).

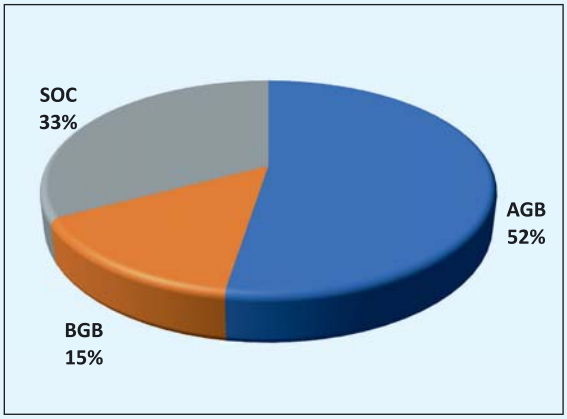

Fig.4.5.: Carbon stock contribution of various carbon pools in Pali Forest Range

Forest Carbon Stock in Pandariya West Forest Range: Average carbon stock density for Pandariya West Forest Range has been estimated to be 86.16 t/ha. Aboveground biomass (AGB) contribution in carbon stock density is recorded to be 46% while the contribution of belowground biomass (BGB) is 13%. Soil organic carbon contributes maximum of 41% in the carbon stock (Fig 4.7).

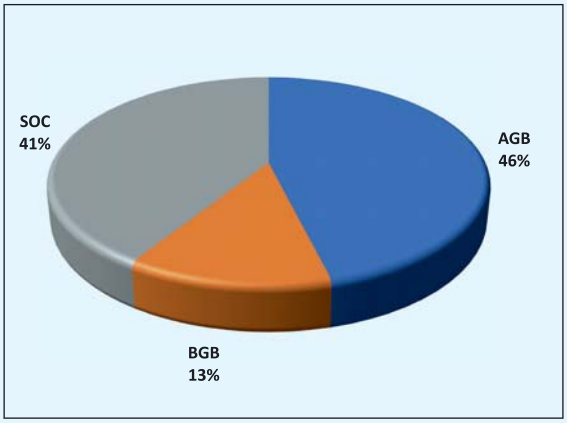

Fig.4.6.: Carbon stock contribution of various carbon pools in Marwahi Forest Range

Changes in Forest Carbon Stock: During the assessment period from 2018-19 to 2022-23, total forest carbon stock was estimated to be increased by 7.51% in the project areas of Chhattisgarh. Total carbon stock of Marwahi Forest Range was estimated to be increased by 8.50% while total carbon stock in Pandariya West Forest Range was estimated to be increased by 6.49%. Total carbon stock of Pali Forest Range and Raghunathnagar Forest Range were estimated to be increased by 7.13% and 7.93% as compared to baseline carbon stock of 2019 (Table 4.11).

Table-4.11: Incremental changes in the total forest carbon stock in project areas of Chhattisgarh

Forest Ranges	Total Forest carbon stock (in Tonnes)		
	2018-19	2022-23	% Increment
Raghunathnagar Forest Range	126538.39	136572.88	7.93
Pali Forest Range	348362.24	373200.47	7.13
Marwahi Forest Range	261660.33	283901.46	8.50
Pandariya West Forest Range	486749.60	518339.65	6.49

The average carbon stock density in Raghunathnagar, Pali, Pandariya West and Marwahi Forest Ranges were 60.07 t/ha, 96.73 t/ha, 80.91 t/ha and 58.73 t/ha respectively in 2019. This increased to 64.83 tC/ha, 103.63 tC/h, 86.16 t/ha and 63.72 t/ha in Raghunathnagar, Pali, Pandariya West and Marwahi Forest Ranges in 2022. The aboveground biomass and soil have maximum share of the total forest carbon stock, whereas deadwood contribution is nil. During the monitoring period (2019-2022), 7.93% carbon stock was estimated to be increased in Raghunathnagar Forest Range while 7.13% carbon stock was estimated to be increased in Pali Forest Range. 6.49% carbon stock was estimated to be increased in Pandariya West Forest Range while 6.49% increased carbon stock in Marwahi Forest Range as compared to baseline in 2019 (Table 4.12).

Table-4.12 : Incremental changes in carbon stock density in project areas of Chhattisgarh

Forest Ranges	Average carbon stock density (t/ha)		
	2018-19	2022-23	% Increment
Raghunathnagar Forest Range	60.07	64.83	7.93
Pali Forest Range	96.73	103.63	7.13
Marwahi Forest Range	58.73	63.72	8.50
Pandariya West Forest Range	80.91	86.16	6.49
Average	**74.11**	**79.58**	**7.51**

In Madhya Pradesh, forests are surrounded by large numbers of villages and most of the tribal populations depend upon forests for their livelihood security (Pande, 2005). Aboveground biomass and carbon stock varied with the degree of anthropogenic pressure in tropical dry deciduous forests in Madhya Pradesh. Several studies indicated that the rural populations of forest fringe villages solely depend upon forest biomass for meeting their livelihood security such as fuel wood, fodder, non-timber forest products etc and degrade the forest quality through over exploitation (Sagar *et al.*, 2003, Pande, 2005; Ramacharitra, 2006, Salunkhe *et al.*, 2014; Salunkhe *et al.*, 2016). Human intervention, land use changes and other activities, released carbon from forests in to the atmosphere (Haripriya, 2003; Bhat and Ravindranath, 2011).

The average forest carbon density for the ESIP areas of Madhya Pradesh (66.71 t/ha) and Chhattisgarh (79.32 t/ha) is lower than the state average of Madhya Pradesh (78.63 t/ha) and Chhattisgarh (89.09 t/ha). The reasons for

lower average carbon density in the project areas of Madhya Pradesh and Chhattisgarh are due to the fact that project areas chosen for implementation of the project intervention/ activities are falling in the central Indian highlands which are part of the 39 percent forest grids of India identified and mapped as 'vulnerable to climate change'. Project areas are also under degradation due to unsustainable land use practices. Forest carbon assessment done by the Forest Survey of India covered forest as well as tree outside the forest areas as a whole whereas the assessment of the forest carbon stock done in the project areas of Madhya Pradesh and Chhattisgarh under ESIP only covered the forest areas.

The forests of the project areas are extremely under anthropogenic disturbances, because the rural communities depend on the forests for their daily needs i.e. fuel wood, fodder, non-wood forest produces etc. Similar types of pressure on the forests under the ESIP areas of Madhya Pradesh and Chhattisgarh have been observed during the field surveys which can be one of the reasons for less forest carbon stock. Poor regeneration of tree species due to heavy grazing, repeated forest fire and invasion by obnoxious weeds have also observed during the field surveys. ICFRE has reported that fuel wood has been used as a primary source of energy for cooking and on an average 20 kg of fuel wood has been collected per day per households from forest in the project areas. Besides the 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 d, 2020 e).

Activities like water conservation, agri-horticulture promotion, fodder cultivation, fire management by the local community can support the growth of the 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 Madhya Pradesh and Chhattisgarh.

Conclusion

5

The total forest carbon stock in project areas of Madhya Pradesh was estimated to be 1302477.11 tonnes with the average carbon density of 66.59 t/ha over the baseline total forest carbon stock of 1172639.19 tonnes. The total forest carbon stock in project areas of Chhattisgarh was estimated to be 1311347.53 tonnes with the average carbon density of 79.58 t/ha over the baseline total forest carbon stock of 1223310.56 tonnes. The current assessment for the year 2022-23 reveals that the forest carbon stock in the ESIP areas of the Madhya Pradesh was increased by 11.25% over the baseline forest carbon stock for the year 2018-19. The forest carbon stock in the ESIP areas of Chhattisgarh was increased by 7.51% over the baseline forest carbon stock. It can be concluded that an increment of 9.38% was estimated in the total forest carbon stock of project areas of Madhya Pradesh and Chhattisgarh over the baseline forest carbon stock.

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