Impact of Climate Change on Forests and Biodiversity of Madhya Pradesh

- An Assessment Report

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This report is prepared under the financial support by **Department for International Development (DFID)** for the project **Strengthening Performance Management in Government (SPMG)** being implemented in Madhya Pradesh state of India. SPMG is an initiative of Department for International Development (DFID) to provide assistance to Government of Madhya Pradesh for strengthening planning and governance systems. One of the key focus areas of SPMG is to ensure environmental sustainability and climate compatible development in the state. As part of this initiative, **Development Alternatives (DA)** is recognized by Government of MP and DFID to provide technical support to Madhya Pradesh **State Knowledge Management Centre on Climate Change (SKMCCC), EPCO**. DA is assisting SKMCCC in facilitating integration of climate change concerns into departmental activities and plans, through strengthening technical capacities and generating strategic knowledge.

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Executive Summary

In view of the recent COP 21 agreement at Paris, forests and terrestrial ecosystems are increasingly assuming a prominent role both as an important carbon sink, as well as an adaptation option due to its role in diversifying livelihood opportunities of the rural communities as well as its moderating impact on climate, climate extremes, land degradation, water resources and biodiversity conservation.

As part of its INDC, India has pledged to carry out massive afforestation and reforestation activities to sequester an additional 2.5-3.0 $GtCO_2$ till 2030. The COP 21 agreement too relies heavily on forests to achieve zero carbon emissions in the next half of this century, in order to limiting warming below 2°C. Forests in MP currently store about 2.5 billion tonnes of CO_2, and these forests further represent a large potential sink of carbon as well. Forests are a biological system and hence are highly sensitive to climate change impacts. Questions such as how could climate change potentially impact the forests of the state and its ecosystem services, including carbon sequestration and livelihood security of the communities, in the next half of this century?, are critical to meet the objectives outlined in India's INDC and the COP 21 agreement. In this report, we assess the possible impacts of climate change on the forests and carbon stocks of Madhya Pradesh using state of the art Lund-Postdam and Jena (LPJ) model and by using the latest multiple CMIP5 and RCP based climate change projections.

Populations of many species including the plants are already threatened are expected to be placed even at a greater risk by multiple stresses of changing climate, land-use change and fragmented habitats. Though there are uncertainties with respect to projections of climate change impacts on forest ecosystems, evidence is growing to show that climate change, coupled with socio-economic and land use pressures, is likely to adversely impact forest biodiversity, carbon sink, biomass productivity, and the livelihoods of forest dependent communities. Our research (Chapter 5) suggests that a large number of forested grids especially in the western parts of the state are projected to undergo change; the changes are likely to be triggered by changing moisture, CO_2 fertilization and temperature regimes. Additionally we also find that the net primary productivity in the state is likely to increase leading to more carbon sequestration potential. Carbon stocks in the biomass as well as soil carbon are also likely to increase in the changing climate leading to potential enhanced carbon sequestration benefits in future. However forest fragmentation, forest degradation, moisture and nutrient deficits as well as increased incidents of fire and pest attacks may adversely impact the scenario of increasing productivity. Fragmented and isolated forest patches will act as barriers for efficient seed dispersal and pollination. Thus many forest types may find it hard to expand to more optimally suited locations. Rainfall projections are generally less reliable than the temperature projections; also our modeling has limitations in terms of characterization of forest fires, pest attacks and nutrient cycling of some key elements.

In Madhya Pradesh a large proportion of the population depends on the climate sensitive sectors such as agriculture, forests and fisheries for their livelihood. Forest dependent communities form one of the poorest sections of society that are likely to be adversely impacted due to climate change. Due to poorly developed institutions, markets, technology transfer pathways and lack of financial resources, forest dependent communities have low capacity to cope with or adapt to adverse impacts. Those with the least resources and the least capacity to adapt such as forest dwellers are the most vulnerable (Chapter 6).

In Chapter 7 we list the adaptation practices required for building resilience to the forests and forest dependent communities in the state. Since fragmented and isolated forest patches are likely to be adversely impacted by the climate change, forest conservation, afforestation/reforestation activities in the state should be designed such that these activities reduce the fragmentation and build corridors among the isolated forests. It is important to carry out the forest conservation activities in a way that these activities increase the overall biodiversity richness of these forests, by planting of mix species, and the native species. Such corridors will not be only useful for building resilience within the forest ecosystems, but will also provide migratory paths for different fauna as well, leading to their conservation and reduction of human-animal conflicts. Since water and nutrient deficits are a critical bottleneck for realizing the benefits of increases in the productivity, it is important that water conservation activities accompany the forest conservation activities in the forests of the state. In the state, a large number of people depend on forest resources for their livelihood, to improve the livelihood security of the forest dependent communities in the state it is important that the livelihoods of the forest dependent communities is diversified and modernized via innovative institutional and market linkages.

Chapter 1: Introduction

Madhya Pradesh (MP) has the largest forest area in India and is one of the forest rich states in India with more than 27% of its geographic area falling under the forests and tree cover, as against 24.1% of the national average (FSI, 2013). MP Forests are well spread across the entire state. The figure below displays the forest distribution of different density classes in the state for the year 2013.

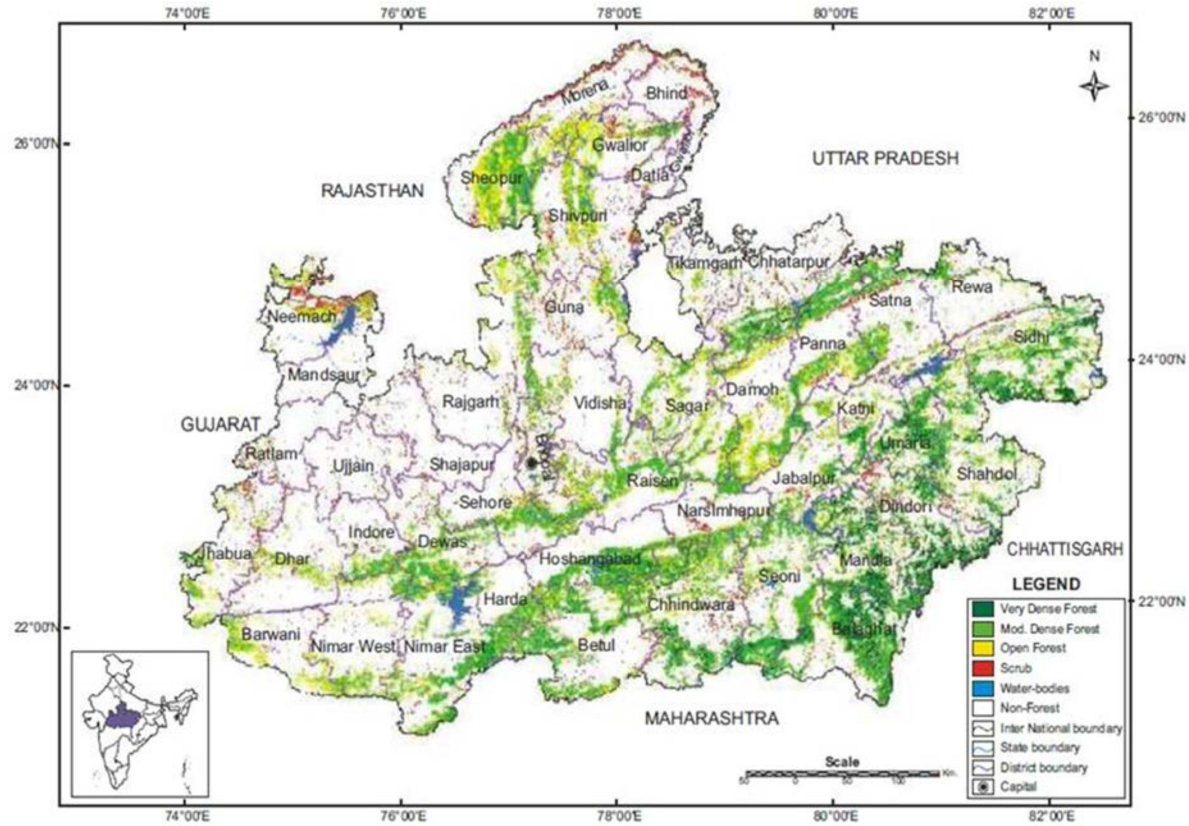

Figure 1.1: Distribution of forest area in Madhya Pradesh (Source: FSI, 2013)

Forest area in Madhya Pradesh remained stable over the last decade despite a population density of 236 persons/ sq. Km, and a livestock population of 40.7 million.

Forests of MP are a rich repository of the diversity in flora and fauna. Forests in this central Indian state are generally divided into the following vegetation types: 1. Moist Teak forest, 2. Moist Mixed forest, 3. Deciduous Forest, 4. Moist Peninsular Sal Forest, 5. Very Dry Teak Forest, 6. Dry Teak forest, 7. Southern Dry Mixed Deciduous Forest, 8. Dry Peninsular Sal Forest, 9. Northern Dry Mixed Deciduous Forest, 10. Dry Deciduous Scrub, 11. Dry Savannah Forest, 12. Dry Grassland, 13. Anogeissus pendula Forest,14. Anogeissus pendula Scrub Forest, 15. Boswellia Forest,16. Butea Forest,17. Dry Bamboo Brakes, 18. Khair-Sissu Forest,19.Ravine Thorn Forest20. Plantations/TOF

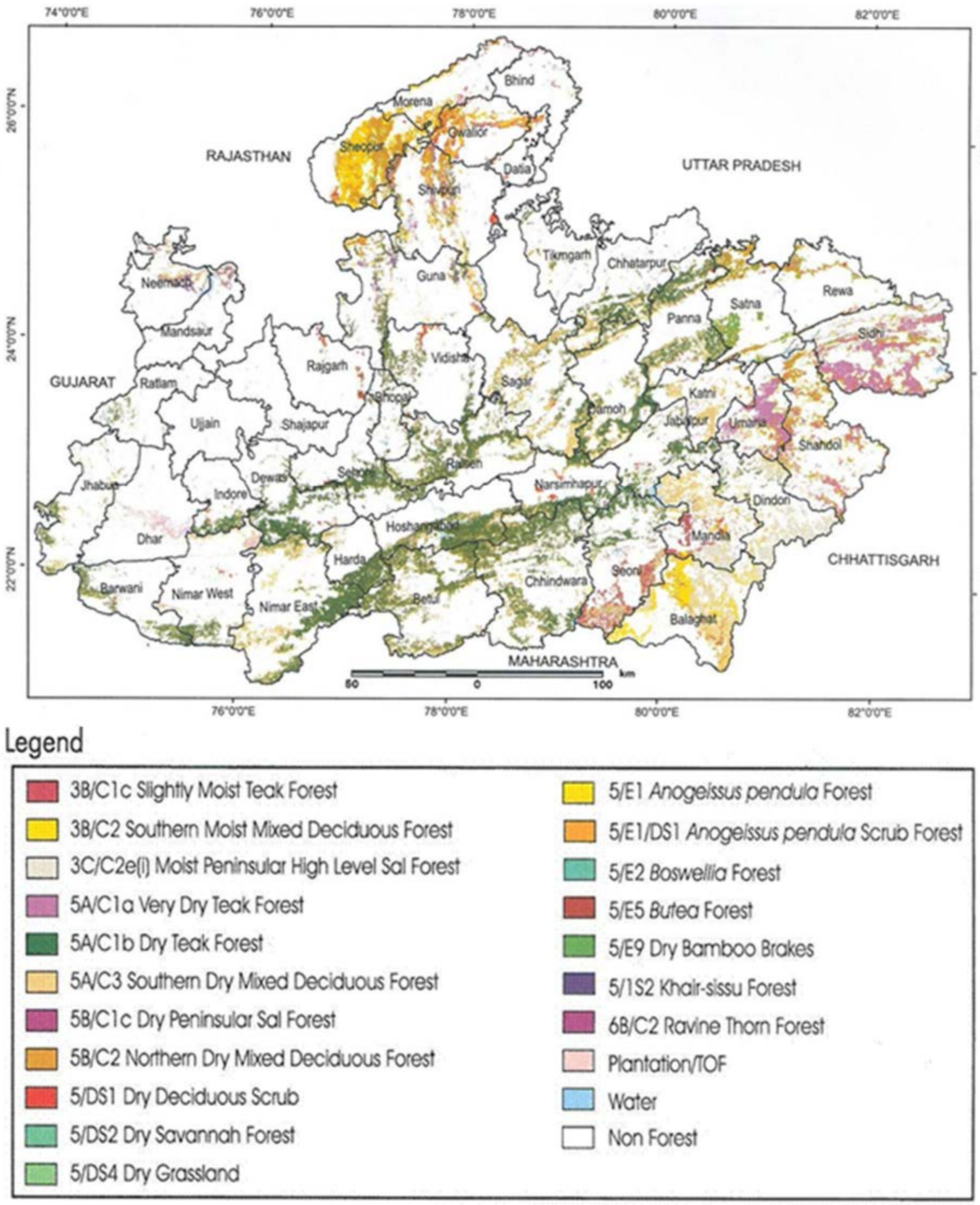

Figure 1.2: Forest type map of Madhya Pradesh as per the Champion & Seth 1968 classification (Source: "FSI, MP Forest Atlas")

It is estimated that the forests in MP stored a total of 682 Million tonnes of carbon in the year 2004 (or about ten percent of India's total forest carbon), of which 368 Mt was stored in biomass, and 314 Mt in the soils (FSI, 2014). Thus, MP forests do provide a valuable service to maintain the equilibrium of the global climate. This forest carbon stock could be impacted by climate change, land-use change, occurrences of uncontrolled fire and pest attacks.

As forests are spread throughout the state, a large number of villages in MP lie inside the forests or at forest fringes. These villages largely depend on the forests for their fuel-wood requirement and the extraction of Non Timber Forest Products (NTFPs). It is estimated that about 66.4% of MP households depend on fuel-wood for cooking and a total of 16.7 million M^3 of fuel-wood was extracted from the forests of Madhya Pradesh in the year 2010 (ICFRE, 2010). The key forest produce from this state include: *Tendu leaves, Neem, palash, mahua, mango* etc. Many of the forest-dependent communities rely on these forest produce for their livelihood security.

In this study, we are keen to understand how the ongoing changes in climate are already impacting the different forest types, livelihood opportunities of the forest-dependent communities, and carbon stocks stored in the forests and forest soils in the state of MP. And, how could the projected climate change scenarios may further impact these forests?

IMD (2013), based on an analysis of observed data from 25 temperature monitoring weather stations and 120 rainfall monitoring weather stations over the 60 year period from 1950-2010, concludes that Madhya Pradesh has witnessed an average annual warming of 0.6°C (with the rate of 0.01°C per year)over this period. Further, IMD (2013) assessment concludes that much of this warming is occurring in the months of September to November, as the warming trend is most pronounced in the post-monsoon season in Madhya Pradesh. MP receives an annual average rainfall of about 1000mm.However, according to IMD (2013), the state has witnessed a declining trend in rainfall at 1.88 mm/year over the period 1951-2010. More than 90% of this decline in rainfall occurred during the monsoon season.

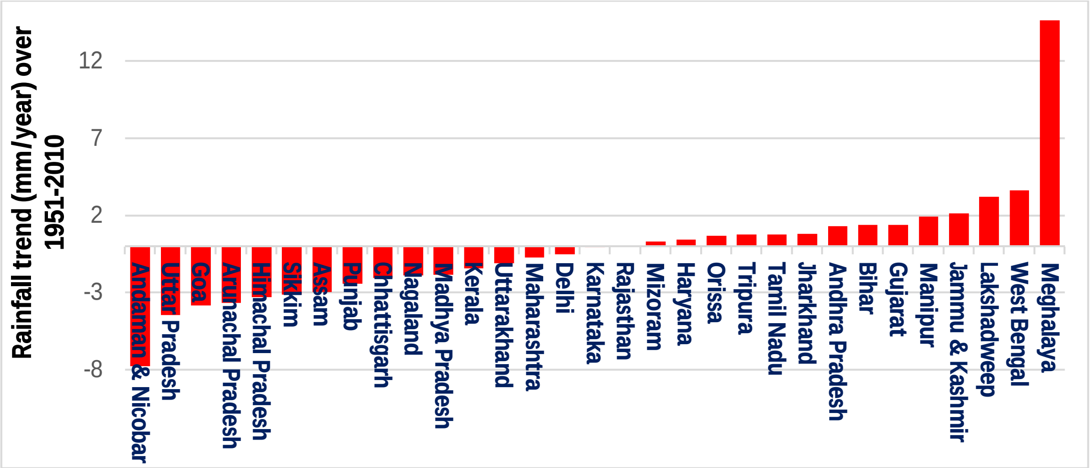

Figure 1.3: Rainfall trend in different states of India, including MP (1951-2010)

While the average annual rainfall in the state has been declining, MP is simultaneously witnessing an increase in extreme rainfall events. Kaladkar et al (2009) scanned through the daily rainfall data of 165 stations across the Indian region (including stations from Madhya Pradesh) to find out their extreme point rainfall events (highest 24-hour rainfall) and examined whether there was any change in the number and the intensity of such events during the past four decades (1960-2009). The study reveals that the number and intensity of extreme rainfall events have gone up considerably after 1960, with an alarming rise in the intensity thereafter. Kaladkar et al (2009) further suggest that these events may be associated with the global and regional warming.

It is important to understand how these ongoing climatic changes in the state are impacting its forests and biodiversity in the long-term. Our long-term research in this field (ecosystem dynamics) suggests that 'phenology', 'growth rates/ productivity' and 'shifting distributions of species and biomes' are the most prominent indicators of change in the forest ecosystems in response to climate change. In terms of forest productivity, Bala et al (2013) estimated that the Net Primary Productivity (NPP) over the Indian region has increased by 3.9% per decade, over the period 1982 to 2006, driven mainly by elevated atmospheric CO_2 concentration in different ecosystems. It is understood from this study that the forests in MP are also experiencing an increase in the net primary productivity over the last three decades. Estimation of 'forest range shifts' requires long-term monitoring of forest inventory/ observation plots. For example, in the case of US, Zhu et al (2012), based on the observations of 92 species collected from more than 43000 forest plots in 31 US states, demonstrated that climate change is occurring more rapidly than the trees can adapt in this part of the World, with 59% of tree species showing signs that their geographic ranges are contracting from both North and South. However, such long-term monitoring plots are not maintained in India and reliable data in this regard is not available in the public domain.

Further, projected climate change is likely to impact the productivity of forests, optimal suitability of species and forest type and their assemblages to a specific location, causing forest range shifts, carbon stock of the forest ecosystems in both the biomass and soil carbon pools, and livelihood of the forest dependent communities. It is projected that under the business-as-usual climate change scenario, the mean annual temperature in India increases by 3.3°C (RCP6.0) to 4.8°C (RCP8.5) and the all India annual rainfall is projected to increase by 6-14 % towards the end of the 21st century (Chaturvedi et al 2012). At the all-India level, Chaturvedi et al 2011, conclude that, the net productivity of the Indian forests increases by 51-68% under the climate change scenarios. And, about 34-39% of the forest grids may experience vegetation type shifts by the end of the 21st century.

There is a need to calibrate and set up a DGVM analysis for the state of MP by using high resolution climate, soil and vegetation information, preferably drawn from the local sources and primary studies, and to assess the impacts of climate change on the vegetation distribution, forest productivity, carbon stocks and livelihood security of the forest-dependent communities in MP. In this context, the study aims to:

1. Assess the impact of observed climate change on the forests of Madhya Pradesh, based on long-term satellite records
2. Assess the impact of climate change on Net Primary Productivity (NPP) of the forests in the state
3. Assess the impact of climate change on soil carbon dynamics in the forests of the state

4. Assess the impact of climate change on distribution of forest types, vegetation and their Phenologies in the state

5. Assess and evaluate the impact of climate change on livelihood security of the forest-dependent communities

6. Develop and suggest adaptation actions to mitigate impacts of climate change on the forests of MP.

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Chapter 2: Methodology

A number of approaches are available to assess the impact of climate change on forests and biodiversity. The models used to predict large-scale vegetation responses to future climate change can be categorized as deterministic and statistical models (as shown in the figure below). Deterministic models can be classified as 'Static' and 'Dynamic'. The static and dynamic models can be based on bio-geography/bio-geochemistry based modules or both.

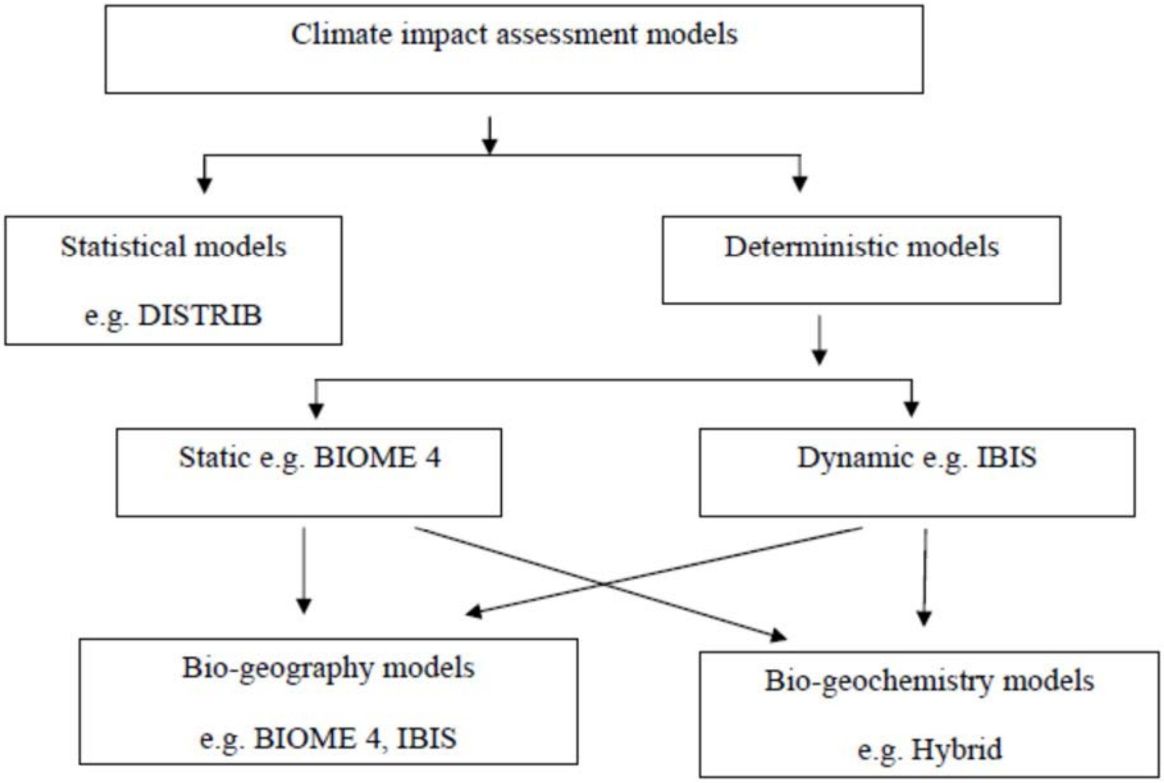

Figure 2.1: Different types of models available for assessment of climate change impacts on the forests and biodiversity

2.1. Model

Fischling et al. (2007) conclude that the most advanced tool to estimate the impact of climate change on vegetation dynamics at global scale include DGVMs. DGVMs simulate time-dependent changes in vegetation distribution and properties, and allow mapping of changes in the ecosystem function and services (Metzger et al. 2006; Schroter et al. 2005). Fishling et al (2007) further conclude that with the adoption of DGVMs, reliability of results has improved in relation to previous generations of models. Hence, in this assessment, we decided to use a DGVM for assessing the impact of projected climate change on forest ecosystems in Madhya Pradesh. Though a number of DGVMs are available, we chose to use one of the most active and advanced DGVMs i.e Lund Postdam and Jena model (LPJ; Sitch et al 2003). The structural outline and processes of the LPJ model are displayed in Figure 2.2.

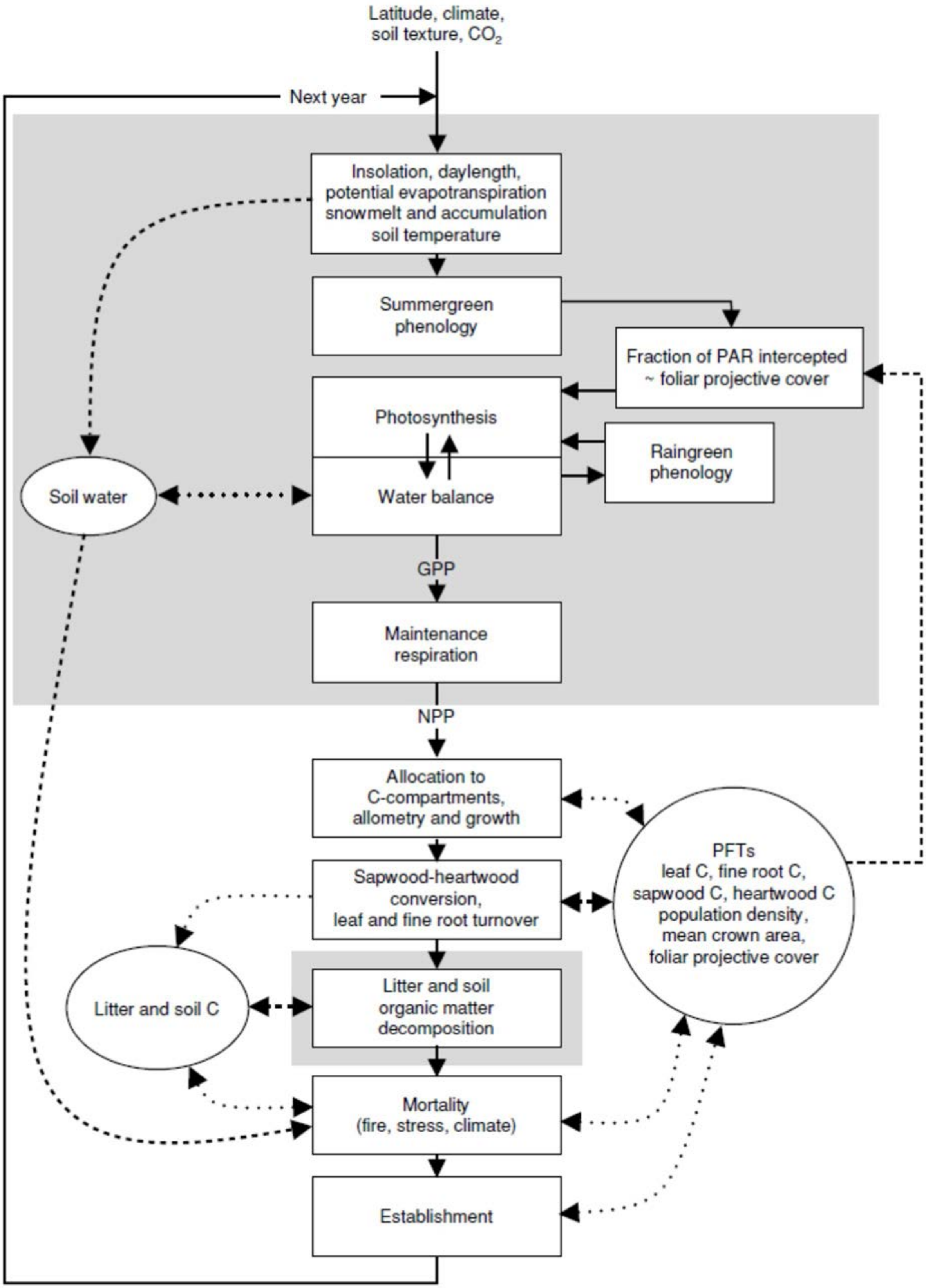

Figure 2.2: Flow-chart showing the model processes (Source: Sitch et al 2003)

2.2. Data needs

Table 2.1 shows the key input data requirements from LPJ and also displays the key outputs from LPJ

Table 2.1:Key inputs variables and outputs for LPJ-DGVM

Input variables	Outputs
1. Monthly mean cloudiness	1. Total soil carbon (SOC)
2. Monthly mean precipitation rate	2. Average evapotranspiration
3. Percentage of sand	3. Fractional cover of canopies
4. Percentage of clay	4. Leaf area index
5. Monthly mean temperature	5. Average soil temperature
6. Topography	6. Net Primary Productivity (NPP)
7. Initial vegetation types	7. Total soil nitrogen
8. Atmospheric CO_2 concentration	8. Average sensible heat flux
	9. Height of vegetation canopies
	10. Vegetation types (PFTs)
	11. Total carbon from exchange of CO_2
	12. Biomass carbon

The LPJ-DGVM uses inputs on monthly climatology, atmospheric CO_2 concentration, and soil type. Its key outputs are vegetation structure, plant functional types (PFT), and biomass carbon. The PFTs represented in the LPJ-DGVM are listed in Table 2.2.

Table 2.2: Representation of different Plant Functional Types in LPJ

Representation of PFTs in LPJ-DGVM	
Trees-based PFTs	
1	Boreal conifer evergreen trees
2	Boreal conifer deciduous trees
3	Temperate conifer evergreen trees
4	Temperate broadleaf evergreen trees
5	Temperate broadleaf cold-deciduous trees
6	Tropical broadleaf evergreen trees
7	Tropical broadleaf deciduous trees
Shrubs and grasses based PFTs	
8	Evergreen shrub
9	Cold grass (C_3)
10	Warm grass (C_4)

Climate models, scenarios and input climate data

By using 18 CMIP5 GCMs, it has been demonstrated by Chaturvedi et al 2012 that the use of multiple climate models facilitates in quantification of the range of uncertainty in climate change projections. Chaturvedi et al 2012 also demonstrated that multi-model ensembles based climate projections help in reducing the uncertainties of both the temperature and precipitation variables. Hence, for this study, we decided to use multi-model ensemble based climate change projections. As per our latest assessment of the climate projections data availability, the following three distinct data sources were available for this study:

a. **CMIP5 multi-model GCM based projections**: Currently, more than 50 CMIP5 GCM based climate projections are available. More than 10 GCMs provide all the required variables for impact assessment modelling in the forest sector.

b. **Statistically downscaled GCMs from NASA** (https://cds.nccs.nasa.gov/nex/): Currently, more than 30 CMIP5 models are statistically downscaled by NASA; however, this database provides projections for only the twin variables of temperature and rainfall and does not provide the other climate variables as required by the LPJ model.

c. **Dynamically downscaled CORDEX model outputs** (http://cccr.tropmet.res.in/cordex/files/downloadsrcp85.jsp): However, the South Asia CORDEX database doesn't provide projections from multiple models (both RCP4.5 and RCP8.5)currently: in addition, none of the CORDEX models provide the climate variable 'Cloudiness' as required by the LPJ model.

Hence, we decided to use the **bias-corrected** and **downscaled (bi-linear interpolation method)** multiple GCM based ensemble from the CMIP5 experiment. For the present, assessment ensemble mean data is used from five CMIP5 climate models, namely BCC-CSM1.1, IPSL-CM5A-LR, MIROC5, MIROC ESM and MIROC ESM CHEM. These climate models were part of the 18 climate models used by Chaturvedi et al. (2012) for assessment of climate change in India. The choice of climate models was guided by the constraint that out of the 18 climate models used by Chaturvedi et al. (2012), only five models provided all the necessary climate variables necessary to drive DGVMs.

The climate data used in the present study was obtained from the CMIP5 data portal (http://pcmdi9.llnl.gov/esgf-web-fe/) for India (latitude 5.25 – 37.25 and longitude 60.25 – 98.75) for three time-periods (historical: 1961-90; short-term: 2021-2050; and long-term: 2070-2099). CMIP5 model climate projections are available at different spatial resolutions from different models and more often at a grid scale coarser than 150 km. As each model has a different spatial resolution, the data is re-gridded to a common spatial scale of 0.5 × 0.5 degree resolution (about 55x55 km^2), using bilinear interpolation. The climate projections are further bias-corrected. In the present study, projections of climate are considered under RCP4.5 and 8.5 scenarios for short (2021-2050) and long term (2070-2099) periods.

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Chapter 3: Description of the Current State of Forests in Madhya Pradesh

In Madhya Pradesh, lush green forests are well spread all across the state. The forest distribution of different density classes in the state for the year 2013 is depicted in Figure 3.1, provided below.

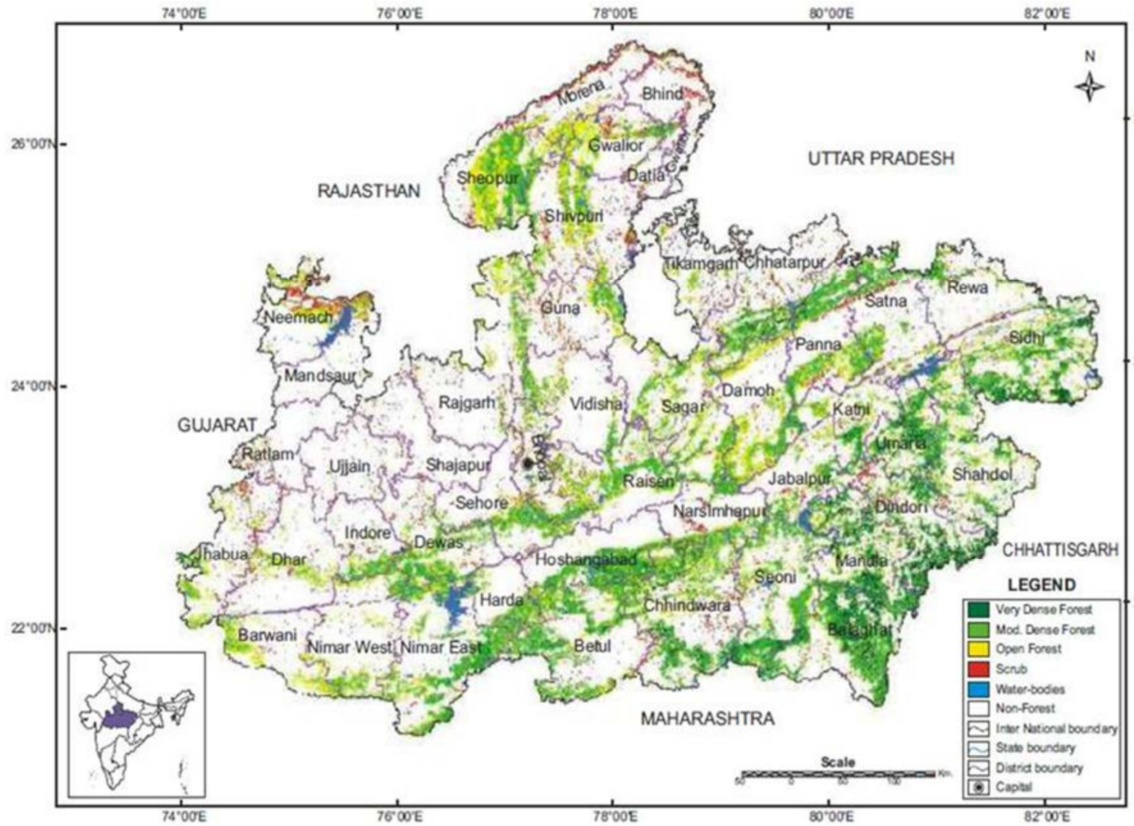

Figure 3.1: Distribution of forest area in Madhya Pradesh (Source: FSI, 2013)

3.1. Forest area and forest cover changes in Madhya Pradesh

Reliable satellite based forest cover information over the last two decades suggests that the forest cover in Madhya Pradesh has remained largely stable and has been slightly improving in the recent years (See Figure 3.2).

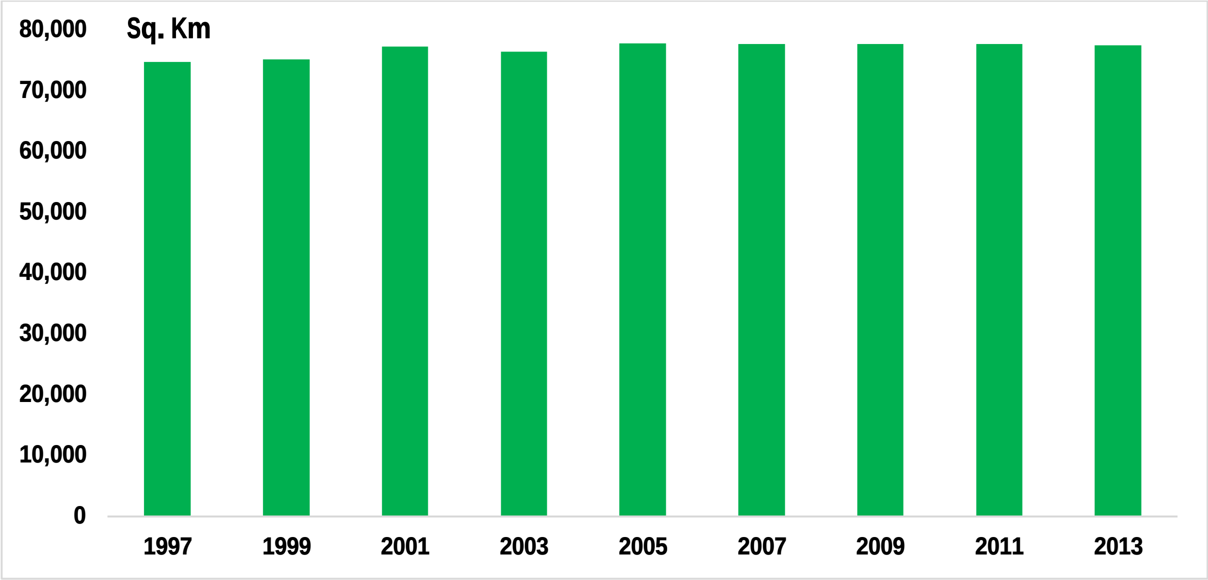

Figure 3.2: Distribution of forest area in Madhya Pradesh (Source: FSI, 2003-2013)

On a positive note, the area of very dense and dense forests has also remained stable in the last decade (Figure 3.3), which suggests comparatively less degradation in the forests of the state.

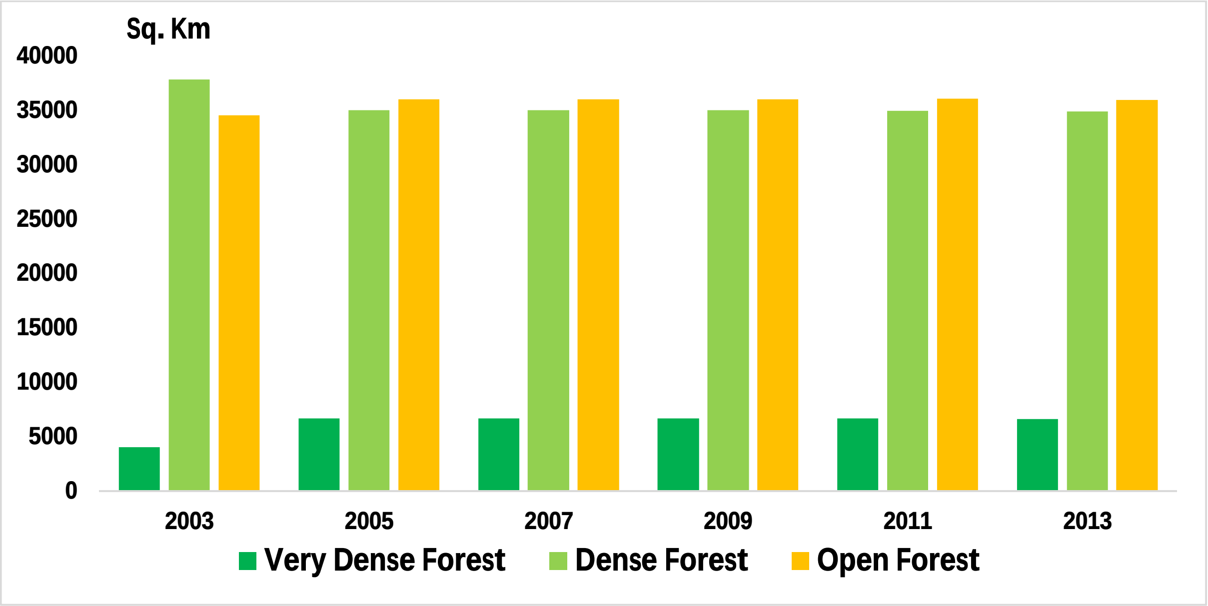

Figure 3.3: Distribution of forest area under different forest categories in Madhya Pradesh over the period 2003-2013 (Source: FSI, 2003-2013)

3.2. Carbon stock and carbon stock changes in the forests of Madhya Pradesh

It is estimated that forests in Madhya Pradesh currently store 0.68 Gt of carbon (or ~2.5 billion tonnes of CO_2). This is a very important carbon sink which is vital for meeting India's climate commitments to

UNFCCC (INDC, 2015) and is extremely vital for stabilization of the global climate at safe levels. Table 3.1 and Figure 3.1 display the distribution of this carbon stock in different carbon pools in MP forests.

Table 3.1: Forest carbon stock in the forests of Madhya Pradesh for the year 2004

Carbon pools	Carbon stock (000 tonnes)
AGB	2,60,335
BGB	99,435
DW	1535
Litter	6990
SOC	3,14,232
Total	**6,82,528**

Source: Forest Survey of India, 2013 (AGB is Above Ground Biomass, BGB is Below Ground Biomass, DW is Dead Wood, and SOC is Soil Organic Carbon)

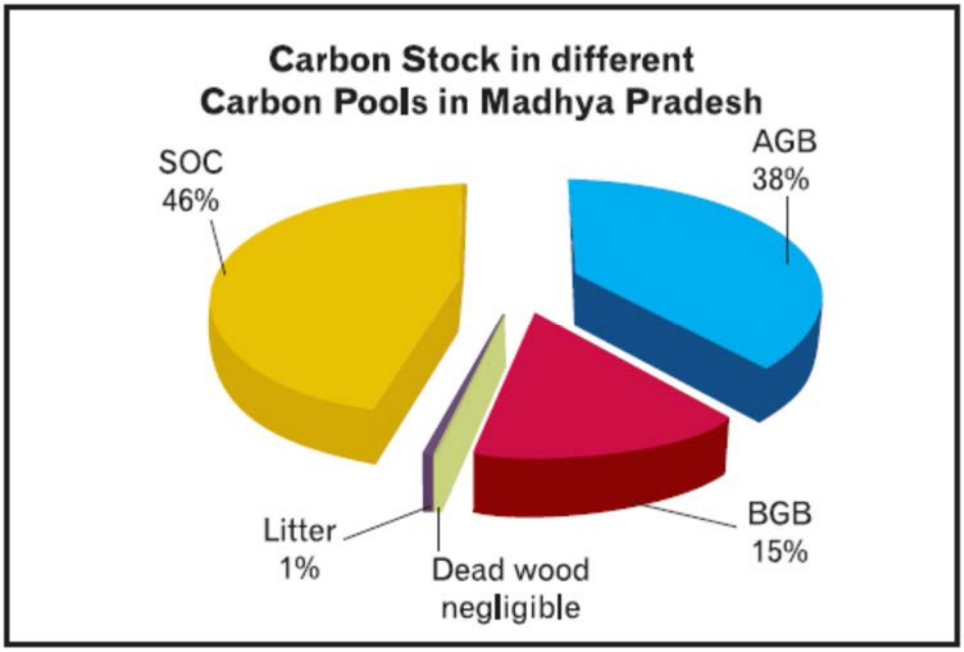

Figure 3.4: Carbon stock in different carbon pools in MP (Source: Forest Survey of India, 2013)

A remote sensing based study by Reddy et al 2015 analyzes the forest cover and carbon stocks in the combined states of MP and Chattisgarh over the last century and concludes that over the period 1935-1995, both the forest cover and carbon stocks declined in the state However, due to the progressive forest conservation policies and management, the forest cover as well the carbon stock in the MP forests has largely stabilized over the last two decades. Further, the study concludes that the forest cover and carbon stock are increasing in the last decade.

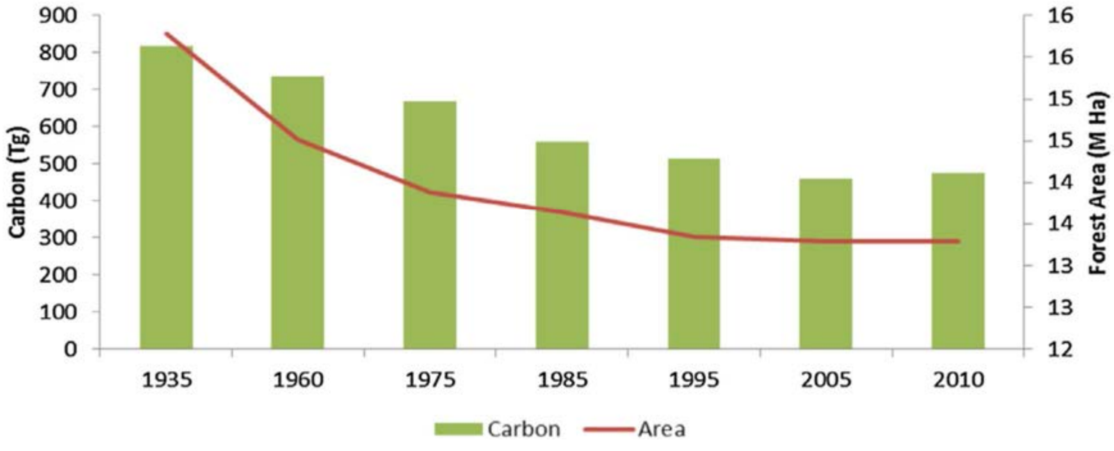

Figure 3.5: Changes in forest cover and above ground biomass in the forests of Madhya Pradesh and Chhattisgarh (Source: Reddy et al 2015)

3.3. Net Primary Productivity in MP, and changes in NPP under elevated CO_2 in Madhya Pradesh

Our long-term research in this field (of ecosystem dynamics) suggests that 'phenology', 'growth rates/ productivity' and 'shifting distributions of species and biomes' are the most prominent indicators of change in forest ecosystems in response to climate change. Figure 3.6 shows the satellite based current distribution of Net Primary Productivity in the state of MP.

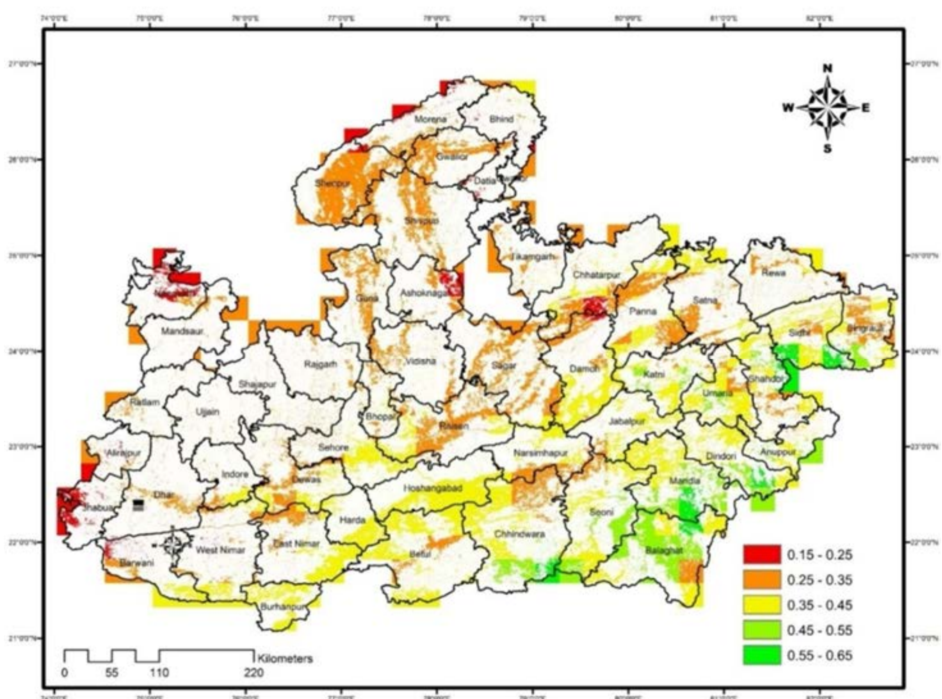

Figure 3.6: Net Primary Productivity (NPP) distribution in the forests of Madhya Pradesh based on the satellite based observations and modeling from 1982-2006 period (Source: Bala et al 2013)

Bala et al 2013 further conclude that the NPP over the entire India is found to be increasing during the period 1982-2006. The NPP from MP state is also found to be increasing at the rate of ~0.8gC/m^2/Yr^2 (Figure 3.7). The study links the increasing NPP to the increasing CO_2 concentration in the atmosphere.

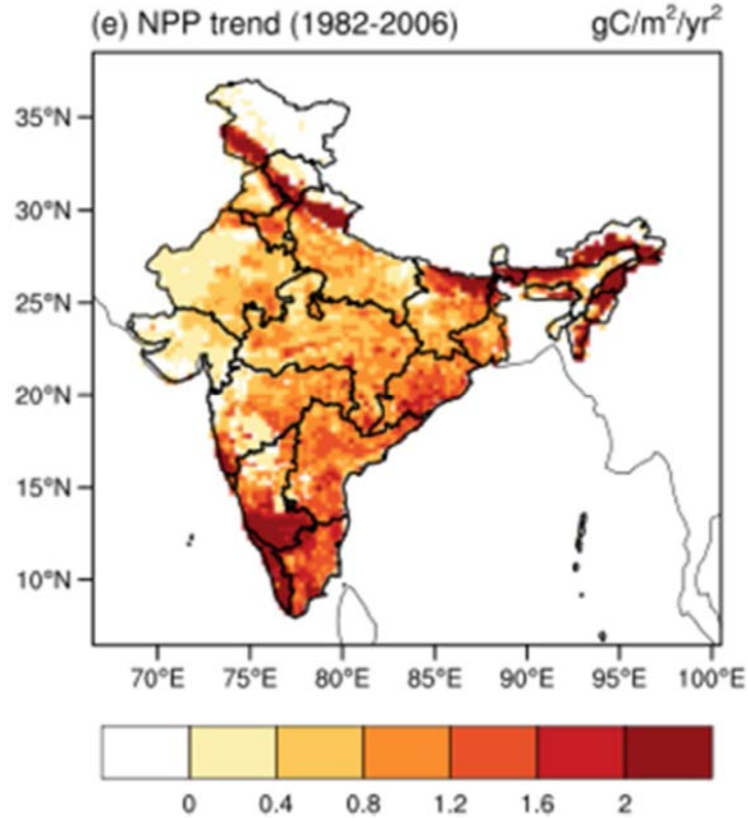

Figure 3.7: Annual trend in NPP in different states of India (Bala et al 2013)

Forests in MP store about 2.5 billion tonnes of CO_2 and thus play a vital role in India's climate mitigation strategy and are equally critical in terms of the global climate benefits. Impacts of climate change are already visible on the forests of MP. Under the climate change scenarios, it is quite possible that forests in MP get adversely impacted due to shifting of the vegetation types. In this study, we have investigated the impacts of climate change on forests in Madhya Pradesh.

References:

1. Bala G., Jaideep Joshi, Rajiv K Chaturvedi, H.V. Gangamani, Hirofumi Hashimoto, Rama Nemani (2013) "Trends and variability of Satellite-derived NPP in India" Remote Sensing 5:810-829

2. Reddy CS, G. Rajashekar, P. Hari Krishna, C.S. Jha, V.K. Dadhwal. (2015) Multi-source and multi-date mapping of deforestation in Central India (1935-2010) and its implication on standing phytomass carbon pool. Ecological Indicators 57:219–227

3. FSI 2003-2013, State of Forests in India. Forest Survey of India. Govt. of India.

4. FSI (2013) carbon inventory of India's forests. Forest Survey of India. Govt. of India

5. INDC, 2015. India's Intended Nationally Determined Contributions to UNFCCC (http://www4.unfccc.int/submissions/indc/Submission%20Pages/submissions.aspx)

Chapter 4: Model Validation

We simulated the current vegetation dynamics, Net Primary Productivity, biomass and soil carbon over MP using the LPJ model for the current climate; and, in order to validate the model for the state of MP, we compared the model-simulated outputs for these variables with the observations obtained from long-term satellite based estimates.

4.1. Comparison of the model simulated Net Primary Productivity distribution over the forest grids of Madhya Pradesh with the satellite based estimates

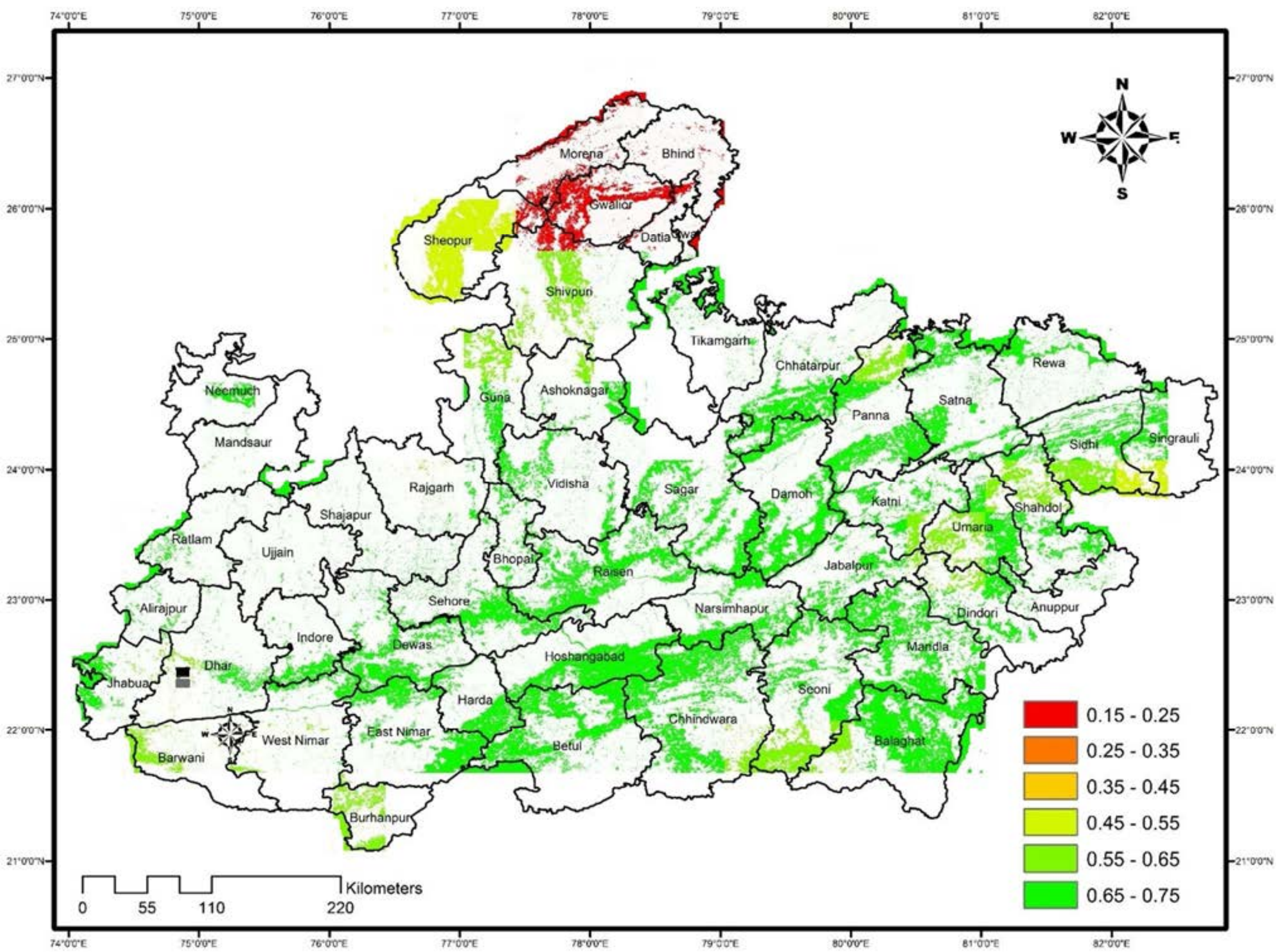

Figure 4.1: NPP as simulated by LPJ (Source: IISc)

The remotely sensed NPP data was obtained from Bala et al 2013 over the period 1982-2006, while the time period of our current climate simulations is 1960-1990. This NPP (Figure 4.2) is compared with the NPP as simulated by the LPJ model over the state of MP (Figure 4.1). LPJ-based NPP simulations depict a reasonable match with satellite observations over the state of Madhya Pradesh.

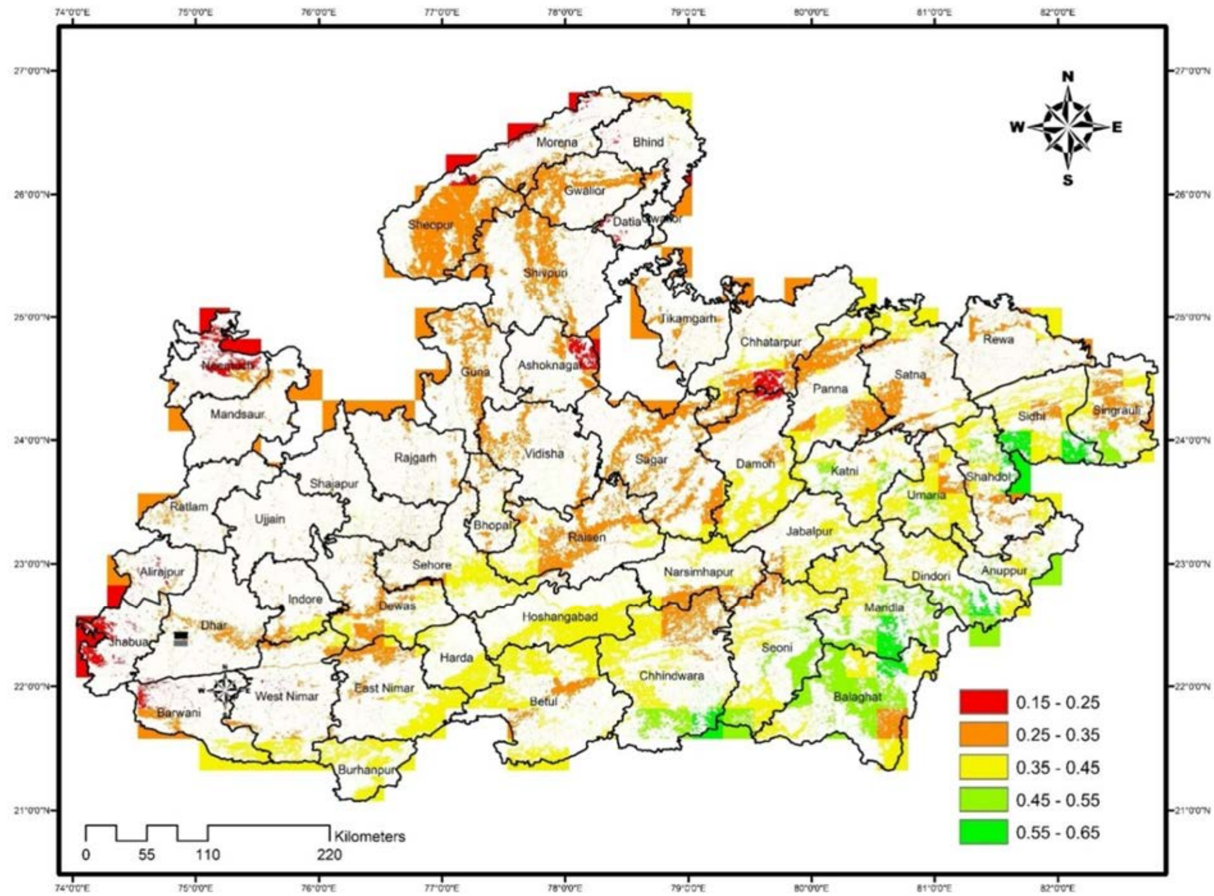

Figure 4.2: Satellite derived NPP as obtained from Bala et al 2013 for the period of 1982-2006

4.2. Comparison of the model-simulated biomass carbon distribution over the forest grids of Madhya Pradesh with the biomass carbon inventories as reported by the Forest Survey of India

Recently, Forest Survey of India provided the most up-to-date and reliable inventories of forest biomass carbon across India, including the forests of MP. In this section, we compared the model-imulated vegetation carbon estimates (figure 4.3) with the biomass carbon inventory, as reported by FSI 2013, over the state of MP. LPJ-based simulations of vegetation carbon display a reasonable match with the carbon inventory estimates, as reported by Forest survey of India, over the state of Madhya Pradesh (See Table 4.1).

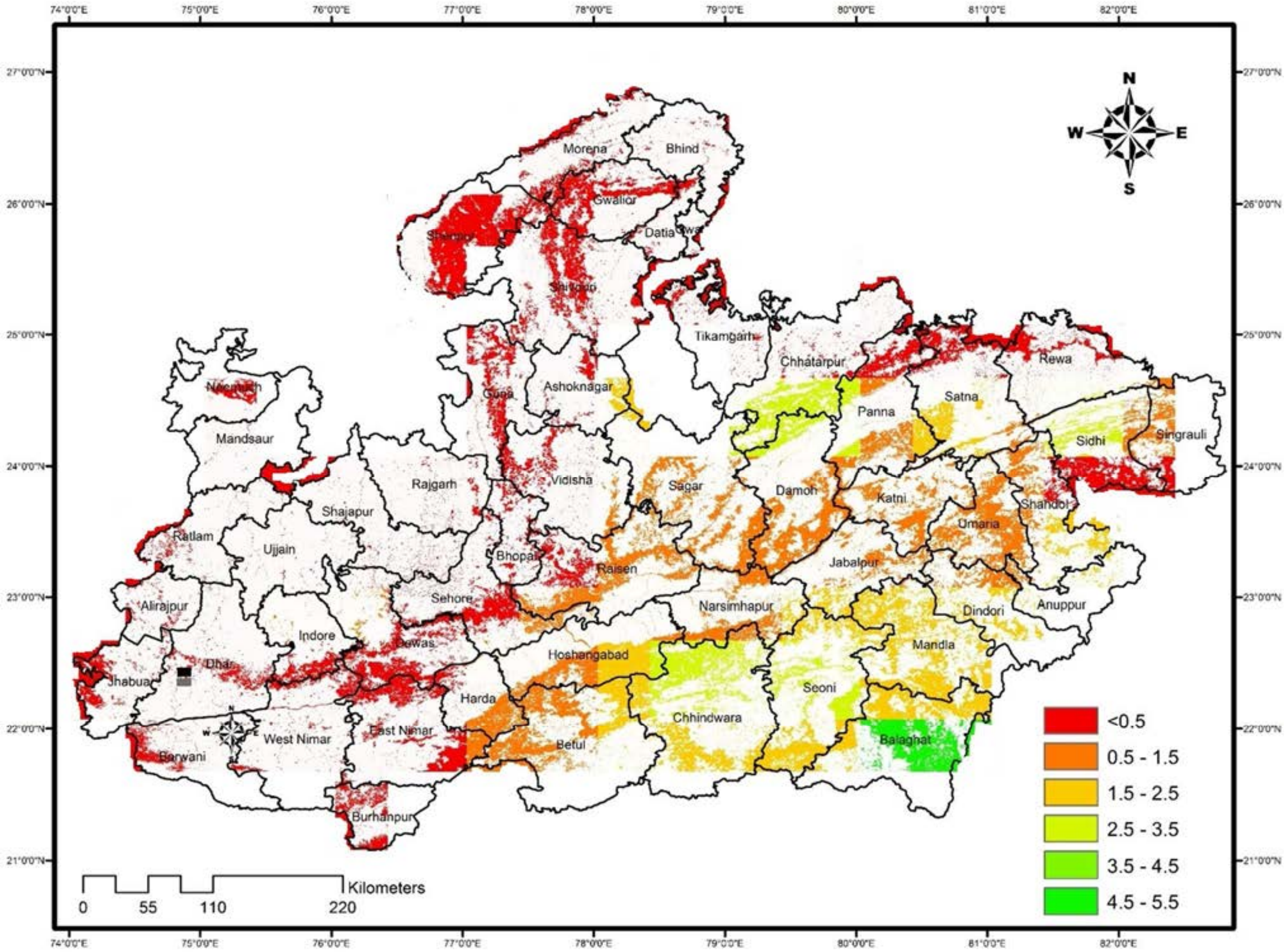

Figure 4.3: Vegetation carbon in MP as simulated by LPJ (Source: IISc)

Table 4.1: Forest carbon inventory in the key pools of Madhya Pradesh Forests as reported by FSI, 2013, for the year 2004

Carbon pools	Carbon stock (000 tonnes)	Forest area (10*Km^2)	tC/ha	KgC/m^2
AGB	260335	7601.3	34.2	3.4
BGB	99435	7601.3	13.0	1.3
DW	1535	7601.3	0.20	0.02
Litter	6990	7601.3	0.91	0.09
SOM	314333	7601.3	41.3	4.1

4.3. Comparison of the model simulated soil carbon distribution over the forest grids of Madhya Pradesh with the soil carbon inventories as reported by the Forest Survey of India

Forest Survey of India inventory also provides the most up-to-date and reliable inventories of forest soil carbon across India, including the forests of MP. In this section, we are comparing the model-simulated soil carbon estimates (figure 4.4) with the biomass carbon inventory as reported by FSI 2013 over the state of MP. LPJ-based simulations of soil carbon show a reasonable match with the carbon inventory estimates as reported by Forest survey of India over the state of Madhya Pradesh (Table 4.1)

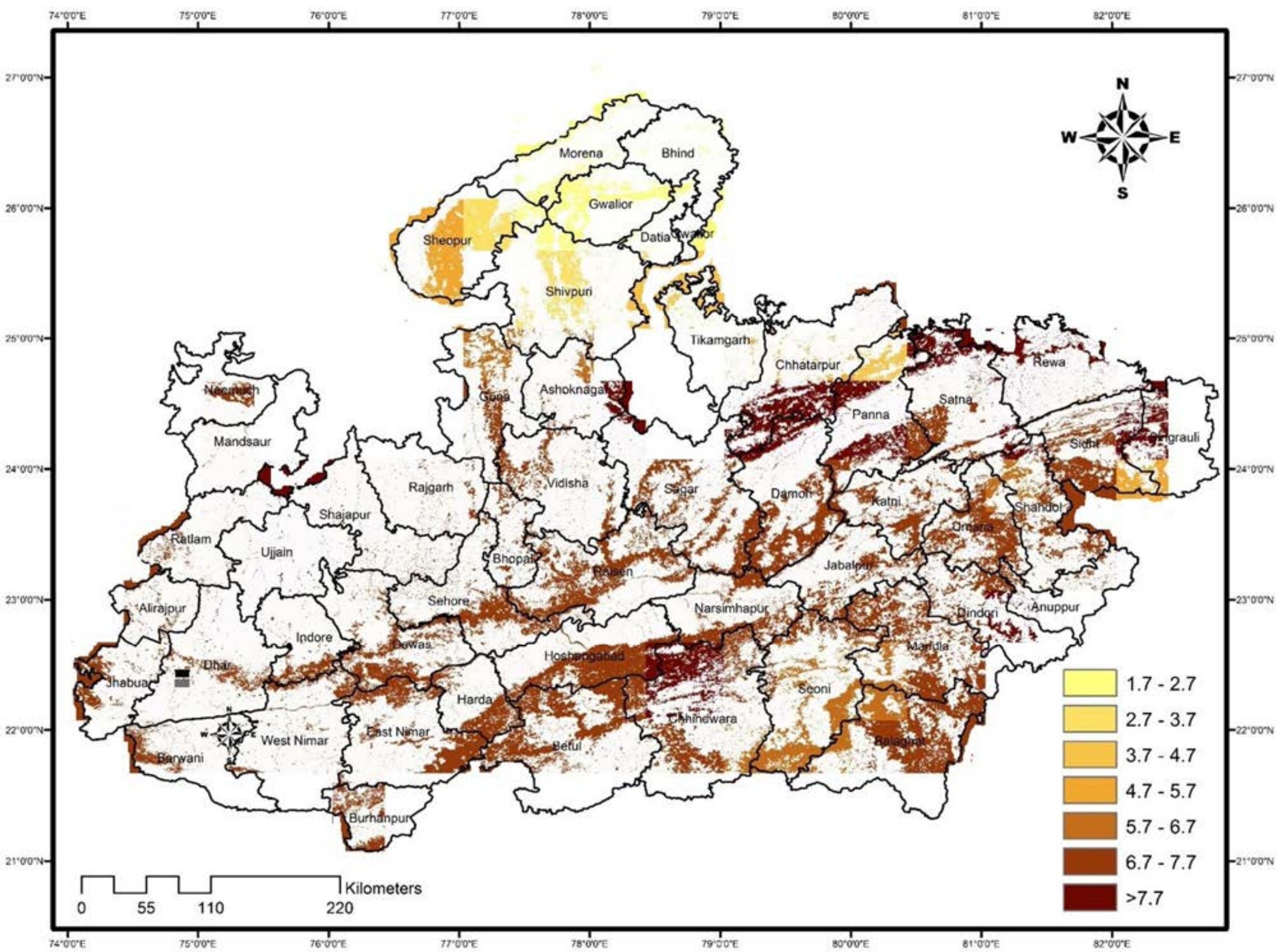

Figure 4.4: LPJ simulated Soil Organic Carbon for the forests of Madhya Pradesh (in KgC/m^2)

References:

1. Bala G., Jaideep Joshi, Rajiv K Chaturvedi, H.V. Gangamani, Hirofumi Hashimoto, Rama Nemani (2013) "Trends and variability of Satellite-derived NPP in India" Remote Sensing 5:810-829

2. FSI (2013) carbon inventory *of India's forests. Forest Survey of India. Govt. of India*

Chapter 5: Impact of Climate Change on the Forests and Biodiversity of Madhya Pradesh

Forest area in the state of MP has remained stable over the last two decades and has been marginally increasing in more recent years. We run the LPJ model for RCP4.5 and RCP8.5 climatology scenarios only for the forested grids. In this chapter, we are presenting the impact of climate change on vegetation distribution, Net Primary Productivity and carbon stocks in vegetation and soils of MP in the short term (2030s) and long term (2080s).

5.1. Impact of Climate Change on vegetation distribution in Madhya Pradesh

According to model simulation, a large number of forested grids, especially in the western parts of the state, are projected to undergo change.

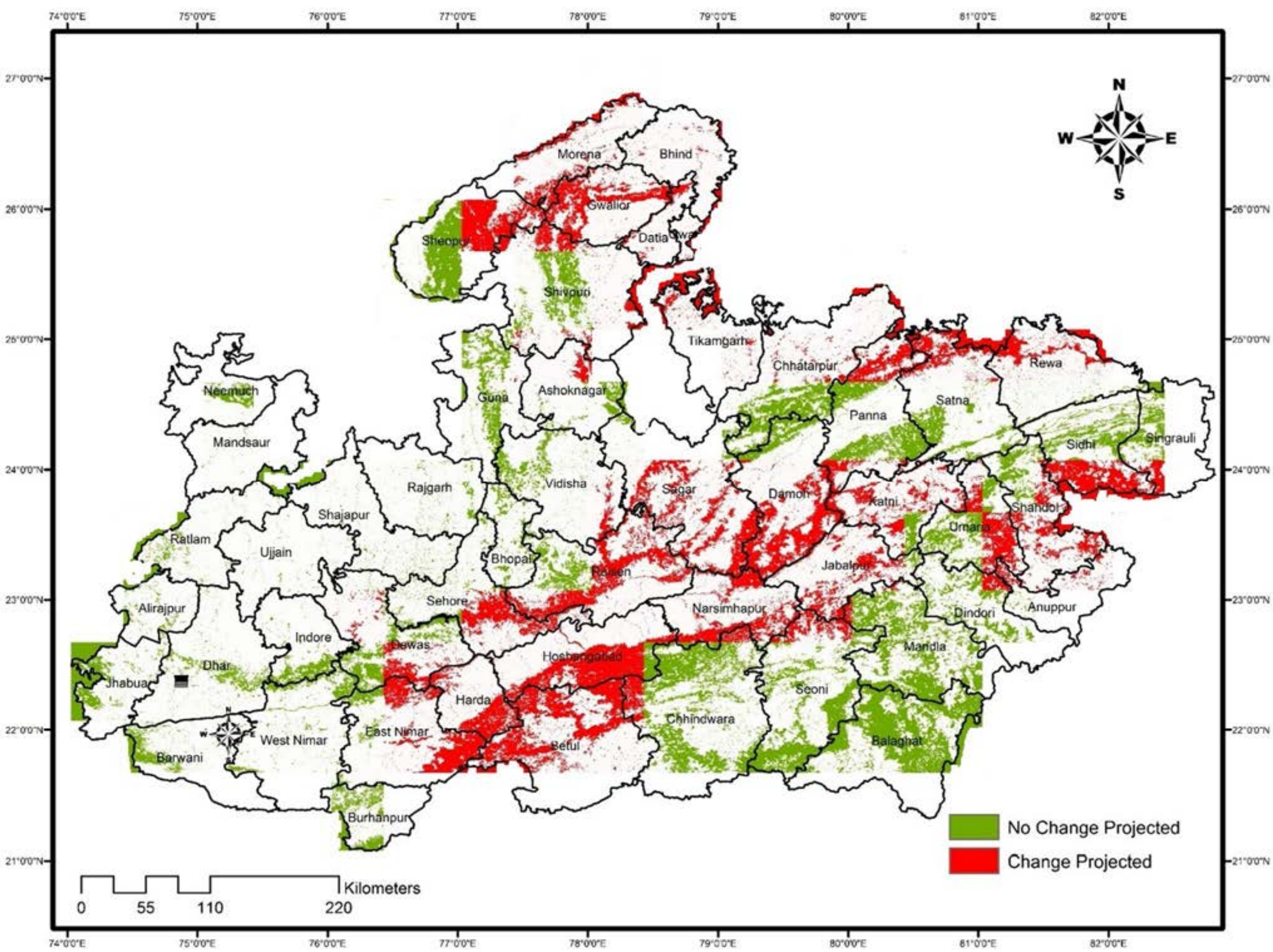

Figure 5.1.1: Model-simulated changes in vegetation distribution in the forests of Madhya Pradesh by 2030s under RCP4.5

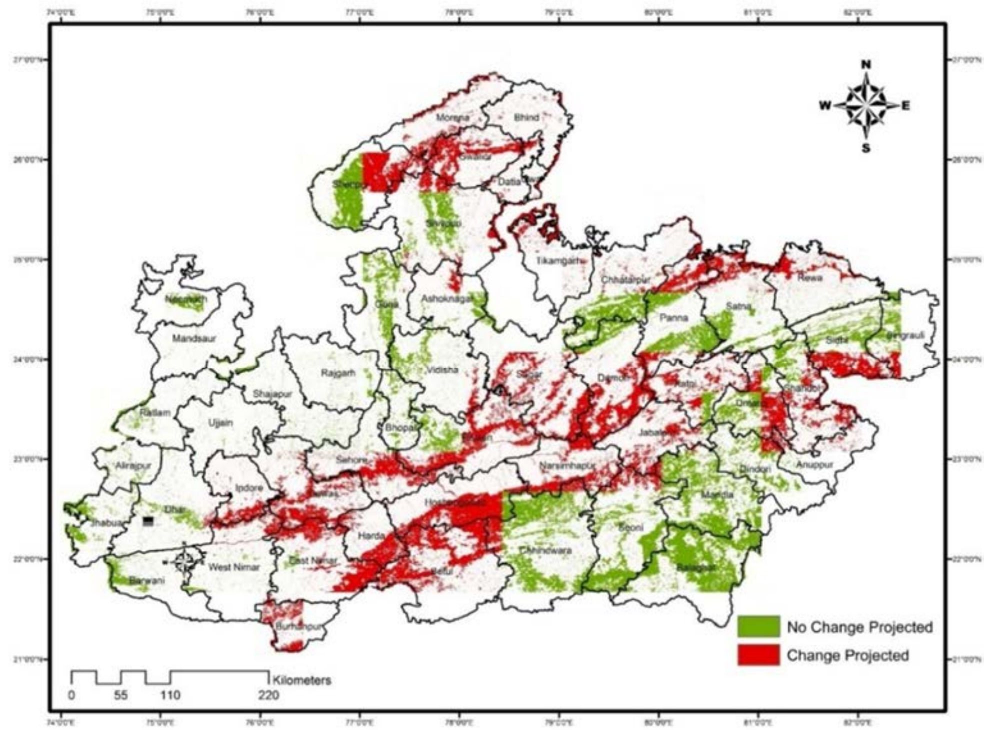

Figure 5.1.2: Model-simulated changes in vegetation distribution in the forests of Madhya Pradesh by 2030s under RCP8.5

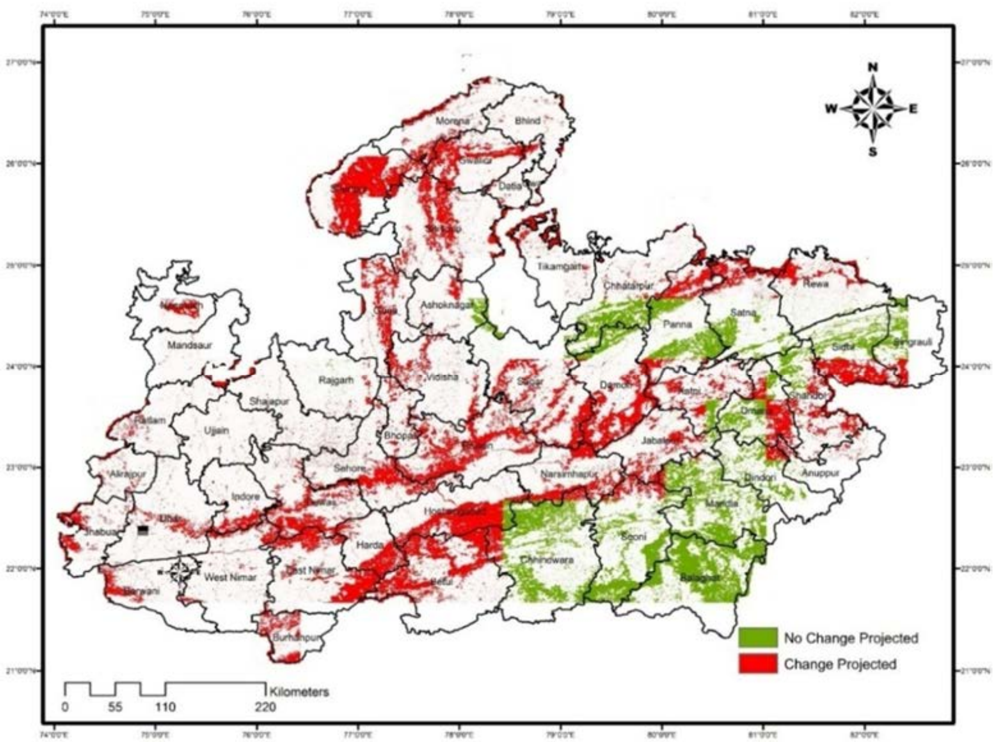

Figure 5.1.3: Model simulated changes in vegetation distribution in the forests of Madhya Pradesh by 2080s under RCP4.5

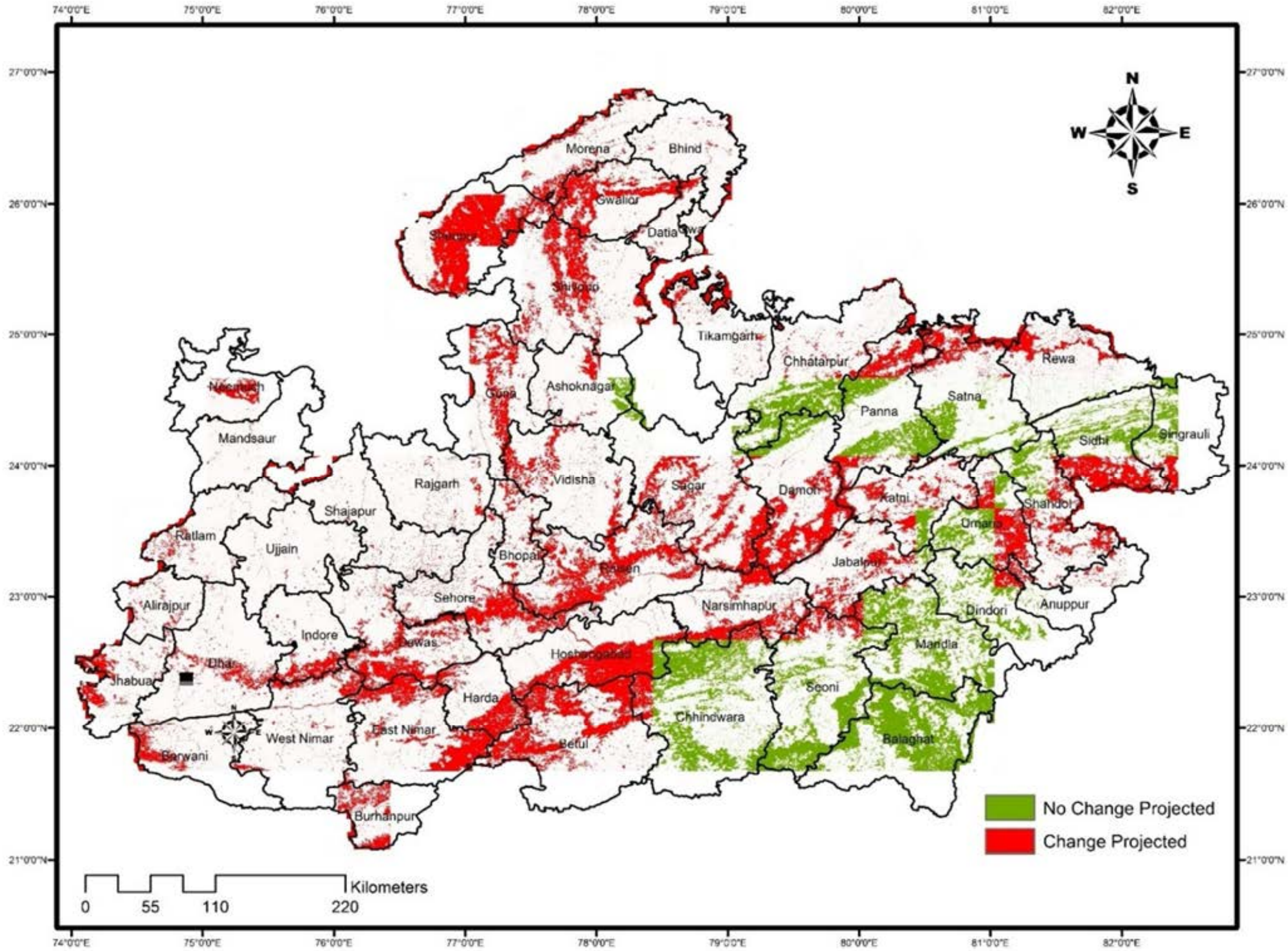

Figure 5.1.4: Model simulated changes in vegetation distribution in the forests of Madhya Pradesh by 2080s under RCP8.5

Our simulations indicate that drier forests are generally likely to be replaced by wetter or moist forest types. Majority of the forest grid changes could be attributed to higher precipitation levels and increased CO_2 concentration in the atmosphere in projected climate scenarios. Northern and western parts of the state, which contain drier vegetation, are projected to change to wetter forest types. While these changes are less pronounced in the short term i.e. 2030s, are more visible in the long-term i.e. 2080s.

Though we have limited long-term observations to assess the impact of the ongoing/observed climate change on the forests of MP, a recent study by ICFRE (2013) has suggested that the dry tropical thorn and scrub forests of MP Ravines, as delineated by Champion & Seth (1968), are currently highly disturbed and are shown to contain thorny and deciduous species. Further, in the tropical deciduous forests of MP,ICFRE (2013) compares the current distribution of ‘very dry teak forests’ with the distribution of the same forest type as presented in Champion & Seth's (1968). ICFRE (2013) finds increased moisture availability in these forests and suggests that these forests could be renamed as ‘dry teak forests' instead of the Champion & Seth (1968) category of 'very dry teak forests' – indicating the increased moisture levels in the erstwhile very dry forests.

These projected forest grid changes could lead to vulnerability of the forest in the case of fragmented and disturbed forests. In such forest patches, seed dispersal may not be efficient in terms of loss or reduction in number of dispersal agents due to human habitation pressures and climate change. It should also be noted that vegetation change projections are associated with uncertainty, largely coming from the uncertainty that is inherent in the climate change projections, especially the uncertainty related to rainfall.

5.2. Impact of Climate Change on Net Primary Productivity (NPP) distribution in Madhya Pradesh

Figure 5.2.1 depicts the current distribution of NPP across the MP forests, which correlates well with the satellite-based observations of NPP (chapter 5). Figure 5.2.1 shows that the current vegetation productivity is higher in the southern and eastern parts of the states, as compared to the northern and western parts.

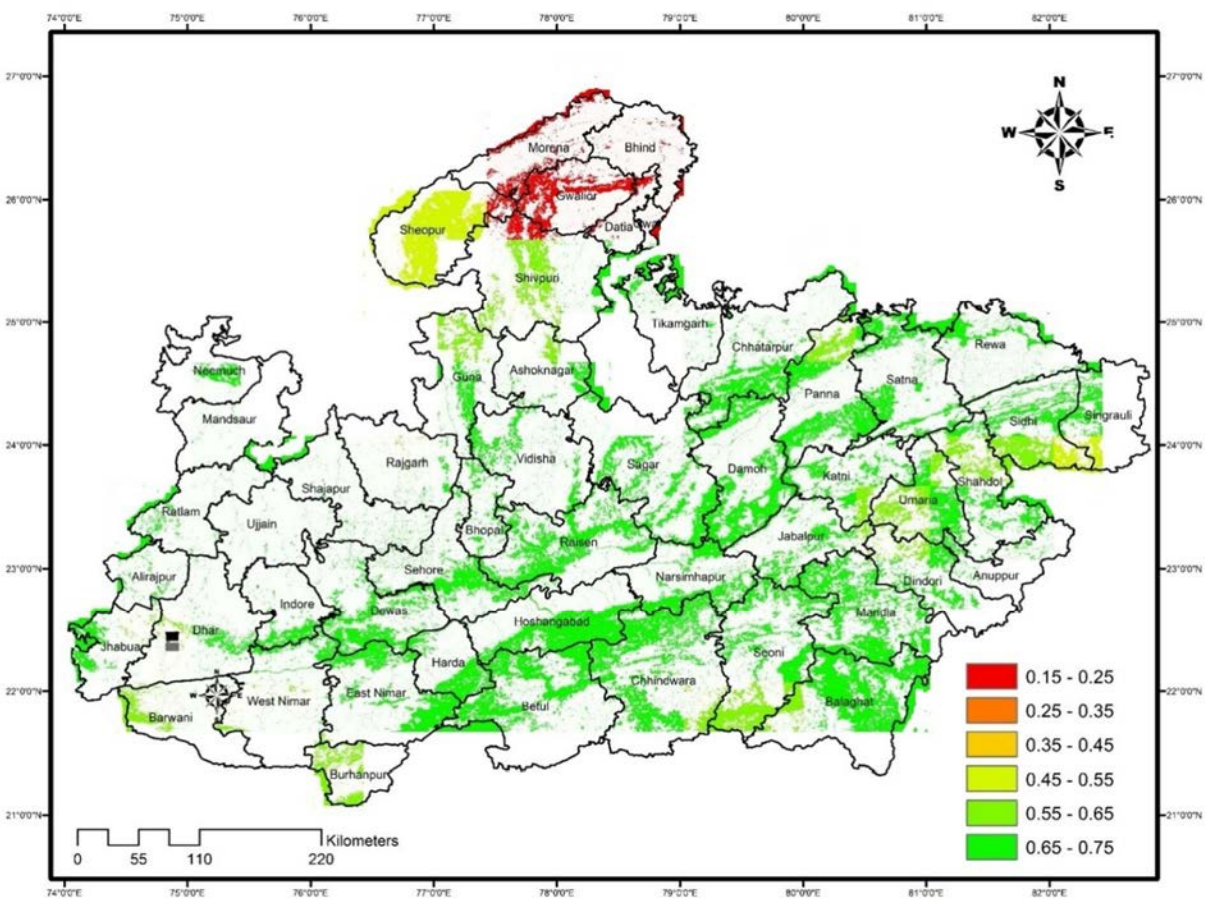

Figure 5.2.1: Model simulated current distribution of NPP (Kg/m2) in the forests of Madhya Pradesh

Figures 5.2.2-5.2.5 shows the impact of climate change on the Net Primary Productivity (NPP) over the forested grids in MP.

The NPP tends to increase all over the state in projected climate scenarios of RCP4.5 and RCP8.5 by 2030s and 2080s. Notably, the current low productivity areas of northern and western areas of the state depict a gain in NPP under climate change projections. The NPP increase is likely to be driven mainly by the CO_2 fertilization effect and increased precipitation projections.

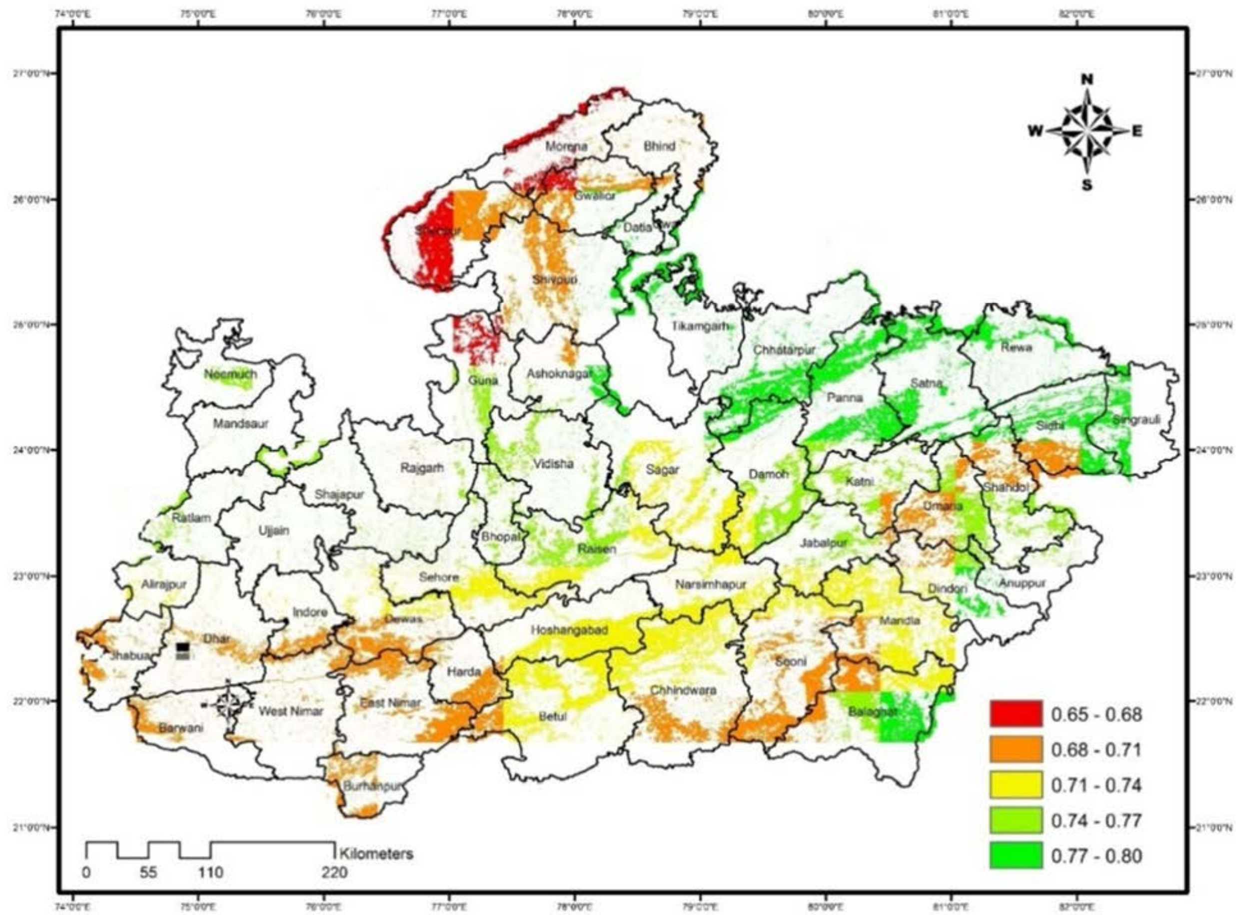

Figure 5.2.2: Projected distribution of NPP (Kg/m2) over the forests of MP under the RCP4.5 scenario by 2030s

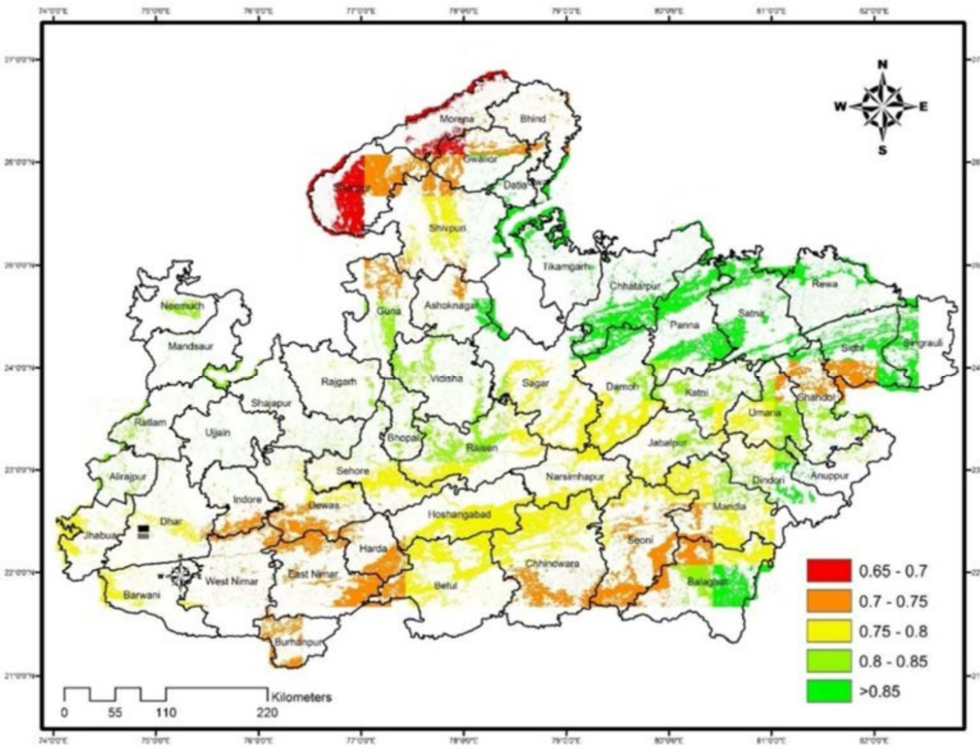

Figure 5.2.3: Projected distribution of NPP (Kg/m2) over the forests of MP under the RCP8.5 scenario by 2030s

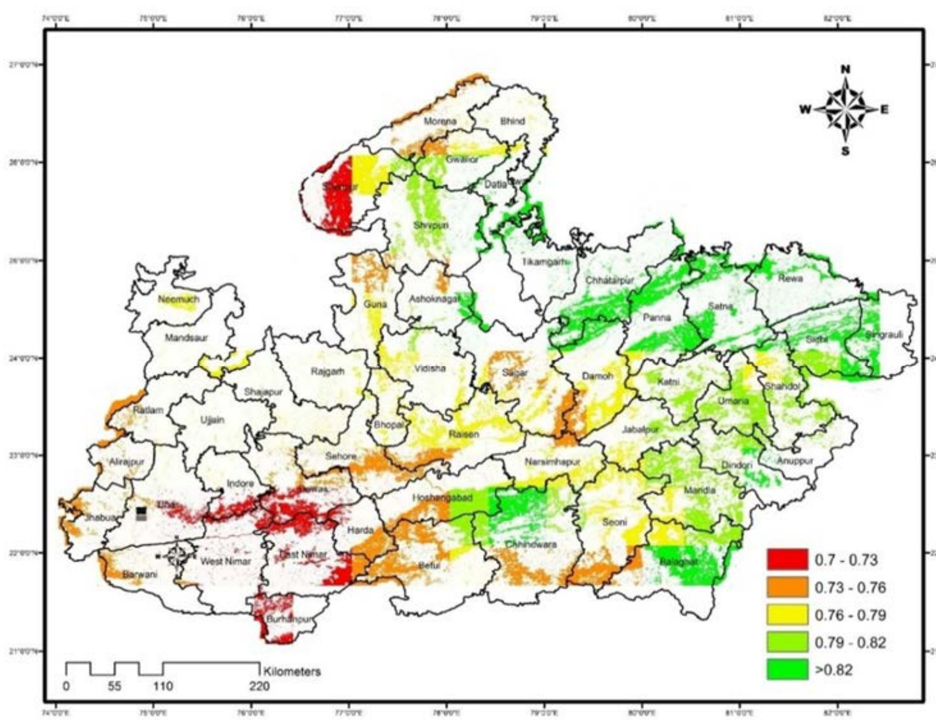

Figure 5.2.4: Projected distribution of NPP (Kg/m2) over the forests of MP under the RCP4.5 scenario by 2080s

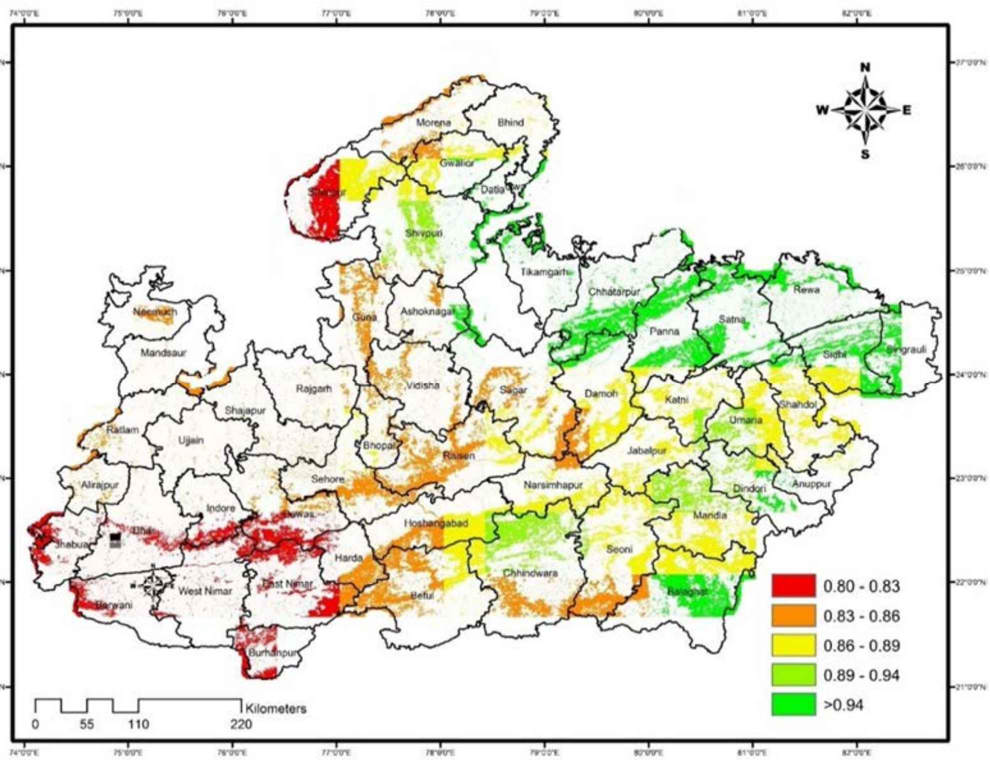

Figure 5.2.5: Projected distribution of NPP (Kg/m2) over the forests of MP under the RCP8.5 scenario by 2080s

Increased NPP mainly implies increased productivity of the forests (in short term) across the state due to the CO_2 fertilization effect and increased precipitation. Increased productivity may translate in an increased supply of forest products including wood, fuel wood and other NTFPs. However, in the longterm, NPP increase could likely be countered by increased losses from heterotrophic respiration, leading to tapering (or decline) in the net ecosystem productivity.

5.3. Impact of Climate Change on Biomass carbon distribution in Madhya Pradesh

Figure 5.3.1 shows the current distribution of biomass carbon as simulated by LPJ model across the forests of MP, which correlates well with the Forest Survey of India based biomass carbon densities (Chapter 5). Figure 5.3.1 indicates that the biomass carbon density is currently higher in the southern and eastern parts of the states as compared to the northern and western parts

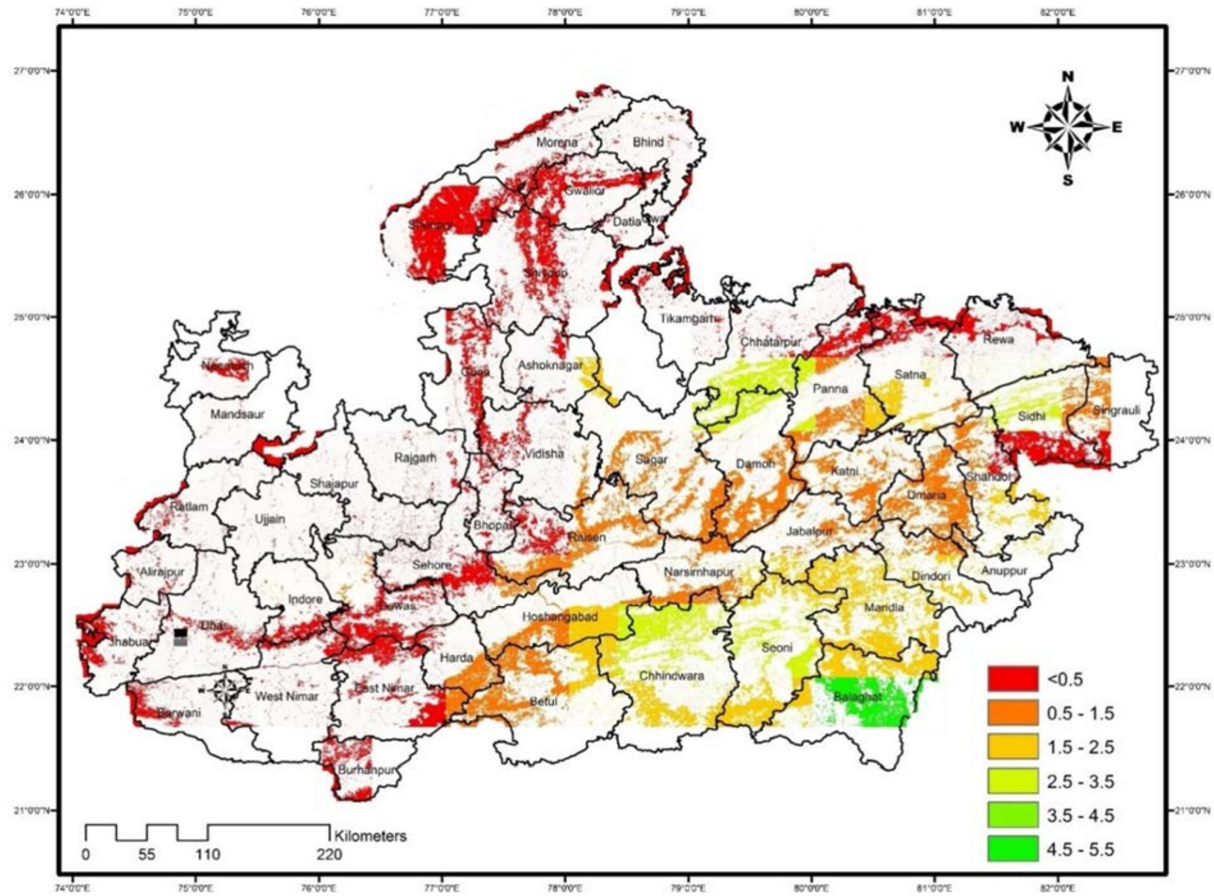

Figure 5.3.1: The current distribution of model simulated Biomass carbon ((Kg/m2) in MP forests

Figures 5.3.2-5.3.5 depict the impact of climate change on the biomass carbon distribution over forested grids in MP.

Biomass carbon densities tend to increase all over the state in projected climate scenarios of RCP4.5 and RCP8.5 by 2030s and 2080s. Notably, the current low biomass density areas of northern and western MP would gain substantially in terms of biomass under climate change projections, mainly through the increased CO_2 fertilization effect and rising precipitation.

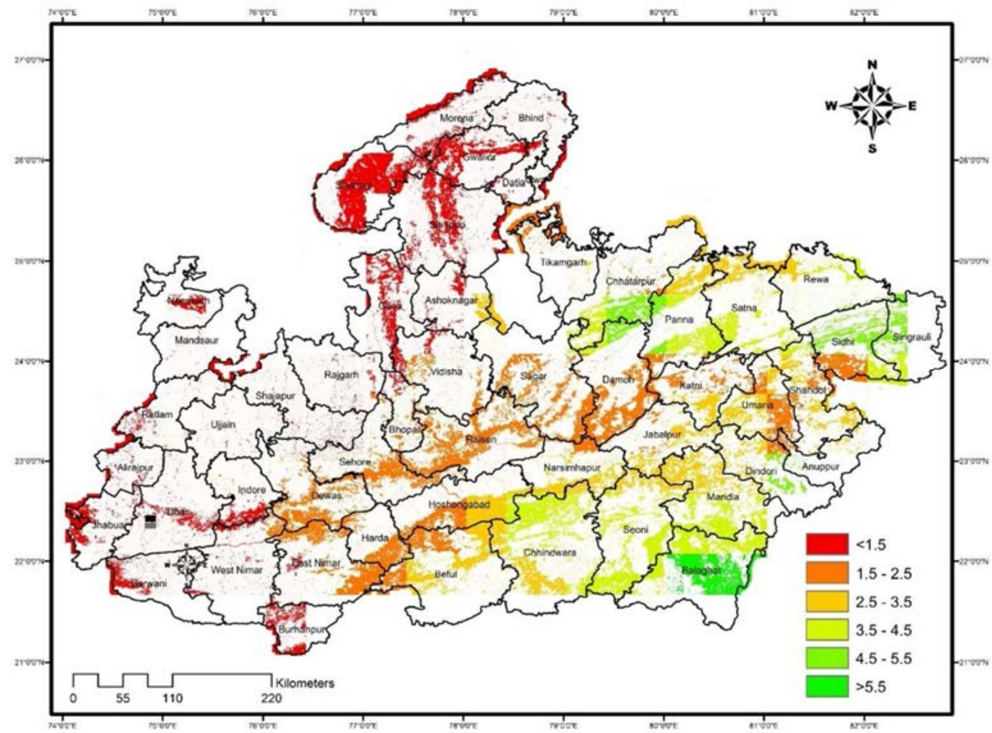

Figure 5.3.2: Projected distribution of Biomass carbon (Kg/m2) over the forests of MP under the RCP4.5 scenario by 2030s

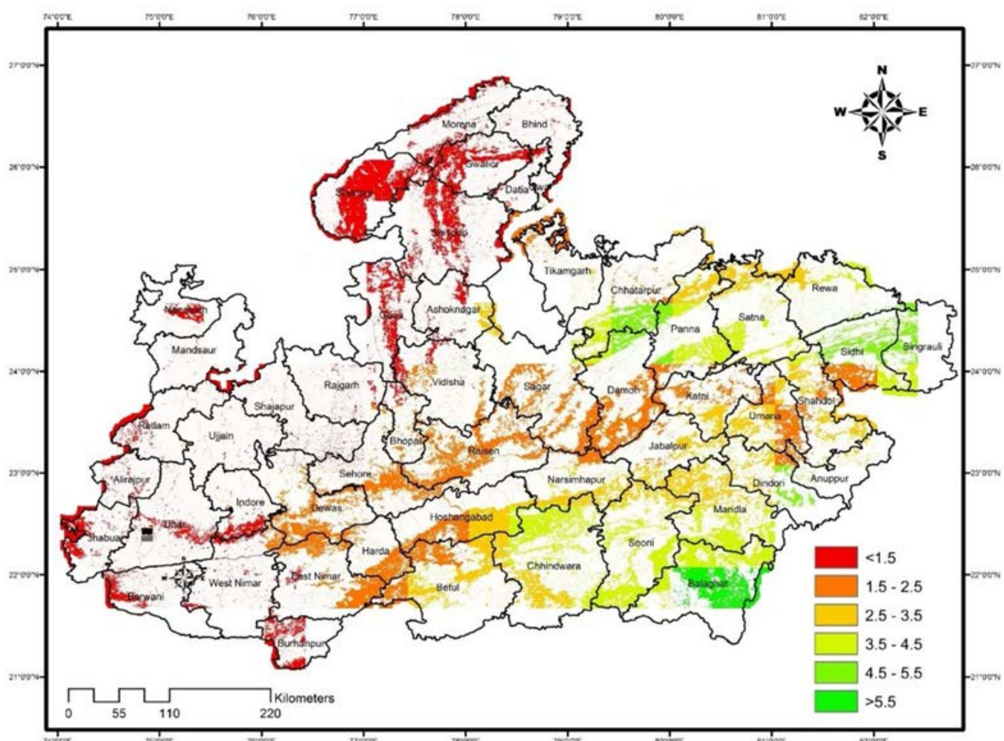

Figure 5.3.3: Projected distribution of Biomass carbon (Kg/m2) over the forests of MP under the RCP8.5 scenario by 2030s

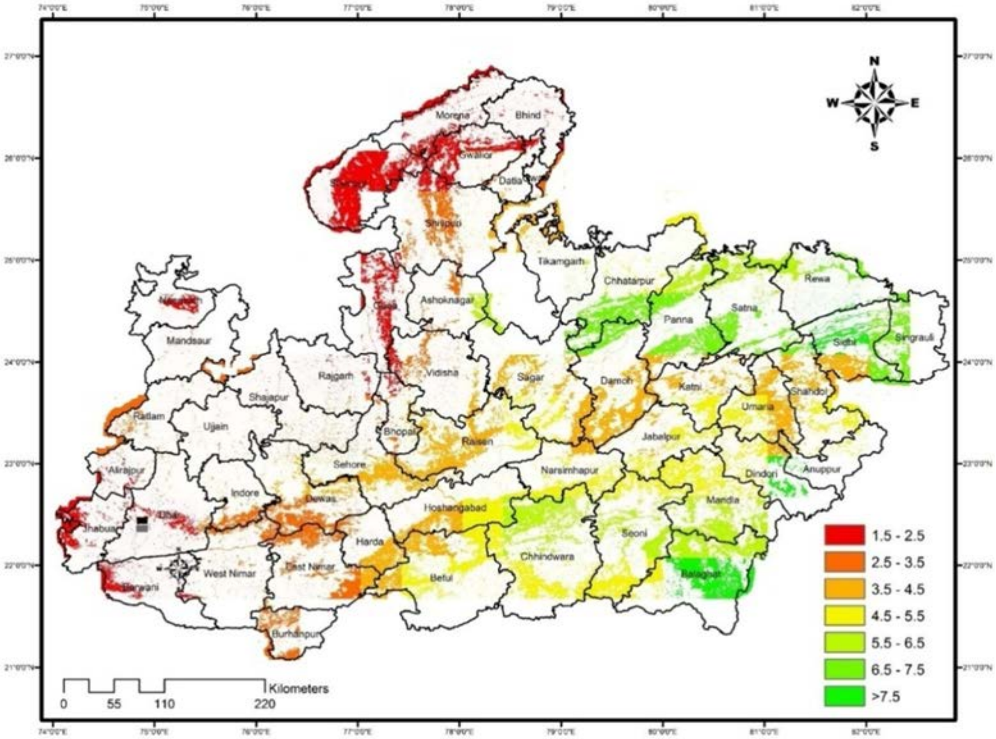

Figure 5.3.4: Projected distribution of Biomass carbon (Kg/m2) over the forests of MP under the RCP4.5 scenario by 2080s

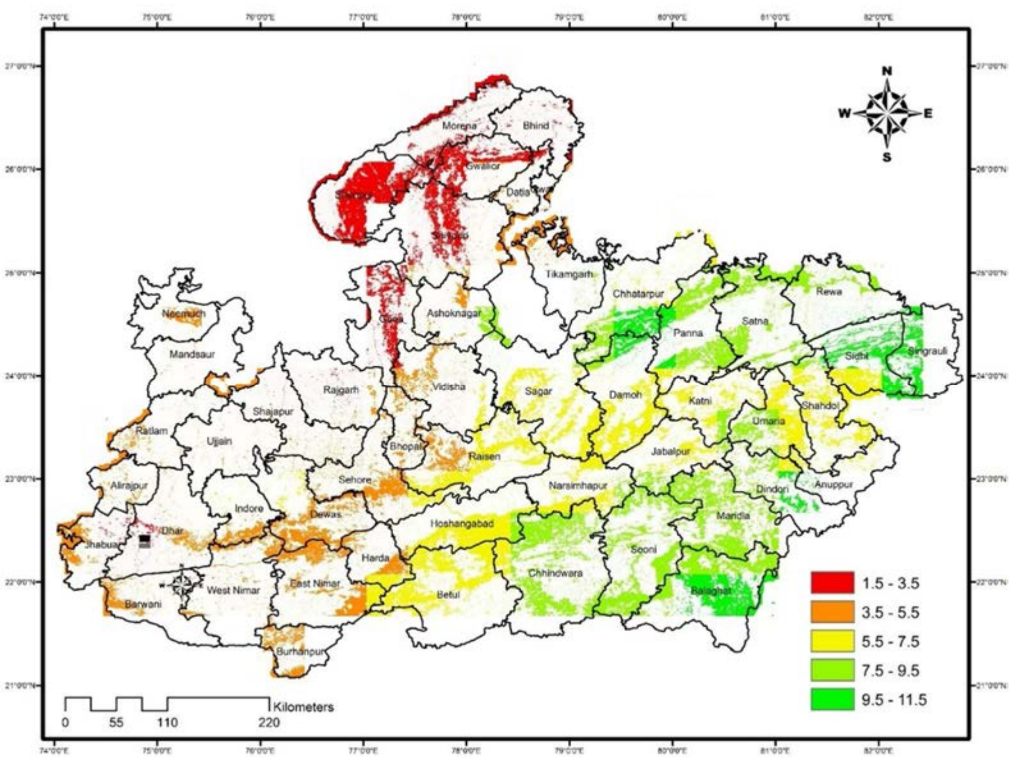

Figure 5.3.5: Projected distribution of Biomass carbon (Kg/m2) over the forests of MP under the RCP8.5 scenario by 2080s

5.4. Impact of Climate Change on Soil Carbon distribution in Madhya Pradesh

Figure 5.4.1 shows the current distribution of soil carbon as simulated by the LPJ model across the forests of MP, which correlates well with the Forest Survey of India based soil carbon density (Chapter 5). Figure 5.4.1 also depicts that the soil carbon density is higher in the southern, western and eastern parts of the state currently. However, the northern parts of MP are low in terms of soil carbon density.

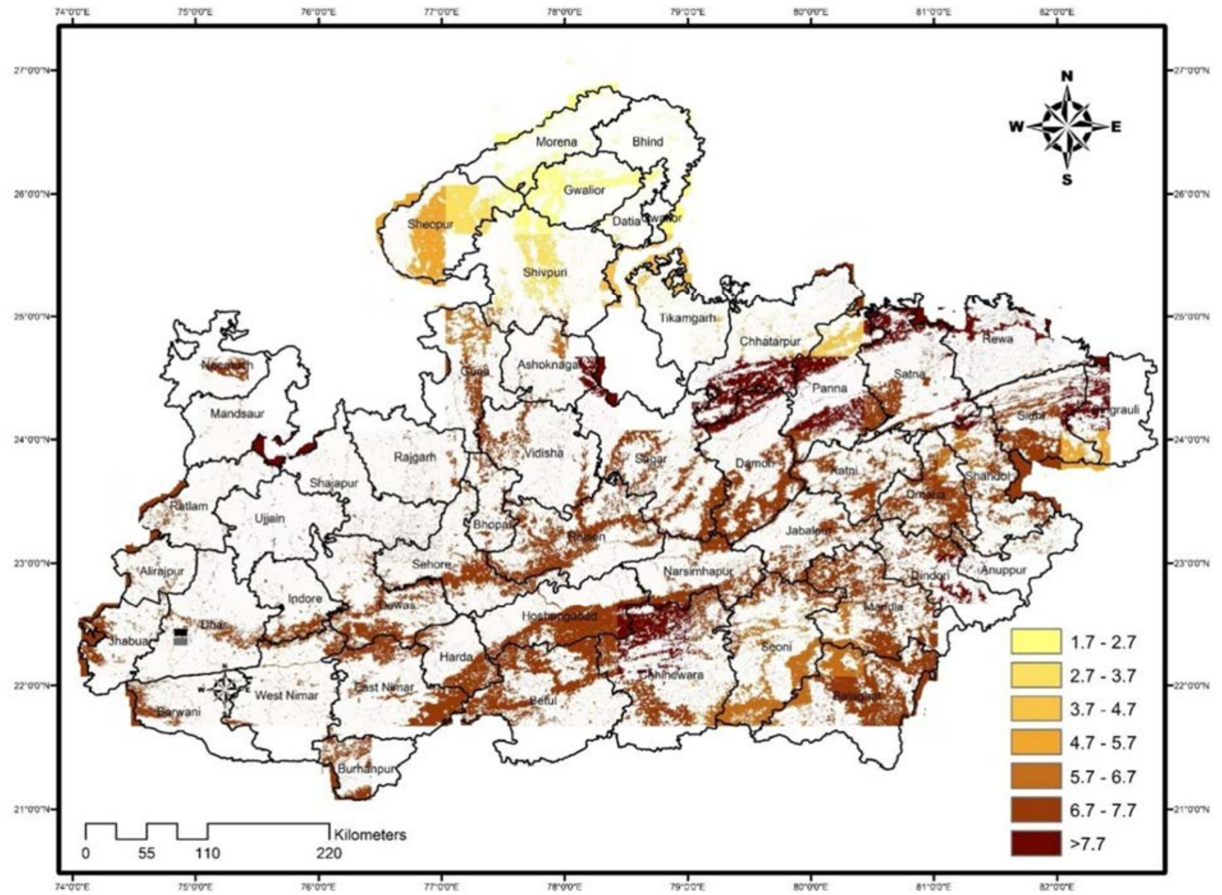

Figure 5.4.1: The current distribution of Soil Carbon (Kg/m2) in the forests of Madhya Pradesh

Figures 5.4.2-5.4.5 shows the impact of climate change on the soil carbon densities over forested grids in MP.

Generally soil carbon densities tend to increase all over the state in projected climate scenarios of RCP4.5 and RCP8.5 by 2030s and 2080s. However maximum soil carbon increase takes place towards the mid-century and thereafter soil carbon tends to decline. Notably, currently low soil carbon density areas of ravines gain substantially in soil carbon under climate change projections, leading to increased productivity

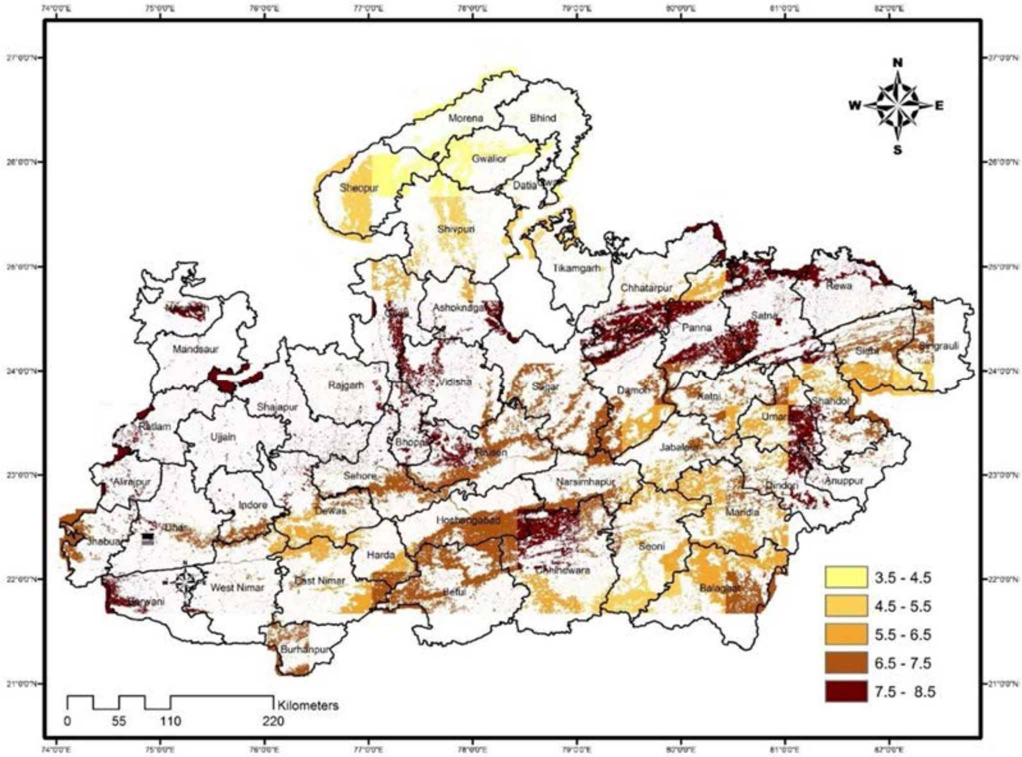

Figure 5.4.2: Projected distribution of Soil Carbon (Kg/m2) in the forests of MP under the RCP8.5 scenario by 2030s

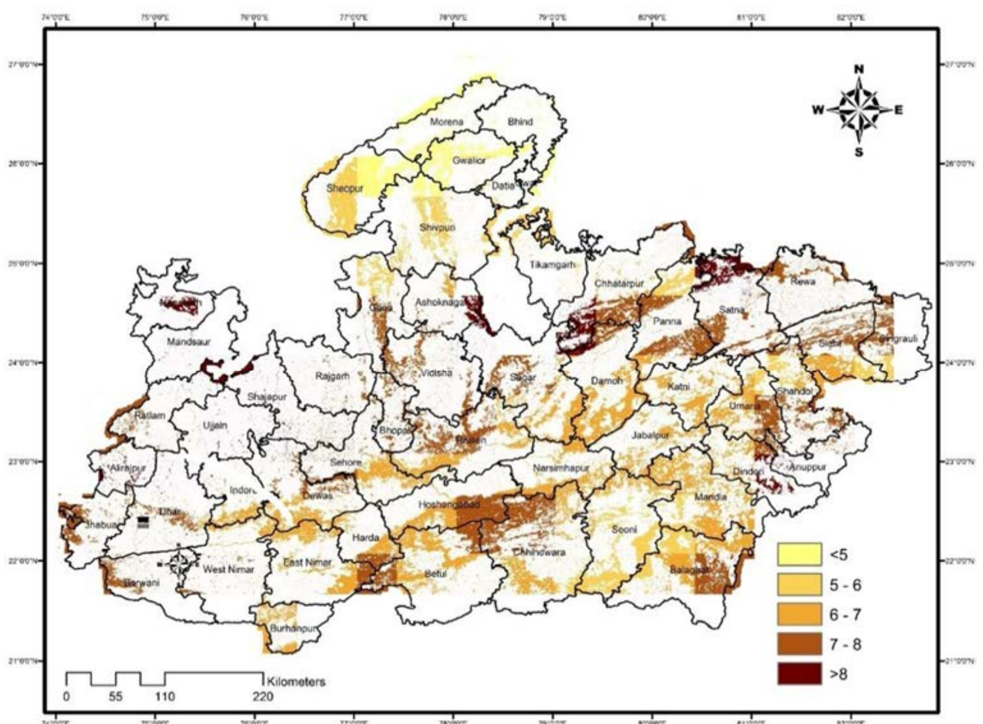

Figure 5.4.3: Projected distribution of Soil Carbon (Kg/m2) in the forests of MP under the RCP4.5 scenario by 2030s

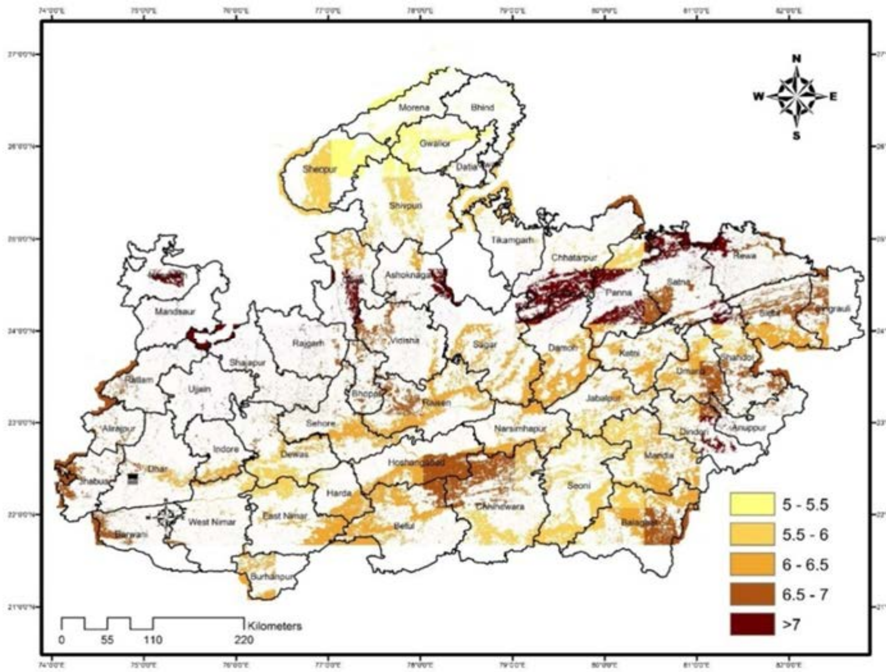

Figure 5.4.4: Projected distribution of Soil Carbon (Kg/m2) in the forests of MP under the RCP4.5 scenario by 2080s

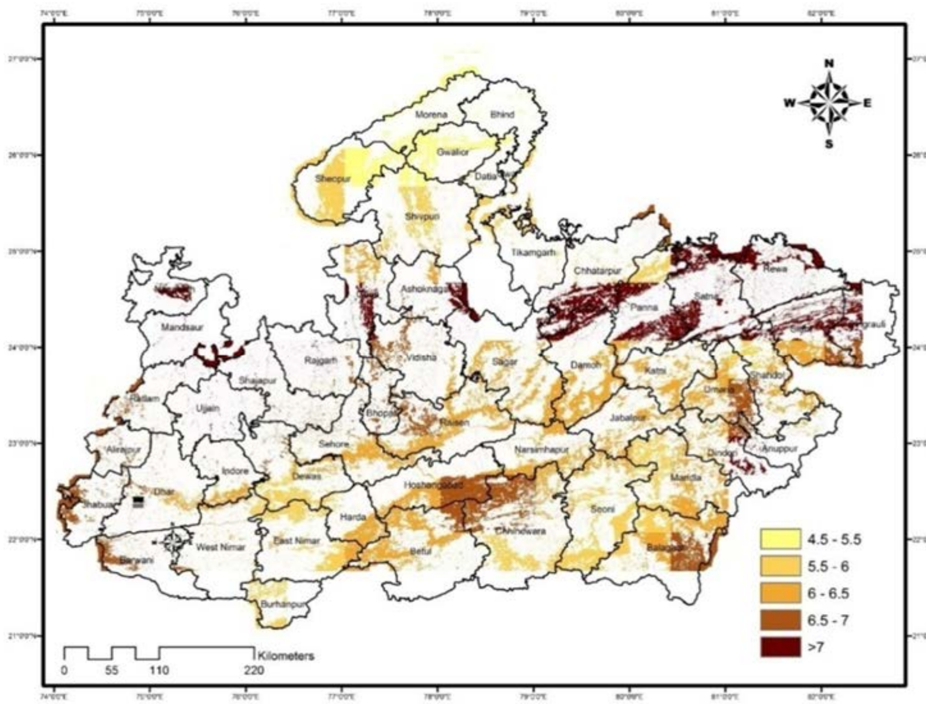

Figure 5.5.5: Projected distribution of Soil Carbon (Kg/m2) in the forests of MP under the RCP8.5 scenario by 2080s

References

ICFRE (2013) Forest types of India revised. Indian Council of Forestry Research and Education, Dehradun

Chapter 6: Climate Change Impact on the Livelihood Security of Forest-dependent Communities

A large portion of Madhya Pradesh's forest area is accessible to the local communities for the purpose of NTFP collection, under surveillance of the forest department. The key NTFPs collected in the state are: Tendu leaves, Palash, Lac, Mahua, Bamboo, Honey, medicinal plants and fruits e.g. mangoes. A large number of villages are situated either inside the forests or at forest fringes. These villages largely depend on the forests for their fuel wood requirements and also for their livelihood security as they extract NTFPs from these woods. Largely, much of the state's population depends on agriculture as their primary occupation; however, livestock rearing and NTFPs provide supplementary livelihood opportunity to majority of the villagers. This diversified source of income, food, timber, fuelwood etc. provides crucial resilience to the communities in the face of different climatic and socio-economic stresses.

It is estimated that about 66.4% of the households of MP depend on fuelwood for cooking; and, a total of 16.7 million cubic metres of fuelwood was extracted from the forests of Madhya Pradesh in the year 2010 (ICFRE, 2010). Given a livestock population of 40.7 million, there is a heavy dependence of livestock on the forest land.. The Working Plan for one of the districts in MP for the year 2013-2014, estimates the average forest produce requirement per family to be '0.22 Cu. m. Timber', '12.62 bamboos' and '7.93 quintals of fuel wood'. Additionally, the Working Plan also recognizes that 'there is 2.9 times more grazing pressure than the carrying capacity' of the grazing land (Forest department Madhya Pradesh, 2014).

It is estimated from this study that under the influence of increasing CO_2, largely due to CO_2 fertilization effect, the net primary productivity of the forests is rising, which is generally beneficial for the growth of biomass and, in turn, for the supply of various non-timber forest products. However, increasing weather extremes such as droughts and extreme precipitation events pose a serious threat to the sustained supply of various NTFPs. Weather extremes are known to have a grave impact upon the agricultural produce as well as on the NTFPs, since both the products thrive on a delicate balance of natural factors. For example, this year's extreme rainfall events not only destroyed the standing rabi crops, but they also damaged the delicate mango flowers. There is no systematic assessment in MP about the impacts of weather extremes on the NTFP production and supply. There exists adire need to undertake such a study. In the future, climate change due to increased CO_2 fertilization may affect the net primary productivity, which is projected to increase under the scenario of good water availability. However, the greatest damage to NTFPs in the future is likely to stem from the extreme weather events. Shifting forest types are also likely to impact the supply of rare plants and herbs along with the production and supply of many of the NTFPs. There is a need to explore the impacts of climate change on NTFPs based on field based long-term observations. Currently, we lack long-term observation plots in the Madhya Pradesh.

References:

1. FSI (2013) State of the forest report, Forest Survey of India, Dehradun

2. ICFRE (2010) Forest sector Report India 2010; Indian Council of Forestry Research and Education, Dehradun Forest department, Madhya Pradesh (2014)Working Plan for the Hoshangabad district.

3. Forest Department Madhya Pradesh

Chapter 7: Adapting to Impacts of Climate Change On Forests and Biodiversity of Madhya Pradesh

In view of the recent COP 21 agreement, forests and terrestrial ecosystems are increasingly assuming a more prominent role, both as a very important carbon sink as well as an adaptation option, due to its positive role in diversifying livelihood opportunities of the rural communities along with its moderating impact on climate, climate extremes, land degradation, water resources and biodiversity conservation.

As part of its INDC, India has promised to carry out a massive afforestation drive to sequester an additional 2.5-3.0GtCO_2 till 2030. Globally, the COP 21 agreement relies heavily on forests to achieve zero carbon emissions in the next half of this century – Which is a pre-requisite for limiting warming to a rise of 2°C. However, the big question that needs urgent answers is the fact that forest ecosystems themselves are highly sensitive to climate change impacts. Addressing questions such as 'How does climate change impact forest ecosystems and carbon stored there-in, in the next half of this century?' is crucial to meet the objectives outlined in India's INDC and the COP 21 agreement.

Populations of many species, including the plants, are already threatened and are expected to be placed even at a greater risk by the multiple stresses of changing climate and land-use changes that fragment the habitats. Though there are uncertainties with respect to projections of climate change impacts on forest ecosystems, evidence is growing to indicate that climate change, coupled with socio-economic and land use pressures, is likely to adversely impact forest biodiversity, carbon sinks, biomass productivity or carbon uptake rates, livelihoods of forest- dependent communities and economies.

Adaptation to projected climate impacts on MP's forest sector is critical due to the following reasons:

a) In Madhya Pradesh, there is a large proportion of population depending on climate-sensitive sectors such as agriculture, forests and fisheries. Forest dwellers form one of the poorest sections of society and are likely to be adversely impacted due to the climate change.

b) Due to poorly developed institutions, markets, technology-transfer pathways and lack of financial resources, forest-dependent communities (in particular) have low capacity to cope with or adapt to adverse impacts. Those with the least resources and the least capacity to adapt, such as forest dwellers, are the most vulnerable communities.

c) Forest sector is likely to be vulnerable to extreme events, such as droughts coupled with warming, leading to increased occurrence of fires to which local governments and institutions, especially in developing countries, could find it difficult to cope with.

d) Development and implementation of adaptation strategies and practices in the forest sector would require long gestation periods, years of research and development, institutional building and education. Inertia in climatic, ecological and socio-economic systems makes adaptation inevitable and extremely essential in some cases.

Our analysis suggests that the ongoing climate change (as well as the projected climate change) presents both an opportunity and a threat to the forests of MP. The opportunity comes by the way of increased net primary productivity; increased biomass and increased soil organic carbon in different parts of the state (see Chapter 5 for details). Satellite-based observations in the last three decades suggest that the NPP is already increasing in the state, largely in response to the increased carbon fertilization. Our simulations further suggest an increase in NPP, biomass and soil carbon in the forests of MP, at least in the short term. Increased NPP and increased biomass have the potential to increase the supply of both timber and non-timber forest products (NTFPs) as well, since it can further enrich the soil carbon and productivity by additional litter-fall.

However, the scenario of increased NPP could be threatened due to 1) lack of adequate water and other nutrients in a warming climate. In this context, it should be noted that our rainfall projections used in this study are associated with large uncertainties; and,2) our model-based simulations suggest that many forested grids, especially in the northern and western parts of the state, may not remain suitable for the drier forests types at present, and may give way to wetter forest types. This scenario presents a serious threat to these forests as majority of these forests are low in biodiversity richness, disturbed and fragmented. In fact, the fragmented and isolated forests in low biodiversity areas are especially vulnerable to the impacts of climate change which, in turn, could hamper the dispersal and migration of species. Hence, it is vital to carry out afforestation and forest restoration activities, keeping in mind the need to build corridors to link fragmented and isolated forests. While building these corridors, a mix of native and relevant species should be selected. Such corridors will not only be useful for building resilience of the forest ecosystems, but they will also provide crucial points for the movement of fauna as well. It needs to be understood that the needs of plants are in synergy with the needs to the animals including the large mammals.

a) Keeping these synergies as well as Govt. of India's large afforestation commitments in mind, the feasibility of an ambitious project like 'interlinking of forests' of the state should be investigated.

b) Forest conservation, afforestation/reforestation activities in the state should be designed such that these activities reduce the fragmentation and degradation of the existing forests. Anticipatory planting and assisted natural migration through transplanting plant species could also be considered.

c) Biodiversity Richness Index of different forests of MP is available from the Department of Space. It is important to carry out the forest conservation activities in a way that these activities increase the overall biodiversity richness of these forests, by planting of mix species, and the native species.

d) Since water and nutrients are a critical bottleneck for realising the benefits of increases in NPP, it is important that water conservation activities are initiated in forests of the state.

e) In the state, a large number of people depend on forest resources for their livelihood (See Chapter 6). However, in a climate change scenario, increasing climate extremes have the potential to disrupt the supply of NTFPs in the short or long term (as this study largely assesses the impact of mean climate changes and does not account for the impacts of extremes of climate on forest ecosystems and NTFPs in the state). Hence, it is important that the livelihoods of the forest-dependent communities is diversified and modernized via market linkages.

f) Govt. of India has proposed large scale afforestation and reforestation activities in its INDC. Afforestation and reforestation activities, proposed as mitigation activities, provide opportunities for adaptation as well. Some examples of adaptation practices that can be (and need to be) incorporated in any afforestation and reforestation mitigation project are as follows: i) Promotion of regeneration of native species through protection and natural regeneration in degraded natural forest lands, to reduce vulnerability to changing climate; ii) Promotion of multi-species plantation forestry incorporating native species, in place of mono-culture plantation of exotic species to reduce vulnerability; iii) Adoption of short-rotation species in commercial or industrial forestry to enable adaptation to any adverse impact of climate change; iv) Incorporation of several silviculture practices such as sanitation harvest, increased thinning to reduce occurrence of pests and diseases; v) Incorporation of fire protection measures to reduce vulnerability of forests to fire hazards due to warming accompanied by droughts; vi) Incorporation of soil and water conservation measures to reduce the adverse impacts of drought on forest growth; vii) Soil and water conservation: a key adaptation practice aimed at reducing vulnerability, which also reduces carbon loss from soils as well as enhances soil carbon density by increasing the biomass growth rate of forests or plantation or grassland; viii) Drought-resistant varieties or clones, which not only reduce vulnerability of tree and grass species to droughts and water stress but also increase carbon sequestration rates; ix) Enhancing soil organic matter content through organic manure to increase the moisture retention and soil fertility, which not only reduces the vulnerability to drought and moisture stress but also increases the carbon sequestration rates of trees as well as grass species; x) Forest and biodiversity conservation, through halting deforestation, expanding protected areas and adopting sustainable harvest practices, is a vital adaptation strategy to reduce vulnerability of forest ecosystems. All such programmes or practices could also be considered as mitigation options to conserve forest carbon sinks; and xi) Urban park and tree planting, which promotes adaptation to heat stress in urban areas by reducing air-conditioning needs and facilitates carbon sequestration in trees and soil as well.

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