11

MAPPING OF CLIMATE CHANGE HOTSPOTS IN INDIAN FORESTS

Introduction 11.1

The planet earth, at various points of time in its history, has witnessed catastrophic changes in its climate and these changes have impacted the geology, geography and evolution of life on earth. In the present time and age, the planet is again being subjected to deleterious changes in climate but this time, it is primarily engined by anthropogenic factors and is way faster than natural events of the past. Climate Change is the outcome of a complex set of processes that include emission of green-house gases (GHGs) from industrial and farm based processes, burning of fossil fuels and biological matter and industrial and anthropogenic effluents that impact water bodies, including the oceans.

Increase in levels of GHG including Carbon dioxide (CO_2) in the atmosphere is leading to a steady increase in mean global atmospheric temperatures. Such rise in temperature is affecting natural phenomena such as precipitation and also impact ecosystems and essential biological processes, which are germane to survival of life on earth. Increase in temperature also leads to faster melting of polar and mountain snow caps and glaciers and contribute to sea level rise which threatens pelagic and coastal biodiversity, impacts livelihoods and even threatens coastal and island dwelling human populations. Climate change negatively impacts weather patterns and thus has a cascading effect on farming and public health.

The levels of atmospheric CO_2 has been steadily increasing since pre-industrial times (middle of 18th century AD). The mean global temperatures have already risen by a little more than 1°C as compared to pre-industrial times (IPCC, 2021[1]). The IPCC AR6 report of 2021 also shows a steady rise in Global Surface Temperature since 1900 to 2020 (Figure 11.1). IPCC in October 2018, released a special report on 'Global Warming of 1.5°C' and highlighted the impacts of the same. The report goes on to state that an increase in temperature by 2°C shall have catastrophic impact on life on earth. To cite an example, the global population exposed to severe heat will be 37% at 2°C as compared to 14% at 1.5°C (IPCC, 2018[2]).

Forests play a vital role in climate change mitigation. Forests are a sink of carbon dioxide and they are the biggest terrestrial reservoir of carbon on the planet. They become source of CO_2 and other GHGs if they are cut, burnt or destroyed.

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[1] *IPCC, 2021: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press.*

[2] *IPCC Special Report (2018). Summary for Policymakers of IPCC Special Report on Global Warming of 1.5°C approved by governments.*

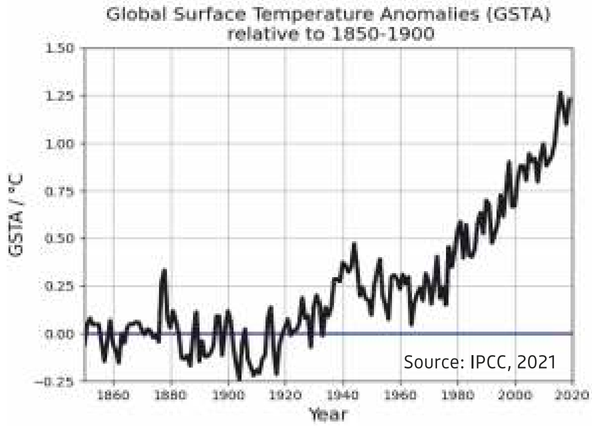

Figure 11.1 Global Surface Temperature Anomalies

Countries across the globe have committed to create a new international climate agreement by the conclusion of the U.N. Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP21) in Paris in December 2015. India too has submitted its Nationally Determined Contribution (NDC) to the UNFCCC in October 2015[3], which outlines the post-2020 climate actions the country intends to take under a new international agreement. As per the fifth and sixth commitment by India in NDC:

- India should create an additional carbon sink of 2.5 to 3 billion tonnes of CO_2 equivalent through additional forest and tree cover by 2030,
- India also should better adapt to climate change by enhancing investments in development programmes in sectors vulnerable to climate change, particularly agriculture, water resources, fisheries, health and disaster management and in regions like coastal region and Himalayan region.

In the recent COP 26 at Glasgow (2021), India is committed to reduce carbon emissions by 1 billion tonnes by the year 2030.

Moreover, by 2030, India also quoted that it will bring down carbon intensity of its economy by more than 45 per cent, whereas, the previous goal was 35%.

Forest Survey of India, in harmony with its mandate of assessing and monitoring forests of the country, has undertaken a collaborative study with Birla Institute of Technology & Science, Pilani (BITS - Goa Campus) to map climate hot spots in the forest areas of the country. The study makes use of the computer model based projections of temperature and rainfall in three time horizons i.e. 2030, 2050 and 2085 (Ashutosh & Chaturvedi *et al.*, 2020[4]) . A climate hotspot refers to an area, which is likely to face severe impacts of climatic change. Enhanced understanding about climate change hotspot areas due to adverse climatic impacts in the forests of India would help in planning and strategizing mitigation of climate change impacts and devising appropriate adaptation measures.

11.2 Importance of the Study under Indian scenario

In 2020, India Meteorological Department (IMD) has reported an increasing trend of 0.61°C/ 100 years in annual mean temperature over India during 1901 to 2019 period (IMD, 2020[5]). While Indian forests are contributing to the greening in India many forested areas are already showing shift in

[3] India's Intended Nationally Determined Contribution: Working Towards Climate Justice (2015), MoEF&CC, GoI

[4] Ashutosh S, Sharma S, Lakhchaura P, Joshi M, Ghosh Sourav, Rao V (FSI, Dehradun); and Chaturvedi R (BITS Pilani, GOA); (2020). Mapping Climate Change Hotspots in Indian Forests Based on Observed Climate Change and High Resolution Climate Model Projections. FSI Technical Information Series, Vol 2 (5): 1-62.

[5] IMD (2020). Statement on Climate of India during 2019, Press Release, 6th January 2020, India Meteorological Department, Ministry of Earth Sciences, New Delhi

vegetation types. Telwala *et al.* (2013[6]) has estimated shift in vegetation patterns for 124 endemic species in the Eastern Himalayan state of Sikkim, over the period 1849-1850 to 2007-2010. The study concludes that the "...present-day plant assemblages and community structure in the Himalaya is substantially different from the last century and is, therefore, in a state of flux under the impact of warming...". It further cautions that the continued warming is likely to result in ongoing elevation range contractions, and eventually species extinctions, particularly at the mountaintops.

Objective of the Study 11.3

The collaborative study was carried out with the objective to map the climatic hotspots over the forest cover in India (FSI, 2019[7]), using computer model based projection of temperature and rainfall data, for the three future time periods i.e. year 2030, 2050 and 2085.

In this chapter 2030 represents near-term timeline that coincides with global short-term climate action horizon. India's NDC also refers to the 2030 period and sixth version of NDC aims to better adapt to climate change in vulnerable sectors. On the other hand, 2050 represents our mid-term timeline and it coincides with global long-term climate action goals. We chose 2085 to represent our long term time horizon, as beyond this time-slice, climate change projections are not available.

Methodology 11.4

Model Selection 11.4.1

Climate projections have been developed by different research groups working on climate data modelling around the world, based on the Representative Concentration Pathway (RCP) scenarios. The RCPs describe four different 21[st] century pathways of greenhouse gas (GHG) emissions and atmospheric concentrations, air pollutant emissions and land use. RCP based climate projections are available from a number of climate models under the Coupled Model Inter-comparison Project (CMIP5) experiment (fifth version), as proposed by World Climate Research Programme (WCRP). WCRP under World Meteorological Organization (WMO) in Geneva, Switzerland, co-ordinates and facilitates international climate research to develop, share and apply climate knowledge.

Greenhouse gases (GHGs) are the key drivers of climate change. Depending on varying levels of socio-economic and technological developments, different GHG patterns are possible in future which are represented through four RCP scenarios: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 (IPCC 2014[8]).

Amongst the four, RCP 8.5 represents the highest emission scenario, while RCP 6.0 and RCP 4.5 are moderate emission scenarios. RCP 2.6 is the 'best case' emission scenario that leads the world to limiting warming below 2°C towards the end of the 21[st] century.

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[6] Telwala Y, Brook BW, Manish K, Pandit MK (2013). Climate-Induced Elevational Range Shifts and Increase in Plant Species Richness in a Himalayan Biodiversity Epicentre. PLoS ONE 8(2): e57103.

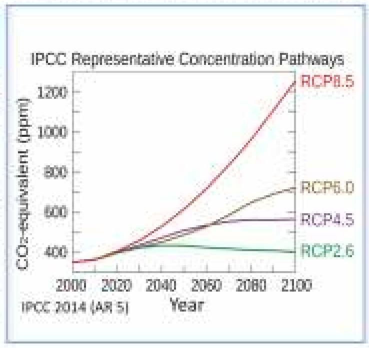
[7] FSI (2019). India State of Forest Report. ISBN: 978-81-941018-0-2.

[8] IPCC (2014) Summary for policymakers, In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field CB, Barros VR, Dokken DJ, Mach KJ, Mastrandrea MD, Bilir TE, Chatterjee M, Ebi KL, Estrada YO, Genova RC, Girma B, Kissel ES, Levy AN, MacCracken S, Mastrandrea PR, White LL (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

In order to adequately represent the risks associated with future projections of climate change, RCP 4.5 and RCP 8.5 scenarios were selected for this study.

Representative Concentration Pathways (RCPs) :- The RCPs describe four different 21st century pathways of greenhouse gas (GHG) emissions and atmospheric concentrations, air pollutant emissions and land use. The four RCP emission scenarios: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 (IPCC, 2014).

RCPs (Considered for Study)	Description	Developed by
RCP 2.6	RCP 2.6 is a "best case" or "peak" scenario, leading to very low greenhouse gas concentration levels . According to the IPCC, RCP 2.6 requires that carbon dioxide (CO2) emissions start declining by 2020 and go to zero by 2100. RCP 2.6 is likely to keep global temperature rise below 2°C by 2100. Its radiative forcing level first reaches a value around 3.1 W/m2 mid-century, returning to 2.6 W/m2 by 2100.	The RCP 2.6 is developed by the IMAGE modeling team of the Netherlands Environmental Assessment Agency. Van Vuuren *et al.* (2007).
RCP 4.5	It is a stabilization scenario where total * radiative forcing is stabilized well before 2100 by employing a range of technologies and strategies for reducing greenhouse gas emissions. The GHG emission reaches its peak in the year 2040.	MiniCAM modelling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI), Maryland, USA, (Wise *et al.* 2009).
RCP 6.0	In RCP 6, emissions peak around 2070 to 2080, then decline. The RCP 6.0 scenario uses a high greenhouse gas emission rate and having a stabilization scenario where total radiative forcing is stabilized after 2100 after reaching radiative forcing at 6.0 W/m² without overshoot by employment of a range of technologies and strategies for reducing greenhouse gas.	The RCP 6.0 is developed by the AIM modeling team at the National Institute for Environmental Studies (NIES), Japan. (Masui et al. 2011)
RCP 8.5	The RCP 8.5 is characterized by increasing greenhouse gas emissions over time representative for scenarios in the literature leading to high greenhouse gas concentration levels. This is the worst case scenario, where GHG emission will remain in increasing trend even in the year 2100.	MESSAGE modelling team and the Integrated Assessment Framework at the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria (Riahi et al. 2007)



* Radiative forcing, a measure, as defined by the Intergovernmental Panel on Climate Change (IPCC), of the influence a given climatic factor has on the amount of downward-directed radiant energy impinging upon Earth's surface.

11.4.2 Data Acquisition

Observed gridded climate data for temperature and precipitation (Pai *et al.* 2014[9]) was obtained from India Meteorological Department (IMD).

IMD provides gridded temperature data at a resolution of 1° X 1° for the time period 1951 to 2019. Between, 1980-2019, IMD has also introduced a new temperature data product at 0.5° X 0.5° resolution, which roughly translates into 50 km in length and 50 km in width (Srivastava *et al.* 2009[10]). To fill in the data gaps, observed gridded temperature climatology for the period 1951-2019 (consistent) at 0.5° X 0.5° resolution was used from Harris *et al.* 2014[11]. The resolution of the observed precipitation dataset from IMD is further improved with the help of a Convolutional Neural Network model (CNN).

This model aims to learn from the spatial distribution of the high-resolution gridded satellite based precipitation data very high resolution gridded precipitation product from GPM (Global Precipitation Monitoring Programme) to fill the gaps in the gridded precipitation dataset.

Temperature dataset (1951-2019) from Harris *et al.* 2014 (as referred earlier) is available at a coarse resolution of 0.5° X 0.5°. The resolution of this data is improved with the help of a Convolutional Neural Network model (CNN) by using the high-resolution gridded satellite based temperature data (Land Surface Temperature - LST from the Moderate Resolution Imaging Spectro-radiometer- MODIS platform). Performance of these models is duly validated.

[9] *Pai DS, Sridhar L, Badwaik MR, Rajeevan M (2014). Analysis of the daily rainfall events over India using a new long period (1901–2010) high resolution (0.25°× 0.25°) gridded rainfall data set. Climate Dynamics, 45:755–776.*

[10] *Srivastava AK, Rajeevan M, Kshirsagar SR (2009). Development of a high resolution daily gridded temperature data set (1969–2005) for the Indian region. Atmospheric Science Letters, 10 (4): 249-254.*

[11] *Harris I, Jones PD, Osborn TJ, Lister DH (2014). Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 Dataset, International Journal of Climatology, 34(3):623-642.*

The gridded precipitation dataset from IMD is available at a much finer spatial resolution i.e. 0.25° X 0.25°. Thus, due to difference in resolution of the precipitation and temperature datasets, the respective datasets were downscaled to a resolution of about 10km X 10km (0.1° X 0.1°) grid by using a newly developed CNN (Convolutional Neural Network) based model.

This model uses high resolution satellite data products (Land Surface Temperature (LST) (1 km X 1 km) for temperature and Global Precipitation Measurement (GPM) (1 km X 1 km)) and coarse resolution observed gridded data with great accuracies (Ghosh 2010[12], Khan *et al.* 2006[13])

Selection of Climatic Hotspots 11.4.3

A temperature hotspot for this study has been defined as any forested grid that is projected to experience a temperature rise over 1.5°C compared to 1860-1900 scenario. On the other hand a precipitation hotspot refers to the change of rainfall greater or less than 20% with respect to the 1960-1990 scenario. The severity of the hotspots has been scaled on the basis of magnitude of increase in temperature over 1.5°C, and change in precipitation greater/less than +/- 20%. Hotspot maps are particularly useful for climate change adaptation planning by identifying forest areas likely to be impacted by climate change and showing them in maps.

Further, hotspot maps hold the promise of transparent and defensible priority setting to address critical issues in a scientific manner.

Categorization of Climatic Hotspots 11.4.4

Temperature change (ΔT in degree C) in 2030/2050/2080 compared to 1860-1900 base spatial distribution over 1.5°C is classified into following:

1. High - Increase of 1.5 to 2.1°C
2. Very High - Increase of 2.1 to 3.3 °C
3. Extremely High - Increase of 3.3 to 5.1 °C
4. Critical - Increase of 5.1 to 6.6 °C

Precipitation change (change in precipitation greater/less than +/- 20% i.e. ΔP in %) in 2030/2050/2080 compared to 1960-1990 base is classified into following:

1. High - 20% to 26 %
2. Very High - 26% to 32%
3. Extremely High - 32% to 38%
4. Critical - 38% to 41%

Thereafter, a composite score combining the temperature and precipitation variables were computed assigning 75% weightage to temperature and 25% to precipitation and classified into following:

1. High - 0.75 to 3
2. Very High - 3 to 4.25
3. Extremely High - 4.25 to 6.75
4. Critical - 6.75 to 8.75

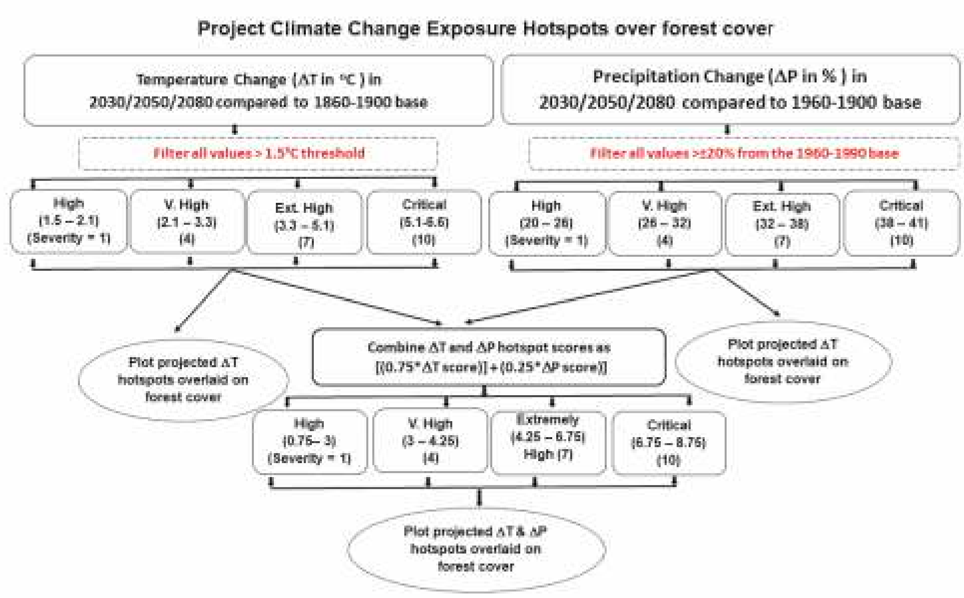
[12] *Ghosh Subimal (2010) SVM-PGSL Coupled Approach for Statistical Downscaling to Predict Rainfall from GCM Output. Journal of Geophysical Research, 115:D22102*

[13] *Khan M, Coulibaly P, Dibike Y (2006) Uncertainty Analysis of Statistical Downscaling Methods. Journal of Hydrology 319(1):357–382.*

11.4.5 Mapping of Hotspot

The identified climatic hotspots categories, such as, 'High', 'Very High', 'Extremely High' and 'Critical' based on temperature and rainfall change parameters; have been further sub-divided into 10 classes depending on their severity. The 'High' category is having 3 severity classes (1, 2, and 3) and are colour coded within the shades ranging from blue to green. The 'Very High' category is further segregated in 3 severity classes (4, 5 and 6) having the colour shades ranging from green to yellow. The hotspot category 'Extremely High' is again sub-divided into 3 severity classes (7, 8 and 9) having the colours varying from yellow to orange.

Figure 11.2
Schema adopted to classify climate change hotspots



The 'Critical' hotspot category is kept as severity class 10, with red as its colour of notification. The 'Critical' hotspot class are expected to lead to the catastrophic impact in the forest environment.

The above 10 sub-categorization with the colour coding has been done to generate self-explanatory thematic maps. These thematic maps at a glance could guide to set respective locational priority, for any future planning activities, to mitigate and adapt adverse projected climate impacts.

11.5 Results and Discussion

The computer model based projection analysis over scaled down (1° X 1°) gridded temperature and rainfall data was carried out to generate National level hotspots database over forest grids based on Forest cover layer of ISFR 2019.

Both RCP 4.5 and RCP 8.5 based model were run using computation based platform to predict the future climatic hotspot. The models predicted climatic hotspots for the year 2030, 2050 and 2085. Accordingly, the thematic maps were generated over the forest cover. The climate change maps show the degree of severity to be faced by Indian forests in different time periods i.e. 2030, 2050, 2085.

Forest cover area in the country under different hotspots classes in different time periods with RCP 4.5 and RCP 8.5 scenarios using combined temperature and precipitation data is given in Table 11.1.

Table 11.1 Forest cover area (sq km) under hotspots in 2030/ 2050/2085 with RCP 4.5 and RCP 8.5 models

(in sq km)

Hotspot Classes	Year 2030		Year 2050		Year 2085	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
High	314969	448367	367334	260883	11804	0
Very High	698	1552	330602	343726	656094	0
Extremely High	0	0	6899	100569	37196	566442
Critical	0	0	0	0	0	138736
TOTAL	**315667**	**449919**	**704835**	**705178**	**705094**	**705178**

It is clearly observed that time period transitions from 2030 to 2050 and 2085; the area under hot spots within forest cover increases. Moreover, the concept of Models RCP 4.5 and RCP 8.5 tells us that RCP 8.5 is the more extreme scenario between these two i.e. the areas under forest hot spot always show higher values in RCP 8.5 scenarios than RCP 4.5 for all the three future projected years i.e. 2030, 2050 and 2085.

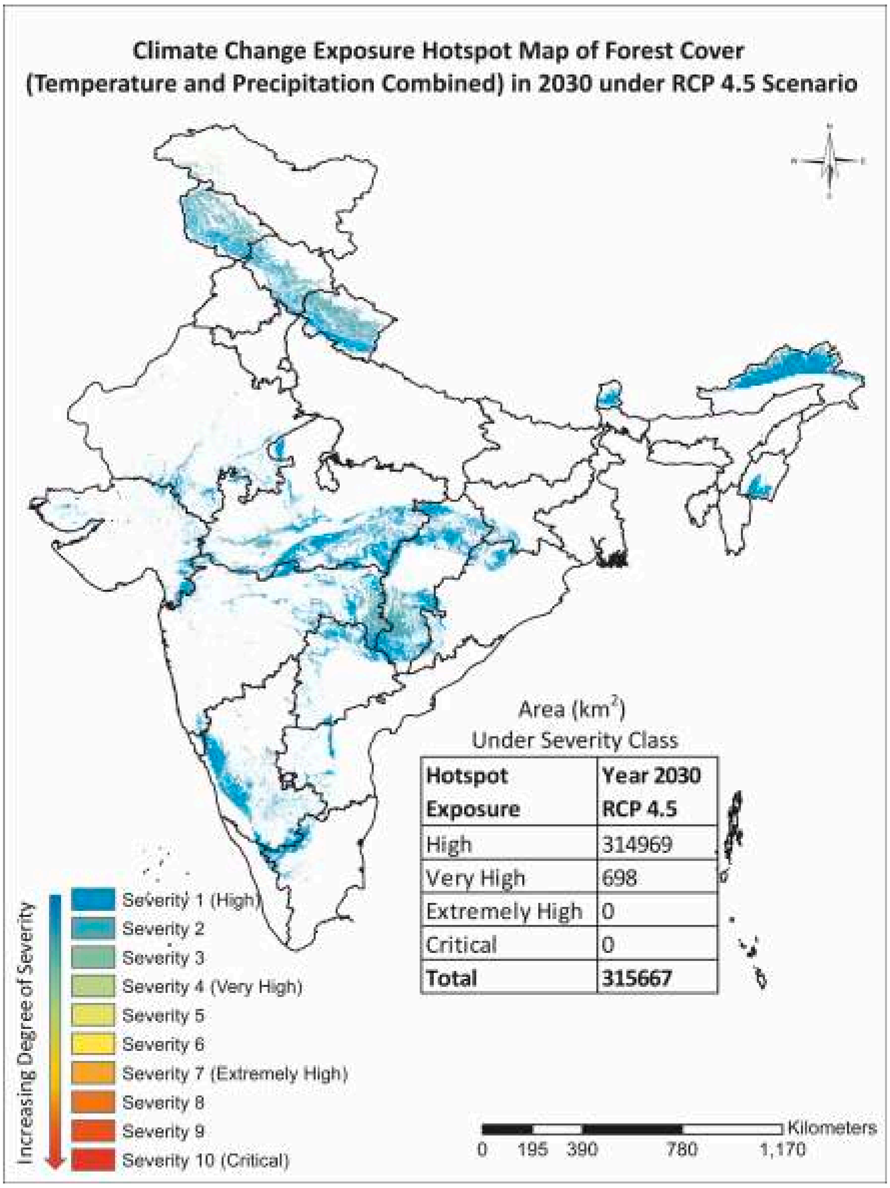


Figure 11.3 Climate change hotspot in 2030 in terms of combined temperature rise and precipitation change for RCP 4.5 (Resolution: 1km X 1km)

Figure 11.4
Climate change hotspot in 2030 in terms of combined temperature rise and precipitation change for RCP 8.5 (Resolution: 1km X 1km)

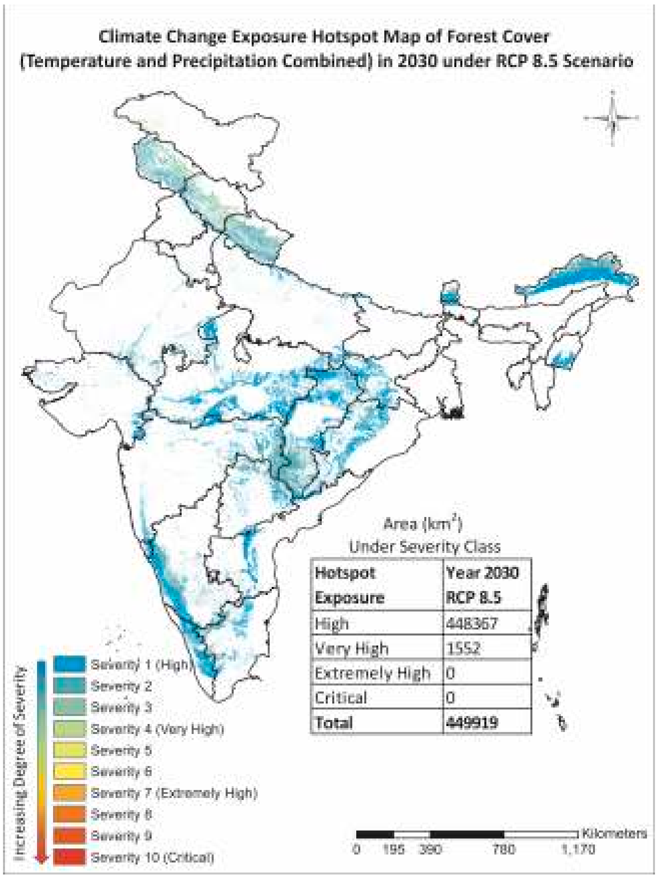
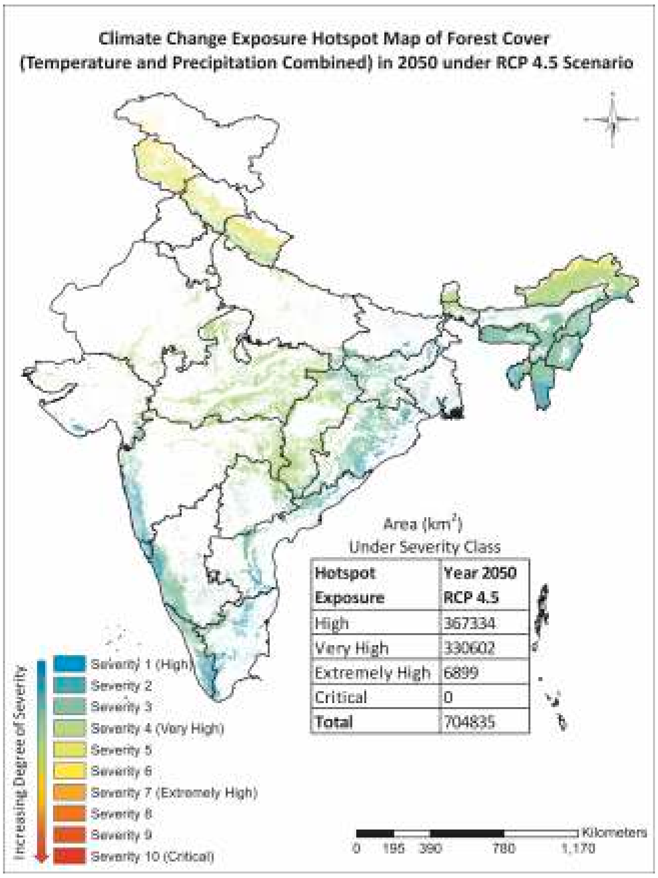


Figure 11.5
Climate change hotspot in 2050 in terms of combined temperature rise and precipitation change for RCP 4.5 (Resolution: 1km X 1km)



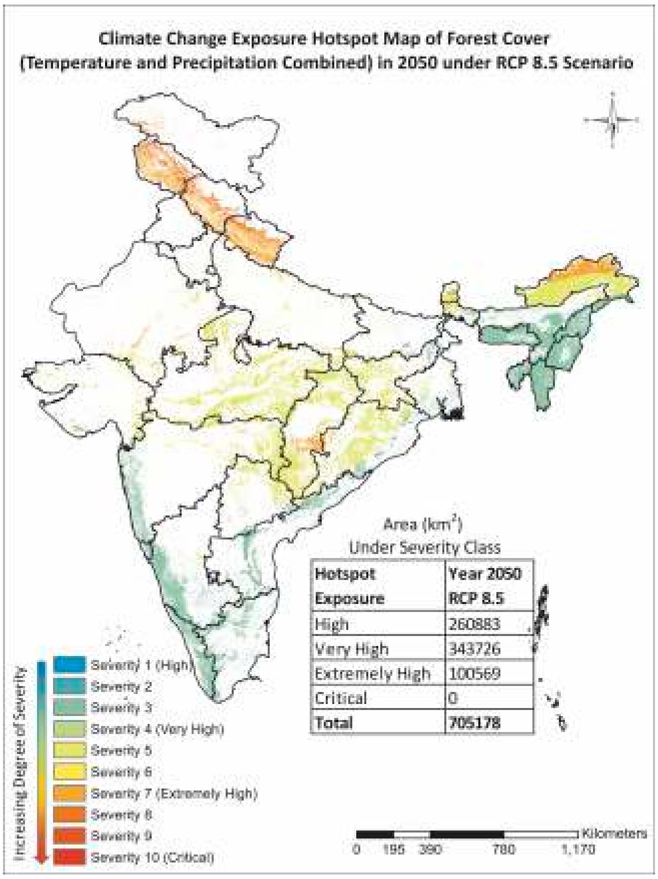


Figure 11.6 Climate change hotspot in 2050 in terms of combined temperature rise and precipitation change for RCP 8.5 (Resolution: 1km X 1km)

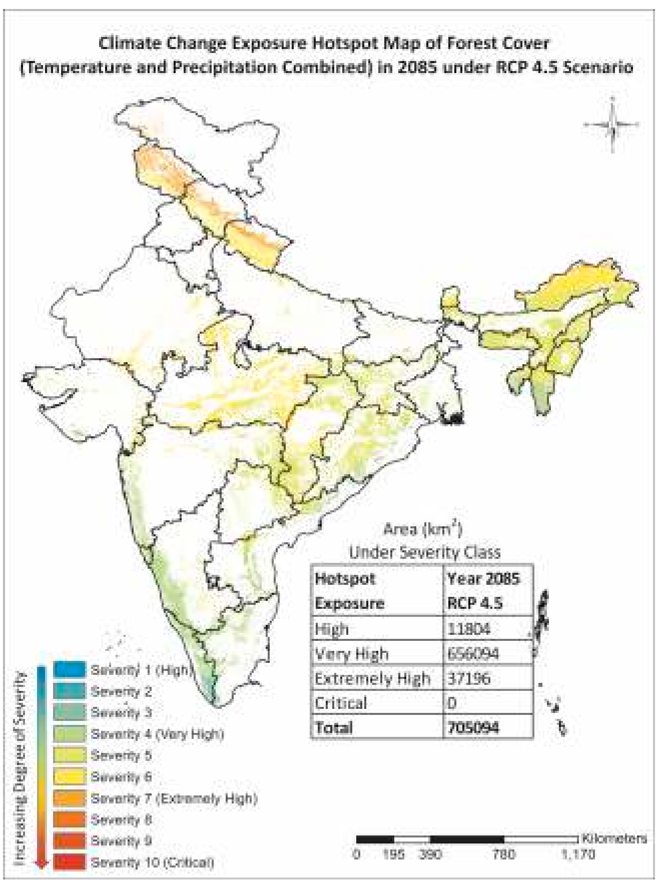


Figure 11.7 Climate change hotspot in 2085 in terms of combined temperature rise and precipitation change for RCP 4.5 (Resolution: 1km X 1km)

Figure 11.8
Climate change hotspot in 2085 in terms of combined temperature rise and precipitation change for RCP 8.5 (Resolution: 1km X 1km)

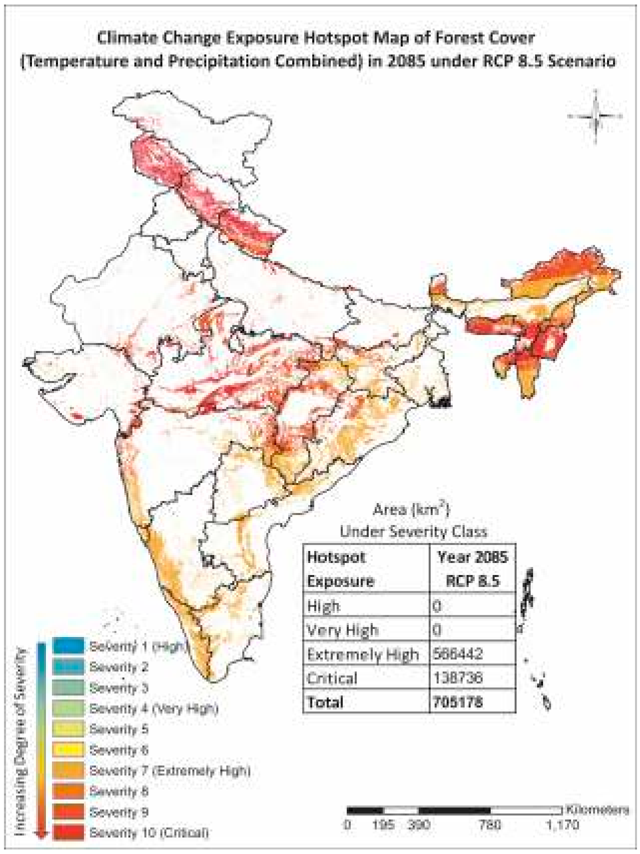


Table 11.2 Projected climate change (temperature and precipitation combined) exposure hotspot area in forest ecosystems in India

Forest Type	Total Area (in 2019), sq km	2030 RCP 4.5
1 Tropical Wet Evergreen Forests	20054	4448
2 Tropical Semi-evergreen Forests	71171	28519
3 Tropical Moist Deciduous Forests	135492	63940
4 Littoral & Swamp Forests	5596	542
5 Tropical Dry Deciduous Forests	313617	172719
6 Tropical Thorn Forests	20877	9738
7 Tropical Dry Evergreen Forests	937	6
8 Subtropical Broad leaved Hill Forests	32706	4934
9 Subtropical Pine Forests	18102	16955
10 Subtropical Dry Evergreen Forests	180	180
11 Montane Wet Temperate Forests	20435	1039
12 Himalayan Moist Temperate Forests	25743	25743
13 Himalayan Dry Temperate Forests	5627	5627
14 Sub-alpine Forests	14995	14866
15 Moist Alpine Scrub	959	959
16 Dry Alpine Scrub	2922	2922

Table 11.2 indicates that 'Tropical Dry Deciduous Forests', 'Tropical Moist Deciduous Forests' and 'Tropical Semi-evergreen Forests'; the three top most dominant forest type groups of the country, covering 313617 sq km, 135492 sq km and 71171 sq km area respectively shall be highly vulnerable to climate change. Results from both the models i.e. RCP 4.5 and RCP 8.5, depict that almost the entire area under these dominant forest type groups will be falling within climate hot spots in the coming years from 2050 onwards.

Climate Change hotspot area under projected temperature and precipitation combined (sq km)				
2030 RCP 8.5	2050 RCP 4.5	2050 RCP 8.5	2085 RCP 4.5	2085 RCP 8.5
10077	16343	19717	19717	19717
43046	71171	71171	71171	71171
85122	135492	135492	135492	135492
2003	3808	5596	5596	5596
245501	313617	313617	313617	313617
12931	16020	16026	16026	16026
311	896	896	896	896
7080	21116	21116	21116	21116
18054	18059	18100	18100	18100
180	180	180	180	180
1641	5333	5333	5333	5333
25743	25743	25743	25743	25743
5627	5627	5627	5627	5627
14995	14995	14995	14995	14995
959	959	959	959	959
2922	2922	2922	2922	2922

Table 11.3 State wise Distribution of hotspots (sq km) in 2030 under RCP 4.5 and RCP 8.5 scenarios

States / UTs	Forest Cover (sq km) ISFR 2019	Projected Area (in sq km) of Hotspots				
		RCP 4.5				
		(Hot Spots with Increasing Degree of Severity from High to Critical)				
		High	Very High	Extremely High	Critical	Total
Andhra Pradesh	29137	3977	0	0	0	3977
Arunachal Pradesh	66688	26360	0	0	0	26360
Assam	28327	0	0	0	0	0
Bihar	7306	0	0	0	0	0
Chhattisgarh	55611	46937	0	0	0	46937
Delhi	195	0	0	0	0	0
Goa	2237	671	0	0	0	671
Gujarat	14857	10549	0	0	0	10549
Haryana	1602	293	0	0	0	293
Himachal Pradesh	15434	13846	0	0	0	13846
Jammu & Kashmir	21122	20741	0	0	0	20741
Jharkhand	23612	3165	0	0	0	3165
Karnataka	38575	28534	0	0	0	28534
Kerala	21144	1522	0	0	0	1522
Ladakh	2490	1694	698	0	0	2392
Maharashtra	50778	34170	0	0	0	34170
Manipur	16847	3937	0	0	0	3937
Meghalaya	17119	0	0	0	0	0
Mizoram	18006	92	0	0	0	92
Madhya Pradesh	77482	50159	0	0	0	50159
Nagaland	12486	0	0	0	0	0
Odisha	51619	8895	0	0	0	8895
Punjab	1849	259	0	0	0	259
Rajasthan	16630	12613	0	0	0	12613
Sikkim	3342	2460	0	0	0	2460
Telangana	20582	12341	0	0	0	12341
Tamil Nadu	26364	7826	0	0	0	7826
Tripura	7726	0	0	0	0	0
Uttar Pradesh	14806	890	0	0	0	890
Uttarakhand	24303	23038	0	0	0	23038
West Bengal	16902	0	0	0	0	0
Total	**705178**	**314969**	**698**	**0**	**0**	**315667**
% Hotspot severity classes existing in Forest Present in the above mentioned States/UTs (ISFR 2019)		**45**	**0.1**	**0**	**0**	**45**

Note: Although the total Forest Cover in India is 7,12,249 sq km (as per ISFR 2019) but in this study the forest cover areas of UTs like; Andaman & Nicobar Islands, Chandigarh, Dadra & Nagar Haveli, Daman & Diu, Lakshadweep, Puducherry are not considered due to in adequate number of Grids for future climate projection.

over Indian Forests with various Degree of Severity for the year 2030

RCP 8.5

(Hot Spots with Increasing Degree of Severity from High to Critical)

% of Forest Cover	High	Very High	Extremely High	Critical	Total	% of Forest Cover
14	14653	0	0	0	14653	50
40	38099	0	0	0	38099	57
0	0	0	0	0	0	0
0	1218	0	0	0	1218	17
84	55139	0	0	0	55139	99
0	118	0	0	0	118	61
30	1800	0	0	0	1800	80
71	10752	0	0	0	10752	72
18	1163	0	0	0	1163	73
90	15431	3	0	0	15434	100
98	20736	5	0	0	20741	98
13	15694	0	0	0	15694	66
74	36800	0	0	0	36800	95
7	15018	0	0	0	15018	71
96	847	1544	0	0	2392	96
67	36227	0	0	0	36227	71
23	4640	0	0	0	4640	28
0	0	0	0	0	0	0
1	23	0	0	0	23	0
65	56131	0	0	0	56131	72
0	0	0	0	0	0	0
17	30205	0	0	0	30205	59
14	1843	0	0	0	1843	100
76	13833	0	0	0	13833	83
74	3131	0	0	0	3131	94
60	19632	0	0	0	19632	95
30	21594	0	0	0	21594	82
0	0	0	0	0	0	0
6	8526	0	0	0	8526	58
95	23561	0	0	0	23561	97
0	1552	0	0	0	1552	9
45	**448367**	**1552**	**0**	**0**	**449919**	**64**
	64	**0.2**	**0**	**0**	**64**	

Table 11.4 State wise Distribution of hotspots (sq km) in 2050 under RCP 4.5 and RCP 8.5 scenarios

States / UTs	Forest Cover (sq km) ISFR 2019	Projected Area (in sq km) of Hotspots				
		RCP 4.5				
		(Hot Spots with Increasing Degree of Severity from High to Critical)				
		High	Very High	Extremely High	Critical	Total
Andhra Pradesh	29137	29137	0	0	0	29137
Arunachal Pradesh	66688	9313	57240	0	0	66553
Assam	28327	26623	1644	0	0	28267
Bihar	7306	6460	846	0	0	7306
Chhattisgarh	55611	12723	42888	0	0	55611
Delhi	195	0	195	0	0	195
Goa	2237	2237	0	0	0	2237
Gujarat	14857	7024	7684	0	0	14708
Haryana	1602	0	1602	0	0	1602
Himachal Pradesh	15434	95	15005	334	0	15434
Jammu & Kashmir	21122	100	17110	3912	0	21122
Jharkhand	23612	23612	0	0	0	23612
Karnataka	38575	38110	465	0	0	38575
Kerala	21144	21144	0	0	0	21144
Ladakh	2490	0	0	2490	0	2490
Maharashtra	50778	19191	31587	0	0	50778
Manipur	16847	16847	0	0	0	16847
Meghalaya	17119	17119	0	0	0	17119
Mizoram	18006	18006	0	0	0	18006
Madhya Pradesh	77482	85	77397	0	0	77482
Nagaland	12486	12486	0	0	0	12486
Odisha	51619	46477	5142	0	0	51619
Punjab	1849	0	1849	0	0	1849
Rajasthan	16630	0	16630	0	0	16630
Sikkim	3342	0	3342	0	0	3342
Telangana	20582	9610	10972	0	0	20582
Tamil Nadu	26364	26364	0	0	0	26364
Tripura	7726	7726	0	0	0	7726
Uttar Pradesh	14806	3677	11129	0	0	14806
Uttarakhand	24303	0	24140	163	0	24303
West Bengal	16902	13168	3734	0	0	16902
Total	**705178**	**367334**	**330602**	**6899**	**0**	**704835**
% Hotspot severity classes existing in Forest Present in the above mentioned States/UTs (ISFR 2019)		**52**	**47**	**1**	**0**	**100**

Note: Although the total Forest Cover in India is 7,12,249 sq km (as per ISFR 2019) but in this study the forest cover areas of UTs like; Andaman & Nicobar Islands, Chandigarh, Dadra & Nagar Haveli, Daman & Diu, Lakshadweep, Puducherry are not considered due to in adequate number of Grids for future climate projection.

over Indian Forests with various Degree of Severity for the year 2030

RCP 8.5

(Hot Spots with Increasing Degree of Severity from High to Critical)

% of Forest Cover	High	Very High	Extremely High	Critical	Total	% of Forest Cover
100.0	27672	1465	0	0	29137	100.0
99.8	4777	42879	19032	0	66688	100.0
99.8	23995	4332	0	0	28327	100.0
100.0	2282	5024	0	0	7306	100.0
100.0	0	47877	7734	0	55611	100.0
100.0	0	195	0	0	195	100.0
100.0	2237	0	0	0	2237	100.0
99.0	1725	13069	63	0	14857	100.0
100.0	0	1032	570	0	1602	100.0
100.0	0	0	15434	0	15434	100.0
100.0	0	0	21122	0	21122	100.0
100.0	1958	21654	0	0	23612	100.0
100.0	36710	1865	0	0	38575	100.0
100.0	21144	0	0	0	21144	100.0
100.0	0	0	2490	0	2490	100.0
100.0	17251	33527	0	0	50778	100.0
100.0	16847	0	0	0	16847	100.0
100.0	16975	144	0	0	17119	100.0
100.0	18006	0	0	0	18006	100.0
100.0	0	77482	0	0	77482	100.0
100.0	12486	0	0	0	12486	100.0
100.0	8681	40960	1978	0	51619	100.0
100.0	0	259	1590	0	1849	100.0
100.0	0	12436	4194	0	16630	100.0
100.0	0	2252	1090	0	3342	100.0
100.0	5014	15568	0	0	20582	100.0
100.0	26364	0	0	0	26364	100.0
100.0	7726	0	0	0	7726	100.0
100.0	0	13751	1055	0	14806	100.0
100.0	0	86	24217	0	24303	100.0
100.0	9034	7868	0	0	16902	100.0
100.0	**260883**	**343726**	**100569**	**0**	**705178**	**100.0**
	37	**49**	**14**	**0**	**100**	

Table 11.5 State wise Distribution of hotspots (sq km) in 2085 under RCP 4.5 and RCP 8.5 scenarios

States / UTs	Forest Cover (sq km) ISFR 2019	Projected Area (in sq km) of Hotspots				
		RCP 4.5				
		(Hot Spots with Increasing Degree of Severity from High to Critical)				
		High	Very High	Extremely High	Critical	Total
Andhra Pradesh	29137	1759	27378	0	0	29137
Arunachal Pradesh	66688	0	63475	3177	0	66653
Assam	28327	0	28327	0	0	28327
Bihar	7306	0	7306	0	0	7306
Chhattisgarh	55611	0	55611	0	0	55611
Delhi	195	0	195	0	0	195
Goa	2237	0	2237	0	0	2237
Gujarat	14857	0	14808	0	0	14808
Haryana	1602	0	1602	0	0	1602
Himachal Pradesh	15434	0	7373	8061	0	15434
Jammu & Kashmir	21122	0	5277	15845	0	21122
Jharkhand	23612	0	23612	0	0	23612
Karnataka	38575	0	38575	0	0	38575
Kerala	21144	5855	15289	0	0	21144
Ladakh	2490	0	0	2490	0	2490
Maharashtra	50778	1	50777	0	0	50778
Manipur	16847	0	16847	0	0	16847
Meghalaya	17119	0	17119	0	0	17119
Mizoram	18006	0	18006	0	0	18006
Madhya Pradesh	77482	0	77482	0	0	77482
Nagaland	12486	0	12486	0	0	12486
Odisha	51619	315	51304	0	0	51619
Punjab	1849	0	1727	122	0	1849
Rajasthan	16630	0	16630	0	0	16630
Sikkim	3342	0	3326	16	0	3342
Telangana	20582	0	20582	0	0	20582
Tamil Nadu	26364	3672	22692	0	0	26364
Tripura	7726	0	7726	0	0	7726
Uttar Pradesh	14806	0	14806	0	0	14806
Uttarakhand	24303	0	16818	7485	0	24303
West Bengal	16902	202	16700	0	0	16902
Total	**705178**	**11804**	**656094**	**37196**	**0**	**705094**
% Hotspot severity classes existing in Forest Present in the above mentioned States/UTs (ISFR 2019)		**2**	**93**	**5**	**0**	**100**

Note: Although the total Forest Cover in India is 7,12,249 sq km (as per ISFR 2019) but in this study the forest cover areas of UTs like; Andaman & Nicobar Islands, Chandigarh, Dadra & Nagar Haveli, Daman & Diu, Lakshadweep, Puducherry are not considered due to in adequate number of Grids for future climate projection.

over Indian Forests with various Degree of Severity for the year 2030

	RCP 8.5 (Hot Spots with Increasing Degree of Severity from High to Critical)					
% of Forest Cover	High	Very High	Extremely High	Critical	Total	% of Forest Cover
100	0	0	29137	0	29137	100
100	0	0	63159	3529	66688	100
100	0	0	22091	6236	28327	100
100	0	0	6364	942	7306	100
100	0	0	55611	0	55611	100
100	0	0	195	0	195	100
100	0	0	2237	0	2237	100
100	0	0	7933	6924	14857	100
100	0	0	1595	7	1602	100
100	0	0	1146	14288	15434	100
100	0	0	0	21122	21122	100
100	0	0	23612	0	23612	100
100	0	0	38575	0	38575	100
100	0	0	21144	0	21144	100
100	0	0	0	2490	2490	100
100	0	0	45693	5085	50778	100
100	0	0	5002	11845	16847	100
100	0	0	8010	9109	17119	100
100	0	0	14592	3414	18006	100
100	0	0	50822	26660	77482	100
100	0	0	12025	461	12486	100
100	0	0	51619	0	51619	100
100	0	0	1342	507	1849	100
100	0	0	13891	2739	16630	100
100	0	0	3338	4	3342	100
100	0	0	20582	0	20582	100
100	0	0	26364	0	26364	100
100	0	0	4819	2907	7726	100
100	0	0	10012	4794	14806	100
100	0	0	8629	15674	24303	100
100	0	0	16902	0	16902	100
100	**0**	**0**	**566442**	**138736**	**705178**	**100**
	0	**0**	**80**	**20**	**100**	

11.5.1 Salient Findings

2030 Scenario

- By the year 2030, under RCP 4.5 scenario, about 3,15,667 sq km of forest cover will fall under climate hotspots while under RCP 8.5 scenario, about 4,49,919 sq km of forest cover will fall under the same. These occupy almost 45% and 64% of India's forest cover respectively, as reported in ISFR 2019.
- By 2030, under both RCP 4.5 and RCP 8.5 scenarios, almost all the States of India (except: Assam, Meghalaya, Nagaland and Tripura) are coming under 'High' category.
- Part of Ladakh (0.1 to 0.2 % of forest cover) is coming under 'Very High' category of climate hotspot.
- In the climate hotspot maps for 2030 (Figure 11.2 and Figure 11.3), the forest cover area under climate hotspot categories are shown by shades of blue, indicating less severity.

2050 Scenario

- By the year 2050, under RCP 4.5 scenario, about 3,67,334 sq km, 330602 sq km and 6899 sq km of forest cover will fall under 'High', 'Very High' and 'Extremely High' severity classes of climate hotspots respectively, thereby covering 52%, 47% and 1% area of the same.
- Under RCP 8.5 scenario, about 2,60,883 sq km, 3,43,726 sq km and 1,00,569 sq km of forest cover will fall under 'High', 'Very High' and 'Extremely High' severity classes of climate hotspots respectively, thereby covering 37%, 49% and 14% area of the same.
- By 2050, entire forest cover of the country is projected to be under climate change hotspots with varying severity classes.
- Under RCP 8.5 scenario, 14% of India's forests come under 'Extremely High' severity class. No climate hotspots are falling under 'Critical' hotspot severity class in the year 2050.
- The States/UT of Himachal Pradesh, Jammu & Kashmir and Ladakh will be under 'Extremely High' severity class even under moderate scenario of RCP 4.5.
- In the climate hotspot maps for 2050 (Figure 11.4 and Figure 11.5), the forest cover area under climate hotspot categories range from yellow to orange. This implies that severity of the hotspots are projected to be increased in the 20 years of time-period from 2030 to 2050.

2085 Scenario

- By the year 2085, under RCP 4.5 scenario, about 11,804 sq km, 6,56,094 sq km and 37,196 sq km are falling under 'High', 'Very High' and 'Extremely High' severity classes of climate hotspots respectively, thereby covering 2%, 93% and 5% area of the same. Over a period of 35 years, between 2050 to 2085, there is a rise of 4% (from 1 % to 5%) in 'Extremely High' severity class.
- Under RCP 8.5 scenario, about 5,66,442 sq km (80%) and 1,38,736 sq km (20%) of forest cover will fall under 'Extremely High' and 'Critical' severity classes respectively. This implies that by 2085 the RCP 8.5 model shows that 20 % of Indian forests may experience catastrophic changes due to adverse impact of climate change.
- The 'Critical' hotspots, i.e. those likely to experience catastrophic effect have been observed mainly in the Western Himalayas and Karakoram ranges across the Union Territories of Jammu-Kashmir, Himachal Pradesh and Uttarakhand. Some 'Critical' hotspots are also identified in north-eastern States like Assam, Manipur, Mizoram, Meghalaya, Tripura, and in few grids of central India and Gujarat.
- In the climate hotspot maps for 2085 (Figure 11.7 and Figure 11.8), the forest cover area under climate hotspot categories range from orange to red, there by indicating extremely high to critical severity in almost entire country under scenario 8.5.

Affected Forest Type Groups

- Forested grids in western Himalayan region and from the north-eastern States are consistently appearing as climate change hotspots across various climate scenarios in three selected time-horizons.
- Himalayan ecosystems and forest types especially Himalayan dry temperate forests, Himalayan moist temperate forests, Sub-Alpine forests, Moist Alpine scrub and Dry Alpine scrub are most exposed throughout the projections of 2030, 2050 and 2085. A large exposure for Subtropical pine forests and Subtropical dry evergreen forests is also identified for 2030 and beyond.
- Tropical thorn forests, Tropical dry evergreen forests, Montane wet temperate forests, Littoral and Swamp forests and Subtropical broad leaved hill forests have relatively lesser exposure to temperature projections
- 'Tropical Dry Deciduous Forests', 'Tropical Moist Deciduous Forests' and 'Tropical Semi-evergreen Forests', which are most dominant in the central India covering major part of the States of Madhya Pradesh, Chhattisgarh, Northern part of Odisha and western part of Jharkhand will be impacted by adverse climate change from 2050 onwards.

Conclusion 11.6

By analysing all the scenarios in the studied periods i.e. 2030, 2050 and 2085; it has been observed that Ladakh, Jammu-Kashmir, Himachal Pradesh and Uttarakhand are projected to witness highest temperature increase while Andaman & Nicobar Islands, West Bengal, Goa, Tamil Nadu and Andhra Pradesh are projected to witness the least temperature rise over these periods. The North-Eastern States and Upper Malabar Coast of India are projected to experience highest increase in rainfall; whereas, part of North-Eastern States like Arunachal Pradesh, Sikkim; North-Western parts of the country namely Ladakh, Jammu & Kashmir and Himachal Pradesh are projected to experience least increase and sometimes even decline in rainfall.

Climate change will affect forests in multiple ways, both directly and indirectly. Keeping in view the projected impact of climate change in forest areas of the country, suitable studies need to be conducted to ascertain the impact on forest, species composition and related biodiversity. Suitable mitigation and adaptation strategies have to be devised as well as implemented.