CLIMATE CHANGE IMPACT AND VULNERABILITY ASSESSMENT OF FORESTS IN THE INDIAN WESTERN HIMALAYAN REGION: A REMOTE SENSING & GIS BASED STUDY OF HIMACHAL PRADESH, INDIA

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ABSTRACT: Climate change impact and vulnerability assessment at state and regional level is necessary to develop adaptation strategies for forests in the critical Himalayan region. The present study assesses forest ecosystem vulnerability to climate change across Himachal Pradesh under a range of climate scenarios and presents ranking of the districts in the order of forest vulnerability under 'current climate' and 'future climate' scenarios. The forests of Himachal Pradesh, which are part of the Indian Himalayan region (IHR), are projected to be impacted over the next decades as a result of climate change. Vulnerability of forests under 'current climate' scenario is assessed by adopting indicator-based approach, while the vulnerability under 'future climate' scenario is assessed using climate and vegetation impact models. Based on the vulnerability index, which combines the projected climate change impacts and the current vulnerability, five districts - Chamba, Kullu, Shimla, Mandi and Kangra are identified as the most vulnerable districts by 2030s under the RCP8.5 scenario. Identifying vulnerable forests will help policy makers and forest managers to prioritise forest management interventions, to restore health and productivity of forests and to build long-term resilience to climate change.

1. INTRODUCTION

Forest ecosystems play an important role in the global biogeochemical cycles and exert significant influence on the earth's climate. The large-scale boundaries of vegetation often closely follow patterns of climatic variables; particularly temperature and/or moisture (Stephenson, 1990). The close link between climate and vegetation, and hence between climate change and vegetation change implies that a dramatic change in one will influence the other (FAO, Forestry paper, 2013). According to IPCC (2014) climate and non-climate stressors are projected to impact forests during the 21st century leading to large-scale forest die-back, biodiversity loss and diminished ecological benefits. In India, national level climate change impacts have been assessed by Chaturvedi *et al* 2011 and Gopalakrishna et al 2011. There is a need for regional level assessment of climate change impacts. The climate projections of the Regional Climate Model of the Hadley Centre (HadRM3) and the dynamic global vegetation model IBIS for A2 and B2 scenarios projected that 39% of forest grids in India are likely to undergo vegetation type change under the A2 scenario and 34% under the B2 scenario by the end of this century (Chaturvedi et al 2011). The study also concluded that the upper Himalayas, northern and central parts of Western Ghats and certain parts of central India are most vulnerable to projected impacts of climate change, while North-eastern forests are more resilient. Analysis of temperature trends in the Himalayas and its vicinities shows that temperature increases are greater in the uplands than that in the lowlands (Shrestha et al 1999). The present study examines the projected impacts of climate change on forests of Himachal Pradesh and identifies the most vulnerable districts. Using indicator based vulnerability assessment and the CMIP5 (Coupled Model Inter-comparison Project phase 5) models-based climate projections under different RCPs and IBIS(Integrated Biosphere Simulation) dynamic vegetation model, most vulnerable districts are prioritized under 'future climate' scenario, to develop adaptation strategies and practices in order to build forest resilience to climate change.

2. STUDY AREA

The hilly, mountainous forests of Himachal Pradesh nested in the Indian Himalayan region (IHR) is located between latitude 30^{0}22' to 33^0 12' N and longitude 75^0 45' to79^0 04' E. The altitude of the state varies from 248m to 6,735 m above the mean sea level and the total geographical area is 55,673 km^2. At present, 26% of the total geographical area of the state is under forest cover with 3224 km^2, 6381 km^2 and 5074 km^{2}of the forests having very dense (>70% canopy density), moderately dense (40-70% canopy density) and open forests (10-40% canopy density), respectively (**Figure 1**). These forests are classified under eight forest type groups namely, Tropical Moist Deciduous Forests, Tropical Dry Deciduous Forests, Sub-tropical Pine Forests, Himalayan Moist Temperate Forests, Himalayan Dry Temperate Forests, Sub-Alpine Forests, Moist Alpine Scrub and Dry Alpine Scrub (Forest Survey of India, 2011).

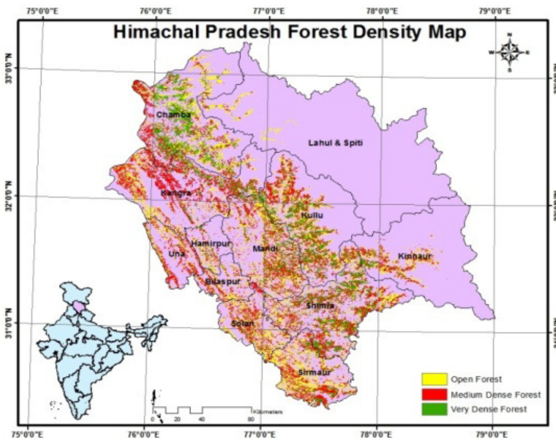

Figure 1: Forest Density map of Himachal Pradesh.

3. METHODS AND MODELS

3.1 Approach and Methods for Vulnerability Assessment under 'Current Climate' Scenario: The present internal state of forests is analyzed by using appropriate indicators to quantify the propensity of forests to suffer losses under future disturbances including climate change, which is communicated through a 'vulnerability index' value. The methodology adopted for this assessment include the following:

1. The factors that determine vulnerability of forests were identified based on literature (Gopalakrishna et al, 2011 and Sharma et al, 2013). The following indicators were selected for vulnerability assessment under 'current climate' scenario, namely, biological richness, disturbance index, canopy cover, forest dependency of communities and ground slope. Weights were assigned to each of these indicators (Table 1) using pair-wise comparison method (PCM) with a Consistency Ratio (CR) of 7.85%. A Consistency Ratio of <10% is acceptable.

2. Entire area of the state was divided into 2736 grids of 2.5'x2.5' each. Out of these, 1865 grids are forested grids. Remaining 871 grids that do not have any area under forest cover were classified as non-forest grids.

3. Vulnerability index value for a grid was obtained as the sum of the area-weighted vulnerability indicator values for that grid. The area-weighted vulnerability indicator value for an indicator for a grid was obtained as the sum of the products of proportion of forest area under different vulnerability classes and the corresponding vulnerability-class values (vulnerability-class values of 3, 2 and 1 correspond to *high*, *medium* and *low* vulnerability).

4. Spatial profile of vulnerability on the landscape was created by classifying the vulnerability values into four vulnerability classes namely, *low, medium, high* and *very high* using the ArcGIS 10.2 Natural Breaks (Jenks Algorithm) program. For district-wise vulnerability profile, the district boundary layer was overlaid on the grid-based vulnerability map for Himachal Pradesh in GIS and value of vulnerability for a district was obtained as the average of vulnerability values for all the grids in a district.

Table 1: Details of indicator components, data source and weights assigned

Indicator	***Source of data***	***Weights****
Biological richness (BR)	IIRS database	0.507
Disturbance index (DI)	IIRS database	0.250
Canopy cover (CC)	FSI database	0.137
Slope (S)	Open access	0.035
Forest dependence of rural communities (FD)	Census of India 2011 and FSI	0.071

3.2 Modeling of Impact of Climate Change on Forests: CMIP5 earth systems model (ESM) based climate projections are used for assessing the impact of climate change on forest ecosystems. Even though climate data is available from nearly 40 ESMs, climate outputs from only five ESMs (BCC-CSM1-1; IPSL-CM5A-LR; MIROC-5; MIROC_ESM and MIROC-ESM-CHEM), which best simulate temperature and precipitation over India, have been used for assessing the impacts of climate change.. The climate change projections are developed for 4 representative concentration pathways (RCPs) scenarios namely; RCP2.6, RCP4.5, RCP6.0 and RCP8.5 Watts/m2. However, in the current study only 2 RCPs are used namely, 4.5 and 8.5. The present study is carried out for two time slices – mid-term (2021-2050) and long-term (2070-2099). A grid size of 0.5x0.5 degree is adopted to simulate climate as well as vegetation projections.

DGVMs (Dynamic Global Vegetation Models) are used to obtain future vegetation projections under projected climate change scenarios. DGVMs simulate time-dependent changes in vegetation distribution and properties, and allow mapping of changes in ecosystem function and services. With the adoption of multiple DGVMs, uncertainty could be reduced. Impact assessment is carried out using the Integrated Biosphere Simulator (IBIS) and Lund Potsdam Jena (LPJ) models over the forests in the state of Himachal Pradesh. In case of LPJ DGVM, the approach has been to make vegetation projections using climatology from 17 climate models individually, one each time, and observe the agreement between (climate) models in simulation of vegetation shift in forest grids. The results of LPJ are considered robust when more than 11 of 17 (about 66%) models projected vegetation shift in a grid. The climate data requirements for the two vegetation models are: while LPJ requires only 3 variables namely, temperature, precipitation and cloudiness, the data requirement of IBIS is much more stringent, as it requires 8 climate variables namely temperature, precipitation, cloudiness, relative humidity, temperature range, wet days, wind speed and deltaT (minimum temperature ever recorded at a particular location minus average temperature of the coldest month).

3.3 Methods for Vulnerability Assessment under 'Future Climate' Scenario: To assess the vulnerability under 'future climate' change scenario, a three-step procedure was adopted. The first step involved developing vulnerability profiles under the 'current climate' scenario as described above. The second step involved assessing the impact of climate change at district level using the dynamic vegetation models. Under this step, the districts that would be impacted by climate change were identified. The third step was to combine the vulnerability profiles under the 'current climate' scenario and district profiles of impact of climate change. Thus, the vulnerability assessment and ranking under climate change scenario was carried out, considering the combined effect of both the impacts of climate change and the current vulnerability of forests.

4. RESULTS AND DISCUSSIONS

4.1 ASSESSMENT OF CURRENT VULNERABILITY OF FORESTS AT DISTRICT–LEVEL: Current vulnerability is assessed and presented at district level. Cluster analysis of vulnerability index (VI) values for the districts under current climate suggests the following clustering of districts in different vulnerability classes: Low – Lahul and Spiti; Medium – Kullu and Kinnaur; High – Chamba, Kangra, Shimla, Hamirpur and Una; and, Very High – Mandi, Bilaspur, Solan and Sirmaur. The dominant forest type in Chamba, Kullu, Mandi and Shimla is Himalayan Moist Temperate forests. In Una and Hamirpur Sub Tropical Pine is the dominant forest type while Bilaspur is dominated by Tropical Dry Deciduous type of forest. The remaining districts of Kangra, Solan and Sirmaur have a combined population of Himalayan Moist Temperate, Sub Tropical Pine and Tropical Dry Deciduous with Sirmaur also rich in Tropical Moist Deciduous forests. The spatial profile of forest vulnerability and the most vulnerable districts on the basis of vulnerability index values under 'current climate' scenario is presented in the **Figure 2**. The details of VI values and ranking of districts as per their vulnerability under current climate scenario are presented in **Table 2**.

Table 2: Ranking of districts on the basis of vulnerability index values under current climate scenario.

District	*Vulnerability index (VI)*	*Vulnerability ranking districts**	*Forest area (km^2)*	*Rural population per km^2 of forest area*
Mandi	1.834	1	1675	559
Bilaspur	1.745	3	362	986
Solan	1.749	2	850	558
Sirmaur	1.701	4	1385	341
Shimla	1.682	5	2386	256
Kangra	1.671	6	2064	688
Una	1.605	8	523	910
Hamirpur	1.663	7	244	1733
Chamba	1.583	9	2437	198
Kullu	1.527	11	1959	202
Kinnaur	1.513	12	600	140
Lahul & Spiti	1.567	10	194	163

**Rank 1 stands for maximum vulnerability, 2 for lesser vulnerability and so on.*

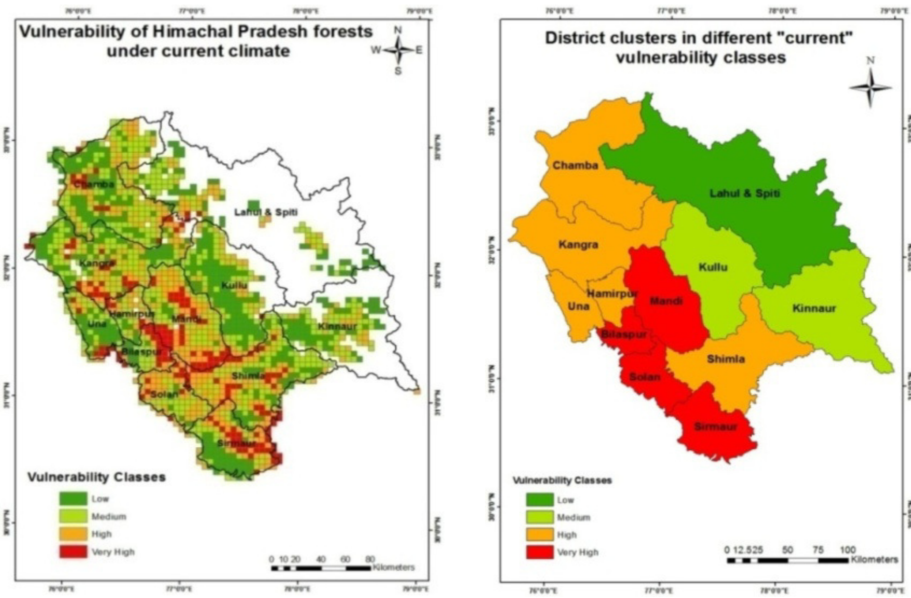

Figure 2: Distribution of forest vulnerability under 'current climate' scenario; a) distribution of vulnerability at grid level; b) distribution of vulnerability at district level.

4.2 Assessment of Vulnerability under 'Future Climate' Change: Impact of climate change on distribution of forest types

4.2.1 Impact according to IBIS: A spatial presentation of forest types and districts projected to undergo change are presented in **Figure 3**. The outputs from the IBIS model show that the forests in the districts of Chamba, Kullu, Mandi, Shimla and Kinnaur are projected to be impacted by climate change in the mid-term (2030s) under RCP4.5 and RCP8.5. Further, the long-term projections show that the forests in the districts of Chamba, Kullu, Mandi, Shimla, Kinnaur and Kangra are projected to be impacted in the in the 2080s under RCP4.5 and RCP8.5.

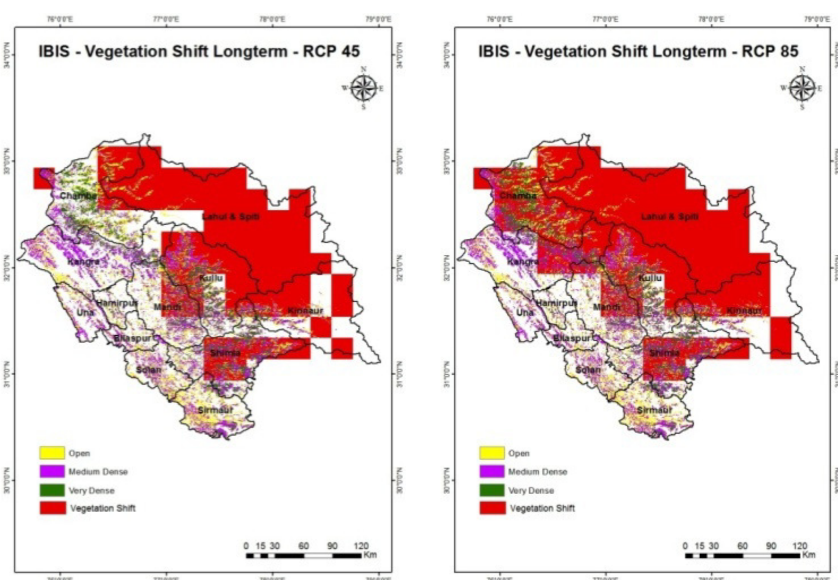

Figure 3: Vegetation shift projected by IBIS dynamic vegetation model long-term (2080s) under RCP4.5 and RCP8.5

4.2.2 Impact according to LPJ: According to the LPJ model, more than 66% of the climate models show that the forests in the districts of Kangra, Chamba, Mandi, Kullu, Kinnaur and Shimla are projected to be impacted in the mid-term under both RCP4.5 and RCP8.5, while the forests in the districts of Chamba, Kullu, Mandi, Shimla, Kinnaur, Kangra and Sirmaur are projected to be impacted in the long-term, under RCP4.5 and RCP8.5 (**Figure 4**). Relatively more districts are projected to be impacted by climate change by 2080s under both RCP4.5 and RCP8.5 compared to 2030s.

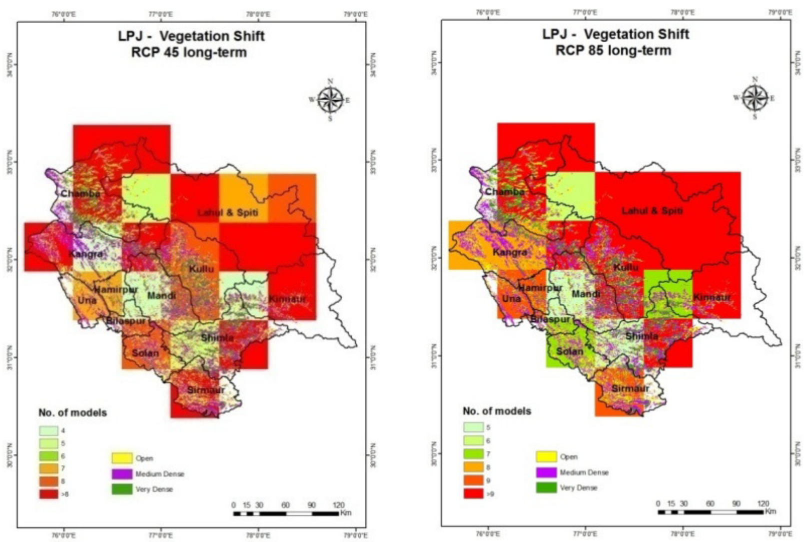

Figure 4: Vegetation shift projected by LPJ dynamic vegetation model in long-term (2080s) under RCP4.5 and RCP8.5

4.2.3 Grids impacted according to both IBIS & LPJ: The forests in the districts of Chamba, Kullu, Shimla, Mandi, Kangra, Kinnaur and Lahul & Spiti are projected to undergo shifts in forest type by both the vegetation models. This shows that the future climate will not be optimal for the existing vegetation and forest types, potentially leading to forest die-back (Cox et al 2004). The existing forests may lose their biodiversity leading to loss of ecosystem services from the existing forest types. The two districts projected to be impacted by both the DGVMs are also those that are ranked 'high' and 'very high' on the vulnerability scale even under current climate.

4.3 Assessment of Vulnerability of Forests under 'Future Climate' Scenario: Vulnerability assessment and ranking, considering the combined effect of both the impacts of climate change and the current vulnerability of forests, is conducted to identify the most vulnerable districts under 'future climate' scenario. This ranking is a combined assessment of climate change impacted districts according to both DGVMs, along with 5 indicators selected for estimating the current vulnerability. **Table 3** presents the most vulnerable districts by 2030s under RCP8.5. The top five most vulnerable districts under future climate scenario are Chamba, Kullu, Shimla, Mandi and Kangra (**Table 3**), considering both climate impacts and current vulnerability. The districts Lahul & Spiti and Kinnaur, although projected to be vulnerable are not ranked, as the forest area in these districts is very low. The remaining districts are not projected to be vulnerable.

Table 3: Ranking of districts on the basis of combined vulnerability index values considering climate change impacts and current climate vulnerability

District (Future Vulnerability Ranking MT85)	*Total Count of grids (Forest Cover [km^2])*	*Vulner ability Index value*	*No. of Veg. change grids- MT45*	*No. of Veg. change grids- MT85*	*No. of Veg. change grids- LT45*	*No. of Veg. change grids- LT85*
Chamba (**1**)	329 (2,437)	1.583	**109**	**109**	**109**	**248**
Kullu (**2**)	214 (1959)	1.527	**198**	**203**	**203**	**211**
Shimla (**3**)	237 (2386)	1.682	**120**	**120**	**122**	**122**
Mandi (**4**)	178 (1675)	1.834	**51**	**51**	**51**	**72**
Kangra (**5**)	253 (2065)	1.671	**4**	**5**	**5**	**70**

5. CONCLUSIONS

The criteria for selecting districts for adaptation interventions should include the projected impacts of climate change on forests based on multiple models, leading to shifts in forest types and the current vulnerability, which reflects the status of forests (biological richness, canopy cover and slope) and the socio-economic pressures (disturbance index and forest dependence). Disturbed, degraded and fragmented forests are more likely to be vulnerable to climate change impacts. The DGVMs do not incorporate these parameters. Thus, a combined vulnerability index incorporating the projected climate change impacts and current vulnerability is ideal to identify the most vulnerable districts requiring adaptation interventions on a priority basis. Based on this, five districts that are identified as the most vulnerable districts for planning adaptation interventions are Chamba, Kullu, Shimla, Mandi and Kangra. Given Himachal Pradesh's unique geographic situation, protecting its rich natural resources assumes greater importance since this would not only impact the very sustenance of the indigenous communities in uplands of the Himalayan Ecosystem but also the life of downstream agro-ecosystem and communities dwellers across India.

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