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Climate Change Impacts and Vulnerability Assessment in Himachal Pradesh

मुख्य मंत्री
हिमाचल प्रदेश

जय राम ठाकुर

सन्देश

आज विश्व जलवायु परिवर्तन जैसी विकट समस्या का सामना कर रहा है। वर्तमान समय में जलवायु परिवर्तन के वैश्विक तथा क्षेत्रीय प्रभावों के कारण यह एक बहस का मुद्दा बना हुआ है। ऐसा मानना है कि इसके दुष्परिणामों के कारण विश्व के अनेक टापू देशों का अस्तित्व खतरे में है। जलवायु परिवर्तन प्रभाव से विकासशील देशों में रह रहे गरीब और हाशिए पर जी रहे लोग ज्यादा प्रभावित हैं। जबकि बहुत से जीव जन्तु व वनस्पति प्रजातियां विलुप्त होने के कगार पर हैं। जलवायु परिवर्तन अब एक सच्चाई के रूप में हम लोगों के सामने आ चुका है। मौसम के चक्र में आकस्मिक परिवर्तन हमारे जीवन को, हमारी आजीविका को, हमारी अर्थव्यवस्थता को अव्यवस्थित करने की क्षमता रखता है अतः यह आवश्यक है कि हम योजनाबद्ध तरीके से इस संभावित खतरे से मुकाबला करने के लिए अपने आप को तैयार करें। अब विश्व के सभी देशों को एकजुट होकर इस जलवायु परिवर्तन की समस्या से निपटना होगा।

इसी संदर्भ में अनेक द्विपक्षीय समझौतों के तहत पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय, भारत सरकार द्वारा राष्ट्रीय स्तर पर अनेक महत्वपूर्ण कार्य किये जा रहे हैं। जिसमें जर्मनी सरकार की संस्था GIZ के साथ द्विपक्षीय समझौते के अन्तर्गत 'भारत के ग्रामीण क्षेत्रों में जलवायु परिवर्तन अनुकूलन' (CCA-RAI) कार्यक्रम को हिमाचल प्रदेश में चलाया जा रहा है। इस कार्यक्रम के अन्तर्गत जलवायु परिवर्तन विषय को लेकर प्रदेश, जिला एवं पंचायत स्तर पर व्याख्यान श्रृंखलाएं एवं जागरूकता कार्यक्रम आयोजित किए जा रहे हैं।

इसी कार्यक्रम के अन्तर्गत **'हिमाचल प्रदेश में जलवायु परिवर्तन के प्रभाव और संवेदनशलीता के आकलन'** पर एक रिपोर्ट तैयार की गई है, जो प्रदेश के वर्तमान जलवायु परिवर्तन विषय के प्रति हमारी जानकारी को और अधिक विकसित करने और जलवायु परिवर्तन के प्रभावों से बेहतर तरीके से निपटने में मददगार होगी।

मुझे खुशी है कि हिमाचल प्रदेश राज्य पर्यावरण, विज्ञान एवं प्रौद्योगिकी विभाग इस दिशा में प्रयत्नशील है तथा जलवायु परिवर्तन अनुकूलन के कार्य करने में प्रयासरत है।

मुझे विश्वास है कि भविष्य में भी प्रदेश को जलवायु परिवर्तन से सम्बन्धित चुनौतियों का सामना करने में जर्मनी सरकार की संस्था GIZ का सहयोग इसी प्रकार मिलता रहेगा।

(जय राम ठाकुर)

Addl. Chief Secretary to the
Govt. of Himachal Pradesh

R. D. Dhiman

MESSAGE

Himachal Pradesh is a State with its economy closely tied to natural-resources and climate-sensitive sectors such as agriculture, water, and forests. Any change in these sectors due to climate change will not only affect the livelihood prospects in the agrarian economy of the mountain region, but also impact livelihoods of millions of people living in the plains.

Recognizing the scope for fueling growth through its natural assets and to tackle the emerging issues of changing climate Government of Himachal Pradesh is implementing various programme in the State. A bilateral project with Ministry of Environment, Forests and Climate Change (MoEF&CC), Govt. of India and Federal Government of Germany (GIZ) on Climate Change Adaptation in Rural Areas of India (CCA-RAI) is being implemented in four states of India i.e. Punjab, Himachal Pradesh, Telangana & Tamil Nadu. The objective of the programme is to strengthen the capabilities of key actors at the State Level for Planning, Implementing, Financing, Monitoring & Evaluating on Climate Change Adaptation Measures.

The Climate Change Vulnerability Assessment is an initial step in a scientific, systematic process of preparing for the adaptation policy planning and accordingly implementation of the actions thereof. I am very happy to learn that a report on "Climate Change Impacts & Vulnerability Assessment in Himachal Pradesh" has been prepared aiming to develop thorough understanding of the current climate change vulnerability of districts of the State of HP and project the impacts of climate change on water and related sectors.

I am sure that this very scientific analysis, vulnerability assessment will help in institutionalization of sectoral climate change adaptation planning process in the State of Himachal Pradesh and would meet the challenges of future climate impacts effectively.

I sincerely acknowledge the joint efforts of GIZ, India, Department of Environment, Science & Technology, Himachal Pradesh for publishing this comprehensive report.

(R.D. Dhiman)
Additional Chief Secretary (Env.,S&T) to the
Government of Himachal Pradesh, Shimla-2.

Director
Department of Environment,
Science & Technology
Govt. of Himachal Pradesh

D.C. Rana

MESSAGE

It gives me immense pleasure to introduce the publication titled “Climate Change Impacts and Vulnerability Assessment in Himachal Pradesh”, one of the outcomes of the project titled “Climate Change Adaptation in Rural Areas-India (CCA-RAI)” under the bilateral cooperation between the German development cooperation institution ‘Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH’ and ‘Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India. CCA-RAI project is being implemented in four states including Himachal Pradesh State.

Climate change poses the greatest challenge to the sustainability of social and economic development of the country and to the livelihoods of communities. Change in climate scenario adversely affects water resources which is a pre-requisite for sustainable development. Rural communities facing economical, geographical and demographical obstacles have difficulty in coping with climate change and preparing for climate change risks. Being predominantly rural with over half the population living in rural areas and mostly dependent on agriculture, Himachal Pradesh State is particularly vulnerable to increasing temperature and varying rainfall patterns.

This publication aims to create a comprehensive understanding of the current vulnerability of all the erstwhile 12 districts in H.P. state and project the effects of changing climatic conditions on the water sector and related sectors such as agriculture and health, in an integrated manner using a Composite Vulnerability Indicator. With the state of Himachal already being in the forefront of implementing massive projects to ensure the supply of adequate water for irrigation, drinking and sanitation, hydropower. This report could not have come at a more opportune time. Understanding the climatic vulnerability of the state helps to review its current water resource management approaches and practices and to integrate climate change adaptation measures into its water planning and policies.

This publication has been coordinated by Department of Environment, Science & Technology, GoHP and supported by GIZ India with the data acquired from various studies and government reports, that were integrated and analysed with a high scientific vigour. The report has also been peer reviewed by various national and international experts in the field of climate change vulnerability assessment and adaptation.

I believe that this publication will prove to be a useful document for reference for decision makers to plan and implement measures for adaptation to the changing climate. I am hopeful that this Joint Cooperation will yield many more such useful publications.

(D. C. Rana)
Director
Department of Environment, Science & Technology
Government of Himachal Pradesh.

Part-I: Current Climate Variability and Future Climate Change Projections

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Climate Change Adaptation in Rural Areas-India (CCA-RAI)
Environment, Climate Change and Natural Resource Management
A2/18, Safdarjung Enclave, New Delhi 110 029 India
T: +91 11 4949 5353
F: +91 11 4949 5391
E: info@giz.de
I: www.giz.de

Responsible
Dr. Ashish Chaturvedi
E: ashish.chaturvedi@giz.de

Authors
Prof. A.K. Gosain, Indian Institute of Technology- Delhi
Dr. Sandhya Rao, Integrated Natural Resource Management

Reviewers:
Prof. N. H. Ravindranath, Indian Institute of Science, Bengaluru

Edited by:
Dr. D.C. Rana, Director and Dr. Suresh C. Attri, Principal Scientific Officer-cum-State Coordinator Himachal Pradesh Knowledge Cell on Climate Change & Department of Environment, Science and Technology, Government of Himachal Pradesh

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Abbreviations

Abbreviation	**Definition**
%	Percent
°	Degree
°C	Degree Centigrade
BL	Baseline
CC	Climate Change
CCAM	Cubic Conformal Atmospheric Model
CDD	Consecutive Dry Days
CLM	Climate Limited-Area Model
CORDEX	Coordinated Regional Climate Downscaling Experiment
COSMO	Consortium for Small-Scale Modelling
COSMO-CLM	COSMO Climate Limited-Area Model
CSC	Climate Service Center
CSDI	Cold Spell Duration Indicator
CSIRO	Commonwealth Scientific And Industrial Research Organisation
CV	Coefficient of Variation
CWD	Consecutive Wet Days
DTR	Diurnal Temperature Range
EC	End-Century
ESM	Earth System Model
ETCCDI	Expert Team on Climate Change Detection And Indices
GCAM	Global Change Assessment Model
GCM	Global Circulation Model
i.e	That is
IITM	Indian Institute of Tropical Meteorology
IMD	Indian Metrological Department
INRM	Integrated Natural Resources Management
IPCC	Intergovernmental Panel on Climate Change
JF	January, February
JJAS	June, July, August, September
kg	Kilogram
LPA	Long Period Average
m	Meter

MAM	March, April, May
MC	Mid-Century
mm	Millimetre
MPI	Max Planck Institute
OND	October, November, December
PRCPTOT	Wet-Day Precipitation
R	Rainfall
R10mm	Heavy Precipitation Days
R20mm	Very Heavy Precipitation Days
R95p	Very Wet Day Precipitation
R99p	Extremely Wet Day Precipitation
RCM	Regional Climate Models
RCP	Representative Concentration Pathway
RR	Daily Rainfall
RX1day	1-Day Maximum Precipitation
RX5day	5-Day Maximum Precipitation
SDII	Simple Daily Intensity Index
SMHI	Swedish Meteorological And Hydrological Institute
sq. km	Square Kilometre
SRES	Special Report On Emission Scenarios
SW	South West
TN	Temperature - Minimum
TN10p	Cool Nights
TN90p	Warm Nights
TNn	Minimum Of Night Time Temperature
TNx	Maximum Of Night Time Temperature
TX	Temperature - Maximum
TX10p	Cool Days
TX90p	Warm Days
TXn	Minimum of Day Time Temperature
TXx	Maximum of Day Time Temperature
WCRP	World Climate Research Programme
WSDI	Warm Spell Duration Indicator

Executive Summary

This technical report assesses the historical climate variability and trends in mean climate (maximum temperature, minimum temperature and precipitation) and climate indices of extremes in the Indian State of Himachal Pradesh and its 12 districts over the period 1951-2013 (63 years), using historical gridded observations from the India Meteorological Department (IMD). Rainfall data grid resolution is 0.25°x0.25° while temperature data grid resolution is 1°x1° which has been used.

The CORDEX South Asia modelled climate data on precipitation, maximum temperature, minimum temperature and another 21 climate extremes indices have been analysed for Himachal Pradesh and its 12 districts for baseline, BL (1981-2010), mid-century, MC (2021-2050) and end-century, EC (2071-2100) periods. Climate change projections for precipitation, maximum temperature and minimum temperature have been analysed while trend analysis has been carried out on the climate extremes indices for the State and its districts. The change in climate extremes indices towards MC (2021-2050) and EC (2071-2100) with respect to BL (1981-2010) has also been analysed. Trend tests are run at 10% level of significance to indicate the presence of statistical significant trends over the period of years. Climate grid-resolutions for the climate projection are 0.5°x0.5° (50km x 50km). Three Regional Climate Models (RCM) namely REMO (from MPI), RCA4 (from SMHI) and CCAM (from CSIRO) - for IPCC AR5 climate scenarios- RCP4.5 (moderate emission scenario) and RCP8.5 (a scenario of comparatively high greenhouse gas emissions) have been used to calculate the ensemble mean for precipitation, maximum temperature, minimum temperature and climate extremes indices data for both IPCC AR5 RCP4.5 and RCP8.5 scenarios. Ensemble mean is chosen to reduce model related uncertainties and ensemble mean climate is closer to observed climate than any individual model.

The summary of the climate data analysis done for state of Himachal Pradesh and its districts are as follows:

Observed Climate Data Analysis

Maximum and Minimum Temperature

- IMD gridded daily temperature data from 1951-2013 (63 years) has been used for the analysis. Mean annual maximum temperature Himachal Pradesh is 25.9°C with a range varying from 24.5°C – 27.1°C. The highest value attained for maximum temperature (30.7°C) is in the monsoon season (JJAS) while its lowest maximum value (16.9°C) is attained in winter season.
- Mean annual minimum temperature is 13.4°C with a range varying from 12.5°C – 14.5°C. Minimum temperature attains its mean highest value (20.6°C) during the monsoon season (JJAS), while it attains its mean lowest value (4.7°C) in winter season.
- For annual maximum temperature the highest value is attained for districts namely, Una, Solan, Hamirpur and Bilaspur lying in the Sub mountain & low hills sub-tropical zone while the lowest value is attained for districts namely, Lahul & Spiti and Kinnaur lying in Very high hills temperate dry zone of Himachal Pradesh for the period 1951-2013 (63 years).

- For annual minimum temperature the highest value is attained for districts Una and Solan while the lowest value is attained for districts Lahul & Spiti and Chamba.
- There is not much temporal variation observed across the districts of Himachal Pradesh in maximum and minimum temperature as is evident from the mean maximum and minimum temperature and very low CV values. However, variability in minimum temperature is higher than that of the maximum temperature.
- Trend analysis shows that the positive trend for annual maximum temperature and minimum temperature are statistically not significant for Himachal Pradesh State.

Observed Precipitation

- Average annual rainfall of Himachal Pradesh is 1284.2 mm with a range varying from 704.7 mm-2062.8 mm over the 63 years period (1951-2013). Amongst all districts, Kangra and Chamba in the North West receive the maximum average annual rainfall while district Kinnaur in the East receive the least.
- The monsoon (June, July, August and September) rainfall contributes the maximum to annual rainfall amounting to approximately 66% for Himachal Pradesh State. Contribution of Pre-monsoon (March, April and May) rainfall on average is 15%, contribution of post- monsoon (October, November and December) rainfall in annual rainfall is about 6.7% and winter rainfall (January, February) contribution is 12.1%.
- For the period 1951-2013, annual rainfall and rainy days shows negative trend which is statistically significant for Himachal Pradesh State.
- Out of 63 years rainfall analysis Himachal Pradesh on average had 46 normal rainfall years, 8 years had excess rainfall and 9 years had deficit rainfall. Sirmaur district receives the maximum number of 17 years of excess rainfall while Chamba and Kinnaur districts have maximum of 18 deficient years of rainfall as compared to the other districts of Himachal Pradesh over the period 1951-2013. Kullu and Shimla districts have maximum of 42 years of normal rainfall.
- The maximum (232.2 mm) and minimum (55.5 mm) annual one day maximum rainfall for Himachal Pradesh State has been recorded on 1958, 21st December and 1972, 24th August respectively.
- 1 day maximum rainfall shows negative trend for the State over the period 1951-2013. However, the negative trend is statistically not significant.
- August month received the highest amount of one day maximum rainfall (29%) followed by July (27%), September (16%) and June 6%. Thus about 78% of 1 day maximum rainfall is received in JJAS (monsoon) months in the period of analysis (1951-2013).
- Annual average number of rainy days (when daily rain >=2.5 mm) for period 1951-2013 in Himachal Pradesh State is 101 days and varies from 74 days to 125 days. Light to rather heavy rainfall ($2.5 \leq R \leq 64.4$) events is 100 on average and ranges from 74 to 124 days. Similarly, days when there are heavy rainfall ($64.4 < R \leq 124.4$ mm) events is 1 on average and ranges from 0 to 3 days, and very heavy to extremely heavy rainfall ($R > 124.4$ mm) days is negligible.
- Over the 63 years period districts namely, Chamba and Kangra have the maximum number of total rainy days while Kinnaur has the least number of total rainy days.

Climate Extremes Indices using observed Climate

Temperature Extremes Indices:

- **Absolute indices:** Maximum of day time temperature (TXx) and Minimum of day time temperature (TXn) show mixed non significant trends for the districts of Himachal Pradesh. Maximum of night time temperature (TNx) show negative trends for all the districts while minimum of night time temperature (TNn) show positive trends for all the districts. However, trend is statistically non significant.
- **Percentile indices:** Cool nights (TN10P) show negative trend while warm nights (TN90P) show positive trend for all the 12 districts.
- **Duration indices:** Warm spell duration indicator (WSDI) shows negative non significant trend for most of the districts. Cold spell duration indicator (CSDI) also shows negative trend for all the districts, however the negative trend is statistically significant for only 2 districts.

Precipitation Extremes Indices:

- **Absolute indices:** Maximum 1 day precipitation show mixed trend while maximum 5 day precipitation show negative trend for all the districts.
- **Percentile indices:** Very wet day precipitation (R95p) and extremely wet day precipitation (R99p) show mixed trend for the districts. However, mixed trend is statistically not significant.
- **Duration indices:** Consecutive dry days positive trend which is statistically not significant. Consecutive wet days show negative statistically significant trend for 10 districts.
- **Threshold indices:** Heavy and very heavy precipitation days (R10mm and R20mm) show negative trend.

Projected Climate Data Analysis

The CORDEX South Asia modelled climate data on precipitation, maximum temperature, minimum temperature and 21 climate extremes indices have been analysed for Himachal Pradesh State and its 12 districts for baseline (BL, 1981-2010), mid-century (MC, 2021-2050) and end-century (EC, 2071-2100). Ensemble mean of 10 RCMs at a spatial resolution of 50kmx50km has been used. The CORDEX South Asia simulations with the models indicate an all-round warming over the study area. Projected increase in temperature and precipitation towards end-century is higher than that towards mid-century. The summary for three time periods-BL, MC and EC is as follows:

Projected Maximum Temperature

- Average annual maximum temperature for IPCC AR5 RCP4.5 scenario is projected to increase by about 1.4°C towards mid-century and by 2.5°C towards end-century while for IPCC AR5 RCP8.5 scenario it is projected to increase by about 1.6°C towards mid-century and 5.0°C towards end-century for Himachal Pradesh State. Thus projected temperature increase in end-century is higher than that of mid-century.
- The projected increase in maximum temperature towards MC varies from 1.2°C in Una lying in Sub mountain & low hills sub-tropical zone to 1.7°C in Lahul & Spiti district lying in Very high hills temperate dry zone for IPCC AR5 RCP4.5 scenario and 1.4°C in Una to 2.0°C in Lahul & Spiti district of Himachal

Pradesh for IPCC AR5 RCP8.5 scenario. It is observed that Northern districts show higher projected increase than the Southern districts of the State.

- The projected increase in maximum temperature towards EC varies from 2.1°C in Sirmaur to 3.3°C in Lahul & Spiti district for IPCC AR5 RCP4.5 scenario and 4.4°C in Una to 5.9°C in Lahul & Spiti district of Himachal Pradesh for IPCC AR5 RCP8.5 scenario.
- Highest maximum temperature increase is projected in winter season (JF) for IPCC AR5 RCP4.5 and RCP8.5 scenarios towards MC and EC for Himachal Pradesh State as compared to the other seasons.

Projected Minimum Temperature

- Average annual minimum temperature for IPCC AR5 RCP4.5 scenario is projected to increase by about 1.4°C towards mid-century and by 2.7°C towards end-century while for IPCC AR5 RCP8.5 scenario it is projected to increase by about 1.8°C towards mid-century and 5.1°C towards end-century for Himachal Pradesh State. Thus projected temperature increase towards EC is higher than that of MC.
- The projected increase in minimum temperature towards MC varies from 1.3°C in Una to 1.7°C in Lahul & Spiti district for IPCC AR5 RCP4.5 scenario and 1.7°C in Bilaspur (Sub mountain & low hills sub-tropical zone) to 2.1°C in Lahul & Spiti district (Very high hills temperate dry zone) of Himachal Pradesh for IPCC AR5 RCP8.5 scenario.
- The projected increase in minimum temperature towards EC varies from 2.5°C in Una to 3.2°C in Lahul & Spiti district for IPCC AR5 RCP4.5 scenario and 4.8°C in Kullu to 5.6°C in Lahul & Spiti district of Himachal Pradesh for IPCC AR5 RCP8.5 scenario.
- Highest minimum temperature increase is projected in monsoon season (JJAS) for IPCC AR5 RCP4.5 scenario and RCP8.5 scenario for both MC and EC for Himachal Pradesh State as compared to the other seasons.
- For both IPCC AR5 RCP4.5 and RCP8.5 scenarios, increase in annual and seasonal minimum temperature is projected for Himachal Pradesh and its districts towards MC and EC. However, IPCC AR5 RCP8.5 scenario shows higher increase than that of IPCC AR5 RCP4.5 scenario.

Projected Precipitation

- Average annual rainfall for IPCC AR5 RCP4.5 scenario is projected to increase by 5.9% towards mid-century and increase by about 13.8% towards end-century while for IPCC AR5 RCP8.5 scenario it is projected to increase by about 14% towards mid-century and end-century for the State. Thus the percentage of the projected rainfall increase is low towards MC and EC for both the climate scenarios.
- Districts in the Very high hills temperate dry zone of Himachal Pradesh namely, Lahul & Spiti and Kinnaur show highest projected increase in rainfall towards MC while Shimla and Sirmaur districts in the South show the highest projected increase in annual rainfall as compared to the other districts of Himachal Pradesh towards EC with respect to BL for IPCC AR5 RCP4.5 scenario. Kullu district in High hills temperate wet zone shows the lowest projected increase towards both MC and EC.

- Lahul & Spiti and Kinnaur districts show the highest projected increase (about 16%) towards MC. Lahul & Spiti district shows the highest projected increase in annual rainfall (about 28%) towards EC with respect to BL for IPCC AR5 RCP8.5 scenario. Kullu and Chamba districts show the lowest projected increase towards both MC and EC.
- In monsoon season (JJAS) highest rainfall increase is projected while in winter (JF) and pre-monsoon season (MAM) rainfall decrease is projected towards MC and EC as compared to BL for Himachal Pradesh State for IPCC AR5 RCP4.5 scenario.
- In monsoon season (JJAS) and post monsoon season (OND) highest rainfall increase is projected while in winter (JF) and pre-monsoon season (MAM) rainfall decrease is projected towards MC and EC as compared to BL for Himachal Pradesh State for IPCC AR5 RCP8.5 scenario.

Climate Extremes Indices using Projected Climate

Temperature Extreme Indices

- Maximum of day time temperature (TXx), Maximum of night time temperature (TNx) and Minimum of day time temperature (TXn) and Minimum of night time temperature (TNn) show positive trends for the State and the districts in BL and MC for IPCC AR5 RCP4.5 scenario and BL, MC and EC for IPCC AR5 8.5 scenario implying increase in temperatures for Himachal Pradesh districts, thus warming up. However the positive trend is significant for some districts while for others it is non-significant.
- The percentage of warm days and warm nights is projected to increase and percentage of cool days and cool nights is projected to decrease towards MC and EC as compared to BL for all the districts for both IPCC AR5 climate scenarios. Decrease (cool days and cool nights) / increase (warm days and warm nights) in frequency of these indices towards EC is higher than that of MC which implies higher warming towards EC than MC compared to BL.
- Cold spell duration indicator is projected to decrease and warm spell duration indicator is projected to increase for all the districts towards MC and EC compared to BL implying warming up over Himachal Pradesh districts.

Precipitation Extreme Indices

- None of the precipitation extreme indices show significant trends for the majority of the districts of Himachal Pradesh for both IPCC AR5 climate scenarios. The model results do not show any consistency in the trend of rainfall indices- for some districts the trend is positive while for others it's negative.
- Annual precipitation and the average precipitation on wet days are projected to increase towards MC and EC as compared to BL for all the districts for the IPCC AR5 RCP4.5 and RCP8.5 scenarios.
- Very wet days precipitation and extremely wet days precipitation are projected to increase towards MC and EC compared to BL for all the 12 districts for both the IPCC AR5 climate scenarios implying that rainfall intensity would increase in the future for the districts.
- Consecutive dry days and consecutive wet days are projected to increase for majority of the districts towards MC and EC as compared to BL, for both the IPCC AR5 climate scenarios. However, towards

EC RCP 8.5 scenario, consecutive wet days are projected to decrease for some of the districts.

- Heavy precipitation days and very heavy precipitation days are projected to increase for all the districts towards MC and EC as compared to BL for both the IPCC AR5 climate scenarios.
- In light of these consistent temporal trends of warming and increasing precipitation in Himachal Pradesh with large geographic variation, the indicators that have been identified should be further evaluated and assessed for their health impact. Geographical differences in climate trends may be of use in informing policy and resource allocation for climate change adaptation.

Observed Climate of Himachal Pradesh

Introduction

Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities (such as temperature and precipitation) over a period of time ranging from months to thousands or millions of years.[1] The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant climate parameters include temperature, precipitation and wind. Climate variability refers to variations in the mean state of the climate parameters such as temperature, monthly rainfall, etc. and other statistics (such as standard deviation, statistics of extremes, etc.) of the climate on all temporal and spatial scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural (e.g. solar and volcanic) external forcing (external variability).

Climate Change is generally defined as “a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer” (IPCC, 2007[2]). Anthropogenic climate change is generally defined as a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere (e.g. increase in greenhouse gases due to fossil fuel emissions) or surface characteristics (e.g. deforestation) and which is in addition to natural climate variability observed over comparable time periods.

At all India level mean annual temperature is reported to have increased by 0.6 °C over the last century (IMD, 2010[3]), and the monsoon rainfall is reported to have declined over the last three decades of the 20th century (Kulkarni et al 2012[4], Krishnan et al 2013[5]) over many parts of the country. A number of studies point to an increasing trend in the observed frequency of heavy precipitation events (Christensen et al.

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[1] Climate Change 2007: Working Group I: The Physical Science Basis, https://www.ipcc.ch/publications_and_data/ar4/wg1/en/annex1sglossary-a-d.html

[2] Climate Change 2007: Synthesis Report – An Assessment of the Intergovernmental Panel on Climate Change. Adapted by IPCC Plenary XXVII (Valencia, Spain, 12-17 November 2007)

[3] Climate Profile of India, Met Monograph No. Environment Meteorology-01/2010, Government of India, Ministry of Earth Sciences, India Meteorological Department

[4] Kulkarni Ashwini (2012) Weakening of Indian summer monsoon rainfall in warming environment, Theoretical and Applied Climatology, 109, August 2012, DOI:10.1007/s00704-012-0591-4, 447-459

[5] Krishnan R, Sabin TP, Ayantika DC, Kitoh A, Sugi M, Murakami H, Turner AG, Slingo JM, Rajendran K (2013) Will the South Asian monsoon overturning circulation stabilize any further? Climate Dynamics. 40:187–211. doi:10.1007/s00382-012-1317-0

2013[6]; Rajeevan et al. 2008[7]; Krishnamurthy et al. 2009[8]; Sen Roy 2009[9]; Pattanaik and Rajeevan 2010[10]) over different parts of the country, and a decreasing trend in light rainfall events (Goswami et al. 2006[11]) and moderate to heavy rainfall events (Krishnan et al. 20135). Further, the newly developed representative concentration pathways (RCPs) under the Coupled Model Inter-comparison Project 5 (CMIP5) based projections suggest that under the high emission scenarios the mean warming in India could increase to 1.7 to 2°C by 2030s and 3.3 to 4.8°C by 2080s relative to the preindustrial times; and the all-India precipitation could increase by 4 to 5% by 2030s and 6 to 14% towards the end of the century (2080s) compared to the 1961–1990 baseline.[12]

The issue of climate change raises a wide range of burning questions related to the impacts of climate change and adaptation needs. The demand is rapidly growing for practical information on climate projections and the impacts that can be expected in light of them, in different geographical regions and on different sectors. Until now, most of the general knowledge on climate and weather impacts is based on the experience of earlier experienced events, weather observations, forecasts and reanalyses of historical data. The use of climate model results is much less common. The latter are, however, the principle means of gaining insights on climate change that lies ahead of us. As the concerns on climate change impacts keep on increasing, the use of climate change projections is becoming increasingly essential on all sectors that deal with weather, water and climate.

It is a challenge to transform the vast amount of data produced in climate models into information that is suitable and relevant for climate change impact studies. While annual, seasonal and monthly mean values of temperature, precipitation and other common variables provide essential and indispensable information regarding the climate and how it may change, they are typically not directly linked to climate impacts. During the last few years the need for information more directly linked to impacts has resulted in a wide range of climate extremes indices.

Climate extremes indices are developed to in a simplified way communicate more complex climate change impact relations. Mean temperature and precipitation sums can be seen as (simple) climate indices, and the same applies for various measures of climate extremes. The power of the climate index concept, however, is strikingly illustrated with the more complex climate indices that incorporate information on the sensitivity of a specific system, such as exposure time, threshold levels of event intensity etc.[13]

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[6] Christensen, J.H., K. Krishna Kumar, E. Aldrian, S.-I. An, I.F.A. Cavalcanti, M. de Castro, W. Dong, P. Goswami, A. Hall, J.K. Kanyanga, A. Kitoh, J. Kossin, N.-C. Lau, J. Renwick, D.B. Stephenson, S.-P. Xie and T. Zhou, 2013: Climate Phenomena and their Relevance for Future Regional Climate Change. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA

[7] Rajeevan, M., J. Bhate, and A. K. Jaswal, 2008: Analysis of variability and trends of extreme rainfall events over India using 104 years of gridded daily rainfall data. Geophys. Res. Lett.,35, doi: 10.1029/2008gl035143

[8] Krishnan R, Sabin TP, Ayantika DC, Kitoh A, Sugi M, Murakami H, Turner AG, Slingo JM, Rajendran K (2013) Will the South Asian monsoon overturning circulation stabilize any further? Climate Dynamics. 40:187–211. doi:10.1007/s00382-012-1317-0

[9] Sen Roy, S, 2009: A spatial analysis of extreme hourly precipitation patterns in India, Int. J. Climatol., 29, 345-355

[10] Pattanaik, D. R., and M. Rajeevan, 2010: Variability of extreme rainfall events over India during southwest monsoon season. Meteorol. Appl.,17, 88–104

[11] Goswami, B. N., Venugopal, V., Sengupta, D., Madhusoodanan, M. S., and Prince, K. Xavier. (2006). Increasing Trend of Extreme Rain Events Over India in a Warming Environment, Science, 1 December. 314: 1442-1445

[12] Chaturvedi, RK; Joshi, J; Jayaraman, M; Bala, G; Ravindranath, NH, 2012, Multi-model climate change projections for India under representative concentration pathways, Current Science, 103(7)791-802

[13] Gunn Persson, Lars Bärring, Erik Kjellström, Gustav Strandberg and Markku Rummukainen, 2007, Climate indices for vulnerability assessments, SMHI, RMK No. 111, http://www.smhi.se/polopoly_fs/1.805!Climate%20indices%20for%20vulnerability%20assessments.pdf

This report analyses the historical trends and variability in temperature, precipitation and the extremes of drought and floods, over the state of Himachal Pradesh and its districts, over the period 1951-2013. Further, based on the newly developed regionally downscaled projections from CORDEX simulations, analysis has been made for temperature and precipitation, as well as extreme climate events for the state of Himachal Pradesh under IPCC AR5 moderate and high emission scenarios of RCP4.5 and RCP8.5 towards mid- and end-century.

Data and Methodology

Current Climate Variability and Trend

The high resolution (0.25°x0.25° latitude and longitude) daily gridded rainfall dataset for 90 precipitation grids provided by Indian Meteorological Department (IMD) for the Himachal Pradesh region for a period of 63 years (1951–2013) for precipitation, and 1.0°x1.0° latitude and longitude daily gridded temperature datasets for 8 temperature grids, spanning over 63 years (1951-2013) for maximum and minimum temperature (Rajeevan et al. 2006) has been used to calculate the variability and trend in precipitation and temperature respectively. Annual, seasonal and monthly mean values of precipitation along with 10 precipitation extremes indices for Himachal Pradesh and its districts have been analysed for the time period 1951-2013 (63 years). Similarly annual, seasonal and monthly mean values of maximum temperature, minimum temperature along with 11 climate extremes indices for Himachal Pradesh and its districts have been analysed for the time period 1951-2013 (63 years).

Trends of annual and seasonal maximum and minimum temperature and rainfall variability is studied using the non-parametric Mann-Kendall test, while the increasing or decreasing slope of trends in the time series is determined by using Sen's method (Sen, 1968[14]).

Climate Change Projections and Trend

The CORDEX South Asia modelled data on precipitation, maximum temperature, minimum temperature and another 21 climate extremes indices have been analysed for Himachal Pradesh State and its 12 districts for baseline, BL (1981-2010), mid-century, MC (2021-2050) and end-century, EC (2071-2100). Climate change projections for precipitation, maximum temperature and minimum temperature have been analysed while trend analysis has been carried out on the climate extremes indices for Himachal Pradesh State. The change in climate extremes indices towards MC (2021-2050) and EC (2071-2100) with respect to BL (1981-2010) has also been analysed. Trend tests are run at 10% level of significance to indicate the presence of statistical significant trends over the period of years. Grid-resolutions for the climate projection are 0.5°x0.5° and 39 weather grids data for temperature and precipitation have been used. Climate data from three Regional Climate Models (RCM) of REMO (from MPI), RCA4 (from SMHI) and CCAM (from CSIRO) for IPCC AR5 climate scenarios of RCP4.5 (moderate emission scenario) and RCP8.5 (a scenario of comparatively high greenhouse gas emissions) has been used to calculate the ensemble mean for precipitation, maximum temperature, minimum temperature and climate extremes indices data for both IPCC AR5 RCP4.5 and RCP8.5 scenarios.

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[14] Sen, P.K., 1968. "Estimates of the regression coefficient based on Kendall's Tau". J. Am. Stat. Assoc., 63, 1379-1389

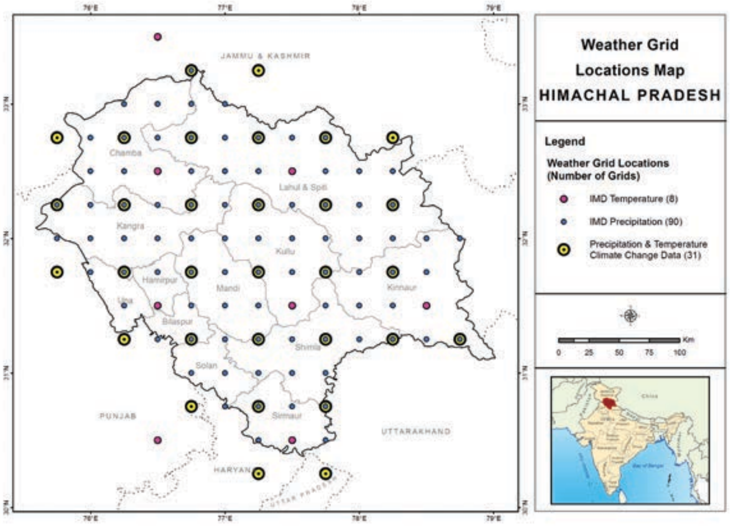
The details of the data used for observed and climate change analysis of Himachal Pradesh and its 12 districts is given in Table 1. The corresponding locations of the grids are shown in Figure 1.

Table 1 : Meta data of Climate Variability and Climate Change Projection data used for Himachal Pradesh

No	Variable	Data Source	Period	Grid resolution(°) and number of grids
1	Observed Maximum Temperature, Minimum Temperature and Climate extremes indices	IMD, Pune (http://imd.gov.in/)	1951-2013 (63 years)	1° x 1° (14 grids)
2	Observed Precipitation and Climate extremes indices			0.25° x 0.25° (157 grids)
3	Projected Maximum Temperature, Minimum Temperature, Precipitation and Climate extremes indices	CORDEX South Asia, IITM Pune (IPCC AR5 climate scenarios- RCP4.5 and RCP8.5) 3 RCMs (Regional Climate Models)*: • SMHI-RCA4 (Rossby Centre regional atmospheric model version 4, Swedish Meteorological and Hydrological Institute(SMHI), Sweden) • CSIRO-CCAM-1391M (CSIRO Marine and Atmospheric Research, Melbourne, Australia) • MPI-CSC-REMO2009 (Climate Service Centre, Hamburg, Germany)	1981-2010 (BL), 2021-2050 (MC), 2071-2100 (EC)	0.5° x 0.5° (39 grids)

*** Climate data from multiple GCM driven CORDEX-Asia Regional Climate simulations have been used to derive ensemble mean for the analysis***

Figure 1 : Weather grid locations for the state of Himachal Pradesh



The long term trends in observed seasonal precipitation and temperature over Himachal Pradesh and its districts using IMD data at daily time scales has been analysed to arrive at current baseline climatology. Summary is presented in the following paragraphs.

Analysis of Current Climate and Climate Variability

The State of Himachal Pradesh lies between 30°22’40” N to 33°12’40” N latitude and 75°45’ 55” E to 79°04’ 20” E longitude. The state of Himachal Pradesh is spread over an area 55,673 km^2 and is bordered by Jammu and Kashmir on the north, Punjab on the southwest, Haryana on the south, Uttarakhand on the southeast and Tibet on the east. Himachal is a mountainous region, rich in its natural resources[15]. Altitude ranges from 450 meters to 6500 meters above sea level. Himachal Pradesh has 13 districts with Shimla as its capital.

The climate varies from hot and sub-humid tropical (450–900 metres) in the southern low tracts, warm and temperate (900–1800 metres), cool and temperate (1900–2400 metres) and cold glacial and alpine (2400–4800 metres) in the northern and eastern high elevated mountain ranges.

Himachal Pradesh has three seasons. The rainy season lasts from July to September, winter from October to March and summer from April to June. In the winter months, some parts of Himachal experiences heavy snow fall. It occurs generally in the months of December to March.

The annual rainfall of Himachal Pradesh is 2909 to 3800 mm. The average temperature in the summer months varies from 280C to 372C. Temperature in general decreases from south to north.

Himachal Pradesh has two major river systems: the Indus and the Ganga river systems. The important rivers of Indus system are Satluj, Beas, Ravi, Chenab and Jhelum. Out of these five rivers, four flows through Himachal Pradesh and along with their tributaries drain parts of Himachal Pradesh. Ganga basin extends from the Eastern face of the Shimla ridge in Himachal Pradesh to the South-Western slopes of the Kanchanjunga massif on the Nepal-Sikkim border. Only a small part of Yamuna river system which is a tributary of Ganga river system flows through the state of Himachal Pradesh.

Agriculture is the main occupation of Himachal Pradesh. Wheat, rice, maize, and barley are the major crops. Forest in Himachal Pradesh covers about 28.6% of the total area of the state.

Observed Temperature Analysis

Annual and Seasonal Observed Temperature Statistics

Table 2 shows average, range and coefficient of variation (CV)[16] of annual and seasonal maximum and minimum temperature. The observed maximum and minimum temperature for the period 1951-2013 (63 years) shows temporal variability.

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15 https://en.wikipedia.org/wiki/Geography_of_Himachal_Pradesh

16 A statistical measure of the dispersion of data points in a data series around the mean. The coefficient of variation represents the ratio of the standard deviation to the mean, and it is a useful statistic for comparing the degree of variation from one data series to another, even if the means are drastically different from each other. The advantage of the CV is that it is unitless. This allows CVs to be compared to each other in ways that other measures, like standard deviations or root mean squared residuals, cannot be. Distributions with CV < 1 are considered low-variance, while those with CV > 1 are considered high-variance.

Table 2 : Observed Temperature Statistics for Himachal Pradesh and its Districts (1951-2013)

State/District	Periods	Maximum Temperature			Minimum Temperature		
		Average (°C)	Range (°C)	CV	Average (°C)	Range (°C)	CV
Himachal Pradesh	Annual	25.9	24.5-27.1	0.020	13.4	12.5-14.5	0.034
	Winter (JF)	16.9	14.9-19.6	0.065	4.7	2.9-7.5	0.165
	Pre Monsoon (MAM)	28.3	24.7-31.9	0.045	14.1	12.3-16.2	0.061
	Monsoon (JJAS)	30.7	29.6-32.7	0.019	20.6	19.7-21.6	0.023
	Post Monsoon (OND)	23.0	19.7-24.2	0.035	8.8	7.6-10.1	0.077
Bilaspur	Annual	26.8	25.4-28.1	0.019	14.0	13.1-15.1	0.033
	Winter (JF)	17.7	15.7-20.5	0.062	5.1	3-8.1	0.158
	Pre Monsoon (MAM)	29.5	25.6-33.2	0.044	14.7	13.1-16.9	0.058
	Monsoon (JJAS)	31.6	30.5-33.8	0.020	21.4	20.4-22.3	0.022
	Post Monsoon (OND)	23.9	20.6-25.1	0.034	9.2	7.9-10.6	0.076
Chamba	Annual	24.8	23.5-26	0.022	12.0	11.1-13	0.037
	Winter (JF)	15.1	12.9-17.7	0.075	3.5	2.2-5.8	0.189
	Pre Monsoon (MAM)	26.5	23.1-29.8	0.050	12.5	10.8-14.5	0.066
	Monsoon (JJAS)	30.7	29.8-32.3	0.017	19.5	18.4-20.6	0.026
	Post Monsoon (OND)	21.8	18.8-23	0.039	7.4	6.2-8.5	0.086
Hamirpur	Annual	26.8	25.4-28.1	0.019	14.0	13.1-15.1	0.033
	Winter (JF)	17.7	15.7-20.5	0.062	5.1	3-8.1	0.158
	Pre Monsoon (MAM)	29.5	25.6-33.2	0.044	14.7	13.1-16.9	0.058
	Monsoon (JJAS)	31.6	30.5-33.8	0.020	21.4	20.4-22.3	0.022
	Post Monsoon (OND)	23.9	20.6-25.1	0.034	9.2	7.9-10.6	0.076
Kangra	Annual	26.1	24.8-27.3	0.020	13.3	12.4-14.3	0.034
	Winter (JF)	16.7	14.6-19.4	0.066	4.4	2.7-7.2	0.172
	Pre Monsoon (MAM)	28.3	24.8-31.8	0.046	13.9	12.1-15.9	0.061
	Monsoon (JJAS)	31.4	30.4-33.3	0.018	20.7	19.7-21.7	0.022
	Post Monsoon (OND)	23.1	20-24.3	0.035	8.5	7.4-9.8	0.079
Kinnaur	Annual	24.2	22.7-25.4	0.021	12.4	11.5-13.6	0.039
	Winter (JF)	15.9	13.9-18.7	0.069	4.2	2.4-7.1	0.181
	Pre Monsoon (MAM)	26.6	23-30.2	0.045	13.1	11.2-15.2	0.068
	Monsoon (JJAS)	28.5	27.2-30.6	0.021	19.2	18.3-20.2	0.024
	Post Monsoon (OND)	21.5	18.2-22.6	0.037	8.3	7.1-9.7	0.081
Kullu	Annual	25.0	23.7-26.2	0.020	12.7	11.8-13.7	0.036
	Winter (JF)	16.0	13.9-18.6	0.068	4.1	2.3-7	0.181
	Pre Monsoon (MAM)	27.2	23.7-30.8	0.047	13.3	11.6-15.4	0.064
	Monsoon (JJAS)	30.0	29-32	0.019	19.8	18.8-20.8	0.023
	Post Monsoon (OND)	22.1	19-23.3	0.036	8.2	7.1-9.5	0.081
Lahul & Spiti	Annual	23.6	22.3-24.8	0.022	11.5	10.6-12.5	0.038
	Winter (JF)	14.4	12.4-17.1	0.076	3.2	2.1-5.7	0.204

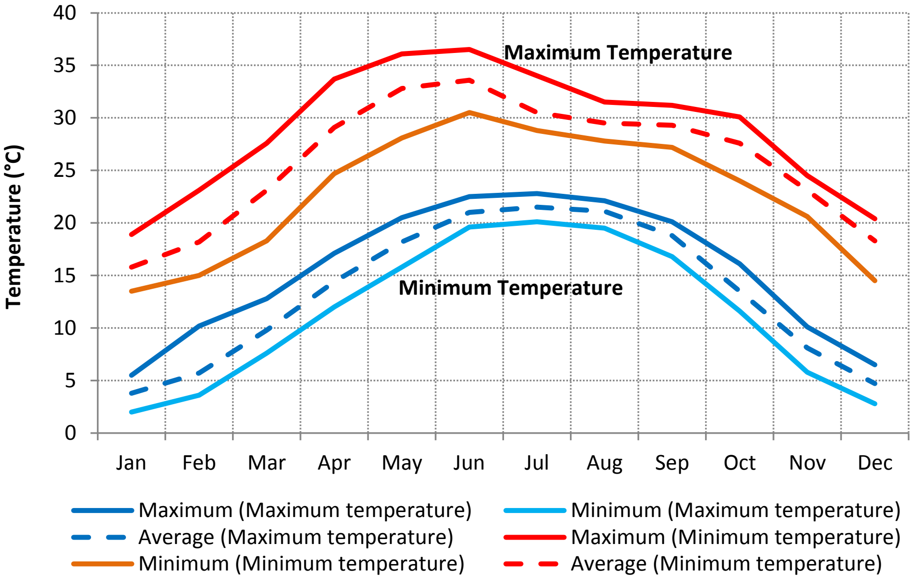
State/District	Periods	Maximum Temperature			Minimum Temperature		
		Average (°C)	Range (°C)	CV	Average (°C)	Range (°C)	CV
	Pre Monsoon (MAM)	25.5	22.2-28.9	0.049	12.0	10.2-14	0.071
	Monsoon (JJAS)	29.0	28-30.9	0.019	18.6	17.7-19.6	0.025
	Post Monsoon (OND)	20.7	17.7-21.9	0.039	7.0	5.9-8.2	0.086
Mandi	Annual	25.7	24.3-26.9	0.020	13.2	12.4-14.3	0.035
	Winter (JF)	16.7	14.6-19.4	0.065	4.7	2.8-7.5	0.163
	Pre Monsoon (MAM)	28.0	24.4-31.6	0.045	13.9	12.2-16	0.062
	Monsoon (JJAS)	30.5	29.4-32.5	0.019	20.3	19.4-21.3	0.023
	Post Monsoon (OND)	22.8	19.6-24	0.035	8.7	7.6-10	0.077
Shimla	Annual	26.1	24.5-27.2	0.019	13.9	13-14.9	0.034
	Winter (JF)	17.5	15.5-20.2	0.062	5.3	3.3-8.1	0.149
	Pre Monsoon (MAM)	28.8	25.1-32.5	0.043	14.7	12.9-16.9	0.059
	Monsoon (JJAS)	30.3	29.1-32.5	0.020	20.8	20.1-21.8	0.022
	Post Monsoon (OND)	23.2	19.8-24.4	0.035	9.4	8.2-10.7	0.072
Sirmaur	Annual	26.2	24.7-27.4	0.019	14.2	13.3-15.3	0.033
	Winter (JF)	17.8	15.8-20.5	0.061	5.6	3.7-8.4	0.141
	Pre Monsoon (MAM)	29.1	25.4-32.8	0.042	15.1	13.3-17.4	0.058
	Monsoon (JJAS)	30.4	29.1-32.5	0.020	21.1	20.3-22	0.021
	Post Monsoon (OND)	23.4	19.9-24.6	0.035	9.8	8.5-11.1	0.069
Solan	Annual	27.0	25.5-28.2	0.019	14.5	13.7-15.6	0.032
	Winter (JF)	18.3	16.3-21.1	0.059	5.7	3.7-8.5	0.142
	Pre Monsoon (MAM)	30.0	26.2-33.7	0.042	15.5	13.7-17.7	0.056
	Monsoon (JJAS)	31.4	30.2-33.6	0.020	21.7	20.9-22.7	0.021
	Post Monsoon (OND)	24.1	20.6-25.3	0.034	9.9	8.6-11.3	0.070
Una	Annual	28.3	26.8-29.5	0.018	15.0	14.2-16.2	0.030
	Winter (JF)	18.9	16.8-21.7	0.058	5.7	3.7-8.7	0.143
	Pre Monsoon (MAM)	31.0	27.1-34.8	0.042	15.9	14.1-18.1	0.054
	Monsoon (JJAS)	33.2	32.1-35.3	0.019	22.8	21.8-23.7	0.020
	Post Monsoon (OND)	25.1	21.7-26.4	0.033	10.0	8.8-11.5	0.071

Long term monthly (1951-2013) maximum and minimum temperature summary of Himachal Pradesh is 25.9°C with a range varying from 24.5°C – 27.1°C. It is evident from Table 2 and Figure 2 that the highest value attained for maximum temperature (30.7°C) is in the monsoon season (JJAS) while its lowest maximum value (16.9°C) is attained in winter season. It is also seen that for annual maximum temperature the highest value is attained for districts namely, Una, Solan, Hamirpur and Bilaspur lying in the Sub mountain & low hills sub-tropical zone while the lowest value is attained for districts namely, Lahul & Spiti and Kinnaur lying in Very high hills temperate dry zone of Himachal Pradesh for the period 1951-2013 (63 years).

The districts in the Sub mountain & low hills sub-tropical zone namely, Una, Solan, Hamirpur and Bilaspur shows relatively higher maximum temperature as compared to the districts in the other parts of the State in all four seasons as can be observed (Figure 4).

Mean annual minimum temperature for Himachal Pradesh is 13.4°C with a range varying from 12.5°C – 14.5°C. Minimum temperature attains its mean highest value (20.6°C) during the monsoon season (JJAS), while it attains its mean lowest value (4.7°C) in winter season. The spatial variation in seasonal temperature can be seen from Figure 4. The variability in temperature is highest in the winter season as is also evident from the Coefficient of variation (CV) value given in Table 2. It is also seen that for annual minimum temperature the highest value is attained for districts Una and Solan while the lowest value is attained for districts Lahul & Spiti and Chamba for the period 1951-2013 (63 years).

Figure 2 : Long term monthly average, maximum and minimum temperature for Himachal Pradesh (1951-2013)

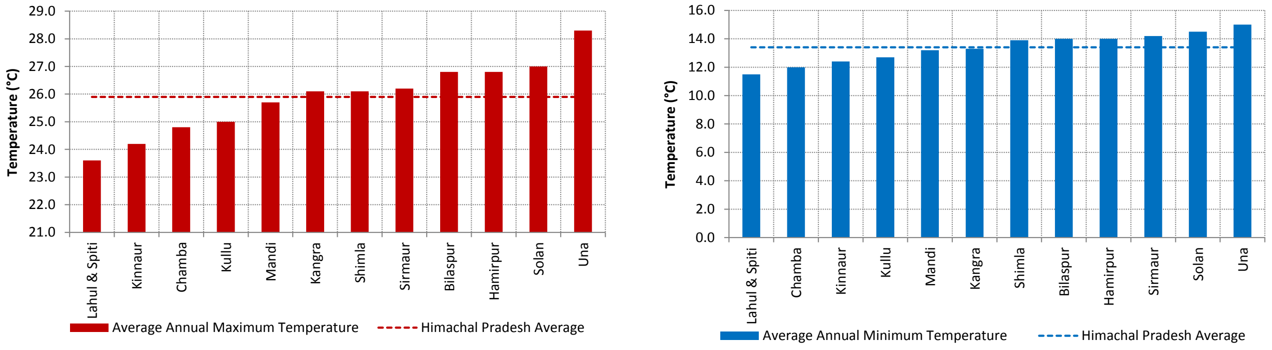


Himachal Pradesh - IMD gridded temperature: 1951-2013

The districts namely, Una and Solan shows relatively higher minimum temperature as compared to the districts in the other parts of the State in all the four seasons as can be observed. Temperature is increasing from very high hills to low hills as can be seen (Figure 4).

District wise average temperature is shown in Figure 3. Figure 4 depicts spatial variation in average annual and seasonal maximum and minimum temperature of Himachal Pradesh districts.

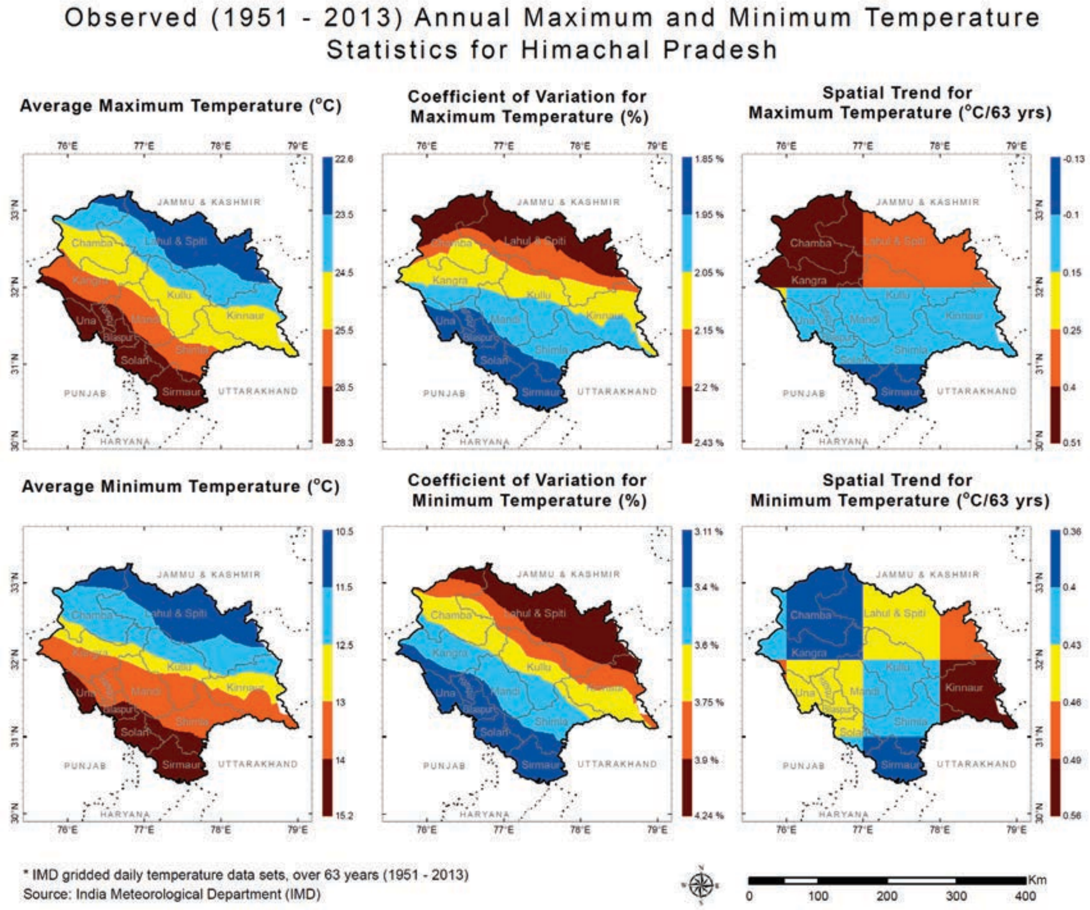
Figure 3 : Long term annual average, maximum and minimum temperature for districts of Himachal Pradesh (1951-2013)



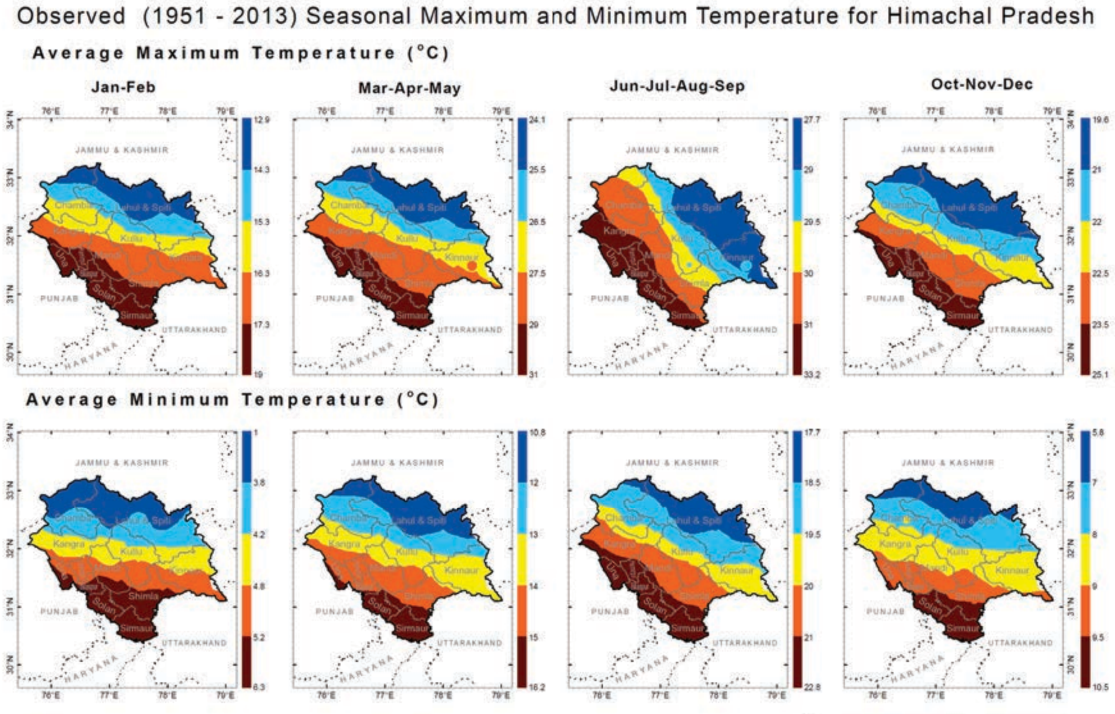
Himachal Pradesh - IMD gridded temperature: 1951-2013

Himachal Pradesh - IMD gridded temperature: 1951-2013

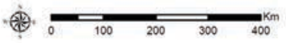
Figure 4 : Spatial variation in observed average annual and seasonal maximum and minimum temperature for Himachal Pradesh (1951-2013)



* IMD gridded daily temperature data sets, over 63 years (1951 - 2013)
Source: India Meteorological Department (IMD)



* IMD gridded daily temperature data sets, over 63 years (1951 - 2013)
Source: India Meteorological Department (IMD)



There is not much temporal variation observed across the districts of Himachal Pradesh in maximum and minimum temperature as is evident from the mean maximum and minimum temperature and very low CV values. However, variability in minimum temperature is higher than that of the maximum temperature. Temporal variability in Northern districts of the State is little higher as compared to the other districts for minimum and maximum temperature (Figure 4).

Observed Temperature Trends

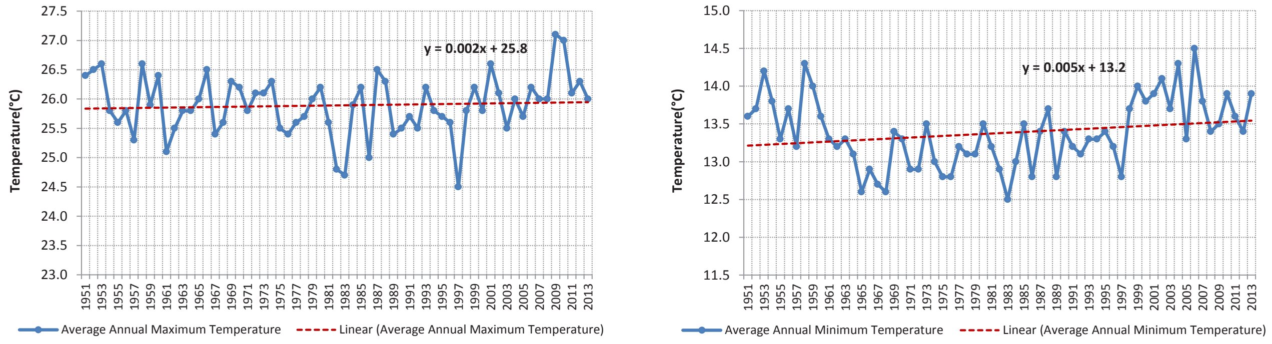
Trend tests have been carried out to analyse the presence of statistical significant trends over the period of years from 1951 to 2013 (63 years). Annual average and linear trend for maximum and minimum temperature for the state of Himachal Pradesh is shown in Figure 5. Summary of annual maximum and minimum temperature trend for the state is shown in Table 3.

Table 3 : Summary of temperature trend for Himachal Pradesh and its districts (1951-2013)

State/District	Annual Maximum Temperature	Annual Minimum Temperature	Annual Maximum Temperature (°C/63 years)	Annual Minimum Temperature (°C/63 years)
Himachal Pradesh	▨	▨	0.20	0.45
Bilaspur	▨	▨	0.13	0.46
Chamba	▨	▨	0.43	0.40
Hamirpur	▨	▨	0.13	0.46
Kangra	▨	▨	0.34	0.45
Kinnaur	▨	▨	0.05	0.49
Kullu	▨	▨	0.24	0.43
Lahul & Spiti	▨	▨	0.30	0.43
Mandi	▨	▨	0.24	0.43
Shimla	▨	▨	0.02	0.48
Sirmaur	🟧	▨	-0.05	0.45
Solan	▨	▨	0.01	0.42
Una	▨	🟩	0.21	0.48

🟩	Positive Significant trend	🟧	Negative Significant trend	🟦	No Change
▨	Positive Non-significant trend	🟨	Negative Non-significant trend	⬛	NA

Figure 5 : Observed average annual maximum and minimum temperature of Himachal Pradesh (1951-2013)

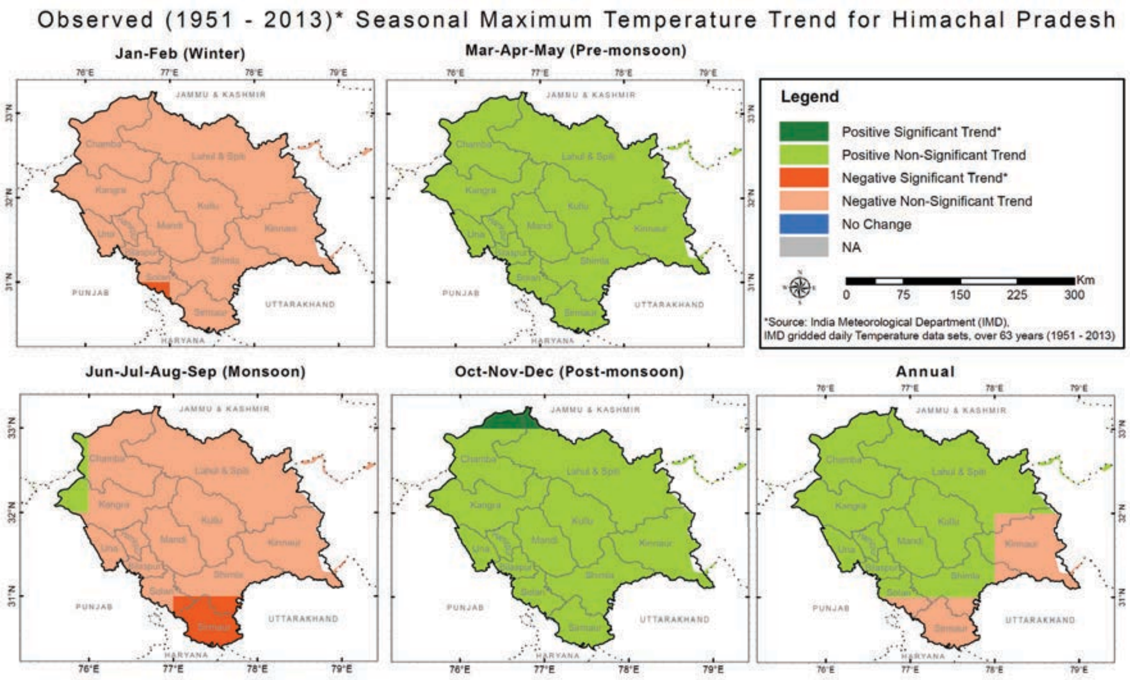


Himachal Pradesh - IMD gridded temperature: 1951-2013

Himachal Pradesh - IMD gridded temperature: 1951-2013

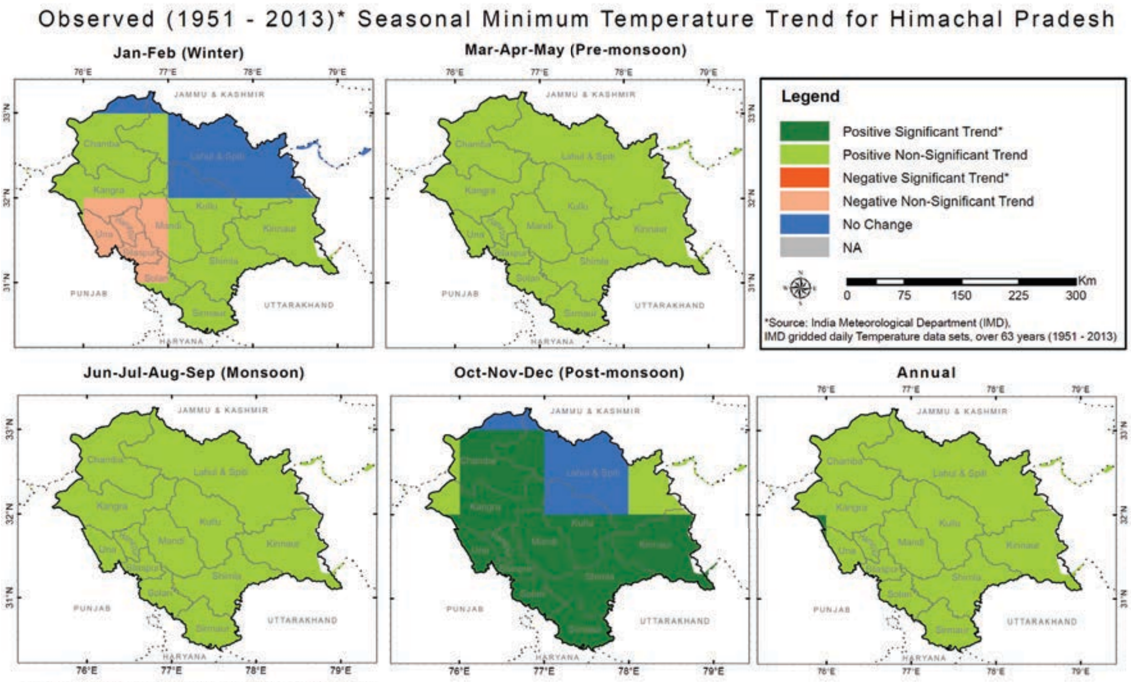
The spatial variation in trend in annual and seasonal maximum and minimum temperature for the districts of Himachal Pradesh is shown in Figure 6.

Figure 6 : Spatial variation in observed annual and seasonal maximum and minimum temperature trend



*Source: India Meteorological Department (IMD), IMD gridded daily Temperature data sets, over 63 years (1951 - 2013)

* The significance is calculated at > 90% confidence level



*Source: India Meteorological Department (IMD), IMD gridded daily Temperature data sets, over 63 years (1951 - 2013)

* The significance is calculated at > 90% confidence level

Summary of the trend analysis from Table 3, Figure 5 and Figure 6 is as follows:

- Positive trend in both mean annual maximum temperature and mean annual minimum temperature is observed for Himachal Pradesh State. The change per year for annual minimum temperature is 0.01°C while for annual maximum temperature is negligible.

- Trend analysis shows that the positive trend for annual maximum temperature and minimum temperature are statistically not significant for Himachal Pradesh State. The districts also show non significant positive trend for both maximum and minimum temperature. However, district namely Una shows statistically significant positive trend for annual minimum temperature.
- In winter (JF) and monsoon season (JJAS) districts show non significant negative trend while in pre-monsoon (MAM) and post monsoon (OND) season the districts show non significant positive trend in maximum temperature. However, district Sirmaur show a significant fall in temperature in the monsoon season.
- In all four seasons- winter (JF), pre monsoon (MAM), monsoon season (JJAS) and post monsoon (OND) season the districts show positive trend in minimum temperature. However, the trend is significantly positive trend for the districts only in the post monsoon (OND).

Thus it can be concluded that there is significant variation in annual maximum and minimum temperature over the period 1951-2013 (63 years) for Himachal Pradesh.

Observed Rainfall Analysis

Information on spatial and temporal variations of rainfall is essential in understanding the hydrological balance on a global or regional scale. The distribution of precipitation is also important for water management in agriculture, power generation and drought-monitoring. In India, rainfall received during the southwest monsoon season (June–September) is crucial for its economy. Real-time monitoring of rainfall distribution on a daily basis is required to evaluate the progress and status of monsoon and to initiate necessary action to control drought/flood situations.

Annual and Seasonal Observed Rainfall Statistics

IMD gridded rainfall has been used for the analysis. Table 4 summarises observed rainfall statistics, namely, average, range and coefficient of variation (CV) of annual and seasonal rainfall for Himachal Pradesh and its districts.

Average annual rainfall of Himachal Pradesh State is 1284.2 mm with a range varying from 704.7 mm-2062.8 mm over the 63 years period (1951-2013). Amongst all districts, Kangra and Chamba in the North West receive the maximum average annual rainfall while district Kinnaur in the East receive the least (Figure 9). The coefficient of variation in annual rainfall lies in the range of 0.18 to 0.34 (18% to 34%) across the districts of Himachal Pradesh thus marginal variability is observed across the districts.

Table 4 : Observed Rainfall Statistics for Himachal Pradesh (1951-2013)

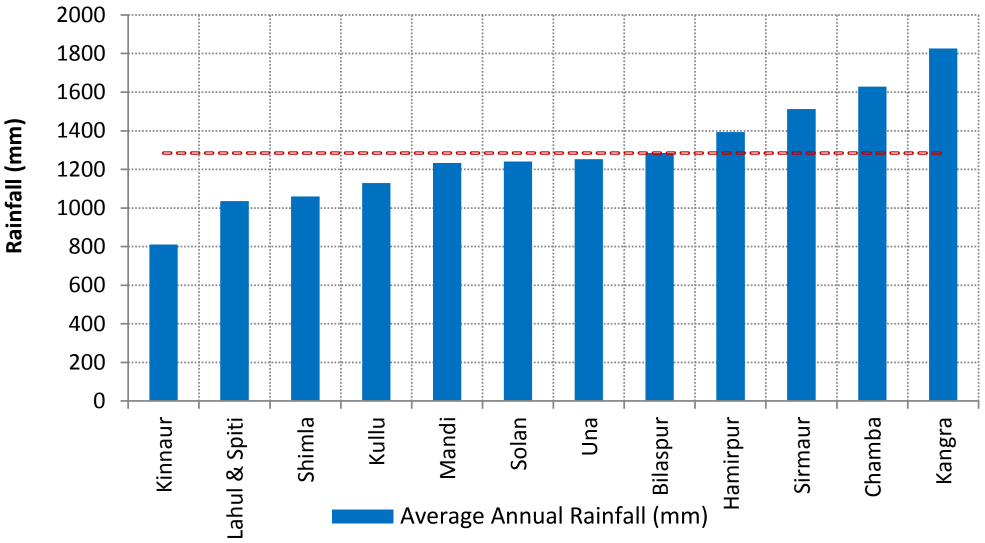
District/State	Season	Average Rainfall (mm)	Range (mm)	Inter-annual variation	Contribution to Annual Rainfall (%)
Himachal Pradesh	Annual	1284.2	704.7-2062.8	0.24	
	Winter (JF)	156	34.1-479.7	0.54	12.1
	Pre Monsoon (MAM)	192.9	49.5-545.6	0.53	15.0
	Monsoon (JJAS)	849.2	352.9-1504.1	0.32	66.1
	Post Monsoon (OND)	86.1	3.7-444.7	0.95	6.7
Bilaspur	Annual	1285.0	912.8-1880	0.18	

District/State	Season	Average Rainfall (mm)	Range (mm)	Inter-annual variation	Contribution to Annual Rainfall (%)
	Winter (JF)	127.3	31.5-339.4	0.50	9.9
	Pre Monsoon (MAM)	149.7	21.7-528.6	0.56	11.6
	Monsoon (JJAS)	937.4	464.1-1456	0.23	72.9
	Post Monsoon (OND)	71.0	0-312	0.89	5.5
Chamba	Annual	1629.0	774.6-2586	0.26	
	Winter (JF)	204.5	58.5-481.2	0.42	12.6
	Pre Monsoon (MAM)	263.9	75.4-516.5	0.40	16.2
	Monsoon (JJAS)	1048.0	295.8-1900	0.36	64.3
	Post Monsoon (OND)	112.5	10.9-504.2	0.77	6.9
Hamirpur	Annual	1393.0	786.3-2069	0.22	
	Winter (JF)	118.0	18-306.3	0.51	8.5
	Pre Monsoon (MAM)	134.2	33.9-456.3	0.56	9.6
	Monsoon (JJAS)	1071.0	495-1696	0.25	76.9
	Post Monsoon (OND)	69.9	1-481	1.05	5.0
Kangra	Annual	1826.0	997.2-2697	0.24	
	Winter (JF)	178.5	41.3-485.9	0.43	9.8
	Pre Monsoon (MAM)	208.8	87.7-554.7	0.47	11.4
	Monsoon (JJAS)	1338.0	383.7-2085	0.29	73.3
	Post Monsoon (OND)	100.8	8.2-551.5	0.89	5.5
Kinnaur	Annual	811.1	353.4-1709	0.34	
	Winter (JF)	169.9	6.4-953.9	0.89	20.9
	Pre Monsoon (MAM)	223.3	17.5-891.6	0.69	27.5
	Monsoon (JJAS)	334.0	126.4-991.6	0.58	41.2
	Post Monsoon (OND)	83.9	1.7-639.3	1.13	10.3
Kullu	Annual	1129.0	688.6-1930	0.23	
	Winter (JF)	195.8	58.9-517.3	0.45	17.3
	Pre Monsoon (MAM)	267.6	64.6-590.4	0.46	23.7
	Monsoon (JJAS)	564.0	247-1089	0.30	50.0
	Post Monsoon (OND)	101.2	8.8-390	0.81	9.0
Lahul & Spiti	Annual	1036.0	545.5-1776	0.27	
	Winter (JF)	219.0	64.8-560.5	0.48	21.1
	Pre Monsoon (MAM)	295.6	87.2-647.7	0.46	28.5
	Monsoon (JJAS)	405.4	146.1-1115	0.44	39.1
	Post Monsoon (OND)	116.0	5.9-399.4	0.77	11.2
Mandi	Annual	1234.0	619.1-1916	0.22	
	Winter (JF)	141.6	39.8-374.6	0.44	11.5
	Pre Monsoon (MAM)	203.3	52.2-509.2	0.48	16.5
	Monsoon (JJAS)	811.9	353.8-1358	0.28	65.8

District/State	Season	Average Rainfall (mm)	Range (mm)	Inter-annual variation	Contribution to Annual Rainfall (%)
	Post Monsoon (OND)	77.3	2.8-281.6	0.84	6.3
Shimla	Annual	1060.0	612.2-1629	0.21	
	Winter (JF)	170.4	20-625.7	0.64	16.1
	Pre Monsoon (MAM)	193.7	53.3-599.2	0.51	18.3
	Monsoon (JJAS)	613.6	310.9-1150	0.28	57.9
	Post Monsoon (OND)	82.2	2.6-347.9	0.96	7.8
Sirmaur	Annual	1513.0	683.9-2414	0.25	
	Winter (JF)	110.3	20.5-344.9	0.61	7.3
	Pre Monsoon (MAM)	122.5	25.6-453	0.66	8.1
	Monsoon (JJAS)	1205.0	555.4-2045	0.28	79.6
	Post Monsoon (OND)	75.0	1.4-452.1	1.09	5.0
Solan	Annual	1241.0	758.6-2258	0.22	
	Winter (JF)	129.4	37.3-398.1	0.57	10.4
	Pre Monsoon (MAM)	147.0	41.6-511.6	0.58	11.8
	Monsoon (JJAS)	891.0	451.6-1556	0.27	71.8
	Post Monsoon (OND)	73.8	0.7-376.5	1.02	5.9
Una	Annual	1253.0	724.4-1890	0.22	
	Winter (JF)	107.3	12-368.2	0.57	8.6
	Pre Monsoon (MAM)	104.6	33.8-288.8	0.54	8.3
	Monsoon (JJAS)	970.9	404.4-1608	0.27	77.5
	Post Monsoon (OND)	70.2	0.2-601	1.22	5.6

District wise average annual rainfall is shown in Figure 7.

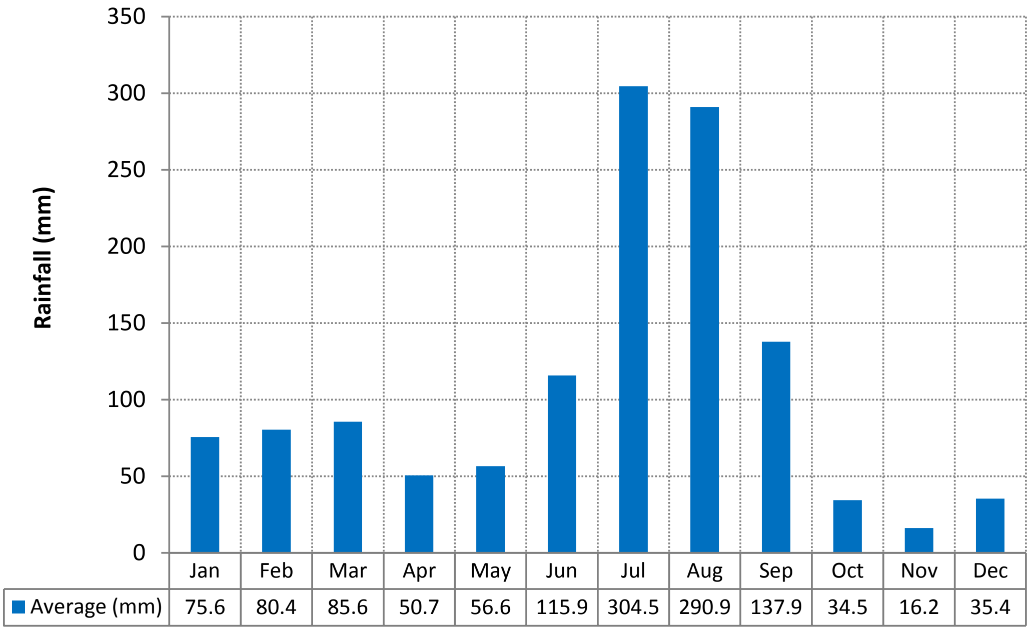
Figure 7 : Characteristics of long term average annual rainfall for Himachal Pradesh districts (1951-2013)



Himachal Pradesh - IMD gridded rainfall: 1951-2013

Monthly average rainfall summary of Himachal Pradesh over 1951-2013 (63 years) is represented in Figure 8.

Figure 8 : Characteristics of long term average monthly rainfall for Himachal Pradesh (1951-2013)



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Average (mm)	75.6	80.4	85.6	50.7	56.6	115.9	304.5	290.9	137.9	34.5	16.2	35.4

Himachal Pradesh - IMD gridded rainfall: 1951-2013

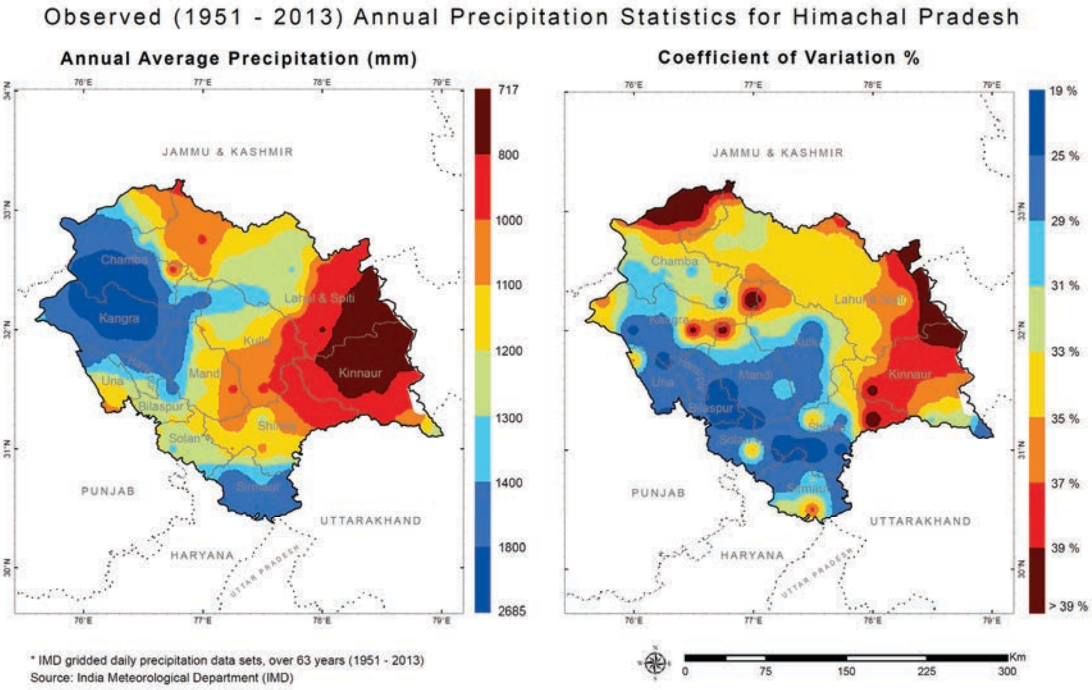
From Table 4 and Figure 8 it can be seen that the monsoon (June, July, August and September) rainfall contributes the maximum to annual rainfall amounting to approximately 66% for Himachal Pradesh State. Contribution of Pre-monsoon (March, April and May) rainfall on average is 15%, contribution of post-monsoon (October, November and December) rainfall in annual rainfall is about 6.7% and winter rainfall (January, February) contribution is 12.1%.

The spatial variation in seasonal rainfall can be seen from Figure 9. In JF, MAM and OND season, Lahul & Spiti district lying in Very high hills temperate dry zone receive the highest rainfall as compared to others. In JJAS season Kangra and Sirmaur districts of the State receive the maximum rainfall. The variability in rainfall is also the least for these districts as compared to others.

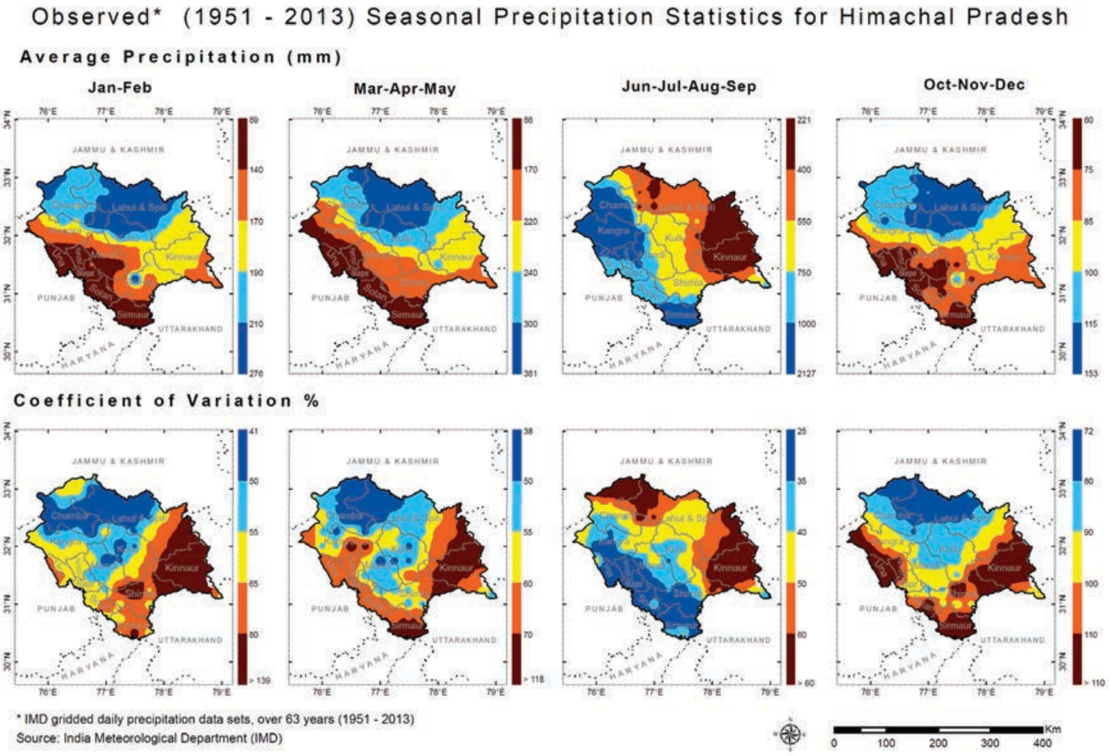
Figure 9 depicts spatial variation in annual rainfall mean and its CV values for Himachal Pradesh districts.

The coefficient of variation (inter annual variation in rainfall) is relatively low during JJAS season as rainfall variability is least during these months while very high during the post-monsoon season due to higher variability in rainfall during post monsoon months (Table 4 and Figure 9).

Figure 9 : Spatial variation in observed average annual and seasonal rainfall for Himachal Pradesh (1951-2013)



* IMD gridded daily precipitation data sets, over 63 years (1951 - 2013)
Source: India Meteorological Department (IMD)



* IMD gridded daily precipitation data sets, over 63 years (1951 - 2013)
Source: India Meteorological Department (IMD)

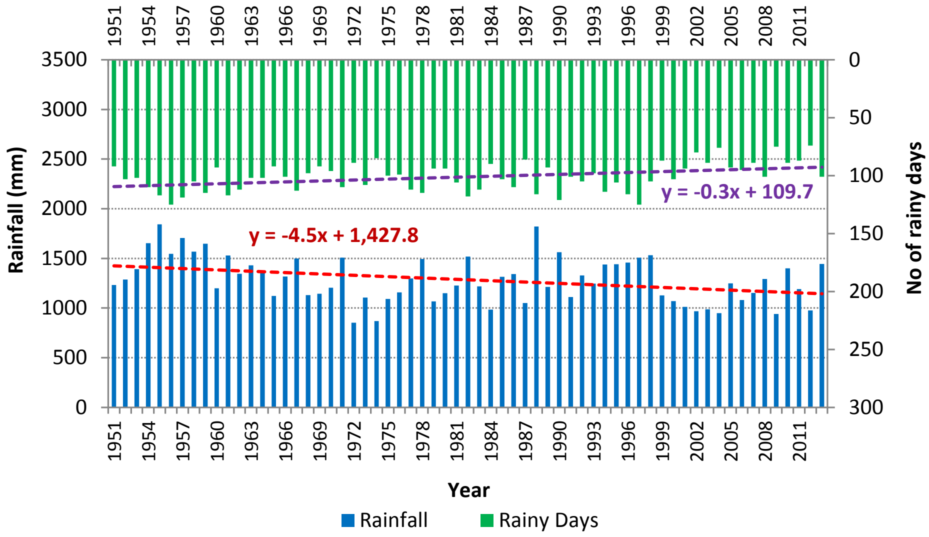
Observed Rainfall Trends

The rainfall received in an area is an important factor in determining the amount of water available to meet various demands, such as agricultural, industrial, domestic water supply and for hydroelectric power generation. Global climate changes may influence long-term rainfall patterns impacting the availability of water, along with the danger of increasing occurrences of droughts and floods. The south west (SW) monsoon, which brings about 66% of the total rainfall over the state, is critical for the availability of fresh water for drinking and irrigation. Changes in climate over Himachal Pradesh, particularly the SW monsoon, would have a significant impact on agricultural production, water resources management and overall economy of the State.

In the view of the above, a number of studies have attempted to investigate the trend of climatic variables at the country scale, regional scale and at the individual stations. Recently, L S Rathore et. al. (2013[17]) examined the trends for monthly, seasonal and annual rainfall series over the states of India and observed decrease in annual and winter rainfall, increase in summer season rainfall and monsoon season rainfall over Himachal Pradesh.

Figure 10 gives the summary of trend in observed annual rainfall (mm) and number of rainy days for Himachal Pradesh for the period 1951-2013 (63 years).

Figure 10 : Characteristics of observed annual rainfall and number of rainy days for Himachal Pradesh



Himachal Pradesh - IMD gridded rainfall: 1951-2013

From Figure 10 it can be inferred that for the period 1951-2013 annual rainfall and rainy days both show negative trend for Himachal Pradesh. However, the trend is statistically not significant for annual rainfall and rainy days.

The spatial variation in trend in annual and seasonal rainfall for the districts is shown in Figure 11. Trend summary for Himachal Pradesh and its districts is shown in Table 5. Trend tests are run at 10% level of significance to indicate the presence of statistical significant trends over the period of years. Since rainfall does not follow a linear pattern, non-parametric trend using Man-Kendall[18] rank statistics has been determined.

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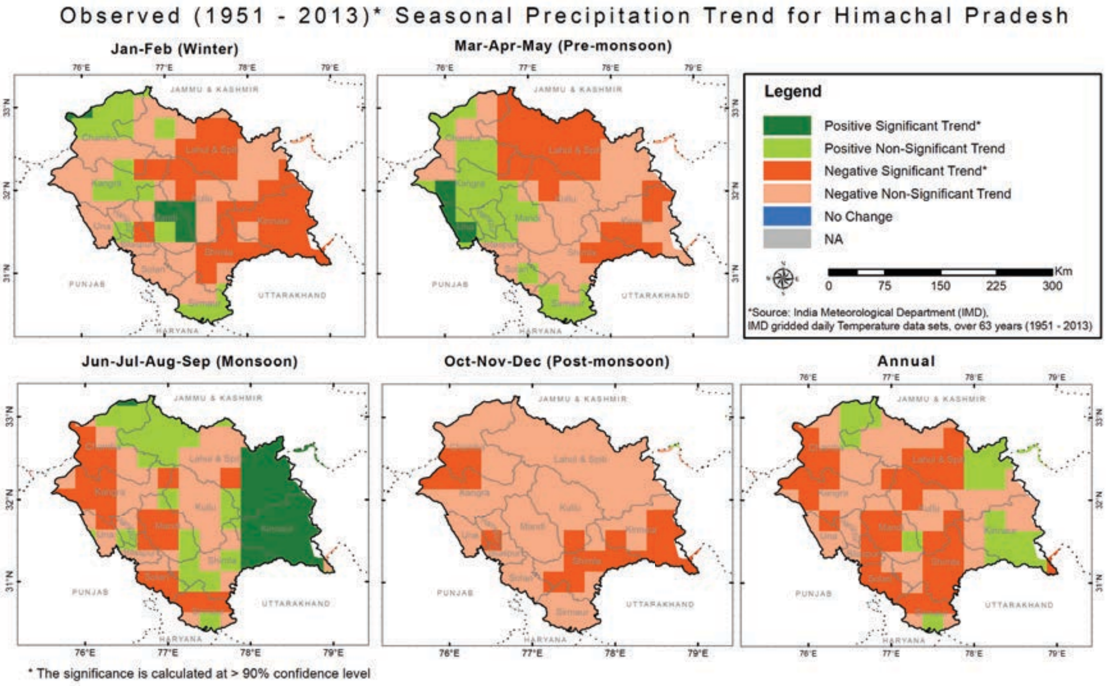
[17] Rathore, L.S., Attri, S.D. and Jaswal, A.K, 2013. “State Level Climate Change Trends in India”. Met. Monograph Environmental Meteorology No 2/2013, pp. 1-147

Figure 11 : Spatial variation in observed annual and seasonal precipitation trend for Himachal Pradesh (1951-2013)



*Source: India Meteorological Department (IMD), IMD gridded daily Temperature data sets, over 63 years (1951 - 2013)

* The significance is calculated at > 90% confidence level

Table 5 : Precipitation trend summary for Himachal Pradesh and its districts

State	Annual Rainfall	Rainy days
Himachal Pradesh	🟧	🟧
Bilaspur	🟧	🟧
Chamba	🟨	🟧
Hamirpur	🟨	🟧
Kangra	🟧	🟧
Kinnaur	🟨	▨
Kullu	🟧	🟧
Lahul & Spiti	🟨	🟧
Mandi	🟧	🟧
Shimla	🟧	🟧
Sirmaur	🟧	🟨
Solan	🟧	🟧
Una	🟨	🟨

🟩 Positive Significant trend
▨ Positive Non-significant trend
🟧 Negative Significant trend
🟨 Negative Non-significant trend
🟦 No Change
⬛ NA

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18 A climate time series is generally not statistically independent but is comprised of patterns of persistence, cycles or trends. For such time series, Mann-Kendall method is used to test for trends over time. It has been widely used to test for randomness against trend in hydrology and climatology. It makes no assumptions about the distribution of the data or the linearity of any trends and also takes care of the extreme values.

Trend analysis results for annual rainfall and rainy days for Himachal Pradesh and its districts (1951-2013) from Figure 10, Figure 11 and Table 5 are summarized as follows:

- Annual rainfall and rainy days shows negative trend which is statistically significant for Himachal Pradesh State. Thus rainfall and rainy days have both declined over the period for the State.
- 7 districts of Himachal Pradesh namely, Bilaspur, Kangra, Kullu, Mandi, Shimla, Sirmaur and Solan show negative significant trend in rainfall while the other 5 districts show negative non significant trend in rainfall (Figure 11 and Table 5).
- All the districts except Kinnaur show negative trend in rainy days. 9 districts namely, Bilaspur, Chamba, Hamirpur, Kangra, Kullu, Lahul & Spiti, Mandi, Shimla and Solan show negative significant trend in rainy days.
- In winter, pre-monsoon and monsoon season mixed trend while in post-monsoon season negative trend in rainfall is observed for the districts. However, the seasonal trend is statistically significant for some districts while for others it is not as can be observed. (Figure 11).

Annual Rainfall Distribution Analysis

Annual rainfall distribution analysis has been done for Himachal Pradesh and its districts. The rainfall is classified as excess, normal deficient or scanty based on the departure of the rainfall from the long period average rainfall (LPA). Based on the India Meteorological Department (IMD) classification, if the rainfall received in that particular year is within + or -19% of the LPA, that year is called as a normal rainfall year, <-19% to -59% of the LPA is deficient rainfall year, <-59% of LPA is grouped under scanty rainfall year. On the other hand, if the rainfall is >+19% to +59% of LPA, it is excess rain fall year and >+59% LPA is termed as wet year.[19] The rainfall for the study area has been classified and Figure 12 shows the frequency of excess, normal, deficient and scanty rainfall years.

From Figure 12 it can be seen that out of 63 years (1951-2013) Himachal Pradesh State on average had 46 normal rainfall years, 8 years had excess rainfall and 9 years had deficit rainfall. It can be seen 2001-2010 is the decade in the State that had maximum of 5 years of deficient rainfall, decades 1961-1970 and 1991-2000 had all normal rainfall years while decade 1951-1960 had maximum of 6 excess rainfall years.

The district wise classification in rainfall can also be seen from the figure. It is seen that Sirmaur district receives the maximum number of 17 years of excess rainfall while Chamba and Kinnaur districts have maximum of 18 deficient years of rainfall as compared to the other districts of Himachal Pradesh over the period 1951-2013. Kullu and Shimla districts have maximum of 42 years of normal rainfall.

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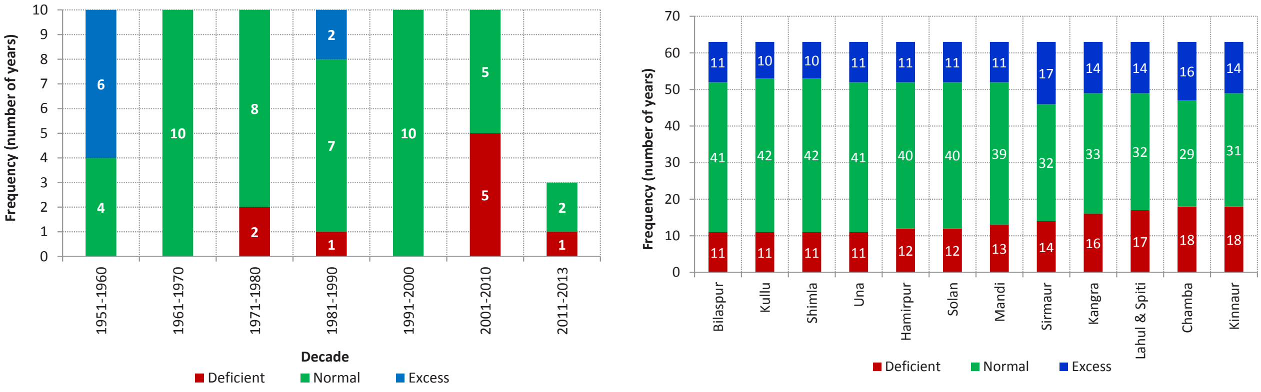
19 http://www.imdpune.gov.in/weather_forecasting/glossary.pdf

Figure 12 : Frequency of scanty, deficient, normal and excess years of annual rainfall - Himachal Pradesh and its districts (1951-2013)



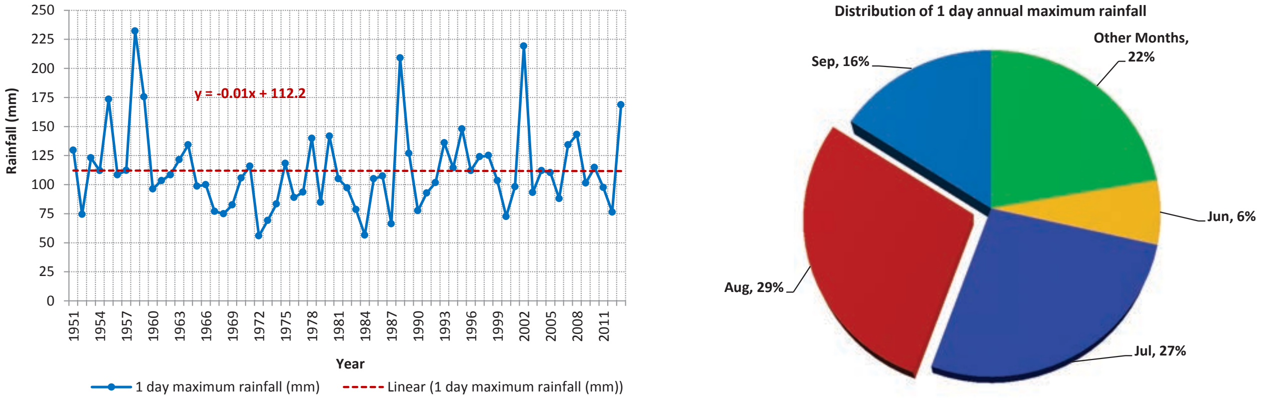
Himachal Pradesh - IMD gridded rainfall: 1951-2013

Himachal Pradesh - IMD gridded rainfall: 1951-2013

1 Day Maximum Rainfall Analysis

In the design of irrigation and other hydraulic structures, evaluating the magnitude of extreme rainfall for is of much importance. Figure 13 show the 1 day maximum rainfall amount as line graph for Himachal Pradesh State.

Figure 13 : 1 Day maximum rainfall for Himachal Pradesh (1951-2013)



Himachal Pradesh - IMD gridded rainfall: 1951-2013

Himachal Pradesh - IMD gridded rainfall: 1951-2013

It can be seen that 1 day maximum rainfall shows negative trend for the State over the period 1951-2013. However, the negative trend is statistically not significant.

The maximum (232.2 mm) and minimum (55.5 mm) annual one day maximum rainfall for Himachal Pradesh State has been recorded on 1958, 21st December and 1972, 24th August respectively.

It can be seen from Figure 13 that August month received the highest amount of one day maximum rainfall (29%) followed by July (27%), September (16%) and June 6%. Thus about 78% of 1 day maximum rainfall is received in JJAS (monsoon) months in the period of analysis (1951-2013).

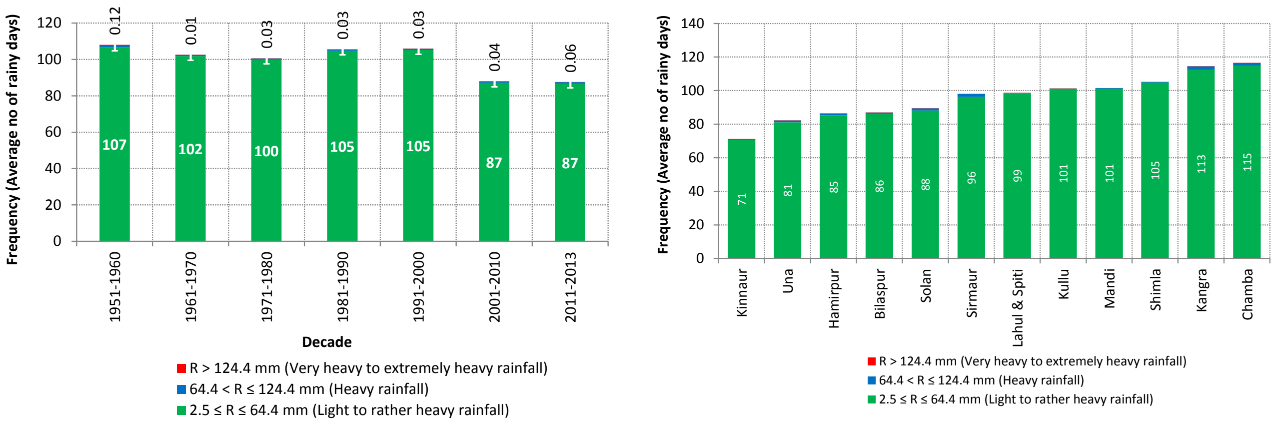
Rainfall Intensity Analysis

Intensity of daily rainfall analysis has been done based on daily rainfall data of Himachal Pradesh from 1951-2013. Daily rainfall has been grouped into three categories according to IMD classification of rainfall, 2.5 ≤ R ≤ 64.4 (Light to rather heavy rainfall), 64.4 < R ≤ 124.4 (heavy rainfall), and R >124.4 (very heavy to extremely heavy rainfall).20

Annual average number of rainy days (when daily rain >=2.5 mm) for period 1951-2013 in Himachal Pradesh State is 101 days and varies from 74 days to 125 days. Light to rather heavy rainfall (2.5 ≤ R ≤ 64.4) events is 100 on average and ranges from 74 to 124 days. Similarly, days when there are heavy rainfall (64.4 < R ≤ 124.4 mm) events is 1 on average and ranges from 0 to 3 days, and very heavy to extremely heavy rainfall (R> 124.4 mm) days is negligible.

Figure 14 gives the decadal average frequency of intensity of rainfall events for Himachal Pradesh as well as the intensity of rainfall events for its districts over the period (1951-2013).

Figure 14 : Frequency of daily rainfall events of different intensity for Himachal Pradesh (1951-2013)



Himachal Pradesh - IMD gridded rainfall: 1951-2013 *Himachal Pradesh - IMD gridded rainfall: 1951-2013*

Days with rainfall in the range 2.5 ≤ R ≤ 64.4 mm are the maximum in the period 1951-1960 amongst all decades. Thus overall number of rainy days is the maximum in the period 1951-1960 compared to the other decades.

The intensity of rainfall events for the districts can also be seen from Figure 14. Over the 63 years period districts namely, Chamba and Kangra have the maximum number of total rainy days while Kinnaur has the least number of total rainy days as compared to the other districts of Himachal Pradesh.

Historical Indices of Climate Extremes

Indices representing climate extremes are developed to communicate more complex climate change impact relations in a simplified way. Mean temperature and precipitation sums can be seen as simple climate extremes indices, and the same applies for various measures of climate extremes. The power of the climate extremes index concept, however, is strikingly illustrated with the more complex climate extremes indices that incorporate information on the sensitivity of a specific system, such as exposure time, threshold levels of event intensity etc.[20]

A total of 21 indices are considered to be the core indices. They are based on daily temperature values or daily precipitation amount. Some are based on fixed thresholds and some are based on thresholds that

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20 http://www.smhi.se/polopoly_fs/1.805!Climate%20indices%20for%20vulnerability%20assessments.pdf

vary from location to location (thresholds are typically defined as a percentile of the relevant data series). RClimDex (1.0)[21] which is designed to provide a user friendly interface to compute indices of climate extremes has been used to derive the relevant indices for Himachal Pradesh. Most of the indices are defined in terms of counts of days crossing the thresholds which are derived as the percentile (variable thresholds). Since percentile thresholds are expressions of anomalies relative to the local climate, the value of the thresholds is site specific. Indices calculated using variable threshold are most suitable for spatial comparisons, because they sample same part of temperature/precipitation) distributions at each site.[22]

Table 6 gives the list of precipitation and temperature extreme indices used for the trend analysis of the Himachal Pradesh districts. These indices were developed by the World Climate Research Programme's Expert Team on Climate Change Detection and Indices (ETCCDI). Both temperature and precipitation indicators can be broadly classified into four different categories based on the method of calculation: (1) Percentile based indices: The percentile-based temperature extreme indices represent the highest (90th) and lowest (10th) deciles for maximum and minimum temperature. The percentile-based indices for precipitation include the upper first and fifth percentile. Percentile thresholds are more evenly distributed in space and meaningful for every region; (2) Threshold indices are defined as the number of days on which a temperature or precipitation value falls above or below a percentile threshold. These thresholds were set to assess moderate extremes that typically occur a few times every year rather than high impact, once-in-a-decade weather events; (3) Absolute indices represent maximum or minimum values within a month; (4) Duration indices define periods of extreme weather and (5) other indices include indices of annual precipitation total (PRCPTOT), and simple daily intensity index (SDII). They do not fall into any of the above categories but may still be of interest.[23]

Percentile: In statistics, a percentile is the value of a variable below which a certain percent of observations fall. To calculate percentiles, sort the data so that x1 is the smallest value, and x_n is the largest, with n = total number of observations.

$$x_i \text{ is the } p_i^{th} \text{ percentile of the data set where: } p_i = 100 * i/(n+1).$$

Percentile is used to calculate the variable threshold. Example: Frequency of maximum temperature > 40 °C, gives the number of days where the maximum temperature is above 40 °C. 40 °C is an absolute threshold value and this may vary at different places (Shimla may be experiencing hot days when maximum temperature exceeds 30 °C, but for Churu in Rajasthan, it may be 45 °C which may be hot day). In order to make the relative threshold based on the prevailing climate parameter, percentile method is adapted. 10th percentile value is the lower threshold and 90th percentile value is the upper threshold. For Maximum temperature 10th percentile value gives cold day and 90th percentile value means hot days. The thresholds are calculated based on the baseline period of 1981-2010.

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[21] http://cccma.seos.uvic.ca/ETCCDI/software.shtml

[22] Trends in Precipitation Extremes over India.U. R. Joshi and M. Rajeevan. 2006, Research Report No: 3/2006, National Climate Centre. India Meteorological Department,

[23] http://sheridan.geog.kent.edu/pubs/2012-AQAH.pdf

Table 6 : List of Climate Extremes Indices

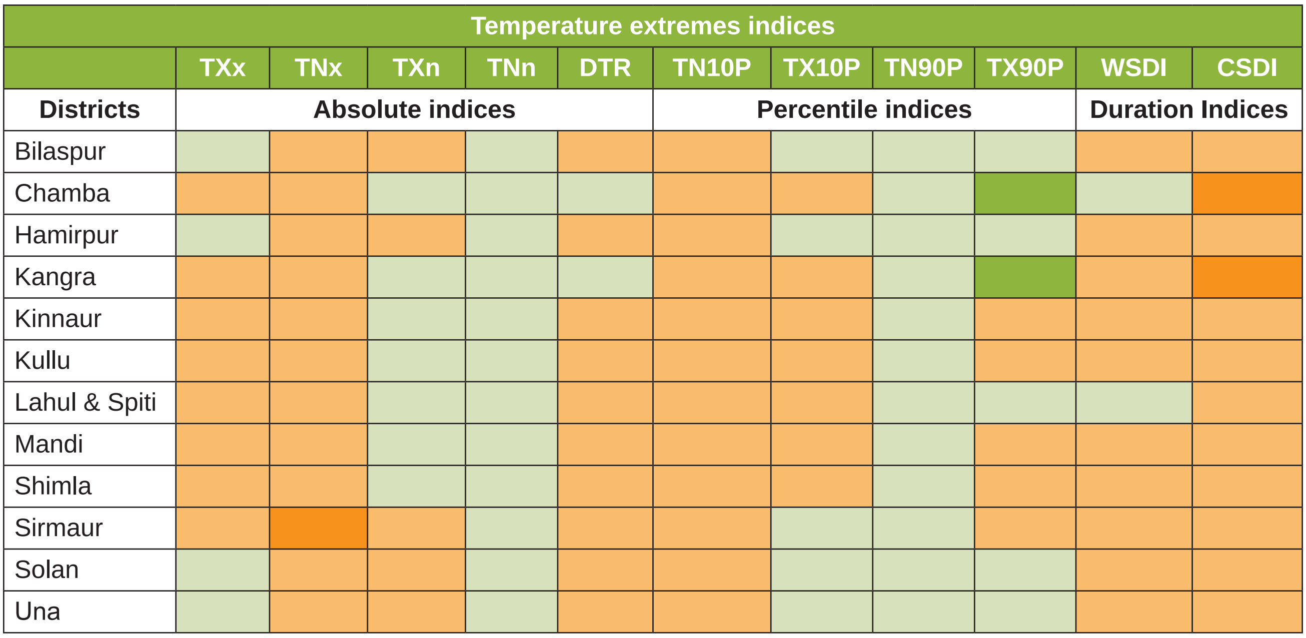
Index	Descriptive Name	Definition	Units
Temperature extremes indices: TX is the daily maximum temperature; TN is daily minimum temperature;			
Absolute indices			
TXx	Maximum of Day time Temperature	Monthly maximum value of daily maximum temperature	°C
TNx	Maximum of Night time Temperature	Monthly maximum value of daily minimum temperature	°C
TXn	Minimum of Day time Temperature	Monthly minimum value of daily maximum temperature	°C
TNn	Minimum of Night time Temperature	Monthly minimum value of daily minimum temperature	°C
DTR	Diurnal temperature range	Daily maximum temperature - Daily minimum temperature	°C
Percentile indices			
TN10p	Cool nights	Annual Percentage of days where minimum temperature is less than 10th percentile of base period	%
TX10p	Cool days	Annual Percentage of days where maximum temperature is less than 10th percentile of base period	%
TN90p	Warm nights	Annual Percentage of days where minimum temperature is more than 90th percentile of base period	%
TX90p	Warm days	Annual Percentage of days where maximum temperature is more than 90th percentile of base period	%
Duration Indices			
WSDI	Warm spell	Annual count of days with at least 6 consecutive days, when maximum temperature is greater than the threshold (calculated as 90th percentile of base period maximum temperature)	Days
CSDI	Cold spell	Annual count of days with at least 6 consecutive days, when minimum temperature is less than the threshold (calculated as 10th percentile of base period minimum temperature)	Days
Precipitation extremes indices: RR is the daily rainfall rate. A wet day is defined when RR>= 1mm and a dry day when RR<1mm. All indices are calculated annually from January to December.			
Absolute Indices			
RX1day	1-day maximum precipitation	Highest precipitation amount in one-day period	Mm
RX5day	5-day maximum precipitation	Highest precipitation amount in five-day period	Mm
Percentile Indices			
R95p	Very wet day precipitation	Annual total precipitation when precipitation is greater than the Threshold (calculated as 95th percentile of base period precipitation)	Mm

Index	Descriptive Name	Definition	Units
R99p	Extremely wet day precipitation	Annual total precipitation when precipitation is greater than the Threshold (calculated as 99th percentile of base period precipitation)	Mm
		Duration Indices	
CDD	Consecutive dry days	Maximum length of dry spell (consecutive days with precipitation less than 1mm)	Days
CWD	Consecutive wet days	Maximum number of consecutive wet days	Days
		Threshold Indices	
R10mm	Heavy precipitation days	Annual count of days when precipitation is greater than 10 mm	Days
R20mm	Very heavy precipitation days	Annual count of days when precipitation is greater than 20 mm	Days
		Other Indices	
PRCPTOT	Wet-day precipitation	Annual total precipitation from wet days	Mm
SDII	Simple daily intensity index	Average precipitation on wet days	mm/day

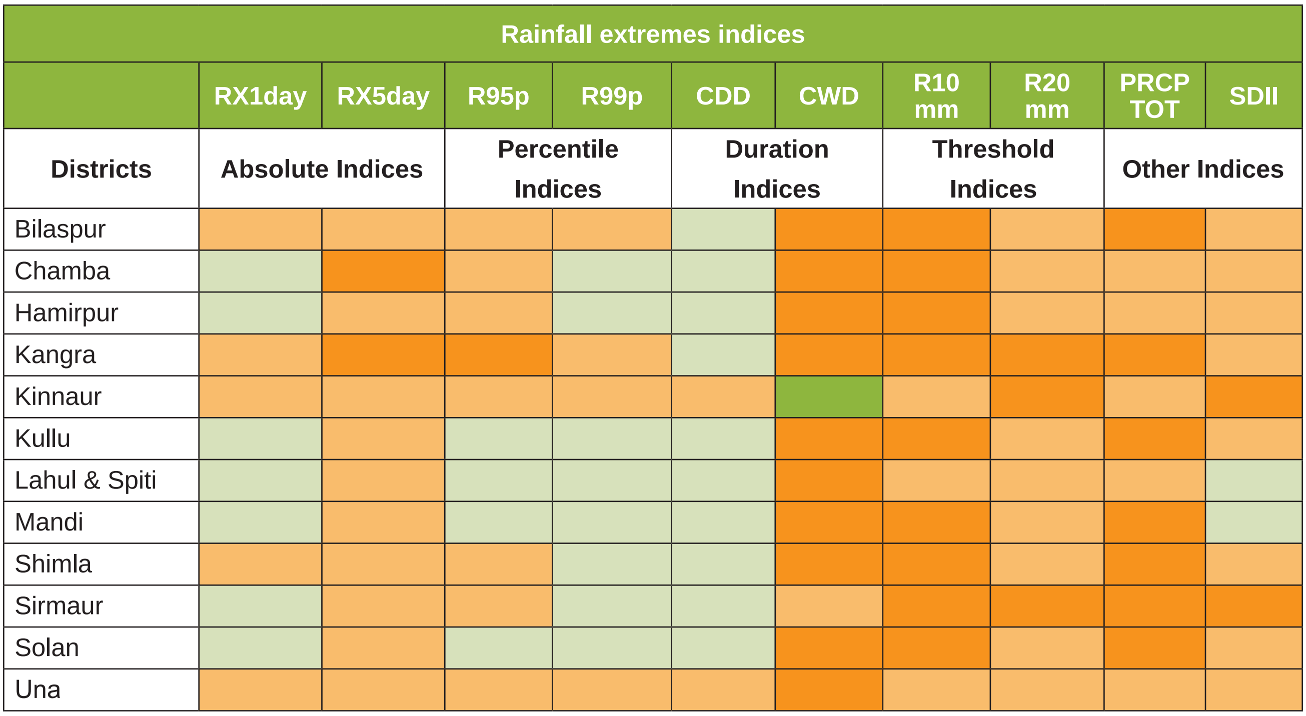
The IMD gridded temperature and rainfall data of Himachal Pradesh districts has been analysed for 21 climate extremes indices (11 temperature and 10 precipitation extremes indices) for periods 1951-2013 (63 years). The annual value of the climate extremes indices have been used for the trend analysis. Trend tests are run at 10% level of significance to indicate the presence of statistical significant trends over the period of years, i.e. only those districts trend will be considered as statistically significant whose confidence level is greater than or equal to 90%.

Table 7 gives the temperature and precipitation extreme indices trend for Himachal Pradesh districts (1951-2013). Figure 15 gives the overall climate extremes indices summary for the districts of Himachal Pradesh.

Table 7 : Temperature and precipitation extreme indices trend summary for districts of Himachal Pradesh



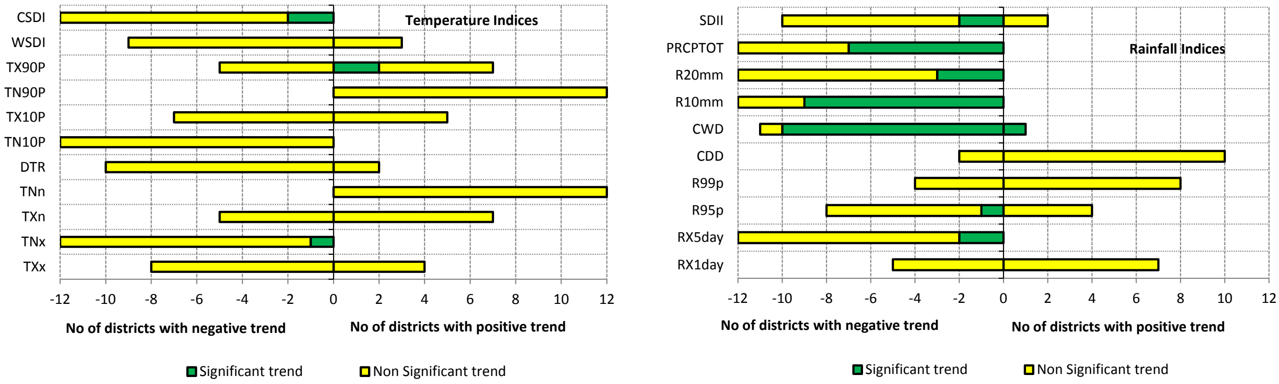
	Temperature extremes indices										
	TXx	**TNx**	**TXn**	**TNn**	**DTR**	**TN10P**	**TX10P**	**TN90P**	**TX90P**	**WSDI**	**CSDI**
Districts	**Absolute indices**					**Percentile indices**				**Duration Indices**	
Bilaspur	⬜	🟨	🟨	⬜	🟨	🟨	⬜	⬜	⬜	🟨	🟨
Chamba	🟨	🟨	⬜	⬜	⬜	🟨	🟨	⬜	🟩	⬜	🟧
Hamirpur	⬜	🟨	🟨	⬜	🟨	🟨	⬜	⬜	⬜	🟨	🟨
Kangra	🟨	🟨	⬜	⬜	⬜	🟨	🟨	⬜	🟩	🟨	🟧
Kinnaur	🟨	🟨	⬜	⬜	🟨	🟨	🟨	⬜	🟨	🟨	🟨
Kullu	🟨	🟨	⬜	⬜	🟨	🟨	🟨	⬜	🟨	🟨	🟨
Lahul & Spiti	🟨	🟨	⬜	⬜	🟨	🟨	🟨	⬜	⬜	⬜	🟨
Mandi	🟨	🟨	⬜	⬜	🟨	🟨	🟨	⬜	🟨	🟨	🟨
Shimla	🟨	🟨	⬜	⬜	🟨	🟨	🟨	⬜	🟨	🟨	🟨
Sirmaur	🟨	🟧	🟨	⬜	🟨	🟨	⬜	⬜	🟨	🟨	🟨
Solan	⬜	🟨	🟨	⬜	🟨	🟨	⬜	⬜	⬜	🟨	🟨
Una	⬜	🟨	🟨	⬜	🟨	🟨	⬜	⬜	⬜	🟨	🟨



Rainfall extremes indices										
	RX1day	RX5day	R95p	R99p	CDD	CWD	R10 mm	R20 mm	PRCP TOT	SDII
Districts	Absolute Indices		Percentile Indices		Duration Indices		Threshold Indices		Other Indices	
Bilaspur	🟠	🟠	🟠	🟠	🟢	🟧	🟧	🟠	🟧	🟠
Chamba	🟢	🟧	🟠	🟢	🟢	🟧	🟧	🟠	🟠	🟠
Hamirpur	🟢	🟠	🟠	🟢	🟢	🟧	🟧	🟠	🟠	🟠
Kangra	🟠	🟧	🟧	🟠	🟢	🟧	🟧	🟧	🟧	🟠
Kinnaur	🟠	🟠	🟠	🟠	🟠	🟩	🟠	🟧	🟠	🟧
Kullu	🟢	🟠	🟢	🟢	🟢	🟧	🟧	🟠	🟧	🟠
Lahul & Spiti	🟢	🟠	🟢	🟢	🟢	🟧	🟠	🟠	🟠	🟢
Mandi	🟢	🟠	🟢	🟢	🟢	🟧	🟧	🟠	🟧	🟢
Shimla	🟠	🟠	🟠	🟢	🟢	🟧	🟧	🟠	🟧	🟠
Sirmaur	🟢	🟠	🟠	🟢	🟢	🟠	🟧	🟧	🟧	🟧
Solan	🟢	🟠	🟢	🟢	🟢	🟧	🟧	🟠	🟧	🟠
Una	🟠	🟠	🟠	🟠	🟠	🟧	🟠	🟠	🟠	🟠

🟩	Positive Significant trend	🟧	Negative Significant trend	🟦	No Change
🟢	Positive Non-significant trend	🟠	Negative Non-significant trend	⬛	NA

Figure 15 : Number of districts showing specific trends in climate extremes indices in Himachal Pradesh (1951-2013)



Analysis from Table 7 and Figure 15 for climate extremes indices of Himachal Pradesh districts (1951-2013) is summarized as follows:

Temperature Extremes Indices:

- **Absolute indices:** Maximum of day time temperature (TXx) and Minimum of day time temperature (TXn) show mixed non significant trends for the districts of Himachal Pradesh. TXx show positive trend for 4 districts and negative trend for 8 districts while TXn show positive trend for 7 districts and negative trend for 5 districts. Maximum of night time temperature (TNx) show negative trends for all the districts while minimum of night time temperature (TNn) show positive trends for all the districts.

However, TNx and TNn show non significant trends for the districts. DTR (Diurnal Temperature range) shows non significant negative trend for 10 districts and positive trend for only 2 districts.

- **Percentile indices:** Cool nights (TN10P) show negative trend while warm nights (TN90P) show positive trend for all the 12 districts. Warm days (TX90P) and cool days (TX10P) show mixed trend for the districts. However, the trend is statistically not significant as can be seen from Table 7
- **Duration indices:** Warm spell duration indicator (WSDI) shows negative not significant trend for majority of the districts. Cold spell duration indicator (CSDI) also shows negative trend for all the districts, however the negative trend is statistically significant for only 2 districts.

Precipitation Extremes Indices:

- **Absolute indices:** Maximum 1 day precipitation show mixed trend while maximum 5 day precipitation show negative trend for all the districts. However, trend is significant negative for only 2 districts namely, Chamba nnd Kangra for maximum 5 day precipitation. This implies that the intensity of the rainfall has definitely decreased for some of the districts of Himachal Pradesh over the period 1951-2013 (Table 7).
- **Percentile indices:** Very wet day precipitation (R95p) and extremely wet day precipitation (R99p) show mixed trend for the districts. However, mixed trend is statistically not significant.
- **Duration indices:** Consecutive dry days are rising for 10 districts. However, trend is statistically not significant. Consecutive wet days are falling for 11 districts of Himachal Pradesh. However, trend is statistically significant for 10 districts out of 11. This implies drought like situation for the State.
- **Threshold indices:** Heavy and very heavy precipitation days (R10mm and R20mm) show negative trend, i.e., they are falling for all the districts of Himachal Pradesh; however the decrease is statistically significant for 9 districts for R10mm and only 3 districts for R20mm.
- **Other indices:** Precipitation show negative trend, i.e., they are declining for all 12 districts; however the trend is statistically significant for 7 districts over the period 1951-2013. Average precipitation on wet days (Simple Daily Intensity Index) also show negative trend for majority of the districts (10 districts). However SDII show significant negative trend for only 2 districts namely, Kinnaur and Sirmaur. Thus it’s implied that annual rainfall and its intensity have decreased over the period for the districts of Himachal Pradesh.

Summary of Observed Climate Data

Summary of observed temperature and rainfall for Himachal Pradesh (1951-2013):

Observed Maximum and Minimum Temperature

- IMD gridded daily temperature data from 1951-2013 (63 years) has been used for the analysis. Mean annual maximum temperature Himachal Pradesh is 25.9°C with a range varying from 24.5°C – 27.1°C. The highest value attained for maximum temperature (30.7°C) is in the monsoon season (JJAS) while its lowest maximum value (16.9°C) is attained in winter season.
- Mean annual minimum temperature is 13.4°C with a range varying from 12.5°C – 14.5°C. Minimum temperature attains its mean highest value (20.6°C) during the monsoon season (JJAS), while it attains its mean lowest value (4.7°C) in winter season.

- For annual maximum temperature the highest value is attained for districts namely, Una, Solan, Hamirpur and Bilaspur lying in the Sub mountain & low hills sub-tropical zone while the lowest value is attained for districts namely, Lahul & Spiti and Kinnaur lying in Very high hills temperate dry zone of Himachal Pradesh for the period 1951-2013 (63 years).
- For annual minimum temperature the highest value is attained for districts Una and Solan while the lowest value is attained for districts Lahul & Spiti and Chamba.
- There is not much temporal variation observed across the districts of Himachal Pradesh in maximum and minimum temperature as is evident from the mean maximum and minimum temperature and very low CV values. However, variability in minimum temperature is higher than that of the maximum temperature.
- Trend analysis shows that the positive trend for annual maximum temperature and minimum temperature are statistically not significant for Himachal Pradesh State.

Observed Precipitation

- Average annual rainfall of Himachal Pradesh is 1284.2 mm with a range varying from 704.7 mm-2062.8 mm over the 63 years period (1951-2013). Amongst all districts, Kangra and Chamba in the North West receive the maximum average annual rainfall while district Kinnaur in the East receive the least.
- The monsoon (June, July, August and September) rainfall contributes the maximum to annual rainfall amounting to approximately 66% for Himachal Pradesh State. Contribution of Pre-monsoon (March, April and May) rainfall on average is 15%, contribution of post- monsoon (October, November and December) rainfall in annual rainfall is about 6.7% and winter rainfall (January, February) contribution is 12.1%.
- For the period 1951-2013, annual rainfall and rainy days shows negative trend which is statistically significant for Himachal Pradesh State.
- Out of 63 years rainfall analysis Himachal Pradesh on average had 46 normal rainfall years, 8 years had excess rainfall and 9 years had deficit rainfall. Sirmaur district receives the maximum number of 17 years of excess rainfall while Chamba and Kinnaur districts have maximum of 18 deficient years of rainfall as compared to the other districts of Himachal Pradesh over the period 1951-2013. Kullu and Shimla districts have maximum of 42 years of normal rainfall.
- The maximum (232.2 mm) and minimum (55.5 mm) annual one day maximum rainfall for Himachal Pradesh State has been recorded on 1958, 21st December and 1972, 24th August respectively.
- 1 day maximum rainfall shows negative trend for the State over the period 1951-2013. However, the negative trend is statistically not significant.
- August month received the highest amount of one day maximum rainfall (29%) followed by July (27%), September (16%) and June 6%. Thus about 78% of 1 day maximum rainfall is received in JJAS (monsoon) months in the period of analysis (1951-2013).
- Annual average number of rainy days (when daily rain >=2.5 mm) for period 1951-2013 in Himachal Pradesh State is 101 days and varies from 74 days to 125 days. Light to rather heavy rainfall (2.5 ≤

R ≤ 64.4) events is 100 on average and ranges from 74 to 124 days. Similarly, days when there are heavy rainfall (64.4 < R ≤ 124.4 mm) events is 1 on average and ranges from 0 to 3 days, and very heavy to extremely heavy rainfall (R> 124.4 mm) days is negligible.

- Over the 63 years period districts namely, Chamba and Kangra have the maximum number of total rainy days while Kinnaur has the least number of total rainy days.

Climate Extremes Indices using observed Climate

Temperature Extremes Indices:

- **Absolute indices:** Maximum of day time temperature (TXx) and Minimum of day time temperature (TXn) show mixed non significant trends for the districts of Himachal Pradesh. Maximum of night time temperature (TNx) show negative trends for all the districts while minimum of night time temperature (TNn) show positive trends for all the districts. However, trend is statistically non significant.
- **Percentile indices:** Cool nights (TN10P) show negative trend while warm nights (TN90P) show positive trend for all the 12 districts.
- **Duration indices:** Warm spell duration indicator (WSDI) shows negative non significant trend for most of the districts. Cold spell duration indicator (CSDI) also shows negative trend for all the districts, however the negative trend is statistically significant for only 2 districts.

Precipitation Extremes Indices:

- **Absolute indices:** Maximum 1 day precipitation show mixed trend while maximum 5 day precipitation show negative trend for all the districts.
- **Percentile indices:** Very wet day precipitation (R95p) and extremely wet day precipitation (R99p) show mixed trend for the districts. However, mixed trend is statistically not significant.
- **Duration indices:** Consecutive dry days positive trend which is statistically not significant. Consecutive wet days show negative statistically significant trend for 10 districts.
- **Threshold indices:** Heavy and very heavy precipitation days (R10mm and R20mm) show negative trend.

IPCC AR5 Climate Change Scenarios-Himachal Pradesh

The CORDEX South Asia modelled climate data on precipitation, maximum temperature, minimum temperature and 21 climate extremes indices have been analysed for Himachal Pradesh State and its 20 districts for baseline (BL, 1981-2010), mid-century (MC, 2021-2050) and end-century (EC, 2071-2100). Projected change in climate for precipitation, maximum temperature and minimum temperature has been assessed while trend analysis has been done on the climate extremes indices for the study area. Trend tests are run at 10% level of significance to indicate the presence of statistical significant trends over the period of analysis. Resolution of the projected climate data is at a grid-spacing of 0.5°x0.5° for IPCC AR5 scenarios, namely, RCP8.5 (a scenario of comparatively high greenhouse gas emissions and does not include climate policy interventions) and RCP4.5 (moderate emission scenario and assume climate policy intervention to transform associated reference scenarios). Ensemble mean of 3 regional climate models (RCM), namely, REMO (from MPI), RCA4 (from SMHI) and CCAM (from CSIRO) has been used for the analysis. Ensemble mean is chosen to reduce model related uncertainties and ensemble mean climate is closer to observed climate than any individual model.

Representative Concentration Pathways (RCPs)

The IPCC scenarios provide a mechanism to assess the potential impacts on climate change. Global emission scenarios were first developed by the IPCC in 1992 and were used in global general circulation models (GCMs) to provide estimates for the full suite of greenhouse gases and their potential impacts on climate change. Since then, there has been greater understanding of possible future greenhouse gas emissions and climate change as well as considerable improvements in the general circulation models. The IPCC, therefore, developed a new set of emissions scenarios. The process by which these new scenarios are being produced differs from earlier scenario development.

The new process aims to both shorten the time required to develop and apply new scenarios, and to ensure better integration between socio-economic driving forces, changes in the climate system, and the vulnerability of natural and human systems. Rather than starting with socio-economic scenarios that give rise to alternative greenhouse gas emissions, the new scenarios take alternative futures in global greenhouse gas and aerosol concentrations as their starting point. These are called Representative Concentration Pathways (RCPs)[24]. The Representative Concentration Pathways (RCP) are based on selected scenarios from four modelling teams/models working on integrated assessment modelling, climate modelling, and modelling and analysis of impacts.

RCPs are four greenhouse gas trajectories adopted by the IPCC for its fifth Assessment Report (AR5). The four RCPs; RCP2.6, RCP4.5, RCP6, and RCP8.5, are named after a possible range of radioactive forcing values in the year 2100. Table 8 gives the overview of four RCPs.

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[24] http://sedac.ipcc-data.org/ddc/ar5_scenario_process/index.html

Table 8 : Overview of Representative Concentration Pathways (RCPs) adopted by IPCC AR5.

RCP	Description	IA Model	Publication – IA Model
RCP8.5	Rising radioactive forcing pathway leading to 8.5 W/m2 in 2100.	MESSAGE	Riahi et al. (2007), Rao&Riahi (2006)
RCP6	Stabilization without overshoot pathway to 6 W/m2 at stabilization after 2100	AIM	Fujino et al. (2006), Hijioka et al. (2008)
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m2 at stabilization after 2100	GCAM (MiniCAM)	Smith and Wigley (2006), Clarke et al. (2007), Wise et al. (2009)
RCP2.6	Peak in radiative forcing at ~ 3 W/m2 before 2100 and decline	IMAGE	van Vuuren et al. (2006; 2007)

Source: http://sedac.ipcc-data.org/ddc/ar5_scenario_process/RCPs.html

In contrast to the IPCC AR4 SRES scenarios, RCPs represent pathways of radioactive forcing and not detailed socioeconomic narratives or scenarios. Central to the process is the concept that any single radiative forcing pathway can result from a diverse range of socioeconomic and technological development scenarios. There are four RCP scenarios: RCP2.6, RCP4.5, RCP6.0 and RCP8.5 – these scenarios are formulated such that they represent the full range of stabilization, mitigation and baseline emission scenarios available in the literature (Hibbard et al., 2011[25]). The naming convention reflects socio-economic pathways that reach a specific radioactive forcing by the year 2100. For example RCP8.5 leads to a radiative forcing of 8.5 Wm-2 by 2100.

Coordinated Regional climate Downscaling Experiment (CORDEX) is a WCRP-sponsored program to organize an international coordinated framework to produce an improved generation of regional climate change projections world-wide for input into impact and adaptation studies within the AR5 timeline and beyond. CORDEX produces an ensemble of multiple dynamical and statistical downscaling models considering multiple forcing GCMs from the CMIP5 archive, for the newly developed Representative Concentration Pathways (RCPs). Initially 50 km grid spacing has been selected, favouring engagement of wider community.

Analysis of the Climate Change Scenarios

The CORDEX South Asia climate data on precipitation, maximum and minimum temperature have been analysed for Himachal Pradesh and its districts for baseline (1981-2010), mid-century (2021-2050) and end-century (2071-2100) for IPCC AR5 climate scenarios- RCP4.5 (moderate emission scenario) and RCP8.5 (a scenario of comparatively high greenhouse gas emissions) using multi model ensemble of the three RCMs ((REMO (from MPI), RCA4 (from SMHI) and CCAM (from CSIRO)).

The CORDEX South Asia simulations with the models indicate an all-round warming over the study area. Projected temperature increase towards EC is higher than that of MC. For IPCC AR5 RCP4.5 and RCP8.5 scenario, minimum temperature show higher projected increase than the maximum temperature towards MC and EC for Himachal Pradesh. However, IPCC AR5 RCP8.5 scenario shows higher increase than that of IPCC AR5 RCP4.5 scenario.

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[25] Hibbard, K. A., Van Vurren, D. P. and Edmonds, J., A primer on the representative concentration pathways (RCPs) and the coordination between the climate and integrated assessment modeling communities .CLIVAR Exchanges, 2011, 16, 12-15

Brief on RCM (Regional Climate Model)

CSIRO CCAM

CSIRO (Commonwealth Scientific and Industrial Research Organisation) CCAM (Cubic Conformal Atmospheric Model 805) RCM (Regional Climate Model) from CSIRO Marine and Atmospheric Research, Melbourne, Australia is a dynamically downscaled model from the GFDLSST reanalysis Climate Model output to 50 km resolution.

Rossby Centre Regional Atmospheric Model, RCA4

Eight atmosphere-ocean general circulation models (AOGCMs) from the fifth phase of the Coupled Model Intercomparison Project (CMIP5) were downscaled over the Asia-CORDEX domain (Jones et al. 2011[26]) at the Rossby Centre (SMHI), Sweden by a regional climate model, RCA4.

From individual simulations in terms of precipitation, RCA4 is not very sensitive to the driving GCMs and simulates similar precipitation climatology when driven by different GCMs. At the same time the driving GCMs produce very disperse precipitation climatology with a large spread across the GCMs which is substantially reduced by RCA4.

Similar evaluation for near-surface temperature shows good simulation of near-surface temperature. Downscaling of the individual GCMs, on average, shows a large-scale cold bias that is also reflected in the ensemble mean

REMO (MPI-CSC, Hamburg, Germany)

REMO (CSC, Hamburg, Germany) – regional model (50km) driven by a global model - MPI-ESM-LR, 1951-2100 projected future climate changes in temperature are similar between regional and global ensembles. List of CORDEX models and their details are given in Table 9.

Table 9 : List of CORDEX models

Asia CORDEX RCMs	RCM	GCM Boundary Condition	Institute	Scenario	Resolution	Daily time period
CCAM Ensemble (Mean)						
ACCESS1-0_CSIRO-CCAM-1391M	CCAM	ACCESS1-0	CSIRO	RCP45, RCP85	0.5X0.5	1970-2099
CNRM-CM5_CSIRO-CCAM-1391M	CCAM	CNRM	CSIRO	RCP45, RCP85	0.5X0.5	1970-2099
MPI-ESM-LR_CSIRO-CCAM-1391M	CCAM	MPI-ESM-LR	CSIRO	RCP45, RCP85	0.5X0.5	1970-2099
SMHI-RCA4 Ensemble (Mean)						
CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	SMHI-RCA4	CNRM	SMHI	RCP45, RCP85	0.5X0.5	1951-2100
NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	SMHI-RCA4	GFDL	SMHI	RCP45, RCP85	0.5X0.5	1951-2100
ICHEC-EC-EARTH_SMHI-RCA4	SMHI-RCA4	IHEC-EC	SMHI	RCP45, RCP85	0.5X0.5	1951-2100

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[26] Jones C, Giorgi F, Asrar G (2011) The coordinated regional downscaling experiment: CORDEX. an international downscaling link to CMIP5. CLIVAR exchanges 16:34-40

IPSL-CM5A-MR_SMHI-RCA4	SMHI-RCA4	IPSL-CM5A	SMHI	RCP45, RCP85	0.5X0.5	1951-2100
MIROC-MIROC5_SMHI-RCA4	SMHI-RCA4	MIRCO	SMHI	RCP45, RCP85	0.5X0.5	1951-2100
MPI-M-MPI-ESM-LR_SMHI-RCA4	SMHI-RCA4	MPI-M	SMHI	RCP45, RCP85	0.5X0.5	1951-2100
REMO2009						
MPI-M-MPI-ESM-LR_MPI-CSC-REMO2009	REMO 2009	MPI-M	MPI-CSC	RCP45, RCP85	0.5X0.5	1961-2100

Ensemble mean has been derived using 10 RCM model runs with multiple driving GCMs and the same has been used for further analysis.

Temperature Projections for Himachal Pradesh

Analysis of Projected Maximum Temperature

Ensemble mean of the CORDEX South Asia climate data for IPCC AR5 RCP4.5 and RCP8.5 scenarios for Himachal Pradesh State and its districts for the annual and seasonal maximum temperature has been analysed. The projected annual and seasonal maximum temperatures changes towards MC and EC with respect to BL for Himachal Pradesh and its districts for IPCC AR5 RCP4.5 and RCP8.5 scenarios are given in the Appendix I Table 10 and Table 11 respectively.

Figure 16 and Figure 17 show change in annual maximum temperature towards MC and EC with respect to BL for Himachal Pradesh State and its districts for IPCC AR5 RCP4.5 and RCP8.5 scenarios. Same has also been depicted as line graph Himachal Pradesh State and as bar graph for the districts. The seasonal changes for the State towards MC and EC with respect to BL are also shown for both IPCC AR5 RCP4.5 and RCP8.5 scenarios. The spatial representation of projected changes in annual and seasonal mean maximum temperature for Himachal Pradesh for IPCC AR5 RCP4.5 and RCP8.5 scenarios is shown in Figure 18 and Figure 19 respectively.

Summary of the projected change in maximum temperature for IPCC AR5 RCP4.5 and RCP8.5 scenarios is as follows:

- Average annual maximum temperature for IPCC AR5 RCP4.5 scenario is projected to increase by about 1.4°C towards mid-century and by 2.5°C towards end-century while for IPCC AR5 RCP8.5 scenario it is projected to increase by about 1.6°C towards mid-century and 5.0°C towards end-century for Himachal Pradesh State. Thus projected temperature increase in end-century is higher than that of mid-century.
- The projected increase in maximum temperature towards MC varies from 1.2°C in Una lying in Sub mountain & low hills sub-tropical zone to 1.7°C in Lahul & Spiti district lying in Very high hills temperate dry zone for IPCC AR5 RCP4.5 scenario and 1.4°C in Una to 2.0°C in Lahul & Spiti district of Himachal Pradesh for IPCC AR5 RCP8.5 scenario as shown in Figure 16 to Figure 19. It is observed that Northern districts show higher projected increase than the Southern districts of the State.
- The projected increase in maximum temperature towards EC varies from 2.1°C in Sirmaur to 3.3°C in Lahul & Spiti district for IPCC AR5 RCP4.5 scenario and 4.4°C in Una to 5.9°C in Lahul & Spiti district of Himachal Pradesh for IPCC AR5 RCP8.5 scenario as shown in Figure 16 and Figure 17.

- Highest maximum temperature increase is projected in winter season (JF) for IPCC AR5 RCP4.5 and RCP8.5 scenarios towards MC and EC for Himachal Pradesh State as compared to the other seasons (Figure 16 and Figure 17).
- For both IPCC AR5 RCP4.5 and RCP8.5 scenarios, increase in annual and seasonal maximum temperature is projected for Himachal Pradesh and its districts towards MC and EC. However, IPCC AR5 RCP8.5 scenario shows higher increase than that of IPCC AR5 RCP4.5 scenario.

Figure 16 : Characteristics of projected annual and seasonal maximum temperature for IPCC AR5 RCP4.5 scenario for Himachal Pradesh

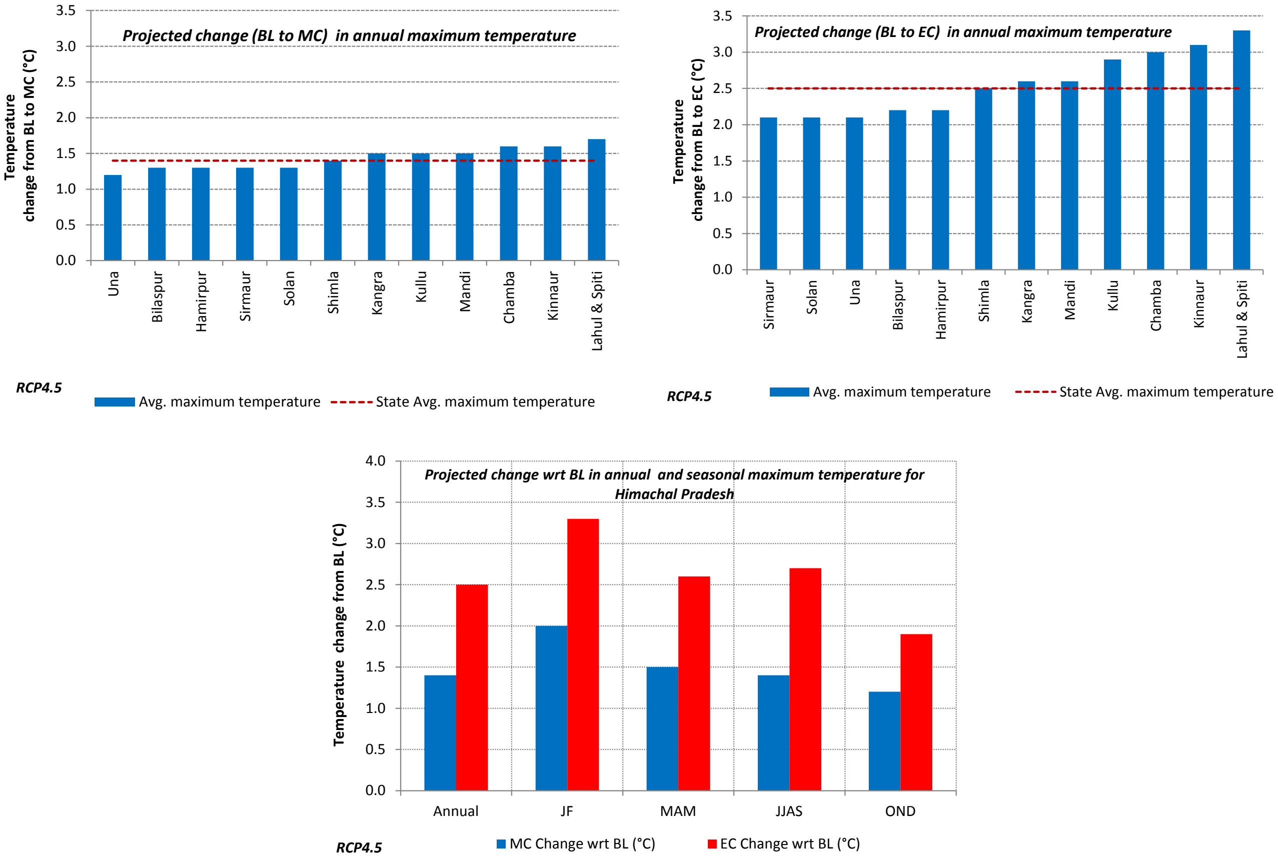
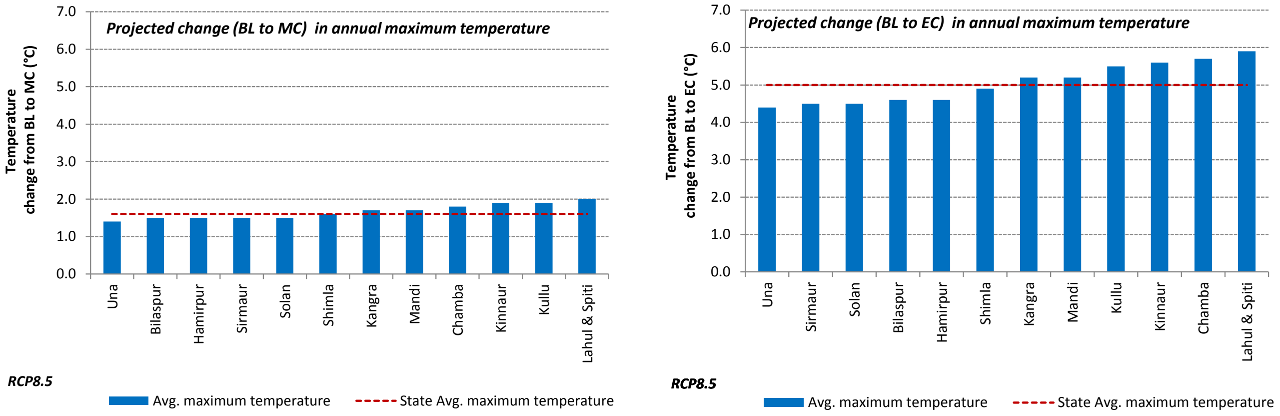
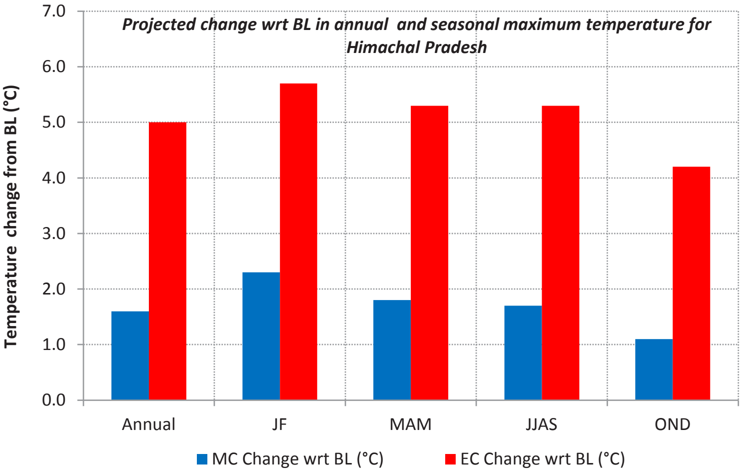


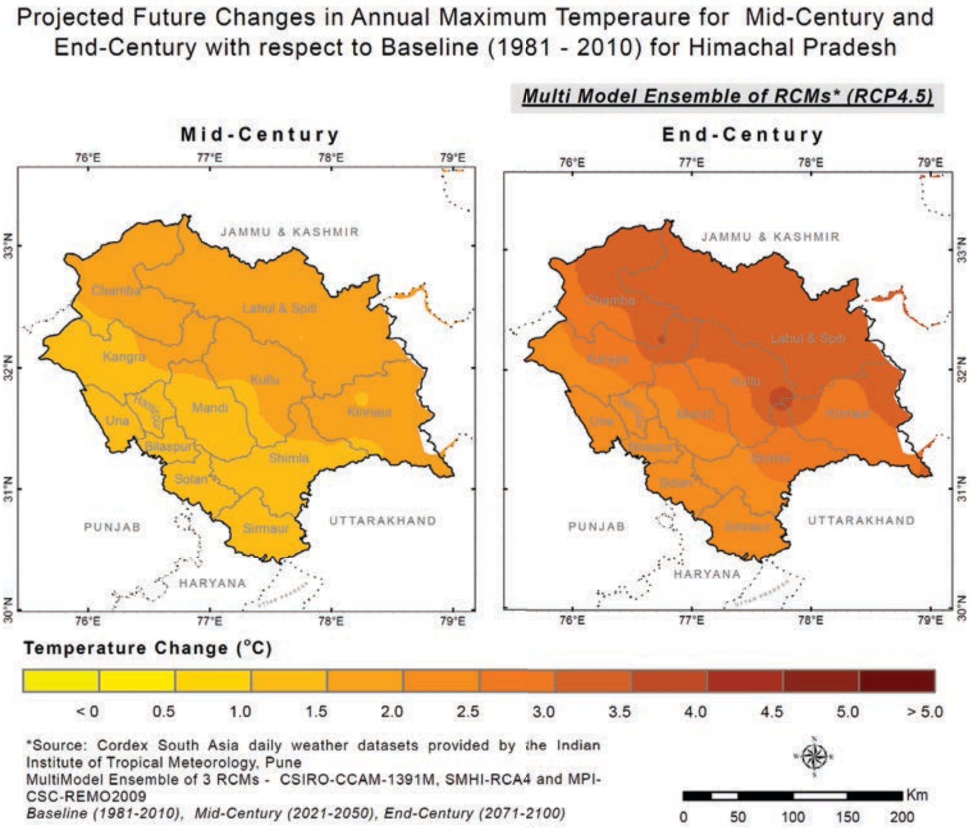
Figure 17 : Characteristics of projected annual and seasonal maximum temperature for IPCC AR5 RCP8.5 scenario for Himachal Pradesh



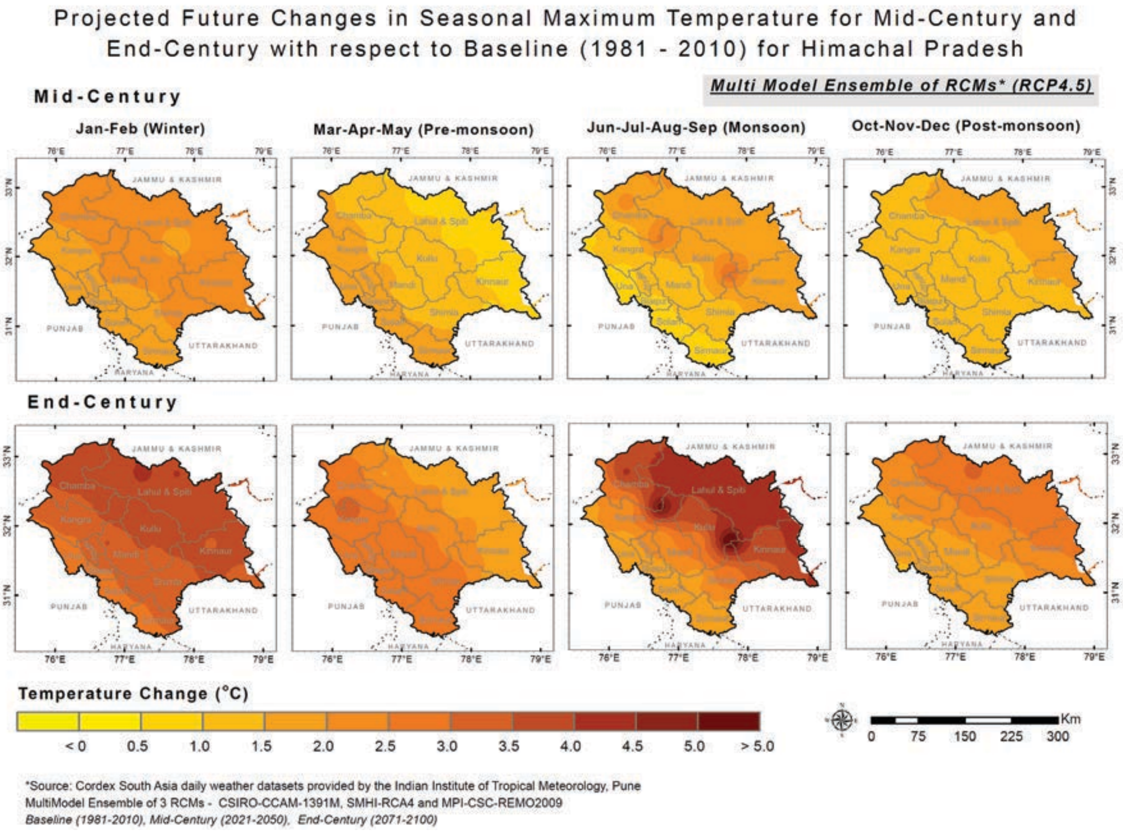


RCP8.5

Figure 18 : Spatial representation of projected changes in annual and seasonal maximum temperature for IPCC AR5 RCP4.5 scenario for Himachal Pradesh

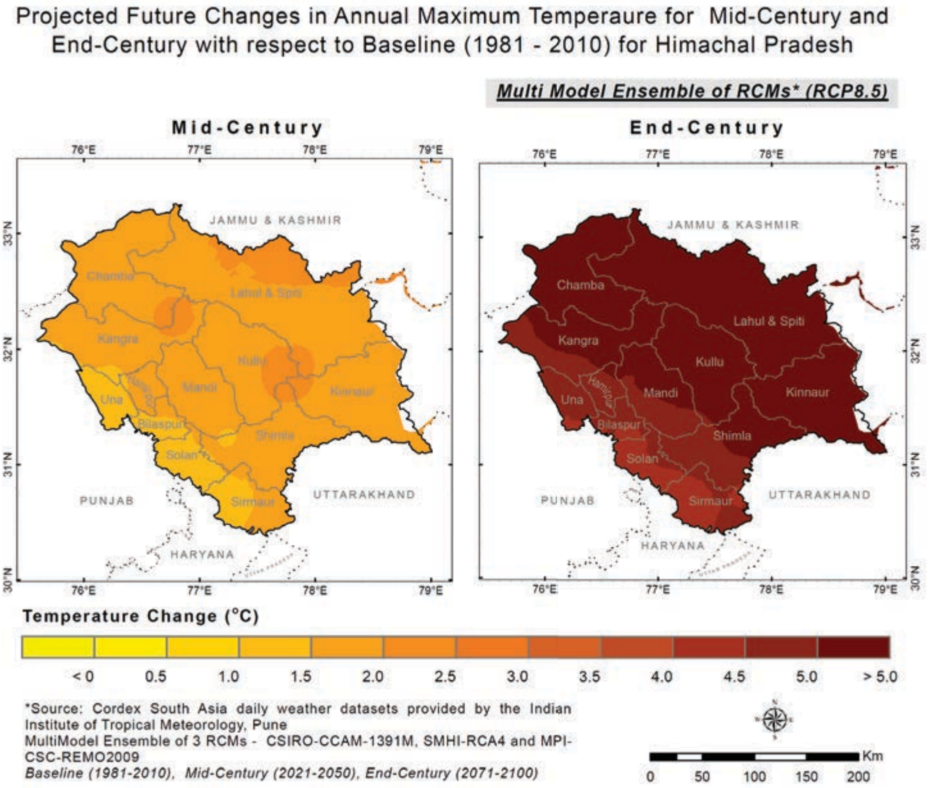


*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 3 RCMs - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

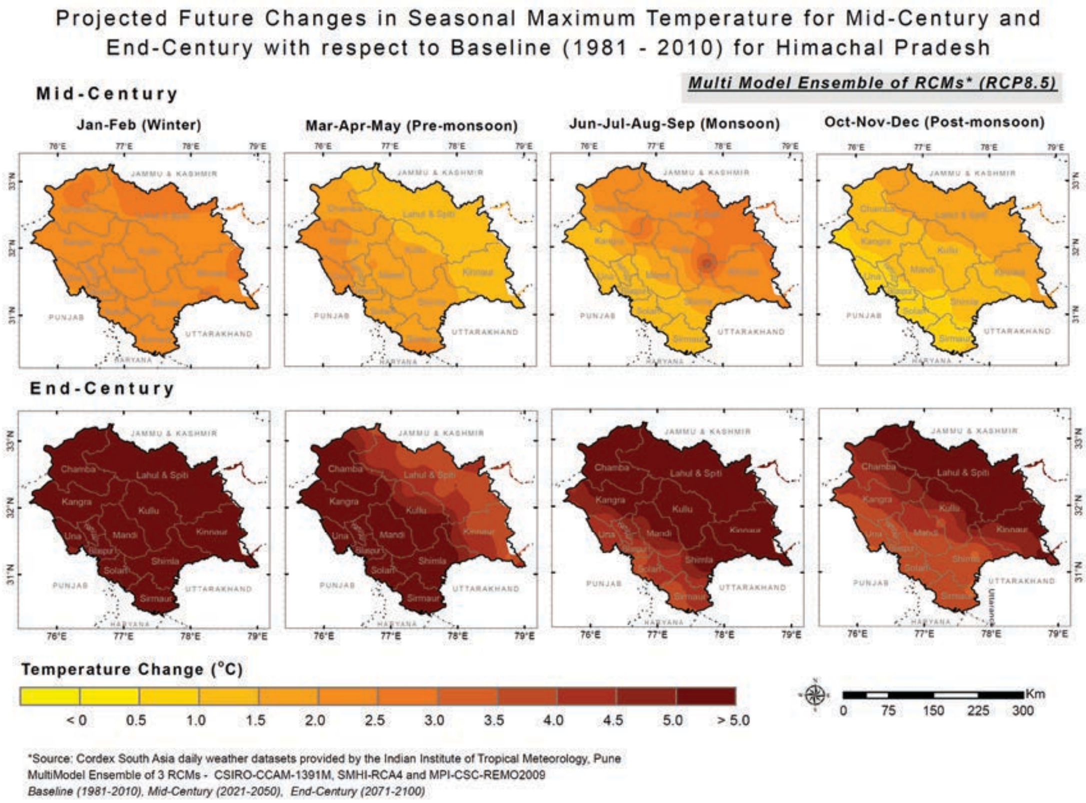


*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 3 RCMs - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Figure 19 : Spatial representation of projected changes in annual and seasonal maximum temperature for IPCC AR5 RCP8.5 scenario for Himachal Pradesh



*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 3 RCMs - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)



Projected Future Changes in Seasonal Maximum Temperature for Mid-Century and End-Century with respect to Baseline (1981 - 2010) for Himachal Pradesh

*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 3 RCMs - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Analysis of Projected Minimum Temperature

Ensemble mean of the CORDEX South Asia climate data for IPCC AR5 RCP4.5 and RCP8.5 scenarios for Himachal Pradesh State and its districts for the annual and seasonal minimum temperature has been analysed. The projected annual and seasonal minimum temperatures changes towards MC and EC with respect to BL for Himachal Pradesh and its districts for IPCC AR5 RCP4.5 and RCP8.5 scenarios are given in the Appendix I Table 12 and Table 13 respectively.

Figure 20 and Figure 21 show change in annual minimum temperature towards MC and EC with respect to BL for Himachal Pradesh State and its districts for IPCC AR5 RCP4.5 and RCP8.5 scenarios. Same has also been depicted as line graph for Himachal Pradesh State and as bar graph for the districts. The seasonal changes for the State towards MC and EC with respect to BL are also shown for both IPCC AR5 RCP4.5 and RCP8.5 scenarios. The spatial representation of projected changes in annual and seasonal mean minimum temperature for Himachal Pradesh for IPCC AR5 RCP4.5 and RCP8.5 scenarios is shown in Figure 22 and Figure 23 respectively.

Summary of the projected change in minimum temperature for Himachal Pradesh for IPCC AR5 RCP4.5 and RCP8.5 scenarios is as follows:

- Average annual minimum temperature for IPCC AR5 RCP4.5 scenario is projected to increase by about 1.4°C towards mid-century and by 2.7°C towards end-century while for IPCC AR5 RCP8.5 scenario it is projected to increase by about 1.8°C towards mid-century and 5.1°C towards end-century for Himachal Pradesh State. Thus projected temperature increase towards EC is higher than that of MC.

- The projected increase in minimum temperature towards MC varies from 1.3°C in Una to 1.7°C in Lahul & Spiti district for IPCC AR5 RCP4.5 scenario and 1.7°C in Bilaspur (Sub mountain & low hills sub-tropical zone) to 2.1°C in Lahul & Spiti district (Very high hills temperate dry zone) of Himachal Pradesh for IPCC AR5 RCP8.5 scenario as shown in Figure 20 to Figure 23.
- The projected increase in minimum temperature towards EC varies from 2.5°C in Una to 3.2°C in Lahul & Spiti district for IPCC AR5 RCP4.5 scenario and 4.8°C in Kullu to 5.6°C in Lahul & Spiti district of Himachal Pradesh for IPCC AR5 RCP8.5 scenario as shown in Figure 20 and Figure 21.
- Highest minimum temperature increase is projected in monsoon season (JJAS) for IPCC AR5 RCP4.5 scenario and RCP8.5 scenario for both MC and EC for Himachal Pradesh State as compared to the other seasons. (Figure 20 and Figure 21).
- For both IPCC AR5 RCP4.5 and RCP8.5 scenarios, increase in annual and seasonal minimum temperature is projected for Himachal Pradesh and its districts towards MC and EC. However, IPCC AR5 RCP8.5 scenario shows higher increase than that of IPCC AR5 RCP4.5 scenario.

Figure 20 : Characteristics of projected annual and seasonal minimum temperature for IPCC AR5 RCP4.5 scenario for Himachal Pradesh

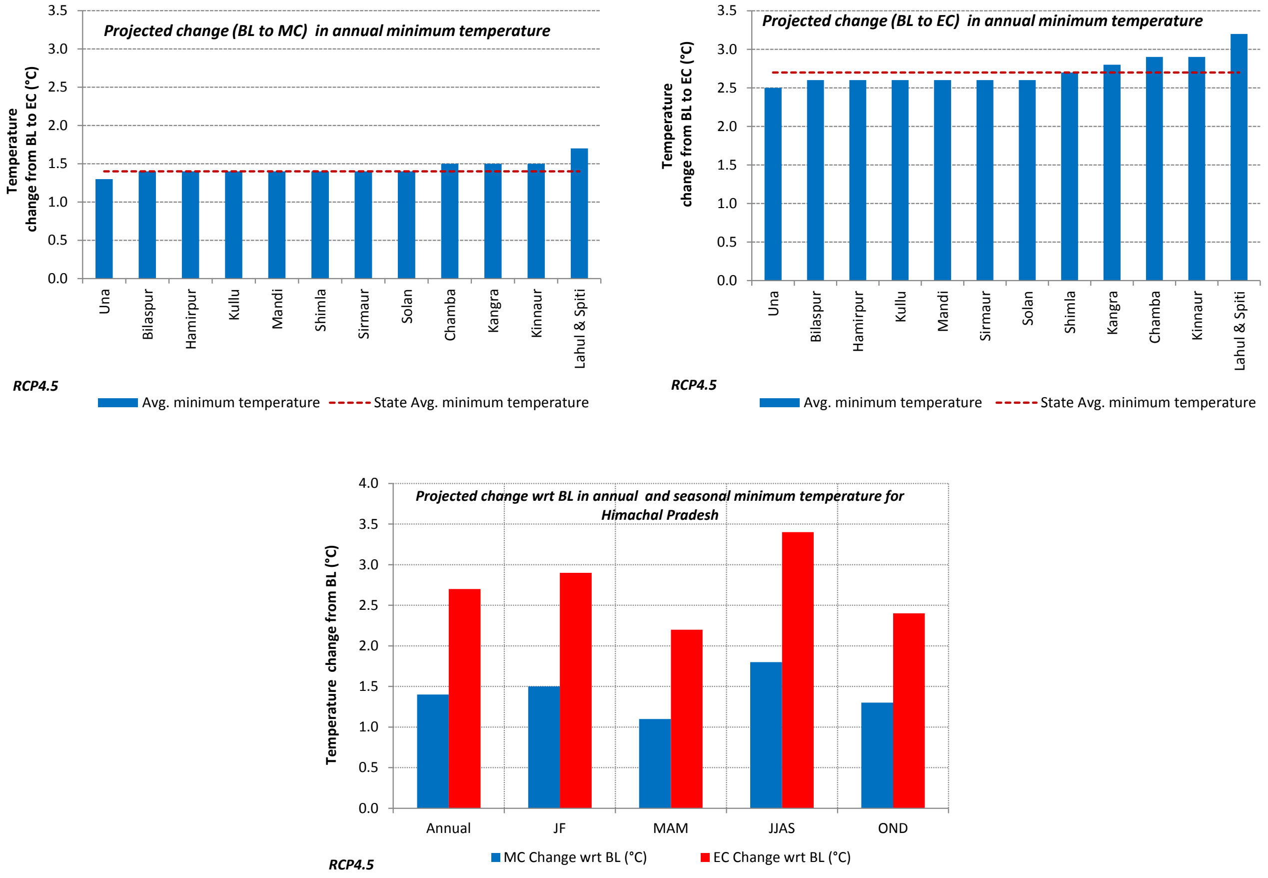


Figure 21 : Characteristics of projected annual and seasonal minimum temperature for IPCC AR5 RCP8.5 scenario for Himachal Pradesh

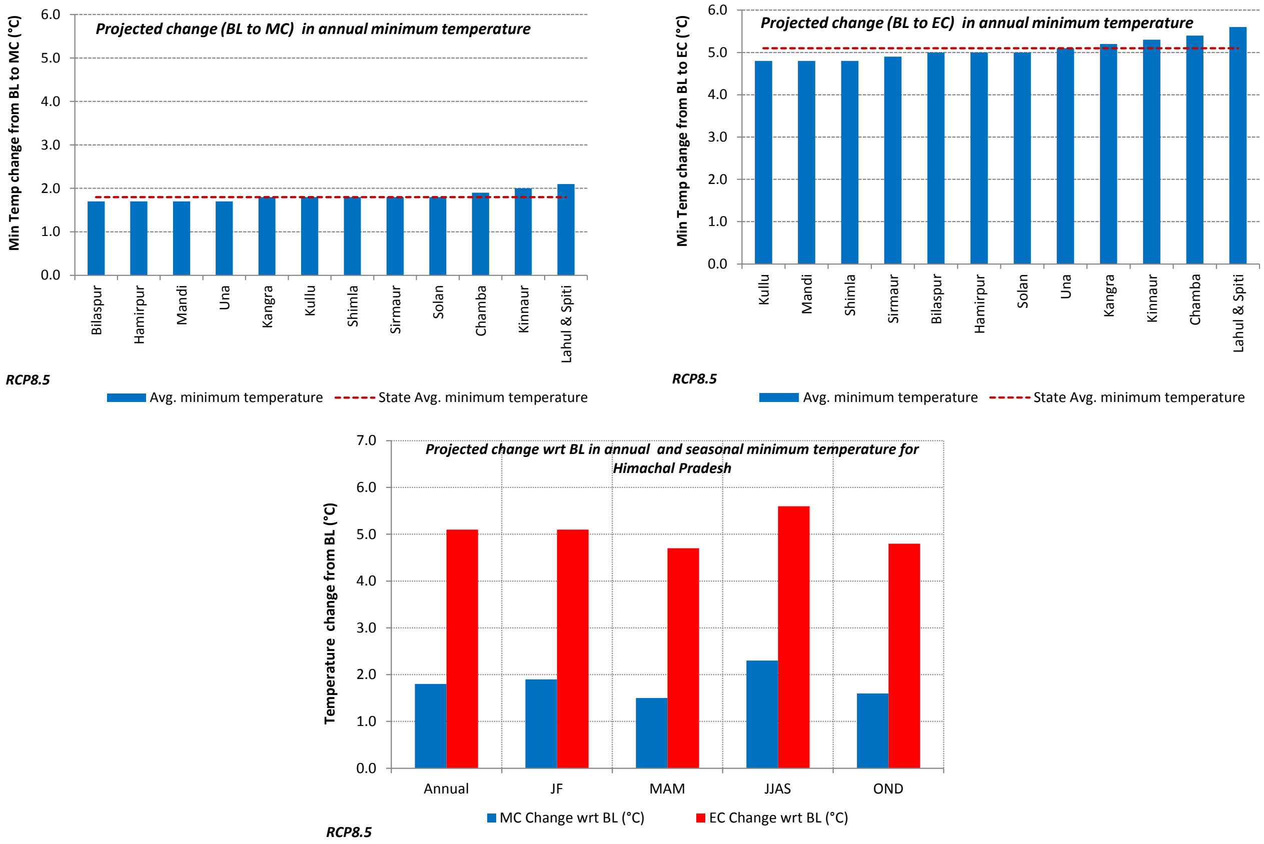
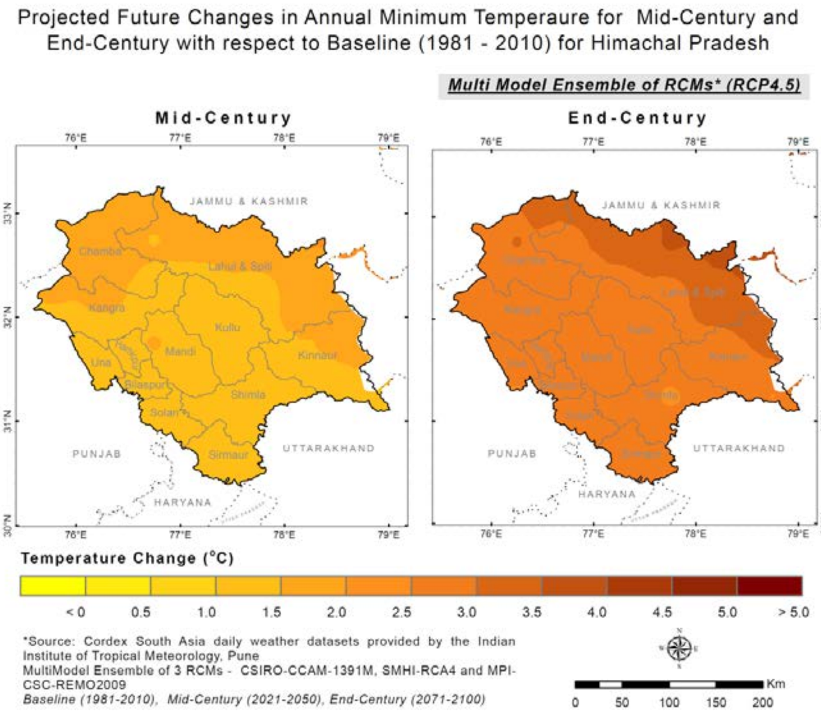
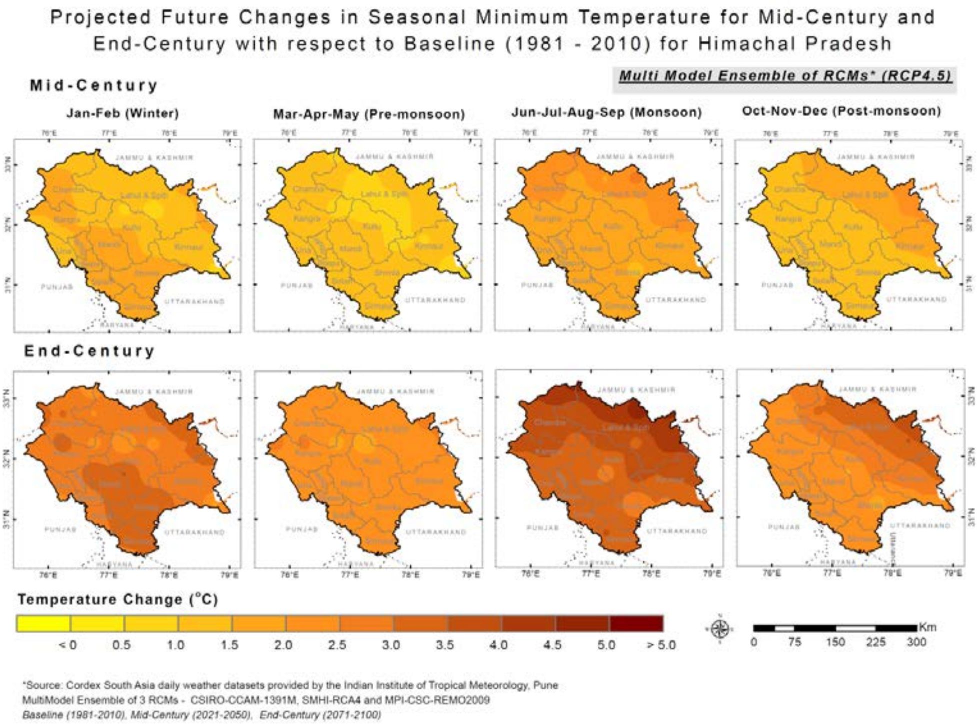


Figure 22 : Spatial representation of projected changes in annual and seasonal minimum temperature for IPCC AR5 RCP4.5 scenario for Himachal Pradesh

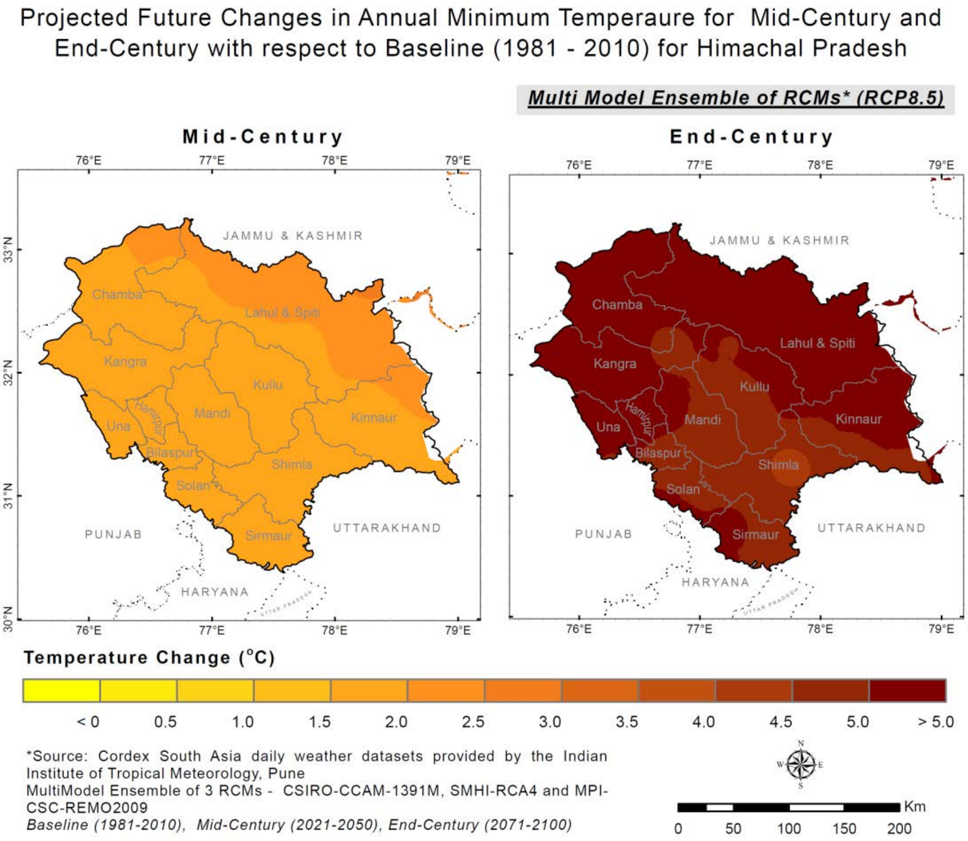

Projected Future Changes in Annual Minimum Temperaure for Mid-Century and End-Century with respect to Baseline (1981 - 2010) for Himachal Pradesh

*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 3 RCMs - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

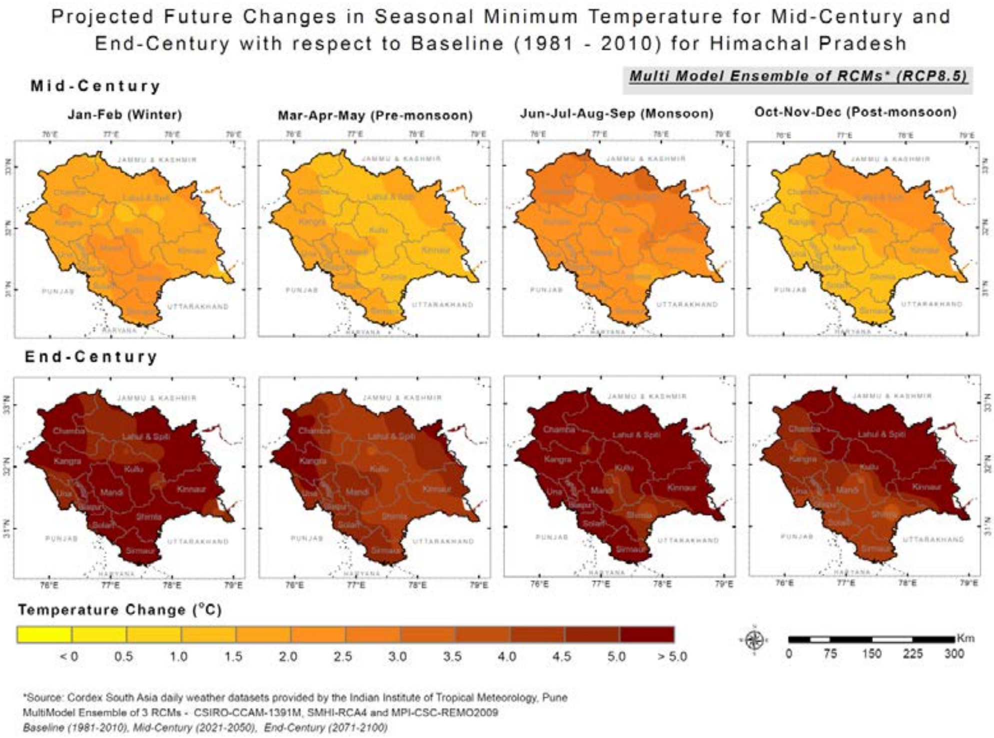

Projected Future Changes in Seasonal Minimum Temperature for Mid-Century and End-Century with respect to Baseline (1981 - 2010) for Himachal Pradesh

*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 3 RCMs - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Figure 23 : Spatial representation of projected changes in annual and seasonal minimum temperature for PCC AR5 RCP8.5 scenario for Himachal Pradesh


Projected Future Changes in Annual Minimum Temperaure for Mid-Century and End-Century with respect to Baseline (1981 - 2010) for Himachal Pradesh

*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 3 RCMs - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)



Projected Future Changes in Seasonal Minimum Temperature for Mid-Century and End-Century with respect to Baseline (1981 - 2010) for Himachal Pradesh

*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 3 RCMs - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Precipitation Projections for Himachal Pradesh

Analysis of Projected Precipitation

Ensemble mean of the CORDEX South Asia climate data for IPCC AR5 RCP4.5 and RCP8.5 scenarios for Himachal Pradesh State and its districts for the annual precipitation has been analysed. The projected annual and seasonal precipitation changes towards MC and EC with respect to BL for Himachal Pradesh and its districts for IPCC AR5 RCP4.5 and RCP8.5 scenarios are given in the Appendix I Table 14 and Table 15 respectively.

Figure 24 and Figure 25 for RCP8.5 show percentage change in annual rainfall towards MC and EC with respect to BL for Himachal Pradesh State and its districts for IPCC AR5 RCP4.5 and RCP8.5 scenarios. Same has also been depicted as line graph for Himachal Pradesh State and as bar graph for the districts. The seasonal changes for the State towards MC and EC as compared to BL are also shown for both IPCC AR5 RCP4.5 and RCP8.5 scenarios. The spatial representation of projected changes in annual and seasonal precipitation for Himachal Pradesh for IPCC AR5 RCP4.5 and RCP8.5 scenarios is shown in Figure 26 and Figure 27 respectively.

Summary of the projected change in precipitation for Himachal Pradesh for IPCC AR5 RCP4.5 and RCP8.5 scenarios is as follows:

- Average annual rainfall for IPCC AR5 RCP4.5 scenario is projected to increase by 5.9% towards mid-century and increase by about 13.8% towards end-century while for IPCC AR5 RCP8.5 scenario it is projected to increase by about 14% towards mid-century and end-century for the State. Thus the percentage of the projected rainfall increase is low towards MC and EC for both the climate scenarios.
- Districts in the Very high hills temperate dry zone of Himachal Pradesh namely, Lahul & Spiti and Kinnaur show highest projected increase in rainfall towards MC while Shimla and Sirmaur districts

in the South show the highest projected increase in annual rainfall as compared to the other districts of Himachal Pradesh towards EC with respect to BL for IPCC AR5 RCP4.5 scenario. Kullu district in High hills temperate wet zone shows the lowest projected increase towards both MC and EC (Figure 24 and Figure 26).

- Districts in the Very high hills temperate dry zone of Himachal Pradesh namely, Lahul & Spiti and Kinnaur show the highest projected increase (about 16%) towards MC. Lahul & Spiti district shows the highest projected increase in annual rainfall (about 28%) towards EC with respect to BL for IPCC AR5 RCP8.5 scenario. Kullu and Chamba districts show the lowest projected increase towards both MC and EC (Figure 25 and Figure 27).
- In monsoon season (JJAS) highest rainfall increase is projected while in winter(JF) and pre-monsoon season (MAM) rainfall decrease is projected towards MC and EC as compared to BL for Himachal Pradesh State for IPCC AR5 RCP4.5 scenario (Figure 24 and Figure 26).
- In monsoon season (JJAS) and post monsoon season (OND) highest rainfall increase is projected while in winter(JF) and pre-monsoon season (MAM) rainfall decrease is projected towards MC and EC as compared to BL for Himachal Pradesh State for IPCC AR5 RCP8.5 scenario (Figure 25 and Figure 27).

Figure 24 : Characteristics of projected annual precipitation for IPCC AR5 RCP4.5 scenario for Himachal Pradesh

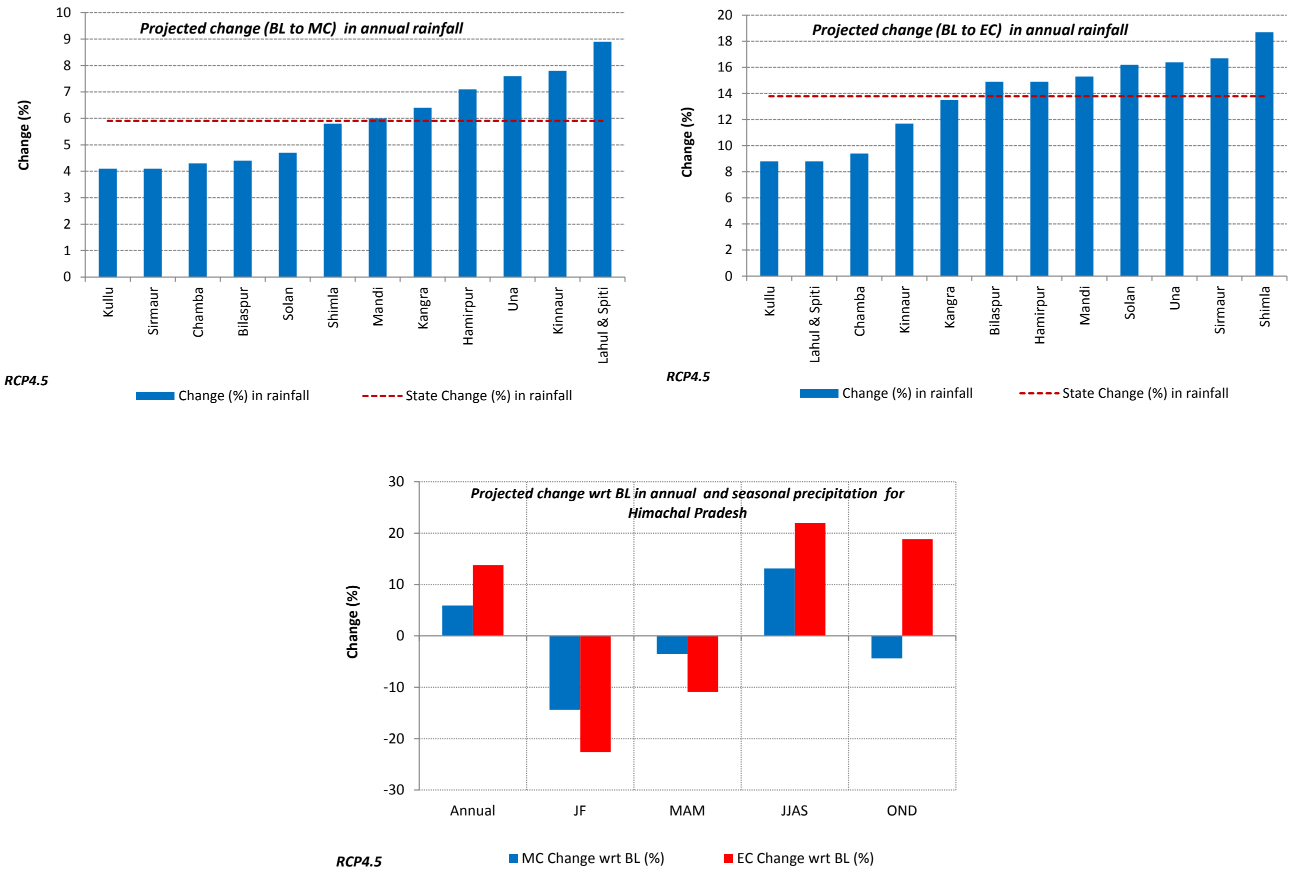


Figure 25 : Characteristics of projected annual precipitation for IPCC AR5 RCP8.5 scenario for Himachal Pradesh

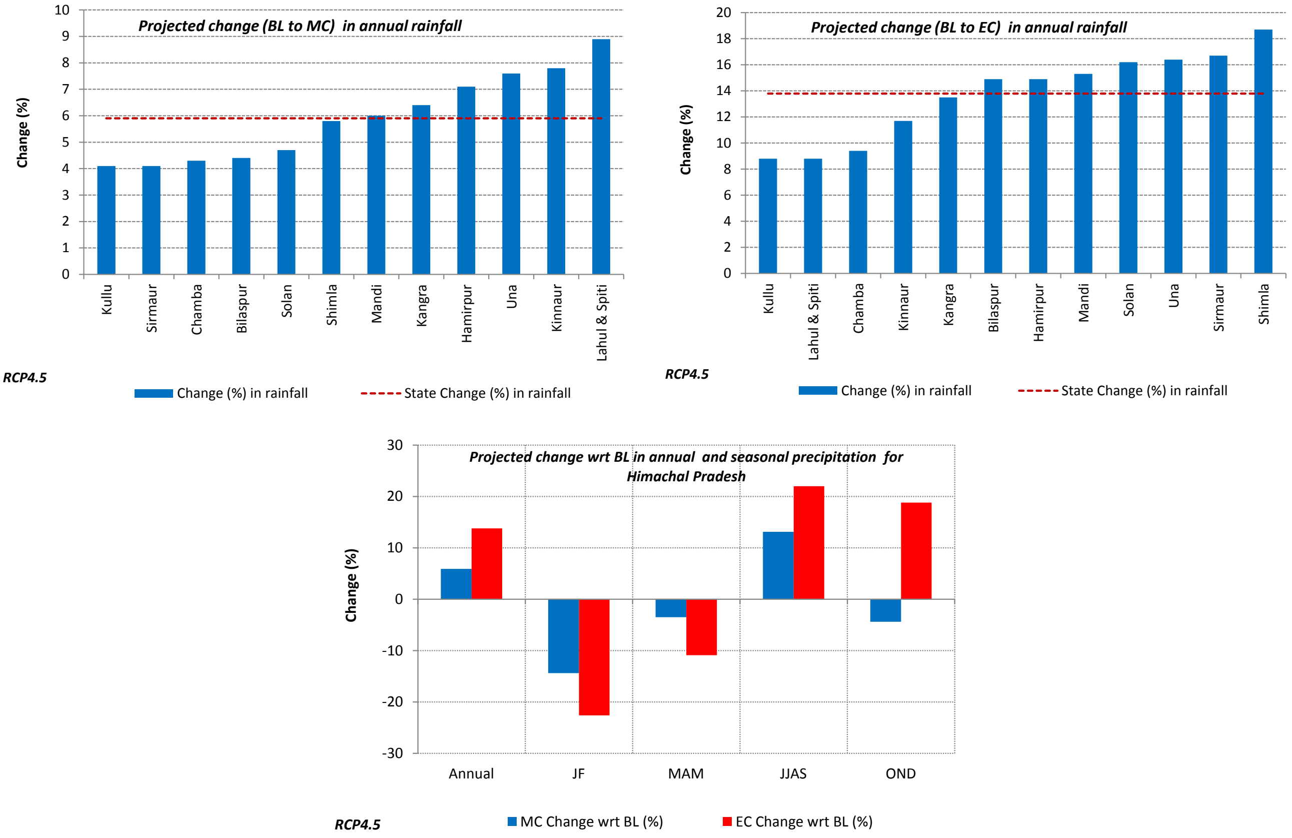
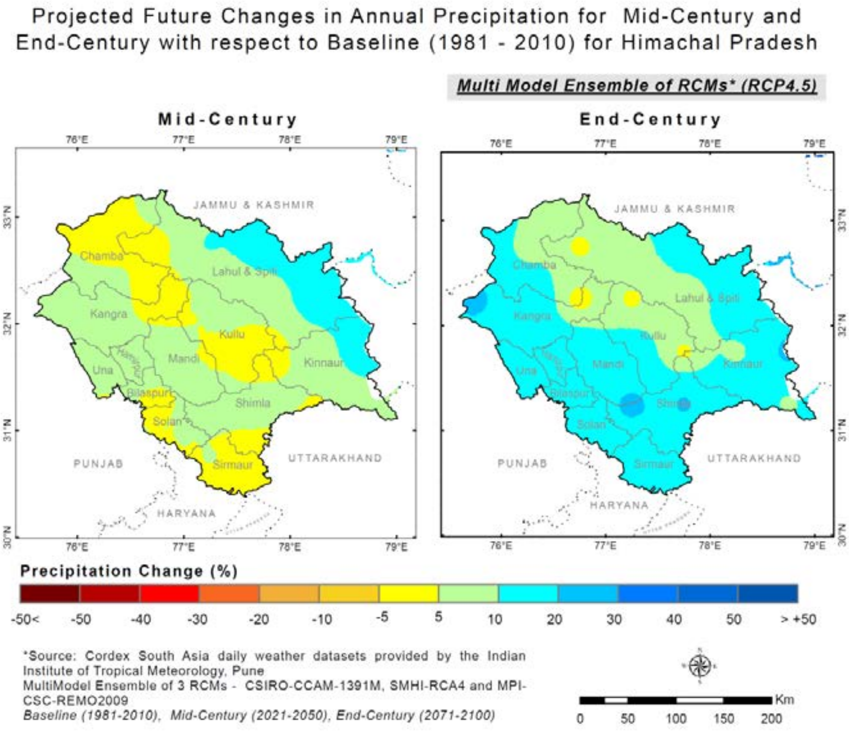


Figure 26 : Spatial representation of projected changes in annual and seasonal precipitation for IPCC AR5 RCP4.5 scenario for Himachal Pradesh



*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 3 RCMs - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

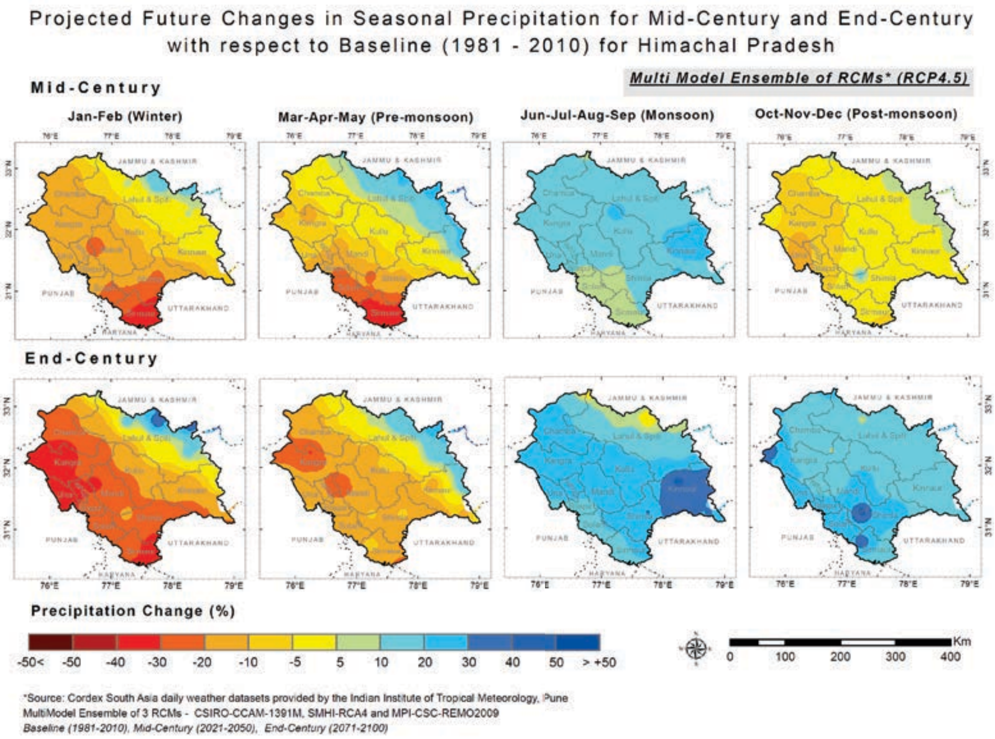
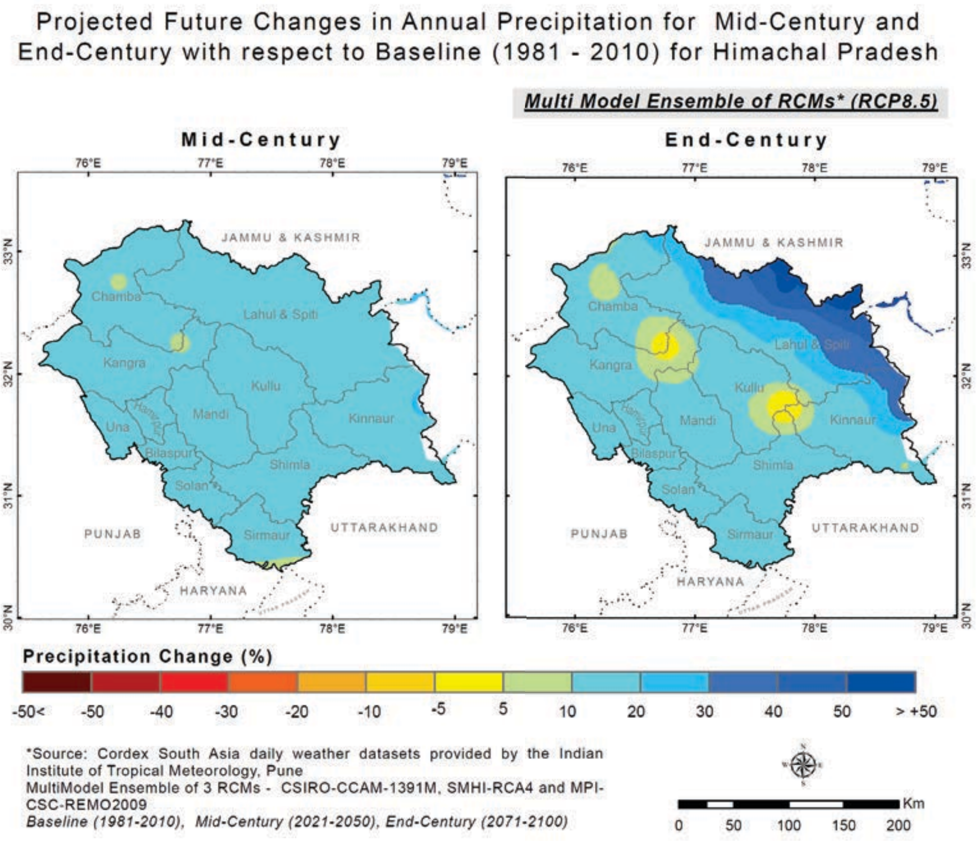
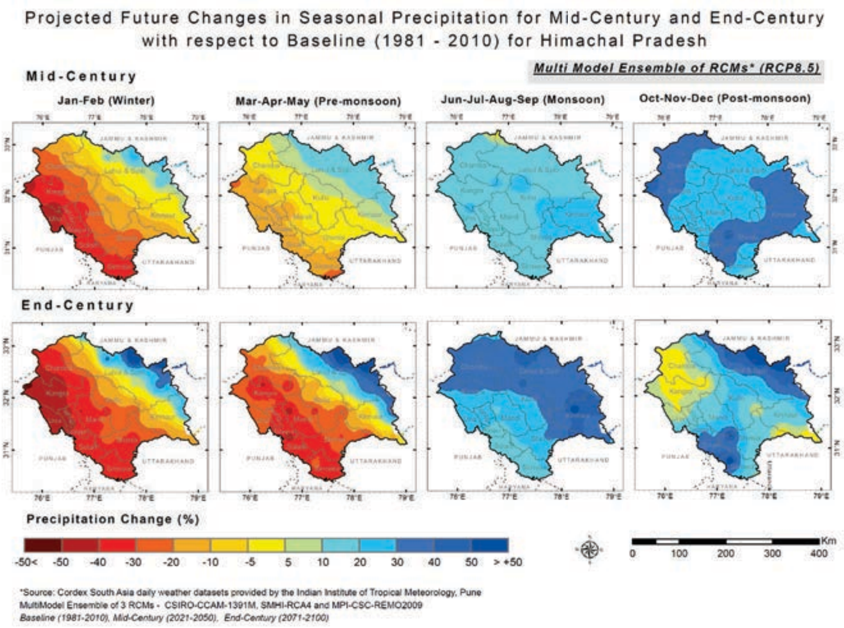


Figure 27 : Spatial representation of projected changes in annual and seasonal precipitation for IPCC AR5 RCP8.5 scenario for Himachal Pradesh





Projected Future Changes in Seasonal Precipitation for Mid-Century and End-Century with respect to Baseline (1981 - 2010) for Himachal Pradesh

*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 3 RCMs - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Projected Future Indices of Climate Extremes

The analysis of extreme weather indices presented in maps is based on individual gridded data while those in tables are based on district data. Each index is assessed based on consistency in direction of a trend as well as the significance of a trend across all districts.

Using the CORDEX South Asia modelled climate data, 21 climate extremes indices (11 temperature and 10 precipitation extremes indices) have been analysed for Himachal Pradesh districts for baseline (1981-2010), mid-century (2021-2050) and end-century (2071-2100). The annual value of the climate extremes indices have been used for the trend analysis. Trend analysis has been done on all the climate extremes indices for the study area for both IPCC AR5 RCP4.5 and RCP8.5 scenarios. Trend for a climate extremes index is run at 10% level of significance to indicate the presence of statistical significant trends for the districts of Himachal Pradesh over the three periods, i.e. only those districts climate data trend will be considered as statistically significant whose confidence level is greater than or equal to 90%. Finally, the temperature extremes indices trends for each district are shown in Table 16 (IPCC AR5 RCP4.5 scenario) and Table 17 (IPCC AR5 RCP8.5 scenario) while the estimated precipitation extreme indices trends for each district are shown in Table 18 (IPCC AR5 RCP4.5 scenario) and Table 19 (IPCC AR5 RCP8.5 scenario).

Grid wise trends of Himachal Pradesh are also mapped to describe spatial variation in trends in temperature and precipitation extreme indices as shown in Figure 28 to Figure 32. Each of BL, MC and EC trend have been run separately and represent the trend for that given period.

The change in climate extremes indices as 30 years average value towards MC (2021-2050) and EC (2071-2100) with respect to BL (1981-2010) has also been plotted as bar graphs and shown in the Appendix I. The temperature extremes indices graphs are shown in Figure 33-Figure 35 and the precipitation extremes indices graphs are shown in Figure 36-Figure 40.

Trend summaries for the Himachal Pradesh districts for IPCC AR5 RCP4.5 and RCP8.5 scenarios for the 11 temperature extremes indices for BL (1981-2010), MC (2021-2050) and EC (2071-2100) are given in the Appendix I as Table 16 and Table 17 and 10 precipitation extremes indices are given in the Appendix I as Table 18 and Table 19. The coloured boxes in the table represent the 30 years trend for the given period. Each of BL, MC and EC trend have been run separately and represent the trend for that given period for the Himachal Pradesh districts. The trend towards MC and EC does not show the change with respect to BL.

Temperature Extremes Indices

Most temperature extreme indices showed trends consistent with warming during the period of analysis. The temperature extremes indices graphs showing change towards MC and EC with respect to BL are shown in Figure 33 to Figure 35 in the Appendix I. The analysis from Table 16, Table 17, Figure 28 to Figure 30 for temperature extremes indices of Himachal Pradesh districts (BL, MC and EC) are summarized as follows:

- **Absolute indices:** Maximum of day time temperature (TXx), Maximum of night time temperature (TNx) and Minimum of day time temperature (TXn) and Minimum of night time temperature (TNn) show positive trends for the State and the districts in BL and MC for IPCC AR5 RCP4.5 scenario and BL, MC and EC for IPCC AR5 8.5 scenario implying increase in temperatures for these districts, thus warming up. However the positive trend is significant for some districts while for others it is non-significant as can be seen from Figure 28. These indices behave differently towards the EC for IPCC AR5 RCP4.5 scenario and show negative significant trend for TXn and TNn while positive non significant trends for TXx and TNx. However, towards EC, TXx and TNx start stabilizing for entire districts of the State for IPCC AR5 RCP8.5 scenario.

Absolute indices values towards MC and EC are increasing as compared to BL for both the climate scenarios, implying that the temperature is projected to increase for the districts of Himachal Pradesh resulting overall warming up (Figure 33).

- **Percentile indices:** For IPCC AR5 RCP4.5 scenario, cool nights (TN10P) and cool days (TX10P) show significant negative trend while warm nights (TN90P) and warm days (TX90P) show significant positive trend for the State and the districts. However towards EC cool days and cool nights, warm days and warm nights start stabilizing. Though the percentage of warm days and warm nights is projected to increase and percentage of cool days and cool nights is projected to decrease towards MC and EC as compared to BL for all the districts, the trend is not significant for these percentile indices towards EC (Figure 29 and Figure 34). Decrease (cool days and cool nights) / increase (warm days and warm nights) in frequency of these indices towards EC is higher than that of MC which implies higher warming towards EC than MC.

For IPCC AR5 RCP8.5 scenario, cool nights and cool days show significant negative trend for Himachal Pradesh State and the districts in BL and MC while warm nights and warm days show significant positive trend in BL, MC and EC. However, towards EC, cool nights and cool days phenomena does not occur (exceeds the threshold) for majority of the districts of the State for IPCC AR5 RCP8.5 scenario (Figure 29).

- **Duration indices:** Cold spell duration indicator (CSDI) in BL show negative trend for all the districts of the State with trend being statistically significant for 6 districts. However towards MC and EC, CSDI phenomena do not occur (value exceeds the threshold) for all the districts of the State for both the IPCC AR5 climate scenarios. Warm spell duration Indicator (WSDI) shows significant positive trend in BL, MC and EC for the State and majority of its districts for both IPCC AR5 RCP4.5 and RCP8.5 scenarios. However towards EC, IPCC AR5 RCP4.5 scenario WSDI starts stabilizing and the projected WSDI trend for the districts is mixed (positive/negative) but not significant (Figure 30).

From Figure 35 it can be seen that cold spell duration indicator is projected to decrease and warm spell duration indicator is projected to increase for all the districts towards MC and EC compared to BL implying warming up over Himachal Pradesh districts.

Precipitation Extreme Indices

Rainfall and intensity of rainfall are projected to increase towards MC and EC for Himachal Pradesh region. The scenario towards MC and EC is projected to change as compared to BL scenario. The precipitation extremes indices graphs showing change towards MC and EC with respect to BL average values are shown in Figure 36 to Figure 40 in the Appendix I. The results from Table 18, Table 19 and Figure 31 and Figure 32 for precipitation extreme indices of Himachal Pradesh districts (BL, MC and EC) are summarized as follows:

- **Absolute indices:** For IPCC AR5 RCP4.5 scenario, 1 day maximum precipitation and 5 day maximum precipitation show positive trend though not significant for most of the districts of Himachal Pradesh in the baseline. Towards MC, they are projected to show positive trend while towards EC negative trend for most of the districts of the State; however, the trend is statistically not significant as shown in Figure 31. For IPCC AR5 RCP8.5 scenario, towards MC most of the districts are projected to show positive trend; however, the trend is statistically not significant. However, towards EC no consistency in trend is projected for these indices; for some districts the trend is positive while for others it’s negative.

However, 1 day maximum precipitation and 5 day maximum precipitation are projected to increase for majority of the districts towards MC and EC compared to BL implying that rainfall intensity would increase in the future for the districts. Towards EC increase is projected to be the highest for districts namely Kullu and Lahul & Spiti as compared to the baseline for RCP8.5 climate scenario (Figure 36).

- **Percentile indices:** For IPCC AR5 RCP4.5 and RCP 8.5 scenarios, very wet days precipitation (R95p) and extremely wet days precipitation (R99p) have projected positive trend for majority of the districts towards MC which is also statistically not significant. However, towards EC these indices are projected to show negative trend though not significant for majority of the districts.

Very wet days precipitation and extremely wet days precipitation are projected to increase towards MC and EC compared to BL for all the 12 districts for both the IPCC AR5 climate scenarios implying that rainfall intensity would increase in the future for the districts (Figure 37).

- **Duration indices:** For IPCC AR5 RCP4.5 and 8.5 scenarios, consecutive dry days (CDD) and consecutive wet days (CWD) have projected mixed trend for MC and EC which is also statistically not significant. However, towards MC RCP 8.5 scenario, consecutive wet days show positive trend for majority of the districts with trend being statistically significant for 8 districts (Figure 32).

Consecutive dry days and consecutive wet days are projected to increase for majority of the districts towards MC and EC as compared to BL, for both the IPCC AR5 climate scenarios. However, towards EC RCP 8.5 scenario, consecutive wet days are projected to decrease for some of the districts (Figure 38).

- **Threshold indices:** For IPCC AR5 RCP4.5 and RCP8.5 scenarios, heavy and very heavy precipitation days (R10mm and R20mm) have projected positive trend for majority of the districts towards MC and EC which is also statistically not significant. However, towards MC RCP 8.5 scenario very heavy precipitation days (R20mm) are projected to have statistically significant positive trend for 2 districts namely, Bilaspur and Sirmaur (Figure 32).

Heavy precipitation days and very heavy precipitation days are projected to increase for all the districts towards MC and EC as compared to BL for both the IPCC AR5 climate scenarios (Figure 39).

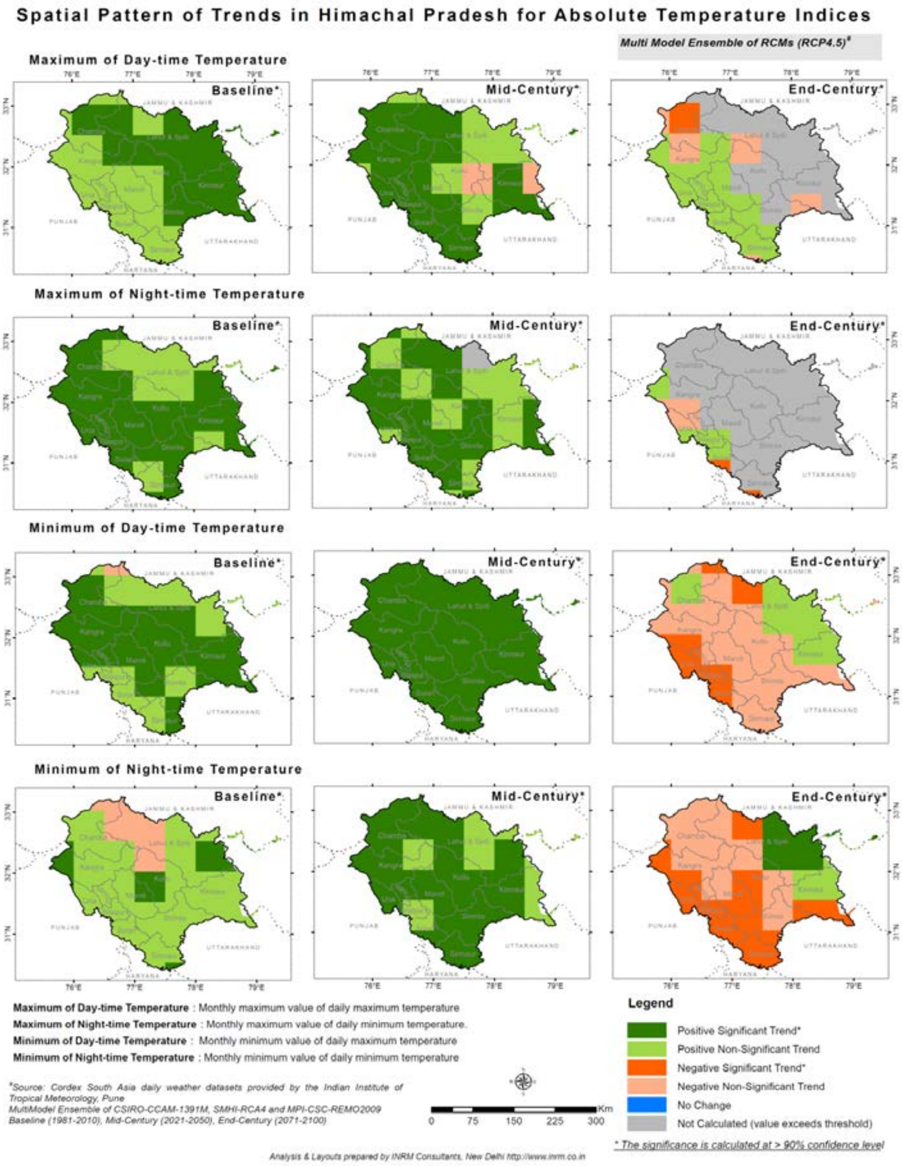
- **Other indices:** For IPCC AR5 RCP4.5, towards MC and EC districts are projected to show mixed non-significant trend for annual total precipitation. However, for RCP8.5 scenarios, towards MC majority of districts are projected to show positive non-significant trend for annual total precipitation.

For IPCC AR5 RCP4.5 and RCP 8.5 scenarios, average precipitation on wet days (Simple Daily Intensity Index) is projected to have positive non significant trend towards MC and EC for majority of the districts of the State.

Annual precipitation and the average precipitation on wet days are projected to increase towards MC and EC as compared to BL for all the districts for the IPCC AR5 RCP4.5 and RCP8.5 scenarios (Figure 40).

Figure 28 : Spatial representation of absolute temperature extremes indices for Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenarios)

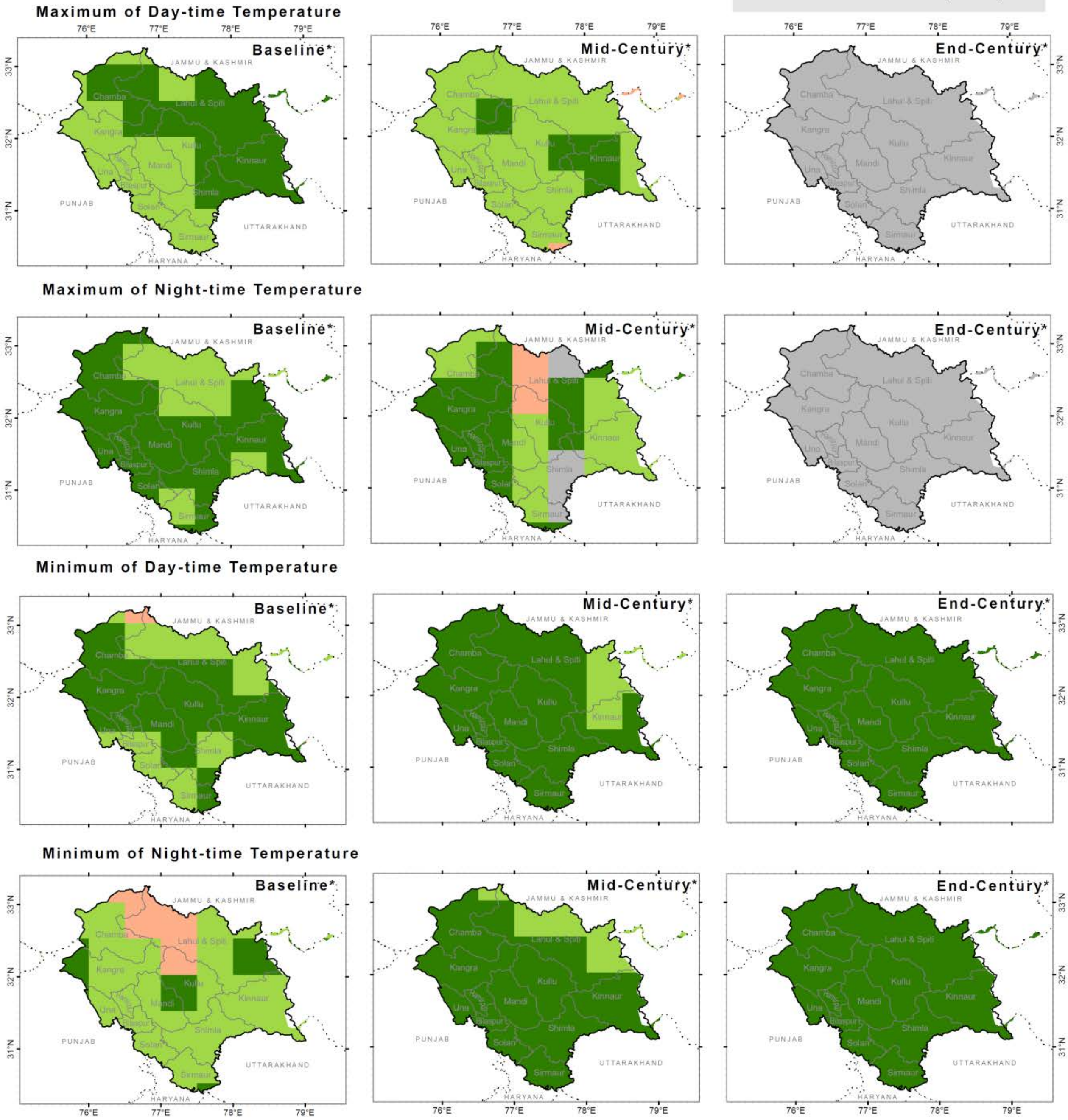
IPCC AR5 RCP4.5 scenario



IPCC AR5 RCP8.5 scenario

Spatial Pattern of Trends in Himachal Pradesh for Absolute Temperature Indices

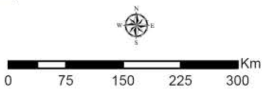
Multi Model Ensemble of RCMs (RCP8.5)#



Maximum of Day-time Temperature : Monthly maximum value of daily maximum temperature
Maximum of Night-time Temperature : Monthly maximum value of daily minimum temperature.
Minimum of Day-time Temperature : Monthly minimum value of daily maximum temperature
Minimum of Night-time Temperature : Monthly minimum value of daily minimum temperature

Legend

- 🟩 Positive Significant Trend*
- 🟩 Positive Non-Significant Trend
- 🟧 Negative Significant Trend*
- 🟧 Negative Non-Significant Trend
- 🟦 No Change
- ⬜ Not Calculated (value exceeds threshold)



#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

** The significance is calculated at > 90% confidence level*

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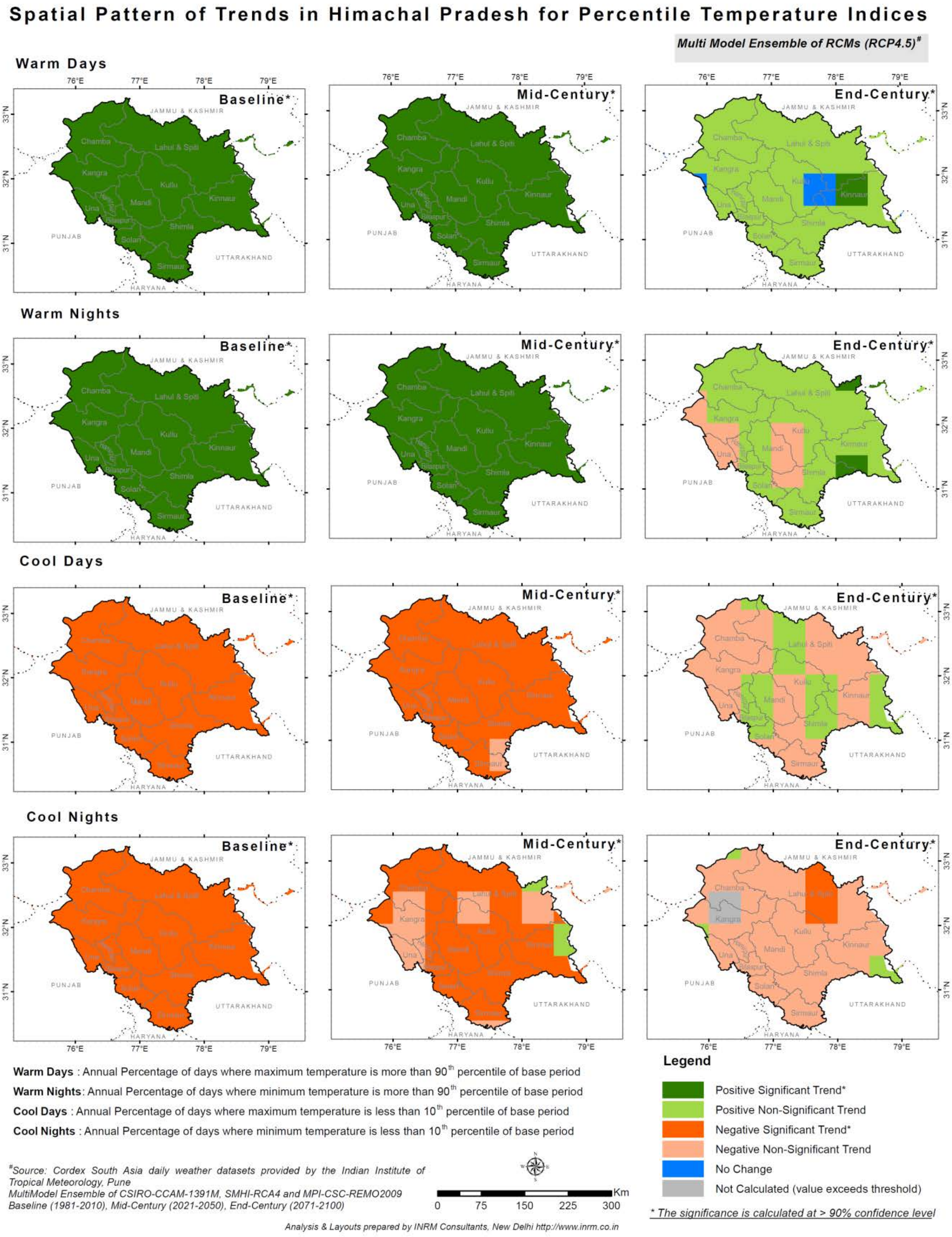
Figure 29 : Spatial representation of percentile temperature extremes indices for Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenarios)

IPCC AR5 RCP4.5 scenario



Warm Days : Annual Percentage of days where maximum temperature is more than 90th percentile of base period

Warm Nights: Annual Percentage of days where minimum temperature is more than 90th percentile of base period

Cool Days : Annual Percentage of days where maximum temperature is less than 10th percentile of base period

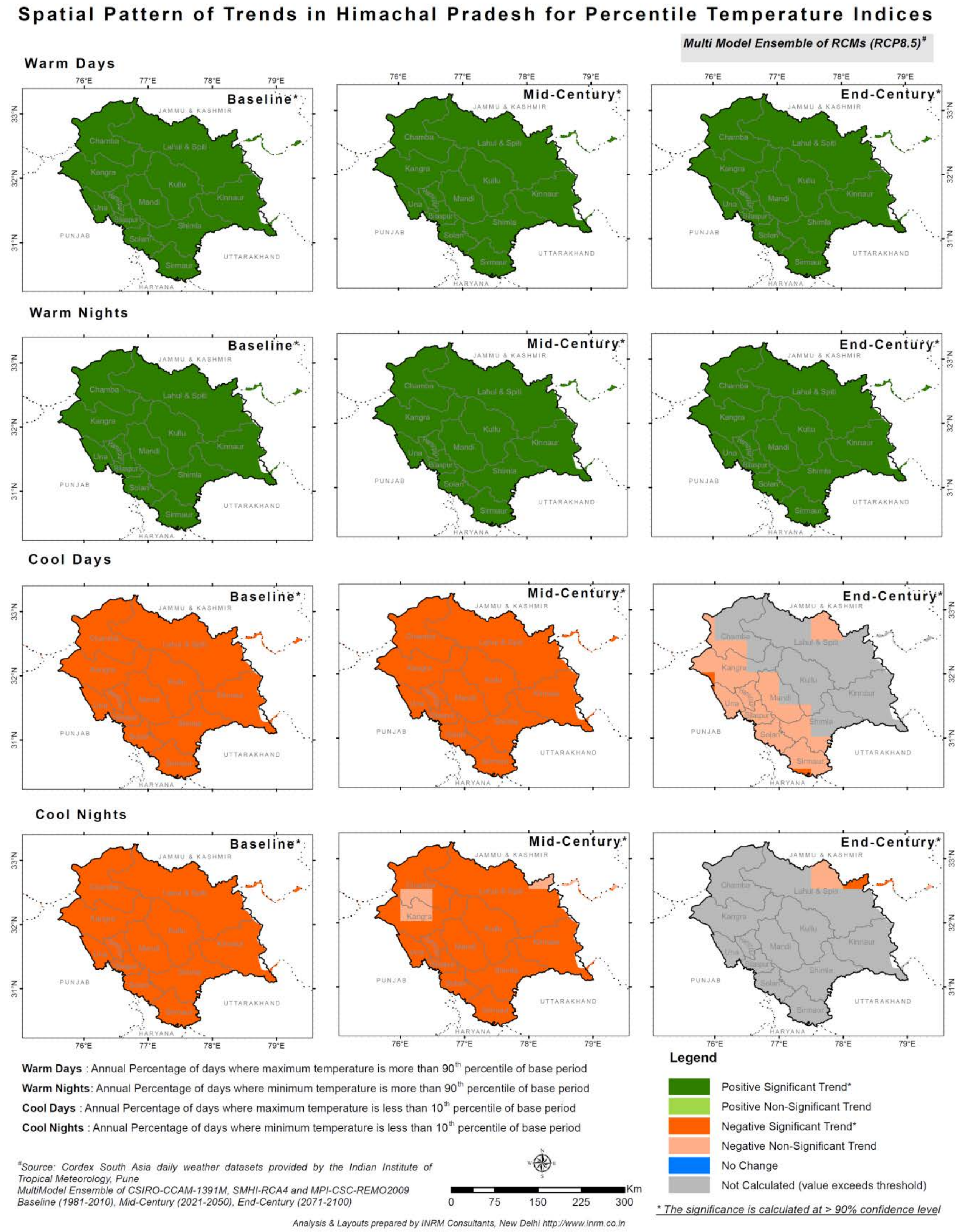
Cool Nights : Annual Percentage of days where minimum temperature is less than 10th percentile of base period

#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

** The significance is calculated at > 90% confidence level*

Analysis & Layouts prepared by INRM Consultants, New Delhi http://www.inrm.co.in

IPCC AR5 RCP8.5 scenario



Spatial Pattern of Trends in Himachal Pradesh for Percentile Temperature Indices

Multi Model Ensemble of RCMs (RCP8.5)[#]

Warm Days : Annual Percentage of days where maximum temperature is more than 90th percentile of base period

Warm Nights: Annual Percentage of days where minimum temperature is more than 90th percentile of base period

Cool Days : Annual Percentage of days where maximum temperature is less than 10th percentile of base period

Cool Nights : Annual Percentage of days where minimum temperature is less than 10th percentile of base period

Legend

- 🟩 Positive Significant Trend*
- 🟩 Positive Non-Significant Trend
- 🟧 Negative Significant Trend*
- 🟧 Negative Non-Significant Trend
- 🟦 No Change
- ⬜ Not Calculated (value exceeds threshold)

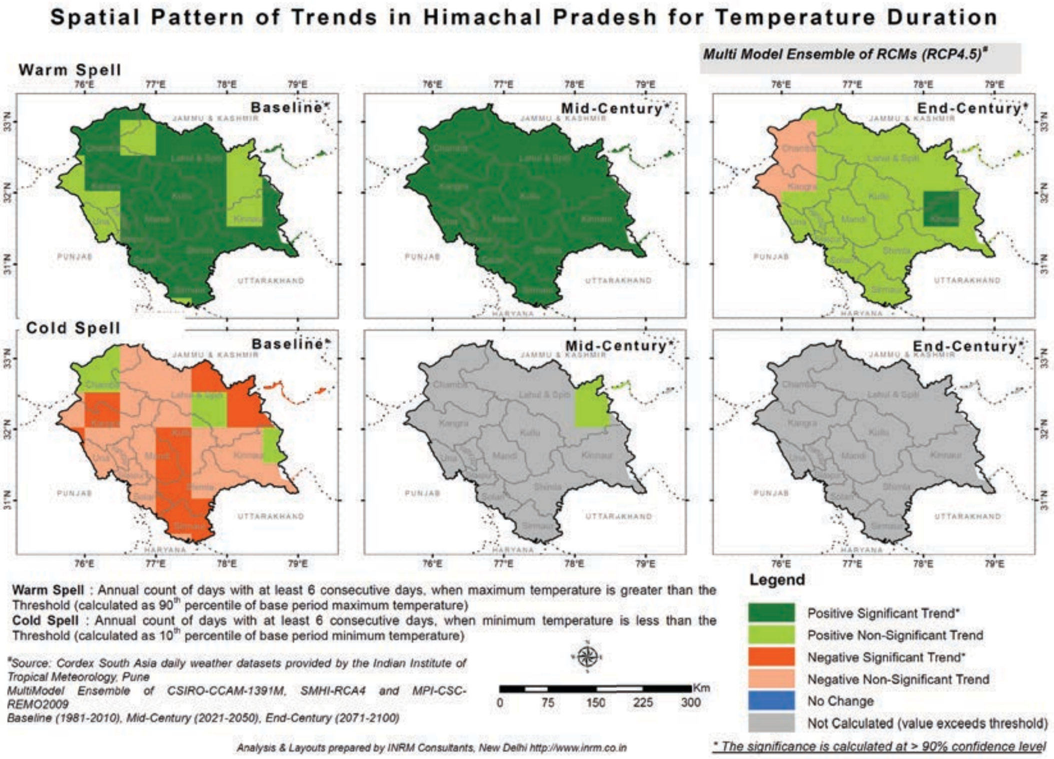
** The significance is calculated at > 90% confidence level*

[#] *Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune*
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Analysis & Layouts prepared by INRM Consultants, New Delhi http://www.inrm.co.in

Figure 30 : Spatial representation of temperature duration indices for Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenarios)

IPCC AR5 RCP4.5 scenario



Spatial Pattern of Trends in Himachal Pradesh for Temperature Duration

Multi Model Ensemble of RCMs (RCP4.5)#

Warm Spell : Annual count of days with at least 6 consecutive days, when maximum temperature is greater than the Threshold (calculated as 90th percentile of base period maximum temperature)
Cold Spell : Annual count of days with at least 6 consecutive days, when minimum temperature is less than the Threshold (calculated as 10th percentile of base period minimum temperature)

#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

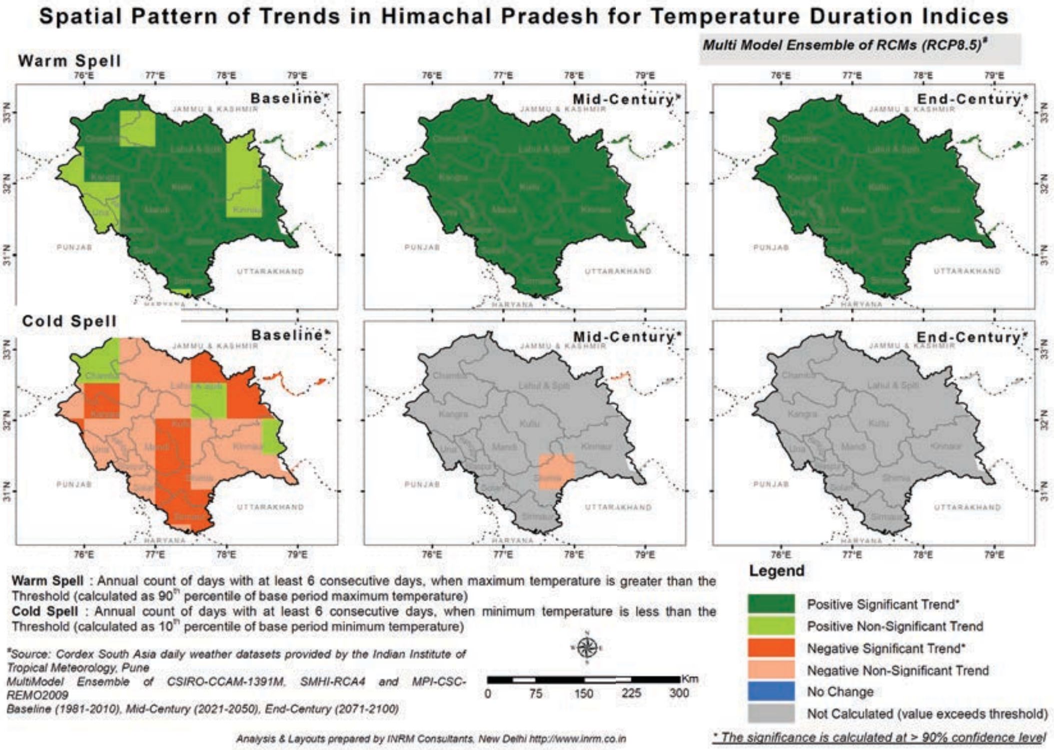
Legend

🟩 Positive Significant Trend*
🟩 Positive Non-Significant Trend
🟥 Negative Significant Trend*
🟧 Negative Non-Significant Trend
🟦 No Change
⬜ Not Calculated (value exceeds threshold)

Analysis & Layouts prepared by INRM Consultants, New Delhi http://www.inrm.co.in

** The significance is calculated at > 90% confidence level*

IPCC AR5 RCP8.5 scenario



Spatial Pattern of Trends in Himachal Pradesh for Temperature Duration Indices

Multi Model Ensemble of RCMs (RCP8.5)#

Warm Spell : Annual count of days with at least 6 consecutive days, when maximum temperature is greater than the Threshold (calculated as 90th percentile of base period maximum temperature)
Cold Spell : Annual count of days with at least 6 consecutive days, when minimum temperature is less than the Threshold (calculated as 10th percentile of base period minimum temperature)

#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Legend

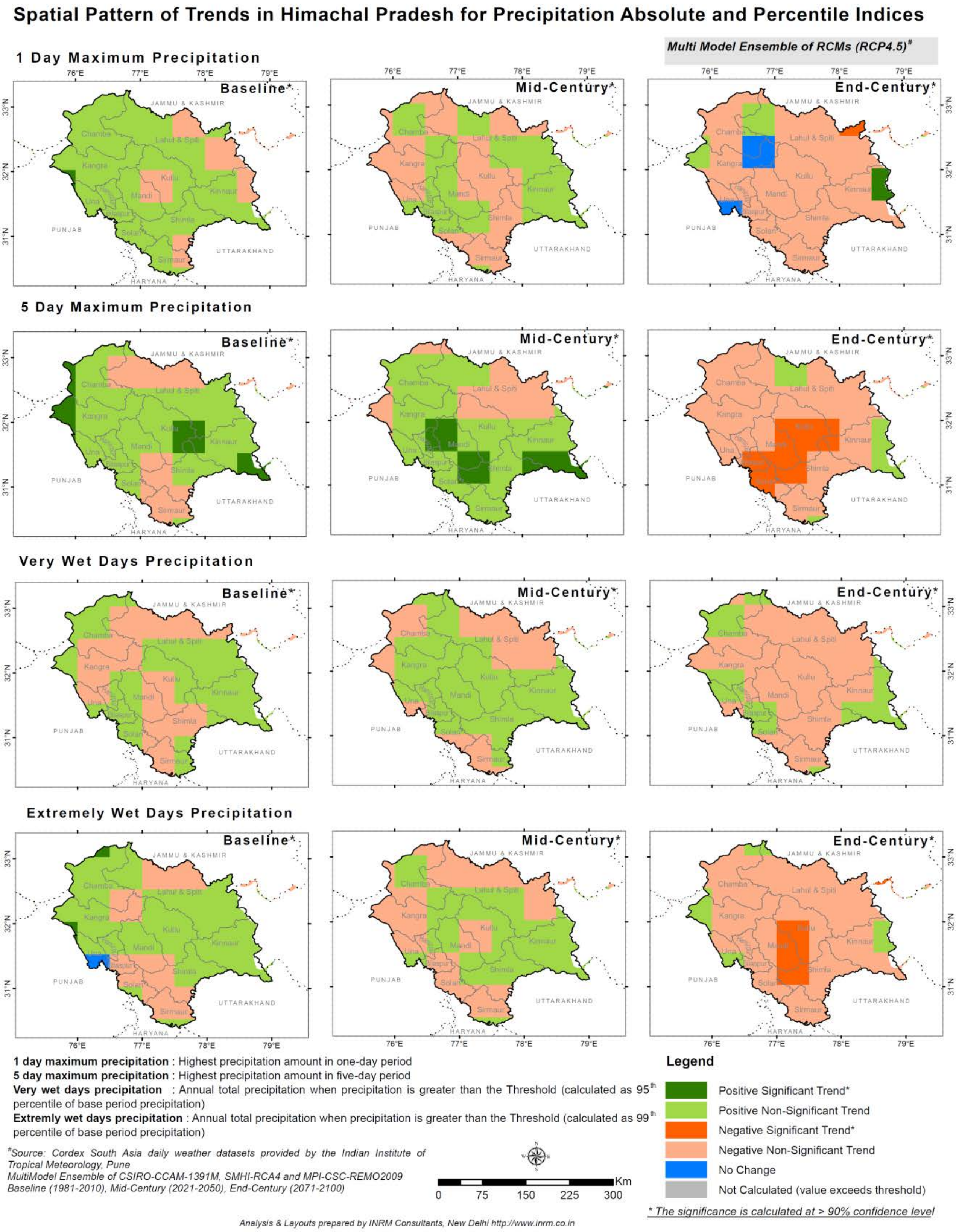
🟩 Positive Significant Trend*
🟩 Positive Non-Significant Trend
🟥 Negative Significant Trend*
🟧 Negative Non-Significant Trend
🟦 No Change
⬜ Not Calculated (value exceeds threshold)

Analysis & Layouts prepared by INRM Consultants, New Delhi http://www.inrm.co.in

** The significance is calculated at > 90% confidence level*

Figure 31 : Spatial representation of precipitation absolute and percentile indices for Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenarios)

IPCC AR5 RCP4.5 scenario



Spatial Pattern of Trends in Himachal Pradesh for Precipitation Absolute and Percentile Indices

Multi Model Ensemble of RCMs (RCP4.5)#

1 day maximum precipitation : Highest precipitation amount in one-day period
5 day maximum precipitation : Highest precipitation amount in five-day period
Very wet days precipitation : Annual total precipitation when precipitation is greater than the Threshold (calculated as 95th percentile of base period precipitation)
Extremly wet days precipitation : Annual total precipitation when precipitation is greater than the Threshold (calculated as 99th percentile of base period precipitation)

#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Legend

- 🟩 Positive Significant Trend*
- 🟩 Positive Non-Significant Trend
- 🟧 Negative Significant Trend*
- 🟧 Negative Non-Significant Trend
- 🟦 No Change
- ⬜ Not Calculated (value exceeds threshold)

** The significance is calculated at > 90% confidence level*

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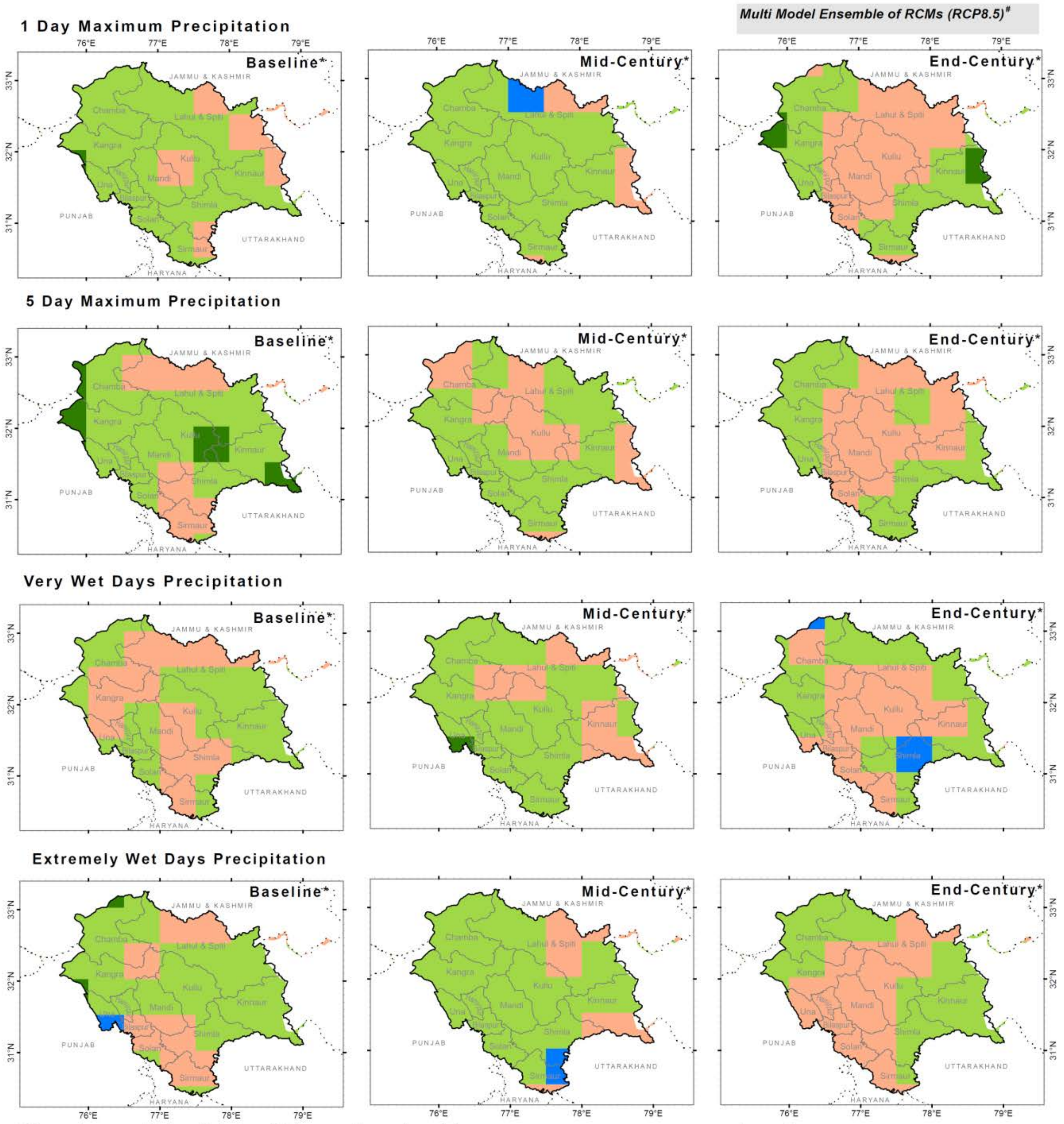
IPCC AR5 RCP8.5 scenario

Spatial Pattern of Trends in Himachal Pradesh for Precipitation Absolute and Percentile Indices



1 day maximum precipitation : Highest precipitation amount in one-day period

5 day maximum precipitation : Highest precipitation amount in five-day period

Very wet days precipitation : Annual total precipitation when precipitation is greater than the Threshold (calculated as 95th percentile of base period precipitation)

Extremly wet days precipitation : Annual total precipitation when precipitation is greater than the Threshold (calculated as 99th percentile of base period precipitation)

Legend

- 🟩 Positive Significant Trend*
- 🟩 Positive Non-Significant Trend
- 🟧 Negative Significant Trend*
- 🟧 Negative Non-Significant Trend
- 🟦 No Change
- ⬜ Not Calculated (value exceeds threshold)

** The significance is calculated at > 90% confidence level*

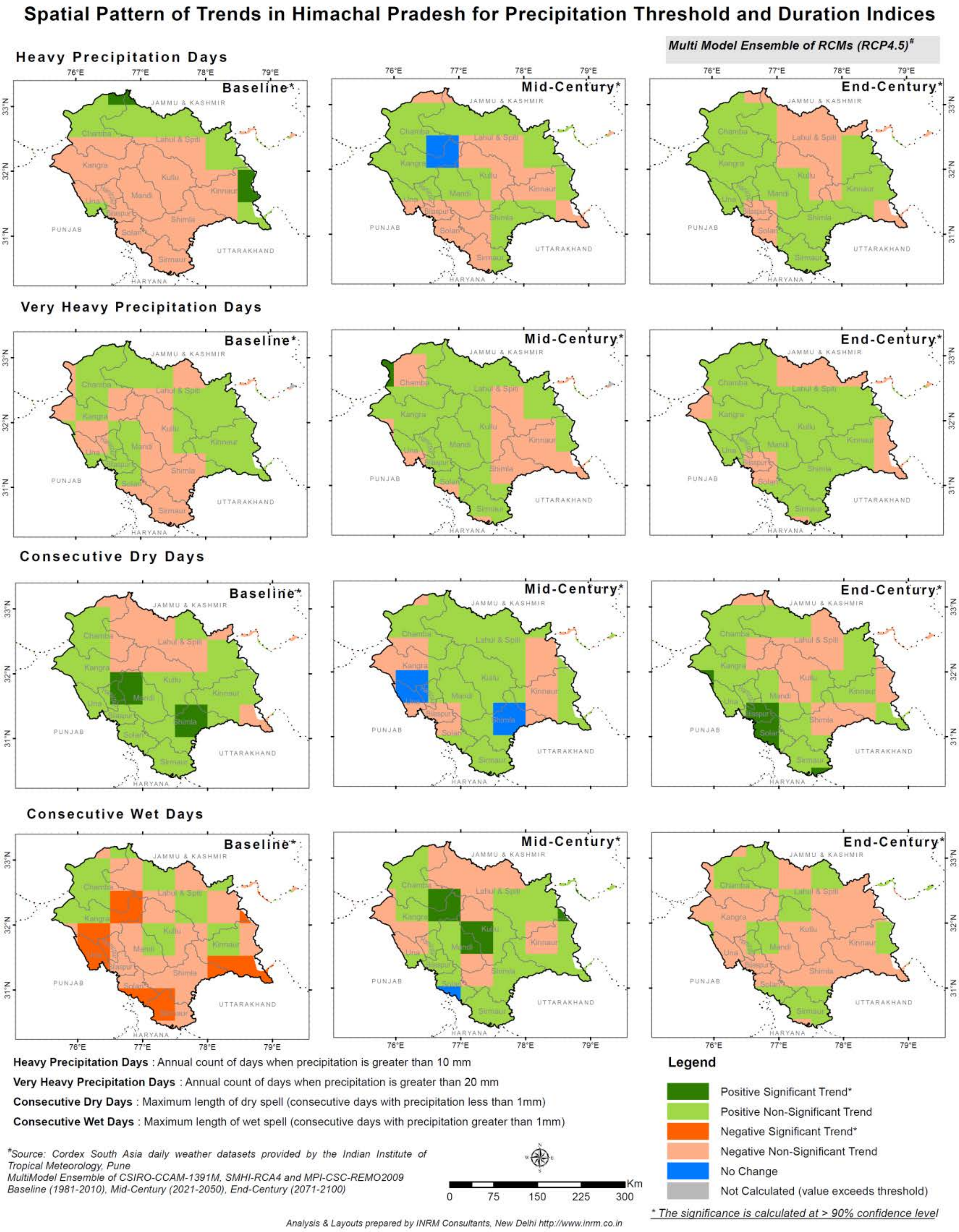
#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

0 75 150 225 300 Km

Analysis & Layouts prepared by INRM Consultants, New Delhi http://www.inrm.co.in

Figure 32 : Spatial representation of precipitation threshold and duration indices for Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenarios)

IPCC AR5 RCP4.5 scenario



Heavy Precipitation Days : Annual count of days when precipitation is greater than 10 mm

Very Heavy Precipitation Days : Annual count of days when precipitation is greater than 20 mm

Consecutive Dry Days : Maximum length of dry spell (consecutive days with precipitation less than 1mm)

Consecutive Wet Days : Maximum length of wet spell (consecutive days with precipitation greater than 1mm)

#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Legend

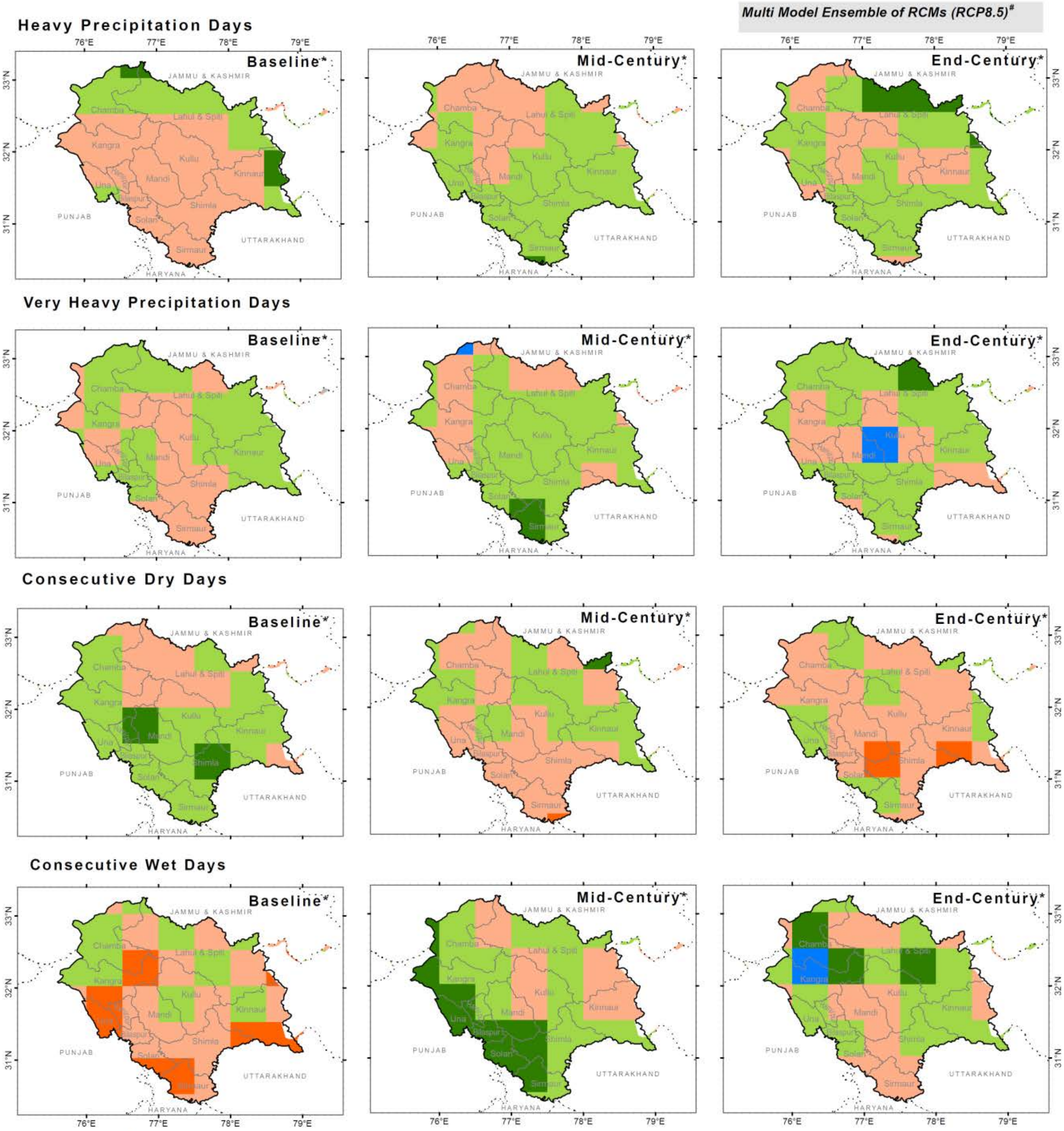
- 🟩 Positive Significant Trend*
- 🟩 Positive Non-Significant Trend
- 🟧 Negative Significant Trend*
- 🟧 Negative Non-Significant Trend
- 🟦 No Change
- ⬜ Not Calculated (value exceeds threshold)

** The significance is calculated at > 90% confidence level*

Analysis & Layouts prepared by INRM Consultants, New Delhi http://www.inrm.co.in

IPCC AR5 RCP8.5 scenario

Spatial Pattern of Trends in Himachal Pradesh for Precipitation Threshold and Duration Indices



Heavy Precipitation Days : Annual count of days when precipitation is greater than 10 mm

Very Heavy Precipitation Days : Annual count of days when precipitation is greater than 20 mm

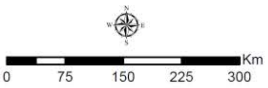
Consecutive Dry Days : Maximum length of dry spell (consecutive days with precipitation less than 1mm)

Consecutive Wet Days : Maximum length of wet spell (consecutive days with precipitation greater than 1mm)

Legend

- 🟩 Positive Significant Trend*
- 🟩 Positive Non-Significant Trend
- 🟧 Negative Significant Trend*
- 🟧 Negative Non-Significant Trend
- 🟦 No Change
- ⬜ Not Calculated (value exceeds threshold)

#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)



** The significance is calculated at > 90% confidence level*

Analysis & Layouts prepared by INRM Consultants, New Delhi http://www.inrm.co.in

Summary - Projected Climate Scenarios for Himachal Pradesh

Projected Climate Data Analysis

The CORDEX South Asia modelled climate data on precipitation, maximum temperature, minimum temperature and 21 climate extremes indices have been analysed for Himachal Pradesh State and its 12 districts for baseline (BL, 1981-2010), mid-century (MC, 2021-2050) and end-century (EC, 2071-2100). Ensemble mean of 10 RCMs at a spatial resolution of 50kmx50km has been used. The CORDEX South Asia simulations with the models indicate an all-round warming over the study area. Projected increase in temperature and precipitation towards end-century is higher than that towards mid-century. The summary for three time periods-BL, MC and EC is as follows:

Projected Maximum Temperature

- Average annual maximum temperature for IPCC AR5 RCP4.5 scenario is projected to increase by about 1.4°C towards mid-century and by 2.5°C towards end-century while for IPCC AR5 RCP8.5 scenario it is projected to increase by about 1.6°C towards mid-century and 5.0°C towards end-century for Himachal Pradesh State. Thus projected temperature increase in end-century is higher than that of mid-century.
- The projected increase in maximum temperature towards MC varies from 1.2°C in Una lying in Sub mountain & low hills sub-tropical zone to 1.7°C in Lahul & Spiti district lying in Very high hills temperate dry zone for IPCC AR5 RCP4.5 scenario and 1.4°C in Una to 2.0°C in Lahul & Spiti district of Himachal Pradesh for IPCC AR5 RCP8.5 scenario. It is observed that Northern districts show higher projected increase than the Southern districts of the State.
- The projected increase in maximum temperature towards EC varies from 2.1°C in Sirmaur to 3.3°C in Lahul & Spiti district for IPCC AR5 RCP4.5 scenario and 4.4°C in Una to 5.9°C in Lahul & Spiti district of Himachal Pradesh for IPCC AR5 RCP8.5 scenario.
- Highest maximum temperature increase is projected in winter season (JF) for IPCC AR5 RCP4.5 and RCP8.5 scenarios towards MC and EC for Himachal Pradesh State as compared to the other seasons.

Projected Minimum Temperature

- Average annual minimum temperature for IPCC AR5 RCP4.5 scenario is projected to increase by about 1.4°C towards mid-century and by 2.7°C towards end-century while for IPCC AR5 RCP8.5 scenario it is projected to increase by about 1.8°C towards mid-century and 5.1°C towards end-century for Himachal Pradesh State. Thus projected temperature increase towards EC is higher than that of MC.
- The projected increase in minimum temperature towards MC varies from 1.3°C in Una to 1.7°C in Lahul & Spiti district for IPCC AR5 RCP4.5 scenario and 1.7°C in Bilaspur (Sub mountain & low hills sub-tropical zone) to 2.1°C in Lahul & Spiti district (Very high hills temperate dry zone) of Himachal Pradesh for IPCC AR5 RCP8.5 scenario.
- The projected increase in minimum temperature towards EC varies from 2.5°C in Una to 3.2°C in Lahul & Spiti district for IPCC AR5 RCP4.5 scenario and 4.8°C in Kullu to 5.6°C in Lahul & Spiti district of Himachal Pradesh for IPCC AR5 RCP8.5 scenario.

- Highest minimum temperature increase is projected in monsoon season (JJAS) for IPCC AR5 RCP4.5 scenario and RCP8.5 scenario for both MC and EC for Himachal Pradesh State as compared to the other seasons.
- For both IPCC AR5 RCP4.5 and RCP8.5 scenarios, increase in annual and seasonal minimum temperature is projected for Himachal Pradesh and its districts towards MC and EC. However, IPCC AR5 RCP8.5 scenario shows higher increase than that of IPCC AR5 RCP4.5 scenario.

Projected Precipitation

- Average annual rainfall for IPCC AR5 RCP4.5 scenario is projected to increase by 5.9% towards mid-century and increase by about 13.8% towards end-century while for IPCC AR5 RCP8.5 scenario it is projected to increase by about 14% towards mid-century and end-century for the State. Thus the percentage of the projected rainfall increase is low towards MC and EC for both the climate scenarios.
- Districts in the Very high hills temperate dry zone of Himachal Pradesh namely, Lahul & Spiti and Kinnaur show highest projected increase in rainfall towards MC while Shimla and Sirmaur districts in the South show the highest projected increase in annual rainfall as compared to the other districts of Himachal Pradesh towards EC with respect to BL for IPCC AR5 RCP4.5 scenario. Kullu district in High hills temperate wet zone shows the lowest projected increase towards both MC and EC.
- Lahul & Spiti and Kinnaur districts show the highest projected increase (about 16%) towards MC. Lahul & Spiti district shows the highest projected increase in annual rainfall (about 28%) towards EC with respect to BL for IPCC AR5 RCP8.5 scenario. Kullu and Chamba districts show the lowest projected increase towards both MC and EC.
- In monsoon season (JJAS) highest rainfall increase is projected while in winter (JF) and pre-monsoon season (MAM) rainfall decrease is projected towards MC and EC as compared to BL for Himachal Pradesh State for IPCC AR5 RCP4.5 scenario.
- In monsoon season (JJAS) and post monsoon season (OND) highest rainfall increase is projected while in winter (JF) and pre-monsoon season (MAM) rainfall decrease is projected towards MC and EC as compared to BL for Himachal Pradesh State for IPCC AR5 RCP8.5 scenario.

Climate Extremes Indices using Projected Climate

Temperature Extreme Indices

- Maximum of day time temperature (TXx), Maximum of night time temperature (TNx) and Minimum of day time temperature (TXn) and Minimum of night time temperature (TNn) show positive trends for the State and the districts in BL and MC for IPCC AR5 RCP4.5 scenario and BL, MC and EC for IPCC AR5 8.5 scenario implying increase in temperatures for Himachal Pradesh districts, thus warming up. However the positive trend is significant for some districts while for others it is non-significant.
- The percentage of warm days and warm nights is projected to increase and percentage of cool days and cool nights is projected to decrease towards MC and EC as compared to BL for all the districts for both IPCC AR5 climate scenarios. Decrease (cool days and cool nights) / increase (warm days and warm nights) in frequency of these indices towards EC is higher than that of MC which implies higher warming towards EC than MC compared to BL.

- Cold spell duration indicator is projected to decrease and warm spell duration indicator is projected to increase for all the districts towards MC and EC compared to BL implying warming up over Himachal Pradesh districts.

Precipitation Extreme Indices

- None of the precipitation extreme indices show significant trends for the majority of the districts of Himachal Pradesh for both IPCC AR5 climate scenarios. The model results do not show any consistency in the trend of rainfall indices- for some districts the trend is positive while for others it's negative.
- Annual precipitation and the average precipitation on wet days are projected to increase towards MC and EC as compared to BL for all the districts for the IPCC AR5 RCP4.5 and RCP8.5 scenarios.
- Very wet days precipitation and extremely wet days precipitation are projected to increase towards MC and EC compared to BL for all the 12 districts for both the IPCC AR5 climate scenarios implying that rainfall intensity would increase in the future for the districts.
- Consecutive dry days and consecutive wet days are projected to increase for majority of the districts towards MC and EC as compared to BL, for both the IPCC AR5 climate scenarios. However, towards EC RCP 8.5 scenario, consecutive wet days are projected to decrease for some of the districts.
- Heavy precipitation days and very heavy precipitation days are projected to increase for all the districts towards MC and EC as compared to BL for both the IPCC AR5 climate scenarios.

In light of these consistent temporal trends of warming and increasing precipitation in Himachal Pradesh with large geographic variation, the indicators that have been identified should be further evaluated and assessed for their health impact. Geographical differences in climate trends may be of use in informing policy and resource allocation for climate change adaptation.

Appendix I

Table 10 : Change in daily maximum temperature (°C) w.r.t. BL (1981-2010) as simulated by South Asia Codex for Himachal Pradesh (IPCC AR5 RCP4.5 scenario)

	Annual		JF (Winter)		MAM (Pre Monsoon)		JJAS (Monsoon)		OND (Post monsoon)	
District	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL
Himachal Pradesh	**1.4**	**2.5**	**2.0**	**3.3**	**1.5**	**2.6**	**1.4**	**2.7**	**1.2**	**1.9**
Bilaspur	1.3	2.2	1.8	3.0	1.5	2.7	0.9	1.7	1.1	1.6
Chamba	1.6	3.0	2.1	3.6	1.4	2.6	1.8	3.5	1.3	2.3
Hamirpur	1.3	2.2	1.8	3.0	1.6	2.8	0.9	1.7	1.1	1.6
Kangra	1.5	2.6	1.9	3.3	1.5	2.8	1.3	2.6	1.2	2.0
Kinnaur	1.6	3.1	2.1	3.6	1.0	2.0	1.9	4.1	1.5	2.5
Kullu	1.5	2.9	2.0	3.5	1.3	2.5	1.7	3.5	1.2	2.1
Lahul & Spiti	1.7	3.3	2.1	3.8	1.0	2.1	2.0	4.2	1.6	2.7
Mandi	1.5	2.6	2.0	3.4	1.5	2.7	1.3	2.6	1.2	1.9
Shimla	1.4	2.5	1.9	3.3	1.4	2.5	1.4	2.7	1.1	1.8
Sirmaur	1.3	2.1	1.9	3.0	1.7	2.8	0.9	1.6	1.2	1.6
Solan	1.3	2.1	1.8	3.0	1.5	2.6	1.0	1.7	1.1	1.6
Una	1.2	2.1	1.6	2.7	1.6	2.8	0.9	1.7	1.1	1.5
Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean										

Table 11 : Change in daily maximum temperature (°C) writ BL (1981-2010) as simulated by South Asia Codex for Himachal Pradesh (IPCC AR5 RCP8.5 scenario)

	Annual		JF (Winter)		MAM (Pre Monsoon)		JJAS (Monsoon)		OND (Post monsoon)	
District	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL
Himachal Pradesh	**1.6**	**5.0**	**2.3**	**5.7**	**1.8**	**5.3**	**1.7**	**5.3**	**1.1**	**4.2**
Bilaspur	1.5	4.6	2.1	5.3	2.0	5.5	1.1	4.1	0.9	3.7
Chamba	1.8	5.7	2.4	6.2	1.7	5.4	2.1	6.6	1.4	4.8
Hamirpur	1.5	4.6	2.1	5.3	2.0	5.6	1.1	4.1	0.9	3.7
Kangra	1.7	5.2	2.2	5.7	2.0	5.6	1.6	5.3	1.1	4.3
Kinnaur	1.9	5.6	2.5	6.0	1.3	4.2	2.5	7.0	1.5	5.0
Kullu	1.9	5.5	2.3	5.9	1.7	5.3	2.2	6.2	1.2	4.5
Lahul & Spiti	2.0	5.9	2.5	6.3	1.3	4.3	2.6	7.2	1.6	5.4
Mandi	1.7	5.2	2.4	5.7	1.9	5.5	1.6	5.4	1.1	4.0
Shimla	1.6	4.9	2.3	5.5	1.7	5.3	1.7	5.1	1.1	3.9
Sirmaur	1.5	4.5	2.2	5.2	2.1	5.7	1.2	3.9	1.0	3.6
Solan	1.5	4.5	2.2	5.2	1.9	5.4	1.2	4.0	0.9	3.6
Una	1.4	4.4	1.9	5.0	2.0	5.6	1.1	4.0	0.8	3.5
Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean										

Table 12 : Change in daily minimum temperature (°C) writ BL (1981-2010) as simulated by South Asia Codex for Himachal Pradesh (IPCC AR5 RCP4.5 scenario)

	Annual		JF (Winter)		MAM (Pre Monsoon)		JJAS (Monsoon)		OND (Post monsoon)	
District	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL
Himachal Pradesh	**1.4**	**2.7**	**1.5**	**2.9**	**1.1**	**2.2**	**1.8**	**3.4**	**1.3**	**2.4**
Bilaspur	1.4	2.6	1.6	2.9	1.2	2.3	1.7	3.2	1.2	2.1
Chamba	1.5	2.9	1.4	2.7	1.1	2.2	2.2	3.9	1.3	2.4
Hamirpur	1.4	2.6	1.6	2.9	1.2	2.4	1.7	3.3	1.2	2.1
Kangra	1.5	2.8	1.4	2.8	1.1	2.3	1.8	3.5	1.3	2.3
Kinnaur	1.5	2.9	1.4	2.9	1.1	2.3	1.9	3.5	1.6	2.8
Kullu	1.4	2.6	1.4	2.9	1.0	2.1	1.7	3.2	1.3	2.4
Lahul & Spiti	1.7	3.2	1.3	2.8	1.0	2.2	2.1	4.0	1.7	3.1
Mandi	1.4	2.6	1.6	3.0	1.1	2.2	1.7	3.2	1.2	2.1
Shimla	1.4	2.7	1.6	3.1	1.1	2.1	1.7	3.2	1.1	2.1
Sirmaur	1.4	2.6	1.7	3.1	1.1	2.3	1.7	3.2	1.1	2.1
Solan	1.4	2.6	1.7	3.1	1.2	2.3	1.7	3.3	1.2	2.1
Una	1.3	2.5	1.3	2.5	1.1	2.3	1.6	3.2	1.1	2.0

Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean

Table 13 : Change in daily minimum temperature (°C) writ BL (1981-2010) as simulated by South Asia Codex for Himachal Pradesh (IPCC AR5 RCP8.5 scenario)

	Annual		JF (Winter)		MAM (Pre Monsoon)		JJAS (Monsoon)		OND (Post monsoon)	
District	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL
Himachal Pradesh	**1.8**	**5.1**	**1.9**	**5.1**	**1.5**	**4.7**	**2.3**	**5.6**	**1.6**	**4.8**
Bilaspur	1.7	5.0	1.9	5.1	1.6	4.8	2.1	5.5	1.4	4.4
Chamba	1.9	5.4	1.7	5.2	1.5	4.7	2.7	6.2	1.6	5.1
Hamirpur	1.7	5.0	1.9	5.1	1.6	4.9	2.2	5.7	1.4	4.5
Kangra	1.8	5.2	1.8	5.1	1.5	4.8	2.3	5.8	1.5	4.8
Kinnaur	2.0	5.3	1.8	5.3	1.5	4.6	2.4	5.5	1.8	5.7
Kullu	1.8	4.8	1.8	5.2	1.4	4.3	2.2	5.0	1.6	4.9
Lahul & Spiti	2.1	5.6	1.7	5.2	1.5	4.5	2.7	6.1	2.1	6.2
Mandi	1.7	4.8	2.0	5.3	1.5	4.6	2.2	5.0	1.4	4.4
Shimla	1.8	4.8	2.0	5.3	1.4	4.4	2.1	5.0	1.4	4.3
Sirmaur	1.8	4.9	2.1	5.2	1.6	4.7	2.2	5.5	1.4	4.3
Solan	1.8	5.0	2.1	5.3	1.6	4.8	2.2	5.6	1.4	4.3
Una	1.7	5.1	1.6	4.6	1.6	4.9	2.0	6.0	1.4	4.4

Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean

Table 14 : Change in precipitation (%) writ BL (1981-2010) as simulated by South Asia Codex for Himachal Pradesh (IPCC AR5 RCP4.5 scenario)

	Annual		JF (Winter)		MAM (Pre Monsoon)		JJAS (Monsoon)		OND (Post monsoon)	
District	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL
Himachal Pradesh	**5.9**	**13.8**	**-14.4**	**-22.6**	**-3.5**	**-10.9**	**13.1**	**22.0**	**-4.4**	**18.8**
Bilaspur	4.4	14.9	-18.3	-25.9	-24.2	-15.2	8.7	17.8	-8.0	22.5
Chamba	4.3	9.4	-14.6	-25.7	-3.2	-15.6	16.7	23.4	-6.7	16.7
Hamirpur	7.1	14.9	-21.5	-31.5	-12.0	-22.9	14.1	20.9	-10.1	18.5
Kangra	6.4	13.5	-17.3	-31.0	-7.8	-21.9	16.3	24.8	-8.1	17.9
Kinnaur	7.8	11.7	-6.2	-15.6	2.8	-8.0	23.4	36.6	0.3	14.2
Kullu	4.1	8.8	-9.5	-17.5	-3.4	-13.8	16.2	25.0	-1.4	18.5
Lahul & Spiti	8.9	8.8	0.1	0.2	11.1	3.7	18.1	13.8	1.7	13.8
Mandi	6.0	15.3	-19.9	-27.7	-12.6	-20.5	12.2	21.7	-4.0	22.4
Shimla	5.8	18.7	-19.7	-26.3	-13.6	-13.3	12.1	26.8	0.6	24.7
Sirmaur	4.1	16.7	-35.2	-29.5	-35.6	-15.7	8.3	19.9	-1.3	21.5
Solan	4.7	16.2	-20.2	-24.1	-30.0	-11.3	8.1	18.0	-2.4	28.0
Una	7.6	16.4	-17.5	-31.6	-10.0	-13.7	14.3	21.1	-13.3	20.4

Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean

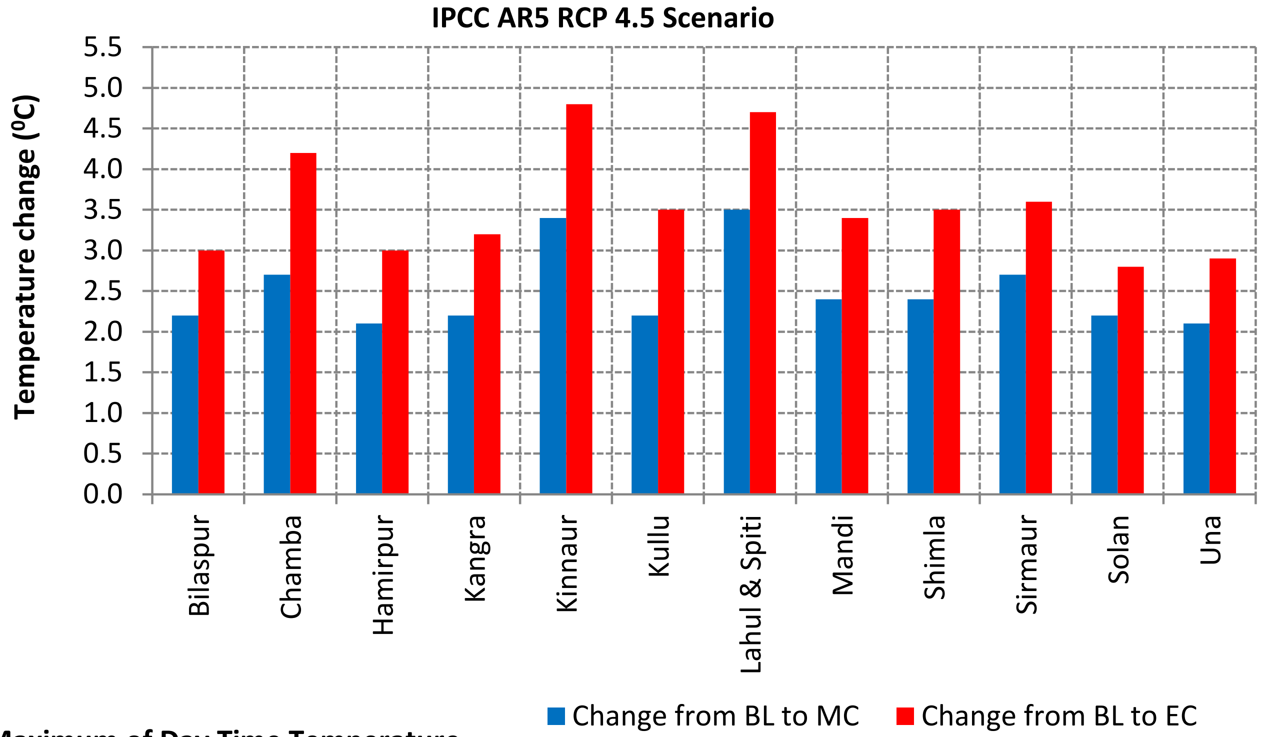
Table 15 : Change in precipitation (%) writ BL (1981-2010) as simulated by South Asia Codex for Himachal Pradesh (IPCC AR5 RCP8.5 scenario)

	Annual		JF (Winter)		MAM (Pre Monsoon)		JJAS (Monsoon)		OND (Post monsoon)	
District	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL	MC-BL	EC-BL
Himachal Pradesh	**14.0**	**14.0**	**-22.3**	**-28.0**	**-0.1**	**-14.0**	**18.1**	**24.2**	**28.9**	**16.5**
Bilaspur	13.7	12.2	-38.3	-37.5	-13.4	-40.7	16.2	15.6	28.3	27.7
Chamba	11.2	10.0	-21.0	-34.2	-0.7	-21.4	15.9	33.9	30.3	4.4
Hamirpur	14.5	13.1	-39.8	-42.4	-16.0	-36.6	19.7	21.7	24.6	11.6
Kangra	13.2	12.2	-30.8	-42.6	-8.2	-32.9	19.4	30.1	29.7	3.3
Kinnaur	16.3	14.9	-6.9	-8.6	4.7	-5.9	24.5	42.9	32.4	11.2
Kullu	13.0	9.0	-11.7	-20.6	1.9	-19.0	20.2	30.0	28.3	17.3
Lahul & Spiti	16.0	27.4	2.1	8.6	12.0	20.9	14.6	39.2	29.2	32.5
Mandi	14.3	12.6	-29.3	-35.9	-10.0	-37.5	18.8	20.3	27.3	21.8
Shimla	15.8	16.1	-22.0	-30.3	-3.7	-30.0	19.6	26.4	32.3	19.4
Sirmaur	13.0	14.2	-34.0	-36.2	-18.1	-30.9	15.4	16.9	25.0	30.0
Solan	13.9	13.5	-36.4	-35.2	-11.3	-37.7	15.4	14.6	31.8	42.7
Una	15.3	16.3	-45.5	-47.1	-13.3	-22.5	19.8	25.3	27.1	6.6

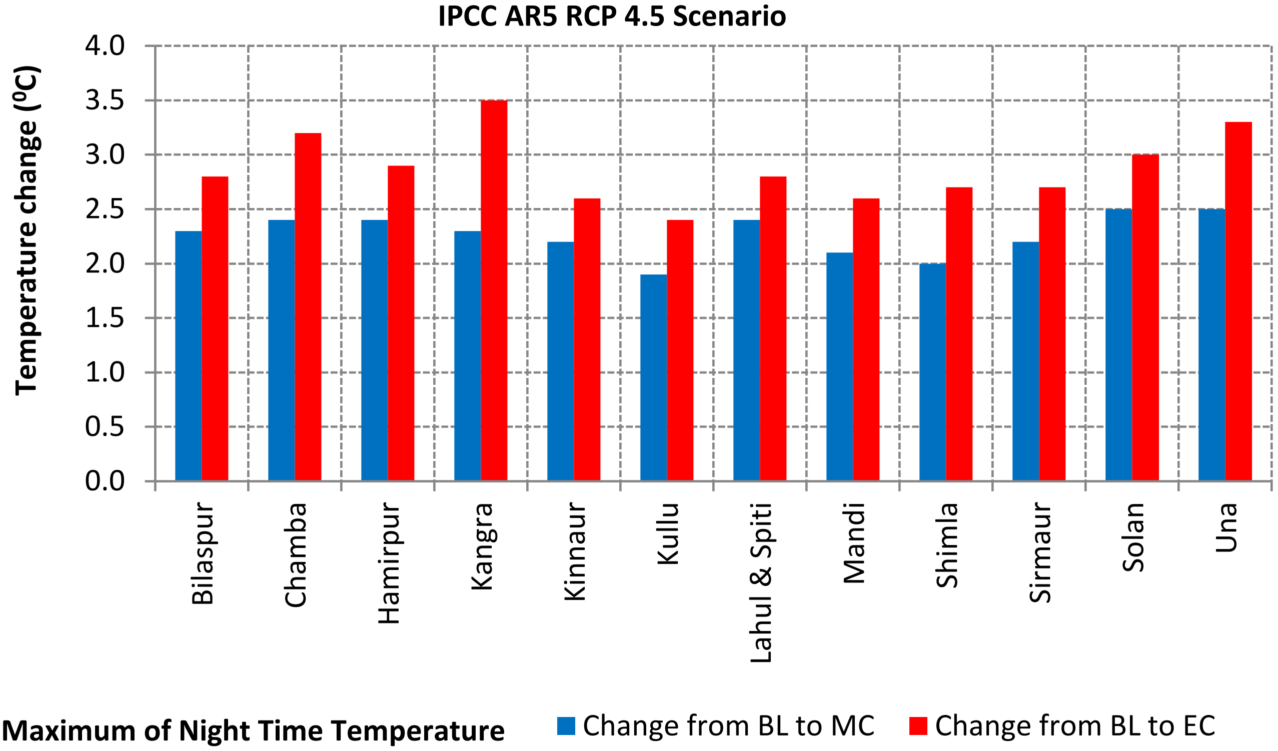
Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean

Temperature Extremes Indices graphs

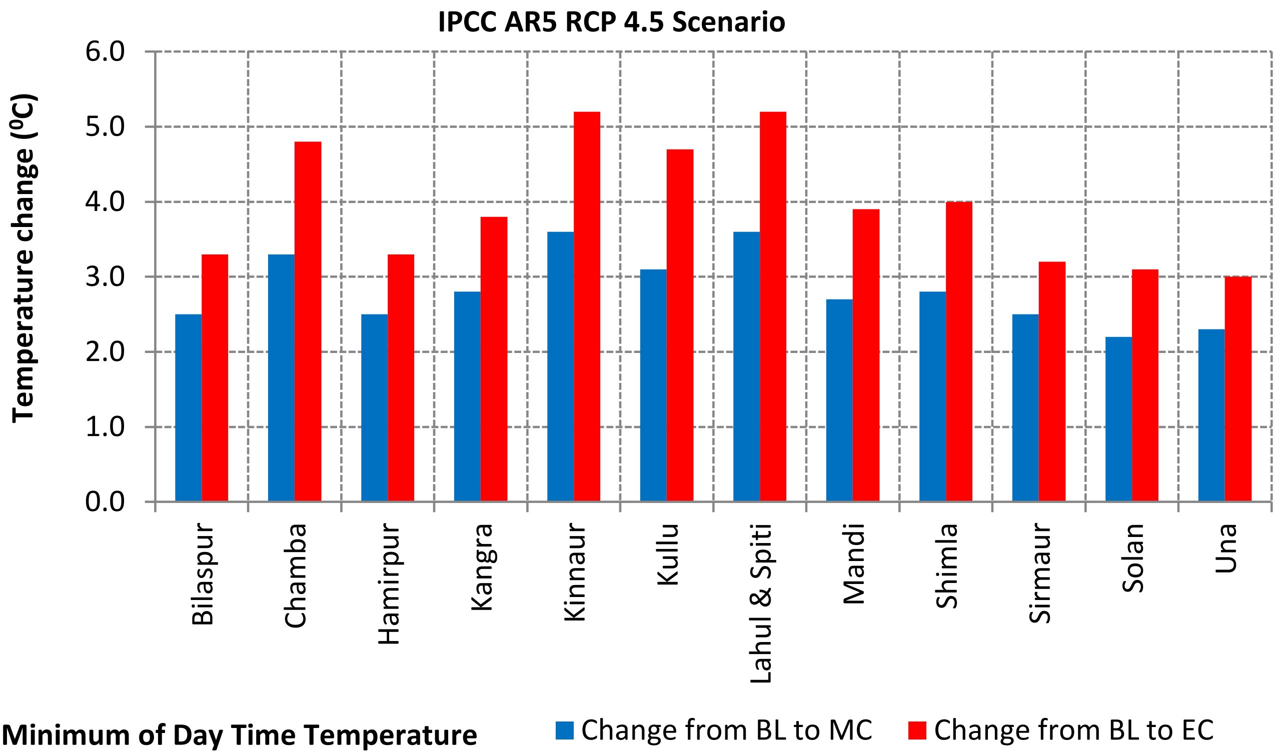
Figure 33 : Characteristics of absolute temperature extremes indices for districts of Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenarios)



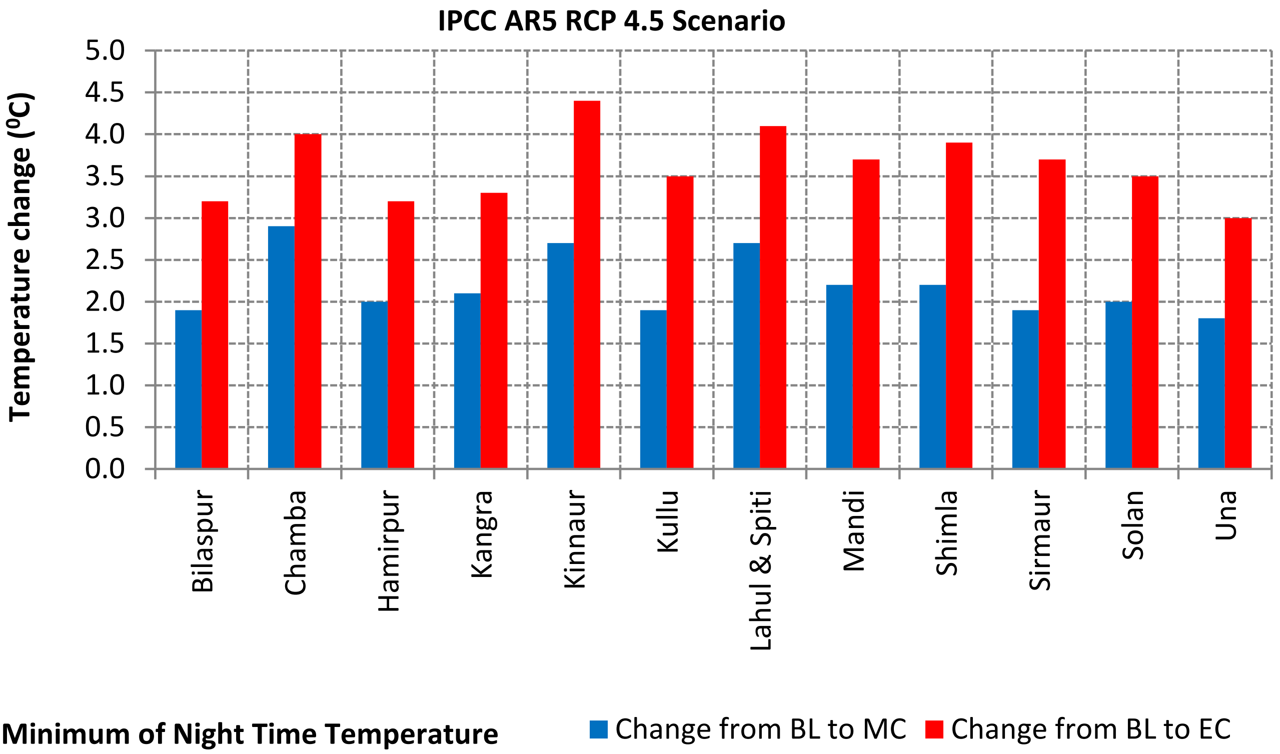
Maximum of Day Time Temperature



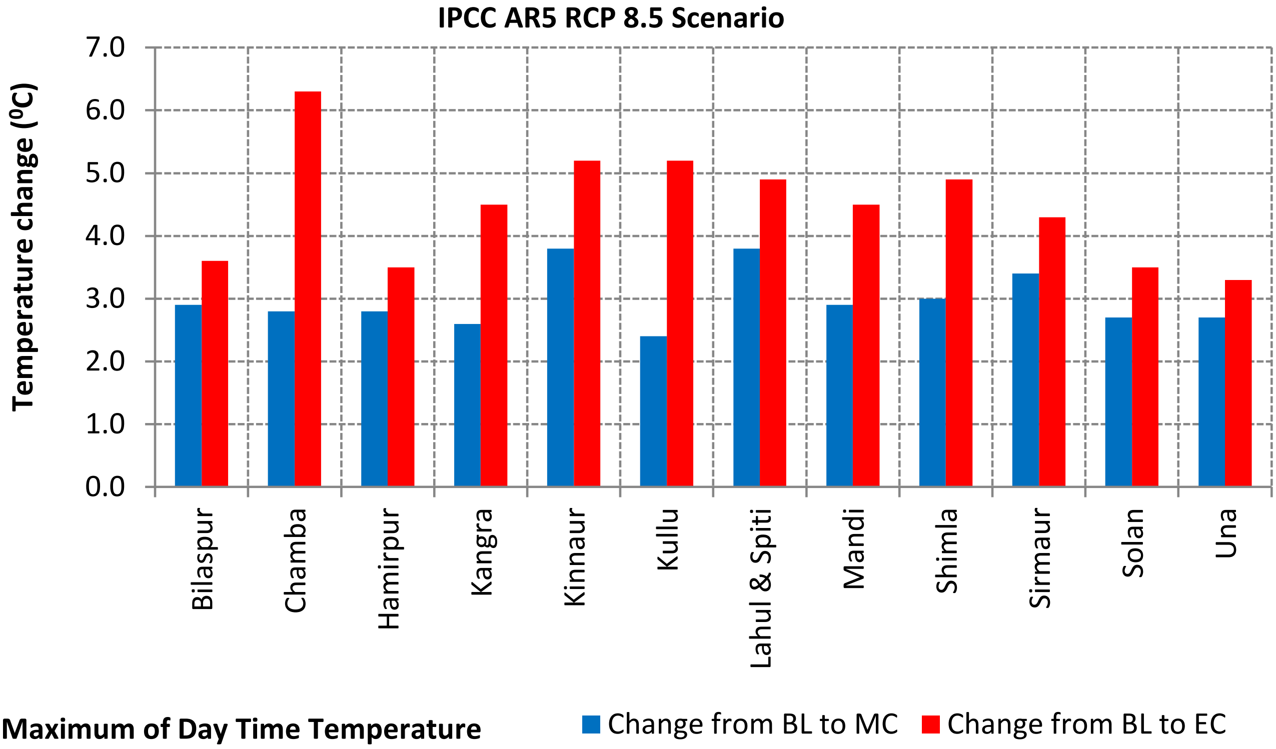
Maximum of Night Time Temperature



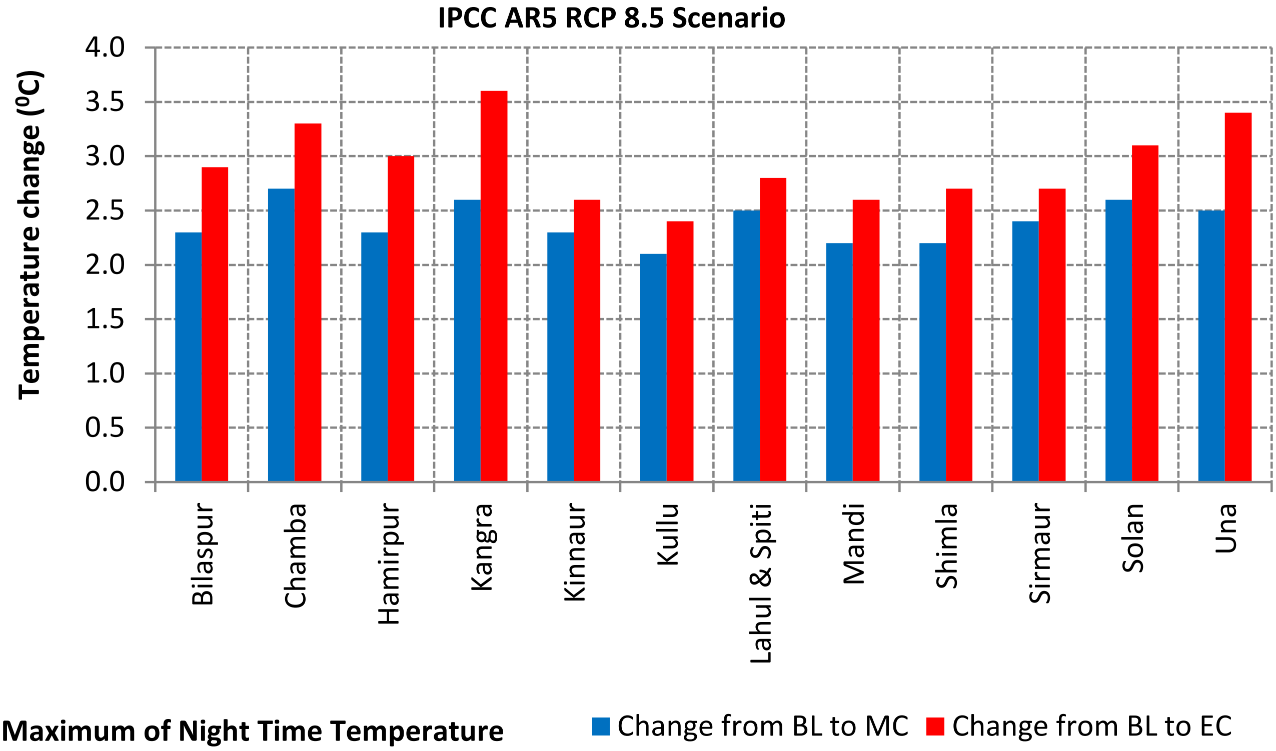
Minimum of Day Time Temperature



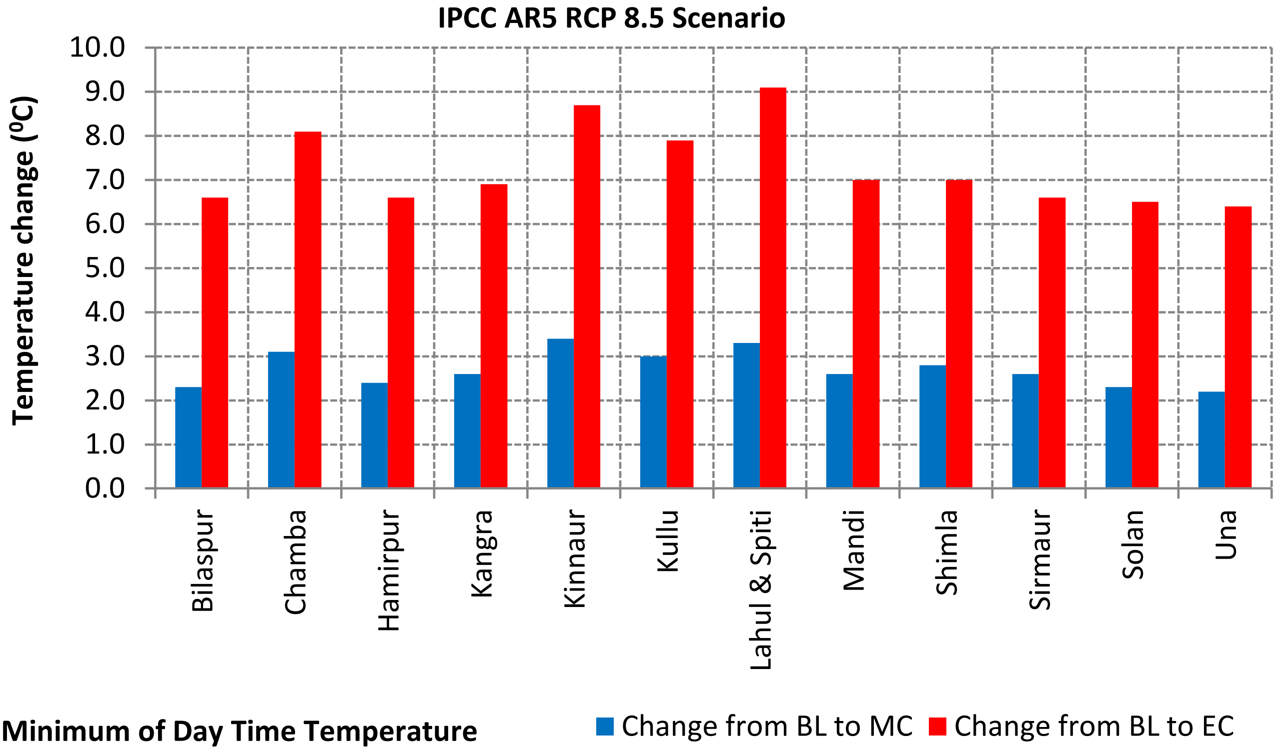
Minimum of Night Time Temperature



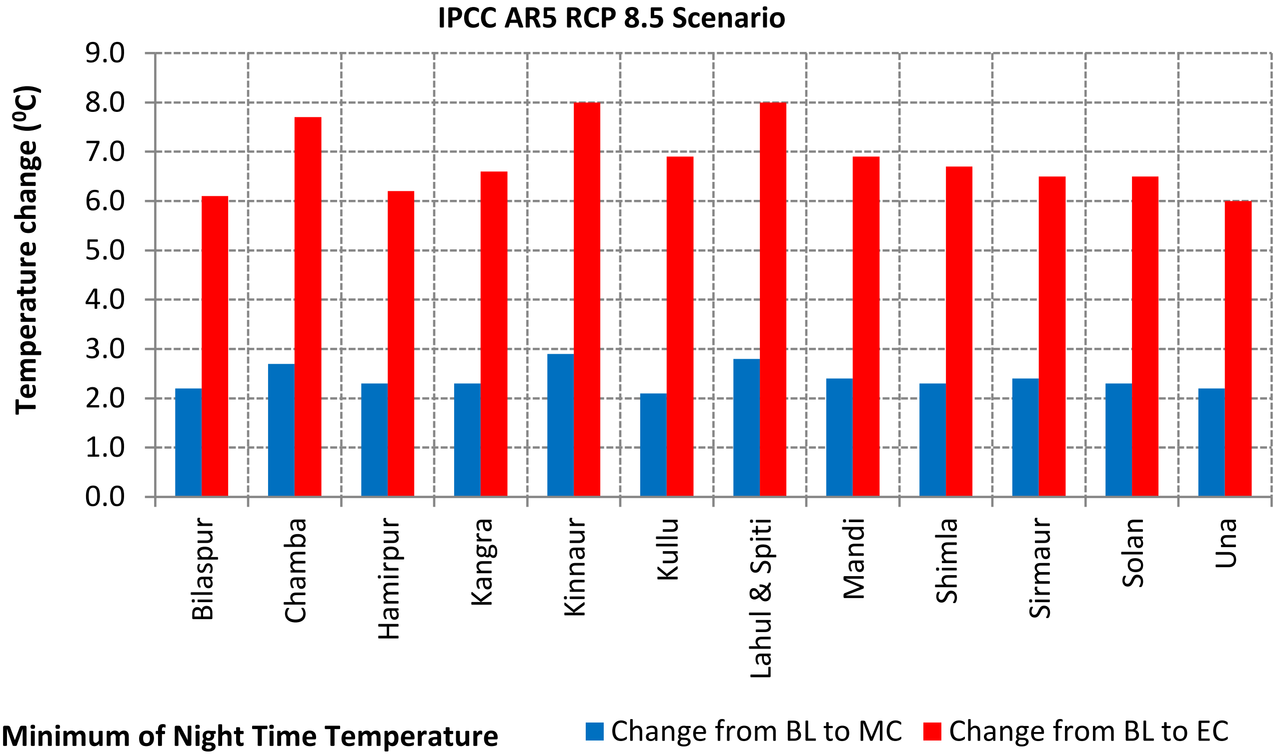
Maximum of Day Time Temperature



Maximum of Night Time Temperature

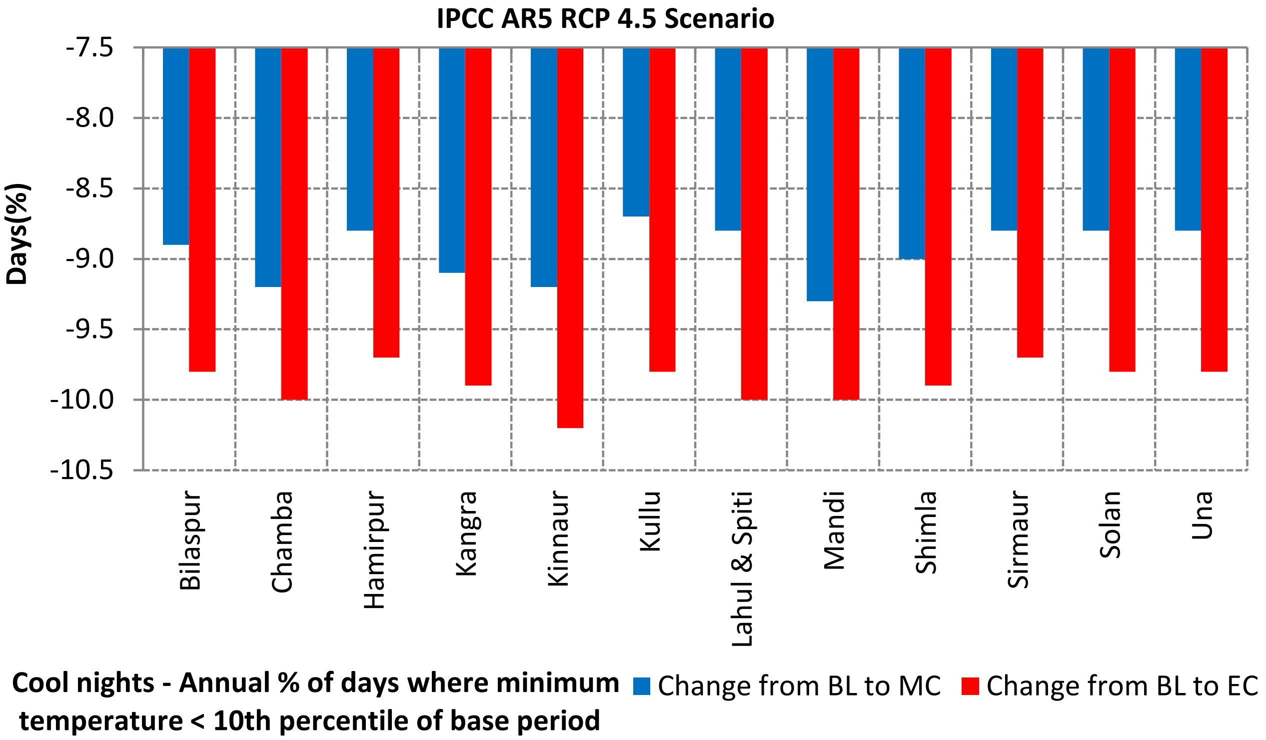


Minimum of Day Time Temperature

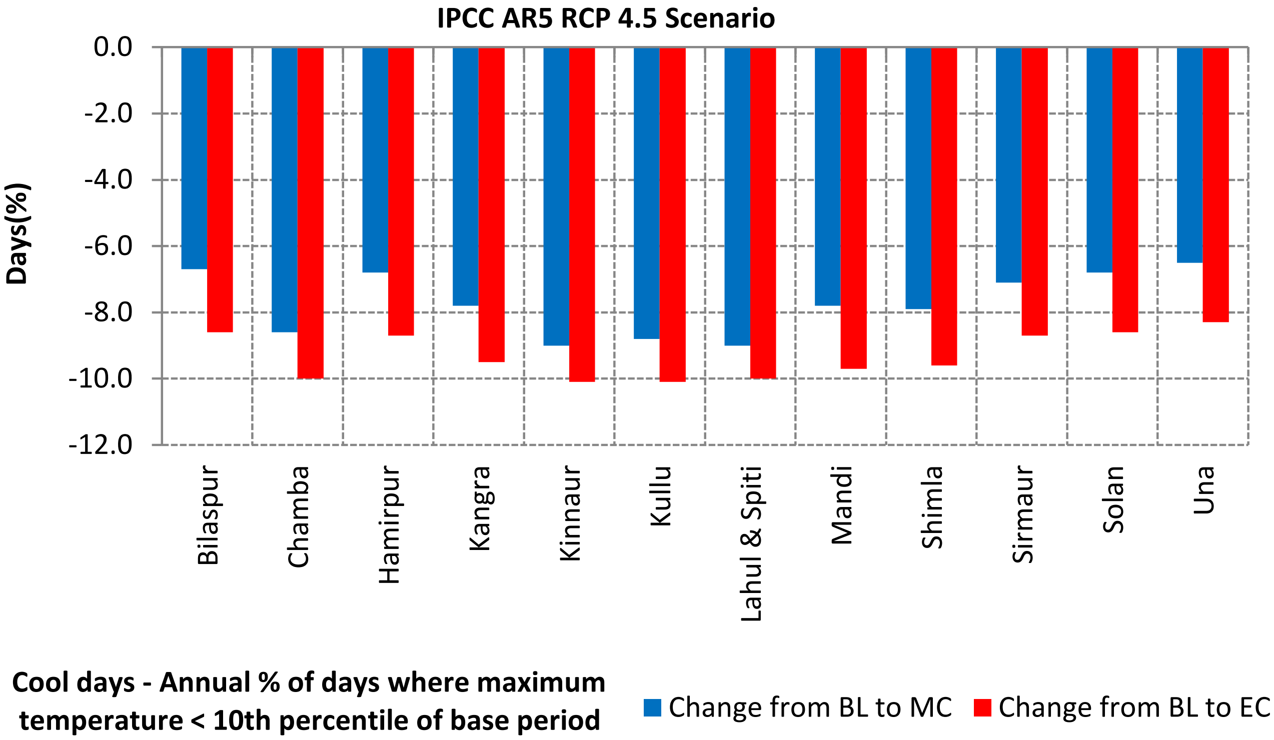


Minimum of Night Time Temperature

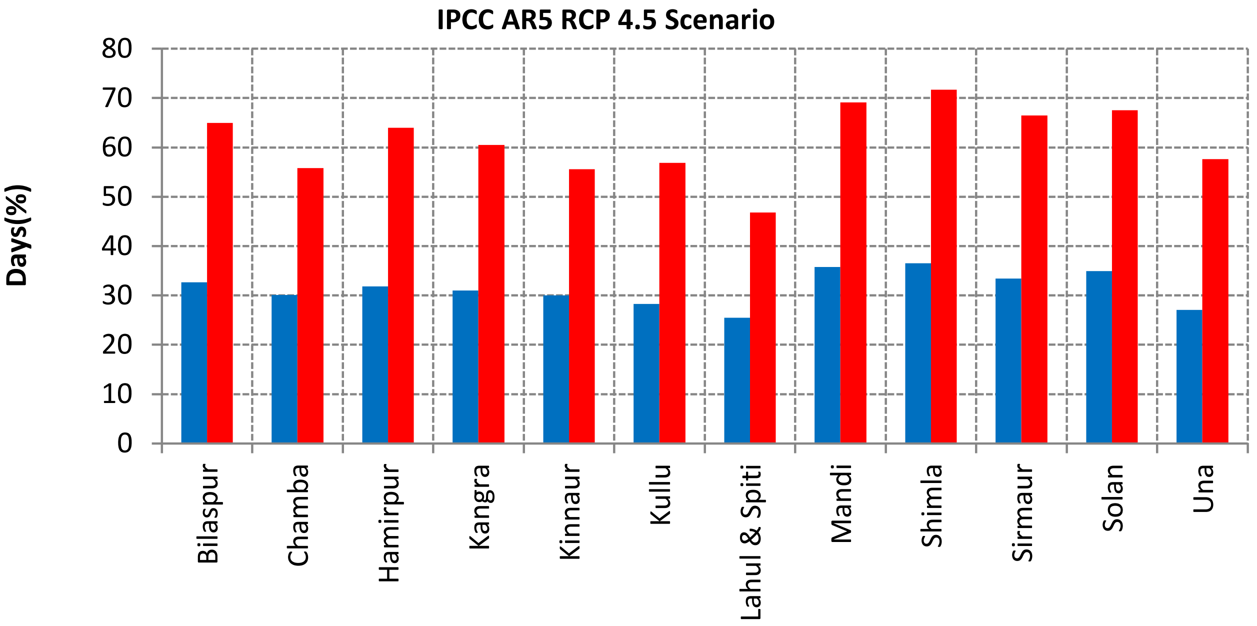
Figure 34 : Characteristics of percentile temperature extremes indices for districts of Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenarios)



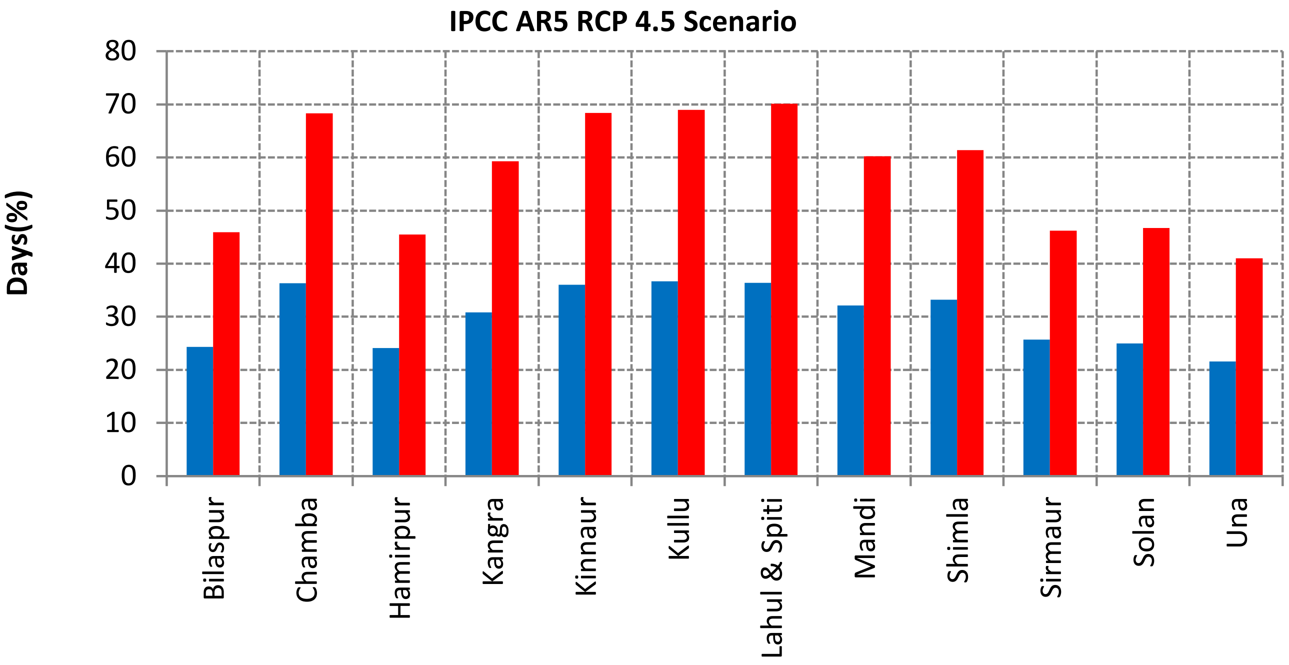
Cool nights - Annual % of days where minimum temperature < 10th percentile of base period



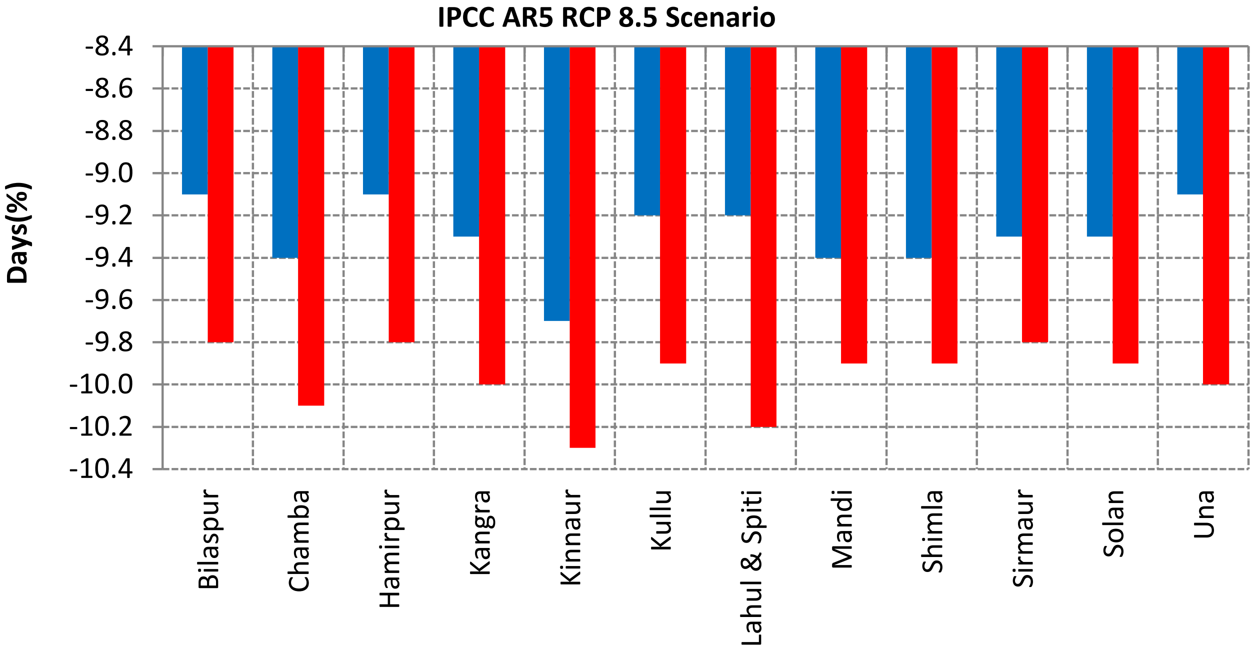
Cool days - Annual % of days where maximum temperature < 10th percentile of base period



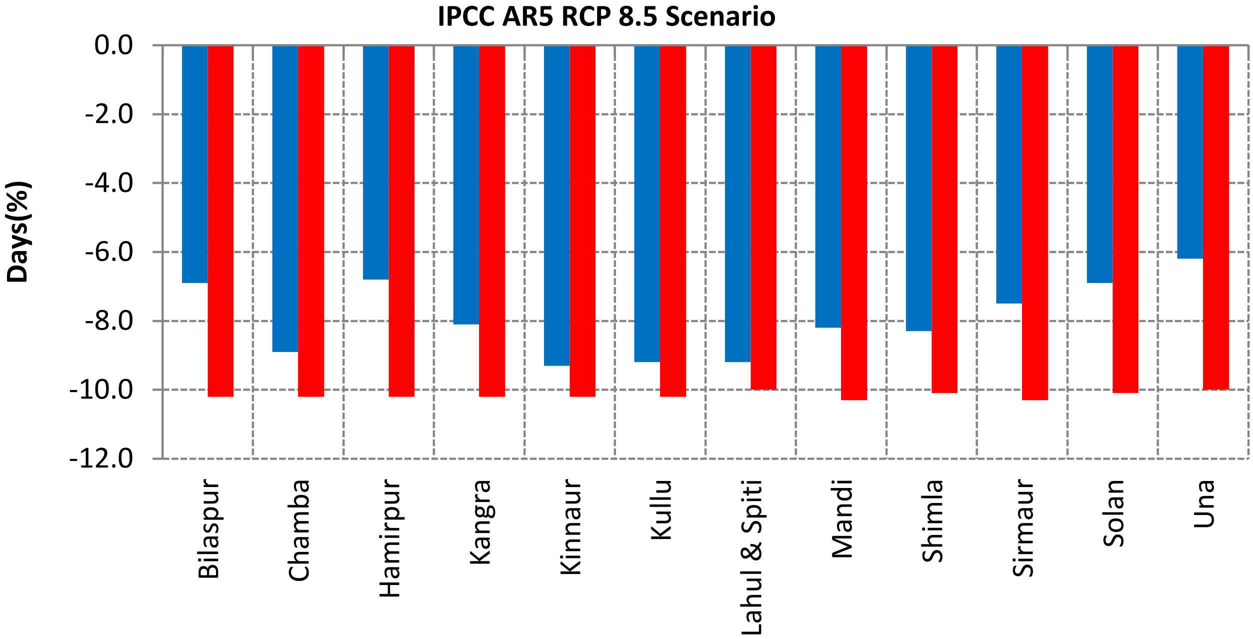
Warm Nights- Annual % of days where minimum temperature > 90th percentile of base period



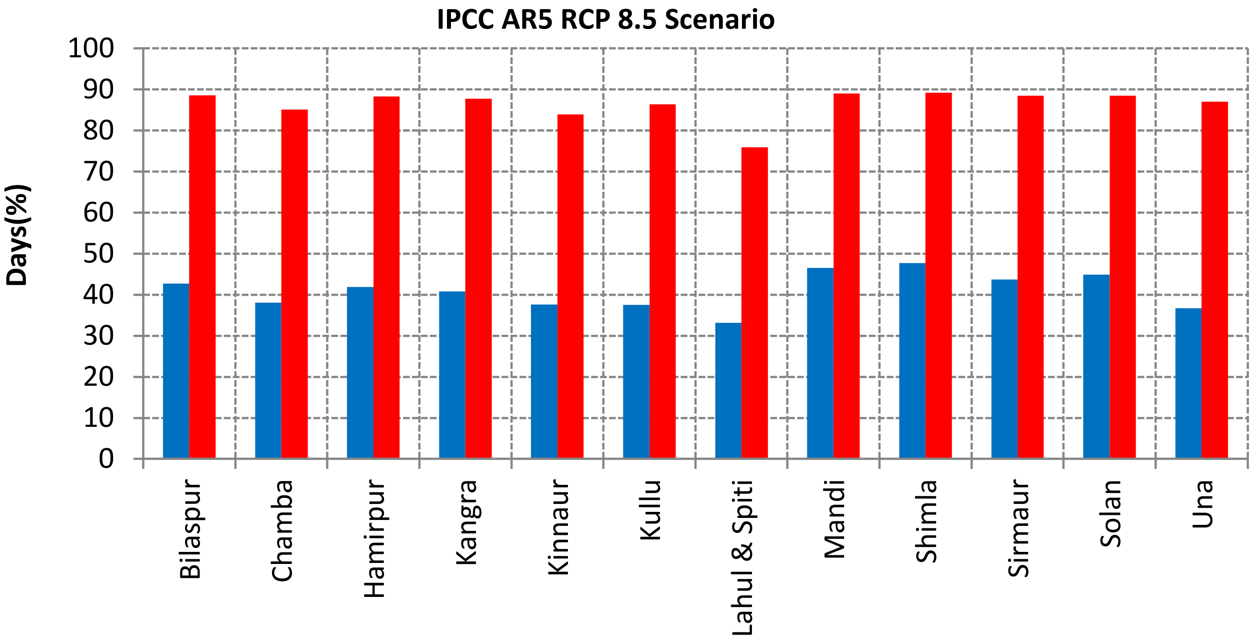
Warm Days- Annual % of days where maximum temperature > 90th percentile of base period



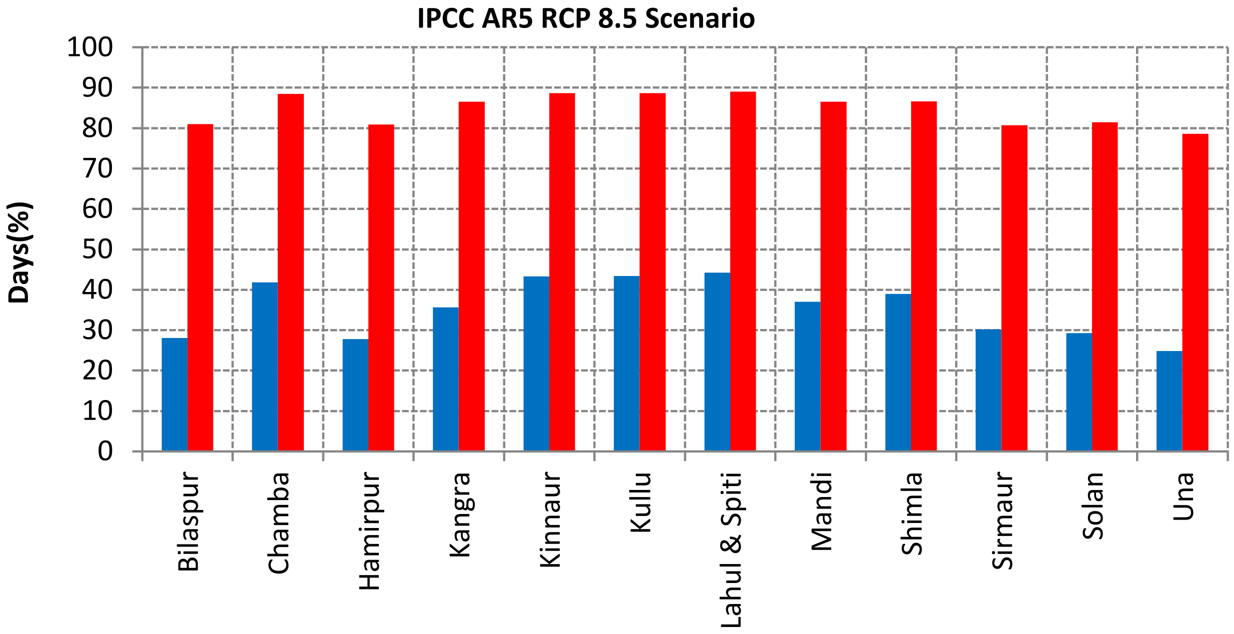
Cool nights - Annual % of days where minimum temperature < 10th percentile of base period



Cool days - Annual % of days where maximum temperature < 10th percentile of base period

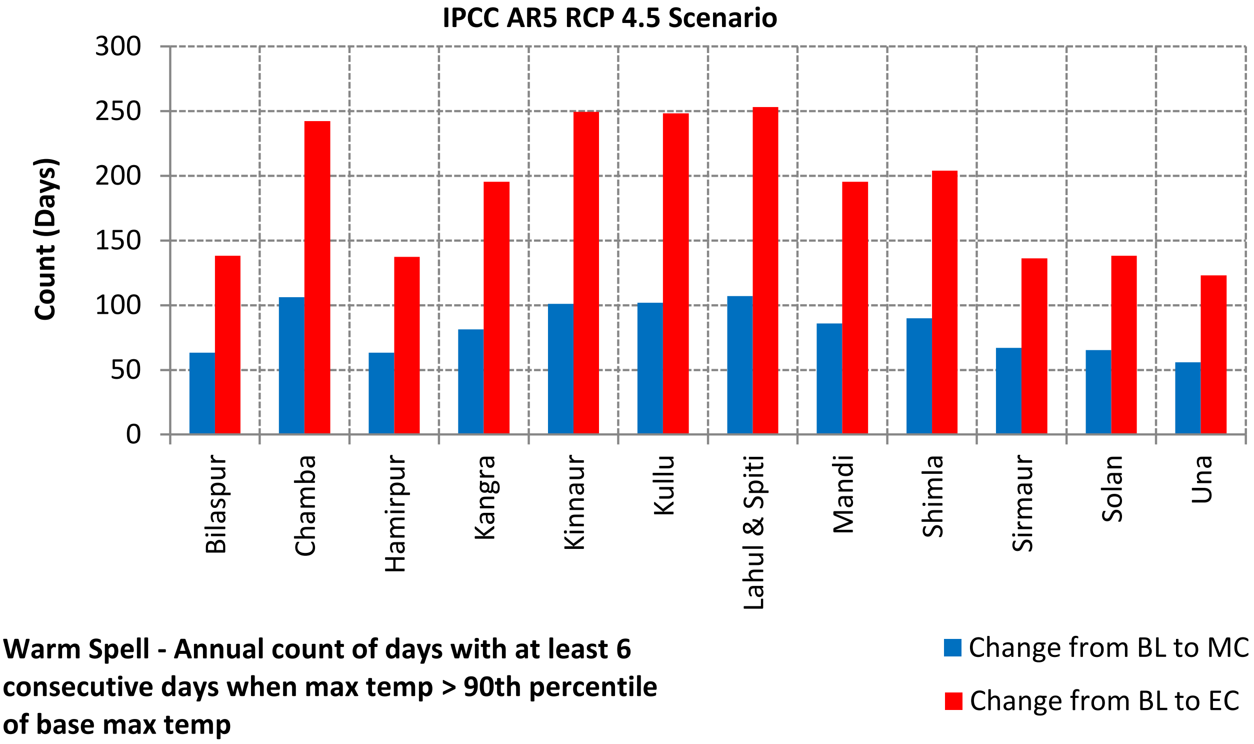


Warm Nights- Annual % of days where minimum temperature > 90th percentile of base period

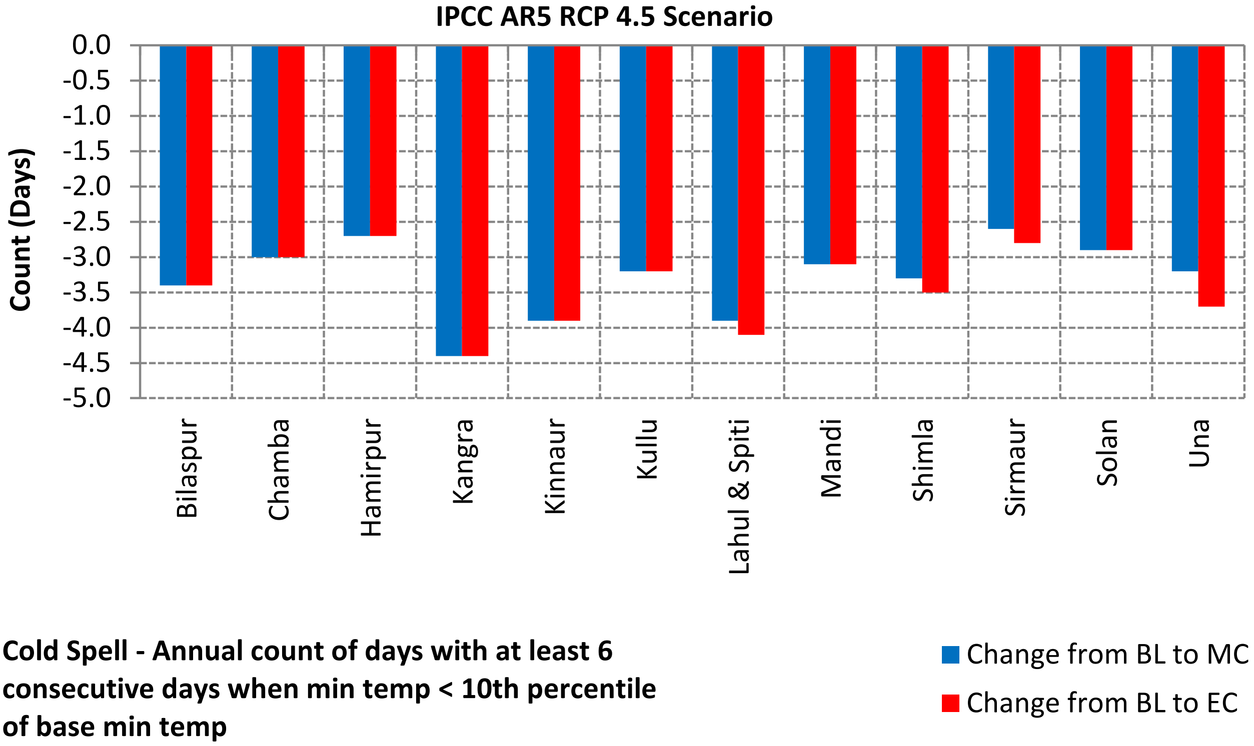


Warm Days- Annual % of days where maximum temperature > 90th percentile of base period

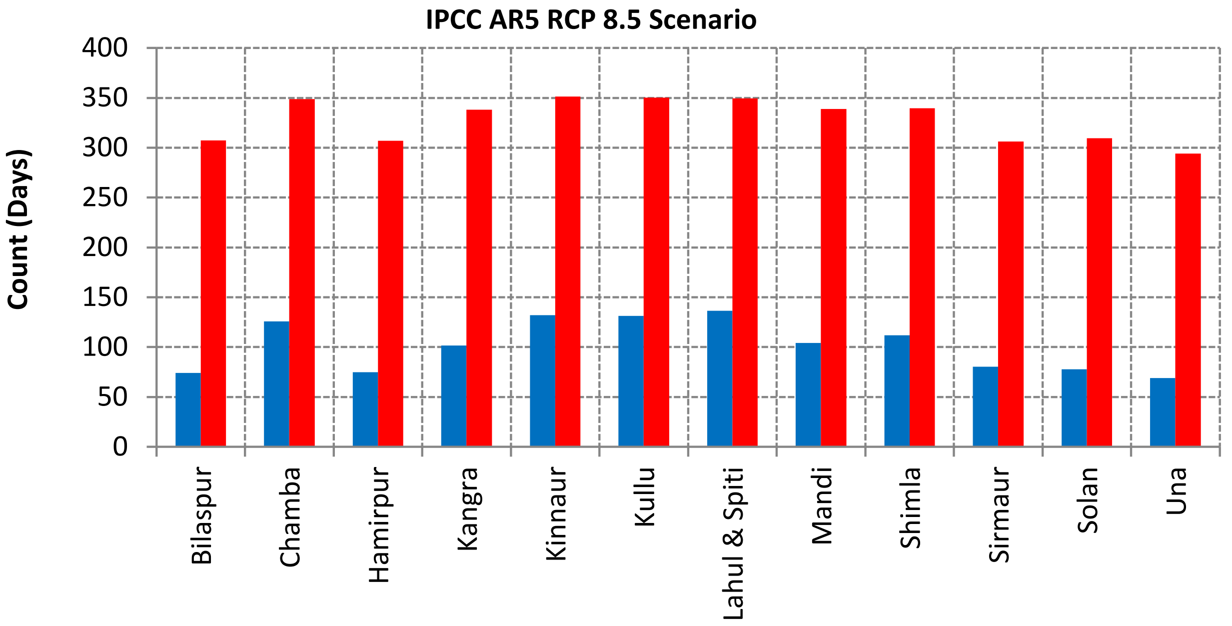
Figure 35 : Characteristics of duration temperature extremes indices for districts of Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenarios)



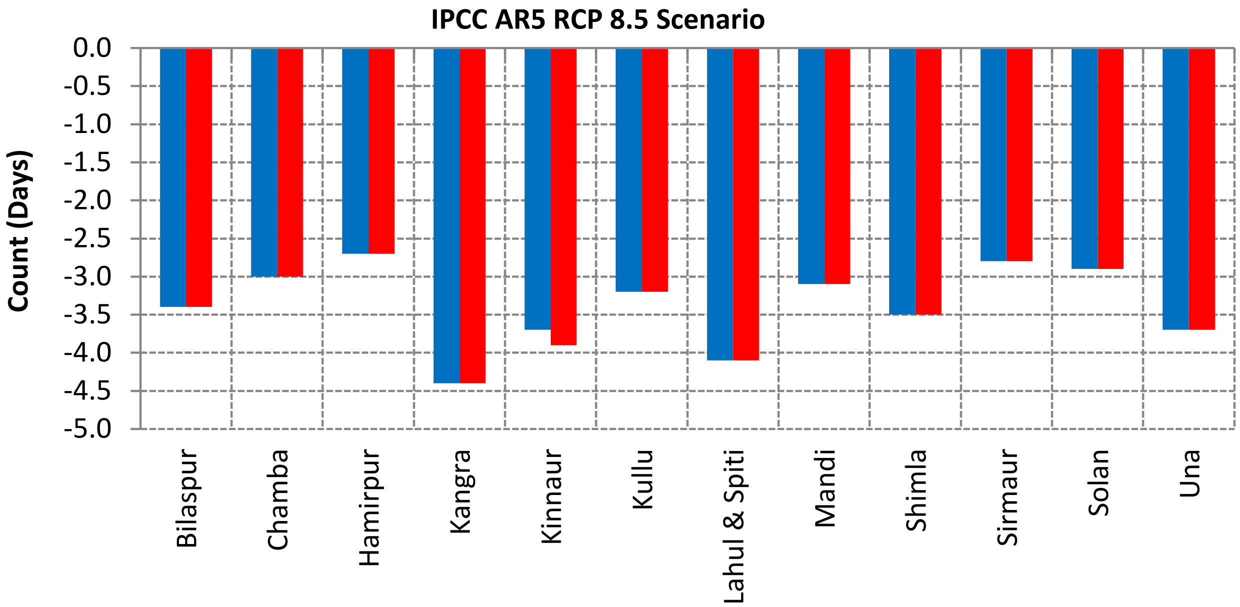
Warm Spell - Annual count of days with at least 6 consecutive days when max temp > 90th percentile of base max temp



Cold Spell - Annual count of days with at least 6 consecutive days when min temp < 10th percentile of base min temp

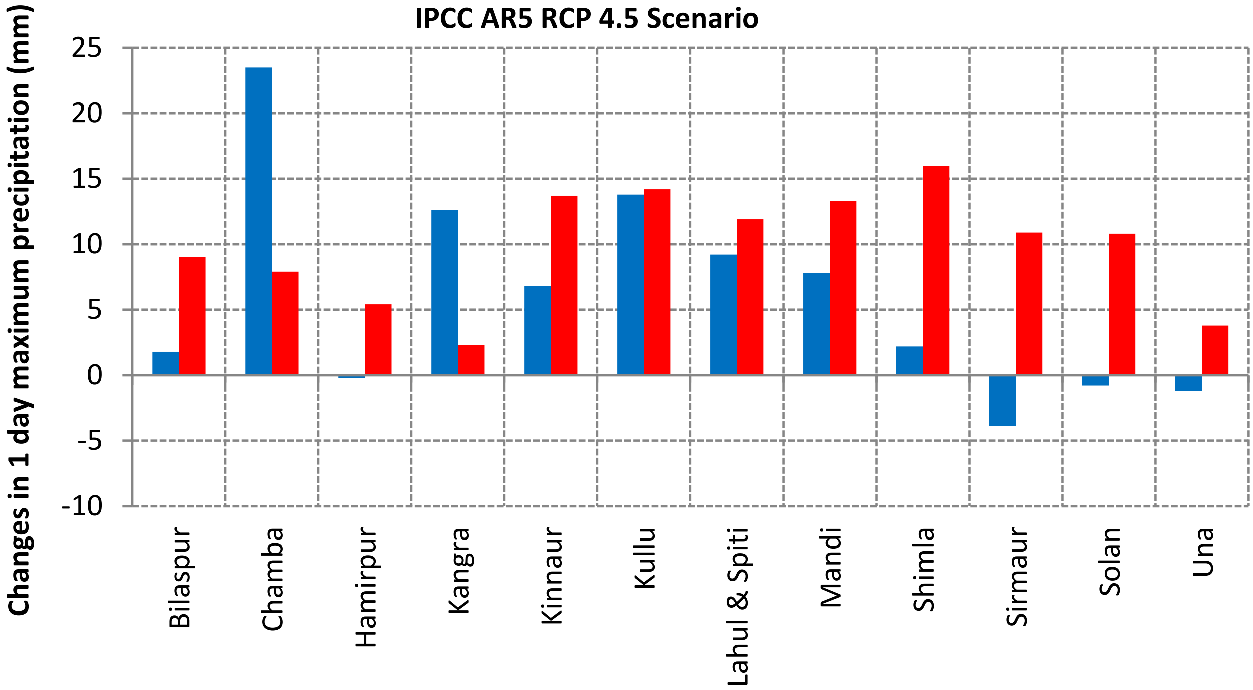


Warm Spell - Annual count of days with at least 6 consecutive days when max temp > 90th percentile of base max temp

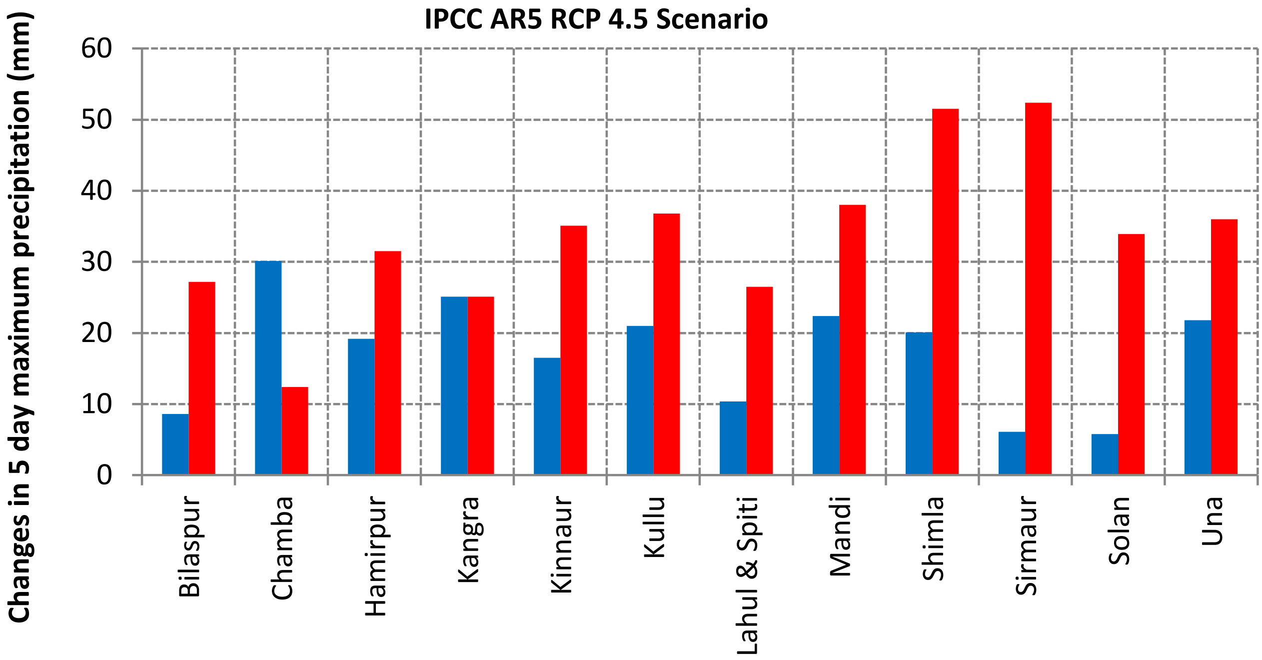


Cold Spell - Annual count of days with at least 6 consecutive days when min temp < 10th percentile of base min temp

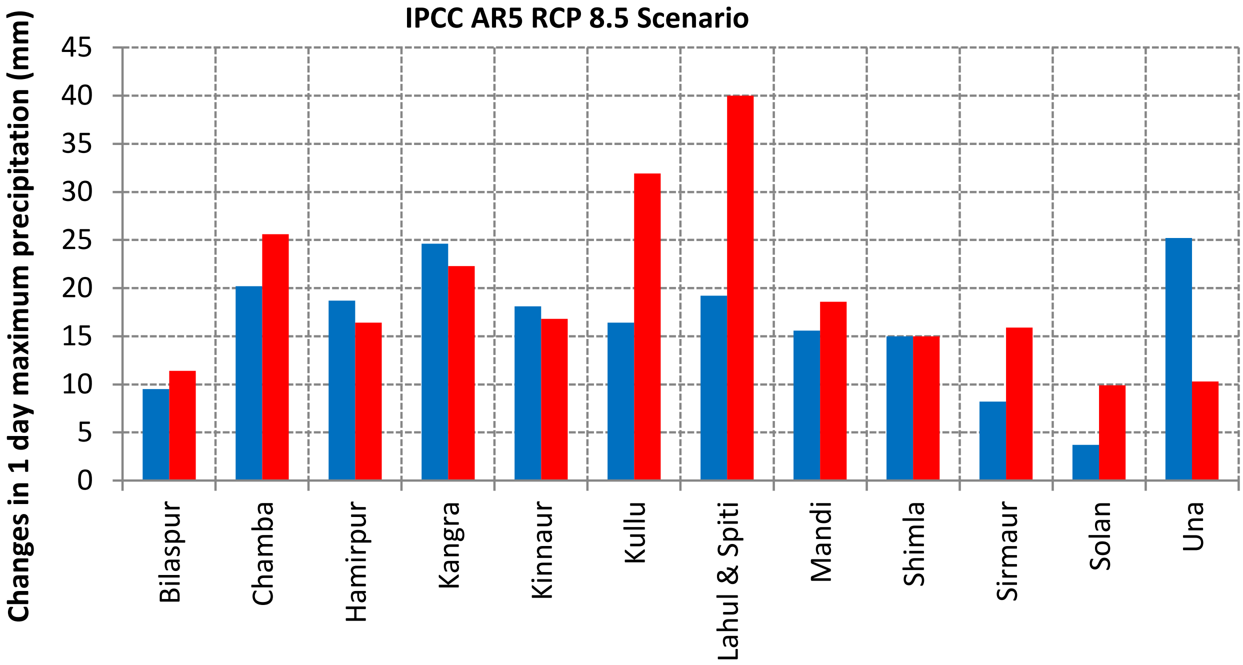
Figure 36 : Characteristics of absolute precipitation extremes indices for districts of Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenarios)



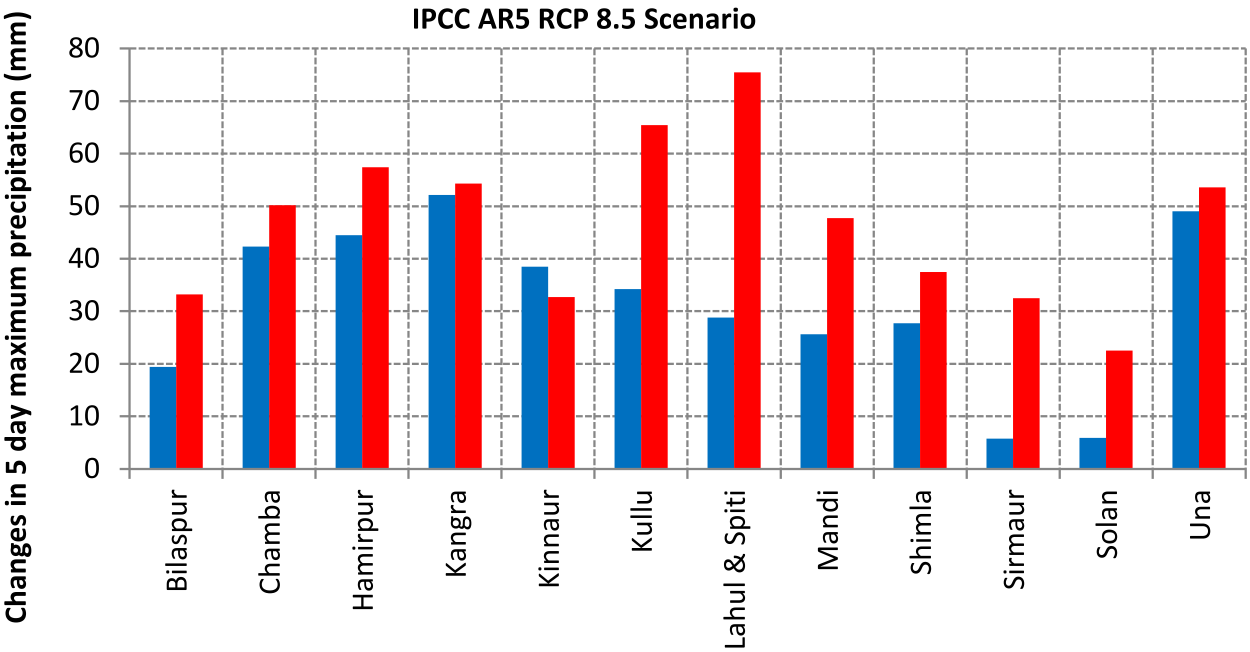
1-day maximum precipitation



5-day maximum precipitation

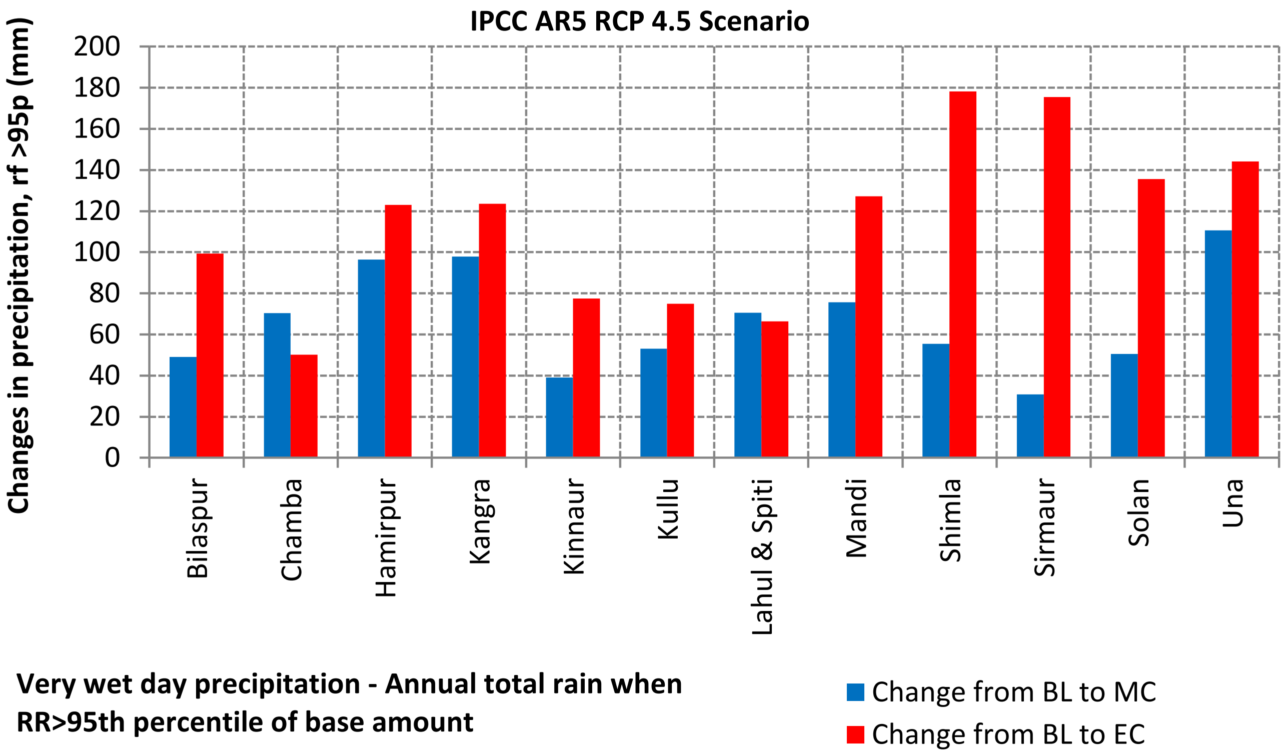


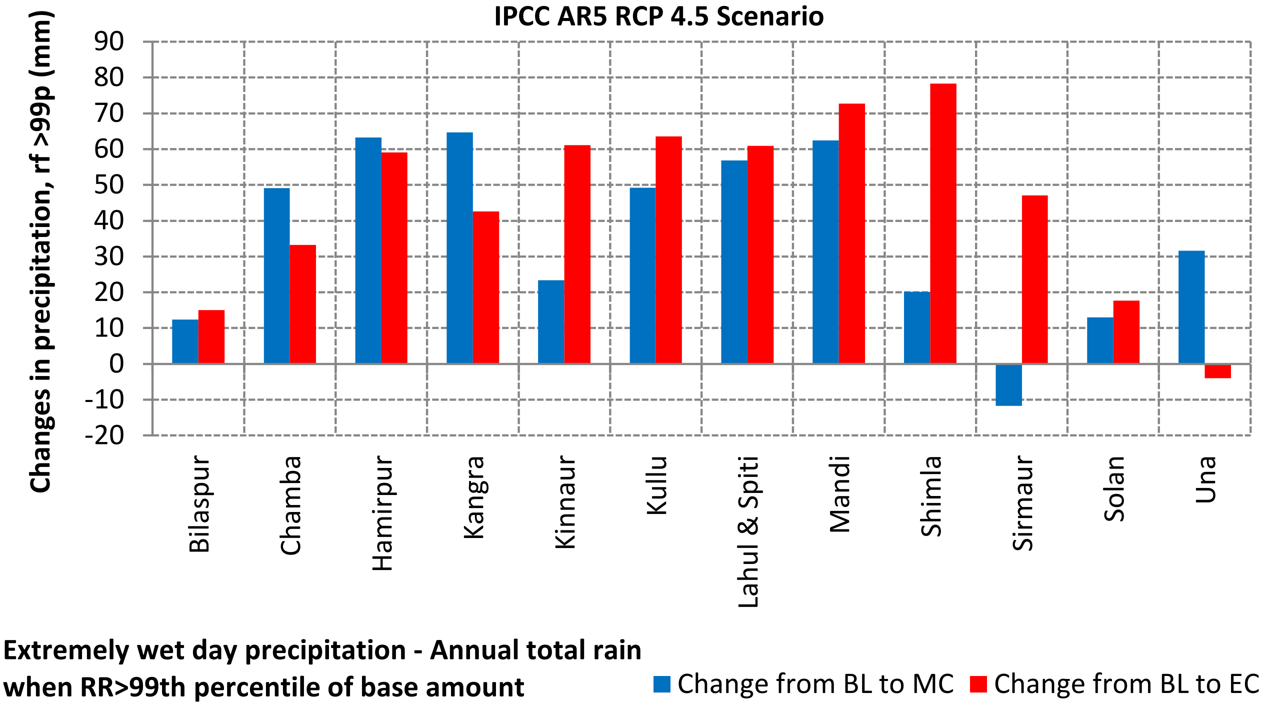
1-day maximum precipitation

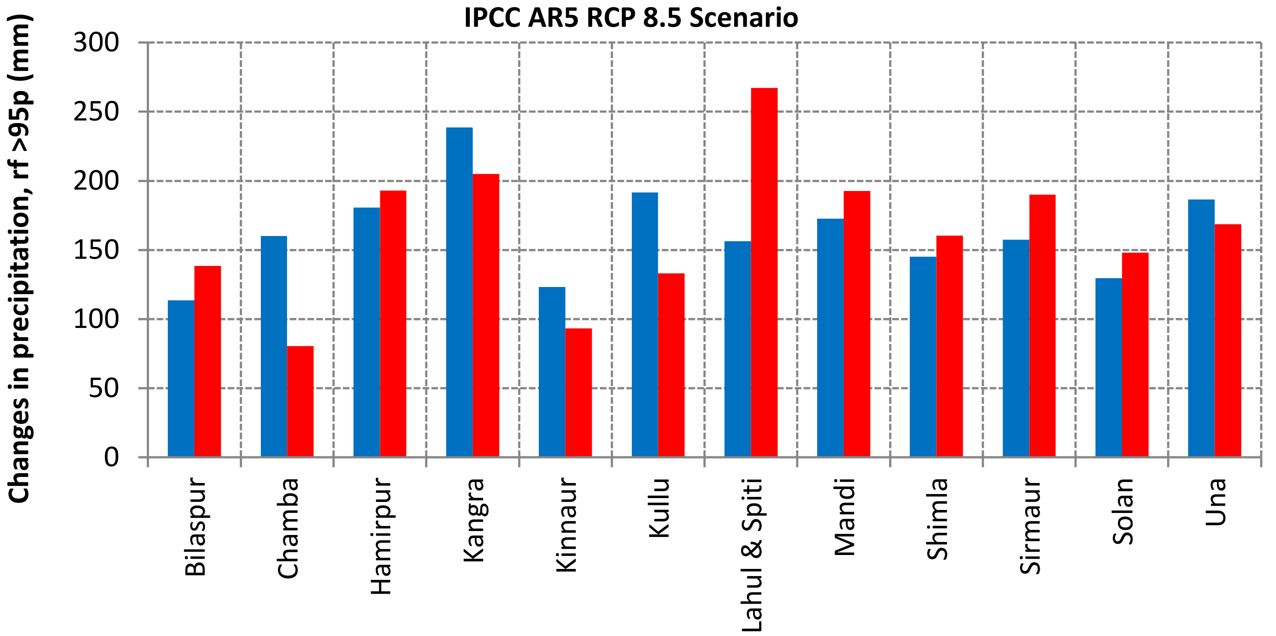


5-day maximum precipitation

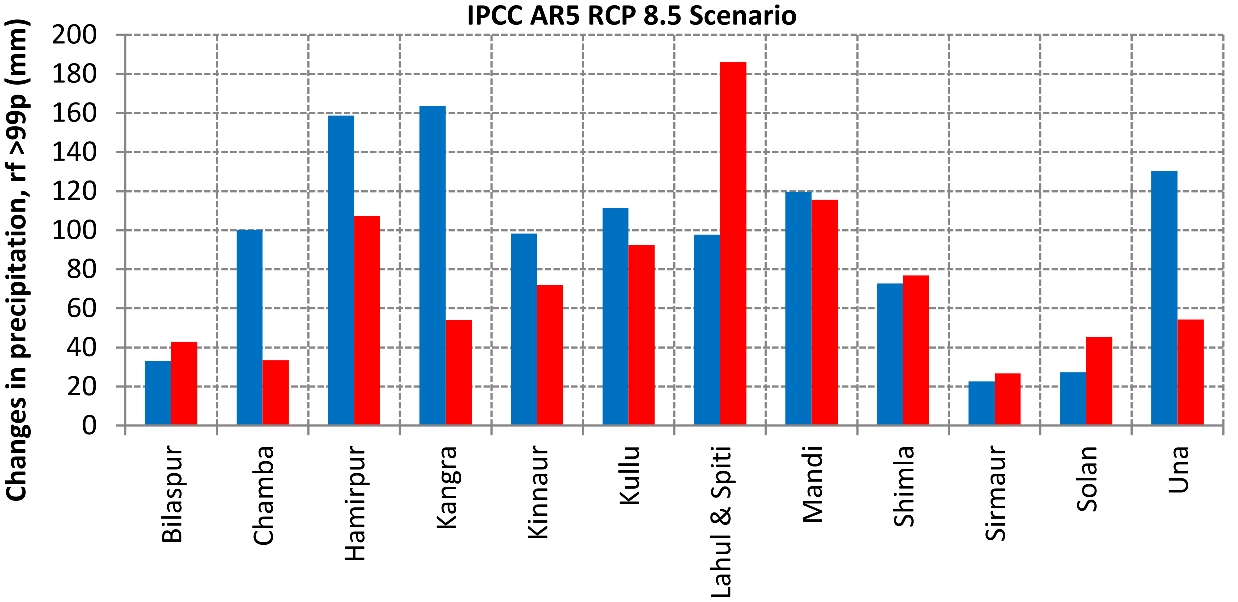
Figure 37 : Characteristics of percentile precipitation extremes indices for districts of Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenarios)





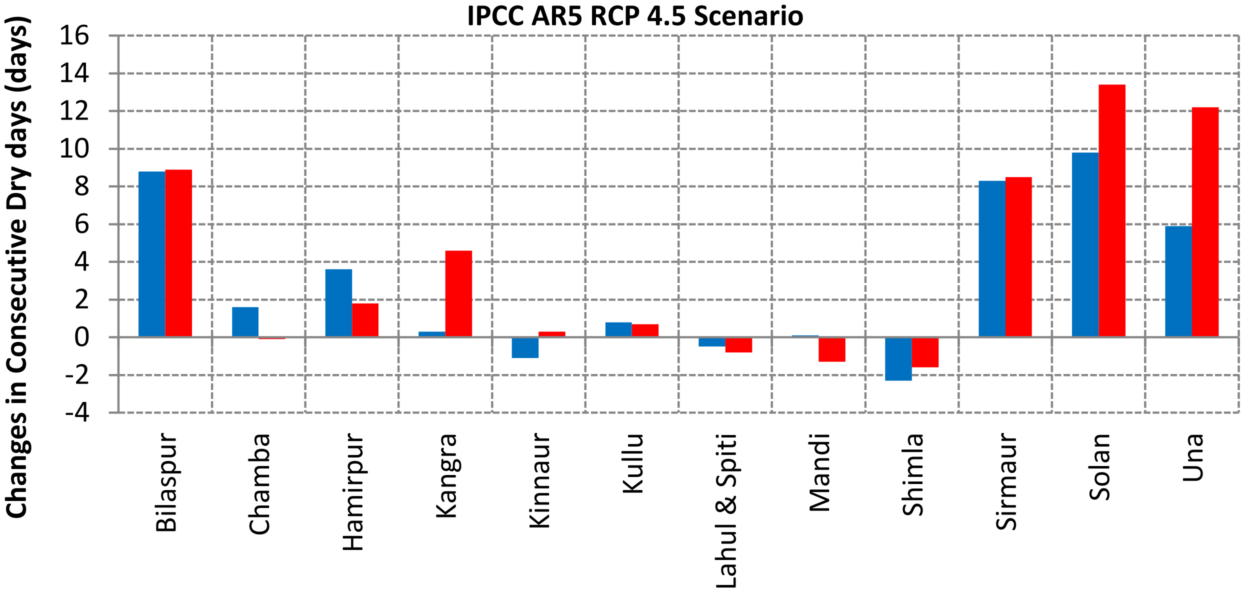


Very wet day precipitation - Annual total rain when RR>95th percentile of base amount

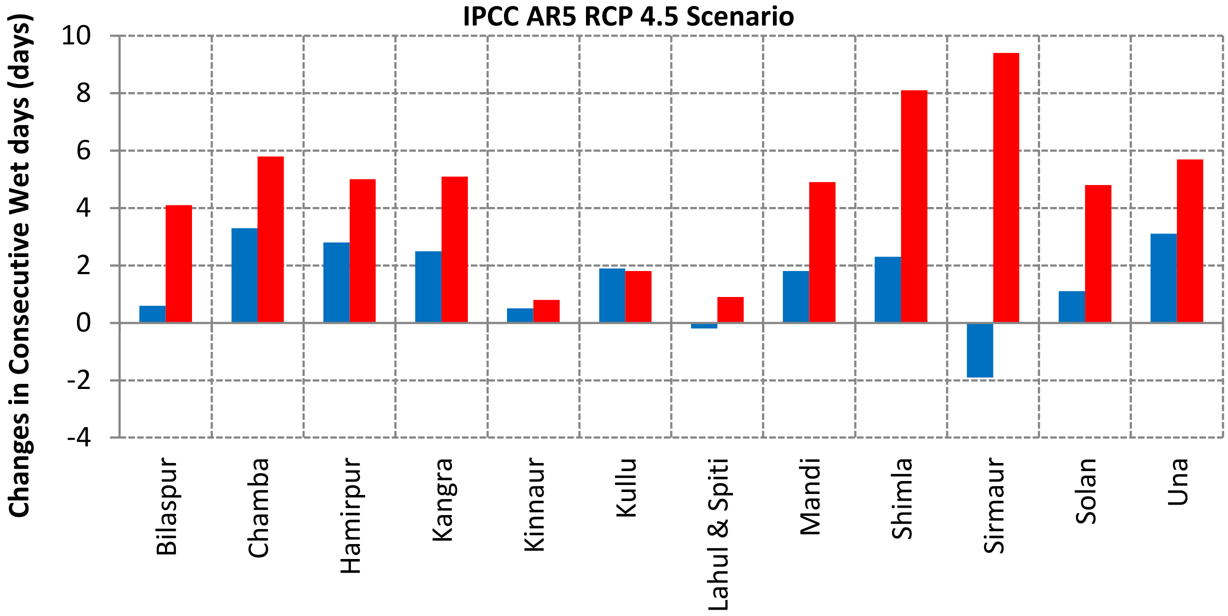


Extremely wet day precipitation - Annual total rain when RR>99th percentile of base amount

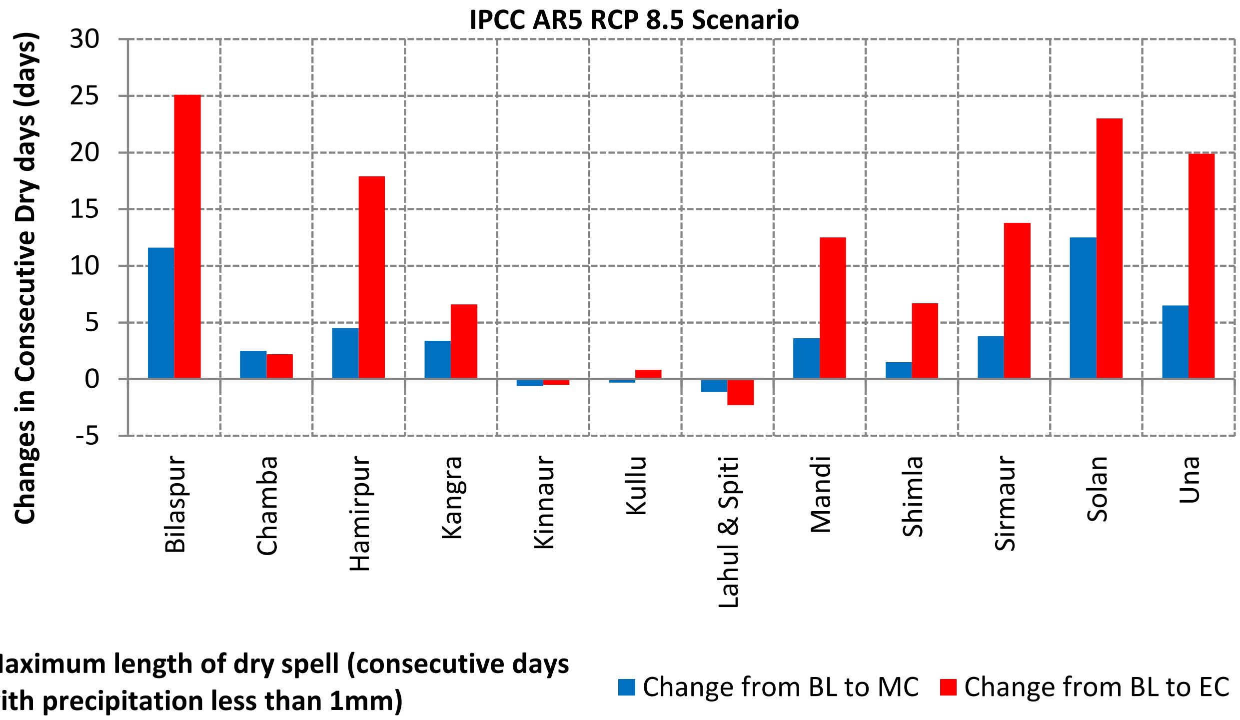
Figure 38 : Characteristics of duration precipitation extremes indices for districts of Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenarios)



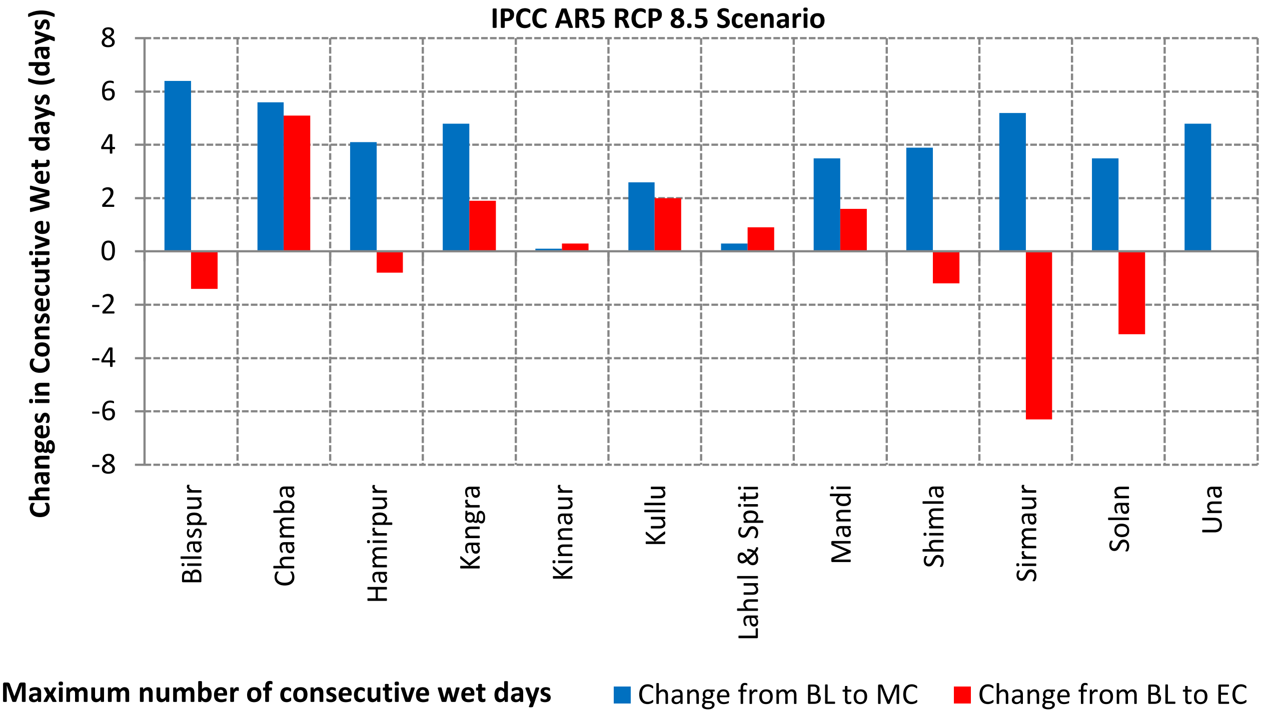
Maximum length of dry spell (consecutive days with precipitation less than 1mm)



Maximum number of consecutive wet days

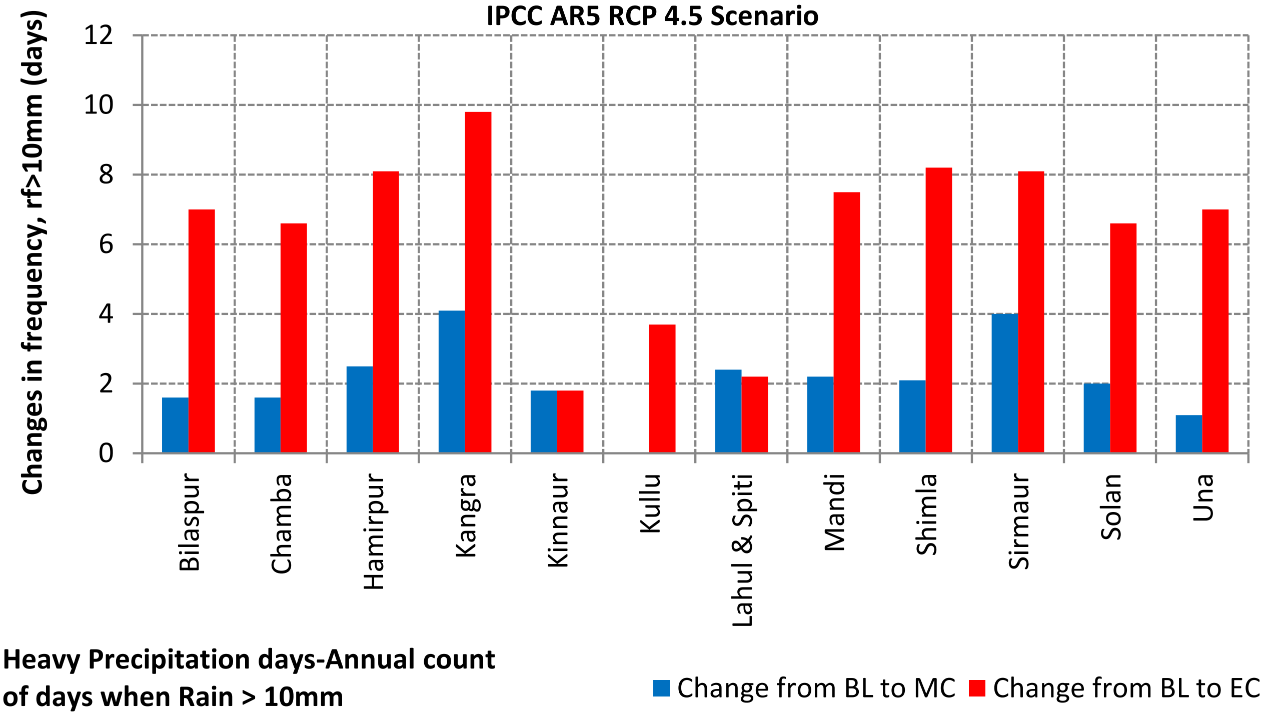


Maximum length of dry spell (consecutive days with precipitation less than 1mm)

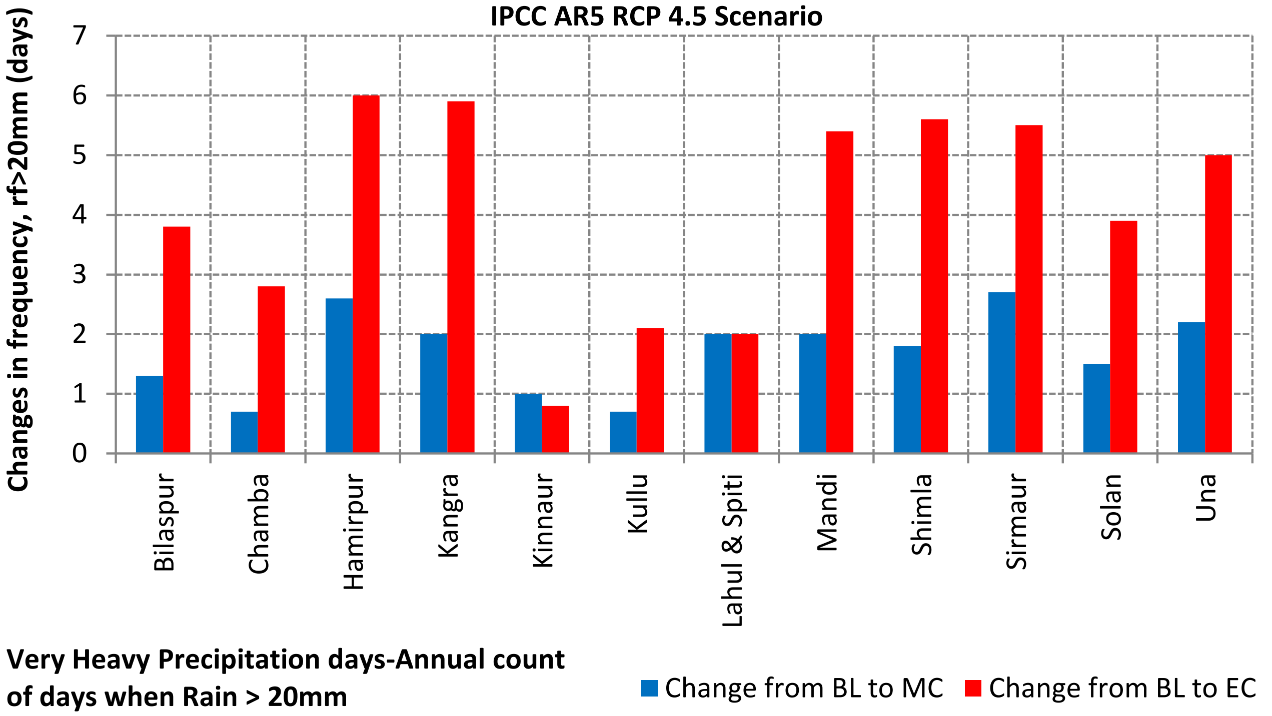


Maximum number of consecutive wet days

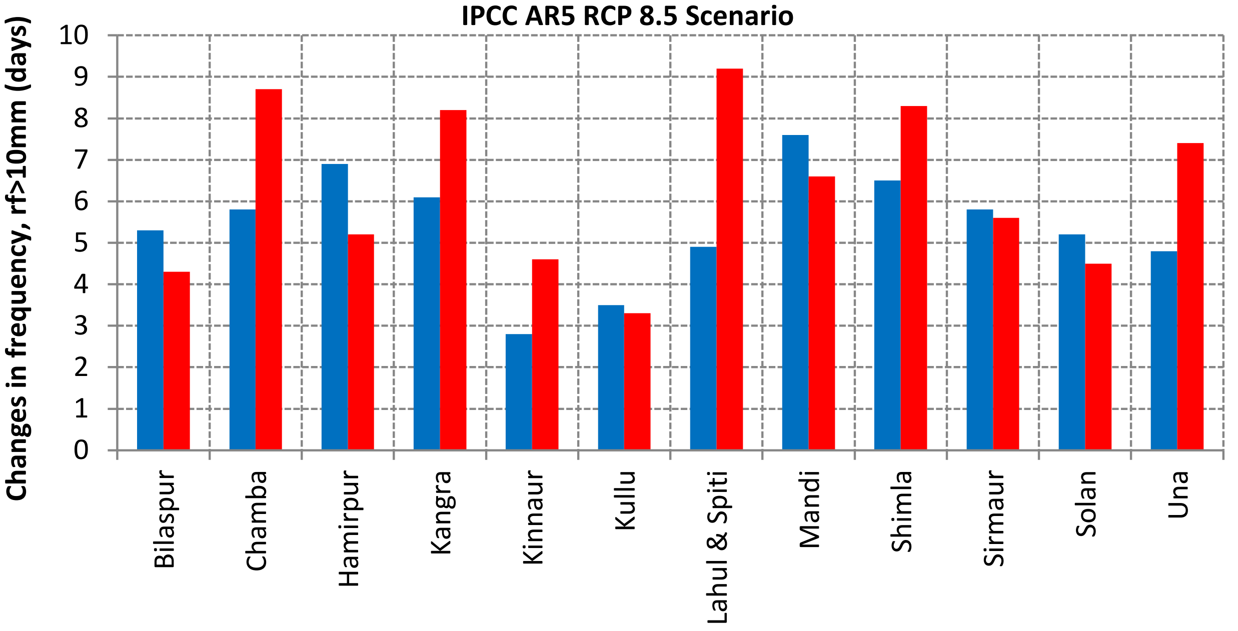
Figure 39 : Characteristics of threshold precipitation extremes indices for districts of Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenario)



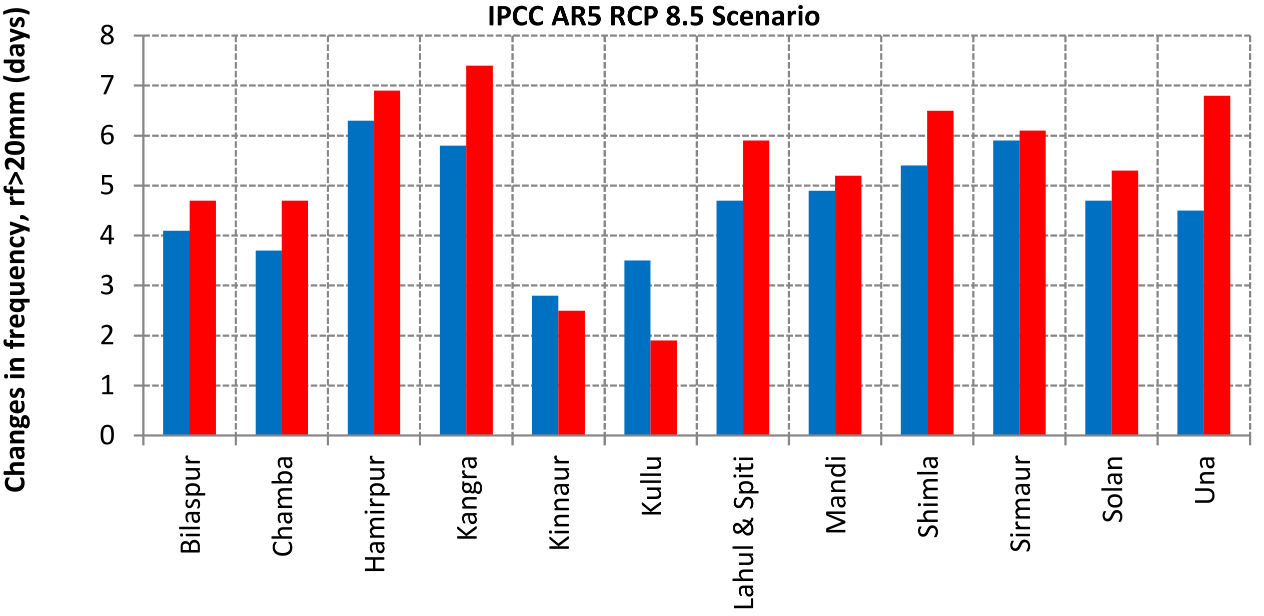
Heavy Precipitation days-Annual count of days when Rain > 10mm



Very Heavy Precipitation days-Annual count of days when Rain > 20mm

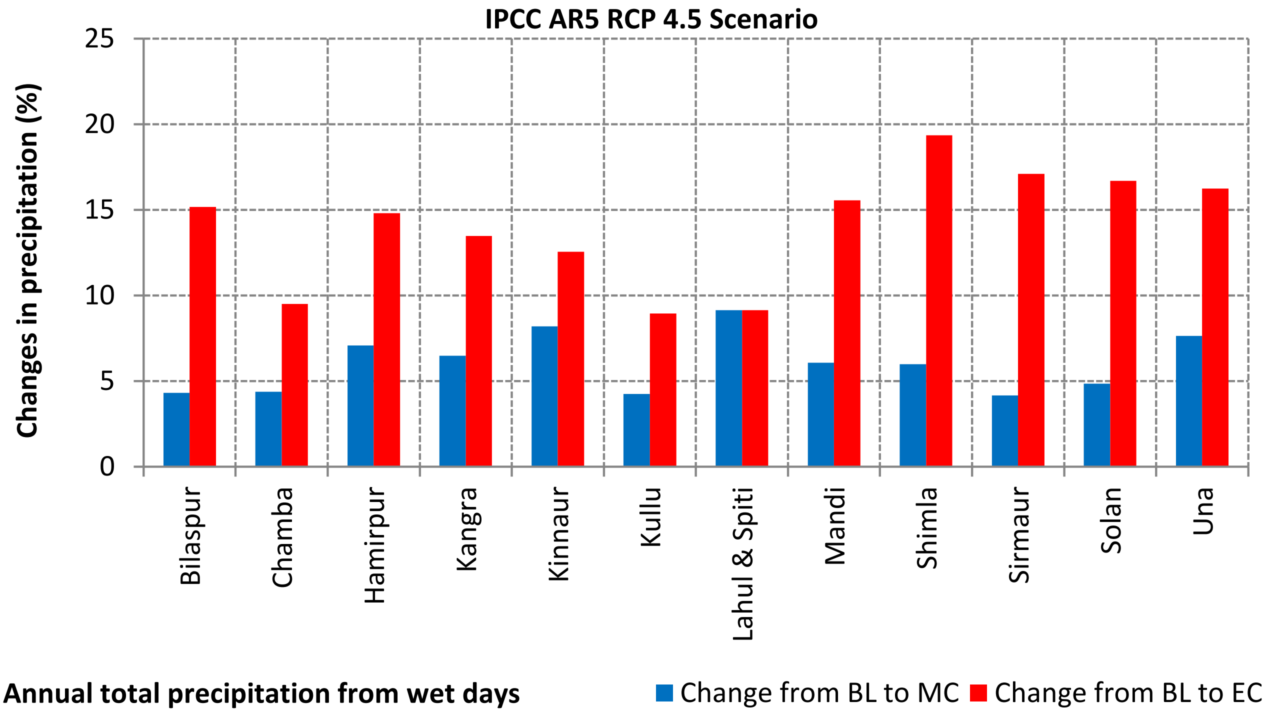


Heavy Precipitation days-Annual count of days when Rain > 10mm

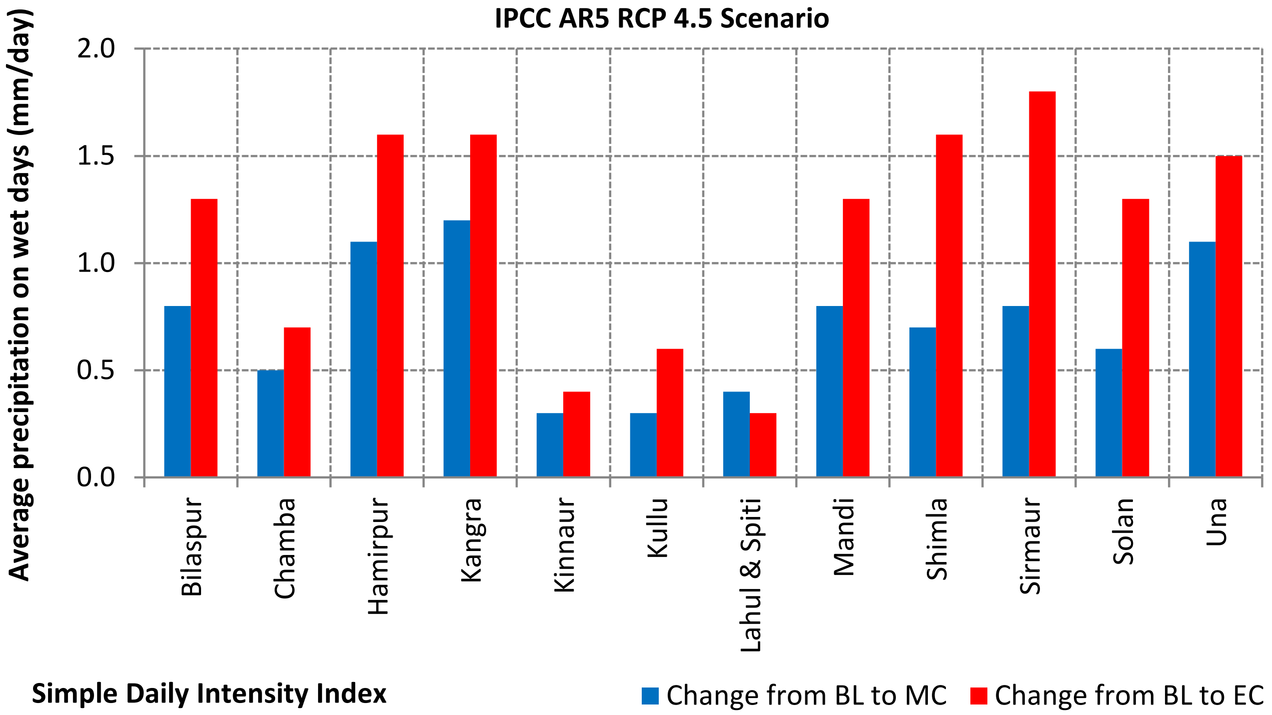


Very Heavy Precipitation days-Annual count of days when Rain > 20mm

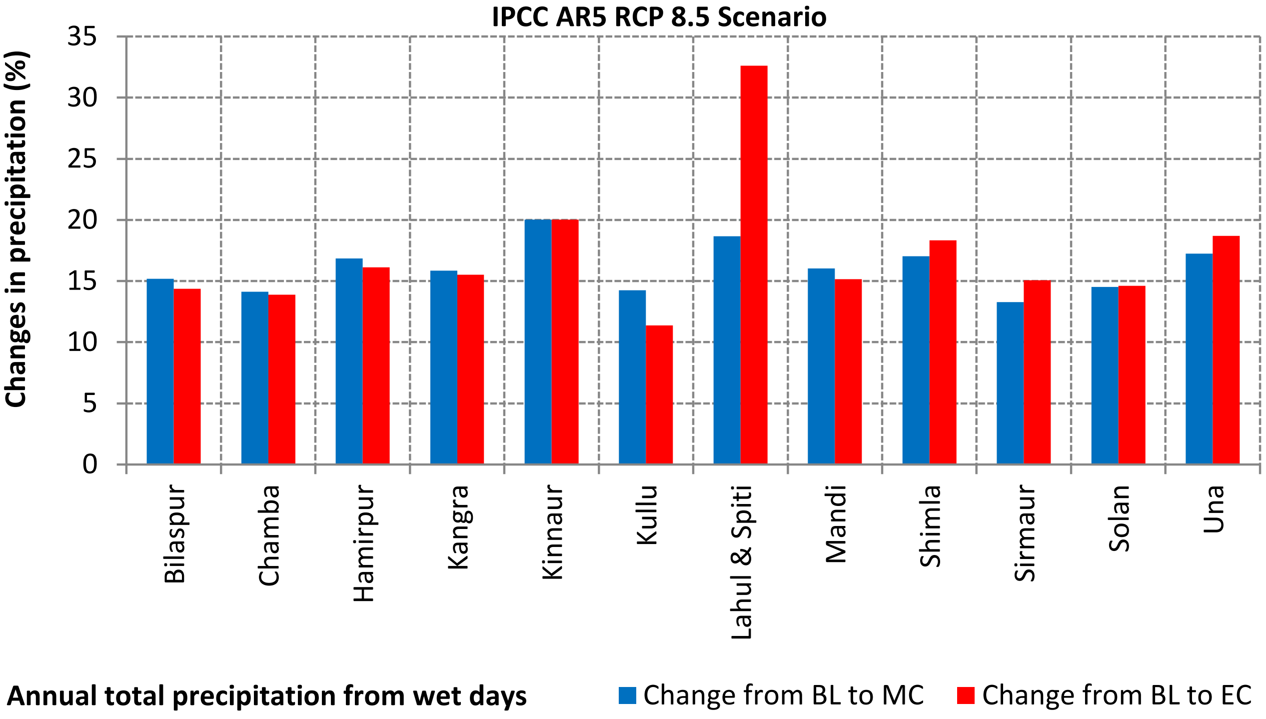
Figure 40 : Characteristics of other precipitation extremes indices for districts of Himachal Pradesh (IPCC AR5 RCP4.5 and RCP8.5 scenario)



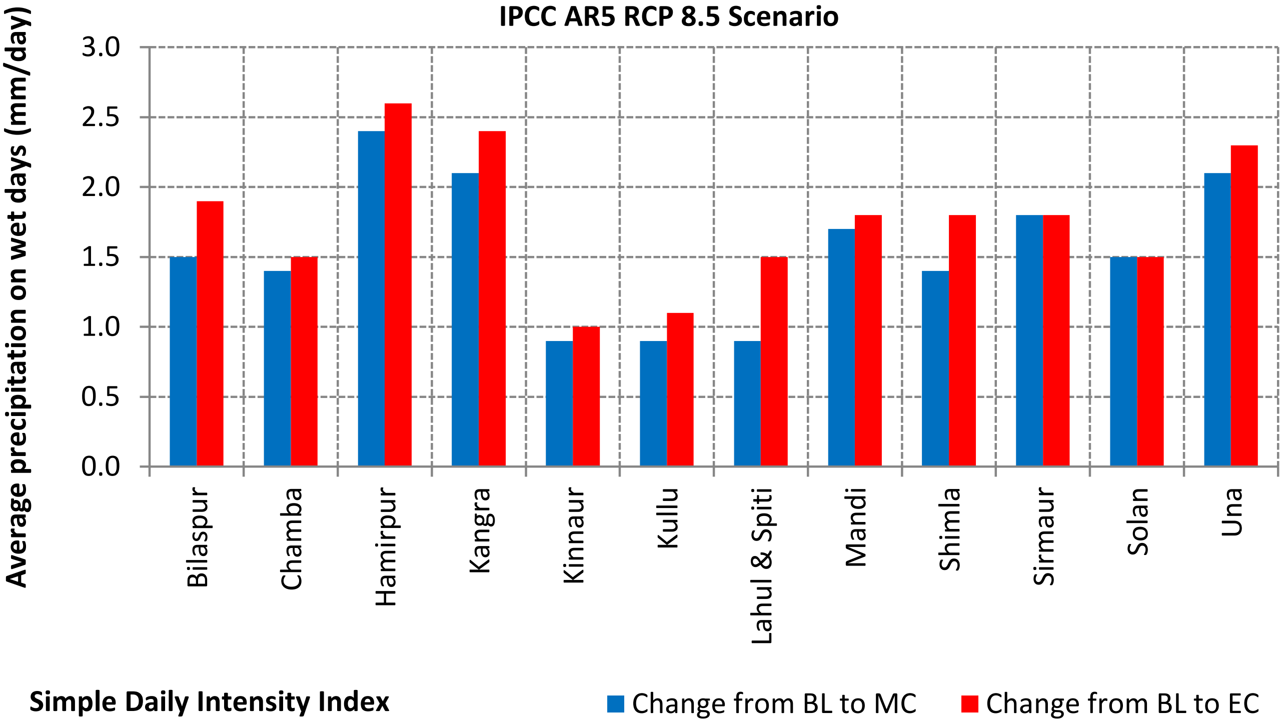
Annual total precipitation from wet days



Simple Daily Intensity Index

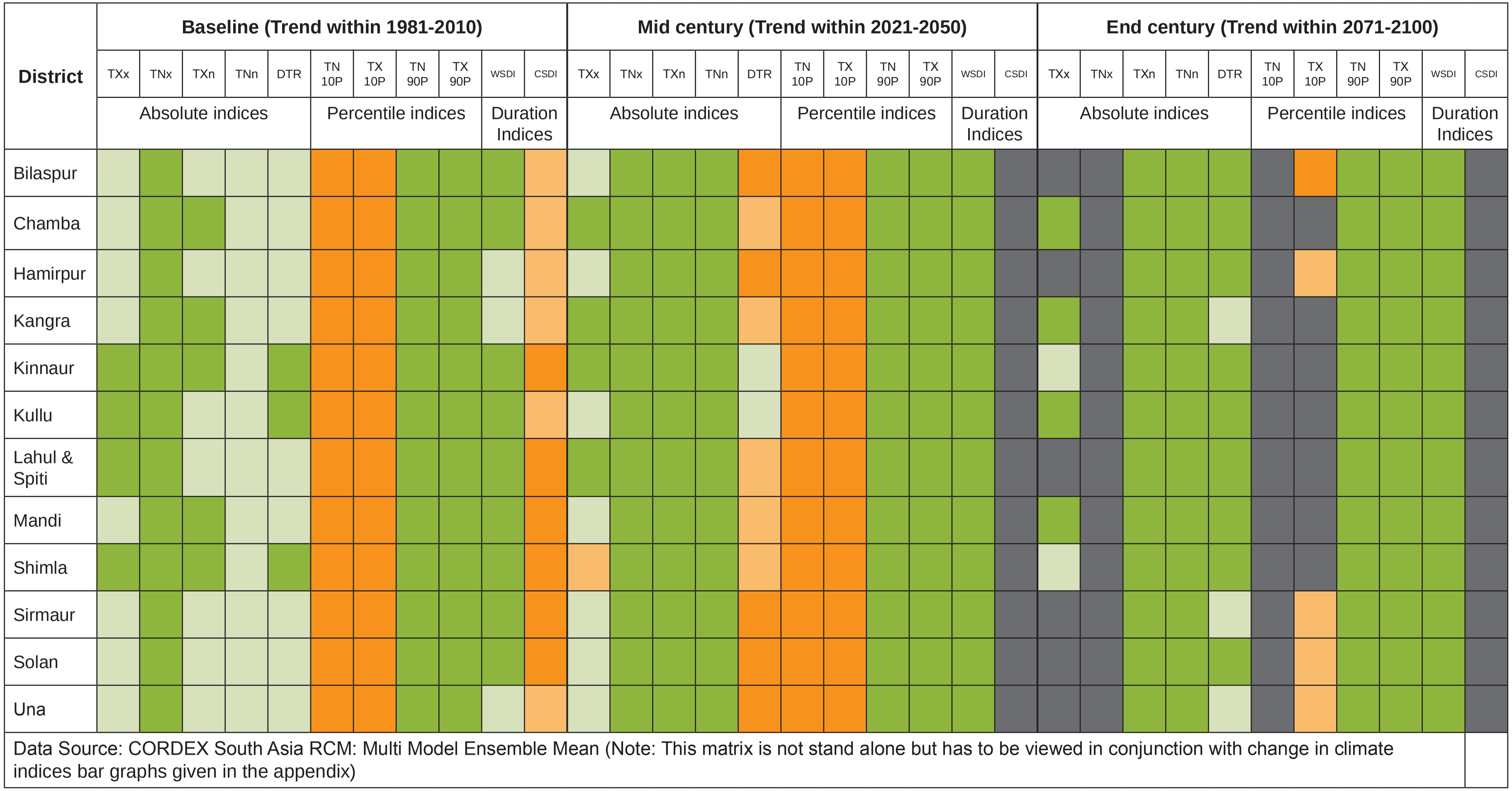


Annual total precipitation from wet days



Simple Daily Intensity Index

Table 16 : Trend in temperature extremes indices for individual time slices for districts of Himachal Pradesh (IPCC AR5 RCP4.5 scenario)



District	Baseline (Trend within 1981-2010)										
	Absolute indices					Percentile indices				Duration Indices	
	TXx	TNx	TXn	TNn	DTR	TN 10P	TX 10P	TN 90P	TX 90P	WSDI	CSDI
Bilaspur	▨	🟩	▨	▨	▨	🟧	🟧	🟩	🟩	🟩	▧
Chamba	▨	🟩	🟩	▨	▨	🟧	🟧	🟩	🟩	🟩	▧
Hamirpur	▨	🟩	▨	▨	▨	🟧	🟧	🟩	🟩	▨	▧
Kangra	▨	🟩	🟩	▨	▨	🟧	🟧	🟩	🟩	▨	▧
Kinnaur	🟩	🟩	🟩	▨	🟩	🟧	🟧	🟩	🟩	🟩	🟧
Kullu	🟩	🟩	▨	▨	🟩	🟧	🟧	🟩	🟩	🟩	▧
Lahul & Spiti	🟩	🟩	▨	▨	▨	🟧	🟧	🟩	🟩	🟩	🟧
Mandi	▨	🟩	🟩	▨	▨	🟧	🟧	🟩	🟩	🟩	🟧
Shimla	🟩	🟩	🟩	▨	🟩	🟧	🟧	🟩	🟩	🟩	🟧
Sirmaur	▨	🟩	▨	▨	▨	🟧	🟧	🟩	🟩	🟩	🟧
Solan	▨	🟩	▨	▨	▨	🟧	🟧	🟩	🟩	🟩	🟧
Una	▨	🟩	▨	▨	▨	🟧	🟧	🟩	🟩	▨	▧

District	Mid century (Trend within 2021-2050)										
	Absolute indices					Percentile indices				Duration Indices	
	TXx	TNx	TXn	TNn	DTR	TN 10P	TX 10P	TN 90P	TX 90P	WSDI	CSDI
Bilaspur	▨	🟩	🟩	🟩	🟧	🟧	🟧	🟩	🟩	🟩	⬛
Chamba	🟩	🟩	🟩	🟩	▧	🟧	🟧	🟩	🟩	🟩	⬛
Hamirpur	▨	🟩	🟩	🟩	🟧	🟧	🟧	🟩	🟩	🟩	⬛
Kangra	🟩	🟩	🟩	🟩	▧	🟧	🟧	🟩	🟩	🟩	⬛
Kinnaur	🟩	🟩	🟩	🟩	▨	🟧	🟧	🟩	🟩	🟩	⬛
Kullu	▨	🟩	🟩	🟩	▨	🟧	🟧	🟩	🟩	🟩	⬛
Lahul & Spiti	🟩	🟩	🟩	🟩	▧	🟧	🟧	🟩	🟩	🟩	⬛
Mandi	▨	🟩	🟩	🟩	▧	🟧	🟧	🟩	🟩	🟩	⬛
Shimla	▧	🟩	🟩	🟩	▧	🟧	🟧	🟩	🟩	🟩	⬛
Sirmaur	▨	🟩	🟩	🟩	🟧	🟧	🟧	🟩	🟩	🟩	⬛
Solan	▨	🟩	🟩	🟩	🟧	🟧	🟧	🟩	🟩	🟩	⬛
Una	▨	🟩	🟩	🟩	🟧	🟧	🟧	🟩	🟩	🟩	⬛

District	End century (Trend within 2071-2100)										
	Absolute indices					Percentile indices				Duration Indices	
	TXx	TNx	TXn	TNn	DTR	TN 10P	TX 10P	TN 90P	TX 90P	WSDI	CSDI
Bilaspur	⬛	⬛	🟩	🟩	🟩	⬛	🟧	🟩	🟩	🟩	⬛
Chamba	🟩	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Hamirpur	⬛	⬛	🟩	🟩	🟩	⬛	▧	🟩	🟩	🟩	⬛
Kangra	🟩	⬛	🟩	🟩	▨	⬛	⬛	🟩	🟩	🟩	⬛
Kinnaur	▨	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Kullu	🟩	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Lahul & Spiti	⬛	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Mandi	🟩	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Shimla	▨	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Sirmaur	⬛	⬛	🟩	🟩	▨	⬛	▧	🟩	🟩	🟩	⬛
Solan	⬛	⬛	🟩	🟩	🟩	⬛	▧	🟩	🟩	🟩	⬛
Una	⬛	⬛	🟩	🟩	▨	⬛	▧	🟩	🟩	🟩	⬛

Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean (Note: This matrix is not stand alone but has to be viewed in conjunction with change in climate indices bar graphs given in the appendix)

🟩 Positive Significant trend
▨ Positive Non-significant trend
🟧 Negative Significant trend
▧ Negative Non-significant trend
🟦 No Change
⬛ NA

Table 17 : Trend in temperature extremes indices for individual time slices for districts of Himachal Pradesh (IPCC AR5 RCP8.5 scenario)

District	Baseline											Mid century											End century										
	TXx	TNx	TXn	TNn	DTR	TN 10P	TX 10P	TN 90P	TX 90P	WSDI	CSDI	TXx	TNx	TXn	TNn	DTR	TN 10P	TX 10P	TN 90P	TX 90P	WSDI	CSDI	TXx	TNx	TXn	TNn	DTR	TN 10P	TX 10P	TN 90P	TX 90P	WSDI	CSDI
	Absolute indices					Percentile indices				Duration Indices		Absolute indices					Percentile indices				Duration Indices		Absolute indices					Percentile indices				Duration Indices	
Bilaspur	🟢	🟩	🟢	🟢	🟢	🟧	🟧	🟩	🟩	🟩	🟠	🟢	🟩	🟩	🟩	🟧	🟧	🟧	🟩	🟩	🟩	⬛	⬛	⬛	🟩	🟩	🟩	⬛	🟧	🟩	🟩	🟩	⬛
Chamba	🟢	🟩	🟩	🟢	🟢	🟧	🟧	🟩	🟩	🟩	🟠	🟩	🟩	🟩	🟩	🟠	🟧	🟧	🟩	🟩	🟩	⬛	🟩	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Hamirpur	🟢	🟩	🟢	🟢	🟢	🟧	🟧	🟩	🟩	🟢	🟠	🟢	🟩	🟩	🟩	🟧	🟧	🟧	🟩	🟩	🟩	⬛	⬛	⬛	🟩	🟩	🟩	⬛	🟠	🟩	🟩	🟩	⬛
Kangra	🟢	🟩	🟩	🟢	🟢	🟧	🟧	🟩	🟩	🟢	🟠	🟩	🟩	🟩	🟩	🟠	🟧	🟧	🟩	🟩	🟩	⬛	🟩	⬛	🟩	🟩	🟢	⬛	⬛	🟩	🟩	🟩	⬛
Kinnaur	🟩	🟩	🟩	🟢	🟩	🟧	🟧	🟩	🟩	🟩	🟧	🟩	🟩	🟩	🟩	🟢	🟧	🟧	🟩	🟩	🟩	⬛	🟢	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Kullu	🟩	🟩	🟢	🟢	🟩	🟧	🟧	🟩	🟩	🟩	🟠	🟢	🟩	🟩	🟩	🟢	🟧	🟧	🟩	🟩	🟩	⬛	🟩	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Lahul & Spiti	🟩	🟩	🟢	🟢	🟢	🟧	🟧	🟩	🟩	🟩	🟧	🟩	🟩	🟩	🟩	🟠	🟧	🟧	🟩	🟩	🟩	⬛	⬛	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Mandi	🟢	🟩	🟩	🟢	🟢	🟧	🟧	🟩	🟩	🟩	🟧	🟢	🟩	🟩	🟩	🟠	🟧	🟧	🟩	🟩	🟩	⬛	🟩	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Shimla	🟩	🟩	🟩	🟢	🟩	🟧	🟧	🟩	🟩	🟩	🟧	🟠	🟩	🟩	🟩	🟠	🟧	🟧	🟩	🟩	🟩	⬛	🟢	⬛	🟩	🟩	🟩	⬛	⬛	🟩	🟩	🟩	⬛
Sirmaur	🟢	🟩	🟢	🟢	🟢	🟧	🟧	🟩	🟩	🟩	🟧	🟢	🟩	🟩	🟩	🟧	🟧	🟧	🟩	🟩	🟩	⬛	⬛	⬛	🟩	🟩	🟢	⬛	🟠	🟩	🟩	🟩	⬛
Solan	🟢	🟩	🟢	🟢	🟢	🟧	🟧	🟩	🟩	🟩	🟧	🟢	🟩	🟩	🟩	🟧	🟧	🟧	🟩	🟩	🟩	⬛	⬛	⬛	🟩	🟩	🟩	⬛	🟠	🟩	🟩	🟩	⬛
Una	🟢	🟩	🟢	🟢	🟢	🟧	🟧	🟩	🟩	🟢	🟠	🟢	🟩	🟩	🟩	🟧	🟧	🟧	🟩	🟩	🟩	⬛	⬛	⬛	🟩	🟩	🟢	⬛	🟠	🟩	🟩	🟩	⬛

Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean (Note: This matrix is not stand alone but has to be viewed in conjunction with change in climate indices bar graphs given in the appendix)

🟩 Positive Significant trend
🟢 Positive Non-significant trend
🟧 Negative Significant trend
🟠 Negative Non-significant trend
🟦 No Change
⬛ NA

Table 18 : Trend in precipitation extremes indices for individual time slices for districts of Himachal Pradesh (IPCC AR5 RCP4.5 scenario)

District	Baseline											Mid century											End century							
	RX 1 day	RX 5 day	R 95p	R 99p	CDD	CWD	R 10mm	R 20mm	PRC PTOT	SDII	RX 1day	RX 5day	R 95p	R 99p	CDD	CWD	R 10mm	R 20mm	PRC PTOT	SDII	RX 1day	RX 5day	R 95p	R 99p	CDD	CWD	R 10mm	R 20mm	PRC PTOT	SDII
	Absolute Indices		Percentile Indices		Duration Indices		Threshold Indices		Other Indices		Absolute Indices		Percentile Indices		Duration Indices		Threshold Indices		Other Indices		Absolute Indices		Percentile Indices		Duration Indices		Threshold Indices		Other Indices	
Bilaspur	🟠	🟢	🟢	🟠	🟢	🟠	🟠	🟠	🟠	🟢	🟠	🟢	🟢	🟠	🟠	🟢	🟠	🟢	🟠	🟢	🟠	🟧	🟢	🟠	🟩	🟠	🟢	🟢	🟠	🟢
Chamba	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟦	🟢	🟠	🟢	🟠	🟠	🟢	🟠	🟢	🟢	🟢	🟢	🟠	🟠	🟢	🟠	🟠	🟠	🟢	🟢	🟢	🟢
Hamirpur	🟢	🟢	🟠	🟠	🟩	🟧	🟠	🟢	🟠	🟢	🟢	🟩	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟠	🟠	🟠	🟠	🟢	🟠	🟢	🟢	🟢	🟢
Kangra	🟢	🟢	🟠	🟢	🟢	🟠	🟠	🟢	🟠	🟢	🟠	🟢	🟠	🟠	🟢	🟢	🟢	🟢	🟢	🟢	🟠	🟠	🟢	🟠	🟢	🟠	🟢	🟢	🟢	🟢
Kinnaur	🟢	🟢	🟢	🟢	🟢	🟧	🟠	🟢	🟢	🟢	🟢	🟩	🟢	🟢	🟠	🟠	🟠	🟠	🟠	🟢	🟢	🟠	🟠	🟠	🟢	🟢	🟢	🟢	🟢	🟠
Kullu	🟢	🟩	🟠	🟢	🟢	🟠	🟠	🟠	🟠	🟠	🟠	🟢	🟢	🟠	🟢	🟢	🟢	🟢	🟠	🟢	🟠	🟠	🟠	🟠	🟠	🟠	🟢	🟢	🟠	🟠
Lahul & Spiti	🟢	🟠	🟢	🟦	🟠	🟠	🟠	🟢	🟢	🟢	🟠	🟢	🟠	🟢	🟢	🟢	🟢	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟢	🟠	🟠	🟠	🟠	🟠
Mandi	🟠	🟢	🟠	🟠	🟢	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟩	🟠	🟧	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟢
Shimla	🟢	🟠	🟢	🟠	🟢	🟠	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟢	🟢	🟠	🟢	🟢	🟢	🟢	🟠	🟠	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟢
Sirmaur	🟠	🟠	🟠	🟢	🟢	🟧	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟠	🟩	🟢	🟠	🟢	🟠	🟠	🟠	🟠	🟠	🟠	🟢	🟠	🟢	🟢	🟠	🟠
Solan	🟢	🟢	🟢	🟢	🟠	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟢	🟠	🟢	🟠	🟠	🟠	🟠	🟠	🟠	🟧	🟠	🟠	🟩	🟠	🟠	🟢	🟠	🟠
Una	🟢	🟢	🟠	🟢	🟢	🟠	🟠	🟢	🟠	🟢	🟠	🟢	🟢	🟢	🟠	🟠	🟠	🟢	🟠	🟢	🟠	🟠	🟠	🟠	🟢	🟠	🟢	🟢	🟢	🟢

Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean (Note: This matrix is not stand alone but has to be viewed in conjunction with change in climate indices bar graphs given in the appendix)

🟩 Positive Significant trend
🟢 Positive Non-significant trend
🟧 Negative Significant trend
🟠 Negative Non-significant trend
🟦 No Change
⬛ NA

Table 19 : Trend in precipitation extremes indices for individual time slices for districts of Himachal Pradesh (IPCC AR5 RCP8.5 scenario)

District	Baseline											Mid century											End century							
	RX 1day	RX 5day	R 95p	R 99p	CDD	CWD	R 10mm	R 20mm	PRC PTOT	SDII	RX 1day	RX 5day	R95p	R99p	CDD	CWD	R 10mm	R 20mm	PRC PTOT	SDII	RX 1day	RX 5day	R 95p	R 99p	CDD	CWD	R 10mm	R 20mm	PRC PTOT	SDII
	Absolute Indices		Percentile Indices		Duration Indices		Threshold Indices		Other Indices		Absolute Indices		Percentile Indices		Duration Indices		Threshold Indices		Other Indices		Absolute Indices		Percentile Indices		Duration Indices		Threshold Indices		Other Indices	
Bilaspur	🟠	🟢	🟢	🟠	🟢	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟩	🟢	🟠	🟩	🟢	🟩	🟢	🟢	🟠	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟠	🟠
Chamba	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟦	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟠	🟠	🟢	🟢	🟢	🟢	🟢	🟠	🟠	🟠	🟠	🟠	🟦
Hamirpur	🟢	🟢	🟠	🟠	🟩	🟧	🟠	🟢	🟠	🟢	🟢	🟢	🟢	🟢	🟢	🟩	🟢	🟠	🟢	🟢	🟢	🟠	🟠	🟦	🟠	🟢	🟦	🟢	🟠	🟠
Kangra	🟢	🟢	🟠	🟢	🟢	🟠	🟠	🟢	🟠	🟢	🟩	🟢	🟢	🟢	🟢	🟩	🟢	🟠	🟢	🟢	🟢	🟢	🟢	🟢	🟠	🟢	🟢	🟠	🟠	🟢
Kinnaur	🟢	🟢	🟢	🟢	🟢	🟧	🟠	🟢	🟢	🟢	🟢	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟢	🟠	🟠	🟢	🟢	🟢	🟢
Kullu	🟢	🟩	🟠	🟢	🟢	🟠	🟠	🟠	🟠	🟠	🟢	🟠	🟢	🟢	🟠	🟠	🟢	🟢	🟢	🟢	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟠	🟢	🟠
Lahul & Spiti	🟢	🟠	🟢	🟦	🟠	🟠	🟠	🟢	🟢	🟢	🟠	🟠	🟢	🟠	🟠	🟢	🟢	🟢	🟠	🟠	🟠	🟠	🟢	🟠	🟢	🟢	🟢	🟢	🟢	🟢
Mandi	🟠	🟢	🟠	🟠	🟢	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟢	🟢	🟠	🟩	🟢	🟢	🟢	🟢	🟠	🟠	🟠	🟠	🟠	🟠	🟢	🟢	🟠	🟢
Shimla	🟢	🟠	🟢	🟠	🟢	🟠	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟢	🟠	🟩	🟢	🟢	🟢	🟢	🟢	🟦	🟢	🟠	🟠	🟠	🟢	🟢	🟢	🟢
Sirmaur	🟠	🟠	🟠	🟢	🟢	🟧	🟠	🟠	🟠	🟠	🟢	🟢	🟦	🟠	🟠	🟩	🟢	🟩	🟢	🟢	🟢	🟢	🟠	🟢	🟢	🟠	🟢	🟢	🟢	🟢
Solan	🟢	🟢	🟢	🟢	🟠	🟠	🟠	🟠	🟠	🟢	🟢	🟢	🟢	🟢	🟠	🟩	🟢	🟢	🟢	🟢	🟠	🟢	🟠	🟠	🟠	🟠	🟢	🟢	🟠	🟠
Una	🟢	🟢	🟠	🟢	🟢	🟠	🟠	🟢	🟠	🟢	🟢	🟢	🟢	🟢	🟢	🟩	🟢	🟠	🟢	🟢	🟢	🟢	🟦	🟢	🟢	🟢	🟠	🟢	🟠	🟢

Data Source: CORDEX South Asia RCM: Multi Model Ensemble Mean (Note: This matrix is not stand alone but has to be viewed in conjunction with change in climate indices bar graphs)

🟩 Positive Significant trend
🟢 Positive Non-significant trend
🟧 Negative Significant trend
🟠 Negative Non-significant trend
🟦 No Change
⬛ NA

Part-II: Climate Change Impacts on Water Resources

Executive Summary

Climate change impacts on water and health has been taken up for the state of Himachal Pradesh.

The analysis is carried out for projected climate in the state over the periods 2021-2050 (mid-century, MC) and 2071-2100 (end-century, EC) using a multi model ensemble from the CORDEX experiment for RCP4.5 and RCP8.5 scenarios.

The sectors are covered in the assessment include:

- Water (Surface water availability and ground water recharge).
- Health (Heat stress on human and livestock).

The following are the methods/models used for the assessment of climate change impacts on the various identified sectors:

- An assessment of the impact of projected climate change on water resources has been made using the hydrologic model, SWAT (Soil and Water Assessment Tool).
- An assessment of the impact of projected climate change on health has been carried out using heat stress.

Summary of the sectoral impacts is presented in the following paragraphs

Impact Assessment on Water Resources

- Calibrated SWAT hydrological model for all the river basins falling in Himachal Pradesh has been run using climate scenarios for near (MC) and long term (EC) periods (2021 – 2050, 2071-2100, respectively) without changing the land use.
- Under the moderate emission scenario (RCP4.5), for south west monsoon season (JJAS) increase in precipitation of 14% and 22% is projected in mid-century and end-century respectively. Spatial variation from 8% to 22% increase in precipitation is projected across districts of Himachal Pradesh. All the districts except Bilaspur, Sirmaur and Solan, are projected to have above 10% increase in precipitation. Most of the districts, except Bilaspur and Solan, show increase in surface run off contributing to stream flow.
- Under the moderate emission scenario, for north east monsoon season (OND) marginal decrease in precipitation is projected towards mid-century and increase by 17% is projected towards end-century. Increase in evaporation is likely for the districts of Chamba, Kangra, Kinnaur, Kullu and Lahul & Spiti.
- Under the high emission scenario (RCP8.5), for south west monsoon season (JJAS) increase in precipitation of 14% and 28% is projected in mid-century and end-century respectively. Significant increase in evapotranspitration is projected. 14% to 23% increase in precipitation and 16% to 41%

decrease in precipitation are projected towards mid-and end-century for different districts. Highest increase is projected for Kinnaur district

- Under the moderate emission scenario, for north east monsoon season (OND) increase in end-century by 29% and 21% is projected towards mid- and end-century. All the districts are likely to have increase in stream flow due to high intensity rainfall. Many districts are likely to have increase in evapotranspiration attributed largely to projected rise in temperature.
- Under moderate emission scenario increase in drought conditions is likely in districts of Chamba, Kangra, Kullu, Lahul & Spiti, Sirmaur and Una towards mid-century. Drought conditions are likely to improve in the districts of Hamirpur, Mandi, Solab Bilaspur and Una towards end-century.
- Under high emission scenario decrease in drought conditions is likely in most of the district mid- and end-century except for the districts of Chmba, Kullu and Lahul & Spiti which are likely to have higher drought conditions.
- The magnitude of peak discharge is projected to increase in flood (extreme) discharge is likely in all districts by 10% to 15% towards mid- and end-century. However, flood magnitude is likely to reduce for all districts except for Chamba, Lahul & Spiti, Sirmaur, Solan and Una, which are likely to experience higher flood magnitude towards end-century under both RCP scenarios.
- Under moderate emission scenario, increase in 75% and 90% dependable flow is likely in most of the districts towards mid- and end-century except for the district of Sirmaur. Districts of Kinnaur, Kulu and Lahul & Spiti are projected to have about higher increase in 75% and 90% dependable flow as compared to other districts.
- Under high emission scenario, increase in 75% dependable flow is likely in all districts except for the district of Sirmaur which is projected to have decrease in low flows.
- Supply to various dam locations in the basins falling in Himachal Pradesh is projected to have increase in the flow towards mid- and end-century under both climate scenarios. Projected increase in dependable flow is higher for Bhakra Dam, Nathpa Jhakri Dam and at Rampur (Sutlej) as compared to other locations.

Impact Assessment on Health

Heat Stress:

- The heat stress is projected to increase for all the districts of Himachal Pradesh towards the mid-century and end-century. The increase towards the end-century is projected to be higher under IPCC AR5 RCP8.5 scenario as compared to the IPCC AR5 RCP4.5 scenario.
- The heat stress conditions are likely to exacerbate, particularly in the months of May to September for the districts of Himachal Pradesh.
- District namely Una located in the Sub mountain & low hills sub-tropical zone of Himachal Pradesh is projected to have the maximum increase in the severity of heat stress towards the mid-century and end-century as compared to the other districts. Mandi, Shimla, Chamba, Kinnaur, Kullu, Lahul & Spiti districts located in the high and very high hill areas of Himachal Pradesh heat stress level is negligible.
- Extreme danger stress level is observed only towards end-century RCP8.5 scenario.

THI

- Months from April to September are significant on account of either high temperature or high humidity.
- Under RCP4.5 scenario the livestock of the districts of Himachal Pradesh are projected to have no stress. The situation is likely to deteriorate slightly towards end-century under RCP8.5 scenario for some South Western districts.
- The increase towards the end-century is projected to be higher under RCP8.5 scenario as compared to the RCP4.5 scenario.
- The THI impact on the dairy animals is projected to be the highest in the districts of Una and Hamirpur. Chamba, Kinnaur, Kullu, and Lahul & Spiti districts have no THI stress level.

Climate change impacts on Water Resources of Himachal Pradesh

Introduction

Climate change impacts on water resources have been taken up for the state of Himachal Pradesh.

The following details under the respective sectors are covered in the assessment:

- Water (Surface water availability and ground water recharge).
- Health (Heat stress on human and livestock).

Methods and Models used for Sectoral Impact Assessment

The following are the methods/models used for the assessment of climate change impacts on the various identified sectors:

- An assessment of the impact of projected climate change on water resources has been made using the hydrologic model, SWAT (Soil and Water Assessment Tool).
- An assessment of the impact of projected climate change on Health has been carried out using heat stress.

Impact Assessment for Water Resources

In order to make the assessment of climate change impacts on water resources, a hydrological model is required to be used. A well known public domain hydrological model, namely SWAT has been used in the present case.

Soil and Water Assessment Tool (SWAT) Model

The Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998[1], Neitsch et al., 2002[2]) is a distributed parameter and continuous time simulation model. The SWAT model has been developed to predict the hydrological response of un-gauged catchments to natural inputs as well as the manmade interventions. Water and sediment yields can be assessed as well as water quality. The model (a) is physically based; (b) uses readily available inputs; (c) is computationally efficient to operate and (d) is continuous time and capable of simulating long periods for computing the effects of management changes. The major advantage of the SWAT model is that unlike the other conventional conceptual simulation

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[1] Arnold, J. G., R. Srinivasan, R. S. Muttiah, and J. R. Williams. 1998. Large-area hydrologic modeling and assessment: Part I. Model development. J. American Water Res. Assoc. 34(1): 73-89

[2] Neitsch, S. L., J. G. Arnold, J. R. Kiniry, J. R. Williams, and K. W. King. 2002a. Soil and Water Assessment Tool - Theoretical Documentation (version 2000). Temple, Texas: Grassland, Soil and Water Research Laboratory, Agricultural Research Service, Blackland Research Center, Texas Agricultural Experiment Station.

models it does not require much calibration and therefore can be used on un-gauged watersheds (in fact the usual situation).

The SWAT model is a long-term, continuous model for watershed simulation. It operates on a daily time step and is designed to predict the impact of land management practices on water, sediment, and agricultural chemical yields. The model is physically based, computationally efficient, and capable of simulating a high level of spatial details by allowing the watershed to be divided into a large number of sub-watersheds. Major model components include weather, hydrology, soil temperature, plant growth, nutrients, pesticides, and land management. The model has been validated for several watersheds.

Input data: Terrain, landuse, soil, daily weather data (rainfall, maximum and minimum temperature, wind speed,, relative humidity and wind speed), cropping pattern, reservoirs and any man made structure with their characteristics.

Outputs: The outputs provided by the model are very exhaustive covering all the components of water balance spatially and temporally. The sub components of the water balance that are more significant and were used for analyses include:

- Precipitation.
- Total flow (Water yield) consisting of surface runoff, lateral and base flow.
- Actual evapotranspiration (Actual ET).
- Base flow.
- Ground water recharge.

Limitations: Resolution of the input data (spatial detail required to correctly simulate environmental processes), SWAT does not simulate detailed event-based flood.

Impact Assessment for Health

Impact on human health and livestock has been derived using CORDEX climate data.

Health model: The temporal and geographic distribution of humidex for human heat stress and temperature humidity index (THI) for livestock has been derived using universally well established equations using temperature and relative humidity.

Input data: Daily weather data (maximum and minimum temperature and relative humidity).

Outputs: Humidex index and THI and temporal and geographic distribution of these indices.

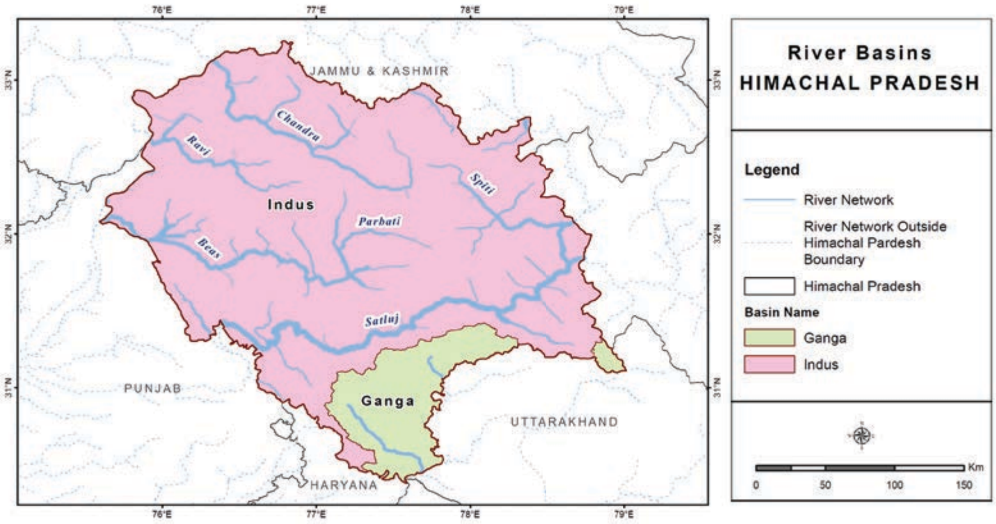
Limitations: Impact on different age group for human health is not considered and similarly only airy animals are considered.

Climate Change Impact Assessment on Water Resources of Himachal Pradesh River Basins using Hydrological Modelling

Himachal Pradesh has two major river systems: the Indus and the Ganga river systems. 90% of Himachal Pradesh's drainage forms the part of Indus river system. The major river systems of Himachal Pradesh are the Sutlej the Chenab, the Beas, the Ravi, and the Yamuna.

For hydrological modelling study, entire Indus basin and Upper Yamuna basin have been considered in order to maintain hydrological continuity. Figure 1 shows part of the Indus basin belonging to the state of Himachal Pradesh.

Figure 1: River basins of Himachal Pradesh



Indus River System: The Indus River rises from the Tibetan plateau and enters the Himalaya in Ladakh. It enters the Kashmir region near its confluence with the river Gurtang, at an elevation of about 4200 metres. The important rivers of this system are Satluj, Beas, Ravi, Chenab and Jhelum. Out of these five rivers, four flows through Himachal Pradesh and along with their tributaries drain parts of Himachal Pradesh.

Satluj one of the main tributaries of Indus enters Himachal Pradesh at Shipki (altitude of 6,608 metres) and flows in the south-westerly direction through Kinnaur, Shimla, Kullu, Solan, Mandi and Bilaspur districts. Its total catchment area in Himachal Pradesh is 20,000 sq. km.

Beas River originates at the Rohtang pass 51 km. north of Manali and flows through Kullu, Mandi, Kangra, and Hamirpur districts of Himachal Pradesh. Its total catchment area in Himachal Pradesh is 12,614 sq. km.

The Ravi River rises from the Bara Banghal as a joint stream formed by the glacier-fed Badal and Tant Gari with a catchment area of about 5,451 sq. km.in Himachal Pradesh. The Chenab rises from the south-east and Bhaga from the north-west of the Baralacha pass. It enters Himachal Pradesh at Pangi valley of Chamba district and has a catchment area of 7,500 sq. km. in Himachal Pradesh.

Ganga River System: The drainage basin of the Ganga river system covers about one third of the western Himalaya and the entire central Himalaya. This basin extends from the eastern face of the Shimla ridge in Himachal Pradesh to the south-western slopes of the Kanchanjunga massif on the Nepal-Sikkim border. Parts of Kinnaur, Shimla, Solan and Sirmaur district of Himachal fall in the Ganga basin.

The Yamuna River enters Himachal Pradesh at Khadar Majri in Sirmaur district and is the eastern-most river of Himachal Pradesh. Its total catchment area in Himachal Pradesh is 2,320 sq. km. It leaves the state near Tajewala and enters into the Haryana state. Tons, Pabbar and Giri, tributaries of the Yamuna River flow through Himachal Pradesh.

Development of Hydrological Model for the River Basins of Himachal Pradesh

In the present analysis, the river basins falling in Himachal Pradesh is used, however, upstream catchment area of Indus and upper Yamuna have been included for hydrological continuity.

Mapping of a basin on to the SWAT hydrological model involves an elaborate procedure. The following paragraphs briefly describe the methodology used for mapping the Indus and Upper Yamuna river systems.

Data Used

Spatial data and the source of data required for the study area include:

- Digital Elevation Model: SRTM 30m Digital Elevation Data[3].
- Drainage Network – Hydroshed[4].
- Soil maps and associated soil characteristics (source: NBSSLUP and FAO Global soil)[5].
- Land use: NRSC Landuse (2007-08) merged with IWMI's Global Map of Irrigated Areas (GMIA) (source: IWMI)[6].

The Hydro-Meteorological data pertaining to the river basin is required for modelling the catchment. These include daily rainfall, maximum and minimum temperature, solar radiation, relative humidity and wind speed. The Weather data were available as per following details;

- IMD gridded weather data (1961–2013) – out of which 4 years of weather data was used as warmup/ setup period thus, outputs are available from 1965 to 2013.

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[3] http://srtm.csi.cgiar.org/

[4] http://hydrosheds.cr.usgs.gov/

[5] http://www.lib.berkeley.edu/EART/fao.html

[6] http://www.iwmigiam.org/info/main/index.asp

- **Climate Change:** CORDEX South Asia Bias Corrected Regional Climate Model outputs for Baseline (1981–2010, BL), near term or mid-century (2021-2050, MC) and long term or end-century (2071-2100, EC) for IPCC AR5 RCP4.5 and RCP8.5 scenarios.

Water demand and abstraction data

- Current management/operation practices, existing irrigation as per crop demand. (Note: Current crop management practices include irrigation sources from Surface and Ground water).

Model Performance

Statistical parameters namely regression coefficients (R^2) and Nash Sutcliffe coefficient (NS) were used to assess the model efficiency on monthly SWAT hydrologic streamflow predictions.

Model Evaluation Statistics (Dimensionless)

Nash-Sutcliffe efficiency (NSE): The Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance (“noise”) compared to the measured data variance (“information”) (Nash and Sutcliffe, 1970[7]). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE is computed as

$$NSE = \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean} \right)^2} \right]$$

Where Y_i^{obs} is the i^th^ observation for the constituent being evaluated, Y_i^{sim} is the i^th^ simulated value for the constituent being evaluated, Y^{mean} is the mean of observed data for the constituent being evaluated, and n is the total number of observations. NSE ranges between −∞ and 1.0 (1 inclusive), with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance, whereas values <0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance[8]

Coefficient of determination (R^2): Coefficient of determination (R^2) describes the degree of co-linearity between simulated and measured data. R2 describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1, with higher values indicating less error variance, and typically values greater than 0.5 are considered acceptable (Santhi et al., 2001[9], Van Liew et al., 2003[10]). R2 is oversensitive to high extreme values (outliers) and insensitive to additive and proportional differences between model predictions and measured data (Legates and McCabe, 1999[11]).

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[7] Nash, J. E., and J. V. Sutcliffe. 1970. River flow forecasting through conceptual models: Part 1. A discussion of principles. J. Hydrology 10(3): 282-290

[8] Moriasi, D. N., J. G. Arnold, M. W. Van Liew, R. L. Bingner, R. D. Harmel, and T. L. Veith, 2007. Model evaluation guidelines for systematic quantification of accuracy in watershed simulations, Transactions of the ASABE, Vol. 50(3): 885−900 2007

[9] Santhi, C, J. G. Arnold, J. R. Williams, W. A. Dugas, R. Srinivasan, and L. M. Hauck. 2001. Validation of the SWAT model on a large river basin with point and nonpoint sources. J. American Water Resources Assoc. 37(5): 1169-1188

[10] Van Liew, M. W., J. G. Arnold, and J. D. Garbrecht. 2003. Hydrologic simulation on agricultural watersheds: Choosing between two models. Trans. ASAE 46(6): 1539-1551

[11] Legates, D. R., and G. J. McCabe. 1999. Evaluating the use of “goodness-of-fit” measures in hydrologic and hydroclimatic model validation. Water Resources Res. 35(1): 233-241

Model Evaluation Statistics (Error Index)

Percent bias (PBIAS): Percent bias (PBIAS) measures the average tendency of the simulated data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is 0.0, with low-magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias (Gupta et al., 1999). PBIAS is calculated as,

$$BIAS = \left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right) * (100)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right]$$

Where PBIAS is the deviation of data being evaluated, expressed as a percentage8.

RMSE-observations standard deviation ratio (RSR): RMSE is one of the commonly used error index statistics. RSR standardizes RMSE using the observations standard deviation, and it combines both an error index and the additional information recommended by Legates and McCabe (1999). RSR is calculated as the ratio of the RMSE and standard deviation of measured data as,

$$RSR = \frac{RMSE}{STDEV_{obs}} = \frac{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{sim}\right)^2}\right]}{\left[\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs} - Y_i^{mean}\right)^2}\right]}$$

RSR incorporates the benefits of error index statistics and includes a scaling/normalization factor, so that the resulting statistic and reported values can apply to various constituents. The lower RSR, the lower the RMSE, and the better is the model simulation performance.8

Mapping the River Basin

Automatic delineation of watersheds was done by using the DEM as input. A digital elevation model (DEM) from the SRTM[12] having a spatial resolution of 30 has been used for basin delineation. The target outflow point is interactively selected. River basins have been delineated using 10,000 hectare as minimum stream threshold and have resulted in 202 sub-basins within the state of Himachal Pradesh with 1832 subbasins in Indus and 20 subbasins in Ganga. These subbasins are further subdivided into 639 hydrological responses units. Care was also taken to incorporate the locations of major/medium dams, reservoirs and diversion structures while undertaking the delineation process.

The major part of Himachal Pradesh is under forest (36%) and grass/shrubs land (29%) followed by agriculture (10%) and glaciers/snow and water bodies. Large portion of agriculture land is under the rainfed (75 % of the crop). Wheat, maize, rice and barley are the major food crop. The major cropping systems are maize-wheat, rice-wheat and maize-potato-wheat. Apple is the principal cash crop. The important fruit crops are apple, plum, almonds and mango etc.

The major soil groups are brown hill soil, sub-mountain soils, mountain meadow soil and red loamy soils. The soils are acidic and low in fertility.

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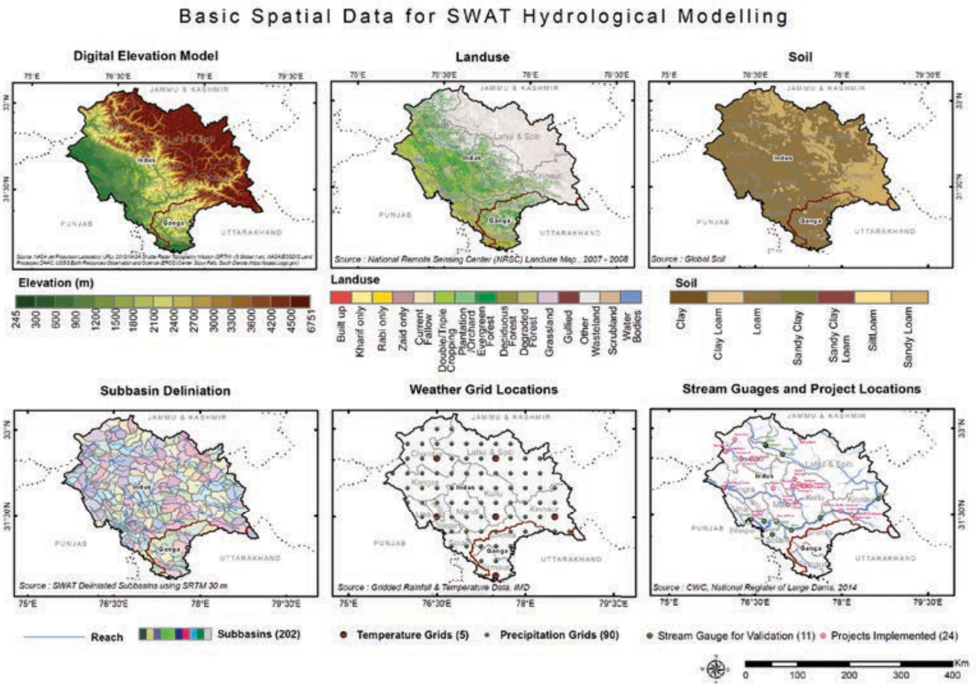
[12] http://srtm.csi.cgiar.org

The daily reanalysis and re-gridded weather data of IMD (rainfall and temperature) has been used. Daily weather data are at a resolution of 0.25° X 0.25° latitude by longitude grid points for rainfall (90 grids) and 1.0° X 1.0° for temperature (5 grids).

About 24 major and medium projects falling within the state of Himachal Pradesh have been considered while setting up of SWAT hydrological model. Figure 2 shows the basic input data used for SWAT hydrological model setup for river basins falling in Himachal Pradesh.

Figure 2: Input data used for SWAT modelling setup for river basins of Himachal Pradesh



SWAT Model Performance for the Indus and Ganga River Basin

Statistical parameters namely Nash Sutcliffe Efficiency coefficient (NSE), percentage volume bias (PBIAS), RMSE-observations standard deviation ratio (RSR) and regression coefficients (R2) were used to assess the model efficiency on monthly SWAT hydrologic stream flow predictions.

For the Ganga basin, IIT Delhi has validated SWAT model for the Ganga river basin at various locations using observed data obtained from CWC (Central Water Commission) for the project ‘Ganga River Basin Management Plan’ (prepared by consortium of seven IITs) under Ministry Water Resources, River Development and Ganga Rejuvenation. Being a trans-boundary river, the flow data for the Ganga comes under classified information. Therefore, for the current modelling exercise, same model parameters used by the IIT consortia has been used with their consent.

Similarly, INRM Team had supported a study conducted by Asian Development Bank (ADB) for National Water Mission Scoping Study for a National Water Use Efficiency Improvement Support Programme in 2011. Under this study Satluj basin hydrological model was calibrated at various stream discharge locations with the observed discharges obtained from CWC (Central Water Commission) and BBMB (Bhakra Beas Management Board). Being a trans-boundary river, the flow data for the Indus River comes under classified information. Therefore for the current modelling exercise, same model parameters have been used.

Before performing statistical comparison of stream flows, the reasonableness of the model for general evapotranspiration, runoff, base flow/return flow, and crop yields against district averages were analyzed and found satisfactory.

Model Assumptions

District crop productions have been used to arrive at close representation of current crop management practices to be incorporated for crop simulation in the SWAT model. Sources of irrigation have been based on district agriculture statistics. General reservoir operating policies have been used for the major and medium projects implemented in the model setup.

Correction factors are necessary to account for change in precipitation and temperature at higher altitudes. The SWAT model is capable of using elevation band to adjust the temperature and rainfall as the altitude changes. In the absence of data, assumption on extent of snow/ glacier, initial glacier depth and spread has been made. However, precipitation and temperature lapse rates were used to represent the orographic effect. A literature based value of -6.5oC/km increase was used as temperature lapse rate and 100 mm/km was used as precipitation lapse rate for those subbasins where the elevation bands were incorporated.

SWAT Model Performance for the Study Area

Although the SWAT model does not require elaborate calibration (Gosain et al., 2005[13]), yet it is required to get some level of validation that is possible within the limited availability of data in the Indus river basin of Himachal Pradesh. Statistical parameters have been used to assess the model efficiency of simulated monthly stream flows. Before performing statistical comparison of stream flows, the reasonableness of the model for general evapotranspiration, runoff, base flow/return flow, and crop yields against district averages were analyzed and found satisfactory.

Stream flow at a few locations on the Indus River provided by the Global Runoff Data Centre (GRDC) through global runoff database[14] has been used for calibration. In general GRDC data were available until 1979 at the monthly scale, thus the comparison were performed at monthly scale only.

The long-term simulation monthly mean at all drainage area levels are on par with observed means, the R^2 and Coefficient of efficiency are above literature acceptable ranges (Table 1).

Table 1: SWAT calibration and model efficiency parameters at two GRDC locations on Indus basin

Site Name	Basin	Catchment Area* (Sq.Km)	Area Difference (%)	Mean Flow* (CMS)	NSE**	PBIAS %	R2
Rampur	Satluj	50000 (49350)	1.3	365.4 (366.0)	0.57	-5.6	0.85
Kasol	Satluj	2490 (2448)	2.0	424 (415)	0.69	2.1	0.87
Mukesar	Ravi	5700 (6614)	-16.0	306.7 (311.1)	0.6	-7.0	0.62
Ghousal	Chenab	2490 (2448)	-1.7	97 (76)	0.64	-21.0	0.84

**** Model values is shown in bracket, ** Nash-Sutcliffe coefficient, + Monsoon months***

The Hydrologic Simulation with Observed IMD Gridded Weather

Following setup, the model has been validated using the available stream flow observation stations. The model has been run on continuous basis at daily interval for all the sub-basins. The outputs provided by

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[13] Gosain, A.K., Sandhya Rao, Srinivasan, R. and Gopal Reddy, N., 2005. "Return-Flow Assessment for Irrigation Command in the Palleru River Basin Using SWAT Model". Hydrological Processess 19, 673-682.

[14] http://www.bafg.de/GRDC/EN/Home/homepage_node.html

the model are very exhaustive covering all the components of water balance spatially and temporally. The sub components of the water balance that are more significant and have been used for analyses include:

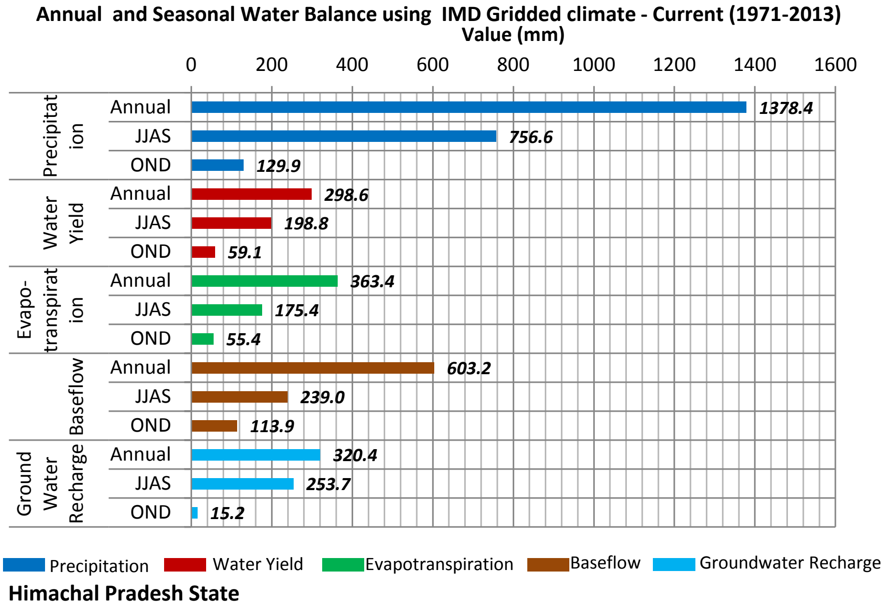
- Precipitation.
- Stream flow (Water yield) consisting of surface runoff, lateral and base flow.
- Actual evapotranspiration (Actual ET).
- Base flow and groundwater recharge

The outputs can be depicted in many ways depending on the focus and requirement of the user. Figure 3 presents the snapshot long-term variability of the key water balance elements for all the basins of Himachal Pradesh taken as a single unit.

These components are expressed in terms of total annual depth of water in mm over the total area of the State. In other words, the total water yield is the equivalent depth in mm, of flow past an imaginary outlet of the State watershed on average annual basis.

The average annual rainfall for river basins of Himachal Pradesh is about 1378 mm. The major part of the rainfall occurs during south west monsoon in the months of June, July, August and September (756 mm). North east monsoon (October, November and December) contributes about 130 mm.

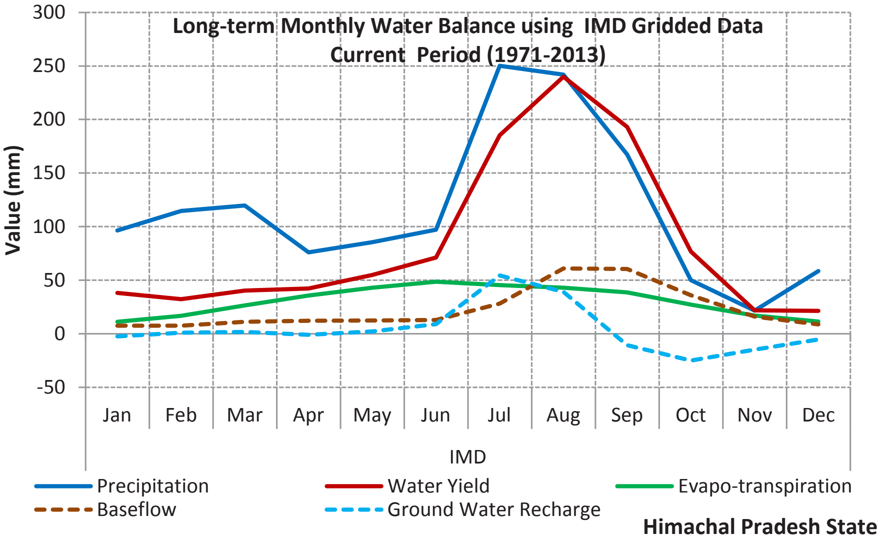
Figure 3: Annual and seasonal water balance components for river basins falling in Himachal Pradesh using IMD gridded weather data



It can be seen from the figure that about 55% of the annual rainfall occurs during south west monsoon and north east monsoon accounts for about 9%. About 22 % of the annual rainfall gets converted to stream flow.

Long-term monthly water balance components are shown in Figure 4.

Figure 4: Long-term Monthly water balance components for river basins using IMD gridded weather data



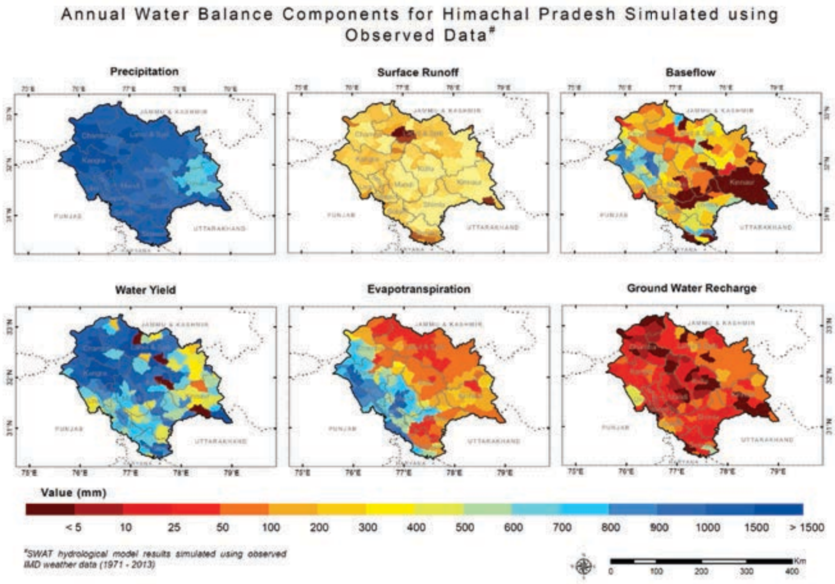
As it can be seen from the figure, July contributes about 18% followed by August (17.5%), September (12%) and June (7%) to annual rainfall.

The precipitation varies both spatially and temporally. Spatial distribution of annual and seasonal water balance components for river basins falling in Himachal Pradesh is shown in Figure 5.

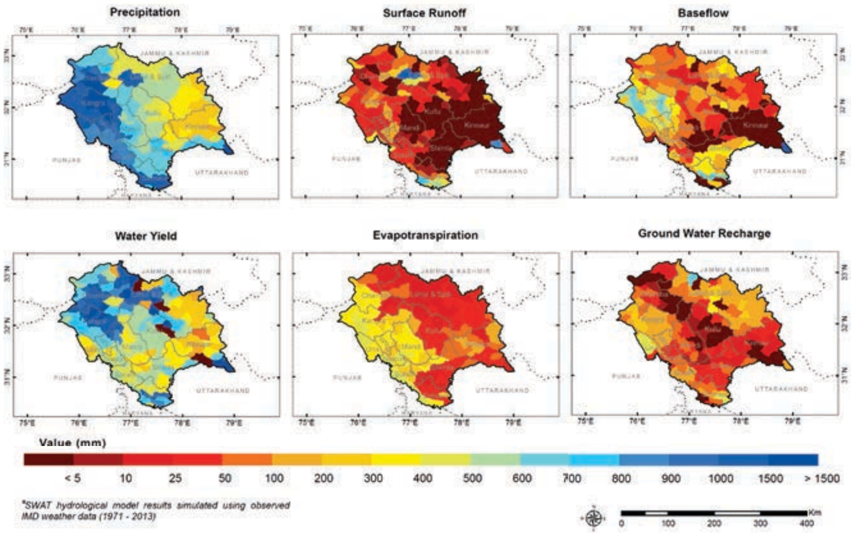
The average annual precipitation ranges from less than 700 mm per year to over 2100 mm per year in different parts of the state. It can be seen from the figure that during monsoon months of June through September the rainfall is higher than the water yield and able to meet most of the crop water requirements. However during non-monsoon months, the evapotranspiration is higher than rainfall, suggesting the water has been either diverted through storage or shallow to deep aquifer withdrawal to meet the crop production demand. It can be seen from Figure 5 that evapotranspiration is higher during the months from May to September.

Evapotranspiration is higher in the districts of Una, Bilaspur, Hamirpur and Mandi.

Figure 5: Spatial distribution of Annual and seasonal water balance components for river basins falling in Himachal Pradesh

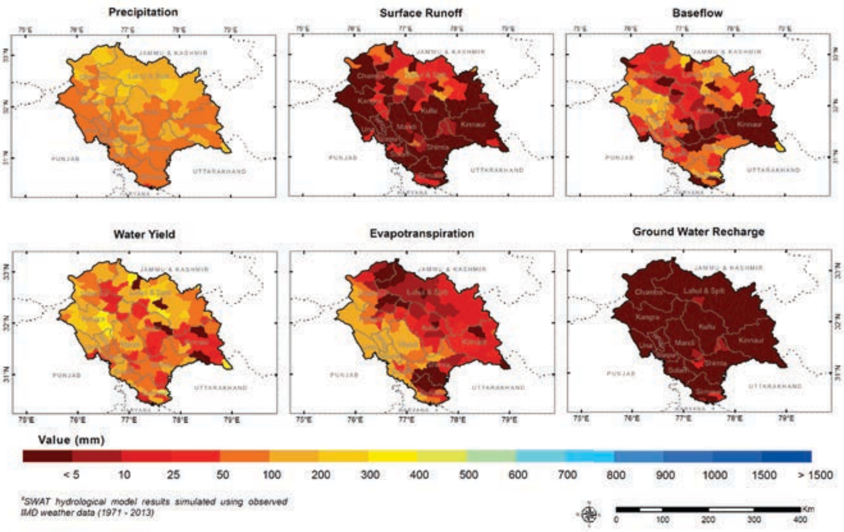


Southwest Monsoon* Water Balance Components for Himachal Pradesh Simulated using Observed Data#



#SWAT hydrological model results simulated using observed IMD weather data (1971 - 2013)

Northeast Monsoon* Water Balance Components for Himachal Pradesh Simulated using Observed Data#



#SWAT hydrological model results simulated using observed IMD weather data (1971 - 2013)

Limitations

Following are some of the limitations of the simulation:

- Sparse stream flow data availability both in space and time.
- In adequate data length for available observed river discharge locations.
- Non availability of data on snow and glacier spread and depth.
- Missing or inadequate information on manmade structures like dams and reservoirs.
- Inadequate information on source and amount of irrigation water.
- Current crop management practices (irrigation from surface and ground water) based on landuse map, irrigation source map, and district-wise average irrigation (by source) information was used.
- Coarse resolution temperature data.

The Hydrologic Simulation with Climate Change Scenarios

South Asia Cordex provided high resolution RCM (regional circulation models) climate change projections in surface climate and the same have been input to hydrological models for performing impact assessment. These high resolution datasets are from 1971-2100 which is the best simulation available currently for the globe with a grid resolution of 0.5° x 0.5°.

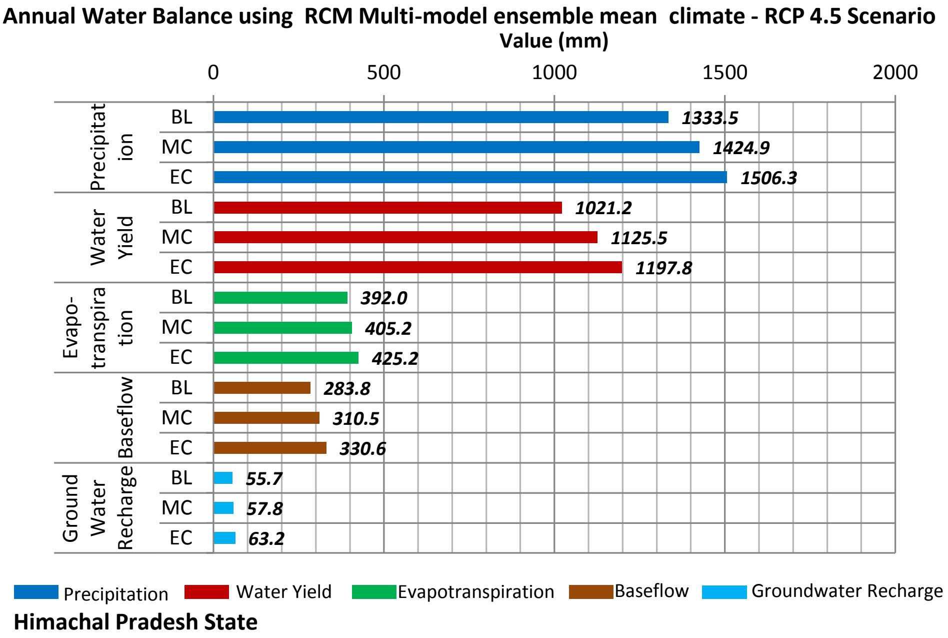
The climate change simulations for water resources are run using bias corrected multimodel ensemble of 10 high resolution RCM models and for IPCC AR5 RCP scenarios RCP4.5 and RCP8.5. The model has been run using climate scenarios for near (MC) and long term (EC) periods (2021 – 2050, 2071-2100, respectively) without changing the land use.

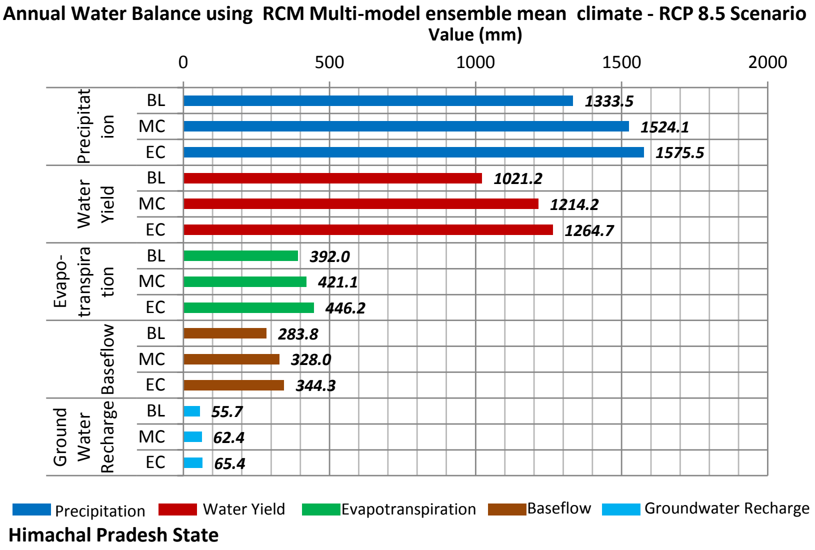
Daily weather parameters (rainfall, temperature, solar radiation, relative humidity, wind speed) have been extracted for the relevant grids falling in the basins of various rivers. Before using climate model data in impact studies, bias correction has been applied to reduce the uncertainties between historical observed weather.

The outputs of these scenarios have been analyzed to evaluate the possible impacts on the runoff, baseflow, soil moisture, ground water recharge and actual evapotranspiration (expressed as change between the baseline and future periods).

Figure 6 and Figure 7 present the snapshot long-term annual, seasonal and monthly variability of the key water balance elements for the river basins of Himachal Pradesh as a single unit. As discussed earlier, these components are expressed in terms of total annual depth of water in mm over the total watershed area.

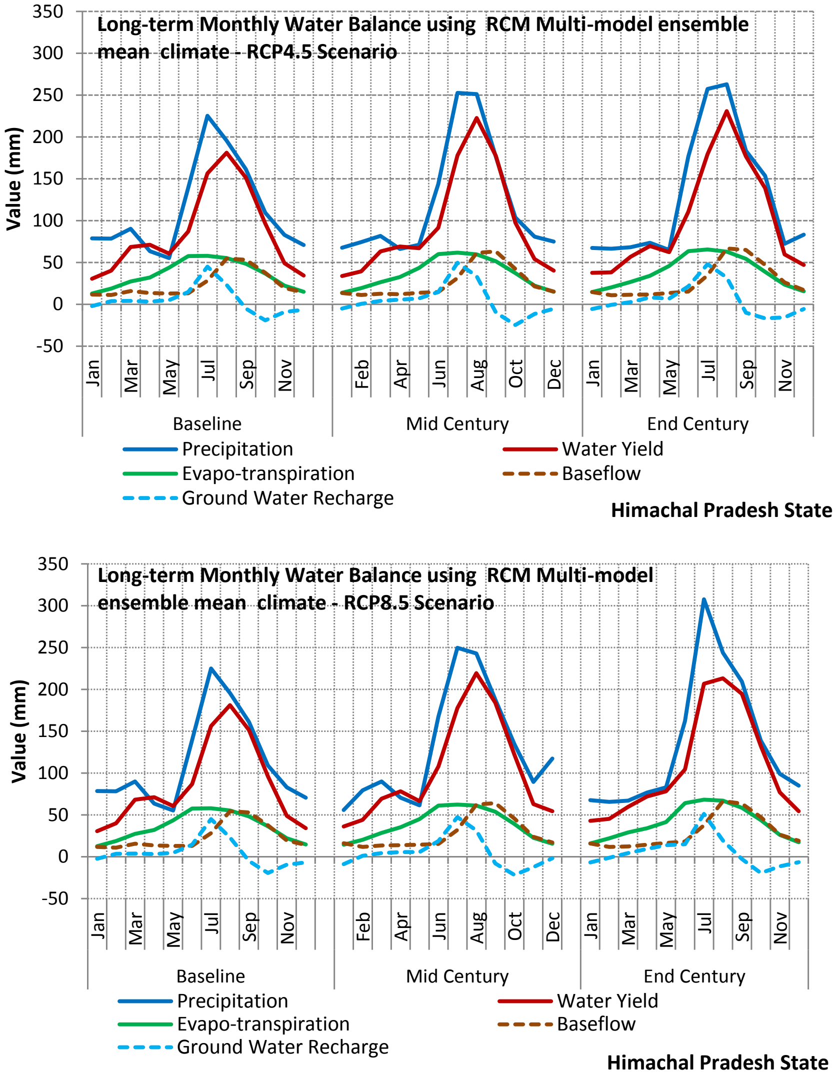
Figure 6: Annual water balance components for BL, MC and EC climate scenarios (IPCC AR5 RCP4.5) for river basins falling in Himachal Pradesh





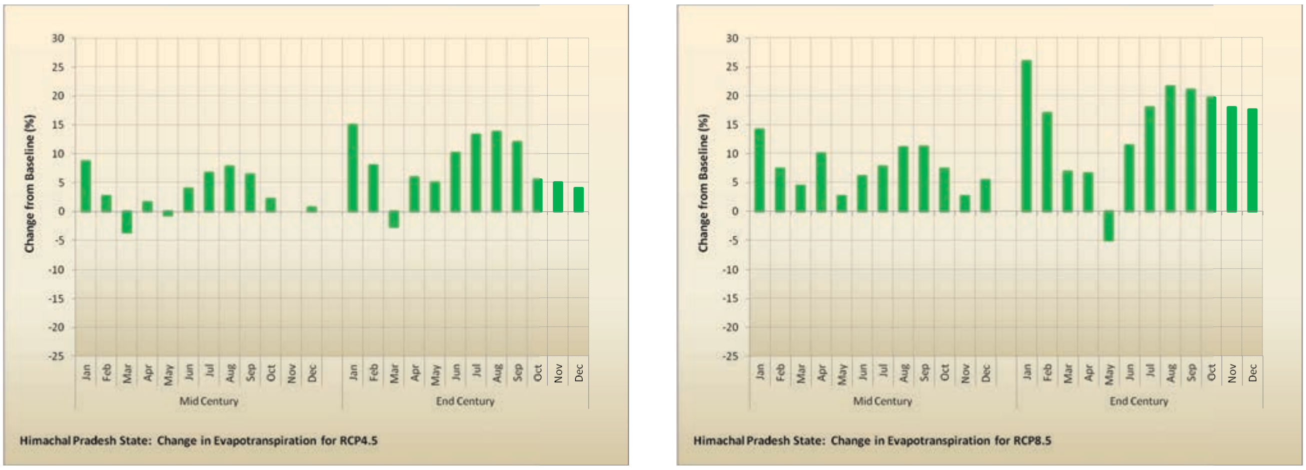
As can be seen from Figure 6, there is increase in annual rainfall and evapotranspiration towards mid- and end-century under both scenarios..

Figure 7: Long-term Monthly water balance components for BL, MC and EC climate scenarios (IPCC AR5 RCP4.5) for river basins falling in Himachal Pradesh



It can be seen from Figure 8 that evapotranspiration is projected to increase in south west monsoon (June, July, August and September) and north east monsoon (October, November and December) months. Higher increase is likely during the south west monsoon. Months of July and August are projected to have the highest increase compared to other months (Figure 8). Projected increase is higher (greater than 10%) in most of the months under RCP8.5 scenario.

Figure 8: Long-term monthly change in evapotranspiration with respect to baseline (IPCC AR5 RCP4.5 and RCP8.5) for river basin falling in Himachal Pradesh



Seasonal Change in Water Balance Components

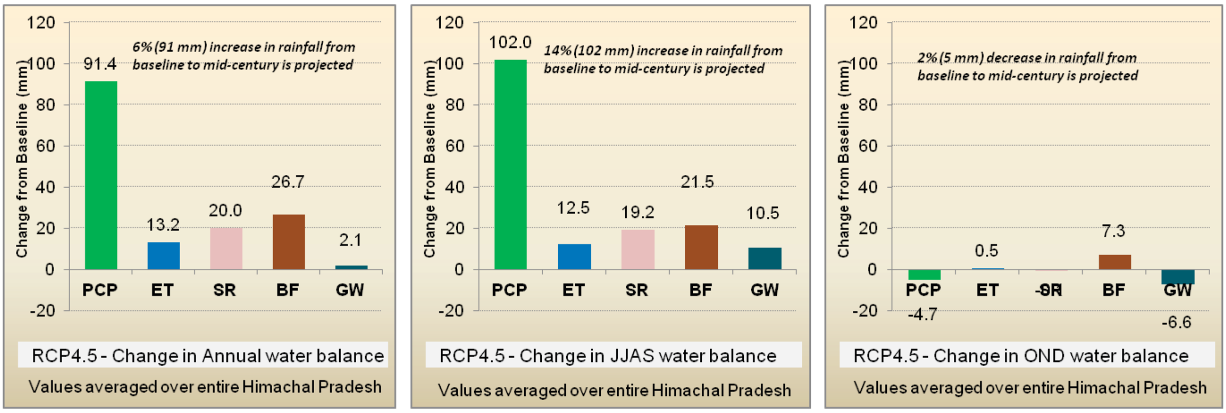
Average water balance components over 30 years; baseline (1981-2010), mid-century (2021-2050) and end-century (2071-2100) scenarios have been used for assessing change from baseline to mid and end-century.

Moderate emission scenario (RCP4.5)

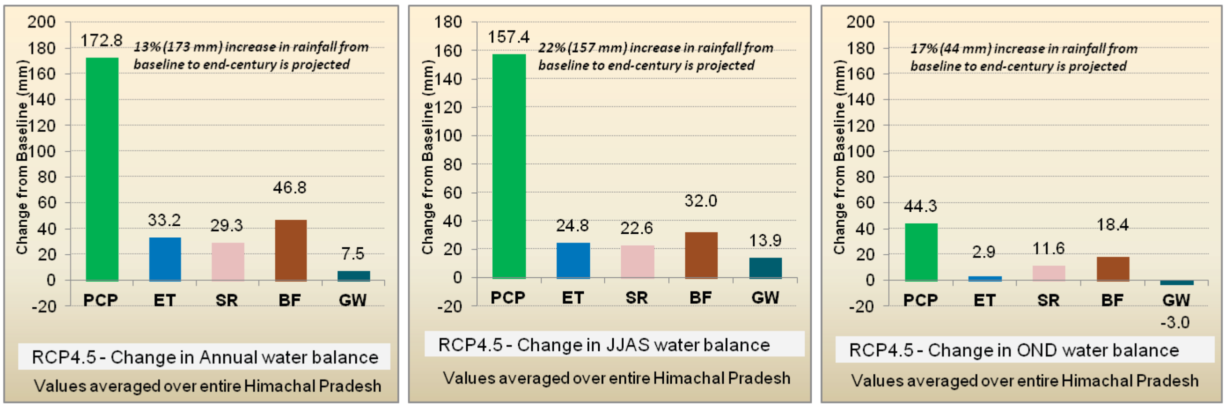
The change in simulated water balance components from the baseline of mid-century and end-century is shown in Figure 9. Graph shows the distribution of the major water balance components averaged over the basins falling in Himachal Pradesh, expressed in depth form (mm).

Figure 9: Seasonal Change in water balance (mm) expressed as percent change in precipitation (IPCC AR5 RCP4.5 scenario) for river basins falling in Himachal Pradesh

Change from Baseline to Mid-century



Change from Baseline to End-century



RCP4.5 - Change in Annual water balance
Values averaged over entire Himachal Pradesh

RCP4.5 - Change in JJAS water balance
Values averaged over entire Himachal Pradesh

RCP4.5 - Change in OND water balance
Values averaged over entire Himachal Pradesh

Moderate emission scenario (RCP4.5) - South West Monsoon (JJAS)

Mid-century: 14% increase (102 mm) in precipitation is projected in south west monsoon (JJAS) for Himachal Pradesh state towards mid-century. Most of the increase in precipitation is projected to contribute to stream flow in the form of direct surface runoff and baseflow. Increase in ground water recharge and evapotranspiration is projected.

Spatial variation from 8% to 22% increase in precipitation is projected across districts of Himachal Pradesh. Highest increase in precipitation for Kinnaur (22%) and lowest increase for Solan (8%) is projected. All the districts except Bilaspur, Sirmaur and Solan, are projected to have above 10% increase in precipitation. Most of the districts, except Bilaspur and Solan, show increase in surface run off contributing to stream flow indicating increase in intensity of rainfall and decrease in number of rainy days. Districts of Chamba, Kangra, Kinnaur, Kullu and Lahul & Spiti show marginal increase in evapotranspiration and ground water recharge, which is a clear indication of increase in temperature and higher snow melt.

End-century: Projected increase in south west monsoon (JJAS) precipitation is about 22% (157 mm) towards end-century. The model results indicate that 23% of this projected increase in precipitation is likely to get converted to runoff, 32% increase in baseflow, 25% increase in evapotranspiration and 14% increase in ground water recharge.

Increase is projected for all 12 districts (12% to 34%) towards end-century for RCP4.5 scenario. Substantial part of this projected increase is likely to result in direct runoff, thus contributing to increase in stream flow.

Groundwater recharge is likely to increase in all districts except for Lahul & Spiti. Increase in evapotranspiration is projected for the districts of Chamba, Kangra, Kinnaur, Kull and Lahul & Spiti and marginal change is likely for the districts of Hamirpur, Shimla, Una, Bilaspur, Mandi, Sirmaur and Solan.

Moderate emission scenario (RCP4.5) - North East Monsoon (OND)

Mid-century: Marginal decrease in precipitation in north east monsoon (OND) is projected towards mid-century. Projected reduction in precipitation is likely to result in marginal change in evapotranspiration and ground water recharge.

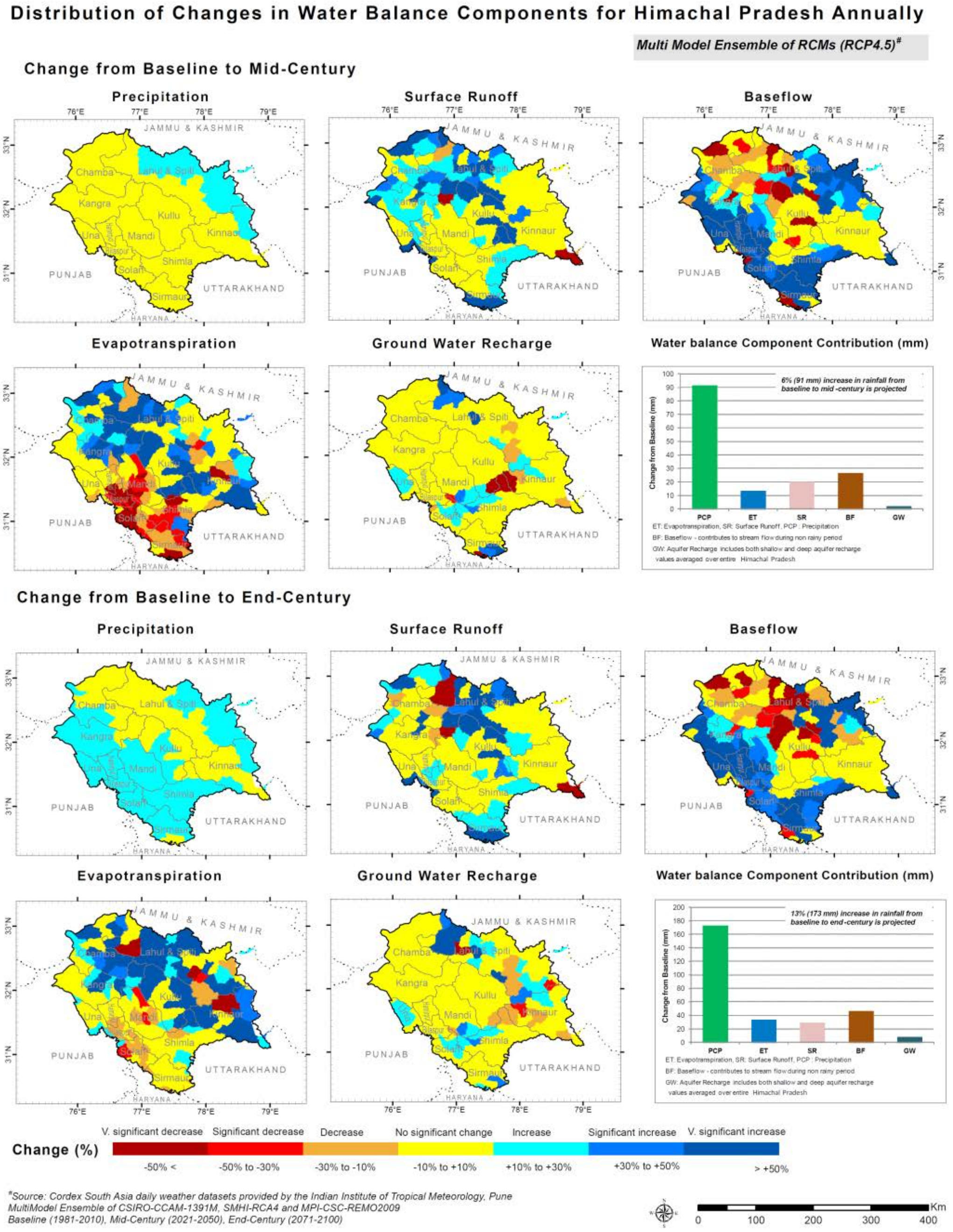
Decrease in precipitation is projected for all districts (marginal to 13%) except for Lahul & Spiti, Kinnaur, Simla and Solan towards mid-century for RCP4.5 scenario. Highest decreaseis likely for Una.. Reduction in winter precipitation would call for additional irrigation for the Rabi crops. Increase in evaporation is likely for the districts of Chamba, Kangra, Kinnaur, Kullu and Lahul & Spiti.

End-century: Increase in precipitation by 17% (44 mm) is projected towards end-century resulting in increase in runoff and baseflow. Marginal increase in evapotranspiration is projected. Increase in precipitation is projected for all districts (12% to 30%). Increase in evaporation is likely for the districts of Chamba, Kinnaur, Kullu and Lahul & Spiti.

The effects of climate change on the water balance components has been analysed spatially with respect to the sub-basins of Himachal Pradesh. The spatial distribution of water balance components have been plotted in terms of the percent change from the baseline period in Figure 10.

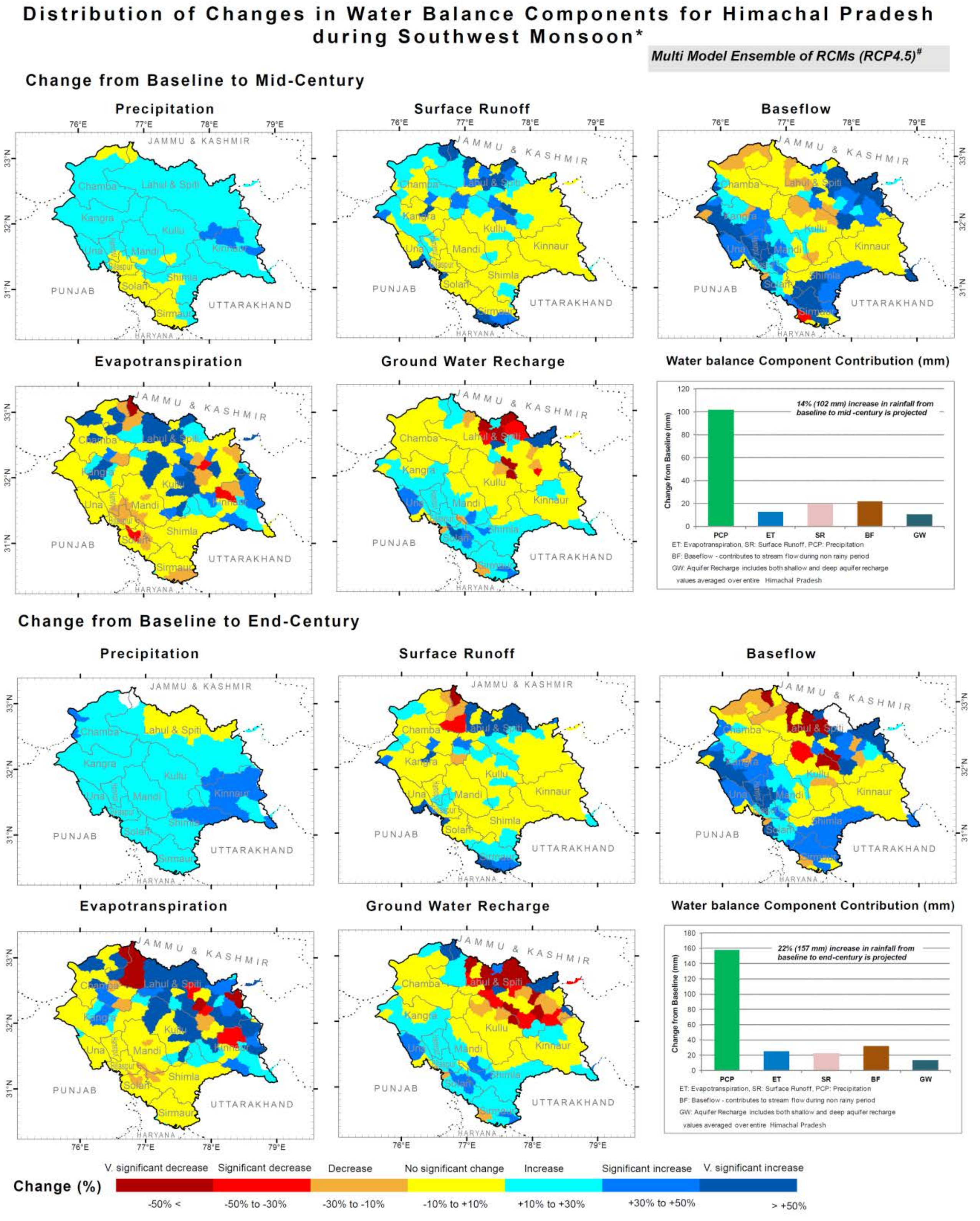
Figure 10: Spatial distribution of change in water balance components towards mid and end-century (IPCC AR5 RCP4.5 scenario) for river basins falling in Himachal Pradesh

Long term Annual Change



#*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune*
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

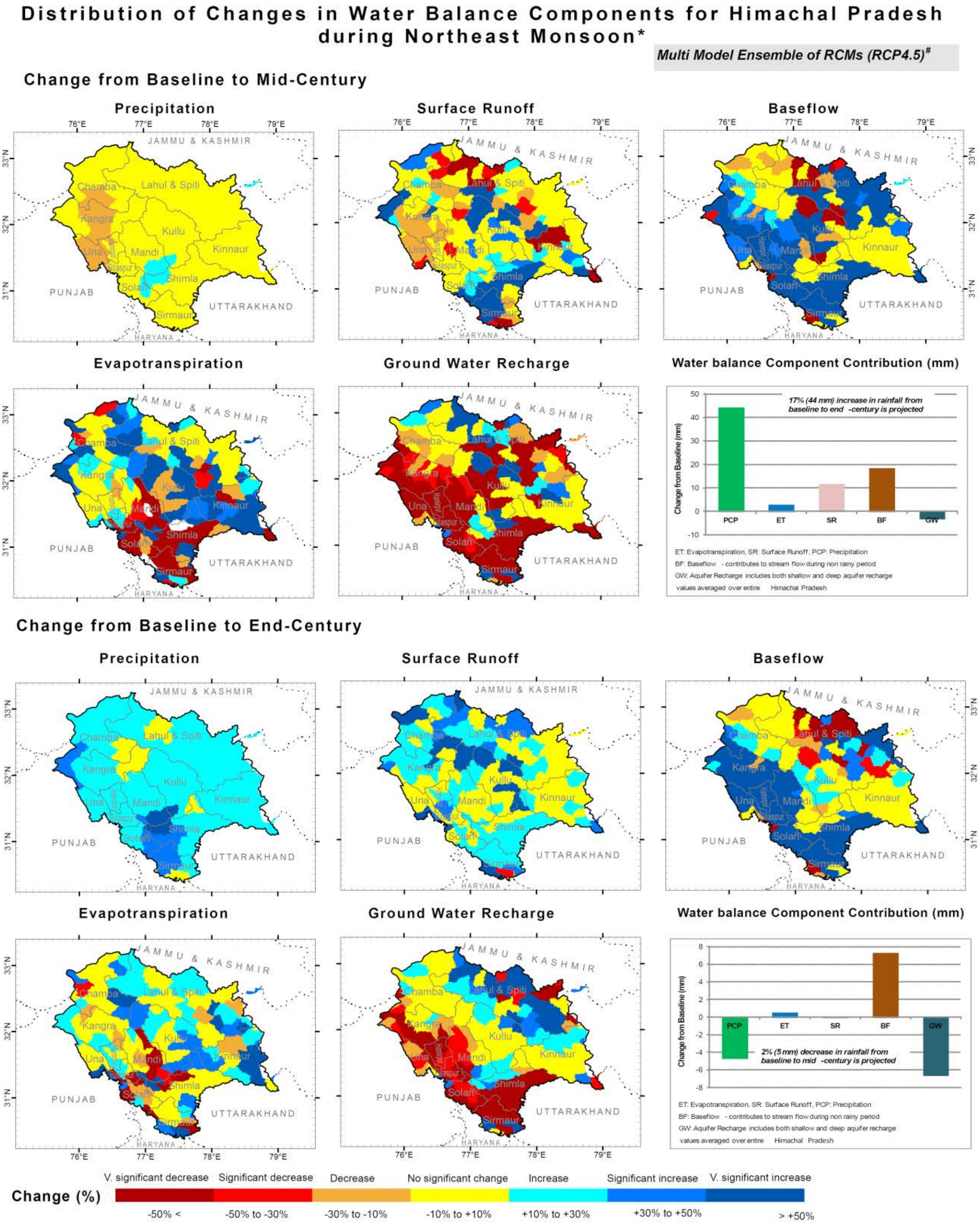
Long term Change during Southwest Monsoon Season



#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

*Southwest Monsoon (June to September - JJAS)

Long term Change during Northeast Monsoon Season



#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

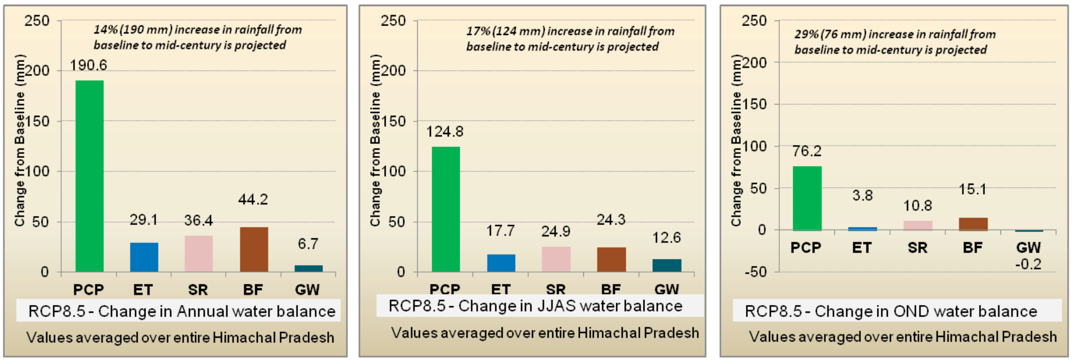
* Northeast Monsoon (October to December - OND)

High emission scenario (RCP8.5)

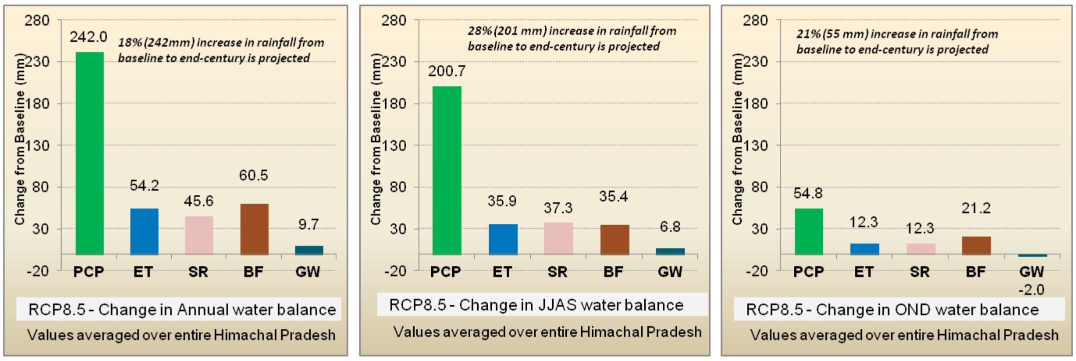
The change in simulated water balance components from the baseline of mid-century and end-century for RCP8.5 scenario is shown in Figure 11.

Figure 11: Seasonal change in water balance (mm) expressed as percent change in precipitation (IPCC AR5 RCP8.5 scenario) for river basins falling in Himachal Pradesh

Change from Baseline to Mid-century



Change from Baseline to End-century



High emission scenario (RCP8.5) - South West Monsoon (JJAS)

Mid-century: Under high end emission scenario projected increase in south west monsoon (JJAS) precipitation is about 14% (191 mm) towards mid-century. 36% of this projected increase in rainfall will contribute to stream flow in the form of direct surface runoff, indicating increase in rainfall intensity. 29% increase in evapotranspiration is projected

14% to 23% increase in precipitation is projected for all districts towards mid-century for RCP8.5 scenario. Highest increase of 41% is projected for Kinnaur district. Districts of Kinnaur, Kullu and Mandi are likely to have more than 20% increases in precipitation and most of this increase is likely to return as direct surface runoff. Increase in evapotranspiration is projected for the districts of Chamba, Kangra, Kinnaur, Kullu, and Lahul & Spiti. Increase in ground water recharge is likely in all districts except for Kullu district.

End-century: Projected increase in south west monsoon (JJAS) precipitation is about 28% (201 mm) by end-century. The model results indicate about 37% of this increase in precipitation will get translated to increase in stream flow. Increase in precipitation and temperature results in significant increase in evapotranspitration by about 36% of the increase in precipitation.

16% to 41% increase in precipitation is projected for all districts towards mid-century for RCP8.5 scenario. Highest increase of 41% is projected for Kinnaur district. Higher increase (more than 20%) in precipitation is projected for districts of Chamba, Hamirpur, Kangra, Kullu, Lahul & Spiti, Mandi, Shimla and Una as compared to other districts. 2% to 36% increase in precipitation is likely to return as stream flow in all districts. Significant increase in evapotranspiration is likely for Chamba, Kinnaur, Kullu and Lahul & Spiti. Most of the districts are likely to have increase in ground water recharge.

High emission scenario (RCP8.5) - North East Monsoon (OND)

Mid-century: 29% (76 mm) increase in precipitation in north east monsoon (OND) is projected towards mid-century for districts of Himachal Pradesh, resulting in increase in evapotranspiration and stream flow.

All districts are likely to have more than 20% increase in precipitation with highest increase of 33% for Solan district. Increase in evapotranspiration is likely for the districts of Chamba, Kangra, Kinnaur, Kullu and Lahul & Spiti, marginal change is projected for rest of the districts.

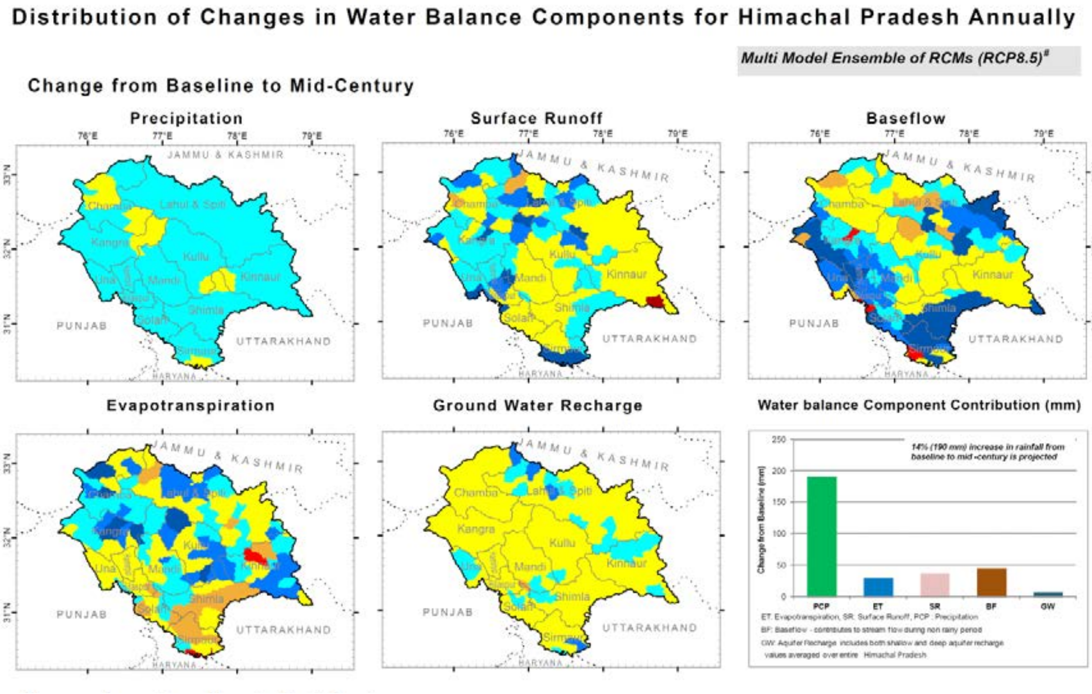
End-century: Increase in precipitation ranging from 21% (55 mm) is likely towards end-century. This increase in precipitation results in significant increase in evapotranspiration, attributed largely to projected rise in temperature.

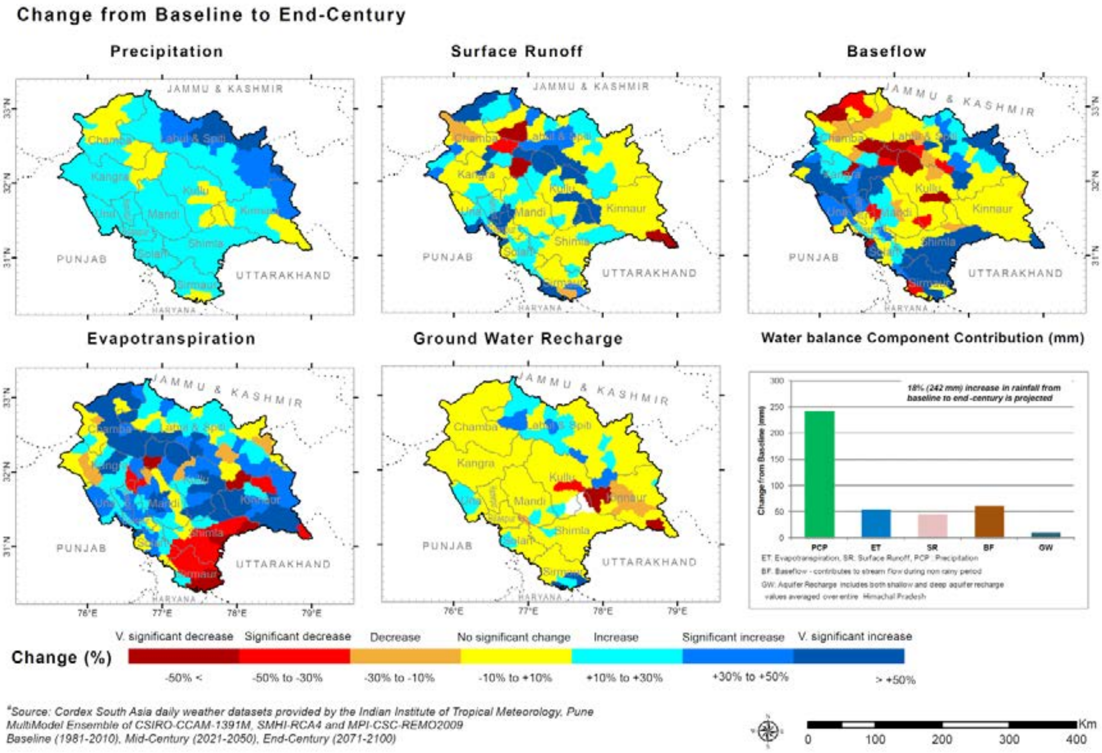
Large spatial variation in precipitation is likely across districts of Himachal Pradesh (2% to 42%). Similarly evapotranspiration also shows a large spatial variation. Reduction in evapotranspiration is likely in the districts of Shimla, Sirmaur and Solan.

The effects of climate change on the water balance components has been analysed spatially with respect to the sub-basins of Himachal Pradesh. The spatial distribution of water balance components have been plotted in terms of the percent change from the baseline period. Figure 12 shows the spatial distribution of change from baseline.

Figure 12: Spatial distribution of change in water balance components towards mid and end-century (IPCC AR5 RCP8.5 scenario) for river basins falling in Himachal Pradesh

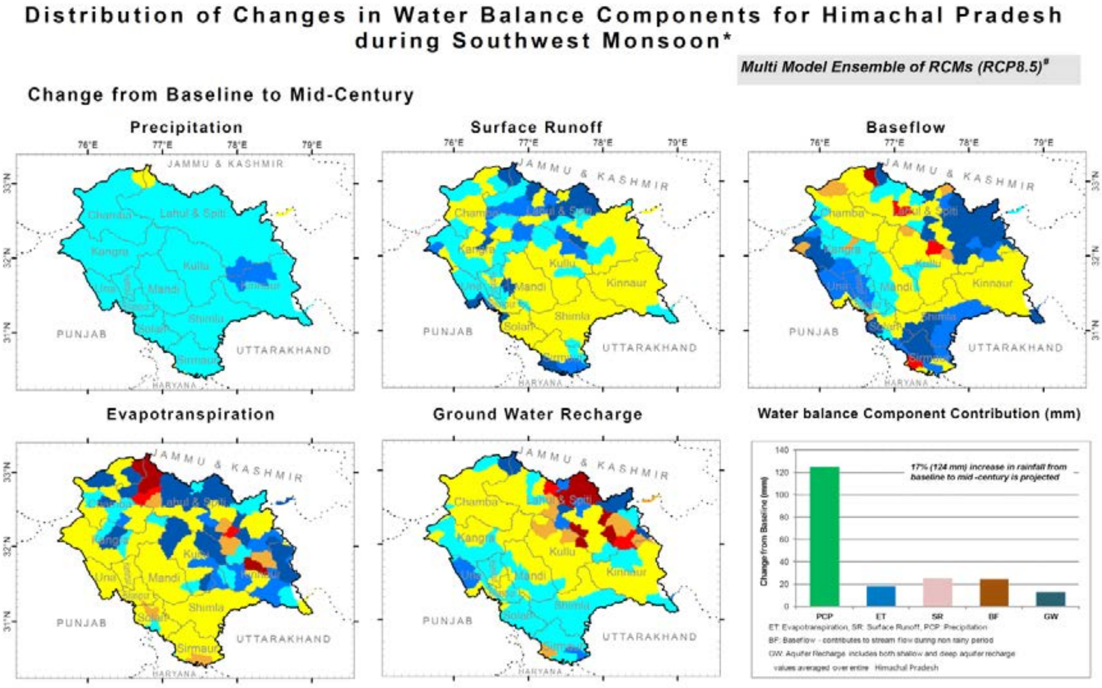
Long term Annual Change

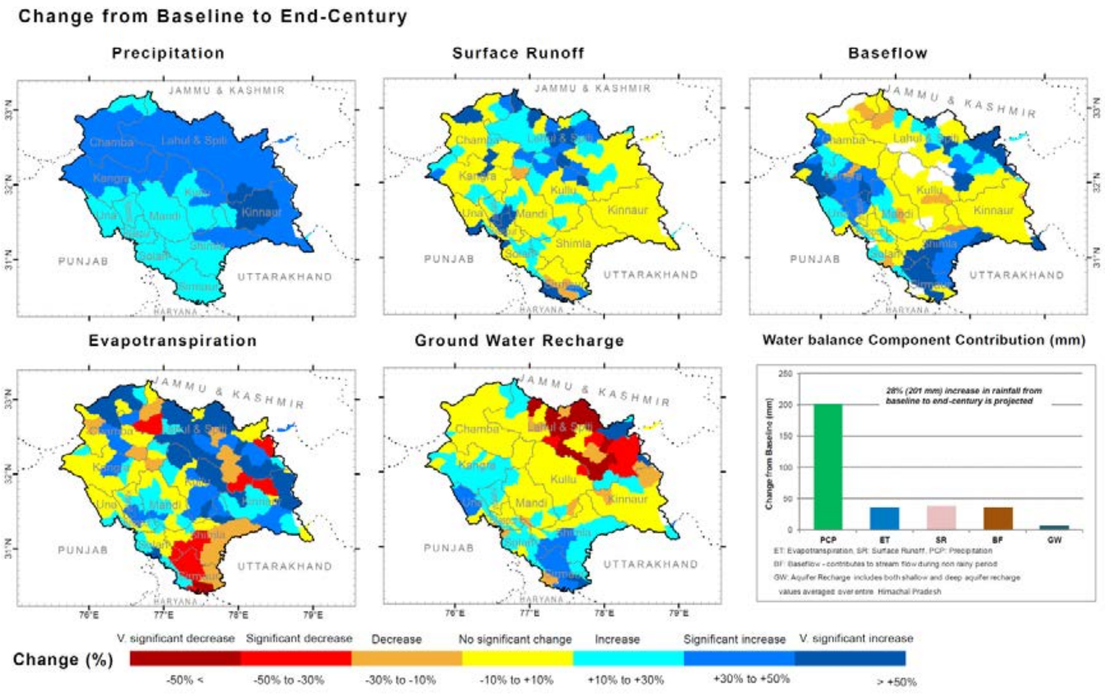




#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Long term Change during Southwest Monsoon Season

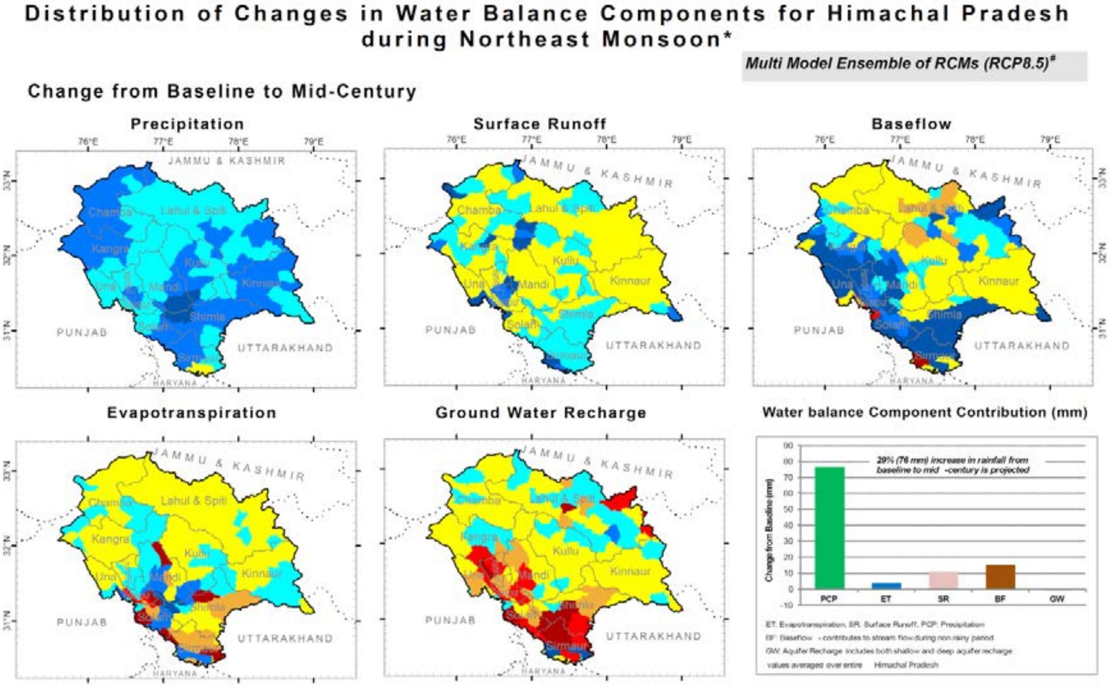


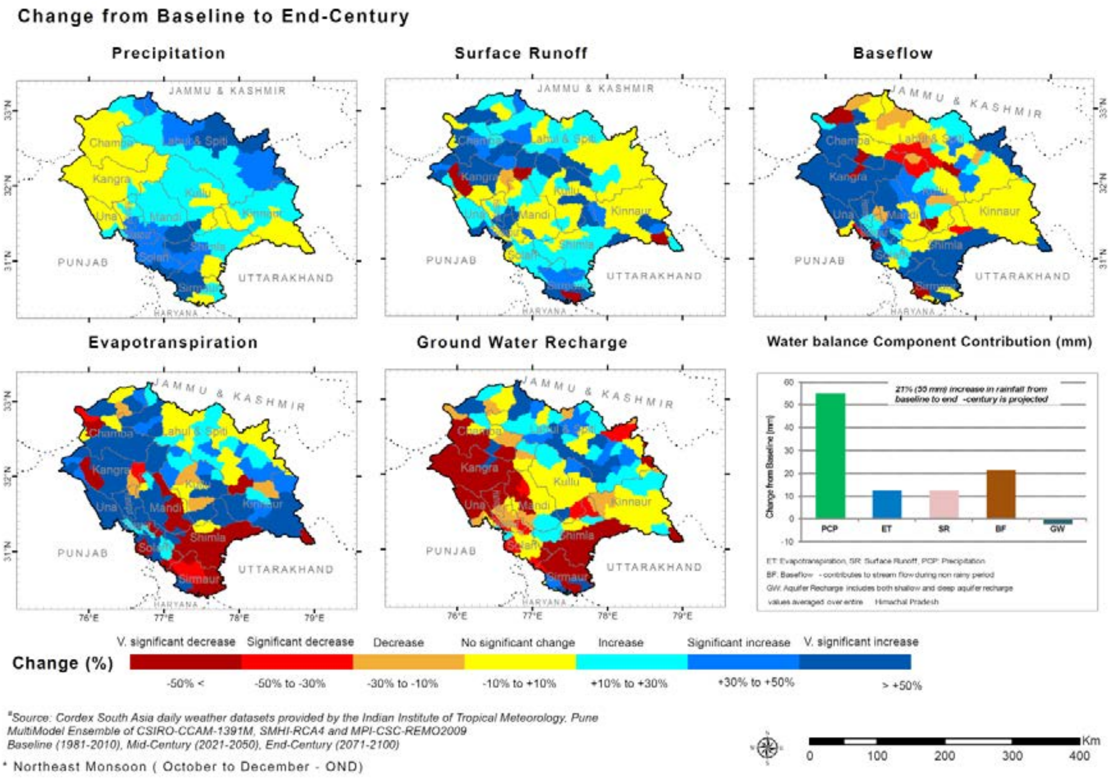


*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

*Southwest Monsoon (June to September - JJAS)

Long term Change during Northeast Monsoon Season


Distribution of Changes in Water Balance Components for Himachal Pradesh during Northeast Monsoon*



Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

* Northeast Monsoon (October to December - OND)

Analysis for Hydrological extremes

The outputs from the hydrological model have been used to assess the impact of the climate change on the river basins in terms of occurrence of droughts and floods. The rainfall, runoff and actual evapotranspiration have been selected from the available model output since they mainly govern the two extreme impacts due to climate change, namely droughts and floods.

Drought Analysis

Drought indices are widely used for the assessment of drought severity by indicating relative dryness or wetness effecting water sensitive economies.

The Palmer Drought Severity Index (PDSI) is one such widely used index that incorporates information on rainfall, land-use, and soil properties in a lumped manner (Palmer 1965[15]). The Palmer index categorize drought into different classes. PDSI value below 0.0 indicates the beginning of drought situation and with a value below -3.0 as severe drought condition.

Soil moisture index developed (Narasimhan and Srinivasan, 2005[16]) to monitor drought severity using SWAT output to incorporate the spatial variability has been used in the present study to focus on the agricultural drought where severity implies cumulative water deficiency. Weekly information has been derived using daily SWAT outputs which in turn have been used for subsequent analysis of drought severity.

The severity of droughts effects is proportional to the relative change in climate. For example, if a climate that usually has very slight deviations from the normal experiences a moderate dry period, the effects

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[15] Palmer, W.C., 1965. Meteorological drought. Research Paper 45. U.S. Department of Commerce, Weather Bureau, Washington, D.C. 58pp.

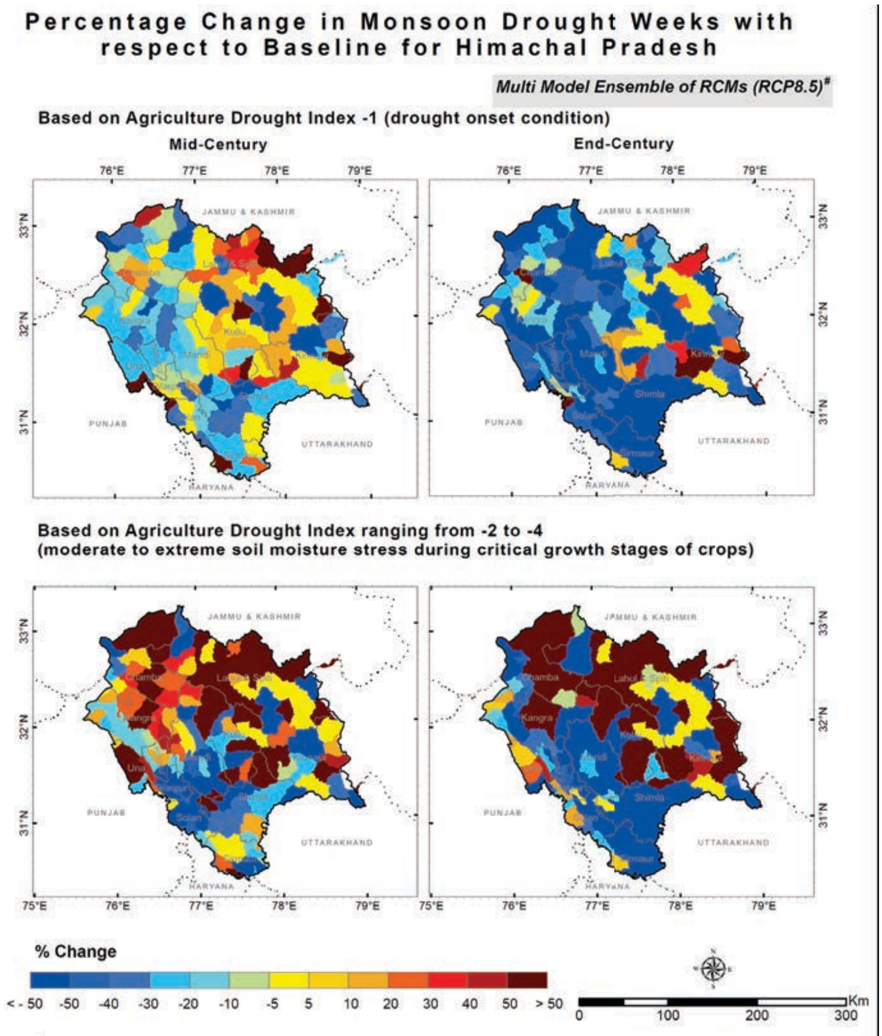
[16] Narasimhan, B. and Srinivasan, R., 2005. Development and evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring, Agricultural and Forest Meteorology 133 (2005) 69–88.

would be quite dramatic. On the other hand, a very dry period would be needed in a climate that is used to large variations to produce equally dramatic effects. In the current context scale 1 (Index between 0 to -1) represent the drought developing stage and scales 2 (Index between -1 to -4) represent mild to moderate and extreme drought condition.

Soil Moisture Deficit Index (SMDI) was calculated for 30 years of simulated soil moisture data from baseline (1981-2010), MC (2021-2050) and EC (2071-2098) climate change scenarios. The change from current condition to mid-century show increased drought like condition (onset of drought) compared to end-century scenario under IPCC AR5 RCP4.5 and RCP8.5. However the long term scenario shows the improvement in the drought onset conditions. The areas which may fall under moderate to extreme drought conditions (drought index value between -1 to -4) during south west monsoon period show the increase in severity of drought from baseline to mid-century scenario which improves towards end-century in RCP8.5 scenario.

The spatial distribution of percentage change (baseline to mid-century and baseline to end-century) in drought weeks during south west monsoon period are also shown using the SWAT output for smaller drainage basins in the GIS format in Figure 13. The hotspot areas can be recognised from the figure.

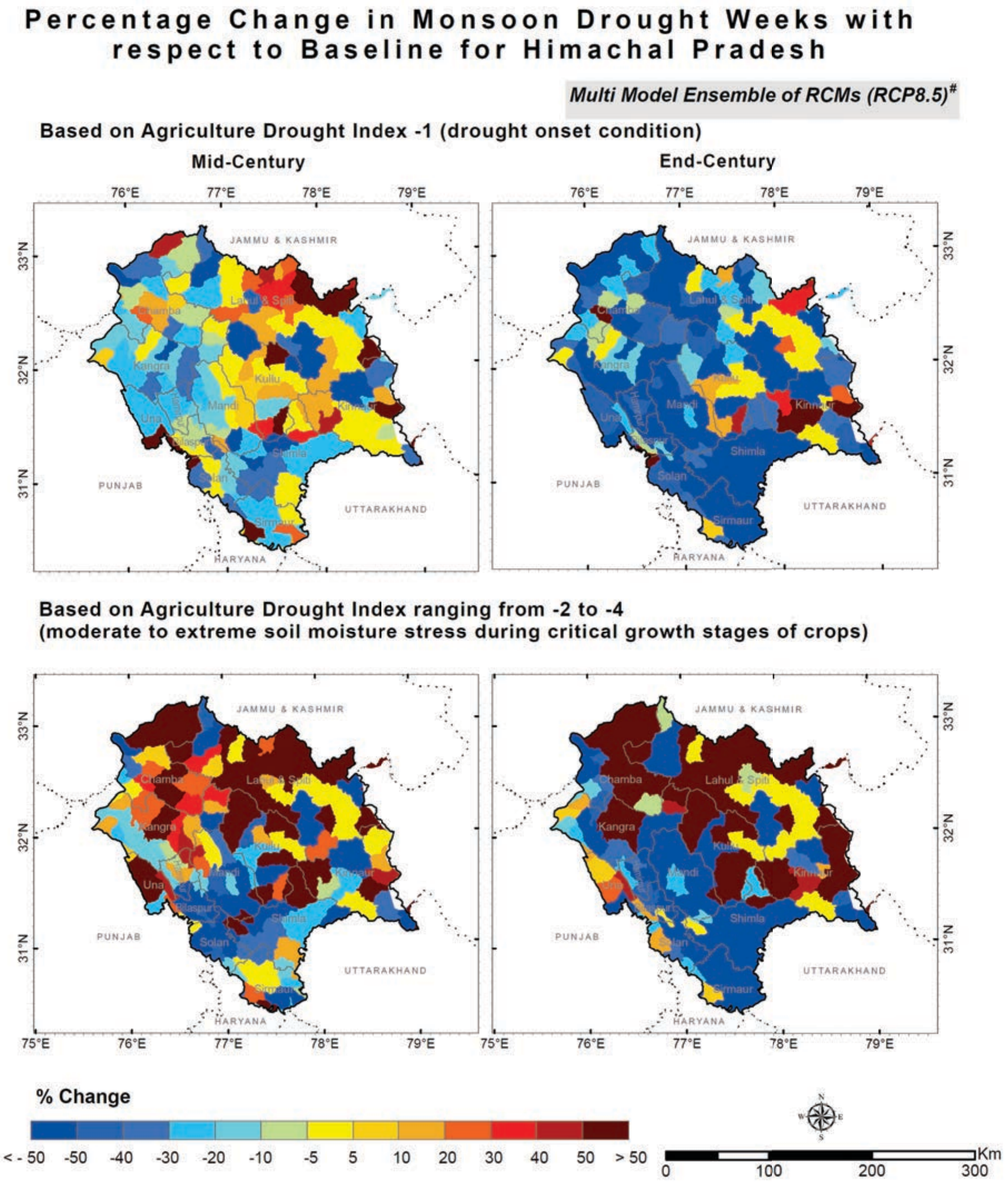
Figure 13: Change in spatial distribution of soil moisture deficit weeks for BL, MC and EC scenarios (IPCC AR5 RCP4.5) for river basins falling in Himachal Pradesh – Southwest Monsoon (JJAS)



*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Figure 14 show distribution of drought weeks for IPCC AR5 RCP8.5 scenario. It can be seen that the drought situation during south west monsoon period improves towards end-century when compared to baseline.

Figure 14: Change in Spatial distribution of Soil moisture deficit weeks for BL, MC and EC scenarios (IPCC AR5 RCP8.5) for river basins falling in Himachal Pradesh – Southwest Monsoon (JJAS)



#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

The concept of drought week is reflective of the change in the normal moisture condition of a location. In this sense, if a dry or desert area is analysed which has uniform conditions over a long period, it shall declare all the weeks to be normal weeks since there is no change in the character of the area on the basis of the conditions prevalent in the specific week of the year over a long period e.g., 30 years. Variability in moisture condition is expected to increase for MC and stabilize in EC scenario. An annual increase of about 2 to 3 weeks under drought is expected in mid-century and end-century for many districts.

RCP4.5 Scenario: For moderate emission scenario, increase in drought conditions is likely in districts of Chamba, Kangra, Kullu, Lahul & Spiti, Sirmaur and Una towards mid-century. Drought conditions are likely to improve in the districts of Hamirpur, Mandi, Solab Bilaspur and Una towards end-century.

RCP8.5 Scenario: For high emission scenario decrease in drought conditions is likely in most of the district mid- and end-century except for the districts of Chmba, Kullu and Lahul & Spiti which are likely to have higher drought conditions.

Flood and Flow Analysis

The vulnerability assessment with respect to the possible future floods as well as flow availability has been carried out using the daily outflow discharge taken for each sub-basin from the SWAT output. These discharges have been analysed with respect to the maximum annual peaks. Maximum daily peak discharge has been identified for each year and for each sub-basin. Analysis has been performed to identify those basins where flooding conditions may deteriorate under the climate change scenario. Two kinds of analysis has been performed, (i) change in the magnitude of flood peaks above 99th percentile, (ii) flow dependability at 95%, 90% and 75% has been evaluated and (ii) flow duration curves have been plotted for various locations on the rivers of Himachal Pradesh for baseline (1981-2010), MC (2021-2050) and EC (2071-2098) based on the simulated monthly flows at various locations.

Average Peak Discharge at 99th Percentile

Figure 15 shows change[17] in peak discharge equal to or exceeding at 99th percentile (1% probability of occurrence) from baseline to MC and EC scenarios for the river basins of Himachal Pradesh. It can be seen from the figure that the magnitude of peak discharge increases in end-century scenario as compared to the mid-century scenario. Projected peak discharge is higher in RCP8.5 scenario. Peak discharges are projected to increase by 20 to 40%.

RCP4.5 Scenario: For moderate emission scenario, increase in flood (extreme) discharge is likely in all districts by 10% to 15% towards mid- and end-century. However, flood magnitude is likely to reduce for all districts except for Chamba, Lahul & Spiti, Sirmaur, Solan and Una, which are likely to experience higher flood magnitude towards end-century.

RCP8.5 Scenario: For high emission scenario, increase in flood discharge is likely in districts of Chamba, Hamirpur, Kinnaur and Lahul & Spiti towards mid- and end-century.

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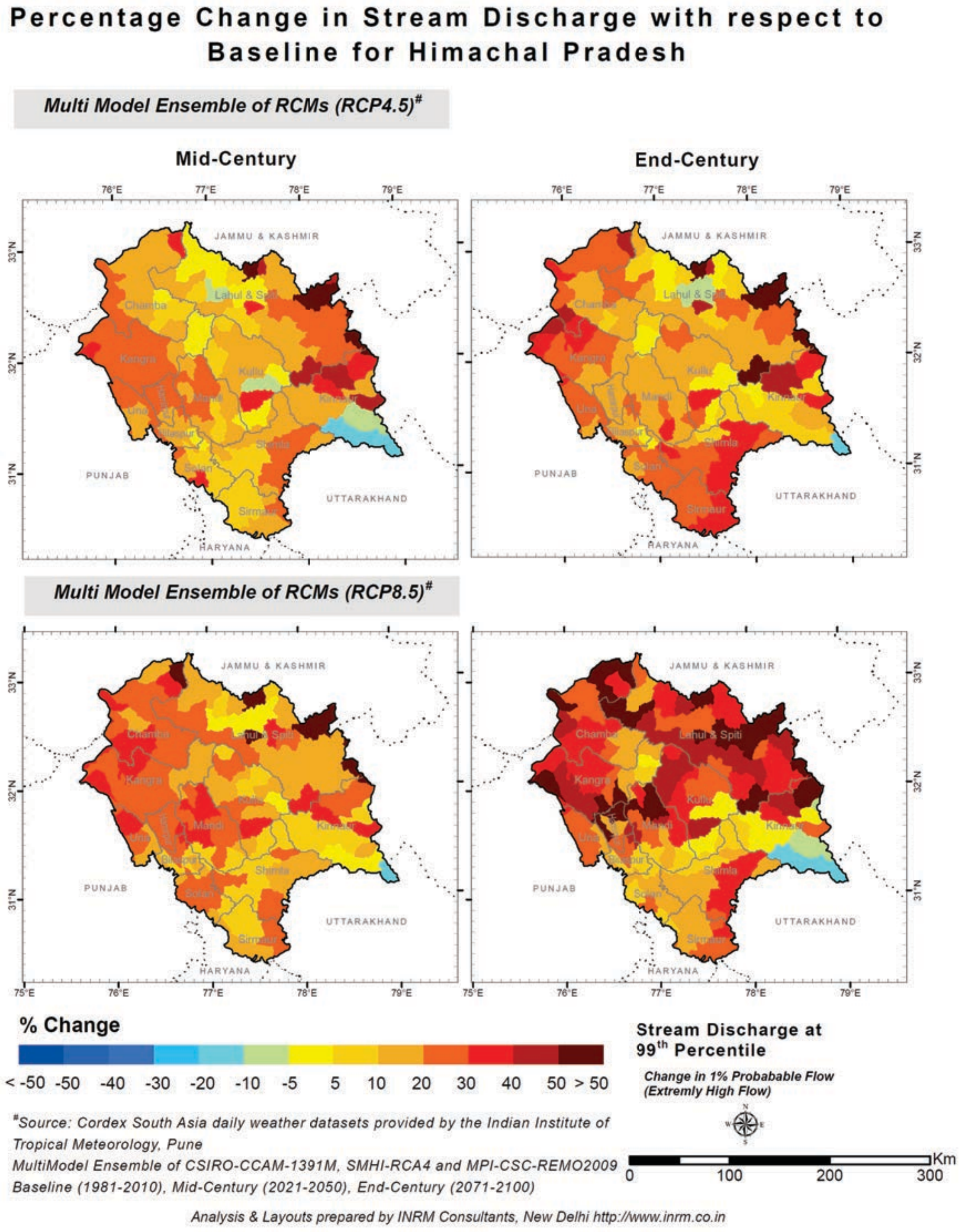
17 Change = 100*(MC-BL)/BL.

Figure 15: Spatial variation in Change in stream discharge at 99th percentile for BL, MC and EC climate scenarios (IPCC AR5 RCP4.5 and RCP8.5) for river basins falling in Himachal Pradesh



#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Analysis & Layouts prepared by INRM Consultants, New Delhi http://www.inrm.co.in

Average Dependable Flow at 95%, 90% and 75% Reliability Using Flow Duration Curve

A flow duration curve characterizes the ability of the basin to provide flows of various magnitudes. Information concerning the relative amount of time that flows past a site are likely to equal or exceed a specified value of interest is extremely useful for the design of structures on a stream. The shape of the curve in the high-flow region indicates the type of flood regime the basin is likely to have, whereas, the shape of the low-flow region characterizes the ability of the basin to sustain low flows during dry seasons[18]. Assessment of dependable lean season flows along with their distribution in time is essential for planning and development of water supply schemes. Irrigation projects are planned using 75% dependable flow. Hydropower and drinking water projects are planned at 90% and 100% dependable flow respectively. The 90% dependable flow is also used as a measure of ground water contribution to stream flow and can be used as a measure of run-of-the river hydropower potential[19].

The impact of the climate change on the dependability of stream flow for river basins of Himachal Pradesh has been analyzed with respect to three levels of 95, 90 and 75 % dependability based on the simulated annual river flows for RCP4.5 and RCP8.5 scenarios. Figure 16 shows the change from baseline to mid-century and end-century dependable flow.

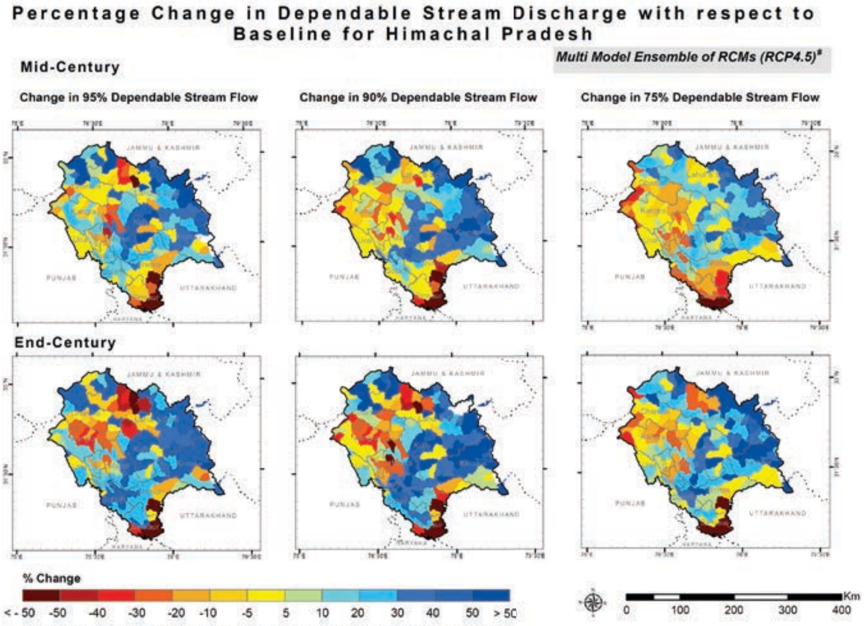
It can be seen from the figure that stream flow at 75% and 90% dependability increases towards mid- and end-century. Projected increase in 95% and 90% dependable flow under RCP8.5 is higher as compared to increase under RCP4.5 scenario. Similarly increase towards end-century is higher than mid-century.

RCP4.5 Scenario: For moderate emission scenario, increase in 75% and 90% dependable flow is likely in most of the districts towards mid- and end-century except for the district of Sirmaur. Districts of Kinnaur, Kulu and Lahul & Spiti are projected to have about higher increase in 75% and 90% dependable flow as compared to other districts.

RCP8.5 Scenario: For high emission scenario, increase in 75% dependable flow is likely in all districts except for the district of Sirmaur which is projected to have decrease in low flows.

Towards end-century most of the districts are likely to have significant increase in 90% dependable flow.

Figure 16: Spatial variation in change in dependable stream flow at 95%, 90% and 75% for BL, MC and EC climate scenarios (IPCC AR5 RCP4.5 and RCP8.5) for river basins falling in Himachal Pradesh



*Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009 ,Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

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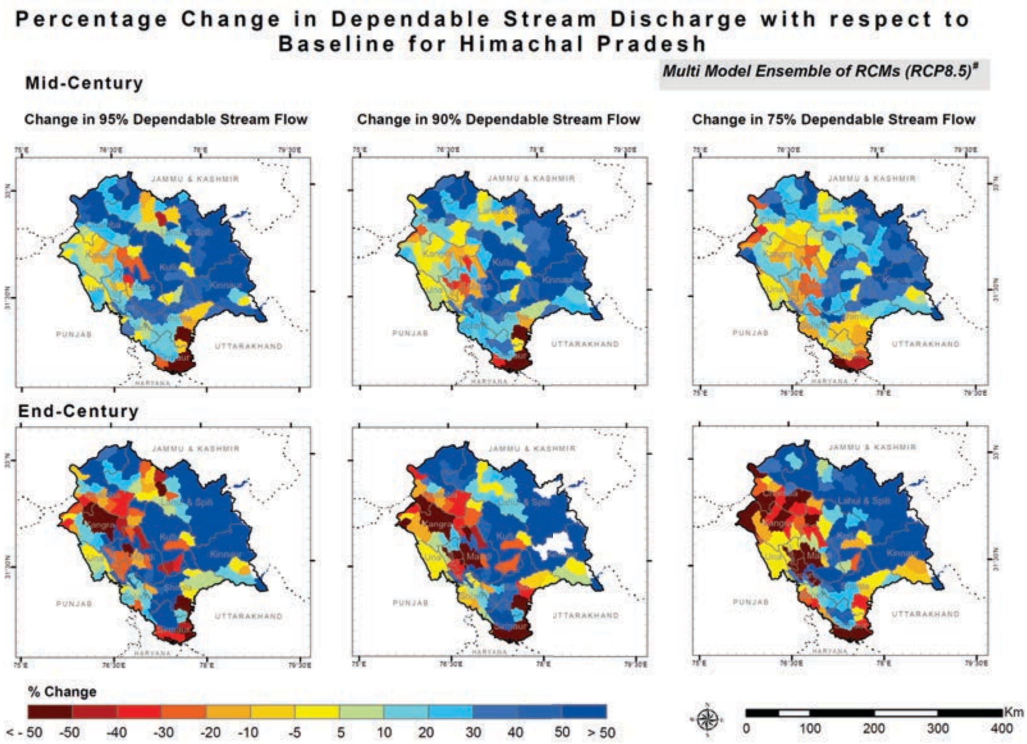
[18] http://streamflow.engr.oregonstate.edu/analysis/flow/.

[19] Water resources systems planning and management, SK Jain, VP Singh 2003, Elsevier Science (Verlag).

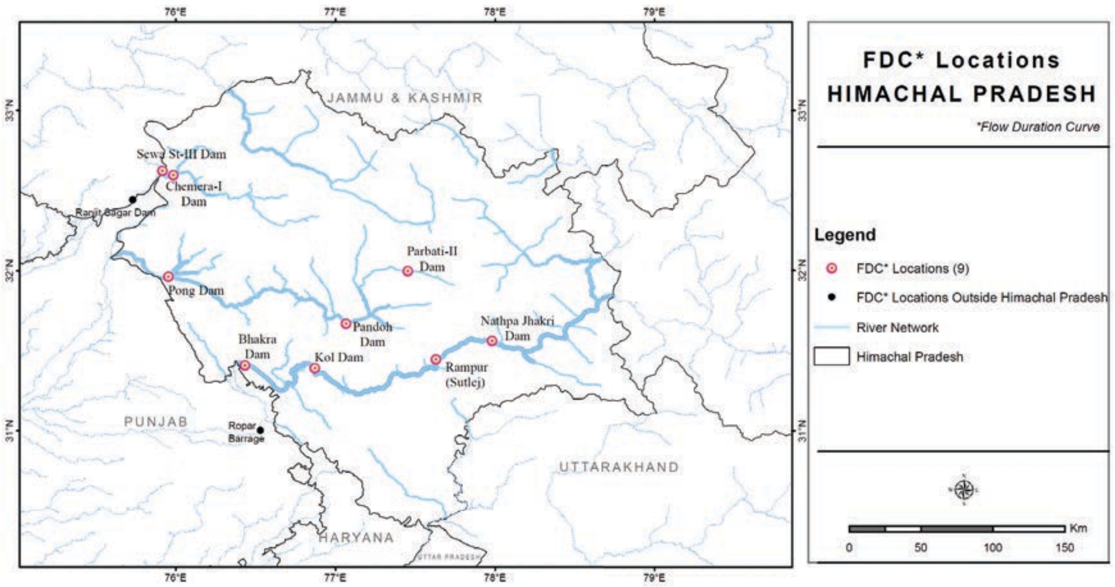


#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009 ,Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Flow Duration Curve and Impact on Reservoirs

Figure 17 shows the locations where flow dependability is assessed for both RCP4.5 and RCP8.5 scenario towards mid-century and end-century.

Figure 17: Locations where Dependable Flow is assessed for BL, MC and EC climate scenarios (IPCC AR5 RCP4.5 and RCP8.5) for river basins falling in Himachal Pradesh



Impact on the dependable flow at various locations based on annual flows is shown in Figure 17 and change in annual dependable flow is given in Table 2.

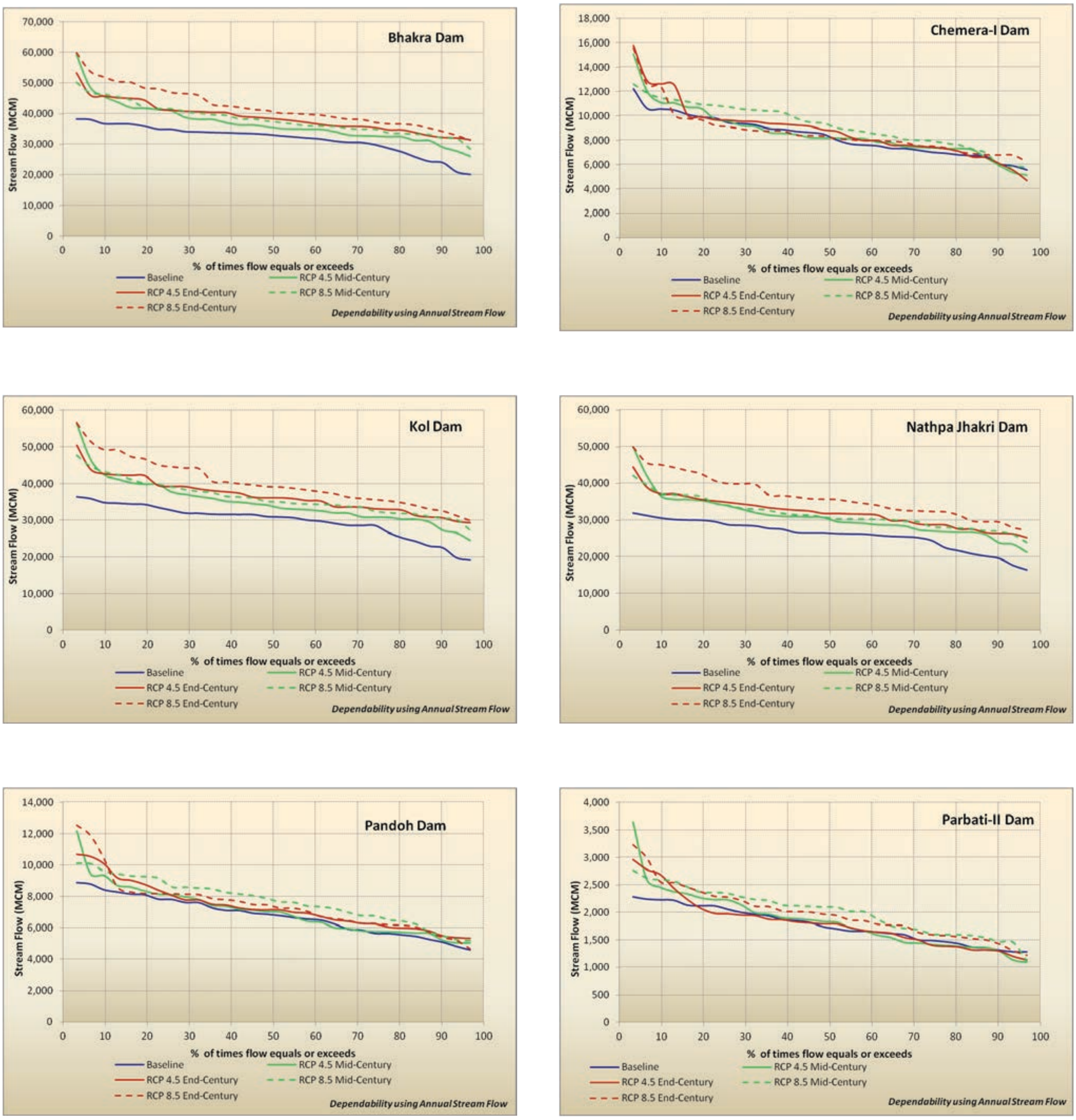
Table 2: Change (%) in annual dependable flow at various locations for IPCC AR5 RCP4.5 and RCP8.5 scenarios

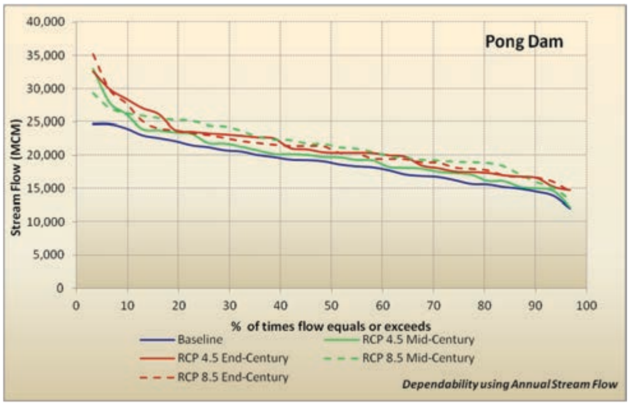
Scenario/Season	RCP 4.5		RCP 8.5	
	Mid Century	End Century	Mid Century	End Century
25 % Dependable Flow MCM				
Bhakra Dam	17.7	18.4	19.4	35.5
Chemera-I Dam	0.8	1.3	12.9	-4.0
Kol Dam	16.3	19.4	19.6	35.9
Nathpa Jhakri Dam	17.9	20.8	18.2	38.6
Pandoh Dam	3.7	4.2	11.8	4.3
Parbati-II Dam	7.6	-4.9	13.4	10.0
Pong Dam	4.3	10.0	16.0	8.7
Rampur (Sutlej)	15.6	20.8	18.6	36.7
Sewa St-III Dam	6.3	24.5	27.7	30.6
50 % Dependable Flow MCM				
Bhakra Dam	7.4	16.5	13.7	23.3
Chemera-I Dam	-0.6	6.4	11.3	0.0
Kol Dam	9.0	16.7	13.5	26.7
Nathpa Jhakri Dam	14.7	21.0	16.2	35.5
Pandoh Dam	2.6	4.5	13.6	7.6
Parbati-II Dam	6.5	4.0	22.0	13.7
Pong Dam	4.7	8.6	13.8	10.8
Rampur (Sutlej)	11.6	17.5	15.0	31.0
Sewa St-III Dam	-0.1	16.5	11.0	13.3
75% Dependable Flow MCM				
Bhakra Dam	10.2	19.4	17.1	25.5
Chemera-I Dam	5.6	5.9	13.0	7.4
Kol Dam	9.7	17.6	15.2	26.7
Nathpa Jhakri Dam	13.2	20.6	18.1	35.6
Pandoh Dam	1.8	9.5	18.5	10.4
Parbati-II Dam	-4.5	-5.9	8.1	7.2
Pong Dam	7.1	9.1	18.2	12.4
Rampur (Sutlej)	11.2	18.6	15.5	29.4
Sewa St-III Dam	-5.5	4.3	5.3	20.9
90 % Dependable Flow MCM				
Bhakra Dam	21.4	34.2	33.7	42.4
Chemera-I Dam	-1.6	0.2	-2.0	11.9
Kol Dam	21.8	35.7	35.2	44.5
Nathpa Jhakri Dam	22.2	34.8	37.5	50.7
Pandoh Dam	2.5	7.7	8.4	5.8
Parbati-II Dam	-1.0	-1.5	12.0	9.1
Pong Dam	3.2	14.4	10.2	14.4
Rampur (Sutlej)	21.6	35.0	35.4	46.8
Sewa St-III Dam	4.5	30.1	11.1	41.8

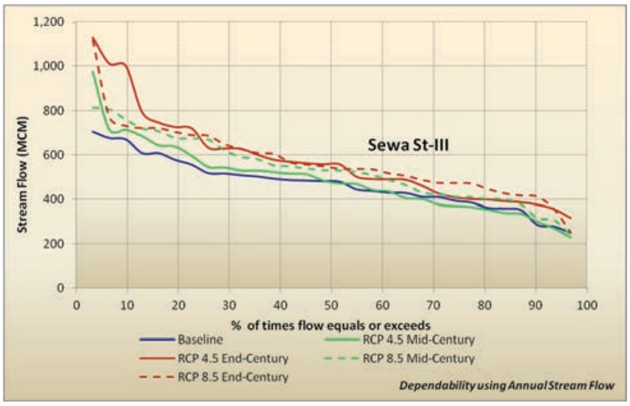
It can be inferred that the supply to various dam locations in the basins falling in Himachal Pradesh are projected to have increase in the flow towards mid- and end-century under both climate scenarios. Projected increase in dependable flow is higher for Bhakra Dam, Nathpa Jhakri Dam and at Rampur (Sutlej) as compared to other locations. Chemera-I Dam and Parbati-II Dam are likely to have reduced flow under RCP4.5 scenario and marginal increase under RCP8.5 scenario.

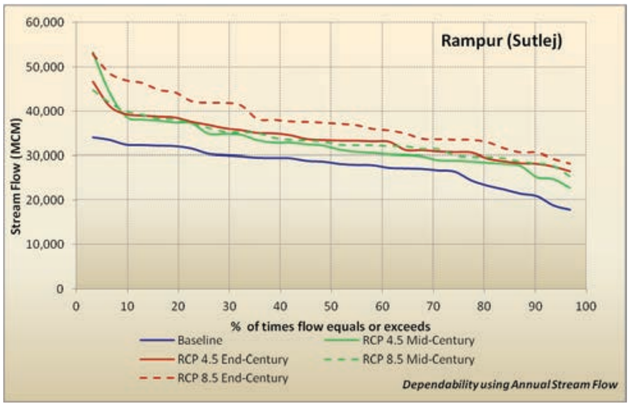
Flow duration curves for selected locations are shown in Figure 18. It can be seen from the figure that the magnitude of high flows are projected to double towards end-century under RCP8.5 scenario.

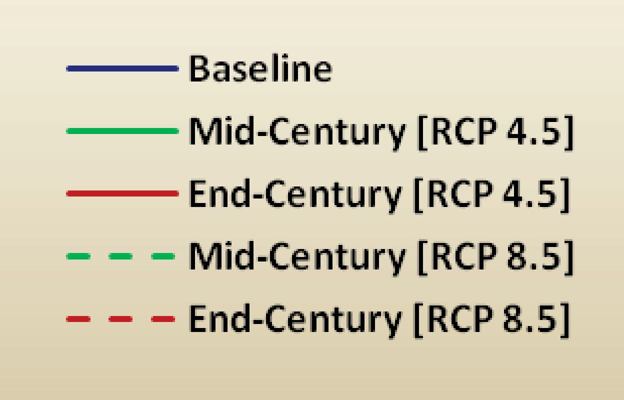
Figure 18: Dependable flow assessed for BL, MC and EC climate scenarios (IPCC AR5 RCP4.5 and RCP8.5) at some selected locations along Indus falling inside Himachal Pradesh











Many reservoirs are likely to experience an increase in peak flow by 20 to 30% towards mid- and end-century under both scenarios. This may call for additional risk management strategy. There is significant increase in low flow dependability as compared to baseline in all the locations.

Impact Assessment on Water Resources - Summary

- Calibrated SWAT hydrological model for all the river basins falling in Himachal Pradesh has been run using climate scenarios for near (MC) and long term (EC) periods (2021 – 2050, 2071-2100, respectively) without changing the land use.
- Under the moderate emission scenario (RCP4.5), for south west monsoon season (JJAS) increase in precipitation of 14% and 22% is projected in mid-century and end-century respectively. Spatial variation from 8% to 22% increase in precipitation is projected across districts of Himachal Pradesh. All the districts except Bilaspur, Sirmaur and Solan, are projected to have above 10% increase in precipitation. Most of the districts, except Bilaspur and Solan, show increase in surface run off contributing to stream flow.
- Under the moderate emission scenario, for north east monsoon season (OND) marginal decrease in precipitation is projected towards mid-century and increase by 17% is projected towards end-century. Increase in evaporation is likely for the districts of Chamba, Kangra, Kinnaur, Kullu and Lahul & Spiti.
- Under the high emission scenario (RCP8.5), for south west monsoon season (JJAS) increase in precipitation of 14% and 28% is projected in mid-century and end-century respectively. Significant increase in evapotranspitration is projected. 14% to 23% increase in precipitation and 16% to 41% decrease in precipitation are projected towards mid-and end-century for different districts. Highest increase is projected for Kinnaur district

- Under the moderate emission scenario, for north east monsoon season (OND) increase in end-century by 29% and 21% is projected towards mid- and end-century. All the districts are likely to have increase in stream flow due to high intensity rainfall. Many districts are likely to have increase in evapotranspiration attributed largely to projected rise in temperature.
- Under moderate emission scenario increase in drought conditions is likely in districts of Chamba, Kangra, Kullu, Lahul & Spiti, Sirmaur and Una towards mid-century. Drought conditions are likely to improve in the districts of Hamirpur, Mandi, Solab Bilaspur and Una towards end-century.
- Under high emission scenario decrease in drought conditions is likely in most of the district mid- and end-century except for the districts of Chmba, Kullu and Lahul & Spiti which are likely to have higher drought conditions.
- The magnitude of peak discharge is projected to increase in flood (extreme) discharge is likely in all districts by 10% to 15% towards mid- and end-century. However, flood magnitude is likely to reduce for all districts except for Chamba, Lahul & Spiti, Sirmaur, Solan and Una, which are likely to experience higher flood magnitude towards end-century under both RCP scenarios.
- Under moderate emission scenario, increase in 75% and 90% dependable flow is likely in most of the districts towards mid- and end-century except for the district of Sirmaur. Districts of Kinnaur, Kulu and Lahul & Spiti are projected to have about higher increase in 75% and 90% dependable flow as compared to other districts.
- Under high emission scenario, increase in 75% dependable flow is likely in all districts except for the district of Sirmaur which is projected to have decrease in low flows.
- Supply to various dam locations in the basins falling in Himachal Pradesh is projected to have increase in the flow towards mid- and end-century under both climate scenarios. Projected increase in dependable flow is higher for Bhakra Dam, Nathpa Jhakri Dam and at Rampur (Sutlej) as compared to other locations.

Climate Change Impact Assessment on Health in Himachal Pradesh

Introduction

The IPCC 5th Assessment Report concluded that until mid-century climate change will act mainly by exacerbating health problems that already exist (Smith et al., 2014[20]). New conditions may emerge under climate change (low confidence), and existing diseases (e.g., food-borne infections) may extend their range into areas that are presently unaffected. But the largest risks will apply in populations that are currently most affected by climate-related diseases.

Likely Impacts of Climate Change on Human Health

Some of the fundamental impacts of climate change as indicated on human health are listed below (Source: Protecting health from climate change – Connecting Science Policy and People, WHO, 2009):

- Extreme air temperature leading to heat waves is a direct contributor to deaths from cardiovascular and air pollution to respiratory disease, particularly among elderly people. High temperatures also raise the levels of ozone and other air pollutants that exacerbate cardiovascular and respiratory disease, and pollen and other aeroallergens that trigger asthma.

- Floods, droughts and contaminated water raise disease risk as more variable precipitation is occurring, with an increase in the frequency and intensity of both floods and droughts. At the same time, higher temperatures are hastening rates of evaporation of surface waters and melting the glaciers that provide fresh water for many populations. Lack of fresh water compromises hygiene, thus increasing rates of diarrhoeal disease. In extreme cases, water scarcity results in drought and famine. Too much water, in the form of floods, causes contamination of freshwater supplies and also creates opportunities for breeding of disease carrying insects such as mosquitoes.

- Rising temperatures and changing patterns of rainfall are projected to decrease crop yields, stressing food supplies. This is deleterious for small and marginal farmers as they are unlikely to have enough income to buy food. This situation is expected to translate directly into wider prevalence of malnutrition. In turn, malnutrition and under nutrition increase the severity of many infectious diseases, particularly among children.

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18 Smith, K.R., A. Woodward, D. Campbell-Lendrum, D.D. Chadee, Y. Honda, Q. Liu, J.M. Olwoch, B. Revich, & R. Sauerborn, 2014: Human health: impacts, adaptation, and co-benefits. 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, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 709-754.

- Expected increases in the frequency and severity of flooding and storms will result in the destruction of homes, medical facilities and other essential services, impacting particularly on people in slums and other marginal living conditions.

Many of the major infectious diseases transmitted by water and contaminated food, and by insect vectors are highly sensitive to climatic conditions and weather extremes. Climate change threatens to slow, halt or reverse current progress against many of these infections.

Likely Impacts of Climate Change on Livestock

Climate change has both direct and indirect effect on animal production, reproduction along with emergence and re-emergence of many animal diseases[21]. It has been estimated that the annual loss in total milk production due to heat stress on livestock is around two per cent in the country, amounting to over Rs.2.661 crore[22].

Impact on Dairy Production Systems

The environmental conditions that induce heat stress on dairy animals can be calculated using temperature humidity index (THI). The heat stress begins to occur in dairy cattle wherein the THI is more than 72(<72 no stress, 72 - 79 mild, 80 - 89 moderate, 90-98 severe and above 98 danger). The decreases in milk production can range from 10 to 25%. It has been estimated that with a temperature rise of 1.0 or 1.2°C with minor change in precipitation during May to August, milk productivity is likely to be marginally affected and during other months productivity will remain relatively unaffected. The negative impact of temperature rise on total milk production for India has been estimated about 1.6 million tonnes in 2020 and more than 15 million tonnes in 2050. An average adult cow or buffalo producing 10-15 lit milk per day requires about 40- 45 lit/day as drinking water on hot days and about 40- 60 lit for other related work thus requiring a minimum of 100 lit/ day/ animal. An organized animal farm following standard management practices and disposal of animal wastes requires additional water about 50- 100 lit/day/animal. Any deficiency in water availability will certainly lead to decline in milk productivity.

Affect on Feed and Fodder

Water scarcity not only affects livestock drinking water resources, but also it has a direct bearing on livestock feed production systems and pasture yield. Rising temperatures also have an additional impact on the digestibility of plant matter. Raised temperatures increase the lignifications of plant tissues and thus reduce the digestibility and the rates of degradation of plant species. This not only affects the health of an animal but also results in the reduction in livestock production which in turn has an effect on food security and incomes of small livestock keepers. Studies have shown that dry matter intake decreases in animals subjected to high temperatures. This decrease in dry matter intake can be either mid-century or end-century depending on the length and duration of heat stress.

Feed and Fodder Availability

Livestock rearing is an integral part of farming in Himachal Pradesh. In Himachal Pradesh the green herbage availability varied from 1.5 to 1.74 t/ha in temperate pastures and 0.5 to 1.0 t/ha in alpine and sub-alpine

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[21] http://www.icar.org.in/files/reports/icar-dare-annual-reports/2010-11/climate-change-AR-2010-11.pdf

[22] Upadhyay R.C, Ashutosh, Singh S.V. Impact of climate change on reproductive functions of cattle and buffalo. In: Aggarwal P.K, editor. Global Climate Change and Indian Agriculture. New Delhi: ICAR; 2009. pp. 107–110,

pastures (Singh, 1995[23]). A gap of about 35.0 and 57.0% from dry and green forages exists respectively in Himachal Pradesh[24]. According to a study by Dev et al. (2006)[25], district-wise forage resources shows that Chamba has the highest area available for grazing (21%) followed by Mandi and Kangra. Kinnaur and Lahaul and Spiti districts showed a surplus fodder in terms of total dry matter basis, while in the other districts of the state there is shortage of green and dry fodder. The grazing pressure and grazing intensity for the state were 1.26 ACU/ha and 0.79 ha/ACU (adult cattle unit with average body weight of 350 kg).

Impact Assessment on Human Health

Heat Stress

Changes in weather and climate affect health, both directly and indirectly. More intense and frequent extreme events directly give rise to several weather-related diseases . Heat Index describes the combined effect of temperature and humidity on human body. This combined effect is causing a serious threat to the health of people because of the changing climate.

Humidex

The humidex also known as the apparent temperature is an index number to describe how hot the weather feels to the average person, by combining the effect of heat and humidity. The humidex is based on the mean air temperature, relative humidity and vapour pressure. The humidex combines the temperature and humidity into one number to reflect the perceived temperature. Because it takes into account the two most important factors that affect summer comfort, it can be a better measure of how uncomfortable the air feels than either temperature or humidity alone.

Table 3 gives the range of humidex value and the comfort or discomfort level with each range.

Table 3: Range of humidex and degree of comfort or discomfort

Heat Index (0F)	Degree of comfort or discomfort
Less than 90	Caution - Fatigue is possible with prolonged exposure and/or physical activity
90 to 103	Extreme Caution - Sunstroke, heat cramps and heat exhaustion are possible with prolonged exposure and/or physical activity
103 to 125	Danger - Sunstroke, heat cramps and heat exhaustion are likely. Heat stroke is possible with prolonged exposure and/or physical activity
Above 125	Extreme Danger - Heatstroke/sunstroke is highly likely with continued exposure
Source: http://www.srh.noaa.gov/ama/?n=heatindex	

Fatigue can be described as the lack of energy and motivation (both physical and mental). Heat cramps are painful, brief muscle cramps. Muscles may spasm or jerk involuntarily. Heat exhaustion is where you become very hot and start to lose water or salt from your body, which leads to the symptoms listed below and generally feeling unwell. If heat exhaustion isn't spotted and treated early on, there's a risk it could lead

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23 Singh, L.N (1995). Temperate Pastures and their Management (in press), IGFRI, Jhansi.

24 Inder Dev (2011), Problems and prospects of forage production and utilization of Indian Himalaya, Envis Bulletin Holume 9, No.2 pp 11-18.

25 Dev, Inder, Misri, B, Pathania, M.S.. (2006). Forage demand and supply in western Himalaya: A balance sheet for Himachal Pradesh. 76. 720-726.

26 McMichael, A. J. et al. (eds), Climate Change and Human Health, World Health Organization, Geneva, 1996.

to heatstroke. Heatstroke is where the body is no longer able to cool itself and a person's body temperature becomes dangerously high. Heatstroke is less common, but more serious. It can put a strain on the brain, heart, lungs, liver and kidneys, and can be life-threatening.

Humidex has been calculated for the state of Himachal Pradesh using IPCC RCP scenarios (RCP4.5 and RCP8.5) baseline, mid-century and end-century data. Months from April to September are significant on account of either high temperature or high humidity. Figure 19 shows the overall weighted heat stress days for districts of Himachal Pradesh for the months of April to September. The weighted heat stress is calculated for each district by assigning weights to the scales of humidex and then multiplying the respective weights for each scale with the number of days of discomfort in the respective heat scale for BL, MC and EC. Humidex scale 80-89°F (caution) is given weight 0.1, scale 90-104°F (extreme caution) is given weight 0.2, scale 103-125°F (danger) is given weight 0.3 and scale >130°F (extreme danger) is given weight 0.4.The highest weight is assigned to the extreme danger stress level and so on.

Figure 19 shows the heat stress levels for Himachal Pradesh state the months of April to September. The colour in Figure 21 layout shows maximum humidex scale (severity of heat stress) attained during a month for the Himachal Pradesh districts and the dots show the number of days in that month for the districts which are projected to have the maximum HI scale.

Figure 19, Figure 20 and Figure 21 shows the increase in heat stress towards mid- and end-century for both the scenarios.

- The heat stress is projected to increase for all the districts of Himachal Pradesh towards the mid-century and end-century. The increase towards the end-century is projected to be higher under IPCC AR5 RCP8.5 scenario as compared to the IPCC AR5 RCP4.5 scenario.
- The heat stress conditions are likely to exacerbate, particularly in the months of May to September for the districts of Himachal Pradesh.
- District namely Una located in the Sub mountain & low hills sub-tropical zone of Himachal Pradesh is projected to have the maximum increase in the severity of heat stress towards the mid-century and end-century as compared to the other districts. Thus extreme caution is needed to avoid sunstroke, heat cramps and heat exhaustion which are possible with prolonged exposure and/or physical activity.
- Mandi, Shimla, Chamba, Kinnaur, Kullu, Lahul & Spiti districts located in the high and very high hill areas of Himachal Pradesh heat stress level is negligible.
- The districts are mostly projected to be under extreme caution in the months of May to September. Extreme caution level is higher towards RCP4.5 scenario as compared to RCP8.5 scenario (Figure 19).
- It can be seen that in the months of April to September districts of Himachal Pradesh are not under danger stress or extreme danger stress level under RCP4.5 scenario while the districts are projected to be under very high impact for some days towards mid-century and end-century RCP8.5 scenario.
- Extreme danger stress level is observed only towards end-century RCP8.5 scenario.

Figure 19: Weighted Heat Stress days for districts of Himachal Pradesh

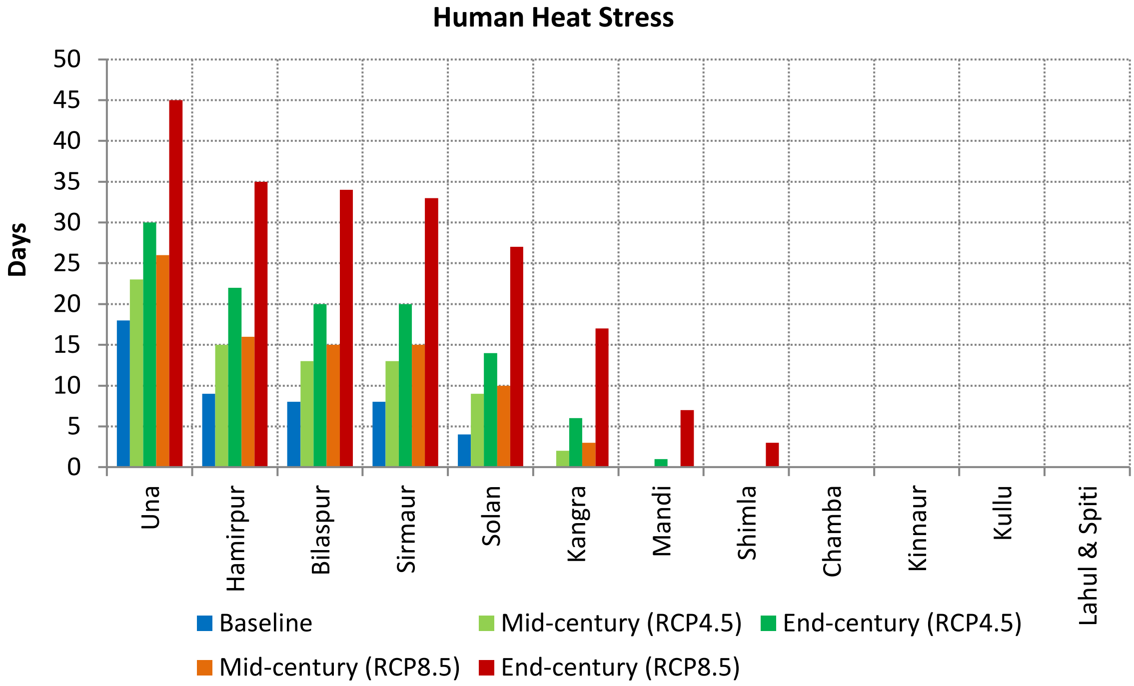
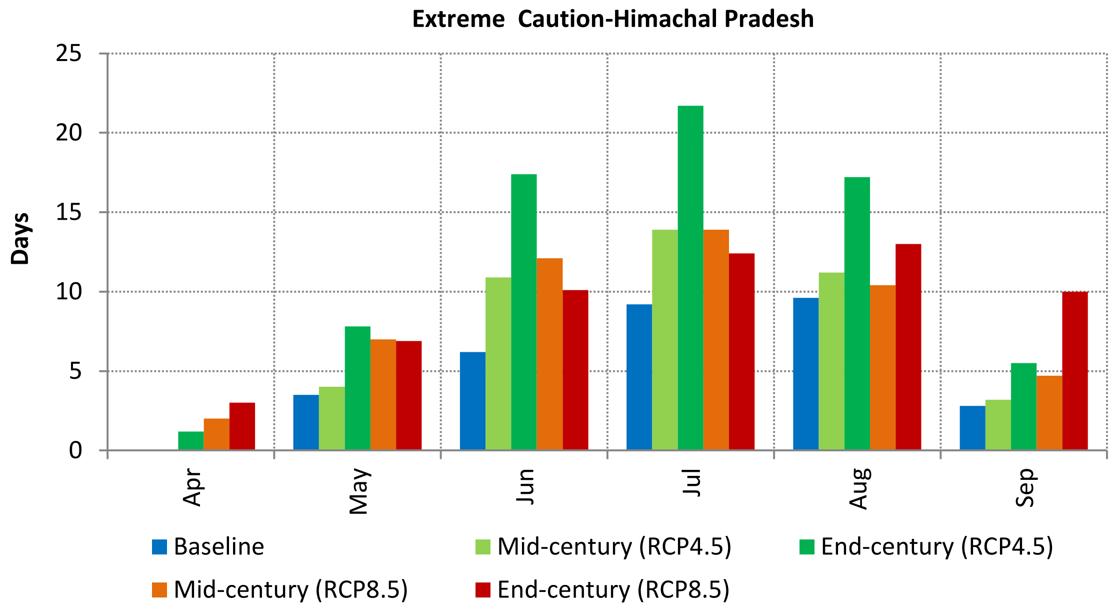
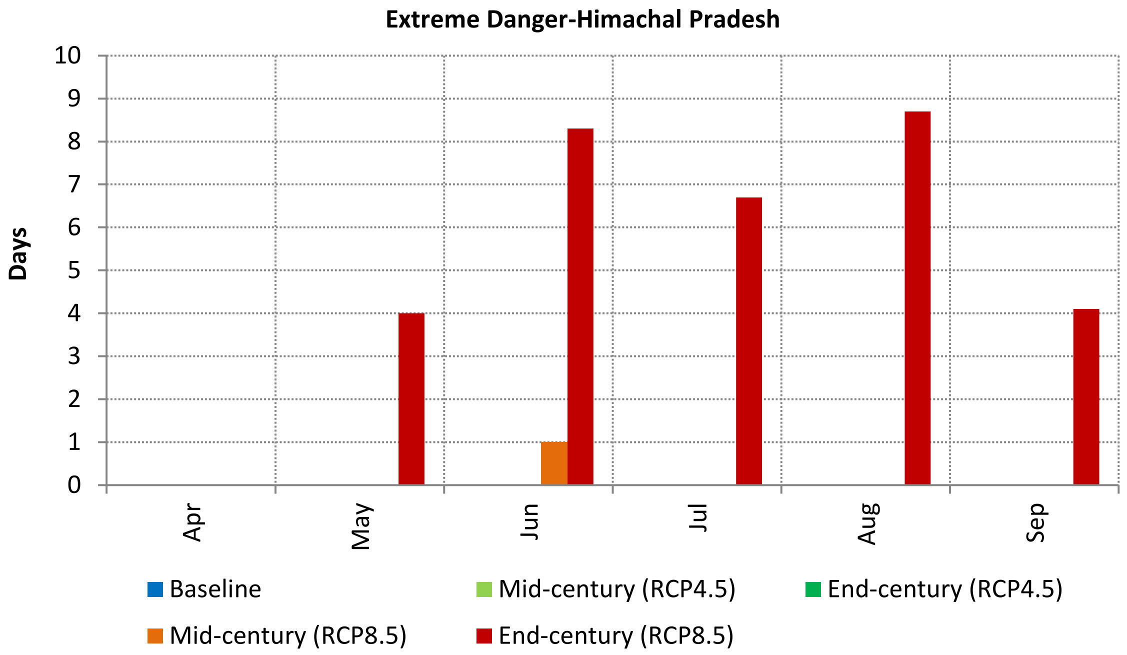


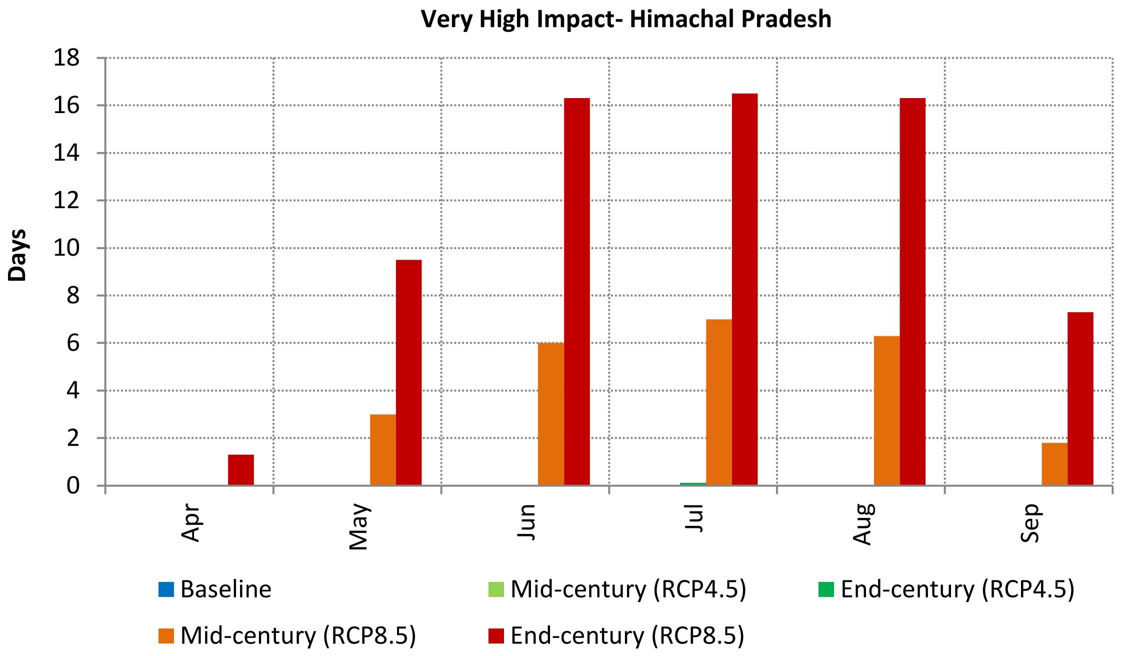
Figure 20: Projected Heat Stress Levels for Himachal Pradesh for the months of April to September



Extreme Caution - Sunstroke, heat cramps and heat exhaustion are possible with prolonged exposure and/or physical activity



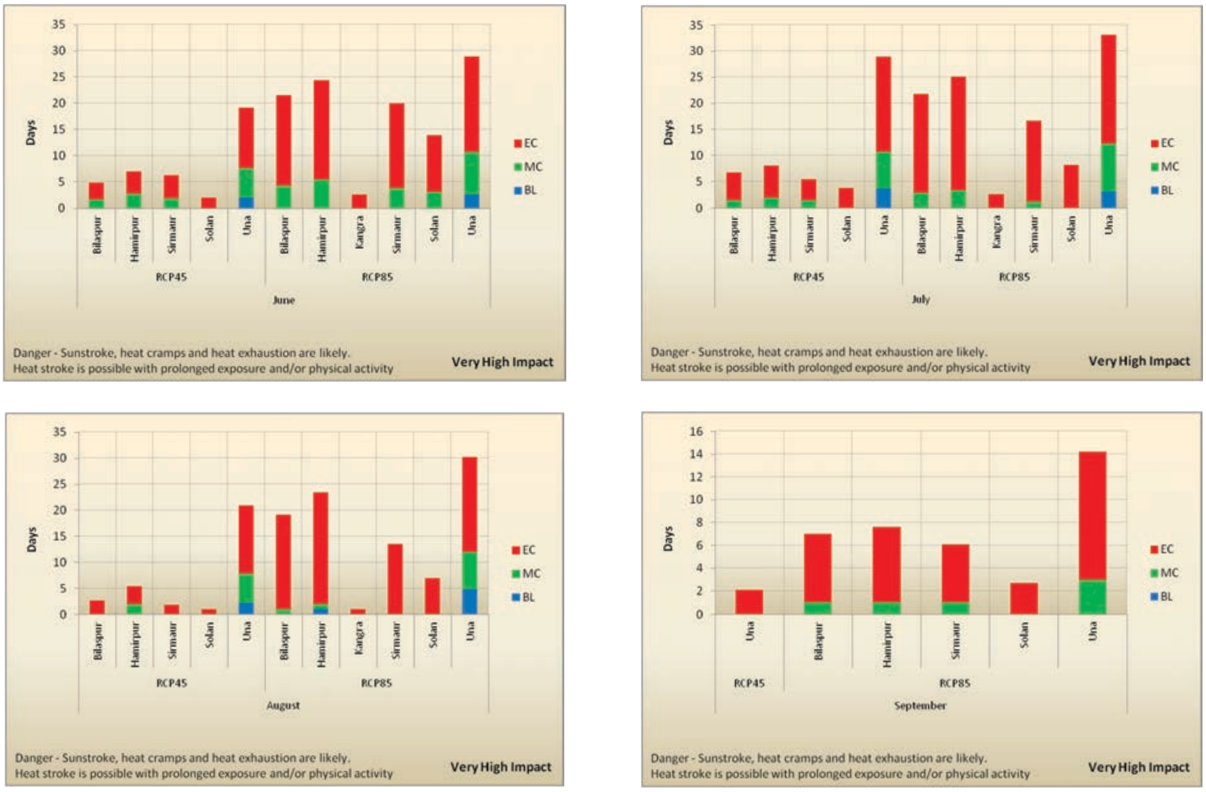
Extreme Danger - Heatstroke/sunstroke is highly likely with continued exposure



Danger - Sunstroke, heat cramps and heat exhaustion are likely. Heat stroke is possible with prolonged exposure and/or physical activity

Figure 21: Projected HI for districts (highest heat stress) in Himachal Pradesh for the months of June, July, August and September

Very High Impact



Extreme Impact

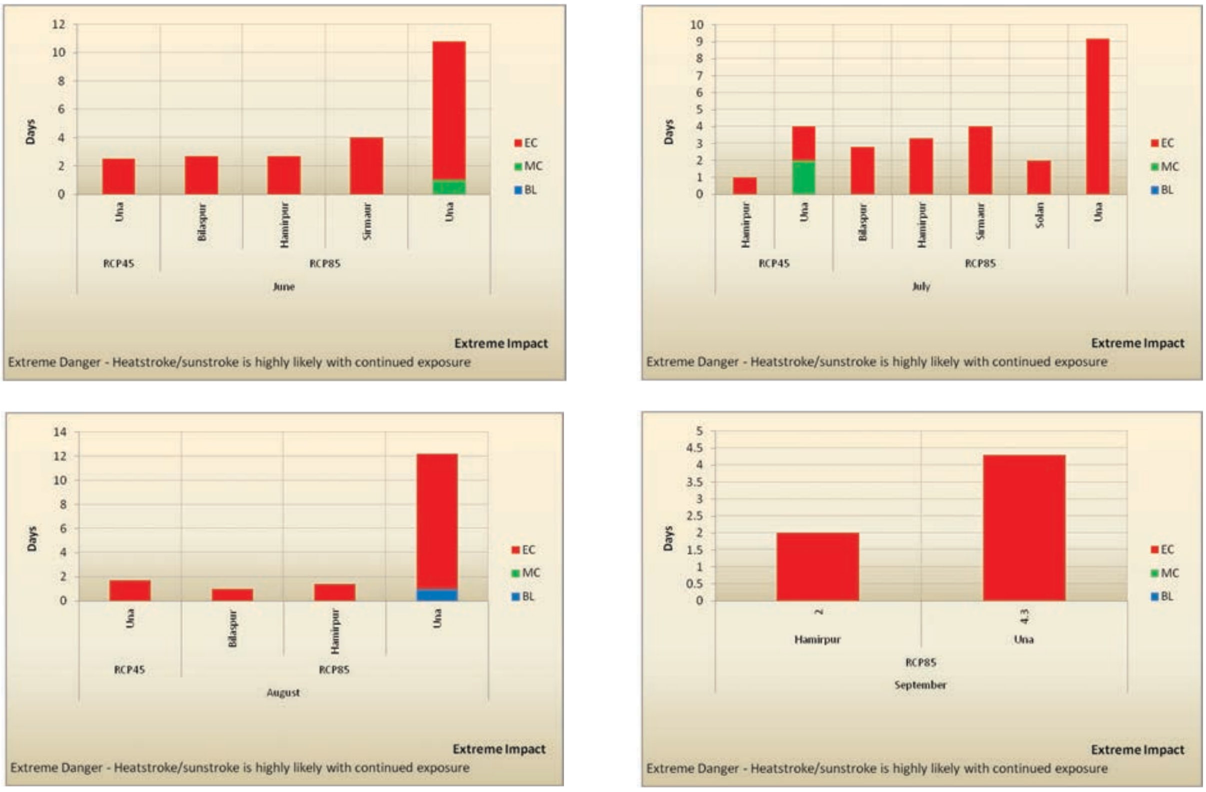
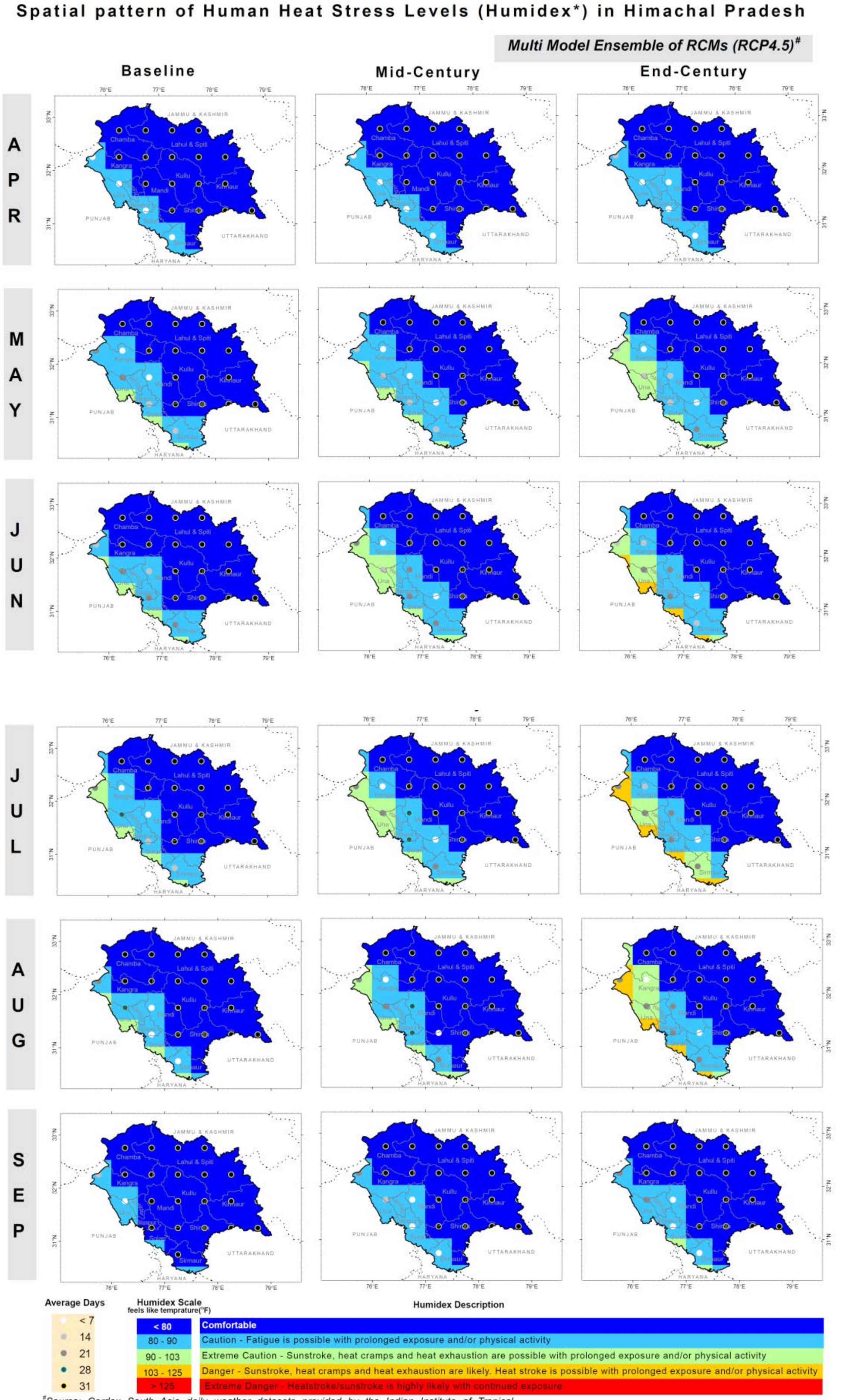


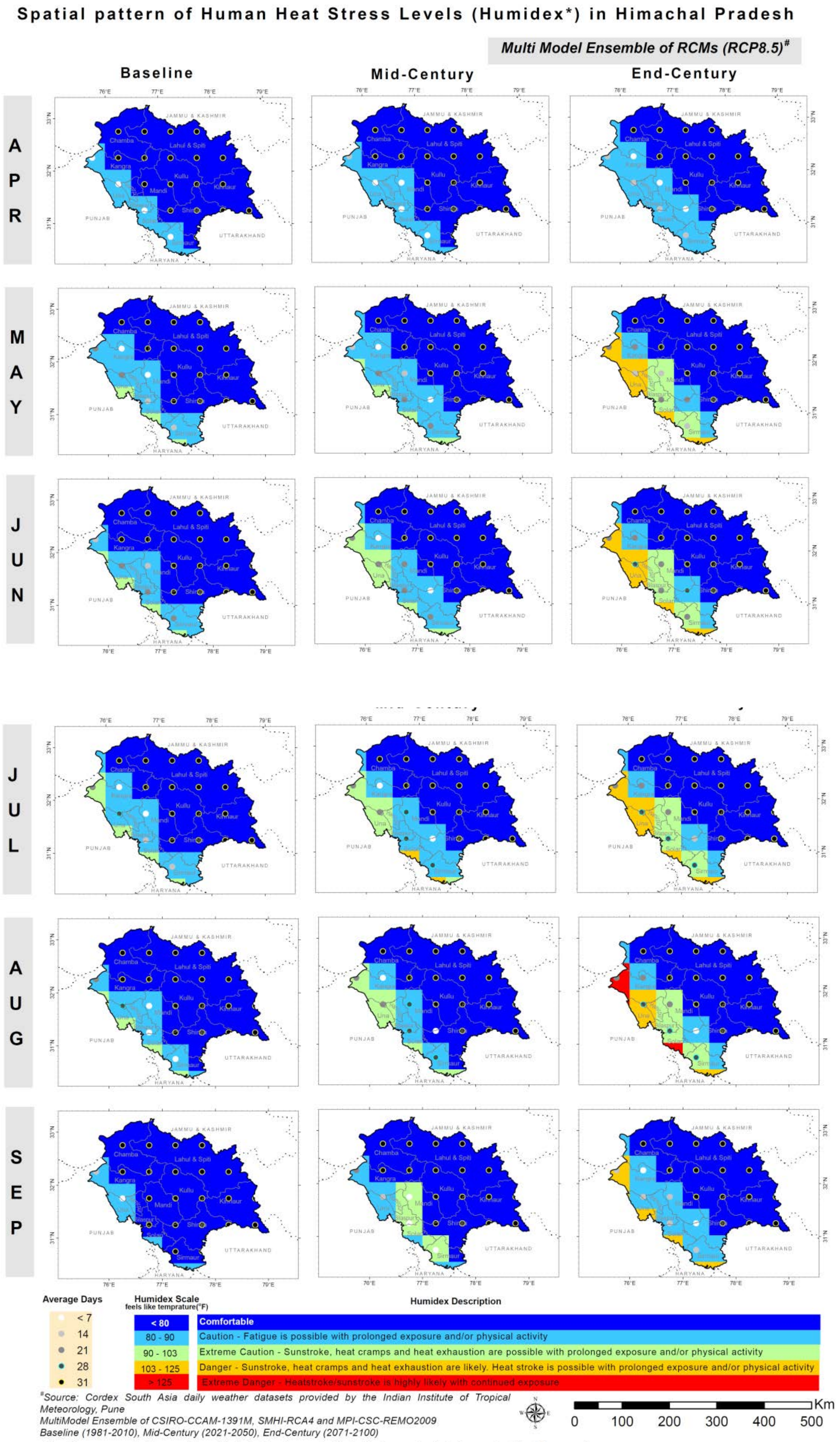
Figure 22: Projected human Heat Stress Levels (Humidex*) in Himachal Pradesh for climate scenarios (IPCC AR5 RCP4.5) for the months from April to September



#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

**Humidex was created to quantify and include the degree of risk for the human body in the event of heat & excessive moisture. The calculation of the humidex is based on mean air temperature, relative humidity & vapor pressure*

Figure 23: Projected human Heat Stress Levels (Humidex*) in Himachal Pradesh for climate scenarios (IPCC AR5 RCP8.5) for the months from April to September



Average Days	Humidex Scale feels like temprature(°F)	Humidex Description
○ < 7	< 80	Comfortable
● 14	80 - 90	Caution - Fatigue is possible with prolonged exposure and/or physical activity
● 21	90 - 103	Extreme Caution - Sunstroke, heat cramps and heat exhaustion are possible with prolonged exposure and/or physical activity
● 28	103 - 125	Danger - Sunstroke, heat cramps and heat exhaustion are likely. Heat stroke is possible with prolonged exposure and/or physical activity
● 31	> 125	Extreme Danger - Heatstroke/sunstroke is highly likely with continued exposure

#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

**Humidex was created to quantify and include the degree of risk for the human body in the event of heat & excessive moisture. The calculation of the humidex is based on mean air temperature, relative humidity & vapor pressure*

Impact Assessment on Livestock

Temperature Humidity Index (THI)

The “19th Livestock Census - 2012” shows an overall decrease in livestock population over 2007 to 2012 from 5.21 million to 4.84 million (excluding 0.03 million stray cattle) registering a negative growth of 7.14% in the total number of animals of various species. Cattle contributes highest with 44.37% followed by goat 23.11%, sheep 16.61%, buffalo 14.78% and 1.13% by others livestock species such as yak, mithun, pigs, camel, mules, donkeys, horses and ponies.

Temperature Humidity Index (THI) is a measure is an easy way to assess the risk of heat stress among the animals. It accounts for the combined effects of environmental temperature and relative humidity. THI is widely used all over the world to assess the impact of heat stress on dairy cows[27]. Animal stress level categorise[28] are shown in Table 4.

Table 4: Temperature Humidity Index (THI) stress level scales

THI*	Stress Level	Comments
<65	None	
66-70	Mild	Dairy cows will adjust by seeking shade, increasing respiration rate and dilation of the blood vessels. The effect on milk production will be minimal
71-74	Moderate	Both saliva production and respiration rate will increase. Feed intake may be depressed and water consumption will increase. There will be an increase in body temperature. Milk production and reproduction will be decreased.
75-80	Severe	Cows will become very uncomfortable due to high body temperature, rapid respiration (panting) and excessive saliva production. Milk production and reproduction will be markedly decreased
>80	Danger	Potential cow deaths can occur

** THI: Feels like Temperature (0F)*

THI has been calculated for Himachal Pradesh using IPCC RCP scenarios (RCP4.5 and RCP8.5) for baseline, mid-century and end-century data. Figure 24 and Figure 25 show the long term monthly THI values across Himachal Pradesh for the months of April to September for baseline, mid-century and end-century for IPCC AR5 RCP4.5 scenario and RCP8.5 scenario respectively. The colour in the layouts shows the maximum THI scale attained during a month for the Himachal Pradesh districts and the colour of the dots show average number of days in that month which are projected to have the maximum THI scale.

Months from April to September are significant on account of either high temperature or high humidity. Under RCP4.5 scenario, as can be seen from Figure 24 that during the months of April to September the districts of Himachal Pradesh are projected to have the maximum number of days in no stress or mild stress level (72-790F) of THI as depicted in shades of blue colour.

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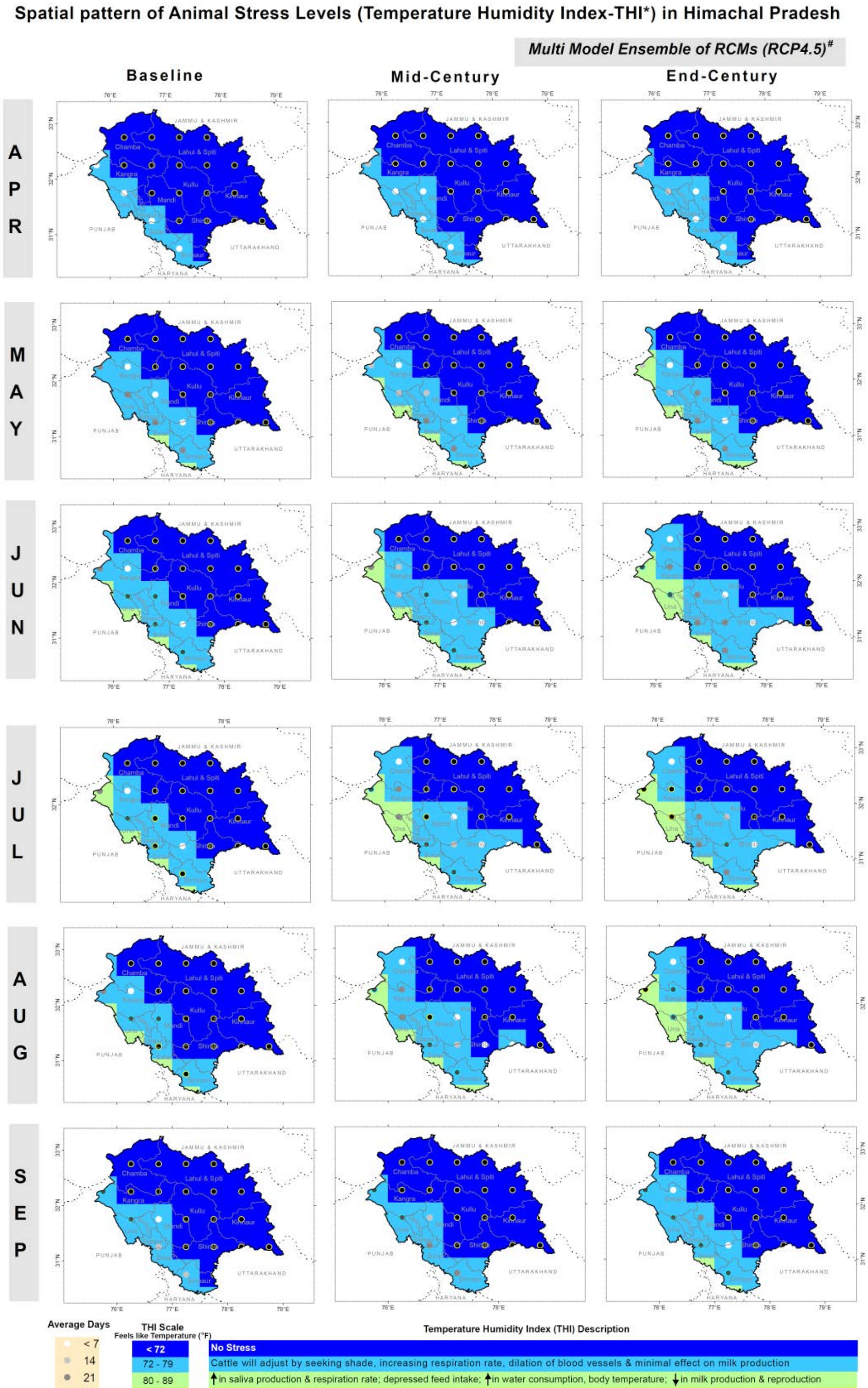
[27] Akyuz, A, Boyaci, S. and Cayli A. (2010), Determination of critical period for dairy cows using thermal humidity index. J. Anim. Vet. Adv., 9(13): 1824-1827.

[28] http://www.icar.org.in/files/reports/icar-dare-annual-reports/2010-11/climate-change-AR-2010-11.pdf

Figure 24: Projected THI for different months in Himachal Pradesh under RCP4.5 Scenario

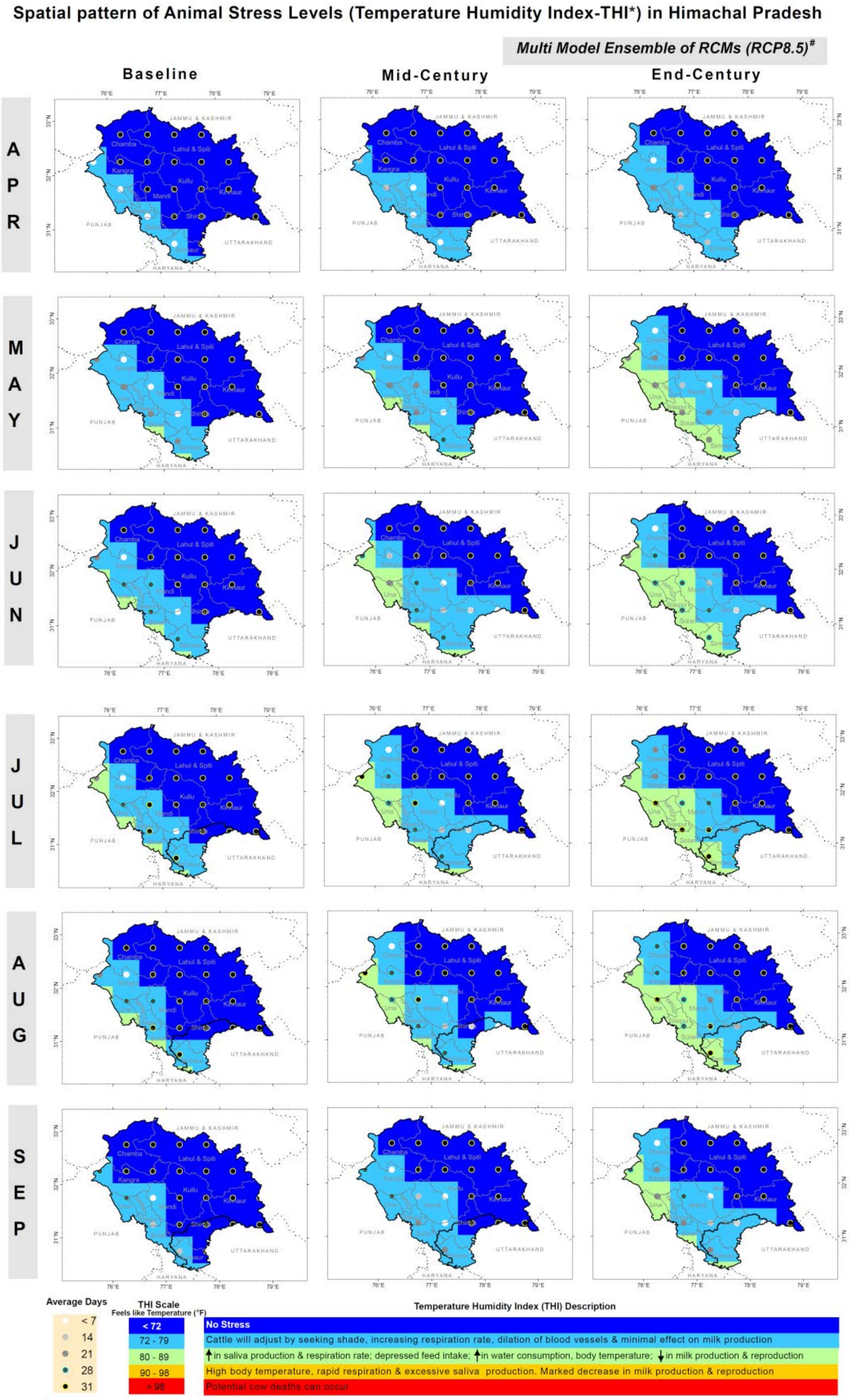


#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

*Temperature Humidity Index (THI) is a measure that has been used since the early 1990s. It accounts for the combined effects of environmental temperature and relative humidity, and is a useful and easy way to assess the risk of heat stress.

Thus it's observed that under RCP4.5 scenario the livestock of the districts of Himachal Pradesh are not under any temperature and humidity stress for BL, MC and EC. The situation is likely to deteriorate slightly towards end-century under RCP8.5 scenario for some South Western districts as the numbers of days having moderate animal stress level (80-890F) are projected to increase during the months of May to September (Figure 25).

Figure 25: Projected THI for different months in Himachal Pradesh under RCP8.5 Scenario



#Source: Cordex South Asia daily weather datasets provided by the Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

**Temperature Humidity Index (THI) is a measure that has been used since the early 1990s. It accounts for the combined effects of environmental temperature and relative humidity, and is a useful and easy way to assess the risk of heat stress.*

Figure 26 shows the overall weighted Temperature Humidity Index (THI) days for districts of Himachal Pradesh for the months of April to September. The weighted THI is calculated for each district by assigning weights to the scales of THI and then multiplying the respective weights for each scale with the number of days of heat stress in the respective heat scale for BL, MC and EC. THI mild stress level scale 72-79°F is given weight 0.1, moderate stress level scale 80-89°F is given weight 0.2, severe stress level scale 90-98°F is given weight 0.3 and danger stress level scale >98°F is given weight 0.4.The highest weight is assigned to the danger stress level and so on.

It is to be noted that none of the districts are projected to be in the danger stress level of THI where the potential cow deaths can occur for any of the months. The THI is projected to increase for all the districts of Himachal Pradesh towards the mid-century and end-century. The increase towards the end-century is projected to be higher under RCP8.5 scenario as compared to the RCP4.5 scenario. Districts namely, Una and Hamirpur are projected to have higher impact. Chamba, Kinnaur, Kullu, and Lahul & Spiti districts have no THI stress level.

Figure 26: Weighted THI days for districts of Himachal Pradesh

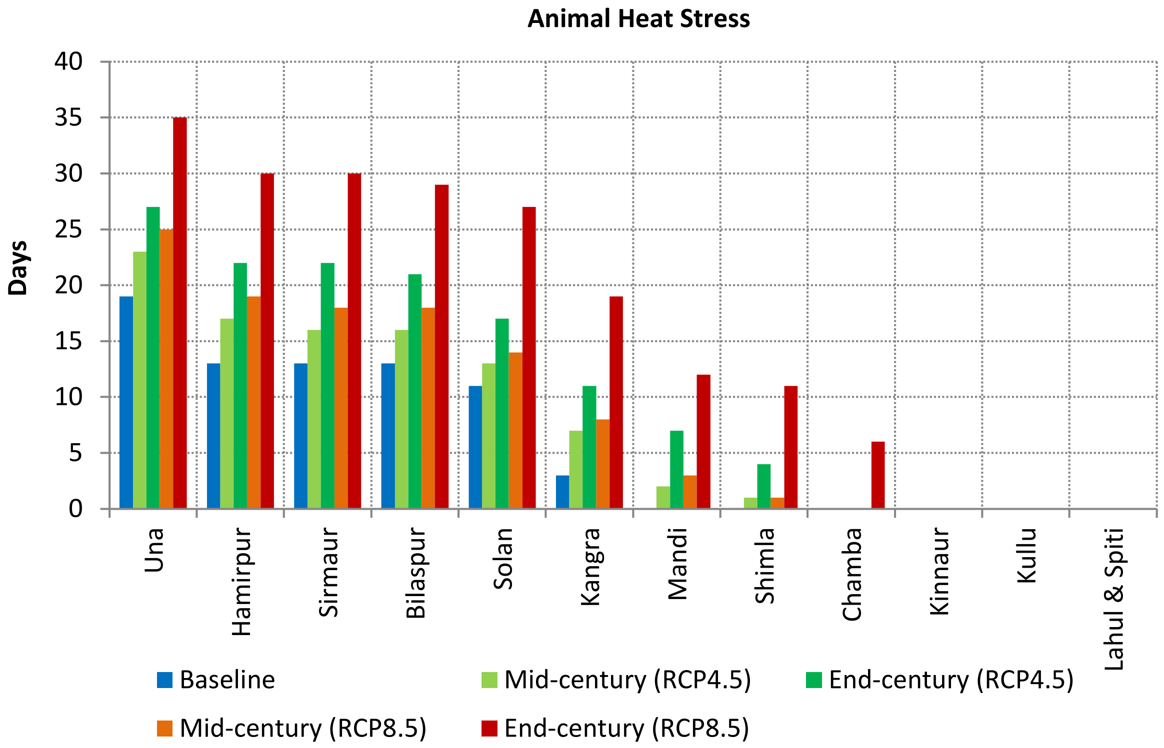
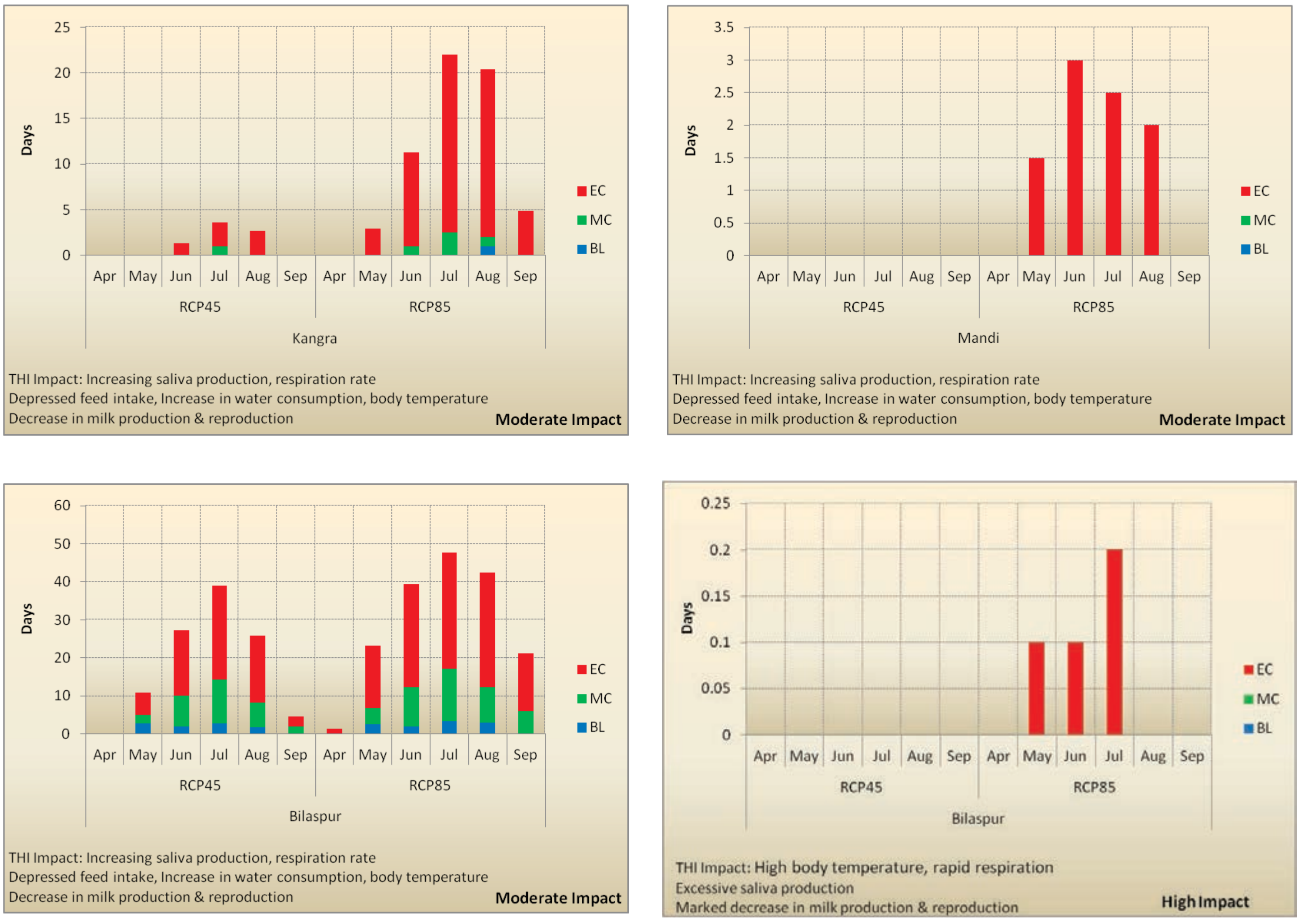


Figure 27 shows impact of temperature and humidity on livestock for districts of Himachal Pradesh. It shows for districts- Mandi and Kangra the number of days in moderate and severe THI stress levels for the months of April to September for baseline, mid-century and end-century for IPCC AR5 climate scenarios- RCP4.5 and RCP8.5. These districts are plotted as they have the highest number of livestock in Himachal Pradesh. Districts- Kinnaur and Lahul & Spiti who have the lowest number of livestock in Himachal Pradesh have no THI stress level.

Figure 27: Projected THI for districts (highest and lowest livestock population) in Himachal Pradesh - April to September



It is observed from Figure 27 that during the months of May, June, July and August the number of days under moderate THI stress levels are relatively higher for Kangra district as compared to Mandi district towards EC RCP8.5 scenario. No severe THI stress is observed.

Impact Assessment on Health - Summary

Heat Stress:

- The heat stress is projected to increase for all the districts of Himachal Pradesh towards the mid-century and end-century. The increase towards the end-century is projected to be higher under IPCC AR5 RCP8.5 scenario as compared to the IPCC AR5 RCP4.5 scenario.
- The heat stress conditions are likely to exacerbate, particularly in the months of May to September for the districts of Himachal Pradesh.
- District namely Una located in the Sub mountain & low hills sub-tropical zone of Himachal Pradesh is projected to have the maximum increase in the severity of heat stress towards the mid-century and end-century as compared to the other districts. Mandi, Shimla, Chamba, Kinnaur, Kullu, Lahul & Spiti districts located in the high and very high hill areas of Himachal Pradesh heat stress level is negligible.
- Extreme danger stress level is observed only towards end-century RCP8.5 scenario.

THI

- Months from April to September are significant on account of either high temperature or high humidity.
- Under RCP4.5 scenario the livestock of the districts of Himachal Pradesh are projected to have no stress. The situation is likely to deteriorate slightly towards end-century under RCP8.5 scenario for some South Western districts.
- The increase towards the end-century is projected to be higher under RCP8.5 scenario as compared to the RCP4.5 scenario.
- The THI impact on the dairy animals is projected to be the highest in the districts of Una and Hamirpur. Chamba, Kinnaur, Kullu, and Lahul & Spiti districts have no THI stress level.

Part-III: Climate Change Vulnerability Assessment for Himachal Pradesh

Executive Summary

District is the most used administrative unit for various actions at the state level. This can also be a useful unit for implementation of the adaptation options for coping up with the implications of climate change. Therefore, vulnerability on account of climate change in Himachal Pradesh has been assessed at the district level. Vulnerability has been assessed at the district level. The vulnerability analysis has been based on Composite Vulnerability Index (CVI) derived using multivariate analysis for current and projected climate (under RCP4.5 and RCP8.5 climate scenario towards mid-century and end-century). The IPCC working definition of vulnerability as a function of exposure, sensitivity, and adaptive capacity has been used and identified 62 indicators have been categorized into adaptive capacity, sensitivity and exposure. Accordingly five sectoral vulnerability indices for social, economic, agriculture, water resources and health (extreme climate conditions) have also been generated. The indices would facilitate the identification of districts, which are vulnerable to climate change and need special attention towards adaptation.

Current Composite Vulnerability

Summary of the district composite vulnerability analysis is as follows:

- District namely, Chamba with rank 12 is the most vulnerable district under current climate. Main sectors contributing to districts vulnerability in the CVI are:
    - Chamba has high social, economic, agriculture and water sector vulnerability.
    - It is the most vulnerable amongst all districts of Himachal Pradesh due to higher gender gap in literacy rate, age dependency ratio, child population, biomass dependency, below poverty line population, infant mortality rate, total fertility rate and relatively low literacy rate, poor access to sanitation facilities and electricity, low per capita income, lower Micro, Small & Medium (MSME) scale industrial units and number of commercial banks. It also has low fertilizer consumption, irrigated area, larger marginal land holdings area, higher exposure to drought weeks, and low ground water availability in South West Monsoon season.
- Two districts namely, Sirmaur and Bilaspur with ranks 11 and 10 respectively fall under high vulnerable category.
- District namely, Lahul & Spiti located in very high hills temperate dry zone of Himachal Pradesh state with rank 1 is the least vulnerable district.
    - It has very low social, economic, agriculture, water sector vulnerability and has lower exposure to extreme climate conditions.
    - The main contributing factors include lower age dependency ratio, access to malaria, crude birth rate, child population, growth rate, student teacher ratio and low infant mortality rate and better access to improved source sanitation, work participation rate, high number of educational institutions, health centers and beds. Highest per capita income, number of commercial banks

and MSME units, high livestock population, milk and egg production per capita, food grains yield, fertilizer consumption, irrigated area, higher rainy days, low consecutive wet days, consecutive dry days, lower sensitivity to heat stress, highest per capita surface and ground water availability in South West Monsoon season, surface water availability in North East Monsoon season and least exposure to flood and drought are also contributing.

Projected Composite Vulnerability

The overall Composite Vulnerability (CV) of the Himachal Pradesh districts is projected to increase towards mid-century and end-century as compared to the baseline for both the IPCC AR5 climate scenarios. District vulnerability is likely to exacerbate under RCP8.5 scenario as compared to RCP4.5 scenario towards end-century.

- Exposure to rainfall variability, extremely wet days, consecutive wet days, consecutive dry days, flood discharge, drought weeks and sensitivity to heat stress, seasonal crop water stress are projected to increase towards the mid-century and end-century as compared to current conditions thus contributing to increase in overall Composite Vulnerability (CV).

The decomposition of the composite vulnerability index can shed light on main factors contributing to overall vulnerability of a particular district. Each sector used in CVI has been further disaggregated to help understand the main factors driving to make districts vulnerable. Summary of disaggregated sectoral vulnerability for social, economic, health/climate extremes, water resources and agriculture is given below:

Social Vulnerability

- District namely, Chamba with rank 12 is currently the most vulnerable district.
- 4 districts namely, Kinnaur, Lahul & Spiti, Solan, Shimla with ranks 1, 2, 3 and 4 respectively are the least vulnerable districts.

Economic Vulnerability

- Chamba and Bilaspur districts with ranks 12 and 11 respectively are the most vulnerable districts.
    - Major contributing economic indicators for high vulnerability of Chamba include low per capita income; lower Micro, Small & Medium (MSME) scale industrial units and number of commercial banks while for Bilaspur includes low per capita income; percentage of households availing banking services and number of commercial banks.
- Lahul & Spiti with rank 1 is the least vulnerable district.

Agriculture Vulnerability

- Hamirpur, Kangra, Chamba and Kinnaur districts with ranks 12, 11, 10 and 9 respectively are currently very highly vulnerable.
    - Main contributing factors for high vulnerability of Hamirpur include low food grains yield, fertilizer consumption, irrigated area, egg production and livestock population while for Kangra includes low food grains yield, milk production and livestock population.
- 3 districts namely, Lahul & Spiti, Kullu and Kinnaur with ranks 1, 2 and 3 respectively are the least vulnerable districts.

Water Resource Vulnerability

- Districts Bilaspur, Mandi, Kinnaur and Solan with ranks 12, 11, 10 and 9 respectively are the most vulnerable.
    - Major contributing factors include less surface water and ground water availability in post monsoon season and high exposure to flood and drought for Bilaspur district, high seasonal crop water, high exposure to flood and drought for Kinnaur district and less seasonal surface water availability and high exposure to drought for Mandi and Solan districts.
- Lahul & Spiti district of Himachal Pradesh with rank 1 is the least vulnerable district.
    - As it has highest per capita surface and ground water availability in South West Monsoon season, surface water availability in North East Monsoon season and least exposure to flood and drought.
- The overall water resources vulnerability of the districts is projected to increase towards mid-and end-century as compared to the current conditions for both the emission scenarios. However, districts vulnerability is likely to exacerbate under RCP4.5 scenario as compared to RCP8.5 scenario towards both mid and end-century. Vulnerability of the districts towards, end-century RCP4.5 scenario is the maximum.
    - Projected increase in WRV is attributed to likely increase in exposure to drought weeks and flood discharge and sensitivity to seasonal crop water stress.
    - Vulnerability of the districts towards, end-century RCP4.5 scenario is the maximum because adaptive capacity to surface and ground water availability in South West monsoon season is the lowest and exposure to drought weeks is the highest relative to all other scenarios.
    - Vulnerability of the districts is relatively less towards mid-century RCP8.5 scenario relative to other three scenarios because adaptive capacity to surface and ground water availability in South West monsoon season is the highest and exposure to drought weeks is the lowest relative to all other scenarios.

Health/Climate Extremes Vulnerability

- Una district lying in sub mountain & low hills sub-tropical zone of Himachal Pradesh, with rank 12 is the most vulnerable district. Exposure to extreme events like consecutive dry days, low rainy days and higher sensitivity to heat stress contributes to make Una district the most vulnerable.
- 3 districts namely, Lahul & Spiti, Kullu and Kinnaur with ranks 1, 2 and 3 respectively are the least vulnerable districts.
- The overall climate extremes vulnerability of the districts is projected to increase towards mid-and end-century as compared to the current conditions for both the emission scenarios. District vulnerability is likely to exacerbate under RCP8.5 scenario as compared to RCP4.5 scenario towards both mid and end-century.
    - Factors contributing to projected increase in climate extremes vulnerability of districts include projected increase in rainfall variability, exposure to extremely wet days, consecutive wet days, consecutive dry days and higher sensitivity to heat stress.

Climate Change Vulnerability Assessment for the State of Himachal Pradesh

Introduction

Climate change vulnerability assessment for water resources sector has been taken up for the state of Himachal Pradesh. The main purpose of vulnerability assessment is to identify and prioritize the regions and sectors which are likely to be adversely impacted by climate change so as to enable development of adaptation practices and strategies to help mainstream the climate change in to the broader developmental programs and projects.

Study Area

Himachal Pradesh is a state of India located in Northern India. Referred to as dev bhoomi or “Land of God”, it is bordered by Jammu and Kashmir on the north, Punjab and Chandigarh on the west, Haryana on the south-west, Uttarakhand on the south-east and by the Tibet Autonomous Region on the east. The word “Himachal” means the abode of snow. Shimla is the capital of Himachal Pradesh. Shimla district has the largest urban population in the state at 25%. Owing to the huge production of apples, Himachal Pradesh is also known as the ‘State of Apples’.

Covering an area of 55,673 square kilometers it is a mountainous state. Most of the state lies on the foothills of the Dhauladhar Range. Himachal Pradesh has a total population of 6,864,602 including 3,481,873 males and 3,382,729 females as per the final results of the Census of India 2011. This is only 0.57 per cent of India’s total population, recording a growth of 12.81 per cent. The total fertility rate (TFR) per woman is 1.8, one of lowest in India.

Himachal Pradesh is famous for its natural beauty, hill stations, and temples. Himachal Pradesh has been ranked fifteenth in the list of the highest per capita incomes of Indian states and union territories for year 2013-14. Many perennial rivers flow in the state, and numerous hydroelectric projects set up. Himachal produces surplus hydroelectricity and sells it to other states such as Delhi, Punjab, and Rajasthan. Hydroelectric power projects, tourism, and agriculture form important parts of the state’s economy.

The state has several valleys and about 90% of the population lives in rural areas. Practically all houses have a toilet and 100% hygiene has been achieved in the state. The villages have good connectivity with roads, public health centres, and now with high-speed broadband. Agriculture contributes over 45% to the net state domestic product. It is the main source of income and employment in Himachal. Over 93% of the population in Himachal depends directly upon agriculture, which provides direct employment to 71% of its people. Hydropower is also one of the major sources of income generation for the state.

The state of Himachal Pradesh, India is a hilly region and it experiences a pleasant climate throughout the year. It even experiences heavy snow fall during the winter months. The weather of Himachal alters with the change of altitude. The best time to visit the state of Himachal is from September to March.

Purpose of Vulnerability Assessment

A vulnerability assessment is the process of identifying, quantifying, and prioritizing (or ranking) the vulnerabilities in a system. Assessment of vulnerability to climate variability and change broadly helps in:

- Understanding current vulnerability.
- Identify the factors that render some regions more vulnerable than others.
- Inform and facilitate the decision-making process.
- Selection of adaptation strategies and practices.

Basic objective for climate change vulnerability assessment of Himachal Pradesh State includes:

- Generating the Himachal Pradesh district level Composite Vulnerability Index (CVI) developed using multivariate analysis of individual sectoral indicators (social, economic, water resources and health/ extreme climate) that are vulnerable to climate change.
- Generating sectoral vulnerability indices - Social Vulnerability Index (SVI), Economic Vulnerability Index (ECVI), baseline Agriculture Vulnerability Index (AGVI), health/climate extremes Vulnerability Index (CLVI) and Water Resources Vulnerability Index (WRVI) for the districts of Himachal Pradesh. The indices would facilitate the identification of districts, which are vulnerable to climate change and need special attention towards adaptation.
- Developing current vulnerability profile at district level due to the current climatic conditions.
- Developing projected vulnerability profile towards mid-century (2021-2050) and end-century (2071-2100) for projected climatic conditions using IPCC AR5 RCP4.5 (moderate emission scenario) and RCP8.5 (high emission scenario) scenarios.
- Grouping the districts according to their degree of vulnerability using cluster analysis, under 6 categories of vulnerability -very low (VL), low (L), moderate (M), high (H), very high (VH), and extremely high (EH).

Definition of Vulnerability to Climate Change

The Intergovernmental Panel on Climate Change (IPCC) is the leading scientific international body for the assessment of climate change. According to the IPCC (2007)[1] definition, vulnerability in the context of climate change is the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity.

IPCC Fifth Assessment Report defines vulnerability to climate change broadly as follows: “The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt”.[2]

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[1] IPCC, 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Annex I., M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, 976pp.

[2] https://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_Glossary.pdf

Climate vulnerability is characterized as a function of both biophysical and socio-economic vulnerabilities, each defined by the three dimensions of exposure, sensitivity and adaptive capacity. When combined with specific likelihood of occurrence (either associated with biophysical changes or socio-economic variables), climate vulnerability becomes climate risk (Preston and Stafford-Smith, 2009[3]).

Exposure is the nature and degree to which a system is exposed to significant climatic variations where the exposure unit is ‘an activity, group, region, or resource that is subjected to climatic stimuli’.

There are two main elements to consider in exposure.[4]

- Things that can be affected by climate change (populations, resources, property, and so on)
- The change in climate itself (sea level rise, precipitation and temperature changes etc.,)

Sensitivity is the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g., a change in crop yield in response to a change in the mean, range, or variability of temperature) or indirect (e.g., damages caused by an increase in the frequency of coastal flooding due to sea-level rise).

Adaptive capacity is the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.[5]

Approach and Methodology

There are several methods for evaluating the level of vulnerability. Selection of a particular method is determined by the context, purpose and scale of analysis as well as by the availability of appropriate data. A common method to quantify vulnerability to climate change is by using a set or composite of proxy indicators. Indicator approach constructs comparative indicators which helps to compare the vulnerability and adaptive capacity of different systems, groups or regions (Adger, W.N. et al., 2004[6]).

The vulnerability studies based on ranking and comparing across regions, countries, and populations have increased in number during the past decade. The main objective of these kinds of studies is the allocation of resources for vulnerability reduction by including decision making authorities like government bodies and other organizations (Dinda, Soumyananda, 2015[7]).

For the present study relative vulnerability approach is followed as it is useful when comparing vulnerability at a regional scale. Here the inter district comparison can be done as to which is more vulnerable compared to the other. If absolute vulnerability is calculated the emphasis is on areas with the greatest number of vulnerable people, not necessarily the most vulnerable. Comparison of vulnerability within the districts is not possible here since the required data/information available is aggregated at these respective levels. Composite index provide a starting point for analysis. While it can be used as summary index to guide

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[3] Preston, B.L. & Stafford-Smith, M. 2009. Framing vulnerability and adaptive capacity assessment: Discussion paper. CSIRO Climate Adaptation Flagship Working Paper, No.1, CSIRO, Australia.

[4] http://know.climateofconcern.org/index.php?option=com_content&task=article&id=144#;

[5] https://www.ipcc.ch/pdf/glossary/tar-ipcc-terms-en.pdf

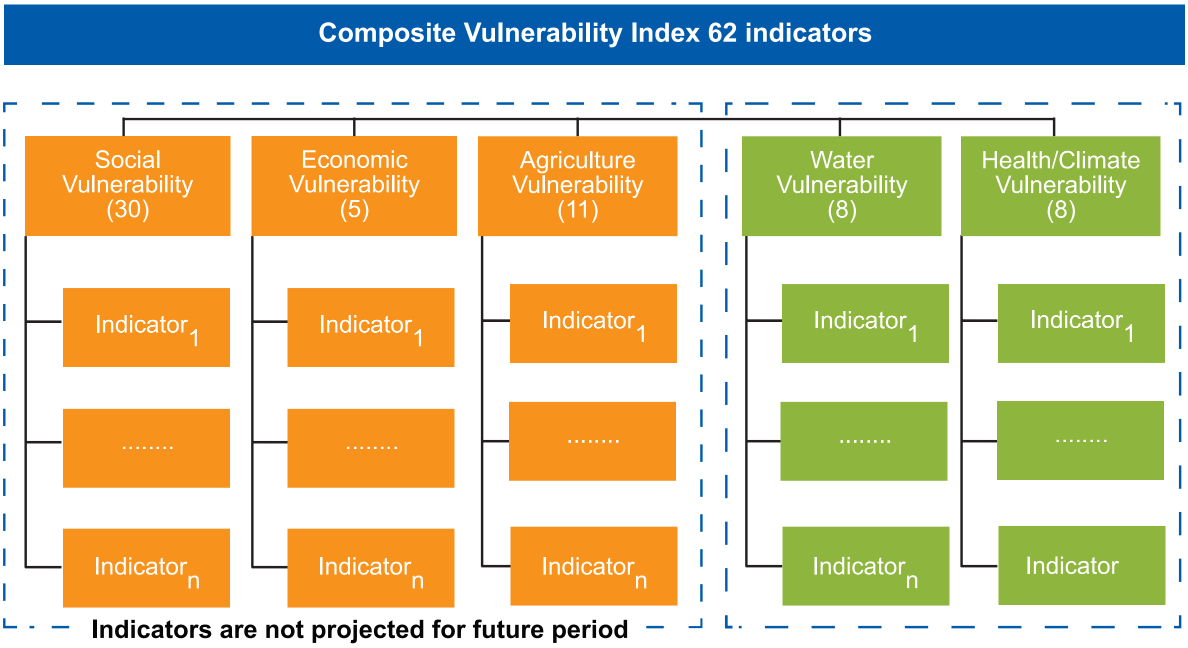
[6] Adger, W.N., Brooks, N., Bentham, G., Agnew, M., Eriksen, S., 2004. New Indicators of Vulnerability and Adaptive Capacity. Technical Report 7, Tyndall Centre for Climate Change Research, University of East Anglia, Norwich.

[7] Dinda, Soumyananda, 2015, Handbook of Research on Climate Change Impact on Health and Environmental Sustainability, IGI Global

policy work, it can also be decomposed such that the contribution of subcomponents and individual indices can be identified (OECD, 2008). Composite index is getting increasingly acknowledged as a tool for summarizing complex and multidimensional issues (Rovan, 2011). How the concepts of exposure, sensitivity, adaptive capacity, and vulnerability has been translated into numerical indices; which variables have been used and how they have been aggregated to construct Composite Vulnerability Indices (CVI) has been described as follows.

Vulnerability has been assessed at the district level. The vulnerability analysis has been based on Composite Vulnerability Index (CVI) derived using multivariate analysis. Figure 1 shows the flowchart for constructing CVI using the identified indicators from the seven sectors considered.

Figure 1: Flowchart for construction of Composite Vulnerability Index



The IPCC working definition of vulnerability as a function of exposure, sensitivity, and adaptive capacity has been used and identified indicators have been categorized into adaptive capacity, sensitivity and exposure. Spatial, temporal and sectoral scope focused in the study includes:

- Spatial Scope of Assessment:
    - District
- Temporal Scope of Assessment:
    - Historical period: 1981-2010.
    - For future climate projection – Mid-century between 2021– 2050 (2030s), end-century between 2071 – 2100 (2080s), for two RCP (4.5 and 8.5) scenarios of IPCC AR5 recommendation, based on CMIP5 and CORDEX regional climate model outputs.

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8 OECD. 2008. Handbook on constructing composite indicators: methodology and user guide. Paris, OECD Publishing.

9 Rovan, Joze, 2011, “Composite Indicators”,”International Encyclopedia of Statistical Science”, Springer Berlin Heidelberg

- Sector scope of Assessment:
    - Social (demographic and infrastructure)
    - Economic (income and banks)
    - Baseline agriculture (crop yield, land holding)
    - Water Resources (surface water availability, ground water recharge, crop water stress, drought and flood)
    - Health/climate (heat stress, extreme temperature and rainfall indices)

Methodology

The steps involved in the vulnerability assessment of the districts of Himachal Pradesh are:

- **Step 1:** Identify set of indicators
- **Step 2:** To classify indicators data (indicators) into three categories of adaptive capacity, sensitivity and exposure.
- **Step 3:** Secondary data collection for the indicators, projection of the selected indicators for future using impact assessment models (for agriculture, climate, water resource) carried out as a part of the same study
- **Step 4:** Normalize indicators data values to make the indicators comparable since indicators are expressed in a variety of statistical units, ranges or scales.
- **Step 5:** Determine unbiased weights using statistical method of multivariate analysis (Principal component analysis, PCA).
- **Step 6**: Aggregation of weights and normalized values to derive Composite Vulnerability Index and the six sectors Vulnerability Indices viz. social, economic, climate, water resources, forest and agriculture.
- **Step 7:** Rank districts based on the calculated index values. Rank 1: least vulnerable (Lowest index values), Rank 12 most vulnerable (Highest index values)
- **Step 8:** Perform cluster analysis[10] on the calculated indices to group them in six vulnerable categories - very low (VL), low (L), moderate (M), high (H), very high (VH), and extremely high (EH).
- **Step 9:** Visualization of the results using spatial maps.

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[10] Cluster analysis helps to sort through the raw data and groups them into clusters. A cluster is a group of relatively homogeneous cases

[11] OECD, European Commission, Joint Research Centre (2008) Handbook on constructing composite indicators: methodology and user guide. OECD Publishing.

[12] A Framework for Climate Change Vulnerability Assessments, Published by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, India Project on Climate Change Adaptation in Rural Areas of India (CCA RAI), September 2014.

[13] Rama Rao, C.A.et al., Atlas on vulnerability of Indian agriculture to climate change. Central Research Institute for Dryland Agriculture, Hyderabad, 2013, p. 116; available at http://www.nicra-icar.in/nicrarevised/images/publicaitons/Vulerability_Atlas_web.pdf.

Selection of Indicators

Indicators should be selected on the basis of their analytical soundness, measurability, spatial coverage, relevance to the phenomenon being measured and relationship to each other (OECD, 2008[11]).

The indicators for this study have been selected based on the availability of data across time and space (districts), literature research (GIZ, 2014[12], CRIDA, 2013[13]), consultation with domain experts (climate, water resources and agriculture) and experiences drawn from previously carried out climate change vulnerability assessment for the Indian states of Madhya Pradesh (2014[14]), West Bengal, Chhattisgarh, Jharkhand, Uttarakhand and Madhya Pradesh.

A set of 62 indicators have been identified for the purpose. Details of the list of identified indicators, their sources and time period along with their functional relationship with vulnerability are given in Table A- 1 of Appendix I. The indicators have been grouped under six sectoral categories viz., social (30 indicators), economic (5 indicators), baseline agriculture (11 indicators), water resources (8 indicators) and health/ climate (8 indicators). Further, the indicators have been classified into exposure indicators (8 indicators), sensitivity indicators (23 indicators) and adaptive capacity indicators (31 indicators).Rationale for the same is given in Table A- 2 of Appendix I.

Data Sources

Data for 62 identified indicators for the vulnerability analysis have been collected from different sources drawn mainly from secondary sources and impact assessment models. Sources include:

- Census of India: C Series - Himachal Pradesh
- Census of India: Himachal Pradesh
- Census of India: House listing and Housing Census - Himachal Pradesh
- Census of India: Primary Census Abstract - Himachal Pradesh
- DACNET (Department of Agriculture Cooperation)- Landuse Statistics Report
- Department of Agriculture and Cooperation, Agriculture Census Database
- Department of Animal Husbandry, Dairying & Fisheries, 19th Livestock Census District Wise Report 2012
- Department of Animal Husbandry, Dairying & Fisheries, 19th Livestock Census District Wise Report 2013
- Department of Economics and Statistics, District Level Economic Indicators
- District Information System for Education-DISE

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[12] A Framework for Climate Change Vulnerability Assessments, Published by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, India Project on Climate Change Adaptation in Rural Areas of India (CCA RAI), September 2014.

[13] Rama Rao, C.A.et al., Atlas on vulnerability of Indian agriculture to climate change. Central Research Institute for Dryland Agriculture, Hyderabad, 2013, p. 116; available at http://www.nicra-icar.in/nicrarevised/images/publicaitons/Vulerability_Atlas_web.pdf.

[14] Vulnerability Assessment of Madhya Pradesh towards Climate Change, 2014, Ministry of Environment & Forests and GIZ on Climate Change Adaptation in Rural Areas of India, www.epco.in/pdfs/ClimateChange/Vulnerability_Assessment_of_MP.pdf.

- Health & Family Welfare Department, Himachal Pradesh: Statistical Report for the Year, 2012
- IIPS Estimates of Vital Statistics Report
- Indicus Analytics
- National Vector Borne Disease Control Programme, Ministry of Health & Family Welfare
- State Industrial Profile of Himachal Pradesh, 2014-2015, MSME Development Institute, Govt. of India, Ministry of MSME
- Statistical Abstract of Himachal Pradesh, 2015-16, Department of Economics and Statistics
- SWAT Hydrological model outputs, CORDEX climate data-RCP 4.5, RCP 8.5.

Limitations of Indicator Base Method

Indicator based assessment for ranking and comparing vulnerability across spatial units (districts) Indicator based assessment for ranking and comparing vulnerability across spatial units (districts) have following challenges and limitations mainly because of subjectivity involved in:

- Selection and creation of appropriate indicators.
- Classification of indicators into exposure, sensitivity and adaptive capacity.
- Underlying assumptions in weighting variables.
- Dynamic nature of vulnerability which requires a constant updating of vulnerability scores.

Strengths and Weaknesses of Principal Component Analysis (PCA)

PCA is a statistics technical and uses orthogonal transformation to convert a set of observations of possibly correlated variables into a set of values of linearly uncorrelated variables. PCA also is a tool to reduce multidimensional data to lower dimensions while retaining most of the information[15]).

Limitations

- If the observed variables are completely unrelated, PCA analysis is unable to produce a meaningful result.
- The weights change whenever data is updated or indicators are added or removed.

Limitations on Data

- Selection of indicators used in this analysis is based on the availability of the data.
- Same time period data was not available for every indicator chosen for this study.
- Most of the data used have been compiled from secondary sources available in public domain.

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[15] Abdi, H., & Williams, L.J. (2010). Principal component analysis. Wiley Interdisciplinary Reviews: Computational Statistics, 2, 433-459.

- The social, economic and agriculture vulnerability indices for the districts have not been projected for the future unlike the other sectors indices used in the analysis due to the projection limitations of the socio economic and agriculture sector variables. Thus only the current vulnerability would be shown for these sectors.

Vulnerability Profiles of District of Himachal Pradesh

In the present study, an assessment of the overall implications of climate change and vulnerability in Himachal Pradesh for water resources and health sectors has been carried out to identify the vulnerable regions (districts) to climate change.

Using indicator based methodology; districts of Himachal Pradesh have been classified into various vulnerability categories. It is seen that socio-economic and environmental (biophysical) indicators vary within the districts of Himachal Pradesh. Composite Vulnerability Index (CVI) has been constructed across the 12 districts of Himachal Pradesh using identified indicators (Table A- 1, Appendix I). Districts are ranked based on the calculated index values. Higher index value represents high vulnerability while lower index value represents low vulnerability for the districts. A rank value 1 indicates that the district is least vulnerable to climate change and rank value 12 indicates that it is the most vulnerable. The Composite Vulnerability analysis and the disaggregated vulnerability analysis for social, economic, agriculture, water resources and health sectors has been presented in the following paragraphs. The disaggregated indices help the decision makers to prioritize the development activities in any chosen district by identifying the sector which makes that district vulnerable. Tables showing the district wise index values, ranks and vulnerability category for current and projected vulnerability for Composite Vulnerability and sectors individually are given from Table A- 3 to Table A- 8 in Appendix I.

District Composite Vulnerability Analysis

Composite indicators are used as a tool for summarizing complex and multidimensional issues. A composite indicator is formed when individual indicators are compiled into a single index, on the basis of an underlying model of the multidimensional concept that is being measured[16].

The Composite Vulnerability Index (CVI) represents an overall view on the entire set of indicators considered. CVI across the 12 districts of Himachal Pradesh has been constructed using 62 indicators from social, economic, agriculture, water resources and health (extreme climate conditions) sectors. The disaggregated indices have been constructed using the indicators belonging to the respective sectors. Spatial representation of CVI category for districts for the baseline is depicted in Figure 2.

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[16] OECD, European Commission, Joint Research Centre (2008) Handbook on constructing composite indicators: methodology and user guide. OECD Publishing

Figure 2: Current Composite Vulnerability map for Districts of Himachal Pradesh

Composite Vulnerability comprises of the following Sectors

Social Indicators : - Demography, Infrastructure and Malaria, **Economic Indicators** : - Per Capita Income and GDP, **Climate Extremes Indicators** : - Indices for Precipitation and Temperature **Climate Extremes** : Indicators - Indices for Precipitation and Temperature and Heat Stress., **Water Indicators** : - Water availability, Crop Water Stress, extreme events of Flood and Drought, **Agriculture Indicators** : - Crop Intensity, Yield, Irrigation, Fertilizer use, Poultry, Livestock, Landholdings.

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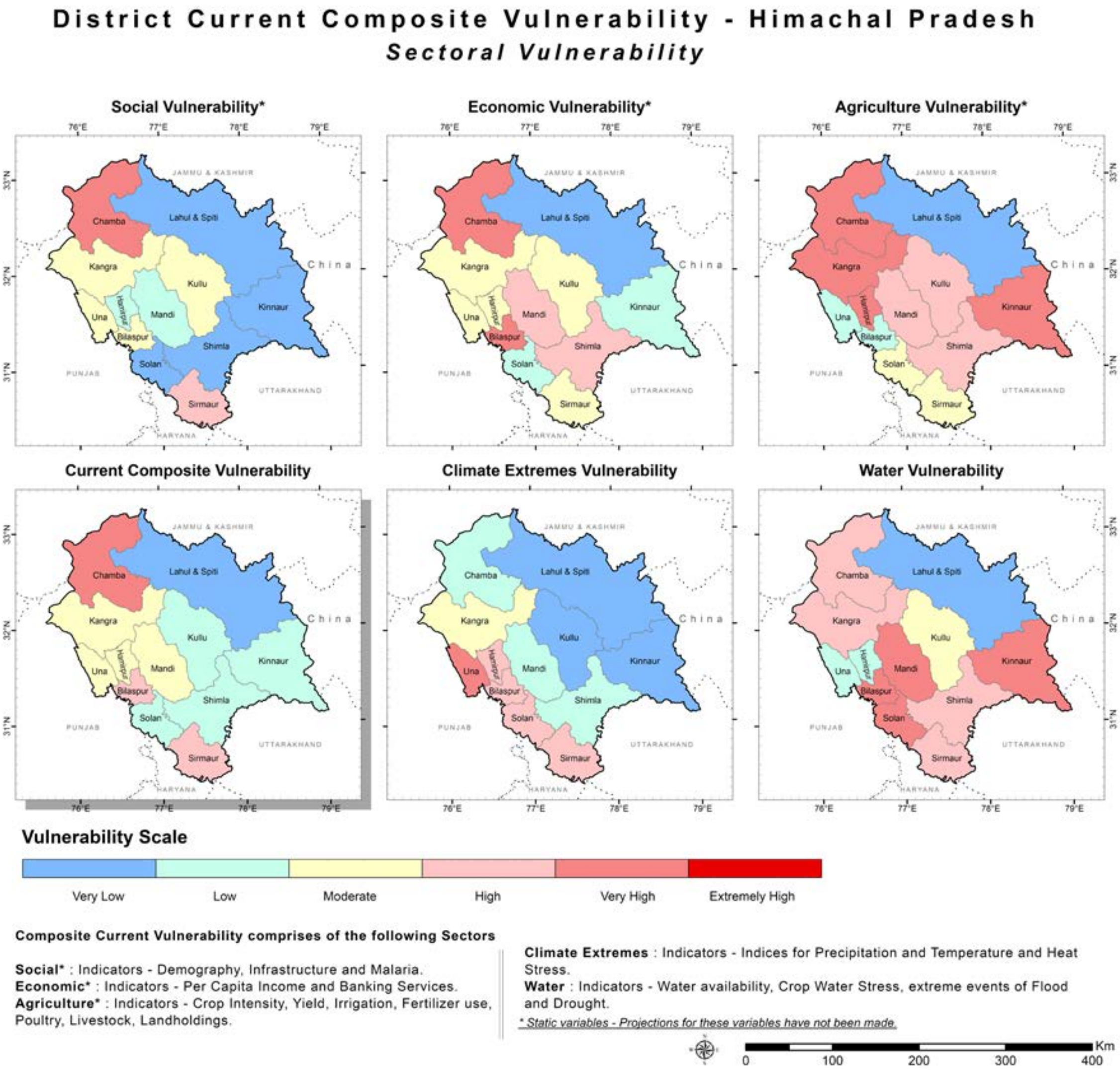
15 Abdi, H., & Williams, L.J. (2010). Principal component analysis. Wiley Interdisciplinary Reviews: Computational Statistics, 2, 433-459.

Spatial representation of disaggregated current sectoral vulnerability for five sectors is depicted in Figure 3.

Figure 3: Disaggregated sectoral vulnerability contributing to current composite vulnerability for districts of Himachal Pradesh



Composite Current Vulnerability comprises of the following Sectors

Social* : Indicators - Demography, Infrastructure and Malaria.
Economic* : Indicators - Per Capita Income and Banking Services.
Agriculture* : Indicators - Crop Intensity, Yield, Irrigation, Fertilizer use, Poultry, Livestock, Landholdings.

Climate Extremes : Indicators - Indices for Precipitation and Temperature and Heat Stress.
Water : Indicators - Water availability, Crop Water Stress, extreme events of Flood and Drought.

** Static variables - Projections for these variables have not been made.*

Current and Projected Vulnerability Profile

Current Vulnerability Profile

Very high vulnerability: District namely, Chamba with rank 12 is the most vulnerable district under current climate as can be seen in brown colour in Figure 2. Main sectors contributing to districts vulnerability in the CVI can be observed from Figure 3.

- Chamba has high social, economic, agriculture and water sector vulnerability.

It is observed that though Chamba is the most vulnerable, it has low exposure to extreme climate conditions.

Chamba with rank 12 is the most vulnerable under current conditions amongst all districts of Himachal Pradesh due to higher gender gap in literacy rate, age dependency ratio, child population, biomass dependency, below poverty line population, infant mortality rate, total fertility rate and relatively low literacy rate, poor access to sanitation facilities and electricity, low per capita income, lower Micro, Small & Medium (MSME) scale industrial units and number of commercial banks. It also has low fertilizer consumption, irrigated area, larger marginal land holdings area, higher exposure to drought weeks, and low ground water availability in South West Monsoon season.

High vulnerability: Two districts namely, Sirmaur and Bilaspur with ranks 11 and 10 respectively fall under high vulnerable category as can be seen in red colour in Figure 2. Main sectors contributing to these districts high vulnerability in the CVI can be observed from Figure 3.

- Sirmaur has high social and water sector vulnerability along with higher exposure to extreme climate conditions.
- Bilaspur has high economic and water sector vulnerability along with higher exposure to extreme climate conditions.

Moderate vulnerability: Four districts namely, Hamirpur, Mandi, Kangra and Una fall under moderate vulnerability. They are depicted in yellow colour in Figure 2.

Low vulnerability: Four districts namely, Kinnaur, Solan, Kullu and Shimla with ranks 2, 3, 4 and 5 respectively fall under low vulnerability.

- Kinnaur has low social and economic sector vulnerability along with lower exposure to extreme climate conditions.
- Solan has low social and economic sector vulnerability.
- Kullu has low water sector vulnerability along with lower exposure to extreme climate conditions.
- Shimla has low social sector vulnerability along with lower exposure to extreme climate conditions.

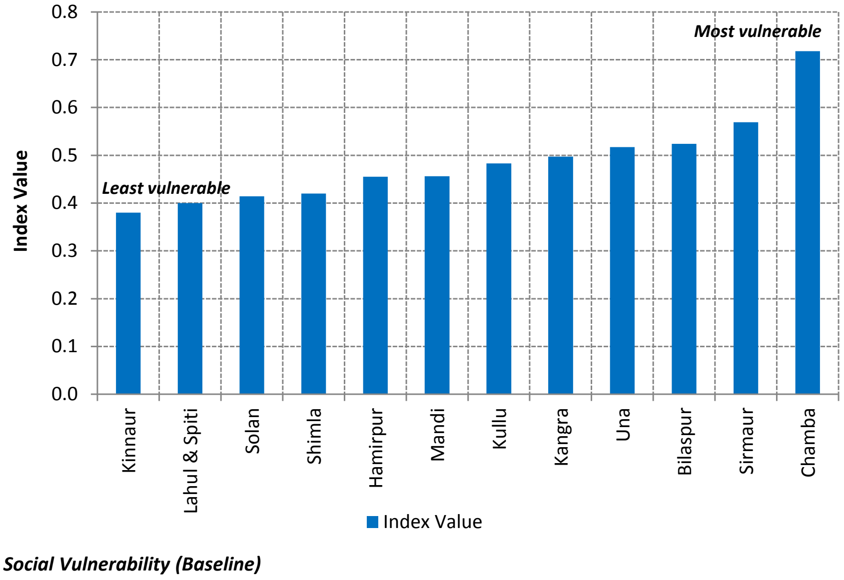
Very Low vulnerability: District namely, Lahul & Spiti located in very high hills temperate dry zone of Himachal Pradesh state with rank 1 is the least vulnerable district. Sectors contributing to very low vulnerability of the district as can be seen from Figure 3 are:

- Lahul & Spiti has very low social, economic, agriculture, water sector vulnerability and has lower exposure to extreme climate conditions. Thus it is observed that it has very low vulnerability in all the five sectors considered.

The main contributing factors to least vulnerability of this district include lower age dependency ratio, access to malaria, crude birth rate, child population, growth rate, student teacher ratio and low infant mortality rate and better access to improved source sanitation, work participation rate, high number of educational institutions, health centers and beds. Highest per capita income, number of commercial banks and MSME units, high livestock population, milk and egg production per capita, food grains yield, fertilizer consumption, irrigated area, higher rainy days, low consecutive wet days, consecutive dry days, lower sensitivity to heat stress, highest per capita surface and ground water availability in South West Monsoon season, surface water availability in North East Monsoon season and least exposure to flood and drought are also contributing.

The index values for current vulnerability are plotted in Figure 4 representing highest to lowest vulnerability.

Figure 4: Current Composite Vulnerability Index values for baseline for Himachal Pradesh districts



Projected Vulnerability Profile

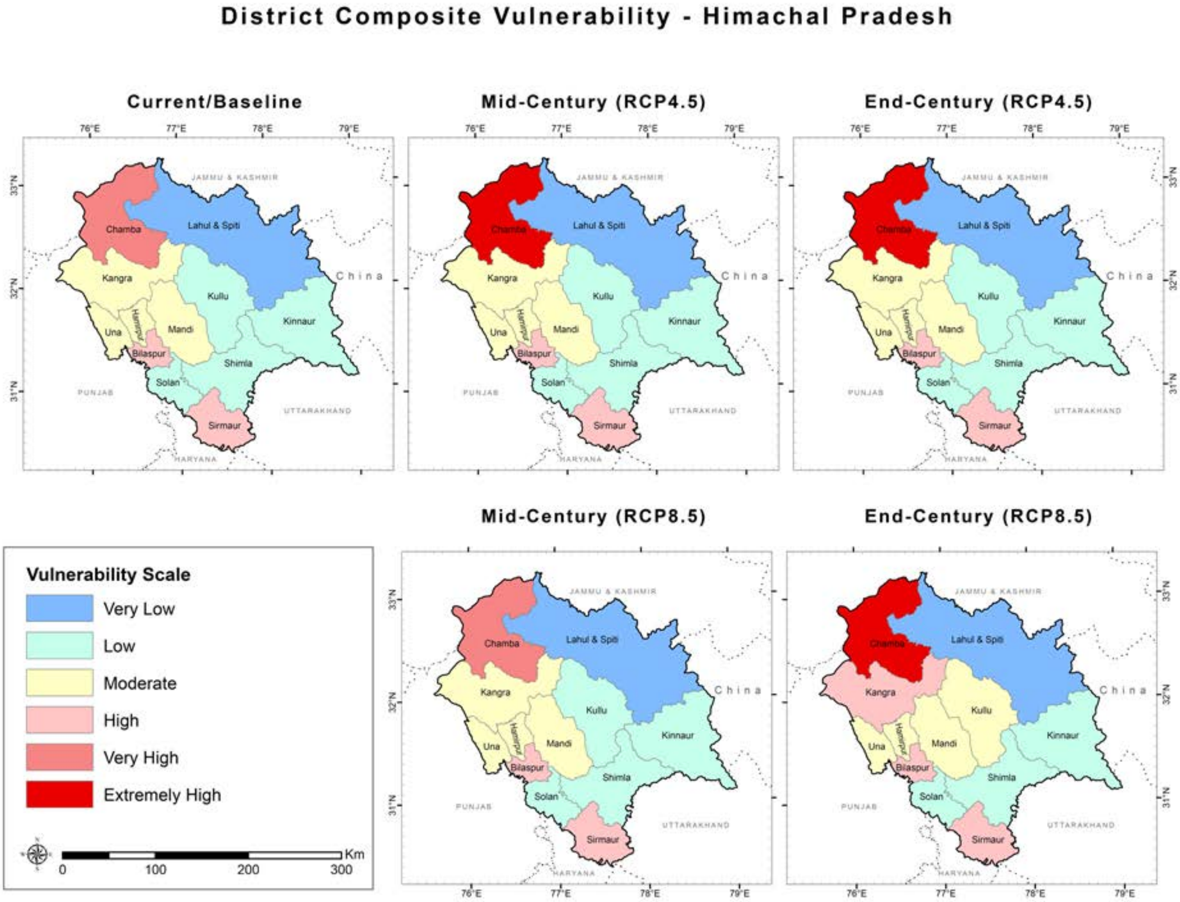
The overall Composite Vulnerability (CV) of the Himachal Pradesh districts is projected to increase towards mid-century and end-century as compared to the baseline for both the IPCC AR5 climate scenarios.

District vulnerability is likely to exacerbate under RCP8.5 scenario as compared to RCP4.5 scenario towards end-century.

- The overall climate extremes vulnerability of the districts is projected to increase towards mid-and end-century as compared to the current conditions for both the emission scenarios. District vulnerability is likely to exacerbate under RCP8.5 scenario as compared to RCP4.5 scenario towards both mid and end-century.
- The overall water resources vulnerability of the districts is projected to increase towards mid-and end-century as compared to the current conditions for both the emission scenarios. However, districts vulnerability is likely to exacerbate under RCP4.5 scenario as compared to RCP8.5 scenario towards both mid and end-century. Vulnerability of the districts towards, end-century RCP4.5 scenario is the maximum.
- Exposure to rainfall variability, extremely wet days, consecutive wet days, consecutive dry days, flood discharge, drought weeks and sensitivity to heat stress, seasonal crop water stress are projected to increase towards the mid-century and end-century as compared to current conditions thus contributing to increase in overall Composite Vulnerability (CV).

Spatial representation of projected CVI category for districts for RCP4.5 and RCP 8.5 scenarios are depicted in Figure 5.

Figure 5: Projected Composite Vulnerability map for districts of Himachal Pradesh for IPCC AR5 RCP4.5 and RCP8.5 scenarios



Composite Vulnerability comprises of the following Sectors

Social Indicators : - Demography, Infrastructure and Malaria, **Economic Indicators** : - Per Capita Income and GDP, **Climate Extremes Indicators** : - Indices for Precipitation and Temperature and **Climate Extremes** : Indicators - Indices for Precipitation and Temperature and Heat Stress **Water Indicators** : - Water availability, Crop Water Stress, extreme events of Flood and Drought, **Agriculture Indicators** : - Crop Intensity, Yield, Irrigation, Fertilizer use, Poultry, Livestock, Landholdings.

RCP4.5, Mid-century: Only one district is projected to move to higher vulnerability category from current lower vulnerability category under RCP4.5 scenario towards mid-century. District Chamba located in very high hills temperate dry zone which has very high current vulnerability is projected to exacerbate further and fall under extremely high vulnerability category. This is mainly due to higher exposure to extreme climate conditions, drought weeks and flood discharge.

Vulnerability category of rest of the districts is projected to remain unchanged and is projected to have same current vulnerability category as baseline. Though they are projected to marginally increase their vulnerability as their index values are projected to increase implying increase in degree of vulnerability as can be seen from Table A - 3 in Appendix I.

RCP4.5, End-century: District Chamba is projected to move to extremely high from current very high vulnerability under RCP4.5 scenario towards end-century. Thus the vulnerability is more or less the same towards end-century as mid-century scenario.

RCP8.5, Mid-century: Districts are projected to remain in the same vulnerability category towards mid-century as in current vulnerability (Figure 5).

RCP8.5, End-century: Vulnerability of three districts is projected to increase under RCP8.5 scenario towards end-century as compared to current vulnerability. These districts are Chamba, Kangra and Kullu. District Kullu is projected to move to moderate from current low vulnerability, Kangra to high from current moderate vulnerability and district Chamba which has very high current vulnerability is projected to exacerbate further and fall under extremely high vulnerability category (Figure 5).

Disaggregated Sectoral Current Vulnerability

Social Vulnerability

Due to projection limitations of the socio economic indicators, only current socio economic vulnerability has been derived. Spatial representation of social vulnerability distribution for districts is depicted in Figure 6 and the index values are plotted in Figure 7, followed by discussion on contributing factors to district social vulnerability category.

Figure 6: Social Vulnerability map for districts of Himachal Pradesh for current vulnerability

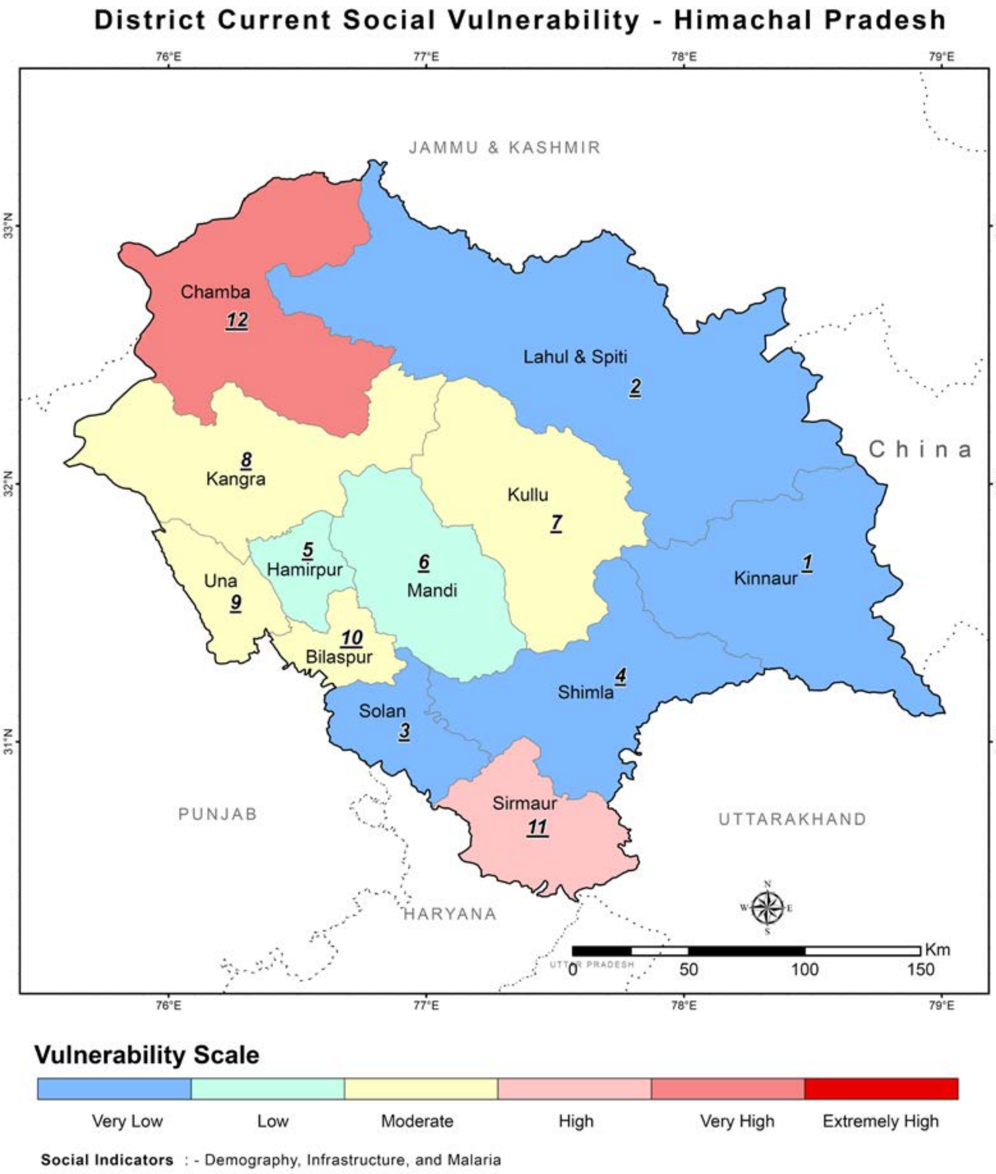
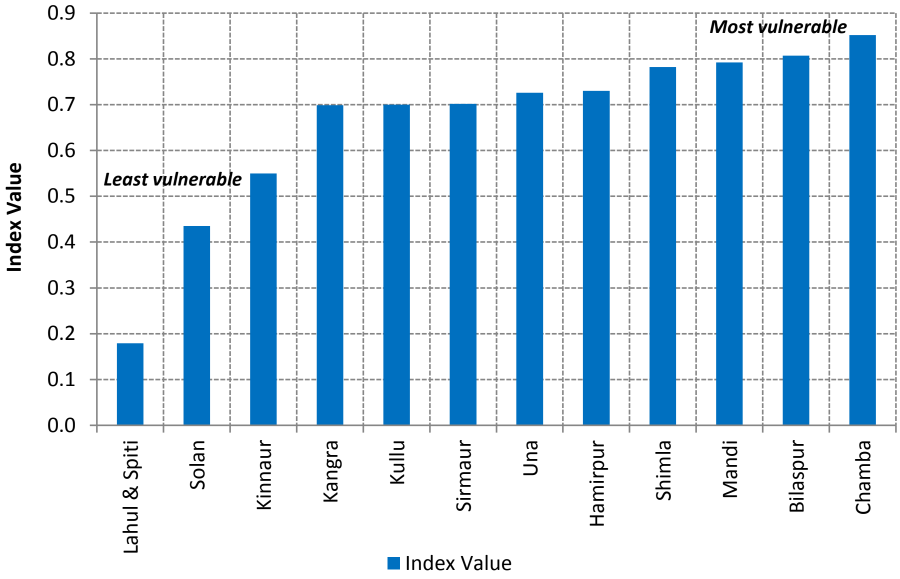


Figure 7: Social Vulnerability Index values for current vulnerability for Himachal Pradesh districts



Economic Vulnerability (Baseline)

Very high vulnerability: District namely, Chamba with rank 12 is currently the most vulnerable district. Higher gender gap in literacy rate, age dependency ratio, child population, biomass dependency, below poverty line population, infant mortality rate, total fertility rate and relatively low literacy rate, poor access to sanitation facilities and electricity are the major factors contributing to high vulnerability of Chamba district under current conditions.

High vulnerability: District namely, Sirmaur with rank 11 is highly vulnerable district as can be seen in red colour in Figure 6. It lies in the mid hills sub humid zone of Himachal Pradesh.

Moderate vulnerability: 4 districts namely, Kullu, Kangra, Una and Bilaspur with ranks 7, 8, 9 and 10 respectively fall under moderate vulnerability, shown in yellow colour in Figure 6.

Low vulnerability: Hamirpur and Mandi districts with ranks 5 and 6 respectively fall under low vulnerability category.

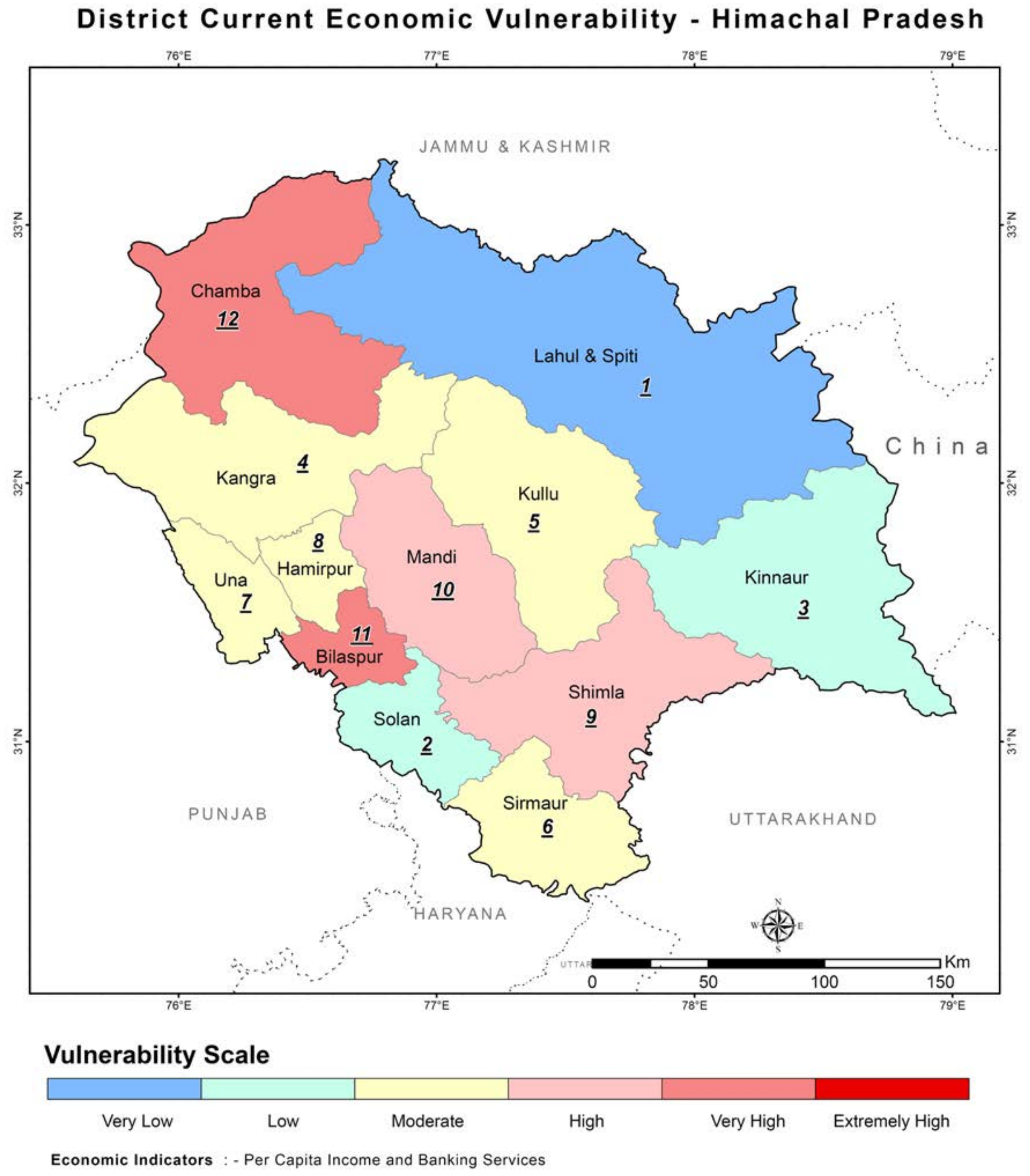
Very low vulnerability: 4 districts namely, Kinnaur, Lahul & Spiti, Solan, Shimla with ranks 1, 2, 3 and 4 respectively are the least vulnerable districts.

Low vulnerability of Kinnaur and Lahul & Spiti districts is associated with lower age dependency ratio, access to malaria, crude birth rate, child population, growth rate, student teacher ratio and low infant mortality rate and better access to improved source sanitation, work participation rate, high number of educational institutions, health centers and beds. Kinnaur district also has low biomass dependency. It can also be seen from Figure 7 that they have the lowest SV index values.

Economic Vulnerability

Similar to social vulnerability, only current economic vulnerability has been analyzed due to limitation on long term projections of economic indicators. Spatial representation of economic vulnerability distribution for districts is depicted in Figure 8. The index values are plotted in Figure 9.

Figure 8: Economic Vulnerability map for districts of Himachal Pradesh for current vulnerability



Very high vulnerability: Chamba and Bilaspur districts with ranks 12 and 11 respectively are the most vulnerable districts. Major contributing economic indicators for high vulnerability of Chamba include low per capita income; lower Micro, Small & Medium (MSME) scale industrial units and number of commercial banks while for Bilaspur includes low per capita income; percentage of households availing banking services and number of commercial banks. Thus low adaptive capacity makes these districts most vulnerable.

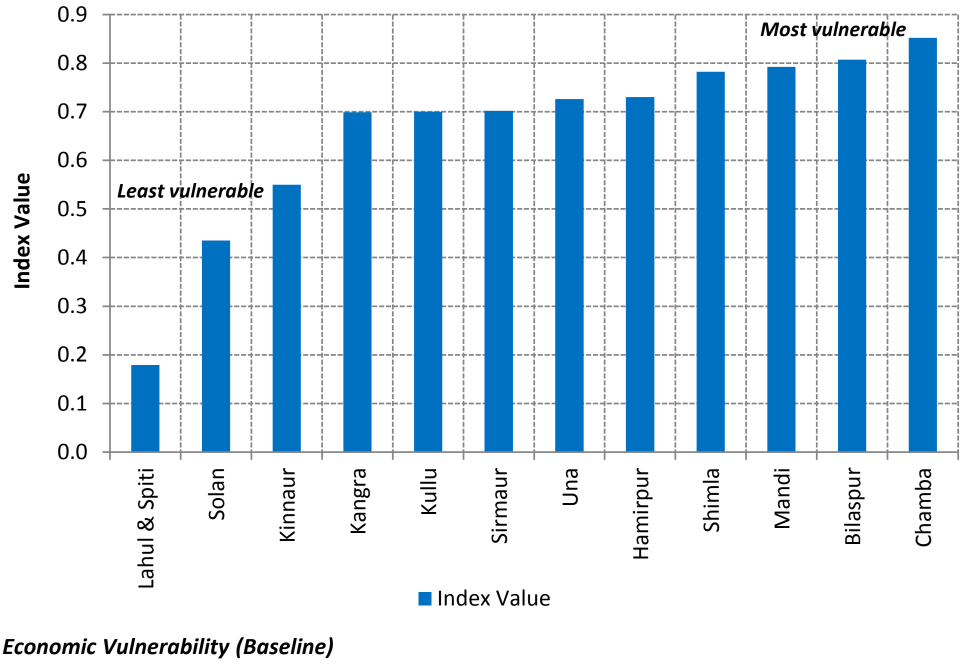
High vulnerability: Two districts namely, Mandi and Shimla with ranks 10 and 9 respectively fall under high vulnerability category. However, these are relatively less vulnerable than the very high vulnerable districts. The location of these districts can be seen in red colour in Figure 8.

Moderate vulnerability: Five districts namely, Kangra, Kullu, Sirmaur, Una and Hamirpur fall under moderate vulnerability category. The location of these districts can be seen in Figure 8 represented in yellow colour.

Low vulnerability: Solan and Kinnaur districts with ranks 2 and 3 respectively have low vulnerability. Higher per capita income, MSME industrial units and number of commercial banks are major contributing factors to make their vulnerability low.

Very low vulnerability: Lahul & Spiti with rank 1 is the least vulnerable district. Highest per capita income, number of commercial banks and MSME units are contributing to enhance the adaptive capacity of Lahul & Spiti to make its vulnerability very low. It can also be seen from Figure 9 that it has the lowest index values.

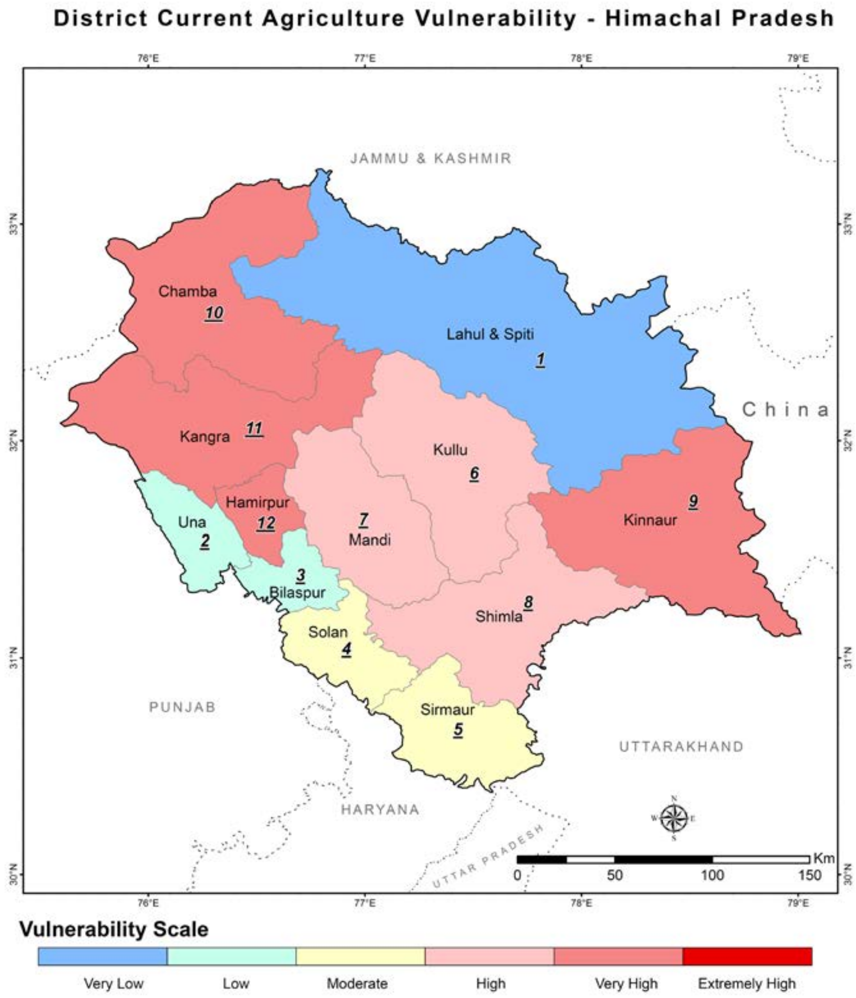
Figure 9: Economic Vulnerability Index values for current vulnerability for Himachal Pradesh districts



Generic Agriculture Vulnerability

Spatial representation of Agriculture Vulnerability category for districts is depicted in Figure 10. The index values are plotted in Figure 11. As discussed earlier, only current vulnerability has been analyzed due to limitation on long term projections of agriculture indicators.

Figure 10: Agriculture Vulnerability map for districts of Himachal Pradesh for current vulnerability



Agriculture Indicators : - Cropping Intensity, Net Sown/Irrigated area, Wasteland (DACNET), Livestock, Poultry (Livestock Census), Per capita milk and egg production

Very high vulnerability: Hamirpur, Kangra, Chamba and Kinnaur districts with ranks 12, 11, 10 and 9 respectively are currently very highly vulnerable.

Main contributing factors for high vulnerability of Hamirpur include low food grains yield, fertilizer consumption, irrigated area, egg production and livestock population while for Kangra includes low food grains yield, milk production and livestock population.

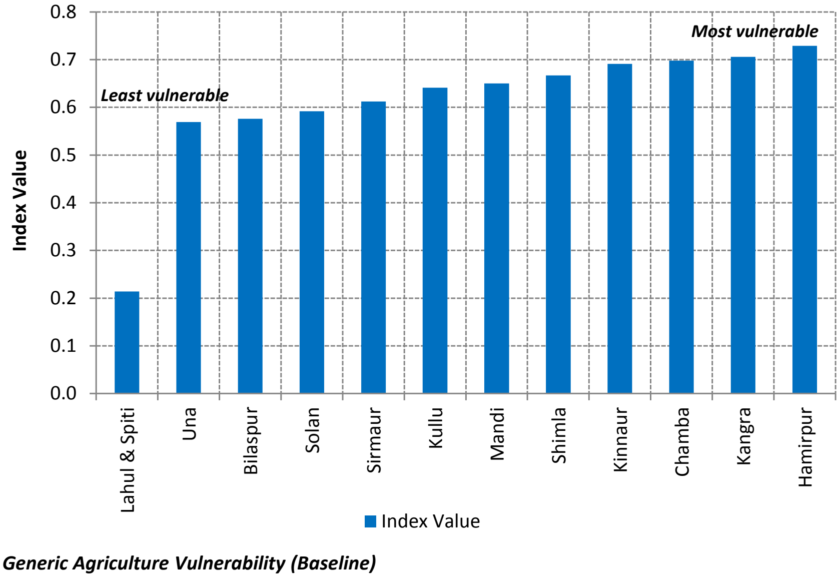
High vulnerability: Three districts namely, Shimla, Mandi and Kullu with ranks 8, 7 and 6 respectively fall under high vulnerability category.

Moderate vulnerability: Districts namely, Solan and Sirmaur with ranks 4 and 5 respectively have moderate vulnerability.

Low vulnerability: Two districts namely, Una and Bilaspur with ranks 2 and 3 respectively fall under low vulnerability category as can be seen in green colour in Figure 10.

Very low vulnerability: District Lahul & Spiti with rank 1 lying in very high hills temperate dry zone is the least vulnerable. High livestock population, milk and egg production per capita, food grains yield, fertilizer consumption and irrigated area contribute to render it least vulnerable.

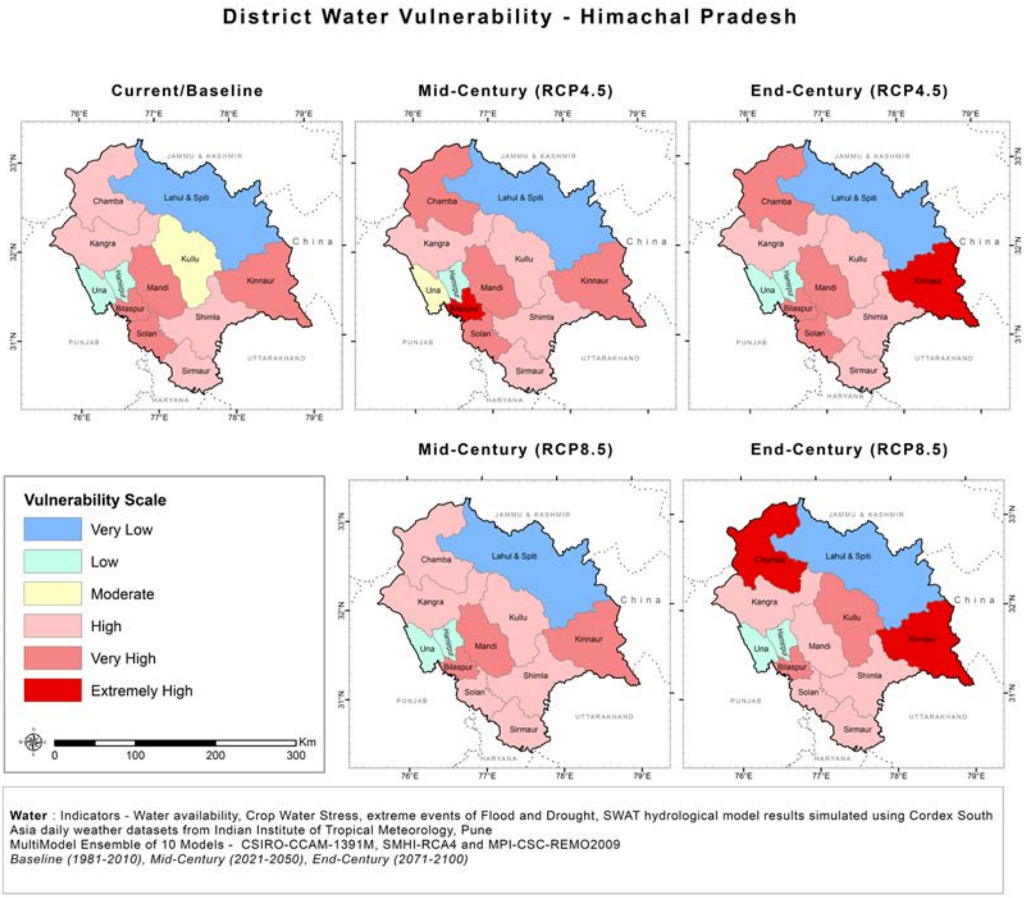
Figure 11: Agriculture Vulnerability Index values for current vulnerability for Himachal Pradesh districts



Water Resource Vulnerability

Spatial representation of Water Resource Vulnerability category for districts is depicted in Figure 12. The index values are plotted in Figure 13.

Figure 12: Water Resources Vulnerability map for Himachal Pradesh districts under RCP4.5 and RCP8.5 scenarios



Water : Indicators - Water availability, Crop Water Stress, extreme events of Flood and Drought, SWAT hydrological model results simulated using Cordex South Asia daily weather datasets from Indian Institute of Tropical Meteorology, Pune
MultiModel Ensemble of 10 Models - CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009
Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Current/Baseline Vulnerability

Very high vulnerability: Districts Bilaspur, Mandi, Kinnaur and Solan with ranks 12, 11, 10 and 9 respectively are the most vulnerable. Major contributing factors include less surface water and ground water availability in post monsoon season and high exposure to flood and drought for Bilaspur district, high seasonal crop water, high exposure to flood and drought for Kinnaur district and less seasonal surface water availability and high exposure to drought for Mandi and Solan districts. It can also be seen from Figure 13 that they have the highest WRV index values.

High vulnerability: Four districts namely, Shimla, Chamba, Sirmaur and Kangra fall under high vulnerability category, seen in red colour in Figure 12.

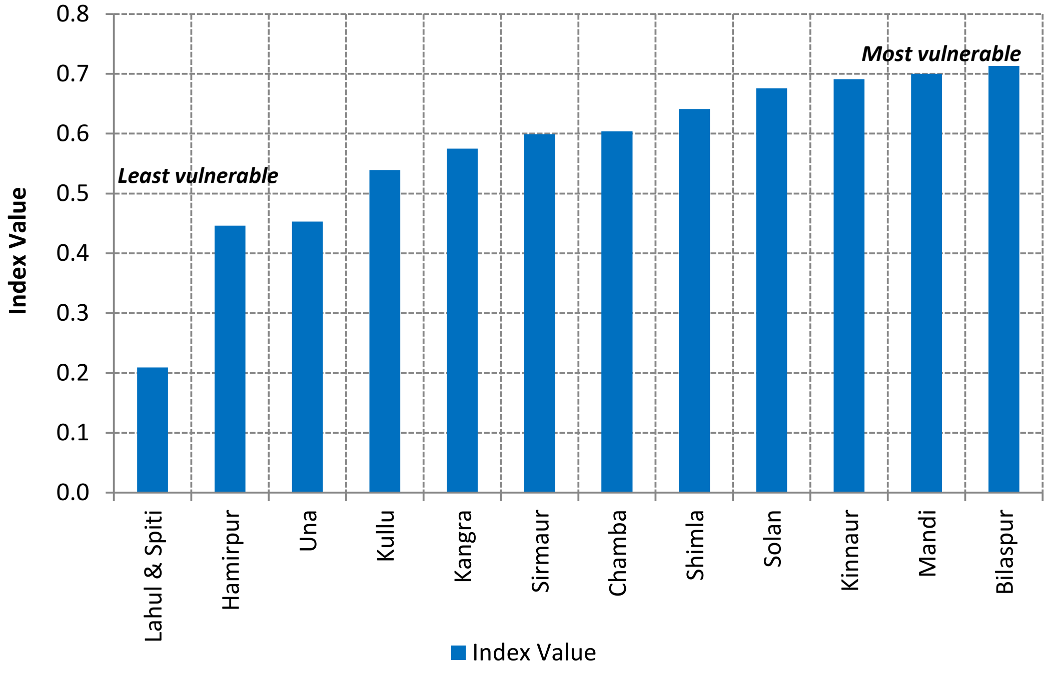
They are highly vulnerable because of low seasonal surface water availability and higher exposure to flood. Chamba and Kangra districts also have relatively higher exposure to drought weeks.

Moderate vulnerability: Kullu district lying in the high hills temperate wet zone of Himachal Pradesh State falls under moderate vulnerability as can be seen in Figure 12 represented in yellow colour.

Low vulnerability: 2 districts namely, Hamirpur and Una with ranks 2 and 3 respectively are the low vulnerable districts.

Very low vulnerability: Lahul & Spiti district of Himachal Pradesh with rank 1 is the least vulnerable district. Very low vulnerability is attributed to highest per capita surface and ground water availability in South West Monsoon season, surface water availability in North East Monsoon season and least exposure to flood and drought as compared to other districts.

Figure 13: Water Resources Vulnerability Index values for current vulnerability for Himachal Pradesh districts



Water Resources Vulnerability (Baseline)

Projected Vulnerability

The overall water resources vulnerability of the districts is projected to increase towards mid-and end-century as compared to the current conditions for both the emission scenarios. However, districts vulnerability is likely to exacerbate under RCP4.5 scenario as compared to RCP8.5 scenario towards both mid and end-century. Vulnerability of the districts towards, end-century RCP4.5 scenario is the maximum.

Projected increase in WRV is attributed to likely increase in exposure to drought weeks and flood discharge and sensitivity to seasonal crop water stress.

Vulnerability of the districts towards, end-century RCP4.5 scenario is the maximum because adaptive capacity to surface and ground water availability in South West monsoon season is the lowest and exposure to drought weeks is the highest relative to all other scenarios.

Vulnerability of the districts is relatively less towards mid-century RCP8.5 scenario relative to other three scenarios because adaptive capacity to surface and ground water availability in South West monsoon season is the highest and exposure to drought weeks is the lowest relative to all other scenarios.

RCP4.5, Mid-century: Vulnerability of four districts is projected to increase under RCP4.5 mid-century scenario as compared to current vulnerability. 4 districts namely, Bilaspur, Chamba, Kullu and Una are projected one fold increase to fall under extremely high vulnerability, very high, high and moderate from current very high, high, moderate and low vulnerability category respectively. The remaining 8 districts are projected to remain in the same vulnerability category as current vulnerability (Figure 12).

RCP4.5, End-century: Vulnerability of three districts is projected to increase under RCP4.5 end-century scenario as compared to current vulnerability. Kinnaur's vulnerability is projected to exacerbate further as it moves from very high to extremely high vulnerability category. District Chamba is projected to fall under very high vulnerability from current high vulnerability and district Kullu to fall under high vulnerability from current moderate vulnerability category (Figure 12).

RCP8.5, Mid-century: Vulnerability of district Kullu is projected to increase while that of Solan is projected to decline under RCP8.5 mid-century scenario as compared to current vulnerability. Solan is projected to fall under high vulnerability from current very high vulnerability as adaptive capacity to surface and ground water availability in South West monsoon season, surface water availability in North East monsoon season is expected to rise and exposure to drought weeks is expected to fall towards RCP8.5 mid-century scenario as compared to current conditions (Figure 12).

RCP8.5, End-century: Vulnerability of three districts is projected to increase while that of two districts is projected to decline under RCP8.5 end-century scenario as compared to current vulnerability. Solan and Mandi are projected to fall under high vulnerability from current very high vulnerability. District namely, Kullu and Chamba are projected two folds decrease to fall under very high and extremely high vulnerability category from current moderate and high vulnerability category respectively. Kinnaur's vulnerability is projected to exacerbate further as it moves from very high to extremely high vulnerability category.

Health/ Climate Extreme Vulnerability

Spatial representation of Climate Extremes Vulnerability category for districts is depicted in Figure 14. The index values are plotted in Figure 15.

Figure 14: Health/Climate Extremes Vulnerability map for Himachal Pradesh districts under RCP4.5 and RCP8.5 scenarios

Agriculture Indicators : - Cropping Intensity, Net Sown/Irrigated area, Wasteland (DACNET), Livestock, Poultry (Livestock Census), Per capita milk and egg production

Current/Baseline Vulnerability

Very high vulnerability: Una district lying in sub mountain & low hills sub-tropical zone of Himachal Pradesh, with rank 12 is the most vulnerable district.

Exposure to extreme events like consecutive dry days, low rainy days and higher sensitivity to heat stress contributes to make Una district the most vulnerable. It can also be seen from Figure 15 that it has the highest CLV index values.

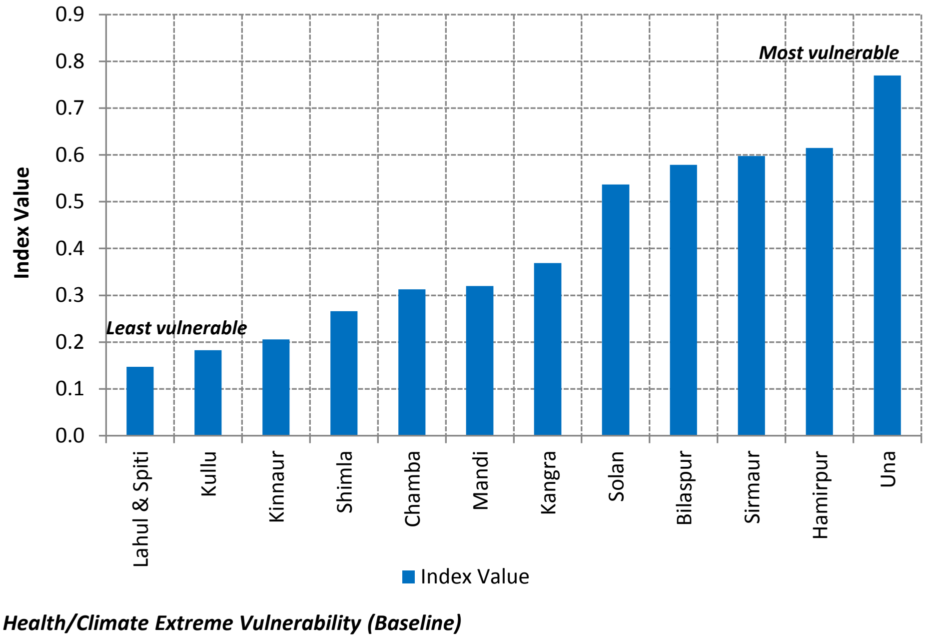
High vulnerability: Hamirpur, Sirmaur, Bilaspur and Solan districts with ranks 11, 10, 9 and 8 respectively fall under high vulnerability category but they are relatively less vulnerable than the very high vulnerable districts. They are located in the South Western part of the State as can be seen in Figure 14.

Moderate vulnerability: District Kangra with rank 7 falls under moderate vulnerability category. The location of this district can be seen in Figure 14 represented in yellow colour.

Low vulnerability: Shimla, Chamba and Mandi districts with ranks 4, 5 and 6 respectively fall under low vulnerability category.

Very low vulnerability: 3 districts namely, Lahul & Spiti, Kullu and Kinnaur with ranks 1, 2 and 3 respectively are the least vulnerable districts. Higher rainy days, low consecutive wet days, consecutive dry days and lower sensitivity to heat stress relative to the other districts are the main factors contributing to low vulnerability of these districts.

Figure 15: Health/climate extremes vulnerability Index values for current vulnerability for Himachal Pradesh districts



Projected Vulnerability

The overall climate extremes vulnerability of the districts is projected to increase towards mid-and end-century as compared to the current conditions for both the emission scenarios. District vulnerability is likely to exacerbate under RCP8.5 scenario as compared to RCP4.5 scenario towards both mid and end-century.

Factors contributing to projected increase in climate extremes vulnerability of districts include projected increase in rainfall variability, exposure to extremely wet days, consecutive wet days, consecutive dry days and higher sensitivity to heat stress.

RCP4.5, Mid-century: Four districts are projected to shift towards higher levels of vulnerability under RCP4.5 mid-century scenario as compared to current vulnerability. Hamirpur is projected to fall under very high from current high vulnerability category, Kangra district to fall under high vulnerability from current moderate category and Mandi, Chamba to fall under moderate vulnerability from current low category. The remaining districts are projected to remain in the same vulnerability category as current vulnerability (Figure 14).

RCP4.5, End-century: Five districts are projected to shift towards higher levels of vulnerability under RCP4.5 end-century scenario as compared to current vulnerability. Sirmaur is projected to fall under very high from current high vulnerability category. The remaining four districts Hamirpur, Kangra, Mandi and Chamba projected shift is same as mentioned under RCP4.5 mid-century scenario.

RCP8.5, Mid-century: Six districts are projected to shift towards higher levels of vulnerability under RCP8.5 mid-century scenario as compared to current vulnerability. One fold increase in vulnerability is projected for 6 districts namely, Hamirpur, Kangra, Mandi, Chamba, Sirmaur and Una. Una's vulnerability is projected to exacerbate further as it moves from very high to extremely high vulnerability category. The remaining five districts projected shift is same as mentioned under RCP4.5 end-century scenario (Figure 14).

RCP8.5, End-century: Ten districts are projected to shift towards higher levels of vulnerability under RCP8.5 end-century scenario as compared to current vulnerability. Two folds increase in vulnerability is projected for Mandi district (fall under high from current low vulnerability category) while one fold for 9 districts namely, Bilaspur, Shimla, Solan, Hamirpur, Kangra, Mandi, Chamba, Sirmaur and Una. Bilaspur and Solan are projected to fall under very high from current high vulnerability category while Shimla district to fall under moderate vulnerability from current low category (Figure 14).

Summary - District Vulnerability

Vulnerability has been assessed at the district level. The vulnerability analysis has been based on Composite Vulnerability Index (CVI) derived using multivariate analysis for current and projected climate (under RCP4.5 and RCP8.5 climate scenario towards mid-century and end-century). The IPCC working definition of vulnerability as a function of exposure, sensitivity, and adaptive capacity has been used and identified 62 indicators have been categorized into adaptive capacity, sensitivity and exposure. Accordingly five sectoral vulnerability indices for social, economic, agriculture, water resources and health/extreme climate conditions have also been generated. The indices would facilitate the identification of districts, which are vulnerable to climate change and need special attention towards adaptation. Sectors which contribute to make a district fall under a specific vulnerability category can be identified from this table, for example: Chamba falls under very high vulnerability category (CVI) as vulnerability is high in social, economic, agriculture and water resource sectors. Though it is complex, one can broadly draw similar inferences for other districts as well.

Table 1 gives the overall summary of the vulnerability of Himachal Pradesh districts for the current period. Table 2 gives the overall summary of the current and projected composite vulnerability of Himachal Pradesh districts.

Sectors which contribute to make a district fall under a specific vulnerability category can be identified from this table, for example: Chamba falls under very high vulnerability category (CVI) as vulnerability is high in social, economic, agriculture and water resource sectors. Though it is complex, one can broadly draw similar inferences for other districts as well.

Table 1: District current composite vulnerability along with disaggregated sub components for districts of Himachal Pradesh

Districts	Rank	CV	SV	ECV	AGV	CLV	WRV
Lahul & Spiti	1	VL	VL	VL	VL	VL	VL
Kinnaur	2	L	VL	L	VH	VL	VH
Solan	3	L	VL	L	M	H	VH
Kullu	4	L	M	M	H	VL	M
Shimla	5	L	VL	H	H	L	H
Hamirpur	6	M	L	M	VH	H	L
Mandi	6	M	L	H	H	L	VH
Kangra	8	M	M	M	VH	M	H
Una	9	M	M	M	L	VH	L
Bilaspur	10	H	M	VH	L	H	VH
Sirmaur	11	H	H	M	M	H	H
Chamba	12	VH	VH	VH	VH	L	H

CV: Composite Vulnerability, SV: Social Vulnerability, ECV: Economic Vulnerability, CLV: Climate extremes vulnerability, WRV: Water Resources Vulnerability, AGV: Agriculture Vulnerability

VL: Very Low, L: Low, M: Moderate, H: High, VH: Very High

Table 2: Districts current and projected composite vulnerability along with disaggregated sub components for districts of Himachal Pradesh

	Composite Vulnerability Index (CVI)						Water Resources VI (WRVI)						Climate Vulnerability Index (CLVI)					
			RCP4.5		RCP8.5				RCP4.5		RCP8.5				RCP4.5		RCP8.5	
Districts	**BL Rank**	**BL**	**MC**	**EC**	**MC**	**EC**	**BL Rank**	**BL**	**MC**	**EC**	**MC**	**EC**	**BL Rank**	**BL**	**MC**	**EC**	**MC**	**EC**
Lahul & Spiti	1	VL	VL	VL	VL	VL	1	VL	VL	VL	VL	VL	1	VL	VL	VL	VL	VL
Kinnaur	2	L	L	L	L	L	10	VH	VH	EH	VH	EH	3	VL	VL	VL	VL	VL
Solan	3	L	L	L	L	L	9	VH	VH	VH	H	H	8	H	H	H	H	VH
Kullu	4	L	L	L	L	M	4	M	H	H	H	VH	2	VL	VL	VL	VL	L
Shimla	5	L	L	L	L	L	8	H	H	H	H	H	4	L	L	L	L	M
Hamirpur	6	M	M	M	M	M	2	L	L	L	L	L	11	H	VH	VH	VH	VH
Mandi	6	M	M	M	M	M	11	VH	VH	VH	VH	H	6	L	M	M	M	H
Kangra	8	M	M	M	M	H	5	H	H	H	H	H	7	M	H	H	H	H
Una	9	M	M	M	M	M	3	L	M	L	L	L	12	VH	VH	VH	EH	EH
Bilaspur	10	H	H	H	H	H	12	VH	EH	VH	VH	VH	9	H	H	H	H	VH
Sirmaur	11	H	H	H	H	H	6	H	H	H	H	H	10	H	H	VH	VH	VH
Chamba	12	VH	EH	EH	VH	EH	7	H	VH	VH	H	EH	5	L	M	M	M	M

BL: Baseline, MC: Mid-Century, EC: End-Century

VL: Very Low, L: Low, M: Moderate, H: High, VH: Very High, EH: Extremely High

Summary of the district composite vulnerability analysis is as follows:

Current Composite Vulnerability

- District namely, Chamba with rank 12 is the most vulnerable district under current climate. Main sectors contributing to districts vulnerability in the CVI are:
    - Chamba has high social, economic, agriculture and water sector vulnerability.
    - It is the most vulnerable amongst all districts of Himachal Pradesh due to higher gender gap in literacy rate, age dependency ratio, child population, biomass dependency, below poverty line population, infant mortality rate, total fertility rate and relatively low literacy rate, poor access to sanitation facilities and electricity, low per capita income, lower Micro, Small & Medium (MSME) scale industrial units and number of commercial banks. It also has low fertilizer consumption, irrigated area, larger marginal land holdings area, higher exposure to drought weeks, and low ground water availability in South West Monsoon season.
- Two districts namely, Sirmaur and Bilaspur with ranks 11 and 10 respectively fall under high vulnerable category.
- District namely, Lahul & Spiti located in very high hills temperate dry zone of Himachal Pradesh state with rank 1 is the least vulnerable district.
    - It has very low social, economic, agriculture, water sector vulnerability and has lower exposure to extreme climate conditions.
    - The main contributing factors include lower age dependency ratio, access to malaria, crude birth rate, child population, growth rate, student teacher ratio and low infant mortality rate and better access to improved source sanitation, work participation rate, high number of educational institutions, health centres and beds. Highest per capita income, number of commercial banks and MSME units, high livestock population, milk and egg production per capita, food grains yield, fertilizer consumption, irrigated area, higher rainy days, low consecutive wet days, consecutive dry days, lower sensitivity to heat stress, highest per capita surface and ground water availability in South West Monsoon season, surface water availability in North East Monsoon season and least exposure to flood and drought are also contributing.

Projected Composite Vulnerability

The overall Composite Vulnerability (CV) of the Himachal Pradesh districts is projected to increase towards mid-century and end-century as compared to the baseline for both the IPCC AR5 climate scenarios. District vulnerability is likely to exacerbate under RCP8.5 scenario as compared to RCP4.5 scenario towards end-century.

- Exposure to rainfall variability, extremely wet days, consecutive wet days, consecutive dry days, flood discharge, drought weeks and sensitivity to heat stress, seasonal crop water stress are projected to increase towards the mid-century and end-century as compared to current conditions thus contributing to increase in overall Composite Vulnerability (CV).

Each sector considered in the analysis contributes differently to the aggregated composite vulnerability index and district rankings. The decomposition of the composite vulnerability index can shed light on main factors contributing to overall vulnerability of a particular district. Each sector used in CVI has been further disaggregated to help understand the main factors driving to make districts vulnerable. Summary of disaggregated sectoral vulnerability for social, economic, health/climate extremes, water resources and agriculture is given below:

Social Vulnerability

- District namely, Chamba with rank 12 is currently the most vulnerable district.
- 4 districts namely, Kinnaur, Lahul & Spiti, Solan, Shimla with ranks 1, 2, 3 and 4 respectively are the least vulnerable districts.

Economic Vulnerability

- Chamba and Bilaspur districts with ranks 12 and 11 respectively are the most vulnerable districts.
    - Major contributing economic indicators for high vulnerability of Chamba include low per capita income; lower Micro, Small & Medium (MSME) scale industrial units and number of commercial banks while for Bilaspur includes low per capita income; percentage of households availing banking services and number of commercial banks.
- Lahul & Spiti with rank 1 is the least vulnerable district.

Agriculture Vulnerability

- Hamirpur, Kangra, Chamba and Kinnaur districts with ranks 12, 11, 10 and 9 respectively are currently very highly vulnerable.
    - Main contributing factors for high vulnerability of Hamirpur include low food grains yield, fertilizer consumption, irrigated area, egg production and livestock population while for Kangra includes low food grains yield, milk production and livestock population.
- 3 districts namely, Lahul & Spiti, Kullu and Kinnaur with ranks 1, 2 and 3 respectively are the least vulnerable districts.

Health/Climate Extremes Vulnerability

- Una district lying in sub mountain & low hills sub-tropical zone of Himachal Pradesh, with rank 12 is the most vulnerable district. Exposure to extreme events like consecutive dry days, low rainy days and higher sensitivity to heat stress contributes to make Una district the most vulnerable.
- 3 districts namely, Lahul & Spiti, Kullu and Kinnaur with ranks 1, 2 and 3 respectively are the least vulnerable districts.
- The overall climate extremes vulnerability of the districts is projected to increase towards mid-and end-century as compared to the current conditions for both the emission scenarios. District vulnerability is likely to exacerbate under RCP8.5 scenario as compared to RCP4.5 scenario towards both mid and end-century.
    - Factors contributing to projected increase in climate extremes vulnerability of districts include projected increase in rainfall variability, exposure to extremely wet days, consecutive wet days, consecutive dry days and higher sensitivity to heat stress.

Water Resource Vulnerability

- Districts Bilaspur, Mandi, Kinnaur and Solan with ranks 12, 11, 10 and 9 respectively are the most vulnerable.
    - Major contributing factors include less surface water and ground water availability in post monsoon season and high exposure to flood and drought for Bilaspur district, high seasonal crop water, high exposure to flood and drought for Kinnaur district and less seasonal surface water availability and high exposure to drought for Mandi and Solan districts.
- Lahul & Spiti district of Himachal Pradesh with rank 1 is the least vulnerable district.
    - As it has highest per capita surface and ground water availability in South West Monsoon season, surface water availability in North East Monsoon season and least exposure to flood and drought.
- The overall water resources vulnerability of the districts is projected to increase towards mid-and end-century as compared to the current conditions for both the emission scenarios. However, districts vulnerability is likely to exacerbate under RCP4.5 scenario as compared to RCP8.5 scenario towards both mid and end-century. Vulnerability of the districts towards, end-century RCP4.5 scenario is the maximum.
    - Projected increase in WRV is attributed to likely increase in exposure to drought weeks and flood discharge and sensitivity to seasonal crop water stress.
    - Vulnerability of the districts towards, end-century RCP4.5 scenario is the maximum because adaptive capacity to surface and ground water availability in South West monsoon season is the lowest and exposure to drought weeks is the highest relative to all other scenarios.
    - Vulnerability of the districts is relatively less towards mid-century RCP8.5 scenario relative to other three scenarios because adaptive capacity to surface and ground water availability in South West monsoon season is the highest and exposure to drought weeks is the lowest relative to all other scenarios.

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List of Indicators for District Vulnerability Assessment

Table A- 1: Sectors of vulnerability and the associated indicators for Himachal Pradesh districts

No	Indicators	Abb	Unit	Functional Relationship with vulnerability	Conceptual Basis	Data Source	Time Period
				Social			
1	Density of Population	DP	Persons / Sq. Km	Increase	Sensitivity	Census of India: Primary Census Abstract - Himachal Pradesh	2011
2	Decadal growth rate of Population	GR	Percentage	Increase	Sensitivity	Census of India: Himachal Pradesh	2011
3	Sex-ratio	SR	No of females /1000 males	Increase	Sensitivity	Census of India: Primary Census Abstract - Himachal Pradesh	2011
4	Literacy Rate	LR	Percentage	Decrease	Adaptive Capacity		
5	Gender gap in literacy rate	GGLR	Percentage	Increase	Sensitivity		
6	Age Dependency ratio	ADR	Percentage	Increase	Sensitivity	Census of India: C Series - Himachal Pradesh	2011
7	Child Population in the age group 0-6	CP	Percentage	Increase	Sensitivity	Census of India: Primary Census Abstract - Himachal Pradesh	2011

No	Indicators	Abb	Unit	Functional Relationship with vulnerability	Conceptual Basis	Data Source	Time Period
8	Households with access to improved source of drinking water (tap water, covered well, hand pump, tube well)	DW	Percentage	Decrease	Adaptive Capacity	Census of India: House listing and Housing Census - Himachal Pradesh	2011
9	Households having access to sanitation facility within the premises	SF	Percentage	Decrease	Adaptive Capacity		
10	Households having electricity as main source of lighting	EL	Percentage	Decrease	Adaptive Capacity		
11	Households still dependent on biomass as fuel for cooking	BM	Percentage	Increase	Sensitivity		
12	Households living in Permanent houses	PH	Percentage	Decrease	Adaptive Capacity		
13	Households with access to communication/transport	COMTR	Percentage	Decrease	Adaptive Capacity		
14	Households Below Poverty Line	BPL	Percentage to Total Rural Households	Increase	Sensitivity	Department of Economics and Statistics, District Level Economic Indicators	2002-07
15	Share of Marginal Workers	MGW	Percentage	Increase	Sensitivity	Census of India: Primary Census Abstract - Himachal Pradesh	2011
16	Agricultural And Cultivators to Main Workers	ACMW	Percentage	Increase	Sensitivity		
17	Total work participation rate	TWPR	Percentage	Decrease	Adaptive Capacity		
18	Gender gap in work participation rate	GWPR	Percentage	Increase	Adaptive Capacity		

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No	Indicators	Abb	Unit	Functional Relationship with vulnerability	Conceptual Basis	Data Source	Time Period
19	Health Centres (Primary Health Centres, Community Health Centres, Sub Centres, Sub divisional and District hospitals)	HC	Number/Lakh of population	Decrease	Adaptive Capacity	Department of Economics and Statistics, District Level Economic Indicators	2014-15
20	Beds available in health institutions	BHC	Number/Lakh of population	Decrease	Adaptive Capacity		
21	Schools (primary, middle, high schools and senior secondary schools)	EI	Number/Lakh of population	Decrease	Adaptive Capacity		
22	Student Teacher Ratio	ST	Number	Increase	Sensitivity	District Information System for Education-DISE	2014-15
23	Level of urbanization	UR	Percentage	Decrease	Adaptive Capacity	Census of India: Primary Census Abstract - Himachal Pradesh	2011
24	Schedule Tribes and Scheduled Caste population	STSC	Percentage	Increase	Sensitivity		
25	Road length	RDEN	Per 100 sq. km	Decrease	Adaptive Capacity	Department of Economics and Statistics, District Level Economic Indicators	2013-14
26	Crude Birth Rate	CBR	Percentage	Increase	Sensitivity	Health & Family Welfare Department, Himachal Pradesh: Statistical Report for the Year, 2012	2012
27	Crude Death Rate	CDR	Percentage	Increase	Sensitivity		
28	Infant Mortality Rate	IMR	Percentage	Increase	Sensitivity	Statistical Abstract of Himachal Pradesh, 2015-16, Department of Economics and Statistics	2014
29	Total Fertility Rate	TFR	Percentage	Increase	Sensitivity	IIPS Estimates of Vital Statistics Report	2001
30	Annual Parasite Index-Malaria	API	Percentage	Increase	Sensitivity	National Vector Borne Disease Control Programme, Ministry of Health & Family Welfare	2010

No	Indicators	Abb	Unit	Functional Relationship with vulnerability	Conceptual Basis	Data Source	Time Period
				Economic			
31	Per Capita Income (GDP) at current prices	GDP	Rs. '000	Decrease	Adaptive Capacity	Indicus Analytics	2013-14
32	Households availing banking services	BNKS	Percentage	Decrease	Adaptive Capacity	Census of India: House listing and Housing Census - Himachal Pradesh	2011
33	Commercial banks	CBNK	Number/Lakh of population	Decrease	Adaptive Capacity	Department of Economics and Statistics, District Level Economic Indicators	2014
34	Total Credit to Total Deposits in Banks	TCTD	Percentage	Decrease	Adaptive Capacity		
35	Micro, Small & Medium Scale Industrial Units	MSME	Number/Lakh of population	Decrease	Adaptive Capacity	State Industrial Profile of Himachal Pradesh, 2014-2015, MSME Development Institute, Govt. of India, Ministry of MSME	2014
				Agriculture			
36	Food grains yield	FY	Kg/hectare	Decrease	Adaptive Capacity	Department of Economics and Statistics, District Level Economic Indicators	2012-13
37	Net Area Sown	NSA	Percentage of the district geographical area	Decrease	Adaptive Capacity	DACNET (Department of Agriculture Cooperation)- Landuse Statistics Report	2013-14
38	Net Irrigated Area	IA	Percentage to Net Sown Area	Decrease	Adaptive Capacity		

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No	Indicators	Abb	Unit	Functional Relationship with vulnerability	Conceptual Basis	Data Source	Time Period
39	Fertilizer Consumption	FC	Kg/ha	Decrease	Adaptive Capacity	Department of Economics and Statistics, District Level Economic Indicators	2014-15
40	Cropping intensity	CI	Percentage	Decrease	Adaptive Capacity	DACNET (Department of Agriculture Cooperation)- Landuse Statistics Report	2013-14
41	Total Wasteland	WL	Percentage of the district geographical area	Increase	Sensitivity		
42	Land Holdings area below 1 Hectare	LH	Percentage	Increase	Sensitivity	Department of Agriculture and Cooperation, Agriculture Census Database	2011
43	Livestock unit	LP	Number per 1000 households	Decrease	Adaptive Capacity	Department of Animal Husbandry, Dairying & Fisheries, 19th Livestock Census District Wise Report 2012	2012
44	Poultry Unit	POP	Number per 1000 households	Decrease	Adaptive Capacity		
45	Milk production per capita	MP	gms/day	Decrease	Adaptive Capacity	Department of Economics and Statistics, District Level Economic Indicators	2014-15
46	Egg Production per capita	EP	eggs/year	Decrease	Adaptive Capacity		

No	Indicators	Abb	Unit	Functional Relationship with vulnerability	Conceptual Basis	Data Source	Time Period
Health/Climate Extreme							
47	Average annual rainfall	RF	mm	Decrease	Exposure	SWAT Hydrological model outputs, CORDEX climate data-RCP 4.5, RCP 8.5 (IITM, Pune)	1981-2010 (BL), 2021-2050 (MC), 2071-2100 (EC)
48	Standard deviation in annual rainfall	STDRF		Increase	Exposure		
49	No. of Rainy Days	RD	Number of Days	Decrease	Exposure		
50	Extremely Wet Days-Annual total rainfall when rainfall>99th percentile	EWD	mm	Increase	Exposure		
51	Consecutive Dry Days-maximum number of Consecutive Days With Rainfall Less Than 1 mm	CDD	Number of Days	Increase	Exposure		
52	Consecutive Wet Days-maximum number of Consecutive Days	CWD	Number of Days	Increase	Exposure		
53	Heat Index	HI	Severity of days	Increase	Sensitivity		
54	Temperature Humidity Index	THI	Severity of days	Increase	Sensitivity		

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No	Indicators	Abb	Unit	Functional Relationship with vulnerability	Conceptual Basis	Data Source	Time Period
Water Resource							
55	Surface Water availability in South West Monsoon season	SWSWM	mm/lakh population	Decrease	Adaptive Capacity	SWAT Hydrological model outputs, CORDEX climate data-RCP4.5, RCP8.5 (IITM, Pune)	1981-2010 (BL), 2021-2050 (MC), 2071-2100 (EC)
56	Surface Water availability in North East Monsoon season	SWNEM	mm/lakh population	Decrease	Adaptive Capacity		
57	Ground Water availability in South West Monsoon season	GWSWM	mm/lakh population	Decrease	Adaptive Capacity		
58	Ground Water availability in North East Monsoon season	GWNEM	mm/lakh population	Decrease	Adaptive Capacity		
59	Crop water Stress(ET/PET) in South West Monsoon season	CWSSWM	Ratio	Increase	Sensitivity		
60	Crop water Stress(ET/PET) in North East Monsoon season	CWSNEM	Ratio	Increase	Sensitivity		
61	Frequency of Drought	DR	Number of weeks	Increase	Exposure		
62	Flood Discharge (1-2% probable flow)	FL	cumecs-day	Increase	Exposure		

Table A- 2: Rationale for classifying indicators of vulnerability as exposure, sensitivity or adaptive capacity

Indicators	Rationale	Reference
Social Indicators		
Density of Population (Sensitivity)	A region with high population density is more sensitive to climate because more people are exposed and therefore the region will need greater humanitarian assistance. High density leads to more problems related with security, water, natural resource stress, etc.	Glwadys Aymone Gbetibouo, Claudia Ringler, 2009, " Mapping South African Farming Sector Vulnerability to Climate Change and Variability", Environment and Production Technology Division, International Food Policy Research Institute (IFPRI)
Decadal growth rate of Population (Sensitivity)	Growth of population reduces output by lowering the per capita availability of capital. Large population creates problem of unemployment and food scarcity, puts pressure on the social infrastructure, etc. hence it's treated as sensitivity.	http://www.economicsdiscussion.net/population-explosion/14-major-negative-effects-of-population-explosion/4461
Sex-ratio (Sensitivity)	Women can have a more difficult time during recovery than men, often due to sector-specific employment, social and cultural structures that place them in inferior social positions, lower wages, education, public voice and family care responsibilities.	"Gender Equality in Education, Employment and Entrepreneurship: Final Report to the MCM 2012", Meeting of the OECD Council at Ministerial Level, Paris, 23-24 May 2012
Literacy Rate (Adaptive Capacity)	Increased overall literacy levels reduce vulnerability by increasing people's capabilities and access to information and thus their ability to cope with adversities, adapt better and also enhances their ability to diversify livelihoods14.	Rama Rao, C.A.et al., " Atlas on vulnerability of Indian agriculture to climate change", Central Research Institute for Dryland Agriculture, Hyderabad, 2013, p. 116;
Gender gap in literacy rate (Sensitivity)	Increased gap in literacy rate increases vulnerability. The low female literacy rate has had a dramatically negative impact on family planning and population stabilisation efforts in India.	P. Suma Latha: Asst. Prof. of ES, "Women Literacy and Development: Research Paper", Vignan's Lara Institute of Technology and Science
Age Dependency ratio (Sensitivity)	It is calculated by adding together the percentage of children (aged under 15 years) and the older population (aged 65+), dividing that percentage by the working-age population (aged 15-64 years), multiplying that percentage by 100 so the ratio is expressed as the number of 'dependents' per 100. As the ratio increases there may be an increased burden on the productive part of the population to maintain the upbringing and pensions of the economically dependent.	Piya, L.; Maharjan, K.L.; Joshi, N.P. Vulnerability of Rural Households to Climate Change and Extremes: Analysis of Chepang Households in the Mid-Hills of Nepal. In 28th International Conference of Agricultural Economists: The Global Bioeconomy; International Association of Agricultural Economists: Foz Do Iguacu, Brazil, 2012; No. 126191.

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Indicators	Rationale	Reference
Child Population in the age group 0-6 (Sensitivity)	The demographic group most affected by disasters, are children hence they are most vulnerable. Child morbidity and mortality, including vector borne diseases, water borne disease mainly affect younger age groups; hence the total burden due to climate change appears to be borne mainly by children	A.P. Pandey and Surendra Kumar Gupta, 2010, Climate Change and Child Health in India: Special Case 0-6 Year Old Children, Journal of Indian Economics Association
Households with access to improved source of drinking water (Adaptive Capacity)	Accessibility to improved water sources is of fundamental significance to lowering the faecal risk and frequency of associated diseases. Its association with other socioeconomic characteristics, including education and income, makes it a good universal indicator of human development. Without clean water, children are at risk of diseases such as diarrhoea	https://blogs.unicef.org/blog/5-facts-on-water-and-climate-change/
Households having access to sanitation facility within the premises (Adaptive Capacity)	Accessibility to adequate excreta disposal facilities is fundamental to decreasing the faecal risk and the frequency of associated diseases.	http://www.popclimate.net/indicators/view/25-chapter-ii-what-kind-of-census-data-can-be-used-and-why-mapping-vulnerabilities-is-relevant-to-climate-change-adaptation
Households having electricity as main source of lighting (Adaptive Capacity)	Access to affordable clean electricity is fundamental to daily life and any level of socioeconomic development. Because it is central to all aspects of our lives - lighting, heating, pumping and purification of water, agricultural productivity, refrigeration of food and medicines, sterilization of equipment and many others - there is an essential correlation between access to electricity and quality of life.	Peter Meisen and Irem Akin, "The Case for Meeting the Millennium Development Goals Through Access to Clean Electricity", Global Energy Network Institute

Indicators	Rationale	Reference
Households dependent on biomass as fuel for cooking (Sensitivity)	Biomass dependency is an indicator of the reliance on natural resources for cooking. In light of climate change, there might be an impact on these natural resources as well. If there is very high dependence on biomass, it would also mean a higher exploitation of natural resources. In terms of emissions excessive biomass burning would mean high amounts of GHG emissions. It would also increase the levels of indoor pollution and subsequent health issues. The biomass here includes firewood, crop residue and cow dung cake.	http://earthobservatory.nasa.gov/Features/BiomassBurning/
Households living in Permanent houses (Adaptive Capacity)	Those houses whose walls and roof are made of permanent materials are considered permanent houses. Permanent houses provide resilience to absorb climate change impacts. In case of disasters, such houses are most likely to withstand the shocks. Higher percentage of permanent houses would indicate better coping capacity.	http://cdkn.org/wp-content/uploads/2013/01/Sheltering-from-a-gathering-storm-Discussion-Paper-Series-Review-of-Housing-Vulnerability.pdf
Households with access to communication/ transport (Adaptive Capacity)	Increased overall communication networks reduce people’s vulnerability by early warning systems in disaster risk management strategies and access to information and thus their ability to cope with adversities.	http://link.springer.com/article/10.1007/s13753-016-0085-6
Population below poverty line (Sensitivity)	Adverse shocks occur more often among the poor because they encounter greater risks in terms of dangerous working conditions, poor nutrition, lack of preventive health care, and exposure to environmental contaminants. Thus, not only are adverse shocks more likely to occur among the poor, but the impact of these shocks on overall well-being is generally greater among them, since any given emergency is likely to absorb a larger share of their limited resources in comparison to the more ample resources of the better-off.	Barbara Parker and Valerie Kozel, "Understanding poverty and vulnerability in India's Uttar Pradesh and Bihar: a mixed method approach", World Bank
Share of Marginal Workers (Sensitivity)	Global warming is expected to heavily impact agriculture, the dominant source of livelihood for the world's poor. Agricultural dependency is measured by the percentage of the workforce employed in agriculture. A high level of agricultural dependency will increase the regions vulnerability to climate variability and fluctuations in agricultural terms of trade.	A.P. Pradeepkumar, F.J. Behr, F.T. Illiyas and E. Shaji, "Proceedings of the 2nd Disaster, Risk and Vulnerability Conference", University of Kerala, 2014

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Indicators	Rationale	Reference
Agricultural And Cultivators to Main Workers (Sensitivity)	This indicates a relatively higher importance of agriculture in the livelihoods of population compared to other sectors. These households derive the bulk of their income from wage employment, as agriculture productivity resulting from adverse climatic conditions decline their income declines.	Rama Rao, C.A.et al., " Atlas on vulnerability of Indian agriculture to climate change", Central Research Institute for Dryland Agriculture, Hyderabad, 2013, p. 116;
Total work participation rate (Adaptive Capacity)	Work participation rates are calculated as the proportion of total workers (main + marginal) to total population. Higher proportion of work participation rate leads to economic growth of a region, thus greater income to sustain livelihood and thus higher adaptive capacity to adapt to climatic stresses.	Climate Change: Impacts, vulnerabilities and adaptation in developing countries, United Nations Framework Convention on Climate Change
Gender gap in work participation rate (Sensitivity)	Higher gap between male and female work participation rate implies higher sensitivity of a region to climate change. Reducing gender gaps of work can yield broad development dividends: improve capacity of women to better support their families and more actively participate in communities and societies, improve child health and education, enhance poverty reduction, and catalyze productivity.	"Gender at Work: A Companion to the World Development Report on Jobs"
Health Centers (Adaptive Capacity)	Health facilities are an important indication of health adaptive capacity in case of disasters and other related health impacts. Sufficient number of hospitals and health centers are a pre-requisite for providing proper medical services in a region. The number of beds in allopathic and ayurvedic hospitals per lakhs of population denotes the level of preparedness available to deal with health related impacts. The projected changes in the climate might lead to an increase in the spread of some diseases. In such cases, better medical facilities would be required as a response measure to cope up with the health impacts.	Divya Mohan and Shirish Sinha, "Facing the Facts: Ganga Basin's Vulnerability to Climate Change", WWF Report, 2011
Beds available in health centers (Adaptive Capacity)		
Schools (Adaptive Capacity)	Education level of a population is seen as an important determinant of its quality of life. Higher education is critical in improving the health practices. The number of schools will show the extent to which a region is developed in terms of education. Lack of sufficient number of schools in the area would leave many students deprived of education. Quality of infrastructure is an important measure of relative adaptive capacity of a district, and districts with better infrastructure are presumed to be better able to adapt to climatic stresses.	Robin Leichenko, Karen O'Brien, Guro Aandahl, Heather Tompkins, Akram Javed, "Mapping Vulnerability To Multiple Stressors: A Technical

Indicators	Rationale	Reference
Student Teacher Ratio (Sensitivity)	Student-teacher ratios are a general way to measure teacher workloads and resource allocations in public schools, as well as the amount of individual attention a child is likely to receive from teachers, thus higher number of students per teacher is considered as sensitive.	http://edglossary.org/student-teacher-ratio/
Level of urbanization (Adaptive Capacity)	Urban population have good quality homes and drainage systems that prevent flooding, by moving to places with less risk or by changing jobs if climate- change threatens their livelihoods.	Ulijana Urosevic, "Prevention of natural disasters due to unregulated and indiscriminate urbanization", Environment Committee
Scheduled Tribes and Scheduled Caste population (Sensitivity)	SC/ST population is, in addition to being relatively poor, also less educated, high male unemployment, poorly integrated with main-stream economy and heavily-dependent on natural resources for their livelihoods tends to be highest amongst them. Thus districts with more tribal population are more sensitive to climate change impacts	Rama Rao, C.A.et al., " Atlas on vulnerability of Indian agriculture to climate change", Central Research Institute for Dryland Agriculture, Hyderabad, 2013, p. 116;
Road length (Adaptive Capacity)	This is indicator of market access as well as of better integration with the economy and the associated spread effects of development14.	
Crude Birth Rate (Sensitivity)	The annual number of births per 1,000 total populations. When the population is too large for the available resources, famine, energy shortages, war, and disease can result. Higher birth rates leads to increasing population hence treated as sensitivity.	https://www.boundless.com/sociology/textbooks/boundless-sociology-textbook/population-and-urbanization-17/population-growth-122/implications-of-different-rates-of-growth-686-10354/
Crude Death Rate (Sensitivity)	The annual number of deaths per 1,000 total populations. In regions with poor diets or a lack of food the death rate increases due to malnutrition.	Manish Tiwari, Dr .M K Mathur, Shiv Charan Mathur "Study on Inter Regional Economic Inequalities in Rajasthan", Social Policy Research Institute, 2010
Infant Mortality Rate (Sensitivity)	High IMR also depicts relative backward character of a region hence treated as sensitive.	Dr .M K Mathur: Shiv Charan Mathur, Manish Tiwari, "Study on Inter Regional Economic Inequalities in Rajasthan" , Social Policy Research Institute: 2010
Total Fertility Rate (Sensitivity)	The average number of children a woman would have assuming that current age-specific birth rates remain constant throughout her childbearing years (usually considered to be ages 15 to 49). TFR acts negatively in the process of development. A region showing a very high TFR generally experiences a high population growth rate and a low level of economic development.	

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Indicators	Rationale	Reference
Annual Parasite Index-Malaria (Sensitivity)	Changes in temperature and rainfall may change the geographic range of vector-borne diseases such as malaria exposing new populations to it. Changes in temperature and rainfall may change the geographic range of vector-borne diseases such as malaria exposing new populations to it. Malaria affects primarily the rural poor, who can neither afford nor access effective protection or healthcare. Children, pregnant women and the displaced are particularly susceptible to the disease.	Malaria WSSD Policy Brief Series: World Health Organization
Economic Indicators		
Per Capita Income(GDP) at current prices (Adaptive Capacity)	Wealth enables communities to absorb and recover from losses more quickly due to insurance, social safety nets, and entitlement programs. The higher the percentage of total population with asset ownership, and access to these income sources the lesser the vulnerability.	Temesgen Deressa, Rashid M. Hassan, Claudia Ringler, "Measuring Ethiopian Farmers' Vulnerability to Climate Change Across Regional States", International Food Policy Research Institute, October 2008
Households availing banking services (Adaptive Capacity)	Banking Facilities are an important indicator of wealth and provide information related to the adaptive capacity of the region in extent of extreme events or climate related shocks. This variable includes the number of banks (public, private and foreign banks), rural banks and non-commercial nationalized banks Cooperative Bank Branches and Cooperative agriculture and Village development branches.	Ajitava Raychaudhuri, Sushil Kr Haldar,"An Investigation into the Inter-District Disparity in West Bengal, 1991-2005"
Commercial banks (Adaptive Capacity)	Greater number of the banks per capita in a region implies easy access of credit to small and marginal farmers.	S.Mahendra Dev, "Small Farmers in India: Challenges and Opportunities", Indira Gandhi Institute of Development Research, Mumbai, June, 2012
Total Credit to Total Deposits in Banks (Adaptive Capacity)	Easy credit to small and marginal framers plays a pivotal role in the development and transformation of the rural and agrarian economy. Credit plays an important role in increasing agriculture productivity.	http://shodhganga.inflibnet.ac.in/bitstream/10603/38509/7/07_chapter%201.pdf

Indicators	Rationale	Reference
Micro, Small & Medium scale industrial units (Adaptive Capacity)	MSMEs are complementary to large industries as ancillary units and this sector contributes enormously to the socio-economic development of the region. It not only play crucial role in providing large employment opportunities at comparatively lower capital cost than large industries but also help in industrialization of rural & backward areas, thereby, reducing regional imbalances, assuring more equitable distribution of national income and wealth.	Kalraj Mishra, Giriraj Singh"MSME at a glance 2016", Ministry of Micro, Small and Medium Enterprises, Government of India
Health/Climate Extremes Indicators		
Temperature indices (Exposure)	An increase in maximum temperature and frequency of hot days implies adverse effects on crop yields. An increase in minimum temperature implies adverse effects on yields, especially for rabi crops like wheat	Rama Rao, C.A.et al., " Atlas on vulnerability of Indian agriculture to climate change", Central Research Institute for Dryland Agriculture, Hyderabad, 2013, p. 116;
Rainfall indices (Exposure)	An increase in extreme rainfall indicates the possibility of crop productivity getting affected. Increase in the intensity of such extreme rainfall event also means higher probability of floods with all the attendant problems.	
Annual rainfall and number of rainy days (Exposure)	The amount of rainfall received over an area is an important factor in assessing the amount of water available to meet the various demands of agriculture, industry, irrigation, hydroelectric power generation, and other human activities. A region with high rainfall and rainy days is better off as compared to that with low rainfall and rainy days. Increase in number of rainy days implies a better distribution of rainfall.	Barakade Ankush Jagannath, "Rainfall Trend in Drought Prone Region in Eastern Part of Satara District of Maharashtra, India", Department of Geography, 2014
Heat Index (Sensitivity)	Higher HI impacts human health and can cause heat strokes, heat cramps and heat exhaustion. Exposure to extreme heat can result in occupational illnesses and injuries. Heat can also increase the risk of injuries in workers. Thus air coolers and ACs need rise to cool the temperature.	http://www.cdc.gov/niosh/topics/heatstress/
Temperature Humidity Index (Sensitivity)	Higher THI leads to additional stress on the dairy animals. It directly affect feed intake thereby, reduces growth rate, milk yield, reproductive performance, and even death in extreme cases hence considered as sensitivity indicator.	http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4823286/

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Indicators	Rationale	Reference
Water Resources Indicators		
Surface Water availability (Adaptive Capacity)	The impacts of climate change on freshwater systems and their management are mainly due to the observed and projected increases in temperature, sea level and precipitation variability. Areas with more productive soil and more groundwater available for agriculture will be more adaptable to adverse climatic conditions and better able to compete and utilize the opportunities of trade. If districts have larger availability of these water sources implies it is less vulnerable to climate change impact.	Leichenko, R., K. O'Brien, G. Aandahl, H. Tompkins, and A. Javed. 2004, "Mapping Vulnerability To Multiple Stressors: A Technical Memorandum" CICERO: Oslo, Norway
Ground Water availability (Adaptive Capacity)		
Crop water Stress(ET/PET) (Sensitivity)	Increasing crop water stress in a region impacts the productivity of the crops.	Nitika Dangwal, "Detection of crop water stress and its impact on productivity of cropland ecosystem", Agriculture and Soils Department Indian Institute of Remote Sensing, Indian Space Research Organization
Frequency of Drought (Exposure)	The increase in natural disasters, primarily floods and droughts, further exacerbate issues over water availability and water quality directly affecting the life and livelihoods of humans. Incidence of more frequent droughts implies more risky agriculture and hence more sensitivity.	Courtenay Cabot Venton, "Climate change and water resources: ERM for WaterAid. Lead consultant", Environmental Resources Management, London
Flood discharge (Exposure)	Increase in floods would add to stress on water resources, food security, human health, and infrastructure, constraining development. Larger area susceptible to flood incidence implies high sensitivity.	Poverty and Climate Change Reducing the Vulnerability of the Poor through Adaptation: African Development Bank, Asian Development Bank, .et. al
Agriculture Indicators		
Food grains Yield (Adaptive Capacity)	Higher crop productivity and yield is directly proportional in reducing the vulnerability of districts by availability of more food being available and more income for farmers and thus their ability to cope with adversities hence it is taken under adaptive capacity.	Sehgal VK, Singh MR, Chaudhary A, Jain N and Pathak H (2013)," Vulnerability of Agriculture to Climate Change: District Level Assessment in the Indo-Gangetic Plains", Indian Agricultural Research Institute, New Delhi p 74.

Indicators	Rationale	Reference
Net Area Sown (Adaptive Capacity)	The total land area on which crops are grown in a region is called net sown area. Higher the area implies higher productivity of agriculture crops in a region hence it is taken under adaptive capacity.	Rama Rao, C.A.et al., " Atlas on vulnerability of Indian agriculture to climate change", Central Research Institute for Dryland Agriculture, Hyderabad, 2013, p. 116;
Net Irrigated Area (Adaptive Capacity)	Irrigation is the artificial application of water to the land or soil. It is used to assist in the growing of agricultural crops, trees, pastures and vegetation of disturbed soils in dry areas and during periods of inadequate rainfall. Hence higher the net area irrigated better is the adaptive capacity of a region.	Shaik Irfan Siddique, Pradeepa S,"Critical Analysis on the Effectiveness of Water Supply System through Singataluru Lift Irrigation Scheme and Recommendations for Modernisation" International Journal of Innovative Research in Science, Engineering and Technology, Vol. 5, Issue 2, February 2016
Fertilizer Consumption (Adaptive Capacity)	Higher use of fertilizers is an indicator of adoption of improved technologies, thus its use increases the productivity of a crop and hence indirectly increases agriculture income14.	Rama Rao, C.A.et al., " Atlas on vulnerability of Indian agriculture to climate change", Central Research Institute for Dryland Agriculture, Hyderabad, 2013, p. 116;
Cropping intensity (Adaptive Capacity)	Cropping intensity denotes the number of crops grown in a year on one piece of land. The agricultural land will be more vulnerable if it is not much used for growing crops. In other words, the vulnerability is inversely proportional to the cropping intensity of that land.	Sehgal VK, Singh MR, Chaudhary A, Jain N and Pathak H (2013) Vulnerability of Agriculture to Climate Change: District Level Assessment in the Indo-Gangetic Plains. Indian Agricultural Research Institute, New Delhi p 74.
Wasteland (Sensitivity)	Productivity levels would be low and highly risky if crops are grown on degraded and waste lands14.	Rama Rao, C.A.et al., " Atlas on vulnerability of Indian agriculture to climate change", Central Research Institute for Dryland Agriculture, Hyderabad, 2013, p. 116;

Appendix I

Indicators	Rationale	Reference
Land Holdings area below 1 Hectare (Sensitivity)	Smaller farm size limits marketable surplus and also the opportunity to diversify the cropping pattern and the low investment capacity of farmers make agriculture more sensitive to any climatic shock14.	
Livestock unit (Adaptive Capacity)	This is an indicator of diversification of agriculture and livelihoods. Although the income share earned from livestock directly is not high, livestock keepers obtain indirect benefits, such as the capacity of livestock to buffer against shocks such as drought or flood. Thus higher livestock population in a region implies greater ability to cope with climatic aberrations.	
Poultry Unit (Adaptive Capacity)	Higher numbers indicate greater purchasing power of people of the given region thus contributes to improved livelihoods and local economic development.	Frands Dolberg, "Poultry production for livelihood improvement and poverty alleviation", University of Århus, Denmark
Milk and egg production per capita (Adaptive Capacity)	Higher temperatures or heat stress lead to reduction in milk or egg production. Thus district with higher numbers are less impacted by heat stress so this is beneficial for the livestock thus treated as adaptive capacity.	Das R, Sailo L, Verma N, Bharti P, Saikia J, Imtiwati, Kumar R (2016),"Impact of heat stress on health and performance of dairy animals: A review", Veterinary World, 9(3): 260-268

Tables for District Vulnerability

Table A- 3: District wise Composite Vulnerability Index values, ranks and vulnerability category under current and projected scenario - RCP4.5 and RCP8.5

	Baseline			RCP4.5						RCP8.5					
				Mid-Century			End-Century			Mid-Century			End-Century		
Districts	Rank	Index value	Category	Rank	Index value	Category	Rank	Index value	Category	Rank	Index value	Category	Rank	Index value	Category
Lahul & Spiti	1	0.294	VL	3	0.303	VL	4	0.306	VL	2	0.295	VL	5	0.311	VL
Kinnaur	2	0.486	L	2	0.488	L	3	0.493	L	2	0.484	L	3	0.498	L
Solan	3	0.500	L	4	0.507	L	4	0.507	L	3	0.503	L	4	0.512	L
Kullu	4	0.514	L	6	0.525	L	6	0.53	L	5	0.522	L	7	0.547	M
Shimla	5	0.518	L	6	0.523	L	6	0.523	L	5	0.521	L	7	0.524	L
Hamirpur	6	0.545	M	8	0.557	M	8	0.555	M	9	0.558	M	9	0.565	M
Mandi	6	0.545	M	7	0.551	M	7	0.547	M	7	0.549	M	7	0.553	M
Kangra	8	0.556	M	10	0.573	M	10	0.573	M	11	0.574	M	11	0.582	H
Una	9	0.557	M	11	0.572	M	10	0.570	M	10	0.571	M	10	0.571	M
Bilaspur	10	0.589	H	11	0 .601	H	11	0.600	H	10	0.595	H	11	0.605	H
Sirmaur	11	0.595	H	12	0.604	H	12	0.612	H	12	0.605	H	12	0.608	H
Chamba	12	0.672	VH	12	0.688	EH	12	0.695	EH	12	0.685	VH	12	0.701	EH

Note: For vertical comparison amongst the districts within a scenario, index values give the true picture if the ranks are same. Higher index value indicates higher vulnerability and vice-versa.

For horizontal comparison within a district and across scenarios, red coloured rank indicates that the vulnerability has increased while green coloured rank indicates that the vulnerability has decreased as compared to the baseline for a district. It is to be noted that ranks may not change for a district across scenarios but the colour represents the change in degree of vulnerability.

VL: Very Low, L: Low, M: Moderate, H: High, VH: Very High, EH: Extremely High

Rank 1: Least Vulnerable; Rank 12: Most Vulnerable

High values of index implies Higher Vulnerability as seen in the table above

Appendix I

Table A- 4: District wise Social Vulnerability Index values, ranks and category for current vulnerability

Districts	Rank	Index value	Category
Kinnaur	1	0.380	VL
Lahul & Spiti	2	0.400	VL
Solan	3	0.414	VL
Shimla	4	0.420	VL
Hamirpur	5	0.455	L
Mandi	6	0.456	L
Kullu	7	0.483	M
Kangra	8	0.497	M
Una	9	0.517	M
Bilaspur	10	0.524	M
Sirmaur	11	0.569	H
Chamba	12	0.718	VH

Table A- 5: District wise Economic Vulnerability Index values, ranks and category for current vulnerability

Districts	Rank	Index value	Category
Lahul & Spiti	1	0.179	VL
Solan	2	0.435	L
Kinnaur	3	0.550	L
Kangra	4	0.699	M
Kullu	5	0.700	M
Sirmaur	6	0.702	M
Una	7	0.726	M
Hamirpur	8	0.730	M
Shimla	9	0.782	H
Mandi	10	0.792	H
Bilaspur	11	0.807	VH
Chamba	12	0.852	VH

Table A- 6: District wise Agriculture Vulnerability Index values, ranks and category for current vulnerability

Districts	Rank	Index value	Category
Lahul & Spiti	1	0.214	VL
Una	2	0.569	L
Bilaspur	3	0.576	L
Solan	4	0.592	M
Sirmaur	5	0.612	M
Kullu	6	0.641	H
Mandi	7	0.650	H
Shimla	8	0.667	H
Kinnaur	9	0.691	VH
Chamba	10	0.698	VH
Kangra	11	0.706	VH
Hamirpur	12	0.729	VH

Table A- 7: District wise Climate Extremes Vulnerability Index values, ranks and vulnerability category under current and projected scenario - RCP4.5 and RCP8.5

	Baseline			RCP4.5						RCP8.5					
				Mid-Century			End-Century			Mid-Century			End-Century		
Districts	**Rank**	**Index value**	**Category**	**Rank**	**Index value**	**Category**	**Rank**	**Index value**	**Category**	**Rank**	**Index value**	**Category**	**Rank**	**Index value**	**Category**
Lahul & Spiti	1	0.147	VL	6	0.201	VL	3	0.181	VL	2	0.164	VL	5	0.190	VL
Kullu	2	0.183	VL	7	0.223	VL	5	0.212	VL	6	0.214	VL	8	0.256	L
Kinnaur	3	0.206	VL	5	0.220	VL	3	0.207	VL	4	0.212	VL	12	0.226	VL
Shimla	4	0.266	L	4	0.297	L	5	0.317	L	5	0.298	L	12	0.364	M
Chamba	5	0.313	L	6	0.376	M	12	0.382	M	12	0.376	M	12	0.376	M
Mandi	6	0.320	L	8	0.380	M	8	0.378	M	9	0.406	M	12	0.477	H
Kangra	7	0.369	M	10	0.480	H	10	0.503	H	10	0.515	H	11	0.557	H
Solan	8	0.537	H	9	0.604	H	9	0.626	H	10	0.627	H	12	0.738	VH
Bilaspur	9	0.579	H	11	0.644	H	11	0.670	H	11	0.672	H	12	0.794	VH
Sirmaur	10	0.598	H	12	0.661	H	12	0.738	VH	12	0.700	VH	12	0.791	VH
Hamirpur	11	0.615	H	12	0.721	VH	12	0.731	VH	12	0.763	VH	12	0.857	VH
Una	12	0.770	VH	12	0.862	VH	12	0.875	VH	12	0.912	EH	12	0.984	EH

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Table A- 8: District wise Water Resources Vulnerability Index values, ranks and vulnerability category under current and projected scenario - RCP4.5 and RCP8.5

	Baseline			RCP4.5						RCP8.5					
				Mid-Century			End-Century			Mid-Century			End-Century		
Districts	Rank	Index value	Category	Rank	Index value	Category	Rank	Index value	Category	Rank	Index value	Category	Rank	Index value	Category
Lahul & Spiti	1	0.209	VL	2	0.240	VL	2	0.270	VL	1	0.202	VL	3	0.302	VL
Hamirpur	2	0.446	L	3	0.463	L	2	0.444	L	2	0.446	L	2	0.438	L
Una	3	0.454	L	4	0.506	M	4	0.478	L	4	0.468	L	2	0.424	L
Kullu	4	0.539	M	5	0.593	H	8	0.631	H	5	0.578	H	12	0.721	VH
Kangra	5	0.575	H	7	0.622	H	7	0.609	H	6	0.604	H	9	0.633	H
Sirmaur	6	0.598	H	8	0.624	H	8	0.629	H	6	0.603	H	5	0.572	H
Chamba	7	0.604	H	12	0.675	VH	12	0.720	VH	12	0.660	H	12	0.768	EH
Shimla	8	0.641	H	9	0.655	H	8	0.641	H	8	0.639	H	6	0.623	H
Solan	9	0.676	VH	9	0.685	VH	8	0.669	VH	7	0.642	H	7	0.636	H
Kinnaur	10	0.692	VH	11	0.701	VH	12	0.744	EH	9	0.681	VH	12	0.764	EH
Mandi	11	0.700	VH	11	0.703	VH	10	0.676	VH	9	0.674	VH	8	0.660	H
Bilaspur	12	0.713	VH	12	0.753	EH	12	0.736	VH	11	0.698	VH	11	0.689	VH

Note: For vertical comparison amongst the districts within a scenario, index values give the true picture if the ranks are same. Higher index value indicates higher vulnerability and vice-versa.

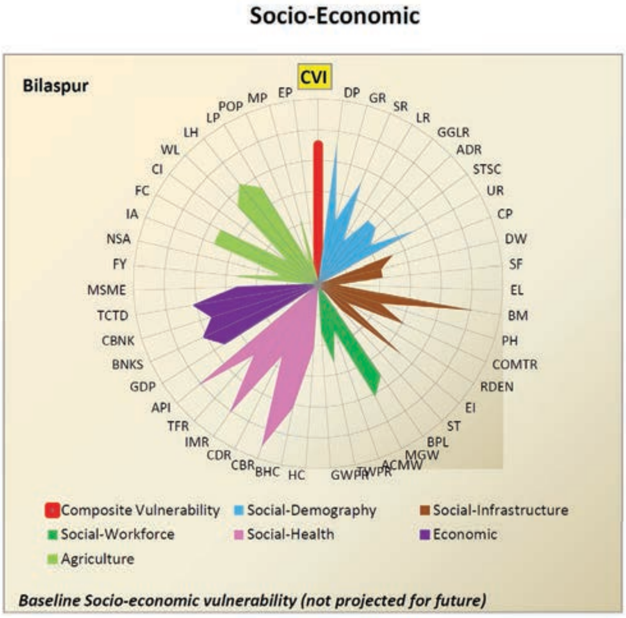
For horizontal comparison within a district and across scenarios, red coloured rank indicates that the vulnerability has increased while green coloured rank indicates that the vulnerability has decreased as compared to the baseline for a district. It is to be noted that ranks may not change for a district across scenarios but the colour represents the change in degree of vulnerability.

VL: Very Low, L: Low, M: Moderate, H: High, VH: Very High, EH: Extremely High

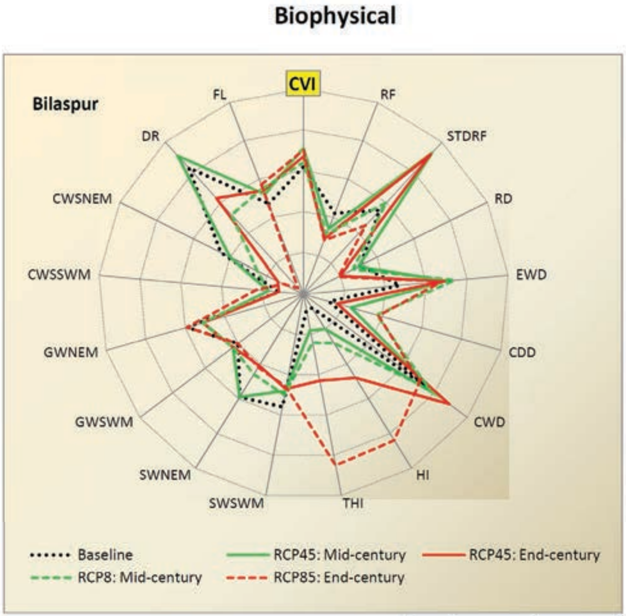
Rank 1: Least Vulnerable; Rank 12: Most Vulnerable

High values of index implies Higher Vulnerability as seen in the table above

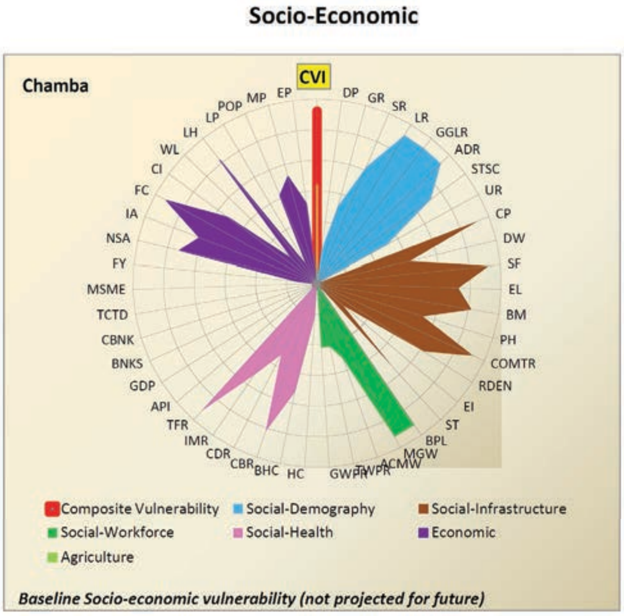
Table A- 9: Illustration of importance of individual vulnerability indicators contributing to Composite Vulnerability Index for districts of Himachal Pradesh


Socio-Economic

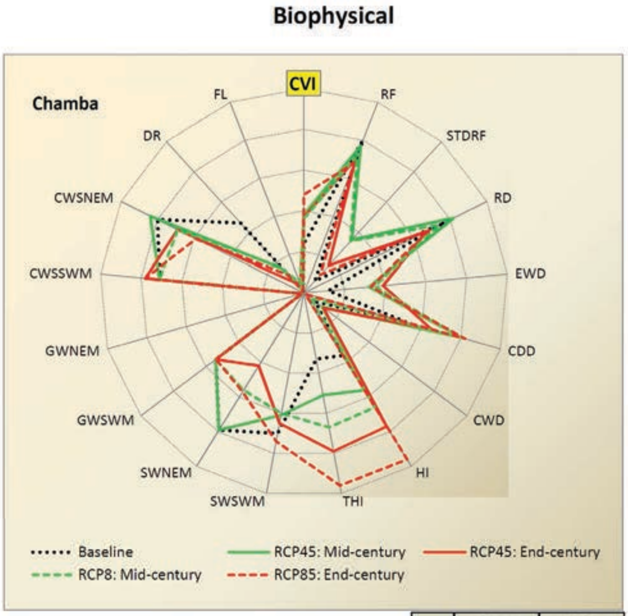
Baseline Socio-economic vulnerability (not projected for future)


Biophysical

	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
H	H	H	H	H


Socio-Economic

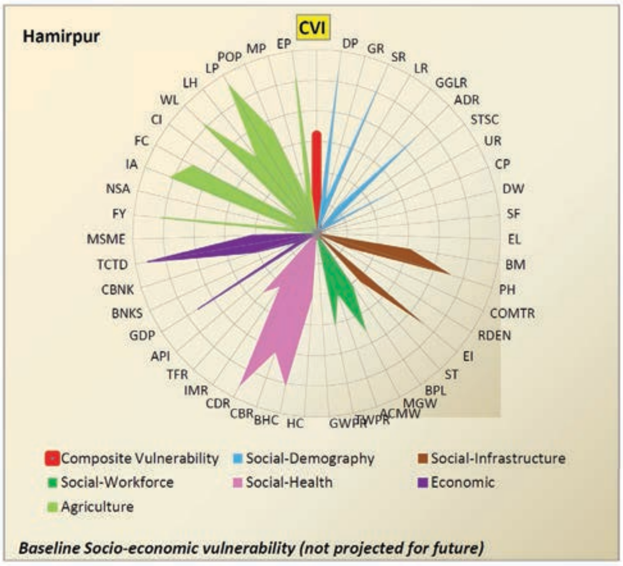
Baseline Socio-economic vulnerability (not projected for future)


Biophysical

	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
VH	EH	EH	VH	EH

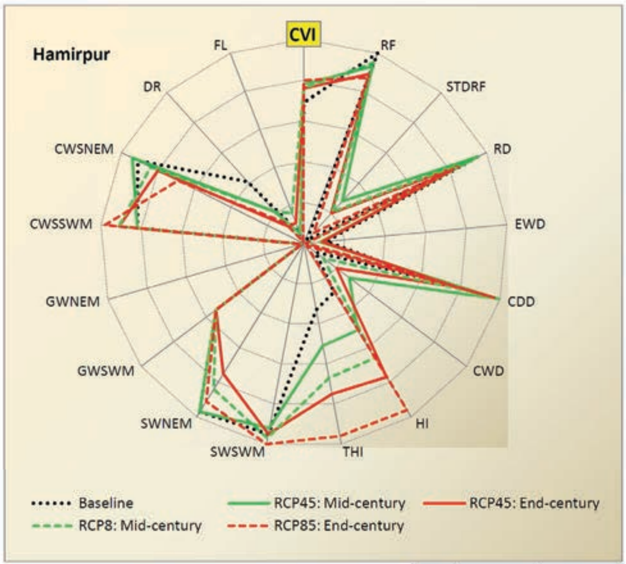
Appendix I

Socio-Economic



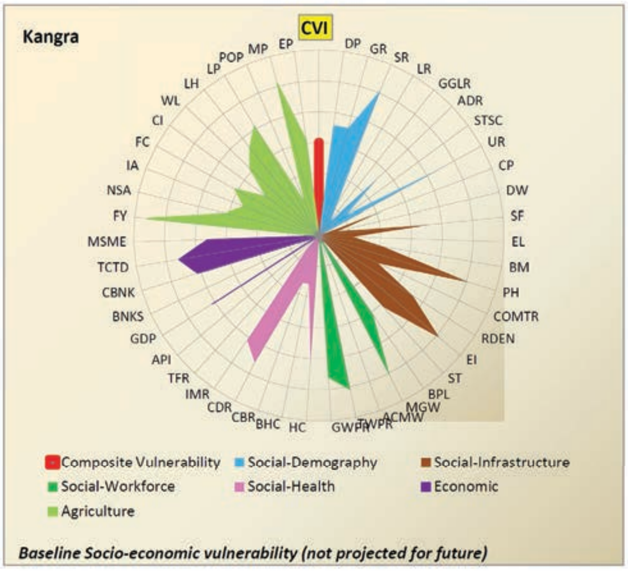
Baseline Socio-economic vulnerability (not projected for future)

Biophysical



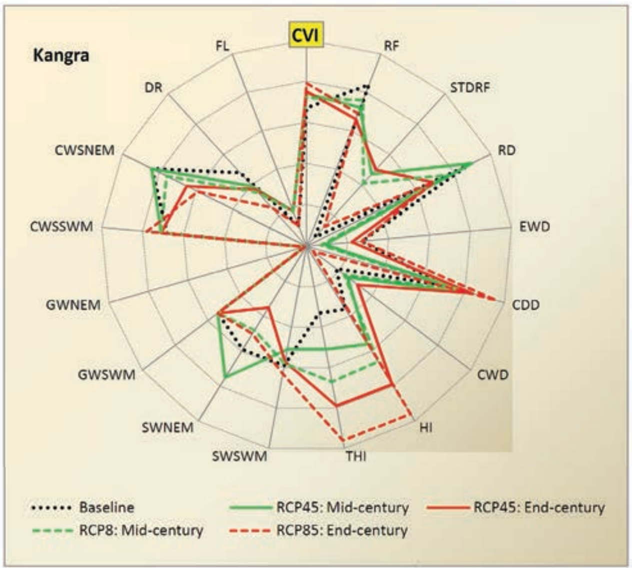
	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
M	M	M	M	M

Socio-Economic

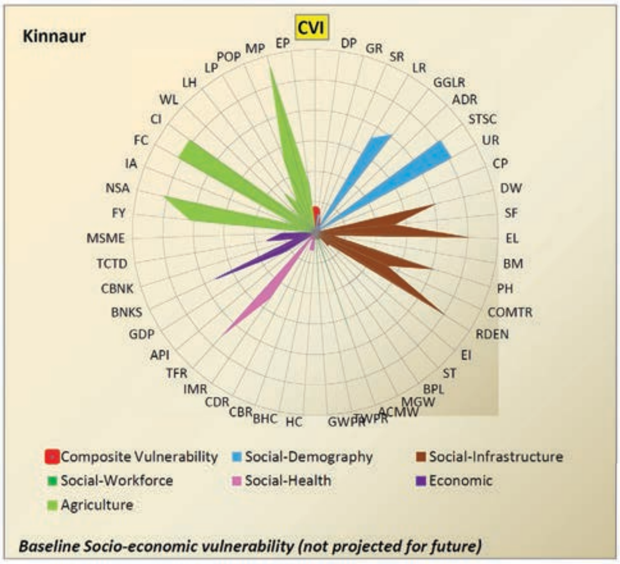


Baseline Socio-economic vulnerability (not projected for future)

Biophysical

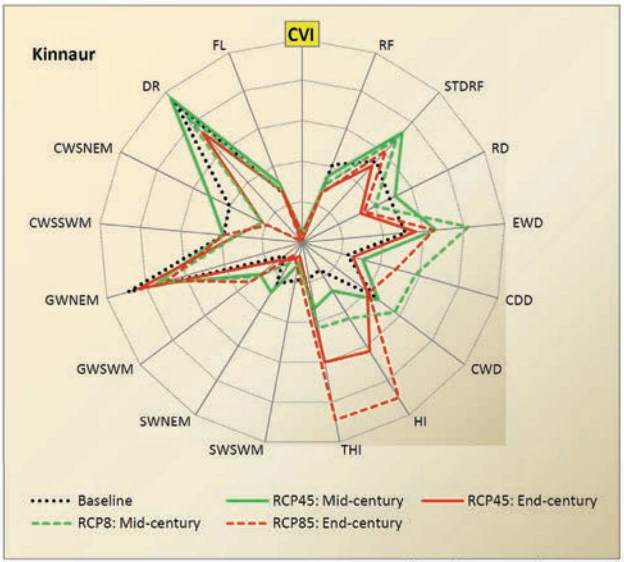


	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
M	M	M	M	H



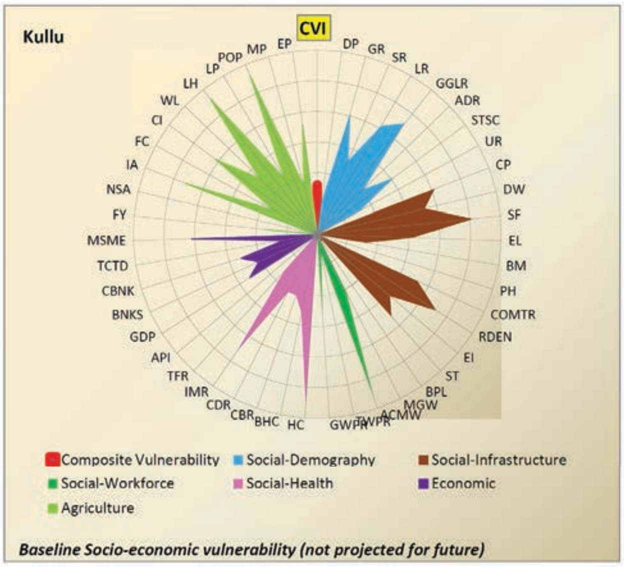
Socio-Economic

Baseline Socio-economic vulnerability (not projected for future)



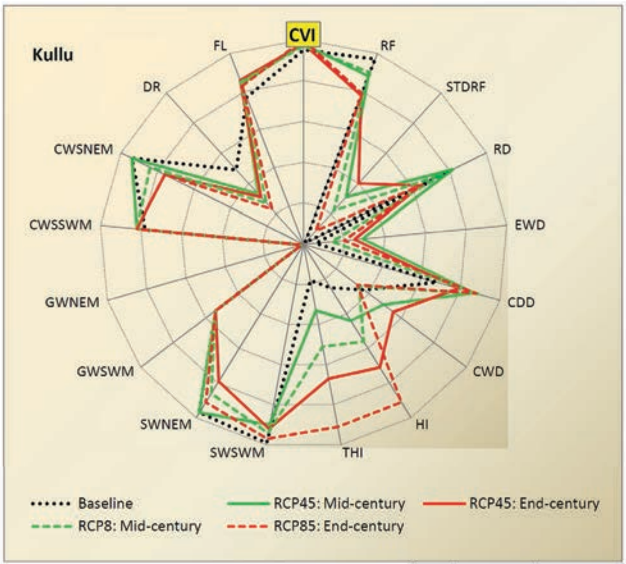
Biophysical

	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
L	L	L	L	L



Socio-Economic

Baseline Socio-economic vulnerability (not projected for future)

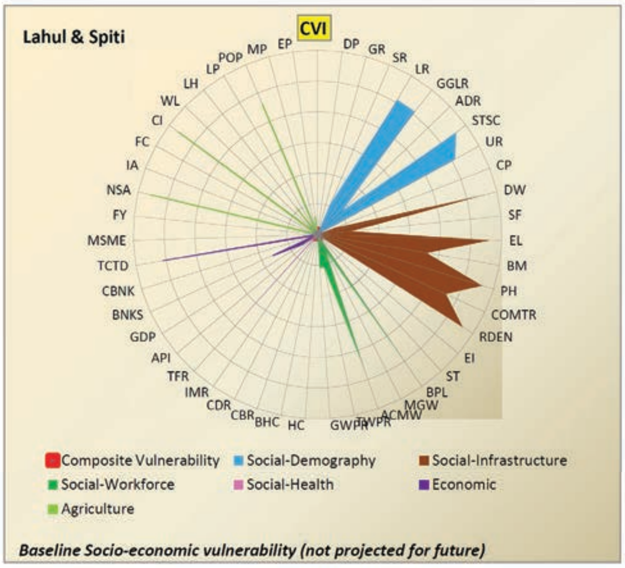


Biophysical

	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
L	L	L	L	M

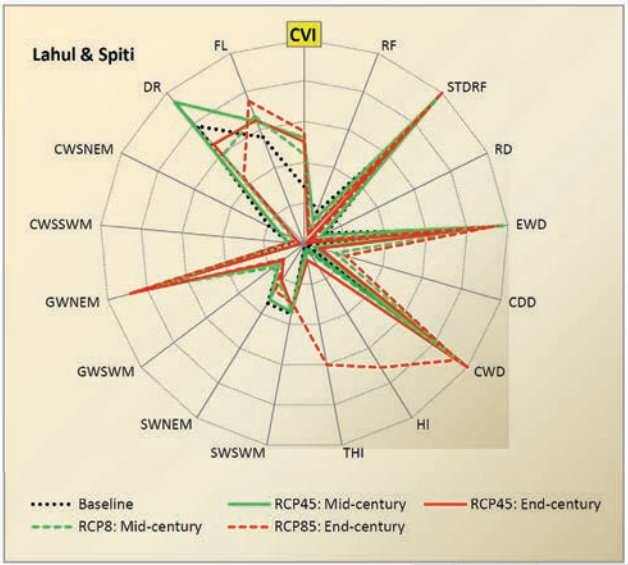
Appendix I

Socio-Economic



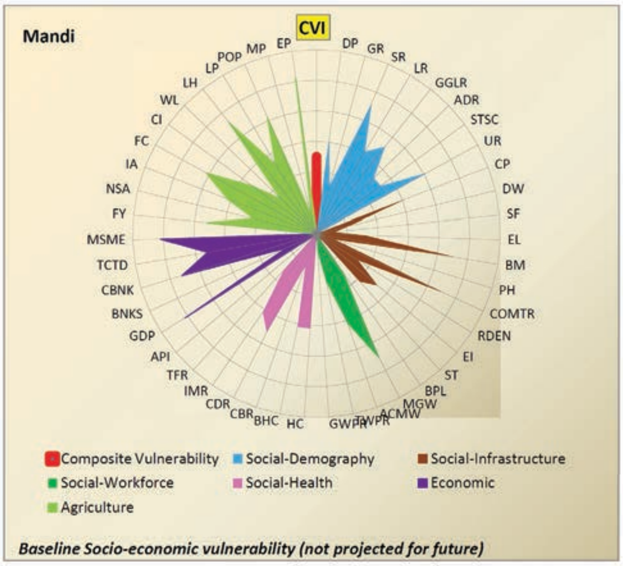
Baseline Socio-economic vulnerability (not projected for future)

Biophysical



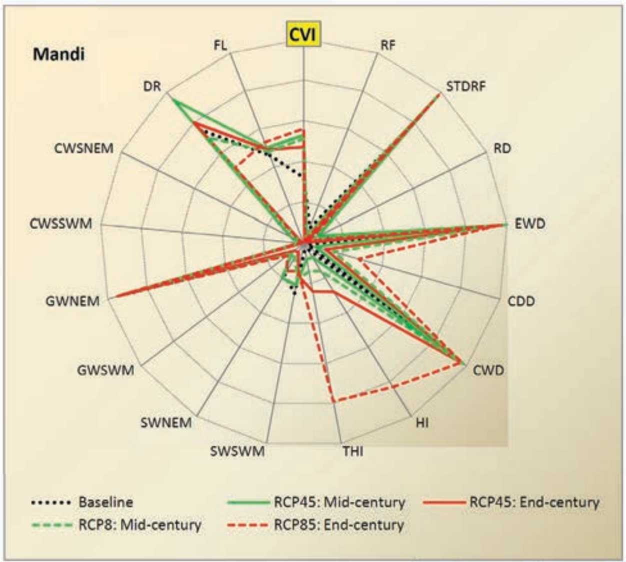
	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
VL	VL	VL	VL	VL

Socio-Economic

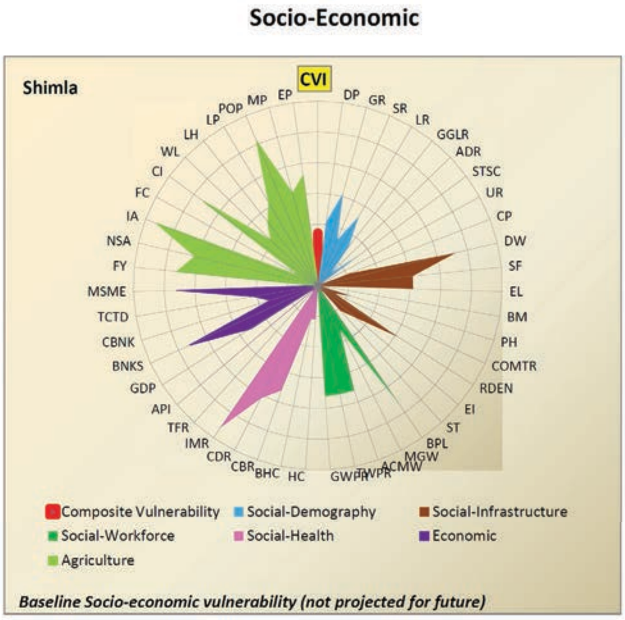


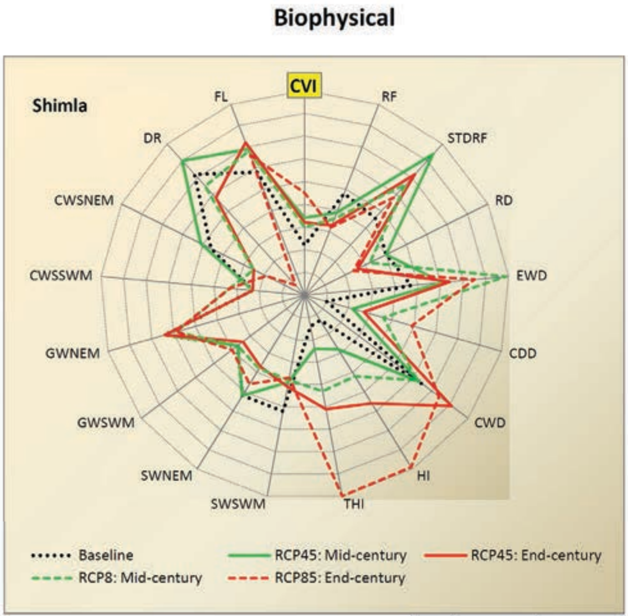
Baseline Socio-economic vulnerability (not projected for future)

Biophysical

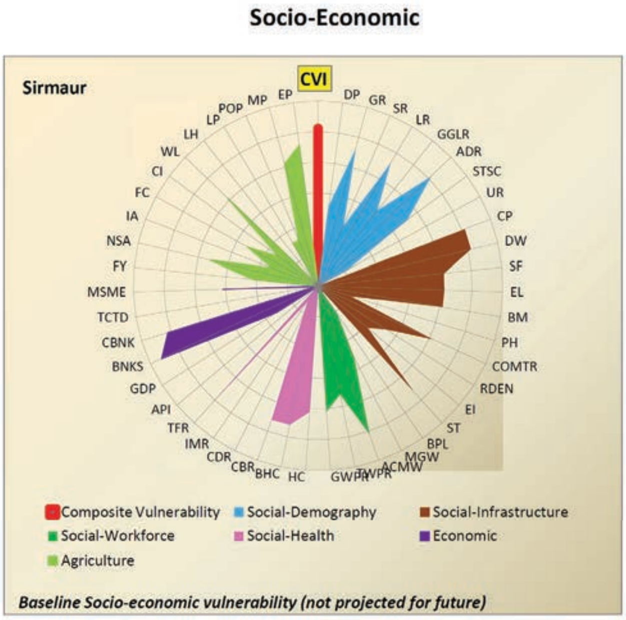


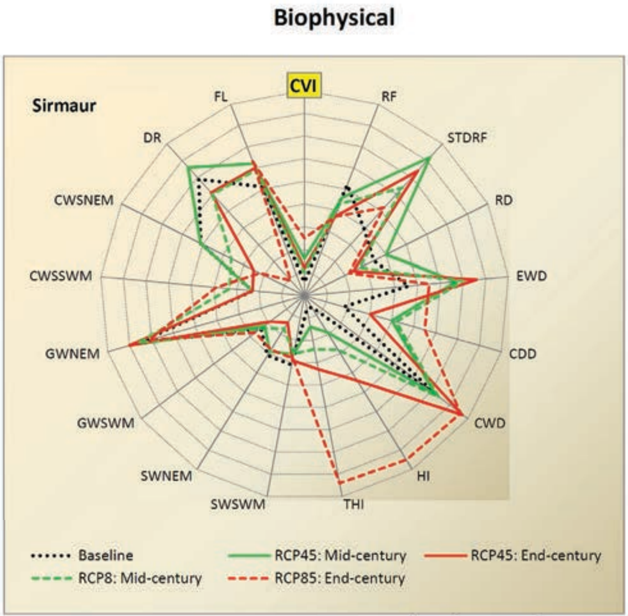
	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
M	M	M	M	M


Socio-Economic


Biophysical

	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
L	L	L	L	L

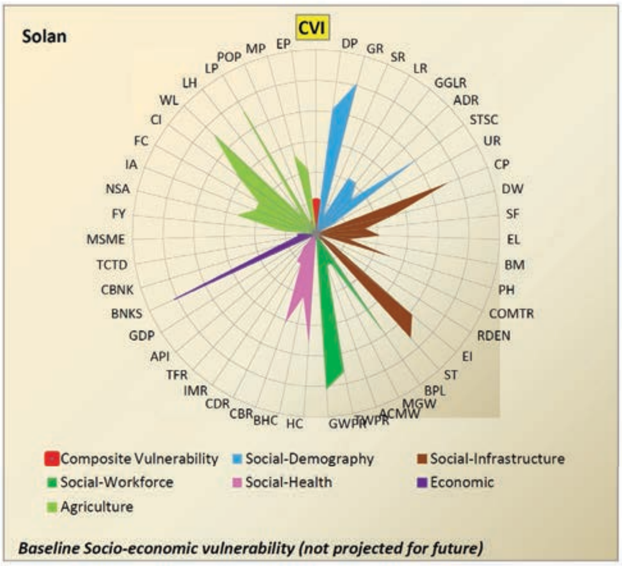

Socio-Economic


Biophysical

	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
H	H	H	H	H

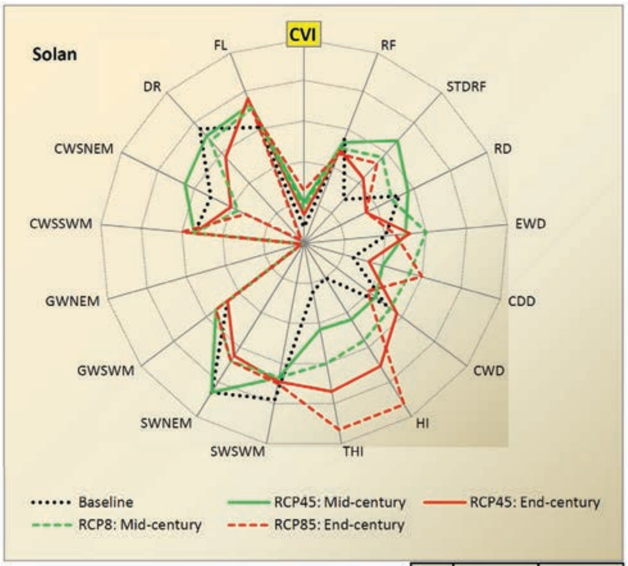
Appendix I

Socio-Economic



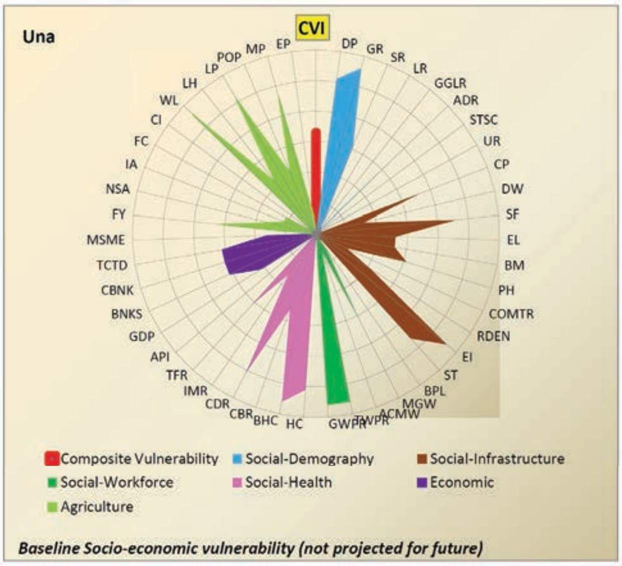
Baseline Socio-economic vulnerability (not projected for future)

Biophysical



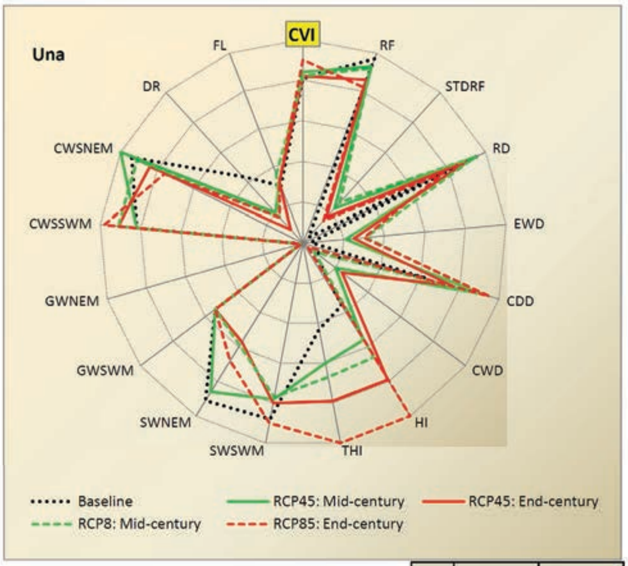
	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
L	L	L	L	L

Socio-Economic

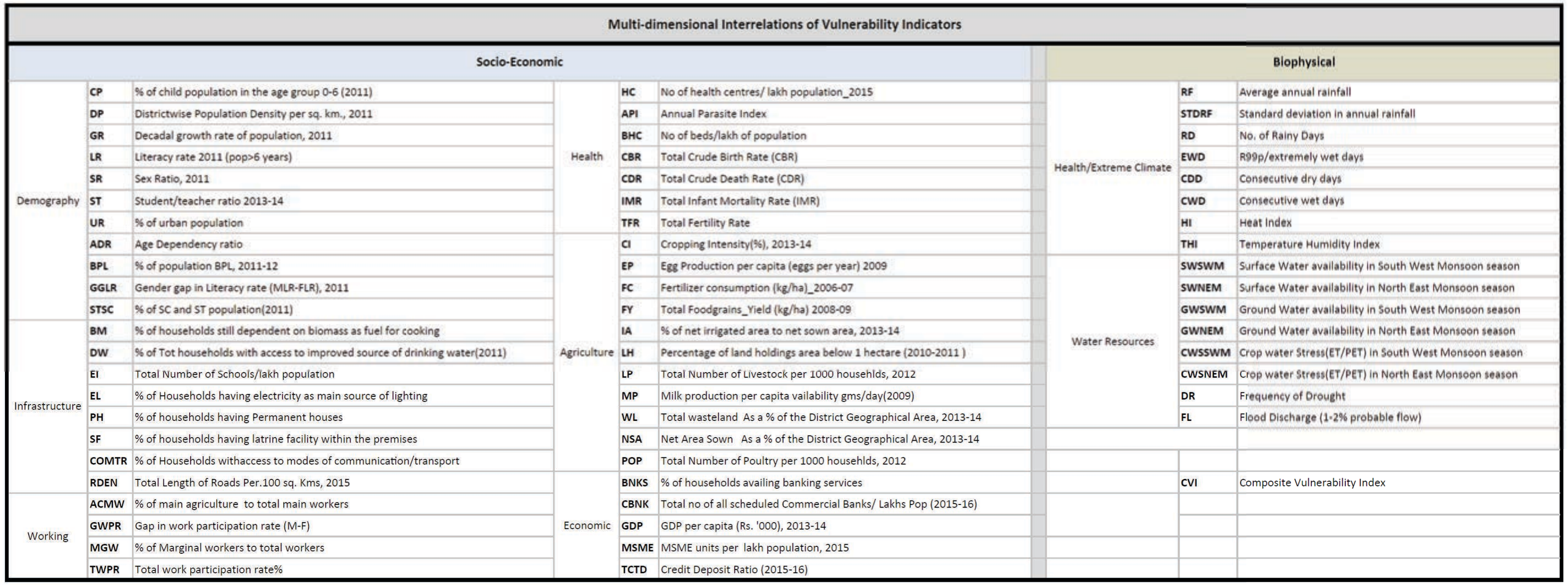


Baseline Socio-economic vulnerability (not projected for future)

Biophysical



	RCP4.5		RCP8.5	
BL	MC	EC	MC	EC
M	M	M	M	M



Multi-dimensional Interrelations of Vulnerability Indicators								
Socio-Economic						Biophysical		
Demography	CP	% of child population in the age group 0-6 (2011)	Health	HC	No of health centres/ lakh population_2015	Health/Extreme Climate	RF	Average annual rainfall
	DP	Districtwise Population Density per sq. km., 2011		API	Annual Parasite Index		STDRF	Standard deviation in annual rainfall
	GR	Decadal growth rate of population, 2011		BHC	No of beds/lakh of population		RD	No. of Rainy Days
	LR	Literacy rate 2011 (pop>6 years)		CBR	Total Crude Birth Rate (CBR)		EWD	R99p/extremely wet days
	SR	Sex Ratio, 2011		CDR	Total Crude Death Rate (CDR)		CDD	Consecutive dry days
	ST	Student/teacher ratio 2013-14		IMR	Total Infant Mortality Rate (IMR)		CWD	Consecutive wet days
	UR	% of urban population		TFR	Total Fertility Rate		HI	Heat Index
	ADR	Age Dependency ratio	Agriculture	CI	Cropping Intensity(%), 2013-14		THI	Temperature Humidity Index
	BPL	% of population BPL, 2011-12		EP	Egg Production per capita (eggs per year) 2009	Water Resources	SWSWM	Surface Water availability in South West Monsoon season
	GGLR	Gender gap in Literacy rate (MLR-FLR), 2011		FC	Fertilizer consumption (kg/ha)_2006-07		SWNEM	Surface Water availability in North East Monsoon season
	STSC	% of SC and ST population(2011)		FY	Total Foodgrains_Yield (kg/ha) 2008-09		GWSWM	Ground Water availability in South West Monsoon season
Infrastructure	BM	% of households still dependent on biomass as fuel for cooking		IA	% of net irrigated area to net sown area, 2013-14		GWNEM	Ground Water availability in North East Monsoon season
	DW	% of Tot households with access to improved source of drinking water(2011)		LH	Percentage of land holdings area below 1 hectare (2010-2011)		CWSSWM	Crop water Stress(ET/PET) in South West Monsoon season
	EI	Total Number of Schools/lakh population		LP	Total Number of Livestock per 1000 househlds, 2012		CWSNEM	Crop water Stress(ET/PET) in North East Monsoon season
	EL	% of Households having electricity as main source of lighting		MP	Milk production per capita vailability gms/day(2009)		DR	Frequency of Drought
	PH	% of households having Permanent houses		WL	Total wasteland As a % of the District Geographical Area, 2013-14		FL	Flood Discharge (1-2% probable flow)
	SF	% of households having latrine facility within the premises		NSA	Net Area Sown As a % of the District Geographical Area, 2013-14			
	COMTR	% of Households withaccess to modes of communication/transport		POP	Total Number of Poultry per 1000 househlds, 2012			
	RDEN	Total Length of Roads Per.100 sq. Kms, 2015	Economic	BNKS	% of households availing banking services		CVI	Composite Vulnerability Index
Working	ACMW	% of main agriculture to total main workers		CBNK	Total no of all scheduled Commercial Banks/ Lakhs Pop (2015-16)			
	GWPR	Gap in work participation rate (M-F)		GDP	GDP per capita (Rs. '000), 2013-14			
	MGW	% of Marginal workers to total workers		MSME	MSME units per lakh population, 2015			
	TWPR	Total work participation rate%		TCTD	Credit Deposit Ratio (2015-16)			

Appendix II

Software Used

- Statistical software STATA
- GIS software ArcGIS
- Microsoft Excel

Normalization of Indicator Data

Normalization is done to convert raw data into a normalized form.

- To make the raw data unit free
- To avoid one variable having an undue influence on the analysis(principal components),
- To get the relative position of each district in respect of the indicators.
- Normalized values always lie between 0 and 1.

Whenever an indicator has positive relationship with vulnerability normalized value for each of the indicator for each district is computed as:

$$NV = \frac{[\mathrm{X} - \mathrm{minimum}\ (\mathrm{X})]}{[\mathrm{maximum}\ (\mathrm{X}) - \mathrm{minimum}\ (\mathrm{X})]}$$

Whenever an indicator has negative relationship with vulnerability then the normalized value is calculated as:

$$NV = \frac{[\ \mathrm{maximum}\ (\mathrm{X}) - \mathrm{X}\ ]}{[\mathrm{maximum}\ (\mathrm{X}) - \mathrm{minimum}\ (\mathrm{X})]}$$

This is possible when, for example, higher literacy leads to lower vulnerability. Where,

NV = Normalized value of X, X is an observed value for the districts for a given variable, Max X is the highest value of the variable across the district, Min X is the lowest value of the variable across the district.

Calculation of Weights

In the development of aggregated index problems arise when the weights of each indicator have to be selected. Components with Eigen value greater than 1 have been used to calculate the weights (Kaiser, 1990). In essence this is like saying that, unless a factor extracts at least as much as the equivalent of one original variable, it is dropped. Each component is a linear combination of indicators multiplied by their loadings on that component. Large values of loadings of the indicators on the PCs (Principal Components) imply that the variable has a large bearing on the creation of that component. The indicators are assigned different weights determined by Principal Component Analysis (PCA) to avoid the uncertainty of equal weighting given the diversity of indicators used.

The PCA (Principal Component Analysis) is used to compute the factor loadings and weights of the indicators. In order to derive the weights of the variable the matrix of loadings are rotated by Varimax Kaiser Normalization criteria.

Absolute values of the eigenvectors or the loadings are considered in order to derive the weights. To derive the weights following formula is used:

$$w\_i = \Sigma|L_{ij}|.Ej \text{ where } j=1, 2, 3,....n$$

wi is the weights of the variables, Lij is the component loading of the ith variable on the jth component; Ej is the Eigen value of the jth component. Taking the Eigen values and component loadings the weights of the indicators are derived according to the above equation .

Calculation of Indices

$$Vulnerability\ Index = \left[\sum_{i=1}^{n}(w_i * NV_i)\right]$$

Where, i = 1 ……..n is the number of indicators, w= weights, NV = Normalized value

Higher index value represents high vulnerability while lower index value represents low vulnerability.

Principle Component Analysis (PCA)

PCA is a multivariate statistical technique used to reduce the number of indicators in a data set into a smaller number of ‘dimensions’. In mathematical terms, from an initial set of n correlated indicators, PCA creates uncorrelated indices or components, where each component is a linear weighted combination of the initial indicators. Indeed, if the original indicators are uncorrelated then the analysis does absolutely nothing. The best results are obtained when the original indicators are very highly correlated, positively or negatively.

Each component is a linear combination of indicators (variables) multiplied by their loadings on that component. Large values of loadings of the variables (i.e. indicators) on the PCs imply that the indicator has a large bearing on the creation of that component. Thus, the most important indicators in each component, that best explain variance; will also be more useful in explaining variability between observations (i.e. districts).

Appendix II

The variance (λi) for each principal component is given by the eigenvalue of the corresponding eigenvector. The components are ordered so that the first component (PC1) explains the largest possible amount of variation in the original data. As the sum of the eigenvalues equals the number of indicators in the initial data set, the proportion of the total variation in the original data set accounted by each principal component is given by (λi)/n. The second component (PC2) is completely uncorrelated with the first component, and explains additional but less variation than the first component, subject to the same constraint. Subsequent components are uncorrelated with previous components; therefore, each component captures an additional dimension in the data, while explaining smaller and smaller proportions of the variation of the original indicators. The higher the degree of correlation among the original indicators in the data, the fewer components required to capture common information.

Cluster Analysis

Cluster analysis or clustering is the task of assigning a set of objects into groups (called clusters) Cluster analysis is a class of statistical techniques that can be applied to data that exhibit “natural” groupings. Cluster analysis sorts through the raw data and groups them into clusters. A cluster is a group of relatively homogeneous cases or observations. Objects in the same cluster are more similar (in some sense or another) to each other than to those in other clusters.

Statistics associated with cluster analysis include:

- Agglomeration schedule: An agglomeration schedule gives information on the objects or cases being combined at each stage of a hierarchical clustering process.
- Cluster centroid: The cluster centroid is the mean values of the variables for all the cases or objects in a particular cluster.
- Cluster centers: The cluster centers are the initial starting points in non-hierarchical clustering. Clusters are built around these centers, or seeds.
- Cluster membership: Cluster membership indicates the cluster to which each object or case belongs.
- Distances between cluster centers: indicate how separated the individual pairs of clusters are. Clusters that are widely separated are distinct, and therefore desirable.

Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
A2/18, Safdarjung Enclave
New Delhi 110 029 India
T: +91 11 4949 5353
E: info@giz.de
www.giz.de/india