

Climate Change Impact and Vulnerability Assessment for Uttarakhand using CORDEX Climate Data

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Outline

- Climate Variability and Climate Change – Uttarakhand
- Impact of Climate Change
 - Water Resources
 - Forest
 - Agriculture
 - Health
 - Infrastructure
- Vulnerability Assessment
 - District level/Block level



Methodology

- Analysis of historical (IMD data from 1951-2013)
- Projected climate data (using ensemble CORDEX Regional Climate Model data)
 - For baseline (1981-2010); mid-century, MC (2021-2050) and end-century, EC (2071-2100)
 - IPCC AR5 Climate scenarios RCP4.5 and RCP8.5
- Perform impact assessment for selected sectors
 - Water resource, forest, agriculture, health and infrastructure
- Assess the vulnerability using indicators derived from the climate change impact assessment



Climate Change Scenarios

- South Asia CORDEX Models for simulated climate data
 - Bias corrected 3 RCMs (11 model runs)
 - CSIRO-CCAM-1391M – (4)
 - MPI-CSC-REMO2009 – (1)
 - SMHI-RCA4 – (6)
 - Bias correction using WATCH data
- Model Boundary Conditions
 - 9 boundary conditions
- Scenario: IPCC SRES AR5 RCP4.5 and RCP8.5
- 3 time periods
 - baseline (1981-2010), mid-century, (2021-2050) and end-century, (2071-2100)
 - Grid resolution of 0.5° x 0.5°.

Sr. no	Asia-CORDEX RCMs bias-corrected	RCM	GCM_BC
1	ACCESS1-0_CSIRO-CCAM-1391M	CCAM	ACCESS1-0
2	CCSM4_CSIRO-CCAM-1391M	CCAM	CCSM4
3	CNRM-CM5_CSIRO-CCAM-1391M	CCAM	CNRM
4	MPI-ESM-LR_CSIRO-CCAM-1391M	CCAM	MPI-ESM-LR
5	MPI-M-MPI-ESM-LR_MPI-CSC-REMO2009	REMO2009	MPI-M
6	CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	SMHI-RCA4	CNRM
7	NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	SMHI-RCA4	GFDL
8	IHEC-EC-EARTH_SMHI-RCA4	SMHI-RCA4	IHEC-EC
9	IPSL-CM5A-MR_SMHI-RCA4	SMHI-RCA4	IPSL-CM5A
10	MIROC-MIROC5_SMHI-RCA4	SMHI-RCA4	MIROC
11	MPI-M-MPI-ESM-LR_SMHI-RCA4	SMHI-RCA4	MPI-M



Climate Summary for Uttarakhand

- Historical
 - No appreciable change in annual max & min temperature
 - No definite trend in annual rainfall
 - annual number of rainy days (<), 1 day maximum rainfall (>)
- Average annual maximum temperature (>)
 - RCP4.5: 1.5°C (Mid), 2.5°C (End)
 - RCP8.5: 1.8°C (Mid), 5.0°C (End)
- Average annual minimum temperature (>)
 - RCP4.5: 1.3°C (Mid), 2.6°C (End)
 - RCP8.5: 1.7°C (Mid), 4.7°C (End)
- Increase in maximum temperature higher than minimum temperature
- Average annual rainfall
 - RCP4.5: 0.8% (< Mid), 7.1% (> End)
 - RCP8.5: 3.6% (> Mid), 5.4% (> End)

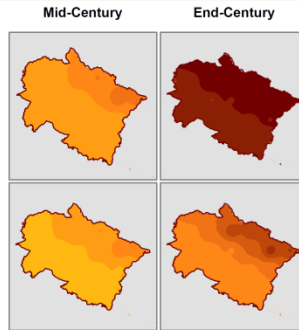
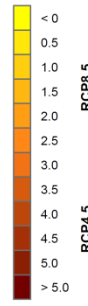
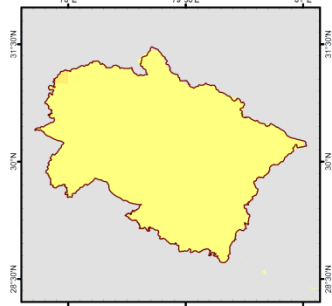


Summary

Annual Maximum Temperature Change

Trend over 1951 - 2013
(°C over period)

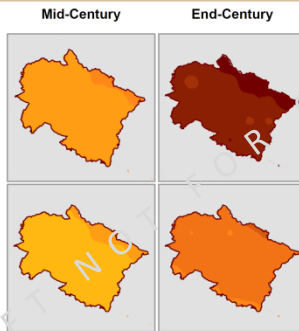
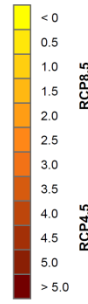
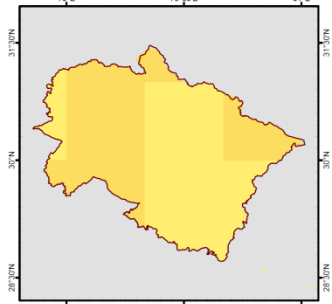
Difference from 1981-2010 mean
(°C)



Annual Minimum Temperature Change

Trend over 1951 - 2013
(°C over period)

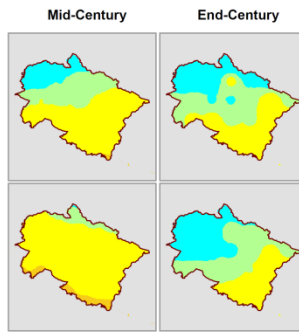
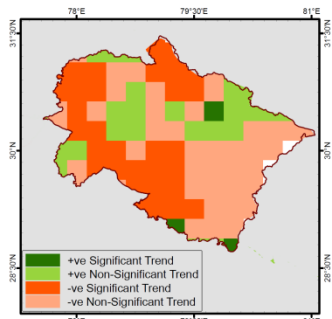
Difference from 1981-2010 mean
(°C)



Annual Average Precipitation

Trend over 1951 - 2013

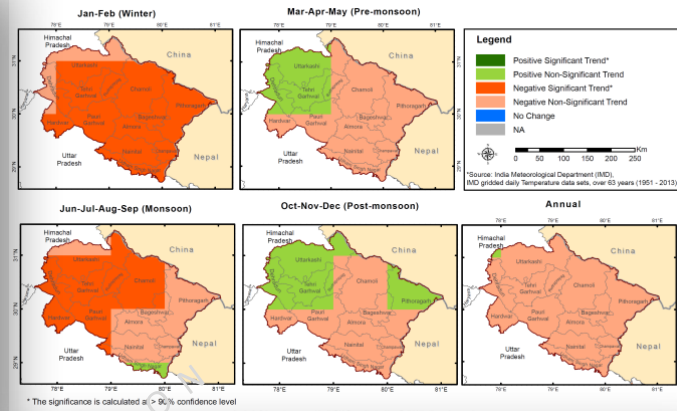
Difference from 1981-2010 mean (%)



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

*Source: CORDEX South Asia multi-model mean climate projections Baseline (1981-2010), Mid-century (2021-2050), End-century (2071-2100)

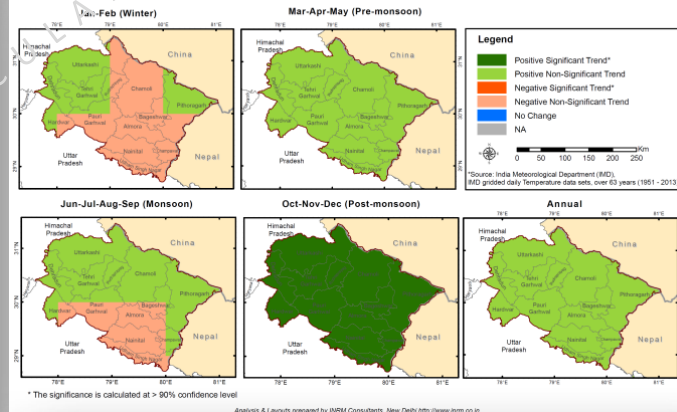
Observed (1951 - 2013)* Seasonal Maximum Temperature Trend for Uttarakhand



*The significance is calculated at > 90% confidence level

Analysis & Layouts prepared by IIRRI Consultants, New Delhi <http://www.iirri.com>

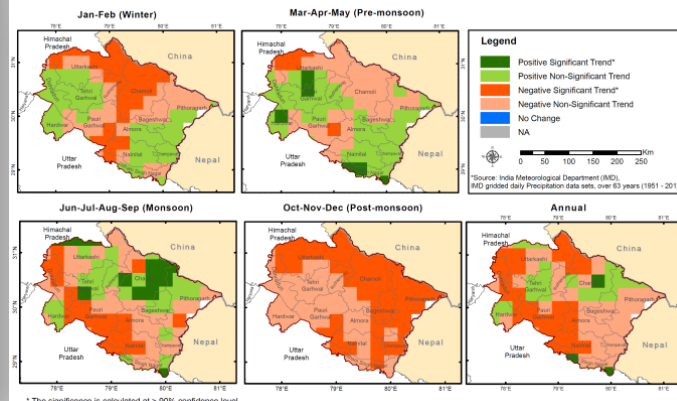
Observed (1951 - 2013)* Seasonal Minimum Temperature Trend for Uttarakhand



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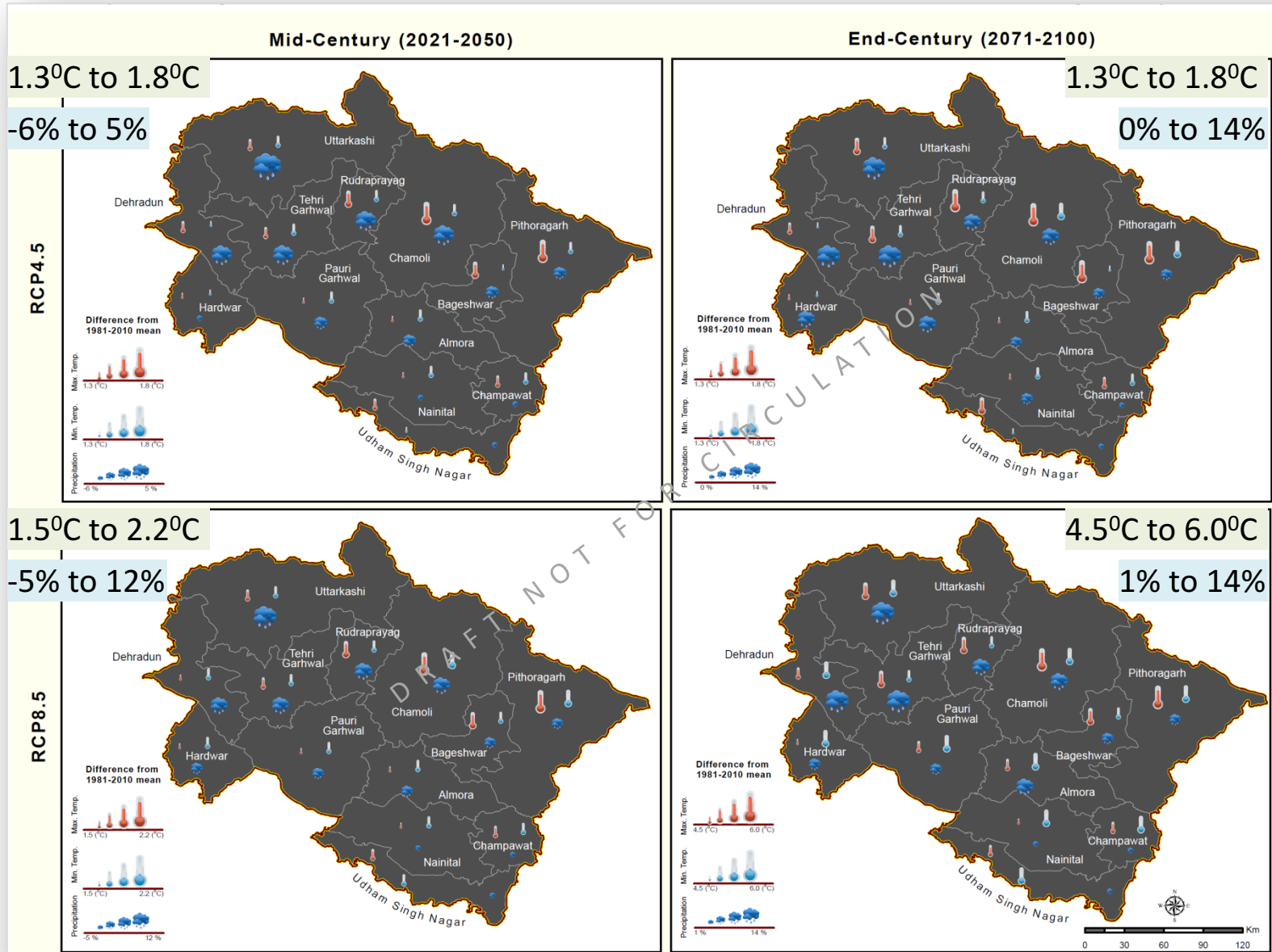
Observed (1951 - 2013)* Seasonal Precipitation Trend for Uttarakhand



*The significance is calculated at > 90% confidence level

Analysis & Layouts prepared by IIRRI Consultants, New Delhi <http://www.iirri.com>

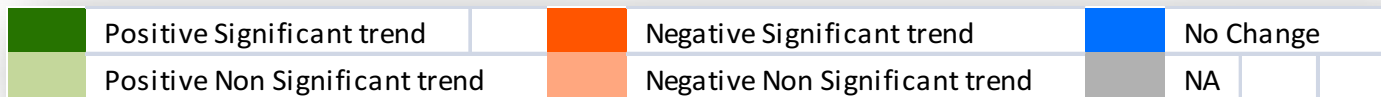
Key Inferences for Uttarakhand - Future Climate Change Projections



Extreme Climate Indices - Observed

Temperature extremes indices*												Precipitation extremes indices										
Districts	TXx	TNx	TXn	TNn	DTR	TN 10P	TX 10P	TN 90P	TX 90P	WSDI	CSDI	Districts	RX1 day	RX5 day	R95p	R99p	CDD	CWD	R10 mm	R20 mm	PRCP TOT	SDII
	Absolute indices					Percentile indices				Duration			Absolute		Percentile		Duration		Threshold		Other	
Almora	Orange	Orange	Orange	Light Orange	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Almora	Light Green	Light Orange	Light Orange	Light Green	Light Green	Orange	Orange	Orange	Orange	Light Orange
Bageshwar	Orange	Orange	Orange	Light Orange	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Bageshwar	Light Green	Light Green	Light Green	Light Green	Light Orange	Orange	Light Orange	Light Orange	Light Orange	Light Green
Chamoli	Orange	Orange	Light Orange	Light Green	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Chamoli	Light Green	Dark Green	Light Green	Light Green	Light Orange	Orange	Light Orange	Dark Green	Light Orange	Dark Green
Champawat	Orange	Orange	Orange	Light Orange	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Champawat	Light Green	Light Green	Light Green	Light Green	Light Orange	Orange	Light Orange	Light Orange	Light Orange	Light Orange
Dehradun	Light Orange	Orange	Light Orange	Light Green	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Dehradun	Light Orange	Orange	Orange	Orange	Light Orange	Light Orange	Orange	Orange	Orange	Orange
Pauri Garhwal	Orange	Orange	Orange	Light Orange	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Pauri Garhwal	Light Orange	Light Orange	Light Orange	Light Green	Light Orange	Orange	Orange	Orange	Orange	Orange
Hardwar	Orange	Orange	Orange	Light Orange	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Hardwar	Light Orange	Light Orange	Light Orange	Light Green	Light Orange	Light Orange	Orange	Orange	Orange	Light Orange
Nainital	Orange	Orange	Orange	Light Orange	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Nainital	Light Orange	Light Orange	Light Orange	Light Orange	Light Green	Orange	Orange	Orange	Orange	Light Orange
Pithoragarh	Orange	Orange	Light Orange	Light Orange	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Pithoragarh	Dark Green	Dark Green	Light Green	Dark Green	Light Orange	Orange	Light Orange	Light Orange	Light Orange	Light Green
Rudraprayag	Orange	Orange	Light Orange	Light Green	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Rudraprayag	Light Green	Light Green	Light Green	Light Green	Light Orange	Orange	Light Orange	Light Green	Light Orange	Dark Green
Tehri Garhwal	Orange	Orange	Light Green	Light Green	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Tehri Garhwal	Light Green	Light Orange	Light Green	Light Green	Light Orange	Orange	Light Orange	Light Orange	Light Orange	Light Green
Udham Singh Nagar	Orange	Orange	Orange	Light Orange	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Udham Singh Nagar	Light Green	Light Green	Light Orange	Light Green	Light Orange	Orange	Light Orange	Light Orange	Light Orange	Light Green
Uttarkashi	Orange	Orange	Light Green	Dark Green	Light Orange	Light Orange	Light Green	Light Green	Light Orange	Light Orange	Light Orange	Uttarkashi	Light Green	Light Green	Light Green	Light Green	Light Orange	Orange	Orange	Light Green	Orange	Light Green

* Spatial Resolution of IMD gridded data for temperature is not sufficient to arrive at long term trend



Sectoral Impact of Climate Change



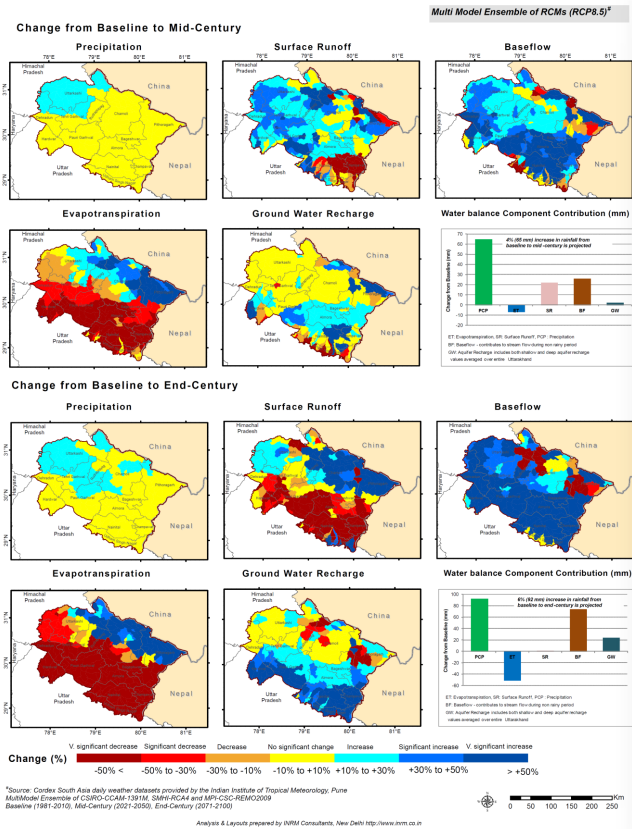
Sectoral Impact Assessment

for Generating Indicator data for Vulnerability Assessment

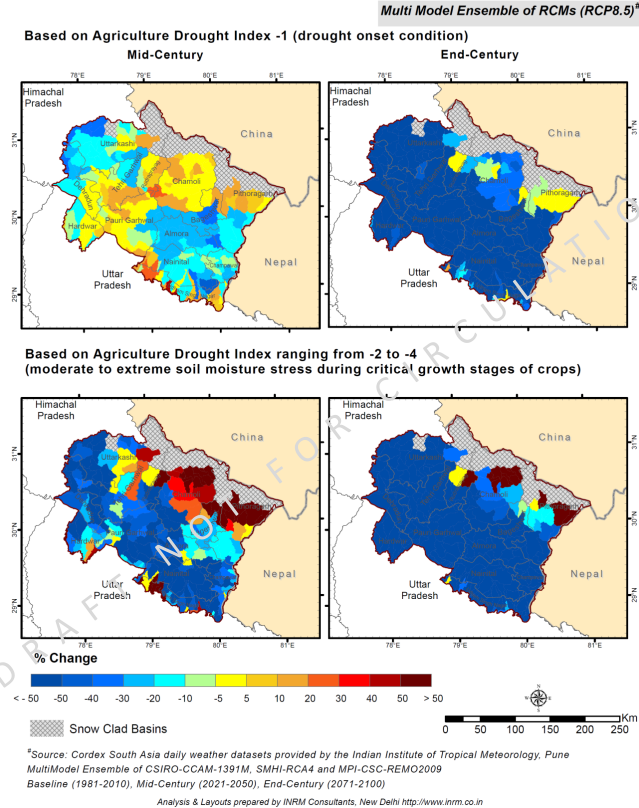
System/ Model	Scale/Unit	Time Current , projected	Indicators
Water SWAT hydrological model	Watershed, River basin	Day/Seasonal/ annual/inter- annual	Surface WA, Ground WA, Crop water requirement, Drought frequency, flood magnitude/frequency
Agriculture DSSAT (Decision Support System for Agrotechnology Transfer)	District	Seasonal/annual	Crop Yield, Crop water requirement, Length of growing period
Forest LPJ	Landscape/ Forest Grids	Decade	Shift in forest boundary, Changes in species mix, NPP, fire, pests and diseases
Health Loosely coupled hydrology and entomology model	Administrative (district/block)	Day/Seasonal/ annual	Heat Stress, vector borne diseases- Malaria, Temperature Humidity Index (THI) for livestock

Water Resources - Impacts

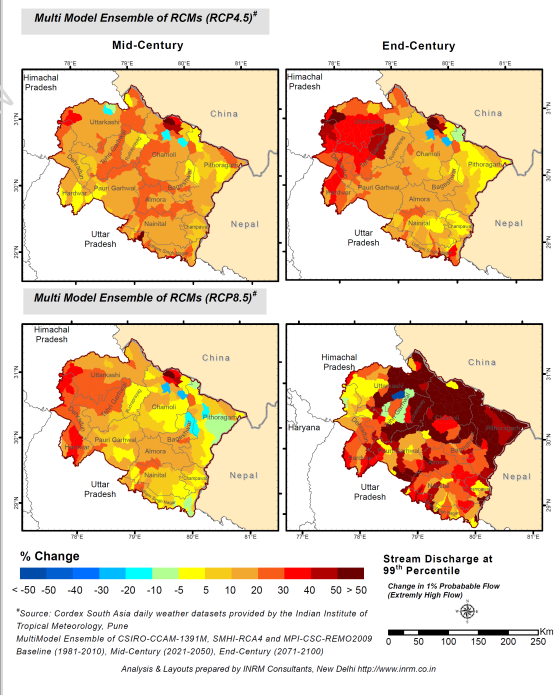
Distribution of Changes in Water Balance Components for Uttarakhand Annually



Percentage Change in Monsoon Drought Weeks with respect to Baseline for Uttarakhand



Percentage Change in Stream Discharge with respect to Baseline for Uttarakhand

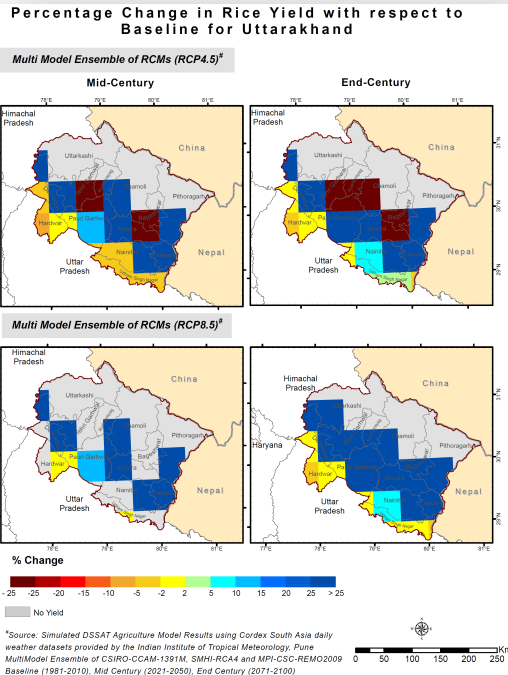


- RCP4.5: stream flow (~Mid), (~> End), peak discharge (> End)
- RCP8.5: stream flow (>), peak discharge (>> End)
- Dependable flow- 95% and 90%: (RCP8.5 > RCP4.5)
- Projected drought conditions likely to increase in hilly regions and improve in mid and lower transects of Uttarakhand
- 100 year return period of baseline flow is likely to return 30 to 40 years earlier

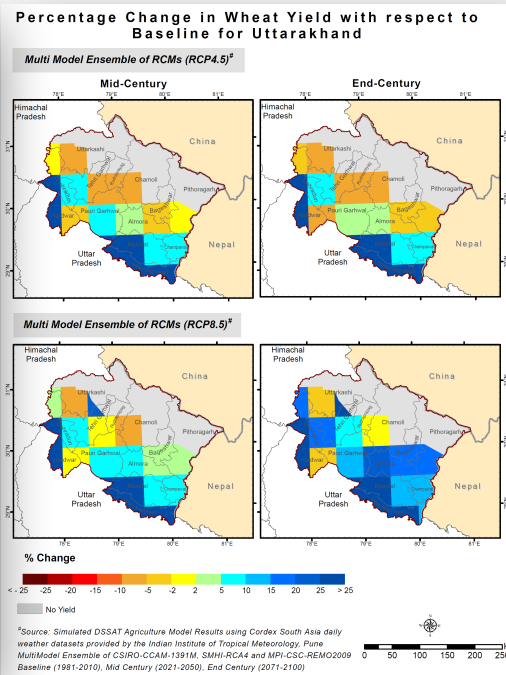


Agriculture - Impacts

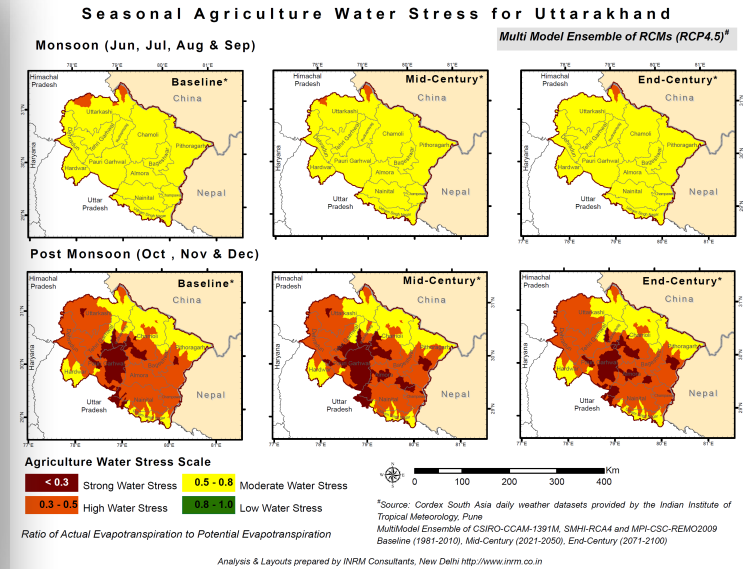
Change in Rice yield



Change in Wheat yield



Agriculture Water Stress

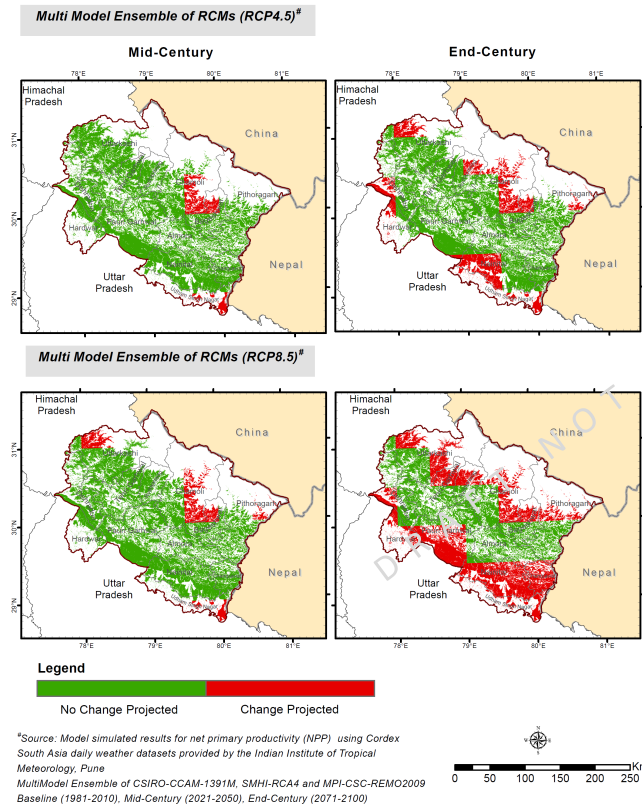


- Marginal increase in Rice yield, 2% to 5%: (RCP8.5 > RCP4.5)
- Increase in Wheat yield, 15 to 20%: (RCP8.5)
- Seasonal (winter/Rabi) crop water stress (>)

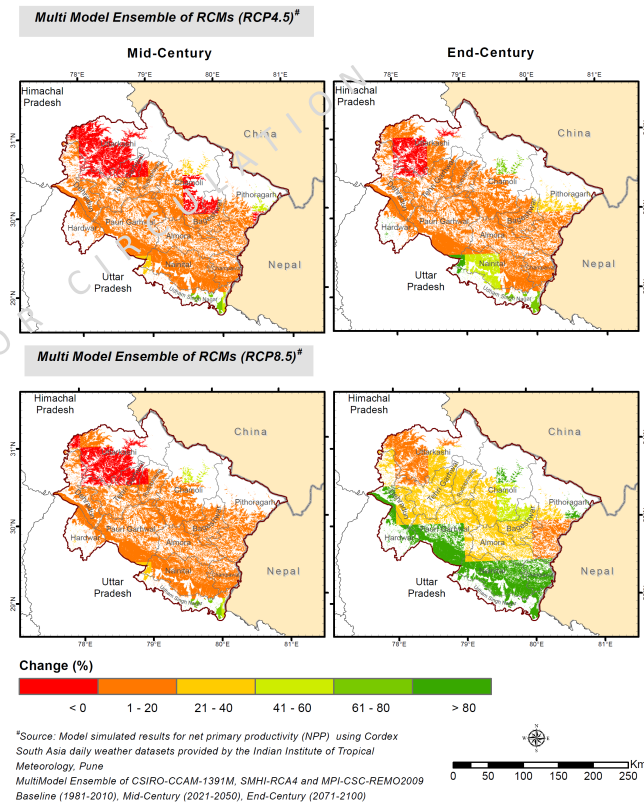


Forest - Impacts

Model Simulated Changes in Vegetation Distribution in the Forests of Uttarakhand



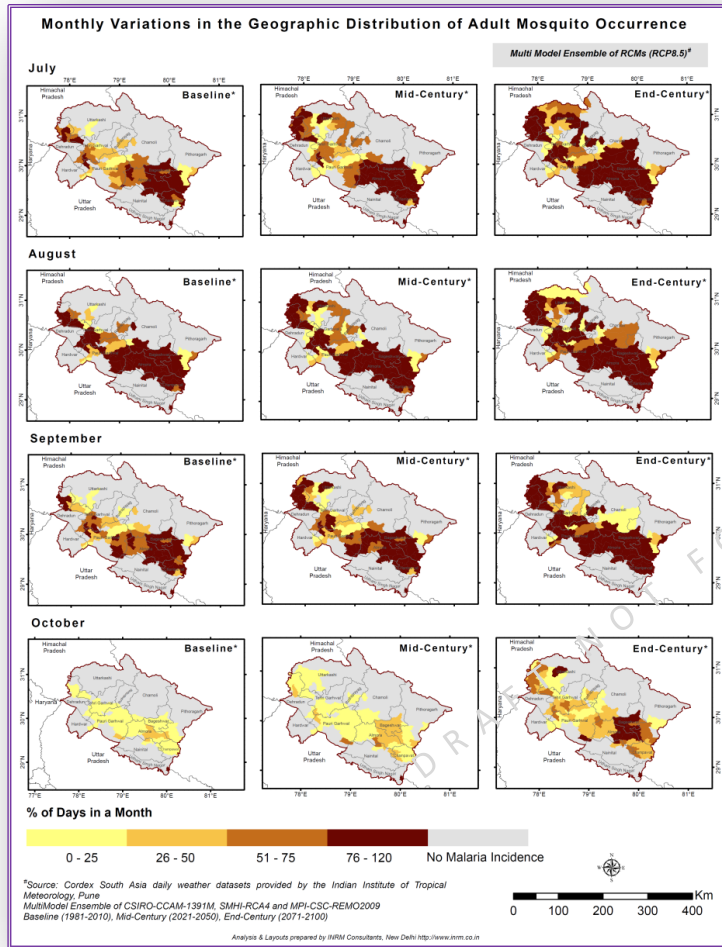
Projected Percentage Change in the distribution of Net Primary Productivity (NPP) over the Forests of Uttarakhand



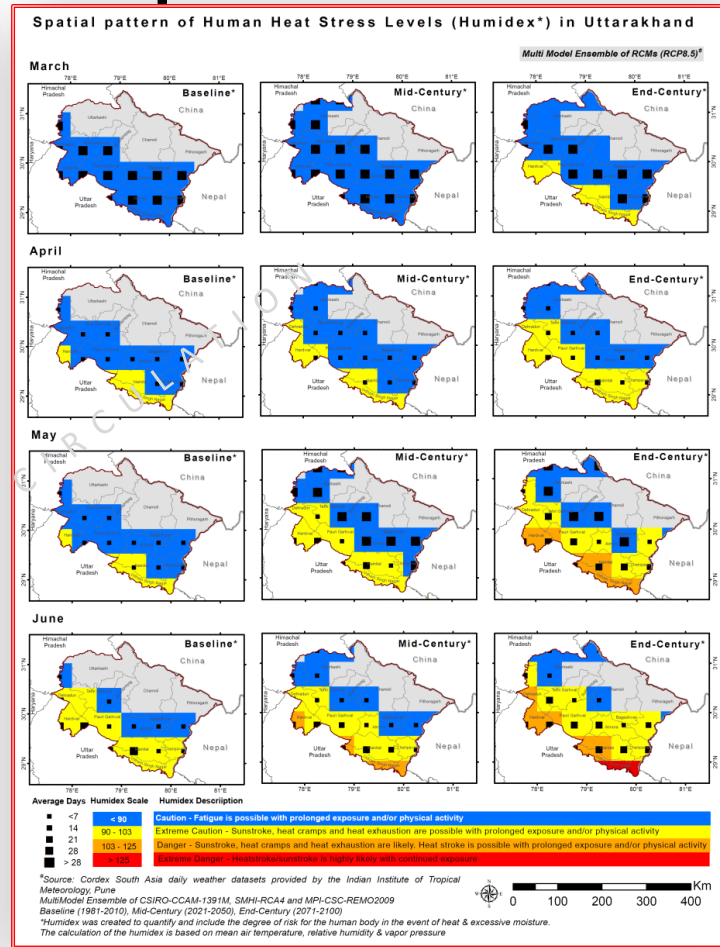
- Increased NPP, biomass production above and below ground, Increased heterotrophic respiration
- Vegetation changes are likely in the two prominent physiological zones of the state
 - Shivalik Himalayas, where plains link to the hills, where species from plains are likely to find refuge from scorching heat
 - Upper reaches of inner Himalaya, where vegetation may spread to the upper Himalayas



Health – Impacts



RCP8.5 July –August Adult Mosquito Occurrence



RCP8.5 March –June Heat Stress

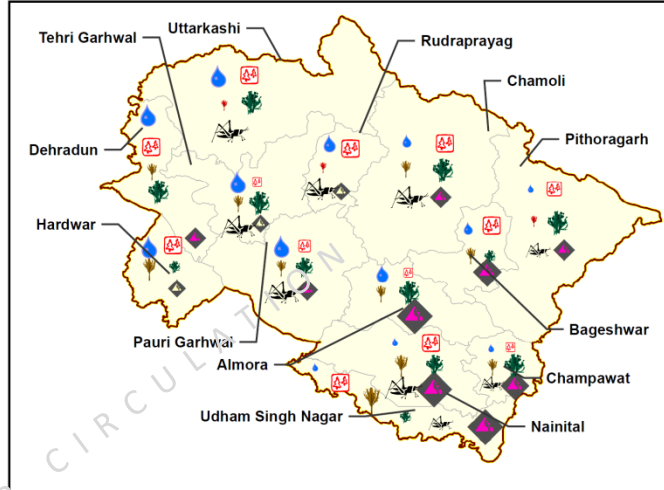
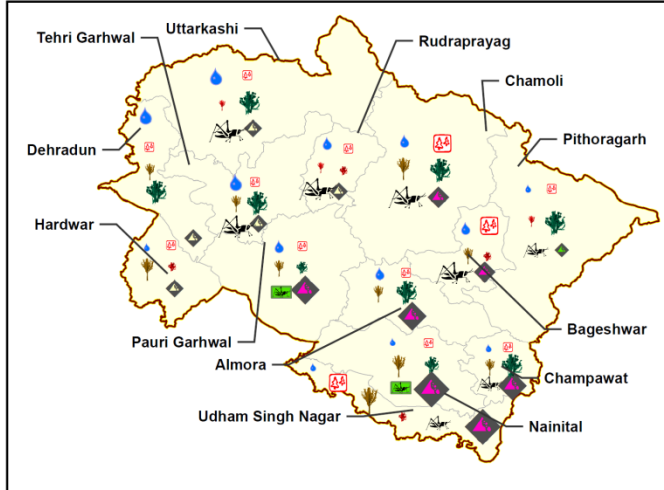
- Heat stress conditions are likely to exacerbate (March to October)
- March, April, May and October are projected to have favourable conditions for mosquito growth (> End)
 - Impact on the animals is projected to be the maximum in the months of June, July and August

Key Messages for Uttarakhand - Sectoral Impacts of Climate Change

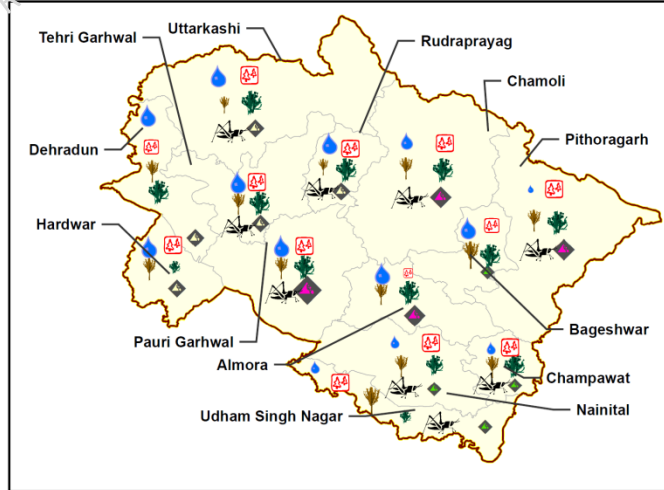
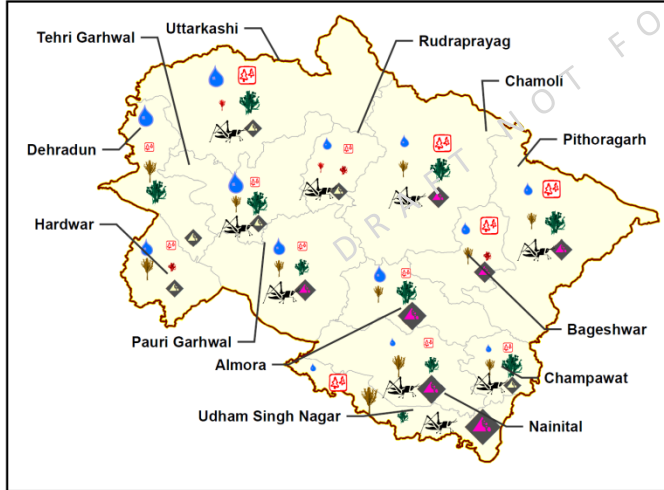
Mid-Century (2021-2050)

End-Century (2071-2100)

RCP4.5

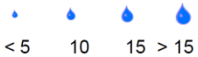


RCP8.5



Change from Baseline (%)

Water Yield



Wheat Yield



Malaria



Forest



Rice yield



Landslide



Key Inferences for Uttarakhand - Sectoral Impacts of Climate Change



Uttarakhand District Vulnerability



Assessment of Vulnerability to Climate Change

- Assessment of vulnerability to climate variability and change broadly helps in:
 - Understanding current vulnerability
 - Understand change in inherent vulnerability under projected climate scenario (near and long term)
 - Identify the factors that render some districts more vulnerable than others (hotspots)
 - Inform and facilitate the decision-making process
 - Selection of adaptation strategies and practices



Methodology

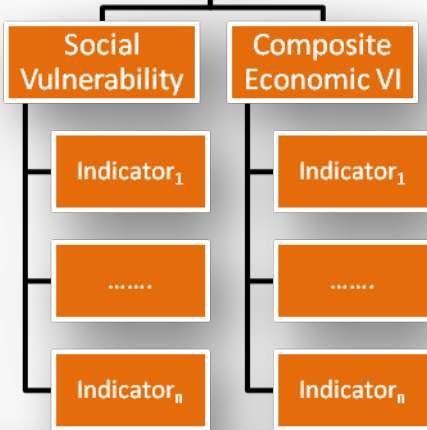
- Steps to assess the vulnerability of the districts
 - Identification of Indicators
 - Data collection, cleaning and quality checking
 - Classification of indicators data into 3 categories :
 - Adaptive Capacity , sensitivity and exposure
 - Normalization of the indicators to make them unit free
 - Assigning unbiased weights to indicators using Principal Component Analysis
 - Aggregation to arrive at Drill down Indices and Composite Vulnerability Index
 - Ranking districts based on the calculated indices
 - Rank 1: least vulnerable (Highest index values), Rank 13: most vulnerable (Lowest index values).
 - Performing cluster analysis on the calculated indices to group
 - in six categories of cluster-very low(1), low(2), moderate (3), high (4), very high (5) and extremely high (6) vulnerability.
 - Mapping the cluster using GIS for spatial visualization



Flow Chart

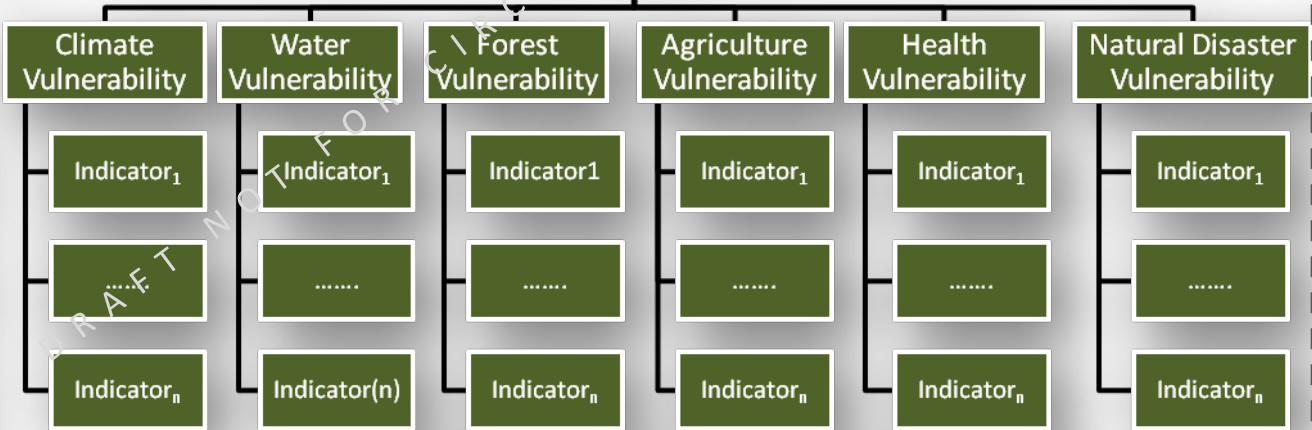
Composite Vulnerability Index

Composite Socio-Economic VI



Used for Current Vulnerability

Composite Environmental VI



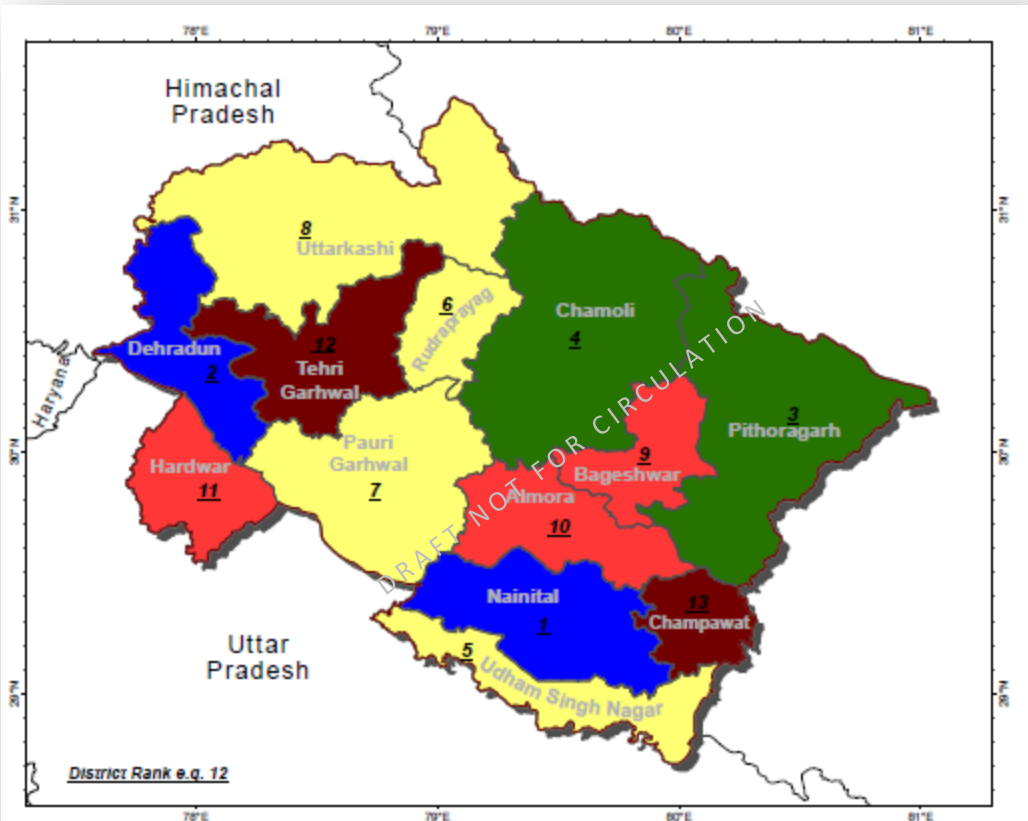
Used for Current and Projected Vulnerability

Composite Vulnerability Index (CVI)

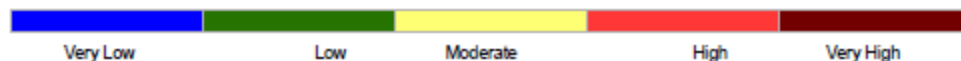
- Developed by multivariate analysis using sectoral indicators
 - social, economic, climate, water resource, forest, agriculture, health and natural disaster
- 78 indicators are used for Current Vulnerability
 - 28 socio-economic
 - 50 environmental indicators
- Projected Vulnerability due to climate change
 - 30 environmental indicators out of the 50 which are climate dependent (direct) have been used



Current Composite Vulnerability District of Uttarakhand

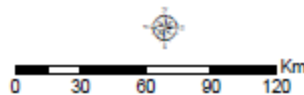


Vulnerability Scale



Sector for Indicators: Composite Current Vulnerability comprises of the following Sectors

Social : Indicators - Demography and Infrastructure
 Economic : Indicators - Per Capita Income and GDP
 Climate : Indicators - Indices for Precipitation and Temperature
 Water : Indicators - Water availability, extreme events of Flood and Drought
 Forest : Indicators - Current Status of Forest (Vegetation Type, Density, Diversity, Dependency and Fragmentation)
 Agriculture : Indicators - Crop Intensity, Yield, Irrigation, Fertilizer use.
 Health : Indicators - Frequency and Magnitude of Heat Stress, Malaria Transmission
 Natural Disaster : Indicators - Area at risk from Flood and Landslide (for 50 year return period events)

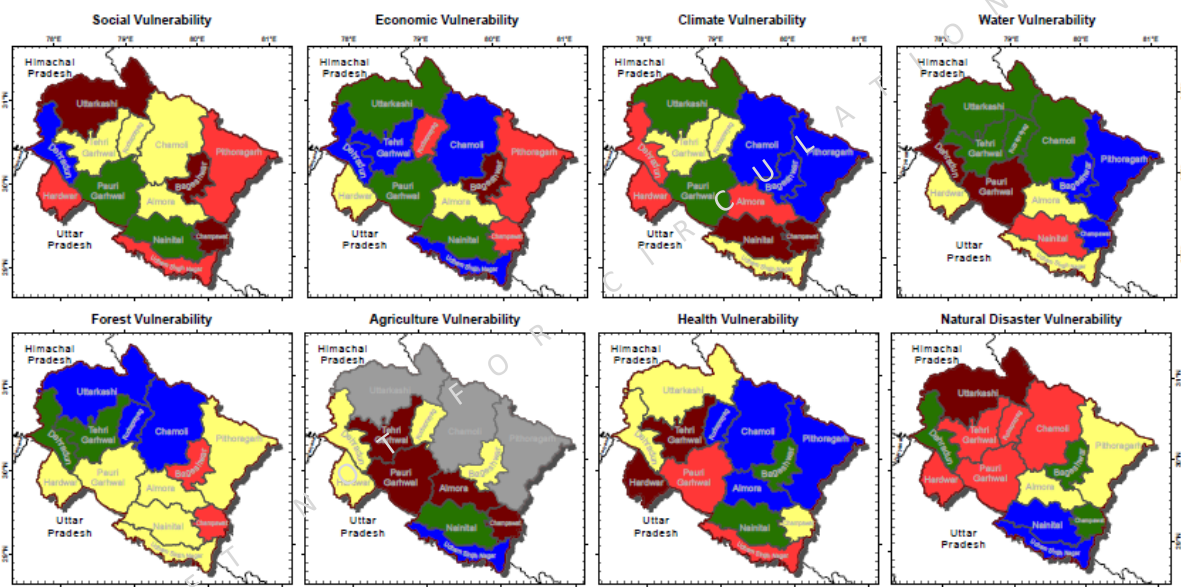


- Very high vulnerability
 - Champawat and Tehri Garhwal with ranks 13 and 12
- High vulnerability
 - Hardwar, Almora and Bageshwar with ranks 11, 10 and 9
- Moderate vulnerability
 - Uttarkashi, Pauri Garhwal, Rudrapur and Udham Singh Nagar (ranks 8, 7, 6, 5)
- Low vulnerability
 - Chamoli and Pithoragarh with ranks 4 and 3
- Very low vulnerability
 - Dehradun and Nainital with ranks 2 and 1

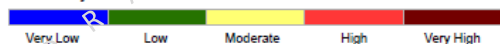


Disaggregated Sectoral Vulnerability - Current

District Current Composite Vulnerability - Uttarakhand
Drilldown Sectoral Vulnerability



Vulnerability Scale



Sector for Indicators: Composite Current Vulnerability comprises of the following Sectors

Social : Indicators - Demography and Infrastructure

Economic : Indicators - Per Capita Income and GDP

Climate : Indicators - Indices for Precipitation and Temperature

Water : Indicators - Water availability, extreme events of Flood and Drought

Forest : Indicators - Current Status of Forest (Vegetation Fragmentation)

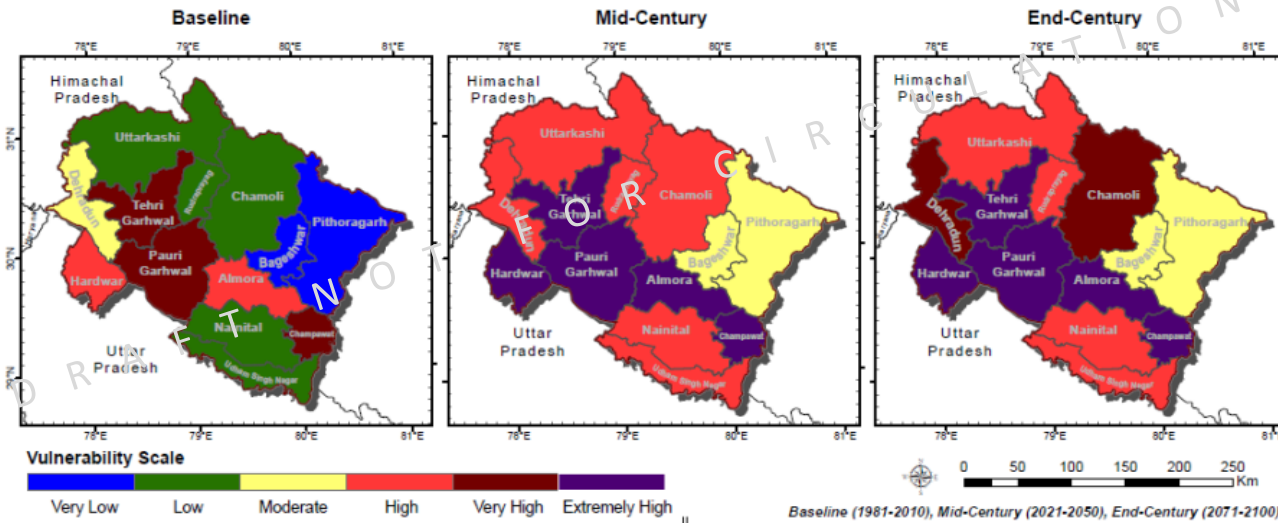
Agriculture : Indicators - Crop Intensity, Yield, Irrigation

Health : Indicators - Frequency and Magnitude of Health Issues

Natural Disaster : Indicators - Area at risk from Floods, Landslides, etc.

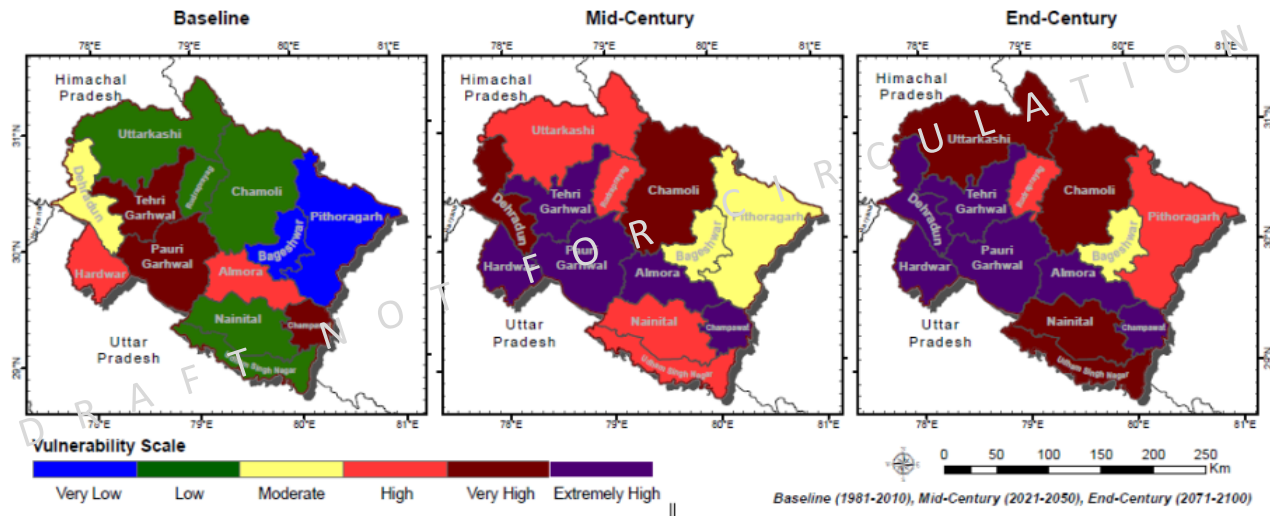
Districts	Rank	CV	SV	ECV	CLV	WRV	FVI	AGV	HLV	NDV
Almora	1	H	M	M	H	M	M	VH	VL	M
Bageshwar	2	H	VH	VH	VL	VL	H	M	L	L
Chamoli	3	L	M	VL	VL	L	VL	NA	VL	H
Champawat	4	VH	VH	H	VH	VL	H	VH	M	L
Dehradun	5	VL	VL	VL	H	VH	L	M	M	L
Hardwar	6	H	H	M	H	M	M	M	VH	H
Nainital	7	VL	L	L	VH	H	M	L	L	VL
Pauri Garhwal	8	M	L	L	L	VH	M	VH	H	H
Pithoragarh	9	L	H	H	VL	VL	M	NA	VL	M
Rudraprayag	10	M	M	H	M	L	VL	M	VL	H
Tehri Garhwal	11	VH	M	VL	M	L	L	VH	VH	H
Udham Singh Nagar	12	M	H	VL	M	M	M	VL	H	VL
Uttarkashi	13	M	VH	L	L	L	VL	NA	M	VH

District Composite Environmental Vulnerability - Uttarakhand IPCC AR5 RCP4.5 Scenario



Projected
Vulnerability
– Change in
Current
Vulnerability

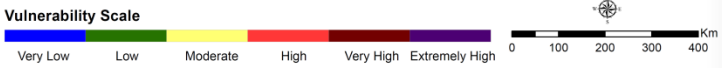
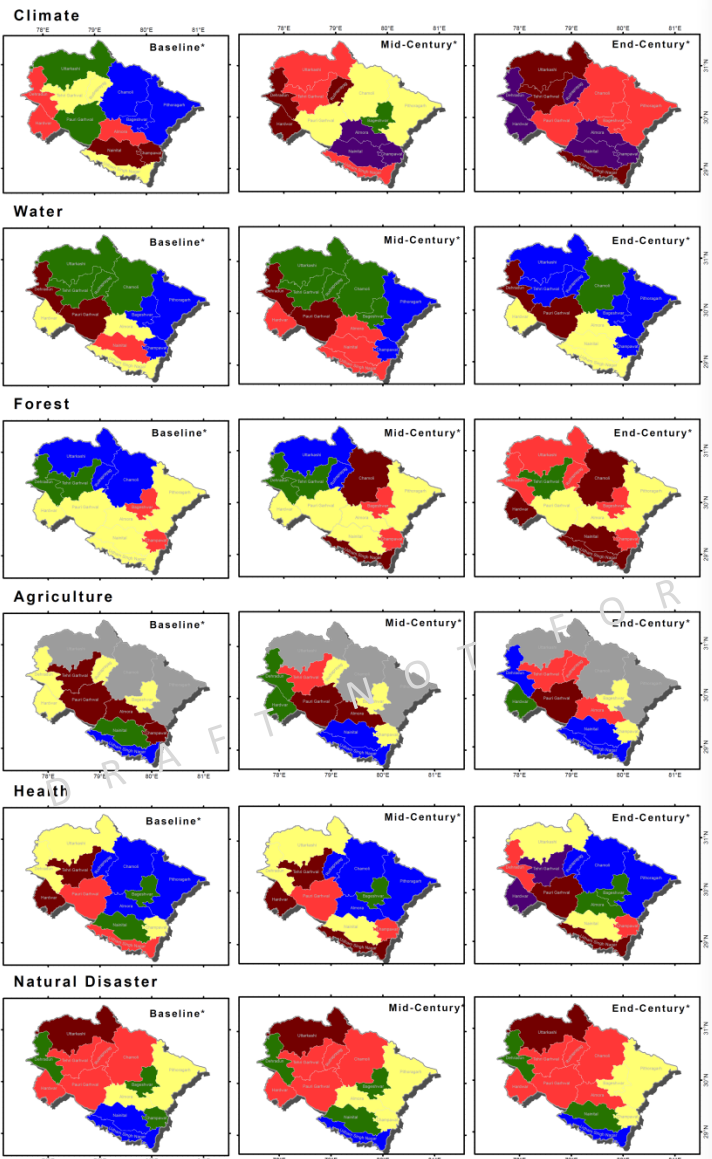
District Composite Environmental Vulnerability - Uttarakhand IPCC AR5 RCP8.5 Scenario



- All 13 districts of Uttarakhand are projected to become more vulnerable
- EC vulnerability > MC vulnerability

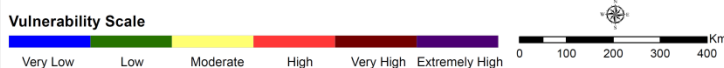
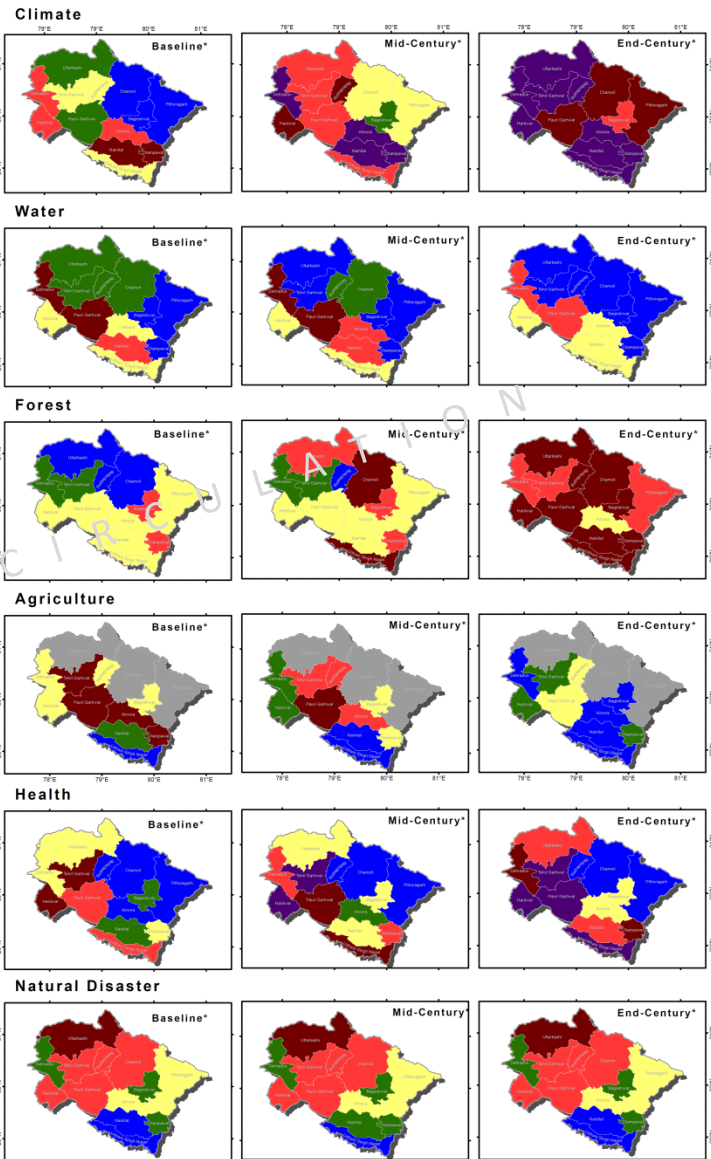


**District Vulnerability for Climate dependent Sectors - Uttarakhand
IPCC AR5 RCP4.5 Scenario**



***Source**
Climate - 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-REM0209.
Water - SWAT hydrological model results simulated using climate data
Forest - Vegetation change projections simulated by dynamic vegetation model using climate data
Agriculture - Crop Yield Simulated by DSSAT crop model using climate data
Health - Projected Heat Stress and Malaria Transmission using climate data
Natural Disaster - Flood Impact Model and Landslide Impact Model using climate data
 Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)
 Analysis & Layouts prepared by INRM Consultants, New Delhi <http://www.inrm.co.in>

**District Vulnerability for Climate dependent Sectors - Uttarakhand
IPCC AR5 RCP8.5 Scenario**



***Source**
Climate - 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-REM0209.
Water - SWAT hydrological model results simulated using climate data
Forest - Vegetation change projections simulated by dynamic vegetation model using climate data
Agriculture - Crop Yield Simulated by DSSAT crop model using climate data
Health - Projected Heat Stress and Malaria Transmission using climate data
Natural Disaster - Flood Impact Model and Landslide Impact Model using climate data
 Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)
 Analysis & Layouts prepared by INRM Consultants, New Delhi <http://www.inrm.co.in>

Dis-aggregated Sectoral Vulnerability - Projected

- Climate, Forest, Health and ND sector vulnerability >
- Water resource, Agriculture vulnerability <
- RCP8.5 Vulnerability > RCP4.5 Vulnerability



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Thank You

