Vulnerability Assessment of Chhattisgarh towards Climate Change






INRM Consultants, New Delhi

Vulnerability Assessment of Chhattisgarh towards Climate Change

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Abbreviations

AGVI	Agriculture Vulnerability Index
ACZ	Agro Climatic Zone
BL	Baseline
CAGR	Compound Annual Growth Rate
CC	Climate Change
CENVI	Environmental Index
CH4	Methane
CLI	Climate Index
CO_2	Carbon Dioxide
CO_{2e}	Carbon dioxide equivalent
CSEVI	Composite Socio Economic Vulnerability index
Cubic km	Volume in Cubic Kilometre
CVI	Composite Vulnerability Index
dist	District
EC	End Century
ECVI	Economic Vulnerability Index
EIA	Environmental Impact Assessment
et al	And Others
ETCCDI	Expert Team On Climate Change Detection And Indices
ECVI	Economic Vulnerability Index
FAO	Food And Agriculture Organization
FI	Forest Vulnerability Index
FSI	Forest Survey Of India
GCM	Global Circulation Models
GDP	Gross Domestic Product
GHG	Green House Gas
GIS	Geographical Information System
GOI	Government Of India
GSDP	Gross State Domestic Product
ha	Hectare
HadAM3	Hadley Centre Coupled Model, version 3
HadCM3	Hadley Centre Coupled Model, version 3
HDR	Human Development Report
IBIS	Integrated Biosphere Simulator
IFPRI	International Food Policy Research Institute
IISc	Indian Institute Of Science
IIT	Indian Institute Of Technology
IITM	Indian Institute Of Tropical Meteorology
IMD	Indian Metrological Department
IPCC	Intergovernmental Panel On Climate Change
ISRO	Indian Space Research Organisation
JF	January, February
JJAS	June, July, August, September
JNNURM	Jawaharlal Nehru National Urban Renewal Mission
Kg	Kilogram
km	Kilometre
km^2	Square Kilometre
kWh	Kilowatt Hours
LBCs	Lateral Boundary Conditions

Lha	Lakh Hectares
LULUCF	Land Use, Land Change And Forestry
m	Meter
m^2	Square Meter
MAM	March, April, May
MC	Midterm
MDRs	Major District Roads
Mha	Million Hectares
mm	Millimetre
MoA	Ministry Of Agriculture
MoEF	Ministry Of Environment And Forests
MW	Megawatt
N2O	Nitrous Oxide
NATCOM	India's National Communication
NDDP	Net District Domestic Product
^oC	Degree Centigrade
ODRs	Other District Roads
OND	October, November, December
PC	Personal Computer
PCA	Principle Component Analysis
PCs	Principal Components
PPE	Perturbed Physics Ensemble
PRECIS	Providing Regional Climates For Impact Studies
QUMP	Quantifying Uncertainty In Model Predictions
RClimDex	Climate Vulnerability Index calculator using statistical package R
RCM	Regional Climate Models
Sq. km	Square Kilometre
SRES	Special Report On Emission Scenarios
SRTM	Shuttle Radar Topography Mission
SS	Sum Of Squares
SI	Social Vulnerability Index
SWAT	Soil And Water Assessment Tool
Tg	Teragrams
TN	Temperature - Minimum
TX	Temperature - Maximum
UK	United Kingdom
WRVI	Water Resource Vulnerability Index

Executive Summary

The study is focused on generating district level Composite Vulnerability Index (CVI) for Chhattisgarh state. The composite indices would facilitate the identification of districts, which are vulnerable to climate change and need special attention towards adaptation. Vulnerability to climate change in Chhattisgarh has been derived using integrated vulnerability assessment approach. Accordingly social, economic (socio-economic) and agriculture, water resource, health, climate and forest (environmental), indicators of vulnerability are employed and classified into adaptive capacity, sensitivity, and exposure. To analyze the data, multivariate statistical method of Principal Component Analysis (PCA) is performed to obtain the Component Scores and Eigen values. These are used to calculate weight for the indicators before arriving at the indices. The selected indicators explained the differences in vulnerability between districts with good agreement. Districts are ranked based on the composite vulnerability indices. Further, this index is developed for the current climatic conditions and for midterm projected climatic conditions (IPCC AR5, RCP 4.5 scenario). Furthermore, cluster analysis is performed on the indices to group the districts according to their degree of vulnerability using Ward Method of Agglomeration. The districts are grouped into low (1), moderate (2), high (3) and very high (4) categories of vulnerability. The cluster outputs are mapped using GIS for spatial visualization.

In this study, CORDEX-based mid-term (2030's, representing climatology over 2021-2050 climate change projections have been assessed for Chhattisgarh at the district-level. Projections available at a grid-spacing of 0.5°x0.5° resolution, using single model (SMHI-RCA4) for RCP 4.5 (moderate emission scenario) has been used due to data availability at the time of preparation of this document.

The analysis of the pattern of vulnerability of districts in Chhattisgarh to climate change has shown that generally the South Western and North Eastern districts are more vulnerable to climate change than the other districts. This is explained by the greater exposure to drought and climate extremes as well as low levels of technology and socio-economic and infrastructure development. Vulnerability can result from environmental, social or economic issues. Hence a single policy for all of the districts would not be appropriate. Rather, judicious and different combinations of policies for different districts could help them in moving closer to achieving sustainability and climate resilience. Nevertheless, this exercise can be regarded as a modest attempt to assess the preparedness of the districts of Chhattisgarh to cope up with the vulnerability issues and board the development pathway.

Analysis based on the Composite Vulnerability Index (CVI) and drilled down indices of the districts for baseline and mid-term RCP 4.5 scenarios show that:

- Balod and Bemetara with ranks 1 and 2 respectively remains least vulnerable districts of Chhattisgarh for baseline and midterm RCP 4.5 scenario since:
    - They have higher adaptive capacity as compared to the other districts of the state which makes them well equipped to cope up with their exposure and/or sensitivity to climatic influences.

- They have relatively higher economic capacity, level of urbanization is high, highest irrigation potential, high literacy rate, less exposure to extreme climatic events, and better access to drinking water, sanitation facilities, electricity, health, education and road infrastructure.
  - They have higher values with regards to both social and economic indices thus their socioeconomic vulnerability is also the least and also Composite Environmental vulnerability is low
- Mungeli, Baloda Bazar, Raipur, Durg, Ghariyaband, Bemetara and Balod remain low vulnerable districts in both baseline and midterm.
- In the baseline 3 districts namely Jashpur, Bijapur and Narayanpur are very highly vulnerable-cluster (4). to climate change since
  - They have very low values of Composite Vulnerability Index (CVI).
  - They have comparatively low adaptive capacity and show higher sensitivity and exposure to climate change with respect to the other districts.
  - They also have very high Social, Economic, Climate, Agriculture and Health sector vulnerabilities thus higher Composite Socioeconomic (CSEVI) and Composite Environmental vulnerability (CENVI).
  - Bijapur and Narayanpur are located in the South West while Jashpur is located in the North East of Chhattisgarh.
  - These districts remain highly vulnerable in midterm also.
- The overall composite vulnerability of districts is projected to be the same in midterm RCP 4.5 compared to the base scenario though change in the relative ranking amongst the districts is observed from BL to midterm.
  - There are no changes observed in the number of districts from baseline to midterm scenario for all 4 vulnerability categories-low, moderate, high and very high vulnerability cluster

Social Vulnerability Index (SVI) analysis outcome:

- 2 districts namely Bijapur and Narayanpur are socially most vulnerable to climate change in the base period.
- It is low literacy rate, large proportion of child population, large percentage of rural households below poverty line, bad sanitation facilities, lack of access to electricity, households residing in kacchha houses, poor health infrastructure, low level of urbanization and high proportion of scheduled caste and scheduled tribes population which makes Bijapur and Narayanpur most vulnerable socially
- 10 districts namely, Bilaspur, Baloda Bazar, Janjgir-Champa, Ghariyaband, Raipur, Rajnandgaon, Bemetara, Durg, Dhamtari and Balod are the least vulnerable districts

Economic Vulnerability Index (ECVI) analysis outcome:

- 8 districts are the most vulnerable namely Narayanpur, Kabeerdham, Bijapur, Uttar Bastar Kanker, Janjgir-Champa, Jashpur, Bilaspur and Mungeli in ECVI
- It is low per capita income (NDDP), less number of banks and poor credit deposit ratio which makes Narayanpur and Kabeerdham most vulnerable
- Baloda Bazar, Ghariyaband and Raipur are least vulnerable districts with rank 1.

Composite Socio Economic Vulnerability Index (CSEVI) analysis outcome:

- 2 districts namely, Bijapur and Narayanpur have very high socio-economic vulnerability These 2 districts show low index values with respect to both social and economic indices and these districts also shows lower values in the CSEVI
- Baloda Bazar, Raipur, Ghariyaband, Dhamtari, Bemetara, Durg and Balod are the least vulnerable districts (cluster 1)

Agriculture Vulnerability Index (AGVI) analysis outcome:

- 6 districts being located in North Eastern and South Western regions of Chhattisgarh have very highly agriculture vulnerability, namely, Jashpur, Janjgir-Champa, Korba, Surguja, Raigarh, and Uttar Bastar Kanker.
- It is low wheat and maize production per capita, larger proportion of wasteland, very less percentage of ground water and surface water irrigation to net sown area, greater share of agricultural and cultivators main workers to total main workers thus more dependence on agriculture income, etc which makes Jashpur and Janjgir-Champa most vulnerable in AGVI.
- Balod and Bemetara are the least vulnerable districts
- Overall Agriculture vulnerability of the Chhattisgarh districts is projected to increase slightly in the MC RCP 4.5 scenario compared to the baseline.

Forest Vulnerability Index (FOVI) analysis outcome:

- Janjgir-Champa, Durg, Raigarh, Rajnandgaon and Jashpur have very highly forest sector vulnerability.
- Dhamtari, Bijapur and Narayanpur are least vulnerable districts in the baseline.
- The top five most vulnerable districts include Surguja, Jashpur, Dakshin Bastar, Bastar and Kabeerdham, considering both climate impacts (IBIS and LPJ)and current vulnerability

Water Resource Vulnerability Index (WRVI) analysis outcome:

- 5 districts namely Kabeerdham, Bemetara, Durg, Raipur, Rajnandgaon have very low values of Water Resource Vulnerability Index (WRVI) thus belong to very high vulnerable category (cluster 4) compared to the other districts of Chhattisgarh
- It is less surface water and ground water availability per capita in monsoon and non monsoon months, high crop water stress in North East Monsoon season which make these districts most vulnerable to climate change.
- 2 districts namely, Bijapur and Narayanpur are the least vulnerable districts
- Overall Water Resource vulnerability of the Chhattisgarh districts is projected to be almost the same in the MC RCP 4.5 scenario compared to the baseline. Though change in the relative ranking amongst the districts is observed from BL to midterm.

Climate Vulnerability Index (CLVI) analysis outcome:

- 6 districts namely have Uttar Bastar Kanker, Balrampur, Jashpur, Narayanpur, Raigarh and Bijapur very high vulnerability to current climate since these 6 districts show greater exposure to extreme events with respect to the other districts.
- 4 districts are in the low vulnerable category namely Balod, Mungeli, Bemetara and Durg.

- the overall Climate vulnerability of the Chhattisgarh districts is projected to increase for some districts in the MC RCP 4.5 scenario while decrease for others compared to the baseline

Health Vulnerability Index (HLVI) analysis outcome:

- Jashpur and Bijapur are very highly vulnerable lying in North East and South West of Chhattisgarh.
- It is high infant mortality rate, high diarrhoea cases and greater sensitivity to Anopheles Mosquito causing Malaria, which makes them most vulnerable
- 12 districts, Bilaspur, Balrampur, Surajpur, Baloda Bazar, Ghariyaband, Surguja, Sukma, Balod, Mungeli, Raipur, Bemetara and Durg are the least vulnerable districts

Composite Environmental Vulnerability Index analysis outcome:

- Cluster results show that 7 districts namely, Jashpur, Raigarh, Bijapur, Janjgir-Champa, Mahasamund, Kabeerdham and Korba have very high composite environmental vulnerability. They also have very high climate, water resource, health and agriculture vulnerability
- Sukma, Durg, Ghariyaband, Mungeli, Bemetara and Balod are the least vulnerable districts. These districts also have very low climate, health and agriculture vulnerability.

- Composite environmental vulnerability (CENVI) of districts is projected to decrease towards midterm RCP 4.5 scenario compared to the baseline.
  - There are 26% of districts (7 out of 27 districts) in moderate vulnerability cluster in the baseline which increases to 33% (9 districts)) in midterm. The percentage of districts in low vulnerable category also increases from 22% (2 districts) in the baseline to 30% (8 districts) in midterm as districts are moving from moderate clusters to low vulnerability clusters.
  - While the percentage of districts in very vulnerable category decreases from 26% (7 districts) in the baseline to 11% (3 districts) in midterm as districts are moving from very high to high vulnerability clusters.

Following the findings, the policy recommendations are suggested to mainstream climate change adaptation into the development process in order to reduce vulnerability of districts of Chhattisgarh.

CVI as one overall figure is good for easy comparison for a non-specialist or policy-makers; there is a trade-off between the component sub-indices when they are viewed in aggregated form. Therefore to add some depth to the overall assessment, drill down sub-indices is also provided to understand about the composition of vulnerability

Chapter 1

Introduction

Introduction

Background

Climate change is proving out to be one of the greatest challenges faced by the global community today. The analysis of past trends and current erratic behaviour in climatic events shows that changes being experienced in the climate of Chhattisgarh are the proof of natural climate variability prevailing in the state. Many studies for the state show that the Chhattisgarh is in precarious situation due to its high climate sensitivity and vulnerability, combined with low adaptive capacity.

The state is already suffering due to its high dependence on mineral resources. Further the forest and water resources in the State are facing threat due to industrial and urban growth and being uneven in distribution both temporally and spatially. Hence the challenge of climate change calls for appropriate, evidence based and coherent policy response, followed by the adequate action that can help reduce its vulnerability and build resilience of the various sectors of the state in the context of climate change impacts.

Adaptation to climate change requires integrated solutions that simultaneously address livelihood improvements and environmental sustainability. Proactive measures for adaptation to climate variability and change can substantially reduce many of the adverse impacts, and thus contribute to livelihood security of the vulnerable rural population. While climate change will affect the nation's economy as a whole, its impact will be more severely felt by the poor who also have the least adaptive capacity. Recognising this, the National Action Plan on Climate Change (NAPCC) clearly outlines its first principle as "protecting the poor and vulnerable sections of the society through inclusive and sustainable development strategy, sensitive to climate change"[1].

The GIZ project "Climate Change Adaptation in Rural Areas of India" (CCA RAI) with the aim to contribute to improving the livelihoods and adaptive capacities of vulnerable rural communities in India aligns itself to the Government of India's National Action Plan on Climate Change. The project focuses on integrating the issue of climate change adaptation in various sector policy decisions that reduce risk and enhance the adaptive capacity of the most vulnerable sectors and groups. It will also develop concrete pilot experiences on adaptation measures together with the Indian state development programmes and supports the up-scaling of successful technical and financial adaptation approaches. In order to achieve this project has the following components:

- Vulnerability and risk assessment
- Development of technical adaptation options
- Climate proofing of rural development programmes,
- Development of adaptation oriented financial instruments
- Information and knowledge management to support mainstreaming national discussions on climate change adaptation.

In addition to these five components GIZ supports selected states with the preparation of State Action Plans on Climate Change (SAPCC). During the initial phase the project is focusing on the vulnerability and risk assessment of the project states viz. Chhattisgarh, Rajasthan, Tamil Nadu and

[1]The GIZ project "Climate Change Adaptation in Rural Areas of India" (CCA RAI)

West Bengal. While vulnerability assessment is important for responding to future climate risks, the assessment process will also help improve the management of current climate risks. For example, the vulnerability assessment can be used to address the following questions of immediate relevance to policy-makers and planners:

- To what extent are the anticipated benefits from existing development projects sensitive to the risk of climate variability and change?
- In what way can considerations of future climate risk be incorporated into the design and implementation of development projects?

Organization of the Report

The Final Report consists of six chapters and an Executive Summary. The Chapter 1 is an introduction to the study and describes the study area with background information. Chapter 2 covers the data sources, limitations and the methodology followed for doing the Vulnerability analysis. Current observed climatology of Chhattisgarh and the predicted climate change analysis is covered in Chapter 3. Impacts and vulnerability due to climate change on various sectors based scientific studies carried out at the national level is presented in Chapter 4. The Chapter 5 covers details of assessment of the vulnerability in Chhattisgarh to identify the vulnerable sectors and regions (districts) to climate change. The Chapter 6 gives the conclusion and recommendations.

Purpose of Vulnerability Assessment

Climate change is one of the biggest environmental threats facing the world. Scientists around the world now agree that the climatic changes occurring internationally are the result of human activity. Although responsibility for the causes of climate change rests primarily with the developed and industrialized nations, the costs of climate change will be borne most directly by the poor.

It is now increasingly realized that even with the currently agreed regime of emissions control, concentrations of greenhouse gases (GHG) are likely to rise over the next few decades and over the millennia. Climate change is likely to threaten all life forms on earth with the extent of vulnerability varying across regions and populations within regions.

The effects of climate change—higher temperatures, changes in precipitation patterns, rising sea levels, and more frequent weather-related disasters like flood, cyclone, drought, etc. pose risks for agriculture, food, human health, water resources, infrastructure, coastal settlements, and natural ecosystems. At stake are recent gains in the fight against poverty, hunger and disease, and the lives and livelihoods of billions of people in developing countries.

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 districts more vulnerable than others.
- Inform and facilitate the decision-making process.
- Selection of adaptation strategies and practices.

Basic objective for Vulnerability assessment of Chhattisgarh state:

- In the present study, an assessment of the overall implications of climate change and vulnerability in Chhattisgarh for seven major sectors social, economic, agriculture, water resource, forest, health and climate has been carried out to identify the vulnerable sectors and regions (districts) to climate change. (Figure 63).
- The objective is to understand the sector-wise vulnerabilities at the district level so that the targeted policies by development agencies can be designed to improve the most vulnerable sectors. The key components incorporated include socioeconomic and environmental vulnerability indicators.
- The study is focused on generating district level Composite Vulnerability Index (CVI) for Chhattisgarh developed by multivariate analysis of individual indicators (social, economic, agriculture, water resource, forest, climate and health) which are vulnerable to climate change. The district level Composite Socio Economic Vulnerability Index (CSEVI) and Composite Environmental Vulnerability Index (CENVI) has also been constructed. The composite indices would facilitate the identification of districts, which are vulnerable to climate change and need special attention towards adaptation.
- Further, current vulnerability profile at district level is developed due to the current climatic conditions and also change in vulnerability profiles developed due to midterm projected climatic conditions-RCP 4.5 scenario
- Furthermore, cluster analysis is performed on the indices to group the districts according to their degree of vulnerability using Ward Method of Agglomeration. The districts are grouped into low (1), moderate (2), high (3) and very high (4) categories of vulnerability. The outputs are shown spatially using maps. Blue colour denotes low (1), yellow denotes moderate (2), Red denotes high (3) and dark brown denotes very high (4) vulnerability category in the layouts.

Definition of vulnerability

A geographically disaggregated map of vulnerability to climate change is helpful for planning adaptation strategies. The IPCC working definition of vulnerability[2] as a function of exposure, sensitivity, and adaptive capacity (IPCC, 2001) is used as measure to derive the district vulnerability to climate change.

Exposure refers to the exposure of a system of interest to stimuli that act on that system. This can be readily conceptualised as climate variability and/or the various changes in the climate system that are often of concern to stakeholders: temperature increases, rainfall variability and change (including extremes), or changes in the frequency or intensity of tropical cyclones.

Example: Frequency of drought weeks which is an exposure indicator in Jashpur is 11weeksin a year on an average which is high compared to Balod (4 weeks).

Sensitivity refers to the responsiveness of a system to climate hazards. This is often represented conceptually as a dose-response model – the more sensitive a system, the larger the rate or

[2] Vulnerability to climate change is the degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes.

magnitude of an adverse response to a given hazard. Sensitivity may vary considerably from one system, sector or population to another.

Example: Percentage of scheduled tribe's and scheduled caste population which is a sensitive indicator in Jashpur is 68% compared to 25.6% in Balod, thus Jashpur is highly vulnerable.

Adaptive capacity refers to the ability of a system to change in a way that makes it better equipped to manage its exposure and/or sensitivity to climatic influences.

Example: Level of urbanization is8.9% in Jashpur compared to 38.4% in Balod, thus the adaptive capacity indicators in Jashpur is not enough to manage its exposure and/or sensitivity to climatic influences making it highly vulnerable compared to Balod.

For the present study relative vulnerability approach is followed as it is useful when comparing vulnerability at a regional or global scale. Here the inter district comparison can be done as to which district 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.

Chhattisgarh State profile

Physiography

Chhattisgarh State lies between $17^0 46'$ to $24^0 5'$N Latitude and $80^0 15'$ to $84^0 20'$ East Longitude. The state is rich in Bio-diversity .It is also known as the 'Rice Bowl of India' and 'Herbal State.[3]Chhattisgarh has area of Total 1,35,191 sq. km and ranks 10th in India in order of area. Chhattisgarh borders the states of Madhya in the north-west, Maharashtra in the south-west, Andhra in the south, Odisha in the east, Jharkhand in the north-east and Uttar Pradesh in the north.

The state was formed on 1stNovember 2000 by partitioning 16Chhattisgarhi-speaking south-eastern districts of Madhya.[4]Raipur is its capital city. Currently the state comprises 27 districts.[5]Two new districts: Bijapur and Narayanpur were formed on May 11, 2007 and nine new districts are formed on January 1, 2012. The new districts have been created by carving out the existing districts to facilitate more targeted, focused and closer administration. These districts are Sukma, Kondagaon, Balod, Bemetara, Baloda Bazar, Gariaband, Mungeli, Surajpur and Balrampur.

The State of Chhattisgarh has the shape of Sea horse. Main physiographic components are the plains of Mahanadi Basin embanked by high plateaus and hills of Dandakaranya and Northern Hills. Overall the area looks like a very broad valley running west to east with a very gentle eastwardly slope. The main physiographic regions are sub-divided into

- Mountains (27% of State Geographical Area)
- Plateaus & Pat regions (9.29% of State Geographical Area)

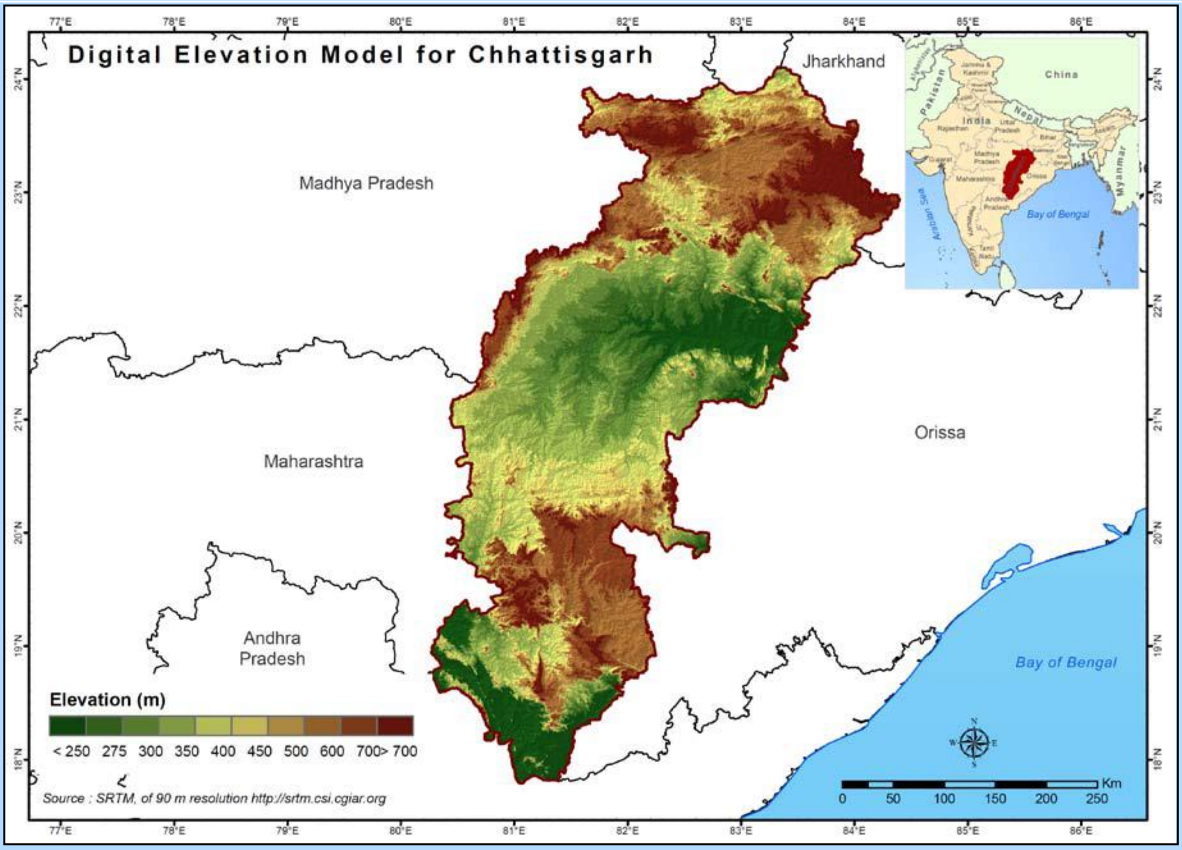
[3]Oil Palm Status in Chhattisgarh
[4]http://explore-chhattisgarh.blogspot.in/2013/03/about-chhattisgarh-census-population.html
[5]http://en.wikipedia.org/wiki/Chhattisgarh

- Plains & River Basins (43% of State Geographical Area).[6]

The topography of Chhattisgarh can be divided into many physiographic divisions. The Indo-Gangetic plain in the state is very fertile. The Satpura Range, Vindhyachal Mountain Range and the Maikal Range form the hilly terrain of Chhattisgarh. The Chhota Nagpur Plateau is another important topographical division of Chhattisgarh.

Geographical context of Chhattisgarh is shown in Figure 1.

Figure 1 : Geographical context of Chhattisgarh



The state is divided into three agro-climatic zones[7]Table 1 gives the details of the zones.[8]Figure 2 shows the agro climatic zones of the state.

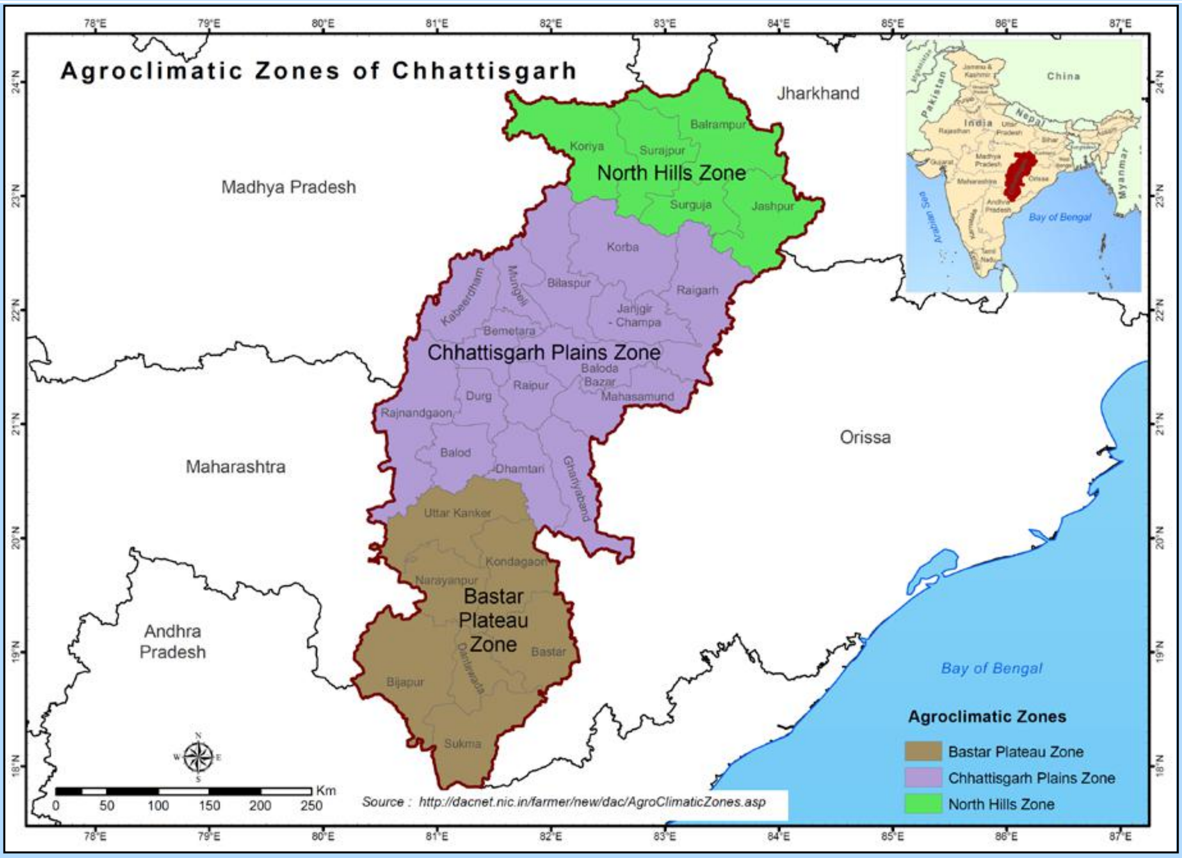
- Northern Hills in the Northern Chhattisgarh,
- Chhattisgarh Plains in Central Chhattisgarh, and
- Bastar Plateau in the South of Chhattisgarh.

Table 1: Agro-climatic zones (ACZs) of Chhattisgarh

[6] http://enviscecb.org/Dagori/3.SITE%20DETAILS.pdf
[7] Oil Palm Status in Chhattisgarh
[8] http://dacnet.nic.in/farmer/new/dac/AgroClimaticZones.asp?SCod=23

ACZs	Zonal Research Station	Districts	Suitable Crops
CG-1 Chattisgarh Plain Zone	Raipur	Durg, Raipur, Balaghat, Rajnandgaon, Bilaspur, Raigarh, Sarangarh and Gharghodatehils of Raigarh and Kanaker tehsil of Bastar.	Rice, Wheat, Maize, Sorghum.
CG-2 Bastar Plateau Zone	Jagdalpur	Bastar except Kanker tehsil.	Rice, Wheat, Maize, Sorghum.
CG-3 North Hill Zone of Chhattisgarh	Ambikapur	Surguja, Singrauli tehsil of Sidhi, Shahdol, Mandla and Jashpur, Dhamajaigarh tehsil of Raighar.	Rice, Wheat, Maize ,Sorghum

Figure 2 : Agro climatic zones of Chhattisgarh



Climate

The climate of Chhattisgarh is mainly tropical, humid and sub-humid. The central part of Chhattisgarh is hot because of its location at the Tropic of Cancer. May is the hottest month and December-January is the coldest months. The general climate of Chhattisgarh is dry sub-humid type where the annual potential evapo-transpiration is slightly higher than the annual rainfall.

During the summer season in Chhattisgarh, the temperature varies from 40^0C to 42.5^0C. The summer season prevails from April to middle of June. In summer very dry wind blows over most parts of the state.[9]

The climatic conditions of Chhattisgarh vary from region to region. The eastern plateau region is largely temperate but in some parts of the state, the climate is often hot. The eastern and Southern parts are humid. Rainfall also varies from region to region. The annual rainfall varies from 1100 mm to 1700 mm and the temperature ranges between 11^0C to 47^0C.

The average annual rainfall of the region is around 1400 mm and about 90 to 95% of this amount is received during south-west monsoon season (June-October). The monsoon sets in around June 10th in the tip of Bastar area and covers the entire area by June 25. Months of July and August are the wettest months. During September, the monsoon starts withdrawing from northern parts and by September 25th, the monsoon withdraws from the state. Rainfall in October month occurs due to cyclonic activity in the Bay of Bengal and October rainfall is most crucial for the productivity of rice in the state.[10]

Natural Resources

Water Resources

Mahanadi, Sheonath, Indravati, Arpa, Hasdeo, Kelo, Son, Rehar, and Kanhar are some of the main rivers. Most of the rivers in the state have a torrential regime characterized by high flow of water for three to four months during monsoon (June to September) during which around 80% of the annual runoff flows. Floods and droughts are the main characteristics of the annual flow of the rivers in Chhattisgarh requiring storage reservoirs for efficient use of the available surface water resources.[11]

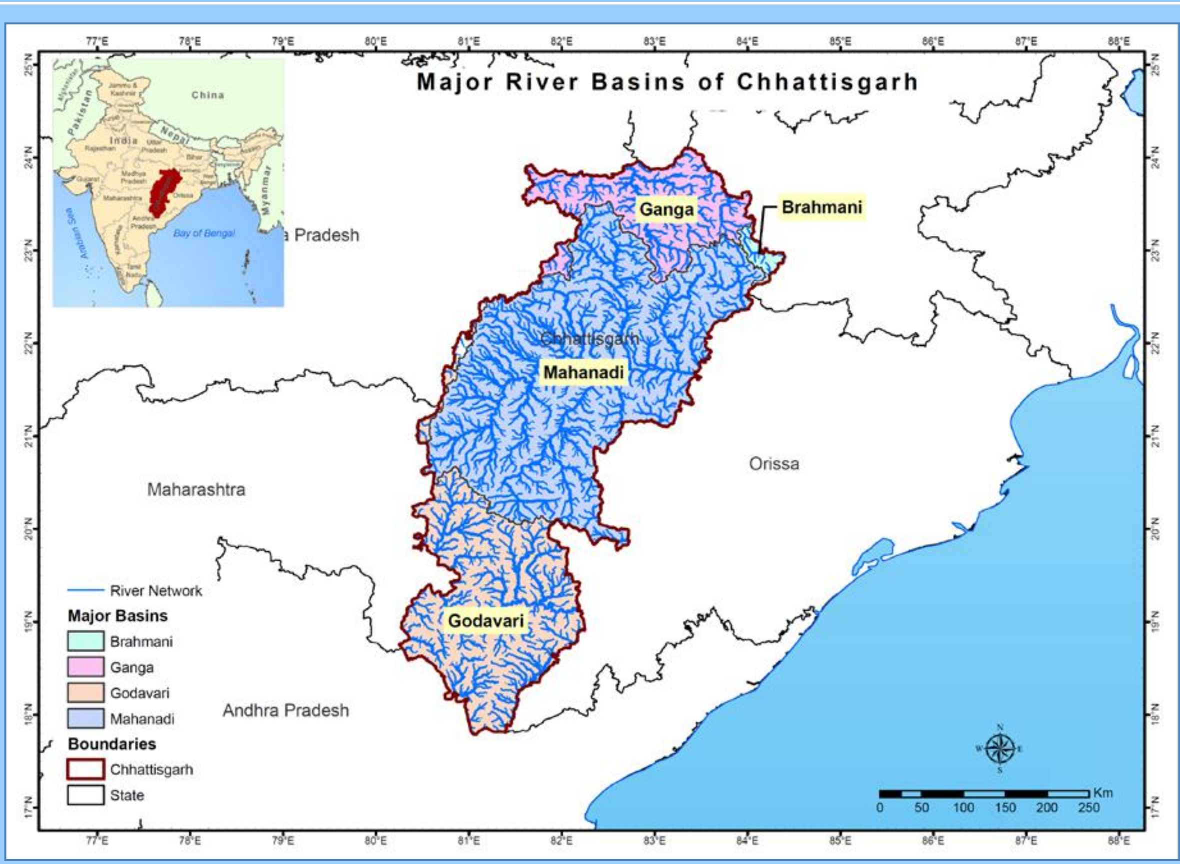
The geographical area of the state is divided into five river basins. Table 2 gives the details of the river basins of the state. Figure 3 shows the river basins of the state.

Table 2: River Basins of Chhattisgarh

River Basins	Area (sq km)	Percentage of total geographical area of the State
Mahanadi Basin (Seonath, Hasdeo, Mand, Ib, Pairi, Jonk, Kelo, Tel)	75858	56.2
Godavari Basin (Indravati, Sabari, Wainganga)	38694	28.6
Ganga Basin (Son)	18407	13.6
Narmada Basin	744	0.6
Brahmani Basin	1394	1

[9]Maps of India
[10]Oil palm status in Chhattisgarh
[11]Water Resources Department, Government of Chhattisgarh

Figure 3 : River basins of Chhattisgarh



Estimated surface water flowing through rivers is 48,296 million m^3 and due to various geographical and interstate constraints the usable surface water in the state is 41,720 million m^3. Surface water being used at present is only about 18,249 million m^3. Estimated ground-water in the state is 14,548 million $m^3$and present exploration is about 18.31%.

Land use

Chhattisgarh is rich in forest and mineral resources. The recorded forest area in the state is 59,772 km^2 which is 44.2% of its geographical area. Land use pattern in Chhattisgarh state mainly agriculture and forest with net sown area (34.16%), forest (46.04 %), about 3.79 % is fallows followed by 2.52% waste land (Table 3). Landuse map is shown in Figure 4.

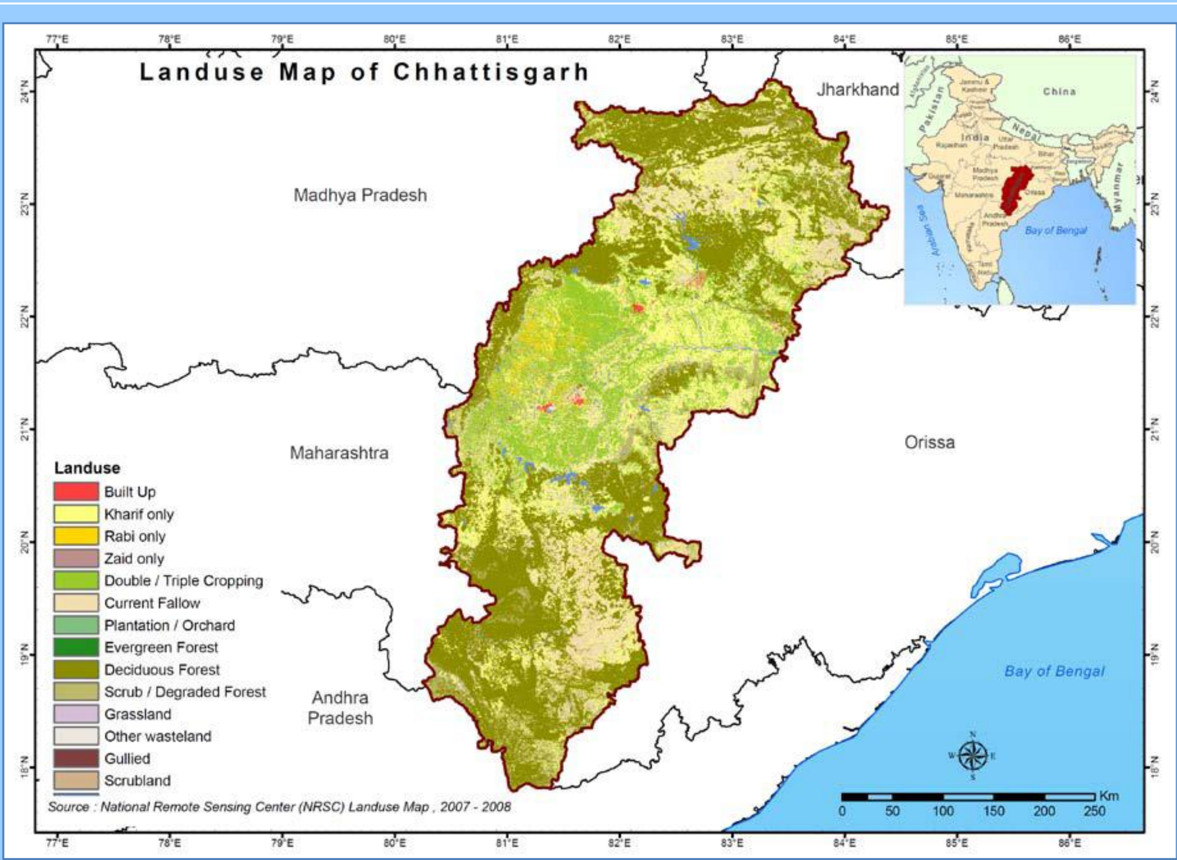
Table 3: Land use pattern of Chhattisgarh

Land Use	Area in '000 ha	Percentage
Total geographical area	13519	
Reporting area for land utilization	13790	100.0
Forests	6349	46.0
Not available for cultivation	1004	7.3
Permanent pasture and other grazing lands	855	6.2
Land under misc. tree crops and groves	1	0.01

Land Use	Area in '000 ha	Percentage
Culturable wasteland	347	2.5
Fallow lands other than current fallows	258	1.9
Current fallows	265	1.9
Net area sown	4710	34.2

Source: Land use statistics, Ministry of Agriculture, GOI, 2008-09

Figure 4 : Landuse of Chhattisgarh



Forest

The forests of the state fall under two major forest types, i.e., tropical moist deciduous forest and the tropical dry deciduous forest with about 22 varied forest sub-type.

The recorded forest area in the state is 59,772 km^2 which is 44.2% of its geographical area. Reserved, protected and unclassified forests constitute 43.13%, 40.21% and 16.65% of the total forest area respectively. The forest cover of state is placed at 55,674km^2 which is 41.18% of the states geographical area. According to forest survey of India assessment (2007) the extent of very dense forest is 4,163 km^2; dense forest 34,911km^{2}and open forest is 16,600 km^2. District wise forest cover of the state is shown in Table 4.The forest cover of the state is shown in Figure 5.

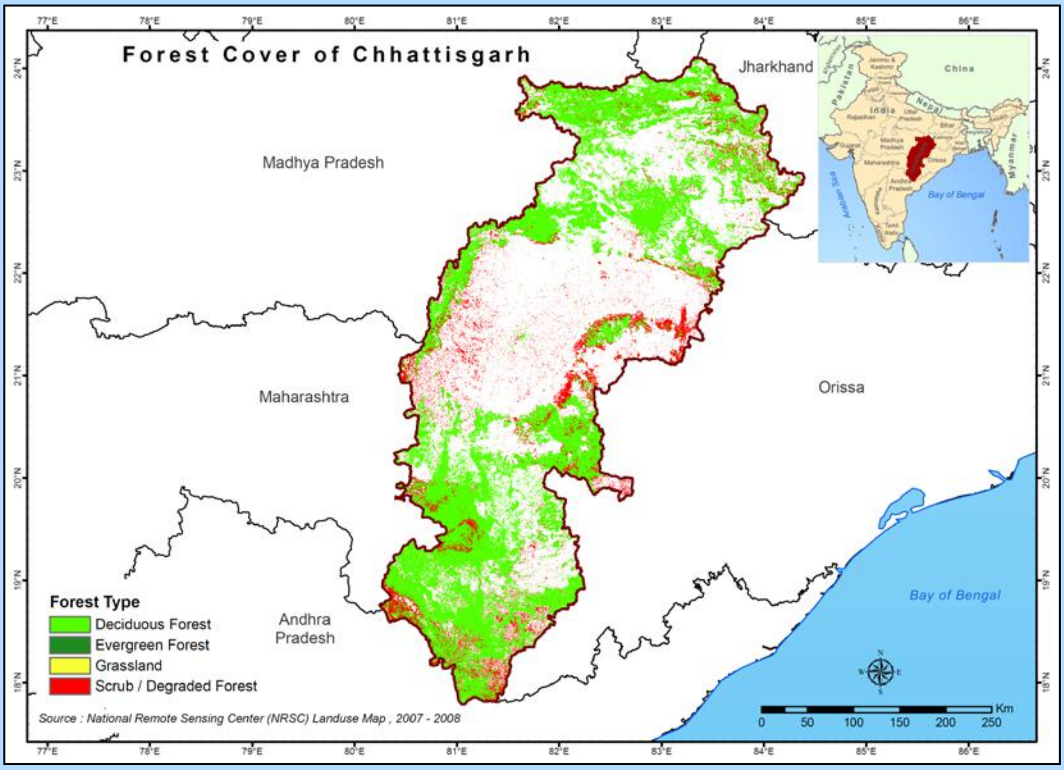
Sal (40.56%), Teak (9.42%) and Mixed (50.02%) are the three main forest types. Figures in brackets represent the proportion of the state forest area for the three types of forest.

Table 4: District-wise Forest Cover Area in Chhattisgarh

District	Geographic area	Forest Cover					Change*	Scrub
		Very Dense forest	Mod. Dense Forest	Open forest	Total	% of G.A.		
Bastar	14,974	1,349	4,333	2,329	8,011	53.50	0	11
Bilaspur	8,270	338	1,623	533	2,494	30.16	0	6
Dantewara	17,634	1,082	6,167	4,079	11,328	64,24	0	22
Durg	8,549	44	521	202	767	8.97	0	4
Janjgir-Champa	3,852	4	26	125	155	4.02	0	2
Jashpur	5,838	111	1,485	568	2,164	37.07	0	11
Kanker	6,506	215	2,044	835	3,094	47.56	0	2
Kawardha	4,223	70	1,126	389	1,585	37.53	0	4
Korba	6,599	203	2,306	840	3,349	50.75	0	6
Koriya	6,604	79	2,605	1,423	4,107	62.19	0	3
Mahasamund	4,789	4	534	422	960	20.05	-1	8
Raigarh	7,086	126	1,697	723	2,546	35.93	-2	13
Raipur&Dhamtari	16,468	189	3,837	1,.435	5,461	33.16	0	7
Rajnandgaon	8,068	29	1,771	720	2,520	31.23	-1	4
Sarguja	15,731	320	4,836	1,977	7,133	45.34	0	16
Grand Total	135,191	4,163	34,911	16,600	55,674	41.18	-4	119

Source: FSI Published report year 2011

Figure 5 : Forest cover of Chhattisgarh



Biodiversity

The state of Chhattisgarh houses an important part of that rich and unique biological diversity conspicuously rich in endemism with respect to many plants having medicinal importance.

Sal (Shorea Robusta) and Teak (Tectona grandis) are the two major tree species in the state. Other notable over-wood species are Bija (Pterocarpus marsupium), Saja (Terminalia tomentosa), Dhawra (Anogeissus latifolia), Mahua (Madhuca indica), Tendu (Diospyros melanoxylon) etc. Amla (Embilica officinalis), Karra (Cleistanthus collinus) and bamboo (Dendrocalamus strictus) constitute a significant chunk of middle canopy of the state forests. From the management point of view, there are four types of forests in the state of Chhattisgarh. These are Teak, Sal, Miscellaneous and Bamboo forests.

Biogeographically, the state falls in Deccan bio-region comprising representative fauna of central India like the tiger (Panthera tigris), leopard (Panthera pardus), gaur (Bos gaurus), sambhar (Cervus unicolor) , chital (Axis axis), nilgai (Boselaphus tragocamelus) and wild boar (Sus scrofa). The state is a proud possessor of rare wildlife like the wild buffalo (Bubalus bubalis) and hill myna (Gracula religiosa) which have been declared as rare and endangered. Apart from the species diversity, the state is also endowed with rich genetic diversity. The variation in the genetic composition of individuals within or among floristic and faunal species is large.[12]

Agriculture

Agriculture is the main economic activity of the state. Net sown area of the state is 4.828 million hectares and the gross sown area is 5.788 million hectares. Horticulture and animal husbandry also engage a major share of the total population of the state. About 80% of the population of the state is rural and the main livelihood of the villagers is agriculture and agriculture-based small industry.

The majority of the farmers are still practicing the traditional methods of cultivation, resulting in low growth rates and productivity. Considering this and a very limited irrigated area, the productivity of not only rice but also other crops is low.

The main crops are rice, maize, kodo-kutki and other small millets and pulses (tuar and kulthi); oilseeds, such as groundnuts (peanuts), soybeans and sunflowers, are also grown. [13].

Horticulture

Horticulture is growing popularity owing to the high value of horticulture produces than agriculture crops. Horticulture plays important role in livelihood security of poor farmers. It provides food security and perennial source of income to poorest of poor. It is a dynamic tool for ensuring ecological sustainability[14].

Fruit Crops - The major fruit crops grown in Chhattisgarh state are mango, guava, lime, litchi, cashew-nut, cheku etc., apart from these major fruit crops minor fruits like sitafal, bael, ber, anola etc., are also grown both as cultivated and wild crop. The total area of the fruit crops in the state is

[12]Forest Department (Government of Chhattisgarh)
[13]http://en.wikipedia.org/wiki/Chhattisgarh
[14]Directorate Horticulture and farm forestry Chhattisgarh

1,851,86.13 Ha along with the production of 15,691,80.54 MT in the year 2011-2012. Agro climatically Mango can be grown in the whole part of the state successfully while the northern hilly area of Sarguja and Jashpur district is suitable for production of litchi. Cashew nut can be grown well in the plateau region of the Bastar and Raigarh district

Vegetables - Main vegetable crops are Cucurbits, Beans, Cabbage, and Cauliflower. The total area of vegetable crops in the state was recorded 3,515,49.52 Ha in the year 2011-2012 with the production of 45,826,29.64 MT.

Spices - Chili, Ginger, Garlic, Turmeric, Coriander and Methi are the major spices grown in the state. The total area of spices recorded in year 2011-2012 was 826,37.76 Ha with the production of 5,413,88.84 MT.

Flowers - Area under flower cultivation is negligible in the state.. The present area under floriculture in the state is 8413 Ha with the production of 32,847.40 MT. approximately in the year 2011-2012.

Aromatic & Medicinal Plants - The medicinal crops grown in the state are Ashwagandha, Serpagandha, Satawar, Butch, Aonla, Tikhur etc. Some aromatic crops like Lemongrass, Pamarosa, Jamarosa, Patchauli, Ecitridora are promoted by the department for commercial cultivation among farmers. The present area of aromatic and medicinal crops in the state is 12,12.93 Ha with the production of 91,411.63 MT in the year 2011-2012.

Animal Husbandry and Dairying

The state has about 14.42million animal population out of which 9.49 million are cattle, 1.6 million are buffaloes and 3.32 million are other animals which includes sheep goat, horse and other species. State has about 14.24million poultry populations.[15]

The state's availability of milk as 'per capita availability of milk' is 126 gm/person in 2009-10, which increased to 128 gm/person in 2010-11 as against Indian average of 300 gm/person. State has 5 Integrated Dairy Project under 1005 center assistance in the tribal district of state-wise- Raigarh, Ambikapur, Jashpur, Korea & Kabirdham under NMPO.

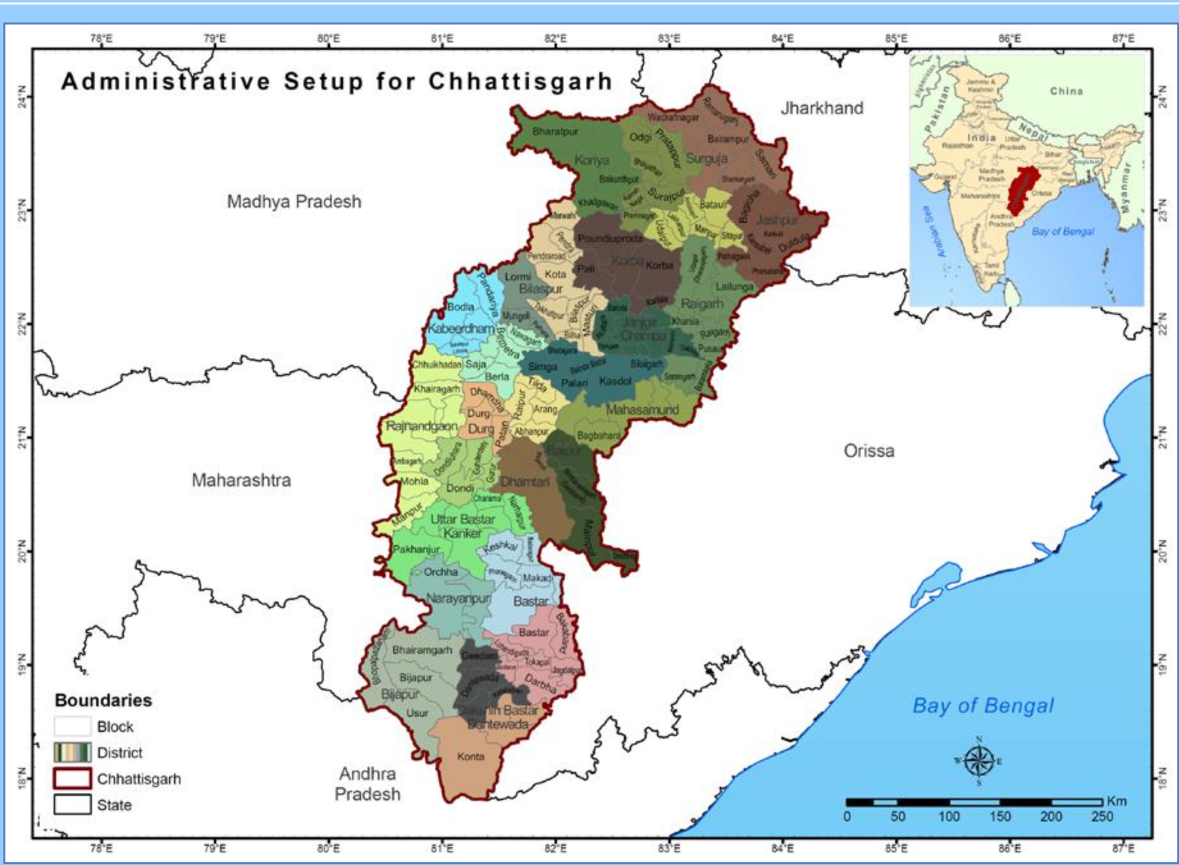
Paddy is the main crop of the state and animals survive on paddy straw for 7 to 8 months in a year. State has constituted Veterinary Council with the aim to provide standard Veterinary Practice in technical as well as infrastructure development.

[15]Department of Animal Husbandry, Government of Chhattisgarh

Demography

Chhattisgarh has been divided into three main revenue divisions broadly and further subdivided into 27 revenue districts with 146 tehsil / block and 19720 inhabited villages[16].(Figure 6).

Figure 6 : Administrative setup of Chhattisgarh



Chhattisgarh is primarily a rural state with only 20% of population residing in urban areas. According to the report from the government of India, at least 34% are Scheduled Tribes, 12% are Scheduled Castes and over 50% belong to official list of OBC. Plain area is numerically dominated by castes such as Teli, Satnami and Kurmi; while forest area is mainly occupied by tribes such as Gond, Halbi, Halba and Kamar/Bujia and Oraon.[17].

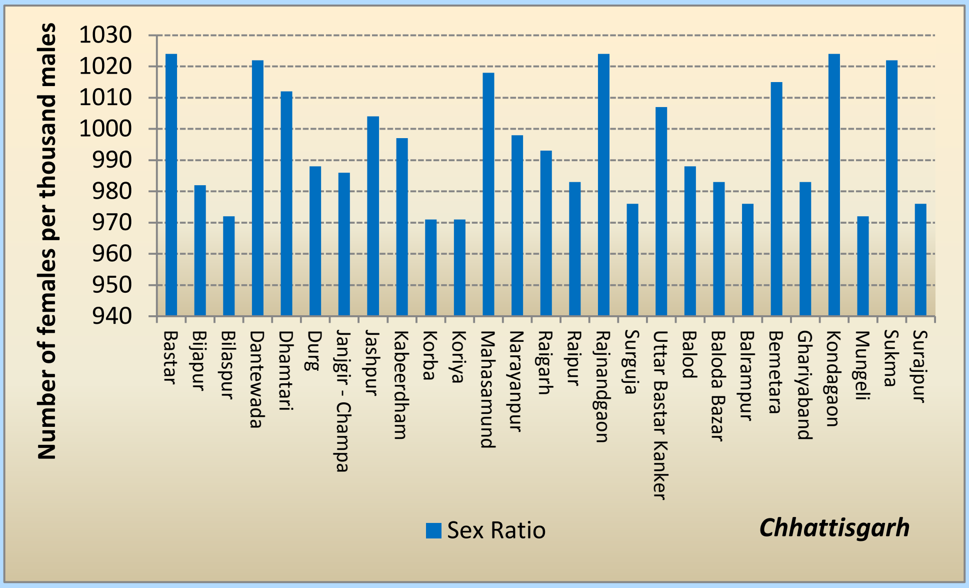
Total Population of Chhattisgarh is 2,55,40,196 as of 2011 census. Male and female population is 1,28,27,915 and 1,27,12,281 respectively. Population Density has increased from 154 to 189 per square km. Sex Ratio is recorded as 991 females per 1000 males, better than national average. Its rank is 5th in Sex Ratio, good for the state. Notably the sex ratio is found maximum in tribal districts of Chhattisgarh. Rural Sex Ratio is recorded 1002, and urban is 956. District wise sex ratio and density of population is shown in Figure 7.

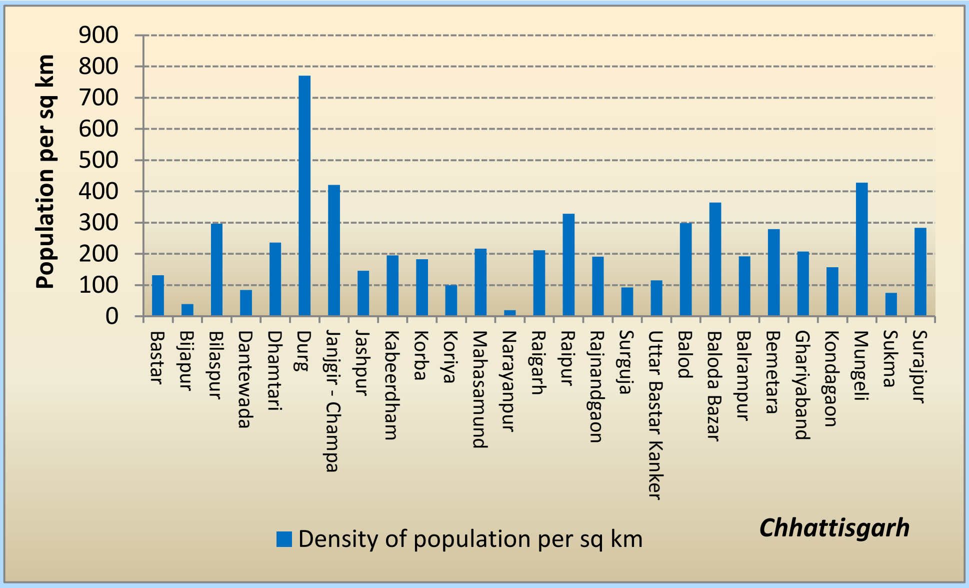
0-6 age group population is found 35,84,028 (35 Lakh). 18,24,987 are male children and 17,59,041 are female children. Child sex ratio declined from 975 to 964 in a decade. Literacy rate has increased

[16]http://cgstate.gov.in/web/animal-husbandry/about-us
[17]http://en.wikipedia.org/wiki/Chhattisgarh#Demographics

from 64.66% to 71.04%. Both male and female literacy has increased. Male literacy rate is recorded 81.45% and female rate is 60.59%. It is ranked 27th in literacy in India, this is very bad situation, because tribal area is less educated.[18].

Figure 7 : Demographic profile of Chhattisgarh





Economy

Chhattisgarh has relatively high growth rates of Net State Domestic Product -NSDP (8.2% vs. 7.1% All India over 2002-2008) and per capita NSDP (6.2% vs. 5.4% All India over 2002-2008). The growth rates of the said parameters are above the national averages and Chhattisgarh still has very low levels of per capita income as compared to the other states.

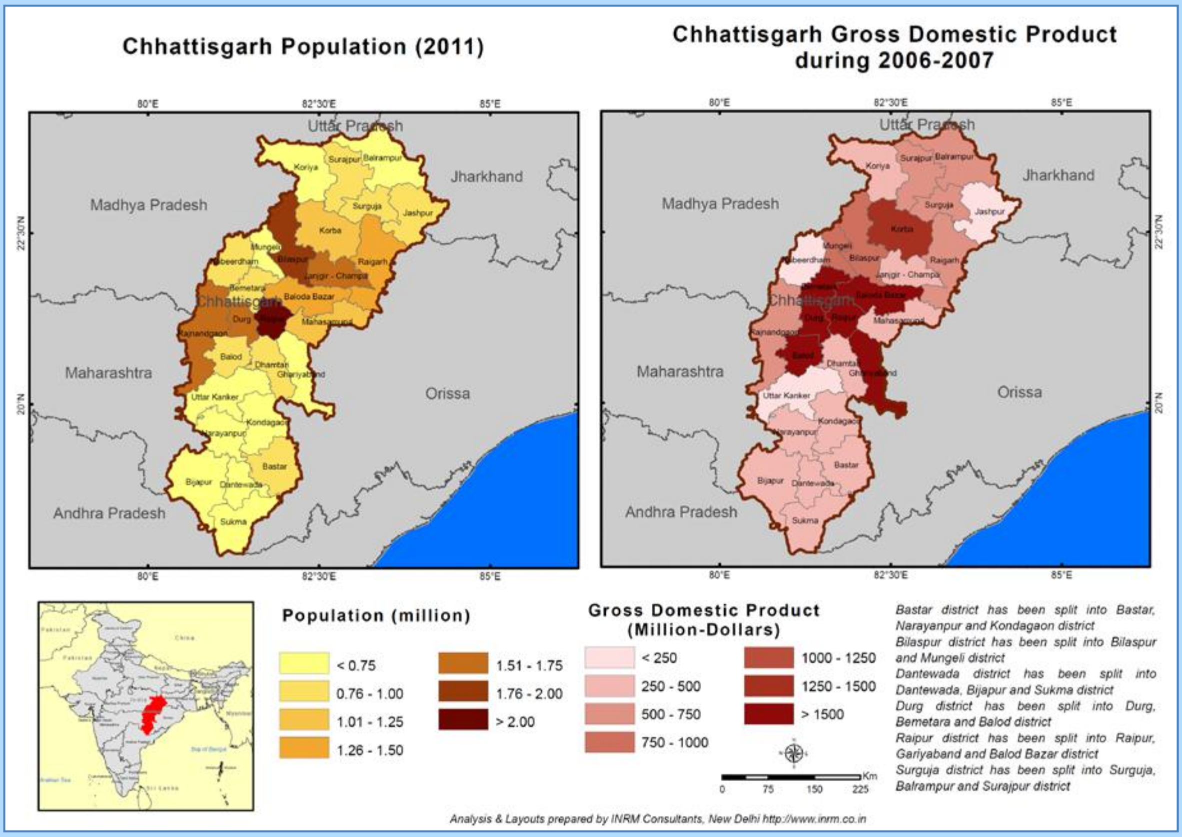
Chhattisgarh's gross state domestic product for 2010 is estimated at INR 601billion in current prices. The economy of Chhattisgarh has grown rapidly in recent years with a growth rate of 11.49 per cent

[18]http://explore-chhattisgarh.blogspot.in/2013/03/about-chhattisgarh-census-population.html

in GDP for 2009–2010. Chhattisgarh's success factors in achieving high growth rate are growth in agriculture and industrial production.[19]

District level gross domestic product (GDP) distribution of the state is shown in Figure 8.

Figure 8 : District Population and Gross domestic Product of Chhattisgarh



Infrastructure

Since its creation in 2000, the state has laid particular emphasis on improving social infrastructure through a focus on poverty alleviation and rural development.

Physical infrastructure like road and transport, irrigation, power, telecommunication etc contributes to economic growth through generation of income and employment and social infrastructure consisting of education, health, housing and financial infrastructure like banking and insurance contributes to the process of growth through generation of human capabilities and capacity building.

Physical infrastructure

Transport

Chhattisgarh has wide coverage of roads which have pan-nation connectivity. The district headquarters, tehsils and development blocks are well connected with good all-weather roads. 11 national highways passing through the state are together 2,184 km in length. This includes NH 6, NH

[19] http://en.wikipedia.org/wiki/Chhattisgarh

16, NH 43, NH 12A, NH 78, NH 111, NH 200, NH 202, NH 216, NH 217, NH 221,[National Highway 30(India)NH30].[20]

The state highways and major district roads constitute another network of 8,031 km. As of 2012, there are a total of 6635 passenger vehicles plying on 2316 roads of the state. Transport is coordinated through 22 computerised transport offices in the state. A motor and driving school has also been proposed to be established.

Almost the entire railway network spread over the state comes under the geographical jurisdiction of the South East Central Railway Zone of Indian Railways centred in and around Bilaspur, which is the zonal headquarters of this zone. The length of rail network in the state is 1,108 km.

The air infrastructure in Chhattisgarh is small compared to other states. Swami Vivekananda Airport in Raipur is its sole airport with scheduled commercial air services. The State Government has signed a MOU with the Airports Authority of India (AAI) in July 2013 to develop Raigarh Airport as the state's second airport for domestic flights.

Irrigation

The level of irrigation in Chhattisgarh is low. Irrigated area is just about one tenth of the total cultivated area in Chhattisgarh. The state has many rivers. Mahanadi, Indrawati, Sheonath, Rinand Hasdeo, Kelo, Mand, Eib, Pairi Sabari, and Arpa are some of the perennial river veins meandering through the state. [21]

These are important sources of irrigation as the water is present throughout the year. However, all these put together, irrigate only 20% of the cultivated land of the state, the rest depends on rain. The underground water potential has not been tapped in any of the regions. Water is available at depths of 50-150 ft. along the river belts.

The main source of irrigation is canals, which provide for three fourths of all irrigation, eight percent of the irrigation is done by tube wells, six percent by tanks and four to five percent by wells. A total of 4 major, 33 medium and 2199 minor irrigation projects have been completed and 5 major, 9 medium and 312 minor projects are under construction, as of 31 March 2006.[22]

Power

Chhattisgarh is one of the few states of India where the power sector is effectively developed. The Chhattisgarh State Electricity Board (CSEB) is in a strong position to meet the electricity requirement of the state. Chhattisgarh provides electricity to several other states because of surplus production and its power hubs are Korba and Bilaspur.

In Chhattisgarh, NTPC has a thermal plant with the capacity of 2100 MW at Sipat, Bilaspur, while CSEB's units have a thermal capacity of 1780 MW and hydel capacity of 130 MW. Apart from NTPC and CSEB, there are a number of private generation units of large and small capacity.

[20]http://en.wikipedia.org/wiki/Chhattisgarh
[21] Oil Palm status in Chhattisgarh
[22]http://en.wikipedia.org/wiki/Chhattisgarh

As per a study made by the Power Finance Corporation Ltd., New Delhi, the state has potential of 61000 MW of additional thermal power in terms of availability of coal for more than 100 years and more than 2500 MW hydel capacity.

Telecommunication

Across states, it has been found that teledensity was below 10 per cent in 2010 for Chhattisgarh.

Urban infrastructure

Chhattisgarh is a land locked state that is surrounded by six Indian states - Uttar Pradesh, Jharkhand, Orissa, Andhra Pradesh, Maharashtra and Madhya Pradesh. This makes its geographic location strategic. By developing its infrastructure the state can use its geographic location to develop a logistics and warehousing network to serve the region. [23]

The existing industrial areas, industrial parks, export zones etc. and those to be set up in future, will be connected by excellent roads with the national / state highways and important railway stations.

Industrial infrastructure

Chhattisgarh has several industrial parks / growth centres, which act as hubs of industrial development in the state. These include industrial parks in Bhilai, Korba, Borai in Durg, Urla in Raipur city, Siltara, Sirgitti in Bilaspur, among others.

These industrial estates are close to major cities and provide basic physical and social infrastructure facilities to industrial units. The Chhattisgarh State Industrial Development Corporation (CSIDC) manages these industrial estates. The state government has also set up a software technology park in Bhilai and another is being established at Korba.

Chhattisgarh State Industrial Development Corporation (CSIDC) has developed various Industrial Growth Centres & Industrial Areas namely Urla, Sarora, Bhanpuri, Rawabhata, Siltara in Raipur, Borai in Durg and Sirgitti, Tifra, Rani Durgawati in Bilaspur.

Social infrastructure

Education sector

Educational Institute (pre primary, primary, middle, high, higher secondary school) is 59432 in the state.[24]

With respect to literacy, the state fared just below the national average. The recent estimates from Census (2011) depict a literacy rate of 71 per cent (81.4% Males and 60.5% Females), which is close to the all India literacy rate of 74 per cent.

Health infrastructure

The two medical college hospitals at Raipur and Bilaspur have strength of over 1,000 beds offering a wide range of specialised services. Chhattisgarh has sexually transmitted diseases (STD) clinics

[23] http://pppinindia.com/infrastructure-chhattisgarh.php
[24] Statistical pocket book of Chhattisgarh 2010-11

established in all its districts. There are blood bank facilities in 12 districts in the state. Table 5 gives the details of the health institutions of the State.

Table 5: Health Infrastructure of Chhattisgarh

Health infrastructure	Number
District Hospitals	18
Community Health Centers	149
Primary Health Centers	755
Sub Health Centers	5111
Polyclinic	1
Civil Hospital	17
Leprosy hospital	3
State Health Family Welfare Centre	1

Source: Statistical pocket book of Chhattisgarh 2010-11

Chapter 2

Data and Methodology

Data and Methodology

Data Sources

Data for the 75 indicators used for the vulnerability analysis of districts of Chhattisgarh are collected from the following sources:

- Census of India 2011
- Analysis of CORDEX climate data (IITM, Pune)-SMHI
- Agricultural Census
- BPL Census 2002
- FSI data used
- Census of India, Chhattisgarh: Exp CG
- Chhattisgarh Annual Health Survey 2010-11, 2011-12
- Chhattisgarh Department of Animal Husbandry
- DACNET- District wise Crop Production Statistics
- DACNET- Landuse Statistics Report
- Directorate of Economics and Statistics, Government of Chhattisgarh
- Directorate, Animal Husbandry, Chhattisgarh
- DSSAT
- Dynamic vegetation models-IBIS and LPJ
- FSI database used
- IIRS database used
- Indiastat
- Open access digital elevation data used
- Rural Health Statistics in India 2012, Ministry of Health and Family Welfare, GOI
- Selected Educational statistics 2004-05
- Statistical pocket book of chhattisarh-2010-11
- SWAT Hydrological model outputs using observed weather, INRM Consultants

Sectors of vulnerability and the associated indicators

Vulnerability to climate change (CC) is a comprehensive multidimensional concept affected by large number of related indicators. These could be related to market, population and other socio-economic factors that act simultaneously together with climate change. Vulnerability due to climate change impacts can be of various types. The factors responsible for such changes are grouped into seven components viz., Social, Economic, Agriculture, Forest, Water Resource, Climate and Health.

Based on a number of studies that have been reviewed, data availability and time constraint a set of 75 indicators are identified for analysis. The exposure sub-index is comprised of the thirteen indicators measuring exposure to variability and extreme values of temperature and precipitation as well as to natural disasters from drought and flood. The sensitivity sub-index is comprised of thirty five indicators and the adaptive capacity sub-index is comprised of twenty seven indicators measuring social, economic, water resources, agriculture and forest related indicators.

Table 6depicts the indicators under each indicator and classifies them as adaptive capacity, sensitivity or exposure variable.

Table 6: Sectors of Vulnerability and the associated indicators

No.	Indicators	Abb	Conceptual Basis	Unit	Source	Time Period
Socio-economic Indicators						
Social						
1	Density of Population	DP	Sensitive	Persons/Sq Km	Census of India, Chhattisgarh: Exp CG	2011, 2050
2	Sex-ratio	SR	Sensitive	Number of females/1000 males	Census of India	2011
3	Literacy Rate	LR	Adaptive Capacity	Percentage	Census of India, Chhattisgarh: Exp CG	2011
4	Child Population in the age group 0-6	CP	Sensitive	Percentage	Census of India	2011
5	Rural households below poverty line	BPL	Sensitive	Percentage	BPL Census 2002	
6	Households with access to improved source of drinking water	DW	Adaptive Capacity	Percentage	Census of India	2011
7	Households having access to sanitation facility within the premises	SF	Adaptive Capacity	Percentage	Census of India	2011
8	Households having electricity as main source of lighting	EL	Adaptive Capacity	Percentage	Census of India	2011
9	Slum population	SP	Sensitive	Percentage to total population	Census of India	2011
10	Households living in a Kachcha House	KH	Sensitive	Percentage	Chhattisgarh Annual Health Survey 2010-11	2011
11	Households with access to communication/transport	COMTR	Adaptive Capacity	Percentage	Census of India	2011
12	Share of Marginal Workers	MGW	Sensitive	Percentage	Census of India	2011
13	Non working population	NWP	Sensitive	Percentage to total population	Census of India	2011
14	Medical institution (Community, Primary and Sub Health Centres, District and Divisional hospitals)	HC	Sensitive	Population Served per institution	Rural Health Statistics in India 2012, Ministry of Health and Family Welfare, GOI	2012
15	Primary, Upper Primary, Middle, Higher Secondary and Intermediate Schools	EI	Adaptive Capacity	Number/Lakh of population	Selected Educational statistics 2004-05	2004-05
16	Level of urbanization	UR	Adaptive Capacity	Percentage	Census of India	2011
17	Schedule Tribes and Scheduled Caste population	STSC	Sensitive	Percentage	Census of India	2011
Economic						
18	Per Capita Income(NDDP) at current prices	NDDP	Adaptive Capacity	Rupees Lakh	Directorate of Economics and Statistics, Government of Chhattisgarh	2007
19	Number of bank branches	BNK	Adaptive Capacity	Number/Lakh of	Indiastat	2005-2006

No.	Indicators	Abb	Conceptual Basis	Unit	Source	Time Period
				population		
20	Total Loan Advances to Total Deposits in Scheduled Commercial Banks	LATD	Adaptive Capacity	Percentage	Statistical pocket book of chhattisarh-2010-11	2007-2011
Environmental Indicators						
Agriculture						
21	Wheat Production	WP	Adaptive Capacity	kg/capita	Outputs from DSSAT crop modeling	1961-1990, 2021-2050
22	Rice Production	RP	Adaptive Capacity	kg/capita	Outputs from DSSAT crop modeling	1961-1990, 2021-2050
23	Maize Production	MP	Adaptive Capacity	kg/capita	Outputs from DSSAT crop modeling	1961-1990, 2021-2050
24	Net Area Sown	NSA	Sensitive	Percentage of the district geographical area	DACNET- Landuse Statistics Report	2001-2012
25	Net Irrigated Area by Ground Water	IAGW	Adaptive Capacity	Percentage to Net Sown Area	DACNET- Landuse Statistics Report	2001-2012
26	Net Irrigated Area by Surface Water	IASW	Adaptive Capacity	Percentage to Net Sown Area	DACNET- Landuse Statistics Report	2001-2012
27	Fertilizer Consumption	FC	Adaptive Capacity	Kg/ha	Indiastat	2002-2003, 2003-2004
28	Land Holdings area below 1 Hectare	LH	Sensitive	Percentage	Agricultural Census	2000-2001, 2005-2006
29	Wasteland	WL	Sensitive	Percentage of the district geographical area	DACNET- Landuse Statistics Report	2010-2012
30	Agricultural And Cultivators to Main Workers	ACMW	Sensitive	Percentage	Census of India	2011
31	Crop diversity	CRD	Adaptive Capacity	Number of crops grown	DACNET- District wise Crop Production Statistics	2001-2012
32	Cropping intensity	CI	Adaptive Capacity	Percentage	DACNET- Landuse Statistics Report	2001-2012
33	Livestock unit	LP	Adaptive Capacity	Per 1 lakh rural population	Chhattisgarh Department of Animal Husbandry	2007
34	Poultry Unit	POP	Adaptive Capacity	Per 1 lakh rural population	Chhattisgarh Department of Animal Husbandry	2007
35	Milk production per capita	MP	Adaptive Capacity	gms/day	Directorate, Animal Husbandry, Chhattisgarh	2007-2011

No.	Indicators	Abb	Conceptual Basis	Unit	Source	Time Period
36	Egg Production per capita	EP	Adaptive Capacity	Number	Directorate, Animal Husbandry, Chhattisgarh	2007-2011
Forest						
37	Biological richness	BR	Adaptive Capacity	Number	IIRS database used	1961-1990
38	Disturbance Index	DI	Sensitive	Number	IIRS database used	1961-1990
39	Canopy Cover	CC	Sensitive	Percentage	FSI database used	2011
40	Ground slope	GS	Sensitive	Percentage	Open access digital elevation data used	1961-1990
41	Forest dependence of rural communities	FD	Sensitive	Rural population density per sq. km of forest area	Census of India 2011 and FSI data used	2011
42	Vegetation shift	VS	Sensitive	Number	Dynamic vegetation models-IBIS and LPJ	2021-2050
Water Resource						
43	Surface Water availability in South West Monsoon season	SWSWM	Adaptive Capacity	m^3/capita	SWAT Hydrological model outputs, INRM Consultants	1961-1990, 2021-2050
44	Surface Water availability in North East Monsoon season	SWNEM	Adaptive Capacity	m^3/capita	SWAT Hydrological model outputs, INRM Consultants	1961-1990, 2021-2050
45	Ground Water availability in South West Monsoon season	GWSWM	Adaptive Capacity	m^3/capita	SWAT Hydrological model outputs, INRM Consultants	1961-1990, 2021-2050
46	Ground Water availability in North East Monsoon season	GWNEM	Adaptive Capacity	m^3/capita	SWAT Hydrological model outputs, INRM Consultants	1961-1990, 2021-2050
47	Crop water Stress(ET/PET) in South West Monsoon season	CWSSWM	Sensitive	Ratio	SWAT Hydrological model outputs, INRM Consultants	1961-1990, 2021-2050
48	Crop water Stress(ET/PET) in North East Monsoon season	CWSNEM	Sensitive	Ratio	SWAT Hydrological model outputs, INRM Consultants	1961-1990, 2021-2050
49	Frequency of Drought	DR	Exposure	Number of weeks	SWAT Hydrological model outputs, INRM Consultants	1961-1990, 2021-2050
50	Flood discharge	FL	Exposure	cumecs	SWAT Hydrological model outputs, INRM Consultants	1961-1990, 2021-2050
Climate						
51	Cool nights- days when minimum temperature < 10th Percentile	CN	Exposure	Percentage	Analysis of CORDEX climate data (IITM, Pune)-SMHI	1961-1990, 2021-2050
52	Warm nights- days when minimum temperature > 90th	WN	Exposure	Percentage	Analysis of CORDEX climate data (IITM,	1961-1990,

No.	Indicators	Abb	Conceptual Basis	Unit	Source	Time Period
	Percentile				Pune)-SMHI	2021-2050
53	Cool Days - Cool nights- days when maximum temperature < 10th Percentile	CD	Exposure	Percentage	Analysis of CORDEX climate data (IITM, Pune)-SMHI	1961-1990, 2021-2050
54	Warm Days - Cool nights- days when maximum temperature > 90th Percentile	WD	Exposure	Percentage	Analysis of CORDEX climate data (IITM, Pune)-SMHI	1961-1990, 2021-2050
55	Warm Spell Duration Indicator (Annual count of days with at least 6 consecutive days when maximum temperature>90th percentile)	WSDI	Exposure	Number of Days	Analysis of CORDEX climate data (IITM, Pune)-SMHI	1961-1990, 2021-2050
56	Cold Spell Duration Indicator (Annual count of days with at least 6 consecutive days when minimum temperature<10th percentile)	CSDI	Exposure	Number of Days	Analysis of CORDEX climate data (IITM, Pune)-SMHI	1961-1990, 2021-2050
57	Average annual rainfall	RF	Exposure	mm	Analysis of CORDEX climate data (IITM, Pune)-SMHI	1961-1990, 2021-2050
58	No. of Rainy Days	RD	Exposure	Number of Days	Analysis of CORDEX climate data (IITM, Pune)-SMHI	1961-1990, 2021-2050
59	Extremely Wet Days-Annual total rainfall when rainfall>99th percentile	EWD	Exposure	mm	Analysis of CORDEX climate data (IITM, Pune)-SMHI	1961-1990, 2021-2050
60	Consecutive Dry Days-maximum number of Consecutive Days With Rainfall Less Than 1 mm	CDD	Exposure	Number of Days	Analysis of CORDEX climate data (IITM, Pune)-SMHI	1961-1990, 2021-2050
61	Consecutive Wet Days-maximum number of Consecutive Days With Rainfall Less Than 1 mm	CWD	Exposure	Number of Days	Analysis of CORDEX climate data (IITM, Pune)-SMHI	1961-1990, 2021-2050
Health						
62	Persons suffering from Diarrhoea/Dysentery	DH	Sensitive	Persons Per 100,000 Population	Chhattisgarh Annual Health Survey 2010-11, 2011-12	2010-2012
63	Infant Mortality Rate	IMR	Sensitive	Percentage	Chhattisgarh Annual Health Survey 2010-11, 2011-12	2010-2012
64	Anopheles Mosquito Causing Malaria in January	MAJAN	Sensitive	Number of generations	SWAT Hydrological model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)-SMHI	1961-1990, 2021-2050
65	Anopheles Mosquito Causing Malaria in February	MAFEB	Sensitive	Number of generations	SWAT Hydrological model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)	1961-1990, 2021-2050
66	Anopheles Mosquito Causing	MAMA	Sensitive	Number of	SWAT Hydrological	1961-

No.	Indicators	Abb	Conceptual Basis	Unit	Source	Time Period
	Malaria in March	R		generations	model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)	1990, 2021-2050
67	Anopheles Mosquito Causing Malaria in April	MAAPR	Sensitive	Number of generations	SWAT Hydrological model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)	1961-1990, 2021-2050
68	Anopheles Mosquito Causing Malaria in May	MAMAY	Sensitive	Number of generations	SWAT Hydrological model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)	1961-1990, 2021-2050
69	Anopheles Mosquito Causing Malaria in June	MAJUNE	Sensitive	Number of generations	SWAT Hydrological model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)	1961-1990, 2021-2050
70	Anopheles Mosquito Causing Malaria in July	MAJULY	Sensitive	Number of generations	SWAT Hydrological model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)	1961-1990, 2021-2050
71	Anopheles Mosquito Causing Malaria in August	MAAUG	Sensitive	Number of generations	SWAT Hydrological model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)	1961-1990, 2021-2050
72	Anopheles Mosquito Causing Malaria in September	MASEP	Sensitive	Number of generations	SWAT Hydrological model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)	1961-1990, 2021-2050
73	Anopheles Mosquito Causing Malaria in October	MAOCT	Sensitive	Number of generations	SWAT Hydrological model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)	1961-1990, 2021-2050
74	Anopheles Mosquito Causing Malaria in November	MANOV	Sensitive	Number of generations	SWAT Hydrological model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)	1961-1990, 2021-2050
75	Anopheles Mosquito Causing Malaria in December	MADEC	Sensitive	Number of generations	SWAT Hydrological model outputs, INRM Consultants, CORDEX climate data (IITM, Pune)	1961-1990, 2021-2051

Rationale for classifying Indicators as Adaptive, Sensitive and Exposure

Table 7 explains the reasons for classifying indicators/variables of vulnerability as adaptive capacity, sensitivity or exposure.

Table 7: Reasons for classifying indicators of vulnerability as adaptive capacity, sensitivity or exposure

Indicators (Conceptual basis)	Rationale
	Social Indicators
Density of Population (Sensitive)	Districts experiencing rapid growth lack available quality housing and the social services network may not have had time to adjust to increased populations, all of which increase vulnerability.
Sex-ratio (Sensitive)	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 thus they have limited adaptive capacity.
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 livelihoods.
Child Population in the age group 0-6 (Sensitive)	The demographic group most affected by disasters, are children hence they are most vulnerable.
Rural households below poverty line (Sensitive)	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.
Households with access to improved source of drinking water (Adaptive Capacity)	Higher its percentage less would be the frequency of associated diseases to climate change.
Households having access to sanitation facility within the premises (Adaptive Capacity)	Accessibility to adequate excreta disposal facilities is fundamental to decrease the frequency of associated disease to climate change.
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.
Slum population (Sensitive)	Increase in this indicator is a sign of deteriorating living conditions in urban areas.
Households living in a Kachcha House (Sensitive)	Cyclone and flood cause larger damages to these houses hence these households are likely to be more vulnerable to hazardous impacts of climate change.
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.
Share of Marginal Workers (Sensitive)	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 district workforce employed in agriculture. A high level of agricultural dependency will increase the district's vulnerability to climate variability and fluctuations in agricultural terms of trade.
Non working population (Sensitive)	They do not have any source of income to sustain livelihood and thus are more vulnerable to climate change
Medical institution (Community, Primary and	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. Quality of

Indicators (Conceptual basis)	Rationale
Sub Health Centres, District and Divisional hospitals) (Sensitive)	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.
Primary, Upper Primary, Middle, Higher Secondary and Intermediate Schools Per Lakh of Population (Adaptive Capacity)	
Level of urbanization (Adaptive Capacity)	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.
Schedule Tribes and Scheduled Caste population (Sensitive)	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.
Economic Indicators	
Per Capita Income(NDDP) 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.
Number of bank branches (Adaptive Capacity)	Greater number of these banks in a district implies easy credit to small and marginal farmers; these play a pivotal role in the development and transformation of the rural and agrarian economy.
Total Loan Advances to Total Deposits in Scheduled Commercial 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.
Agriculture Indicators	
Wheat Production (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.
Rice Production (Adaptive Capacity)	
Maize Production (Adaptive Capacity)	
Net Area Sown (Sensitive)	A relatively higher area under cultivation implies higher relative importance of agriculture in the district and also that more area is affected
Net Irrigated Area By Ground Water (Adaptive Capacity)	Irrigation is an important adaptation-enabler as it enables farmers save crops during dry spells or droughts. It is also strongly related to technology adoption. Groundwater is the primary source of drinking water to nearly half of the world's population and, as the dominant source of water to irrigated land, is critical to global food security.
Net Irrigated Area By Surface Water (Adaptive Capacity)	Higher the net irrigated area by surface water implies pressure on groundwater abstraction for irrigation purposes is minimized hence the vulnerability of a district would be less.
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 income.
Land Holdings area below 1 Hectare (Sensitive)	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 shock

Indicators (Conceptual basis)	Rationale
Wasteland (Sensitive)	Productivity levels would be low and highly risky if crops are grown on degraded and waste lands
Agricultural And Cultivators to Main Workers (Sensitive)	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
Crop diversity (Adaptive Capacity)	Higher the crop diversity better is the coping in case of climate related disasters like flood, drought and pest incidences. It helps to mitigate climate change risks.
Cropping intensity (Adaptive Capacity)	Cropping intensity is defined as a ratio between net sown area (NSA) and gross cropped area (GCA) .Higher the index, greater is the efficiency of land use.
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 district implies greater ability to cope with climatic aberrations.
Poultry Unit (Adaptive Capacity)	Higher numbers indicate greater purchasing power of people of the districts thus contributes to improved livelihoods and local economic development.
Milk 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.
Egg Production per capita (Adaptive Capacity)	
Forest Indicators	
Biological richness (Adaptive Capacity)	Value of BR for a pixel (24x24 m2 area) denotes status of biodiversity and potential to host biodiversity in a pixel; higher potential stands for higher resilience and lower vulnerability. DI as part of BR accounts for level of stress on biological richness.
Disturbance Index (Sensitive)	DI accounts for the change in spatial structural attributes of forests compared to undisturbed situation; under disturbed situation species are under new order and competition; forest resilience is adversely impacted.
Canopy Cover (Sensitive)	Change in canopy cover results in change of on-site conditions (exposure) of temperature, desiccation, wind speed, light and invasive species; loss of canopy cover enhances the exposure and sensitivity of forests and adversely impacts adaptive capacity thus adding to inherent vulnerability.
Ground slope (Sensitive)	Propensity to landslides, soil disturbance and erosion due to higher ground slope enhances inherent vulnerability of forests
Forest dependence of rural communities (Sensitive)	Removal of leaf, fuel wood and other biomass impacts productivity and health of forests; seed removal impacts regeneration status; movement of people and cattle propagates disturbance and facilitates proliferation of invasive species and thereby adds to inherent vulnerability of forests.
Water Resource 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. If districts have larger availability of these water sources implies it is less vulnerable to climate change impact.
Ground Water availability (Adaptive Capacity)	
Crop water Stress(ET/PET) (Sensitive)	Increasing crop water stress in a district is bad for the crops
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.
Flood discharge	Increase in floods/droughts would add to stress on water resources, food

Indicators (Conceptual basis)	Rationale
(Exposure)	security, human health, and infrastructure, constraining development. Larger area susceptible to flood incidence implies high sensitivity.
Climate 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.
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.
Health Indicators	
Persons suffering from Diarrhoea/Dysentery (Sensitive)	Due to heat stress increase in vector borne diseases are killing mostly children and the poor.
Infant Mortality Rate (Sensitive)	High infant mortality is exacerbated because newborns are a vulnerable subgroup that is affected by air pollution
Anopheles Mosquito Causing Malaria (Sensitive)	Changes in temperature and rainfall may change the geographic range of vector-borne diseases such as malaria exposing new populations to it. Young children as well as pregnant women and their unborn children are especially vulnerable to malaria.

Data projections

- In this study, CORDEX-based mid-term (2030's, representing climatology over 2021-2050 climate change projections have been assessed for Chhattisgarh at the district-level). Projections available at a grid-spacing of 0.5°x0.5° resolution using single model (SMHI-RCA4) for RCP 4.5 (moderate emission scenario) has been used for Water Resources, Agriculture, Health and Climate sectors.
- DGVMs (Dynamic Global vegetation Models) - IBIS and LPJ are used to obtain future vegetation projections (midterm RCP 4.5 scenario) under projected climate change scenarios for forest sector.

Limitations of data

- As of 2014, Chhattisgarh has 27 districts, however data for most of the social indicators, economic indicators, 11 agriculture indicators and 2healthindicators are available for 16 or 18 districts only, since 9 districts Kondagaon, Mungeli, Sukma, Balod, Bemetara, Gariyaband, Baloda Bazar, Balrampur, and Surajpur have been formed in 2012and while 2 districts namely, Narayanpur and Bijapur have been formed in 2007 in Chhattisgarh. Therefore for these districts same data is used as the parent district from which they are carved, i.e. Kondagaon(Bastar), Mungeli(Bilaspur), Sukma(Dantewada), Balod(Durg), Bemetara(Durg), Gariyaband(Raipur), Baloda Bazar(Raipur), Balrampur(Surguja), Surajpur(Surguja), Narayanpur(Bastar) and Bijapur(Dantewada).
- 3 variables namely rice, wheat and maize yield have only been projected using DSSAT for midterm RCP 4.5 scenario. Due to the limitations of the data availability, data for rest of the agriculture indicators have been assumed to be the same as the base period.

- Due to the limitations of the data availability, data for socioeconomic indicators a have been assumed to be the same as the base period. Thus no midterm projections have been made for Socio Economic Vulnerability Indicators.
- Same time period data was not available for every indicator chosen for this study.
- Since required data was not accessible during the study period, most of the data used have been compiled from secondary sources available in public domain.
- Confidence level projections: At the time of preparation of this report only single regional model output for single AR5 scenario was available and the same has been used for the climate projections. In order to address uncertainties ensemble models (only for forest impact model climate outputs from GCM multi model ensemble has been used) are recommended. All the impact models used have their own limitations in terms of mimicking the reality along with the coarse input data used.

Software's used

- Commercial statistical software STATA or public domain R statistical software,
- Commercial GIS software ArcGIS or MapWindow Open Source GIS
- Microsoft Excel

Methodology

There are several methods for development of vulnerability index but most of them are having their own limitations. The limitation arises from the assumptions made about the indicators and assigning of weightage in the aggregate index.

To assess the vulnerability of the districts in Chhattisgarh a composite index is developed by multivariate analysis of individual **indicators** (social, economic, agriculture, water resource, forest, climate and health) which are vulnerable to climate change. In the development of aggregated indicators problems arise when the weights of each index have to be selected. 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 (Deressa, Hassan and Ringler, 2008[25]). Principal Components Analysis (PCA) is used as an approach to set the weights as a function of the explained variance (Jollands et al., 2004[26]).

After identification of the sectors, period of assessment and quantification of the variables/indicators, steps involved to assess the vulnerability of the 27 districts of Chhattisgarh are:

- Step 1: To classify indicators data (75 indicators) into 3 categories of adaptive capacity (27 indicators), sensitivity (35indicators), and exposure (13 indicators).
- Step 2: Normalize all the indicators data

[25]Deressa, Temesgen & Hassan, Rashid M. & Ringler, Claudia, 2008. "Measuring Ethiopian farmers' vulnerability to climate change across regional states:," Research briefs 15(5), International Food Policy Research Institute (IFPRI)
[26]Jollands, N., Lermit, J., Patterson, M., 2004.Aggregate eco-efficiency indices for New Zealand — a principal component analysis. Journal of Environmental Management 73, 293–305.

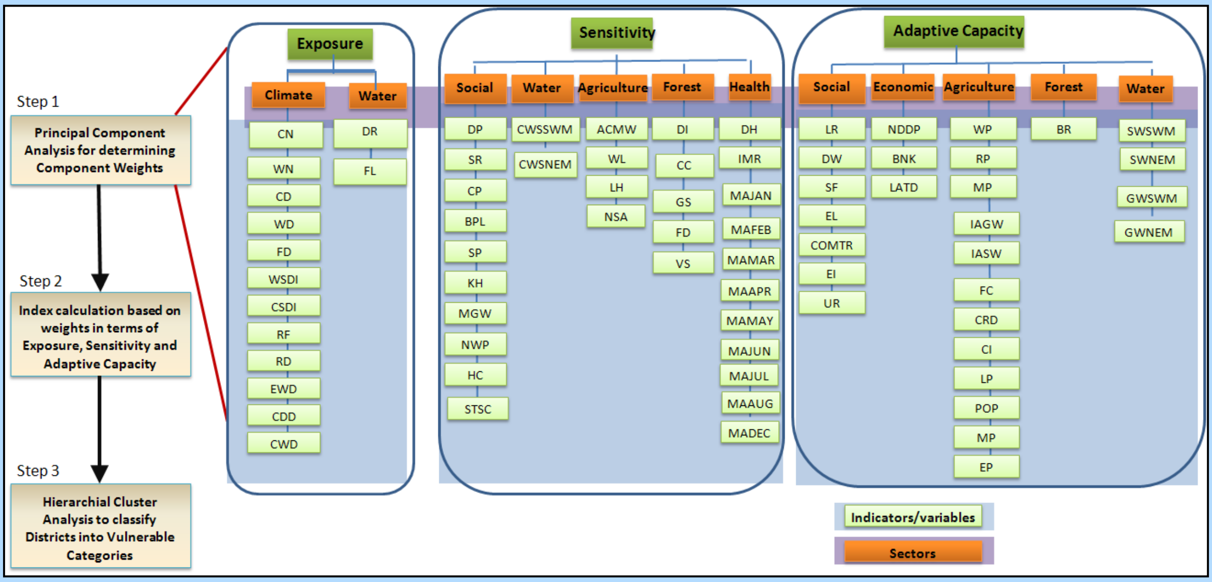
- Step 3: Determine unbiased weights using Principal component analysis (PCA) to calculate the weights of the indicators using statistical package STATA. Components with Eigen value greater than 1 have been used to calculate the weights.
- Step 4:Calculation of Drill down Indices and Composite Vulnerability Index
- Step 5: Rank districts are ranked based on the calculated index values. Rank 1: least vulnerable(Highest index values), Rank 27: most vulnerable(Lowest index values),
- Step 6: Perform cluster analysis on the calculated indices to group them in four categories of cluster-low(1),moderate (2), high (3) and very high (4)vulnerability. The outputs are shown spatially using maps.

The detailed explanation of these 6 steps is explained below:

Step 1: Classify indicator data into adaptive capacity, sensitivity and exposure

Section 2.2 and 2.3 gives the details of classifying the indicators. The indicators are classified into three classes, which consist of adaptive capacity, sensitivity, and exposure (Figure 9).

Figure 9 : Composite Vulnerability Index Flow chart



Refer Table 6 *for abbreviation of indicators*

Step 2: Normalization of indicator data

This step is to convert raw data into a normalized form. This is done

- to make the raw data unit free,
- to avoid one variable having an undue influence on the analysis,
- to get the relative position of each district in respect of the indicators.
- Normalized values always lie between 0 and 1.

NV = [X - minimum (X)]/[maximum (X)– minimum (X)], where NV = Normalized value of X

Step 3: Calculation of unbiased weights

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.[27]

Absolute values of the eigenvectors or the loadings are considered in order to derive the weights. To derive the weights following formula is used:

$W = \Sigma|Lij|.Ej$ where j=1, 2, 3,....n

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.

Step 4: Calculation of Indices

Vulnerability is calculated as:

Vulnerability = (adaptive capacity) - (sensitivity + exposure)

This can be written as:

$V = (wA1+wA2...wAn) - (wS1+wS2...wSn+wE1+wE2...wEn)$

Where V is vulnerability index, w is the weight obtained from the principal component scores, A1 to An are the adaptive indicators, S1, S2, ...,Sn are sensitivity indicators and E1, E2, ...,En are exposure indicators. In the calculation, both exposure and sensitivity are given negative signs because areas that are exposed to changing climate are more sensitive to damages. A higher net value indicates lesser vulnerability and vice versa.

- To construct the Composite Socio Economic Vulnerability index (CSEVI) by taking all indicators used to construct the Social Vulnerability Index (SVI) and Economic Vulnerability Index (ECVI) respectively.
- To construct the Composite Environmental Vulnerability Index (CENVI) by taking all indicators used to construct the Agriculture Vulnerability Index (AGVI), Water Resource Vulnerability Index (WRVI), Forest Vulnerability Index (FOVI), Climate Vulnerability Index (CLVI) and Health Vulnerability Index (HLVI).
- To construct the overall Composite Vulnerability Index (CVI) combining all indicators used to construct the SVI, ECVI, AGVI, WRVI, FOVI, CLVI and HLVI.

Step 5: Assign ranking to the districts

[27] Varimax rotation is an orthogonal rotation of the factor axes to maximize the variance of the squared loadings of a factor (column) on all the indicators (rows) in a factor matrix, which has the effect of differentiating the original indicators by extracted factor. Each factor will tend to have either large or small loadings of any particular variable. A varimax solution yields results which make it as easy as possible to identify each variable with a single factor. This is the most common rotation option.

Districts are ranked based on the indices values. Identify the districts which are most vulnerable to climate change by ranking the districts based on Composite Vulnerability Index.

Step 6: Grouping using Cluster analysis

Cluster analysis was performed on the indices to group the districts in four categories; very high, high, moderate and low according to their degree of vulnerability using Ward Method of Agglomeration [28].

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).

The variance (if) 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 $(\lambda i\ )/n$. 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.

[28]Ward's linkage is distinct from all the other methods because it uses an analysis of variance approach to evaluate the distances between clusters. In short, this method attempts to minimize the Sum of Squares (SS) of any two (hypothetical) clusters that can be formed at each step. In general, this method is regarded as very efficient.

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

Chapter 3

Climate – Current Baseline & Climate Projections

Climate – Current Baseline and Climate Projections

The long term trends in observed seasonal precipitation and temperature over Chhattisgarh using IMD gridded rainfall and temperature at daily time scales has been performed to arrive at current baseline climatology for the state. Summary is presented in the following paragraphs.

Data used

- IMD gridded rainfall at 0.5 degree spatial resolution for the time period 1971-2005 (35 years)
- IMD gridded maximum and minimum temperature at 1 degree spatial resolution for the time period 1969-2005 (37 years)

Observed Precipitation trends

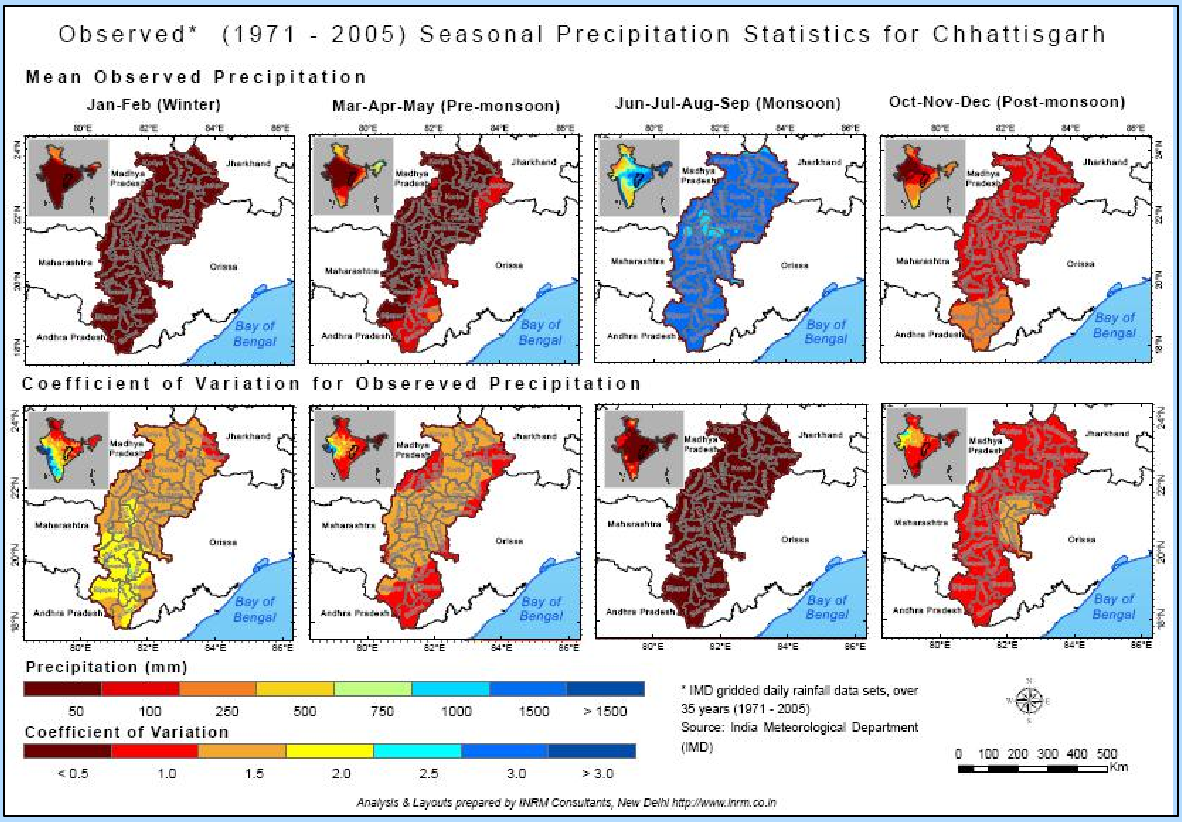
Rainfall in the state of Chhattisgarh varies considerably both in space and time from year to year. Table 8 gives the summary of observed rainfall statistics for Chhattisgarh.

Table 8: Observed Rainfall Statistics for Chhattisgarh (1971-2005)

Season	Statistics	Value	Contribution in Annual Rainfall (%)
Annual	Average (mm)	1287.6	
	Range - Average (mm)	1038.5 - 1790.9	
Winter (JF)	Average (mm)	79.1	6.1
	Range - Average (mm)	52.6 - 138.9	
Pre Monsoon (MAM)	Average (mm)	41.8	3.2
	Range - Average (mm)	19.6 - 132.1	
Monsoon (JJAS)	Average (mm)	1141.5	88.7
	Range - Average (mm)	903.2 - 1562.3	
Post Monsoon (OND)	Average (mm)	25.2	2.0
	Range - Average (mm)	11.2 - 48.2	
Annual	Range- Inter-annual variation	0.2 - 0.4	
Winter (JF)	Range- Inter-annual variation	0.6 - 1.4	
Pre Monsoon (MAM)	Range- Inter-annual variation	0.5 - 1.5	
Monsoon (JJAS)	Range- Inter-annual variation	0.2 - 0.4	
Post Monsoon (OND)	Range- Inter-annual variation	0.9 - 2	
Source: IMD Gridded rainfall data (1971-2005)			

Annual average rainfall for Chhattisgarh from 1971-2005(35 years) is 1287.6 mm. The mean south-west monsoon (June, July, August & September) rainfall (1141.5 mm) contributes 88.7% of annual rainfall. Mean monthly rainfall during July (372.5 mm) is highest and contributes about 28.9% of annual rainfall, followed by August (372.9 mm) which contributes about 29%. The mean rainfall during June is slightly lower and contributes about 15.3% of annual rainfall. September rainfall contributes 15.5 % of annual rainfall. Contribution of pre-monsoon (March, April & May) rainfall and post-monsoon (October, November & December) rainfall in annual rainfall is 3.2% and 2.0% respectively. Rainfall is highest during the monsoon season (June, July, August and September) and coefficient of variation[29] the lowest (Figure 10).Coefficient of variation is highest in the winter season.

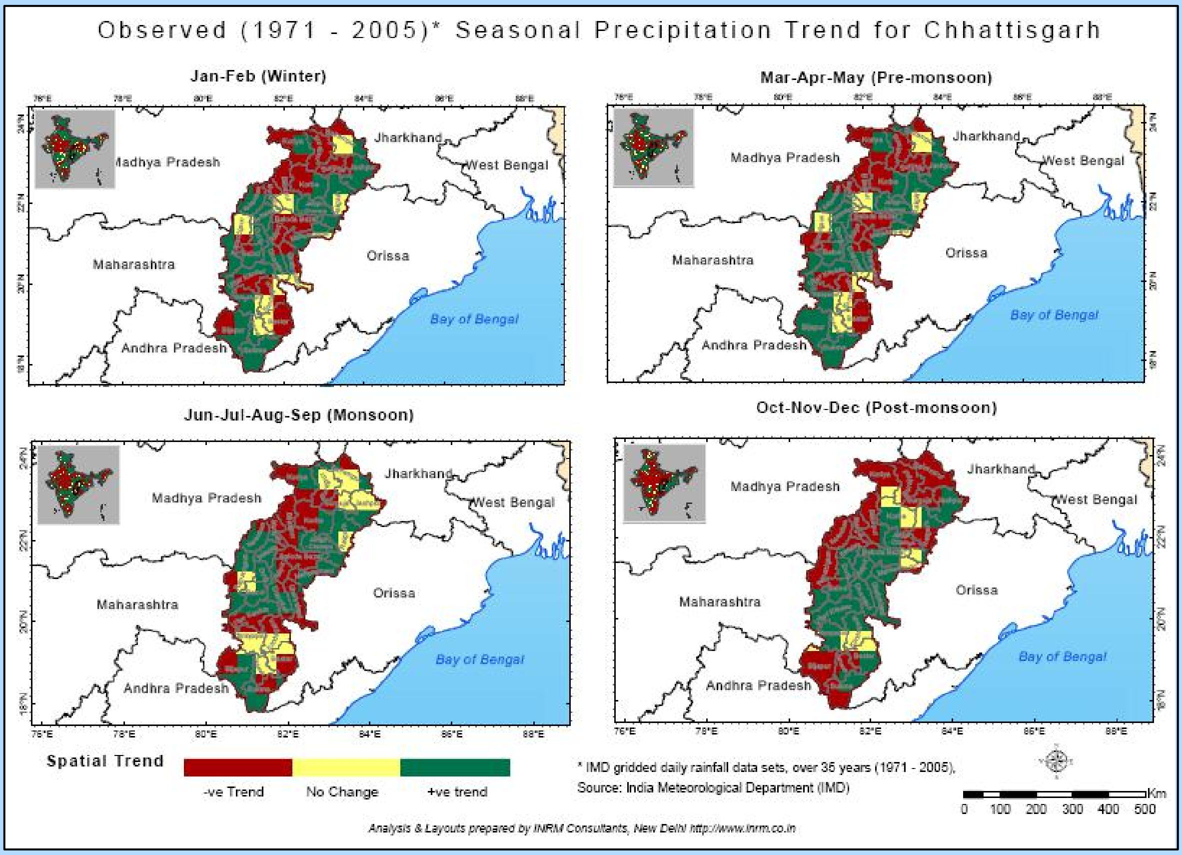
Figure 10 : Mean and Inter annual variation in seasonal rainfall in Chhattisgarh



Temporal variation in monthly, seasonal and annual rainfall over IMD grids belonging to Chhattisgarh has been made for the period from 1971 to 2005. Long term changes in rainfall determined by Man-Kendall rank statistics and linear trend has also been carried out. Figure 11 shows the spatial variation in the trend in seasonal precipitation.

[29]Coefficient Of Variation (CV): 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. Higher the CV, greater is the dispersion in the variable. Distributions with CV < 1 are considered low-variance, while those with CV > 1 are considered high-variance.

Figure 11 : Observed seasonal rainfall trend in Chhattisgarh



From Figure 11 it's seen that positive, negative and no change in trend is scattered in different regions of Chhattisgarh for winter, pre-monsoon and monsoon rainfall. While in the post monsoon season parts of North West, West and South western regions of Chhattisgarh show decreasing trend in rainfall, the other regions show positive trend or no change in rainfall for the observed period (1971-2005).

Rain has been regrouped into three broad categories (Pattanaik and Rajeevan, 2010[30]) for calculating extreme rainfall, i) light to rather heavy rainfall ($0 < R \leq 64.4$ mm), ii) heavy rainfall ($64.4 < R \leq 124.4$ mm) and iii) very heavy to exceptionally heavy rainfall ($R > 124.4$ mm). Rainfall > 124.4 mm is referred as extreme rainfall events. Figure 12 shows these events during monsoon and post monsoon period.

Average number of rainy days in Chhattisgarh during the south west monsoon is about 60 days and varies from 47 days to 72 days. Days when there are heavy precipitation events range from 1 to 3 days and similarly the exceptionally heavy rainfall days are less and is about 1 day.

[30] Pattanaik, D. R. and Rajeevan, M., 2010, Variability of Extreme Rainfall Events over India During Southwest Monsoon Season; 2010, Meteorological Applications Vol. 17, 88-104

Average number of rainy days in the state during the post monsoon (winter) is about 6 days and varies from 4 days to 9 days. Days when there are heavy precipitation events and exceptionally heavy rainfall events are negligible.

Figure 12 : Observed rainfall Statistics –Average Seasonal rainy days during Monsoon and Post-monsoon season

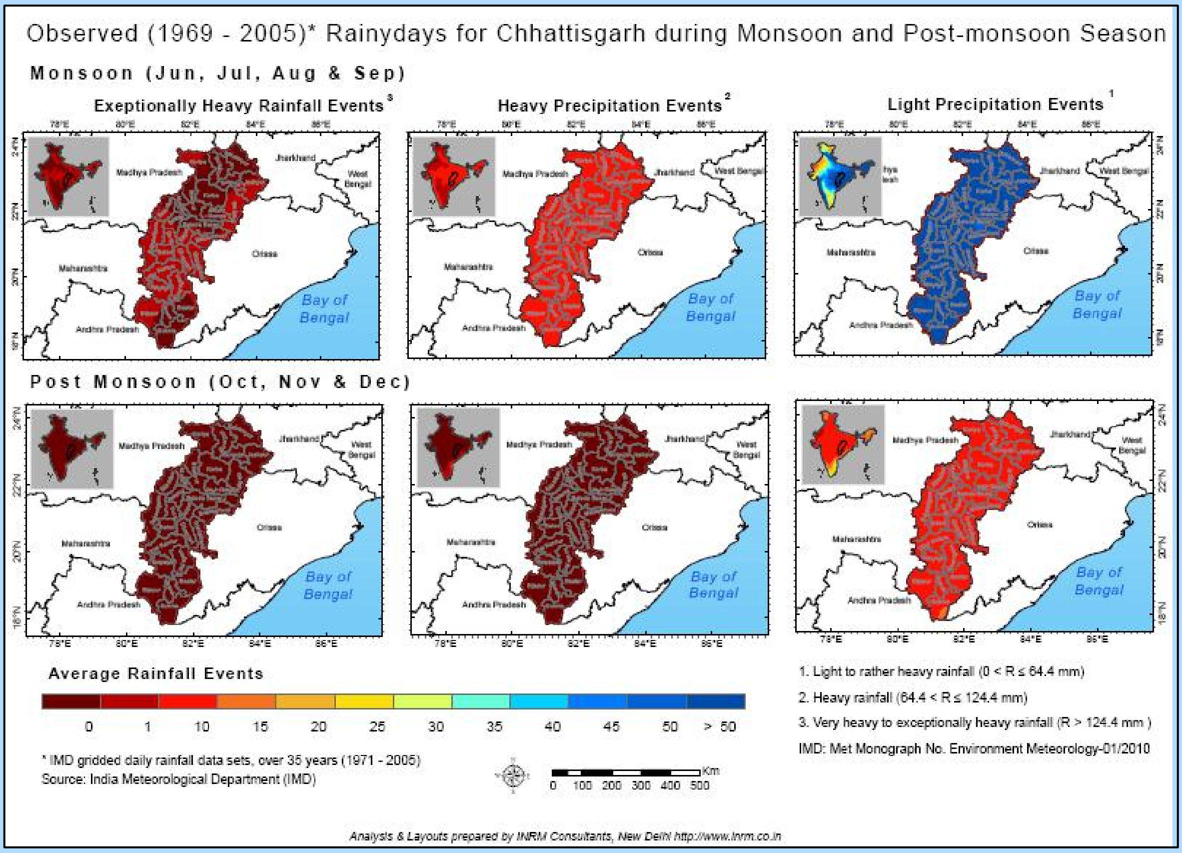
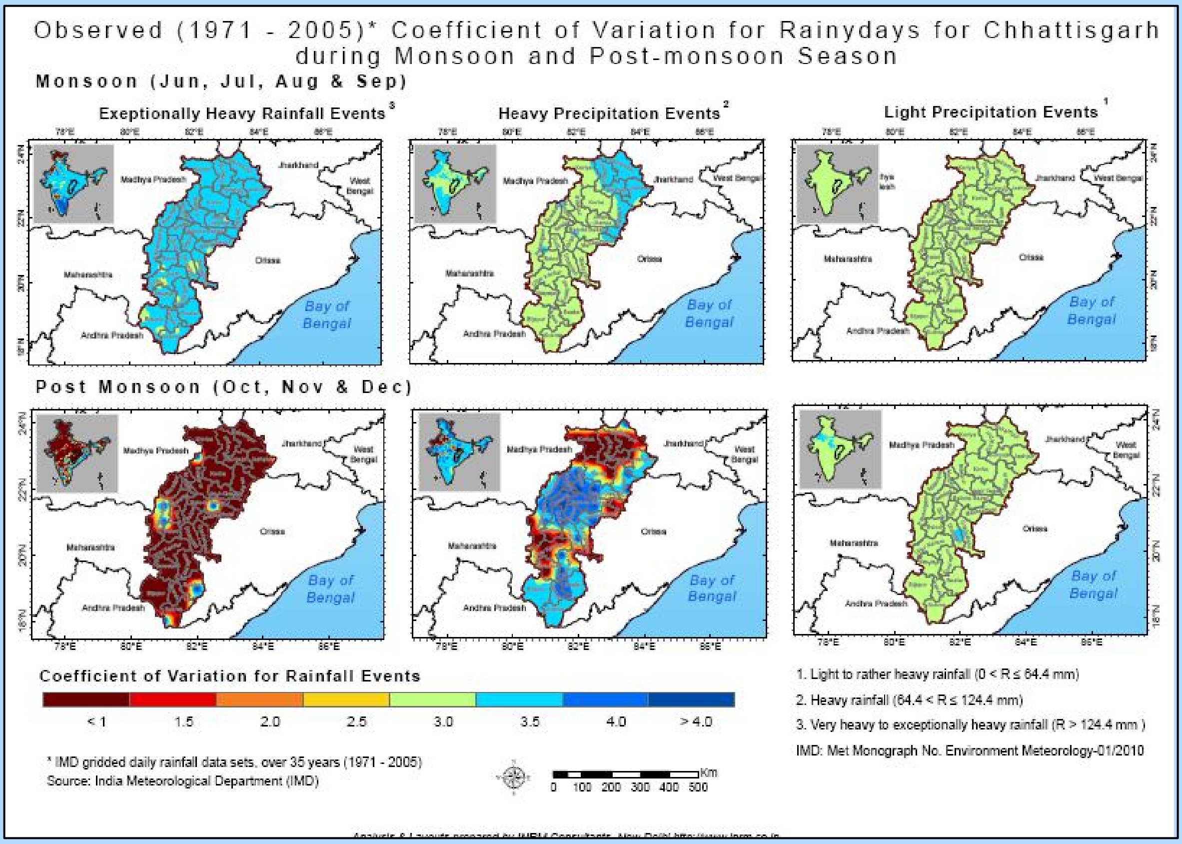


Figure 13 : Observed rainfall Statistics – Inter annual variation in rainy days during Monsoon and Post-monsoon season



There is a large inter annual variation observed for the districts in heavy precipitation days in the post monsoon season. Light precipitation days and exceptionally heavy rainfall events shows relatively less inter annual variation (Figure 13).

Observed Temperature trends

The state of Chhattisgarh shows a spatial as well as temporal variability. Table 9 gives the summary of annual and seasonal temperature statistics.

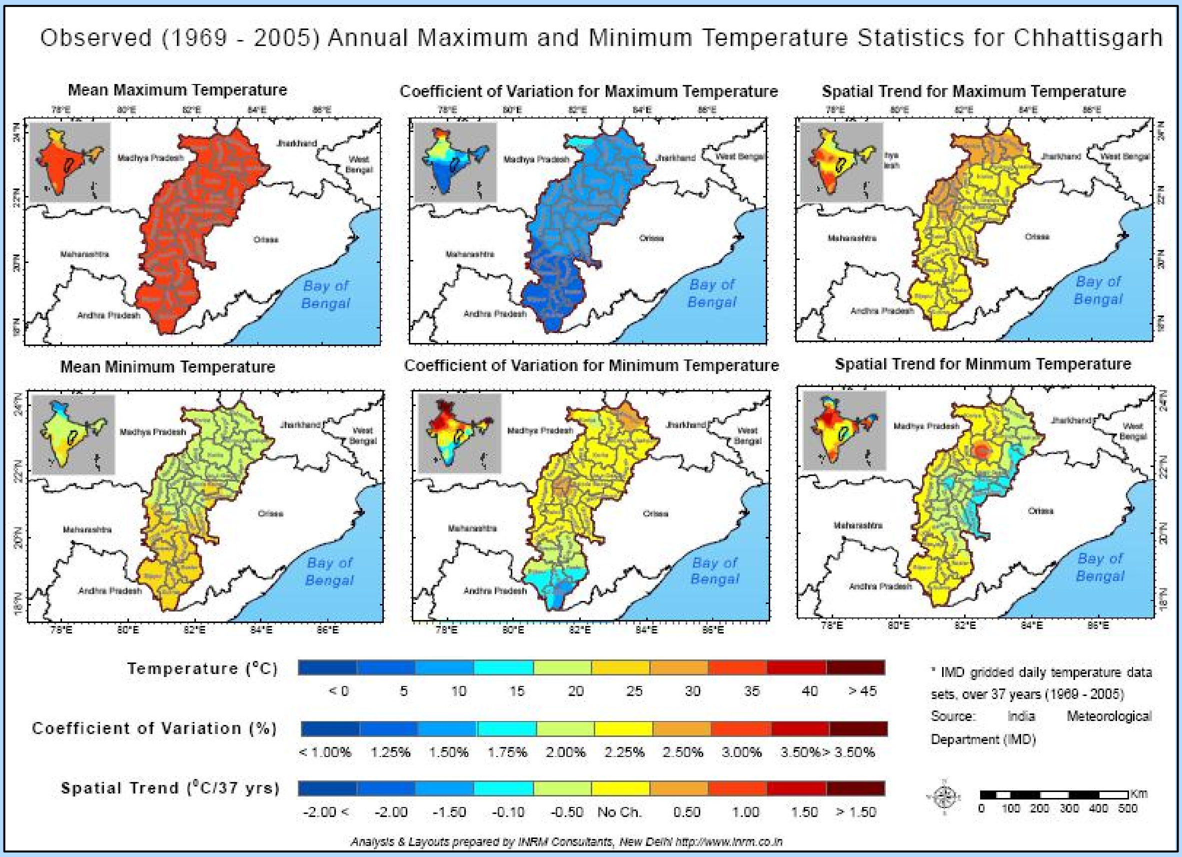
Table 9: Observed Temperature Statistics (1969-2005)

Season	Statistics	Maximum Temperature	Minimum Temperature
Annual	Average (mm)	32.0	19.7
	Range - Average (mm)	31.4 - 32.7	18.5 - 22.1
Winter (JF)	Average (mm)	27.8	13.2
	Range - Average (mm)	25.8 - 30.2	10.6 - 18.1
Pre Monsoon (MAM)	Average (mm)	37.6	22.5
`	Range - Average (mm)	36.3 - 38.5	20.9 - 24.5

Season	Statistics	Maximum Temperature	Minimum Temperature
Monsoon (JJAS)	Average (mm)	32.2	24.0
	Range - Average (mm)	31.8 - 32.7	23.7 - 24.4
Post Monsoon (OND)	Average (mm)	29.0	15.8
	Range - Average (mm)	28.2 - 29.9	14 - 19.5
Annual	Range- Inter-annual variation	0.01 - 0.01	0.01 - 0.02
Winter (JF)	Range- Inter-annual variation	0.02 - 0.03	0.04 - 0.07
Pre Monsoon (MAM)	Range- Inter-annual variation	0.02 - 0.03	0.02 - 0.03
Monsoon (JJAS)	Range- Inter-annual variation	0.02 - 0.02	0.01 - 0.02
Post Monsoon (OND)	Range- Inter-annual variation	0.02 - 0.03	0.04 - 0.06

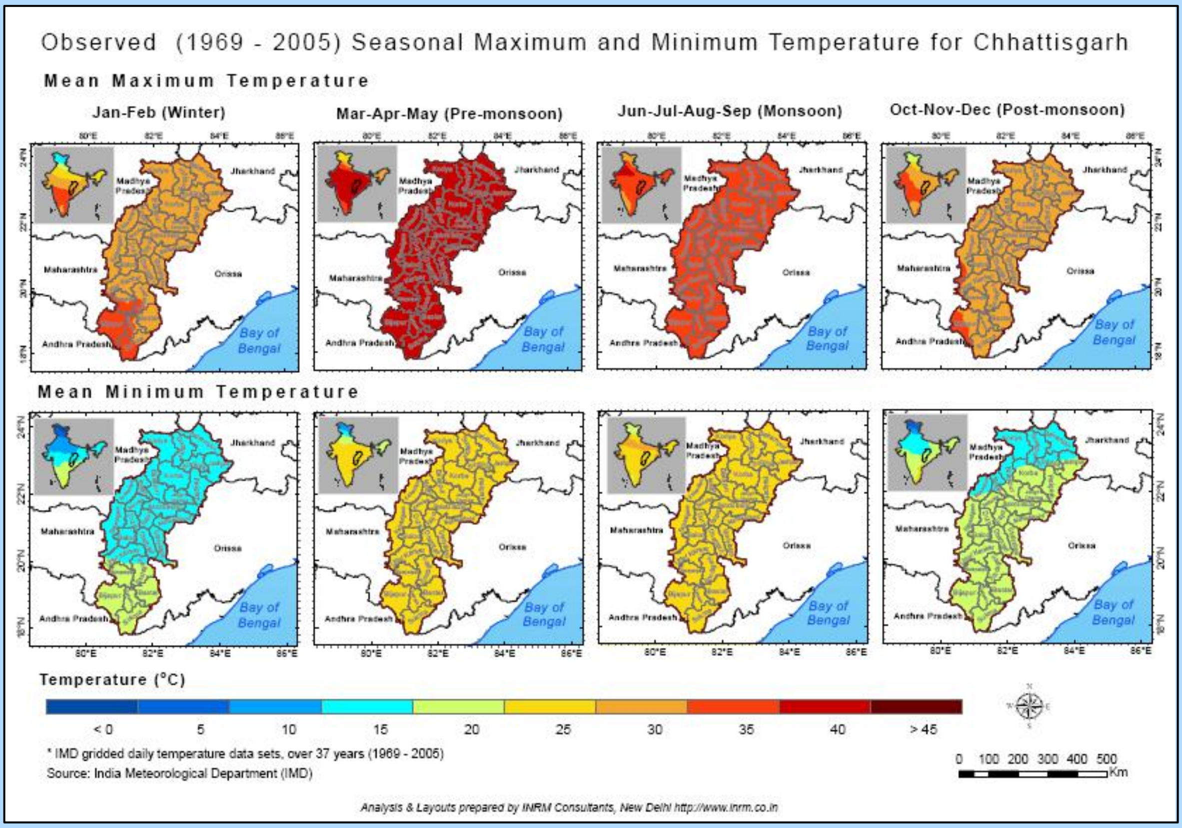
From Table 9 it can be seen that annual average maximum and minimum temperature for Chhattisgarh from 1969-2005 is 32.0^{0}C and 19.7^{0}Crespectively. Figure 14 depicts spatial variation in the long term statistics for mean maximum and minimum temperatures. There is no change in trend in mean maximum temperature for all the districts except for North Western districts namely Kabeerdham, Mungeli, Bemetara, Koriya, Balrampur and Surajpur which shows increasing trend ofabout0.5^{0}C while minimum temperature shows decrease of about 0.5^{0}C to 0.1^{0}C in 37 years in North eastern and Eastern districts of Chhattisgarh. Inter annual variation is higher for minimum temperature than maximum temperature. Spatial variation in mean annual maximum and minimum temperature is found to be around 2^{0}C and 4^{0}C respectively.

Figure 14 : Observed annual maximum and minimum temperature statistics in Chhattisgarh



As seen in Table 9, seasonal average maximum temperature is higher during pre-monsoon season (37.6^{0}C) and ranges between 36.3^{0}C to 38.5^{0}C. Similarly seasonal average minimum temperature is lowest during winter period (13.2^{0}C) and ranges from 10.6^{0}C to 18.1^{0}C. Figure 15 shows the observed seasonal maximum and minimum temperature for Chhattisgarh. Spatial variation in average maximum and minimum temperature is observed in winter and post monsoon season.

Figure 15 : Observed seasonal maximum and minimum temperature in Chhattisgarh



Climate Change Scenarios

During the initial phase of the project climate projection from IPCC AR4 was available. Later in the project, access to IPCC AR5 regional climate data for one model became available. Both the climate change model outputs are used for the current study. The following paragraphs carry description of IPCC AR4 followed by IPCC AR5 climate change projections.

IPCC AR4 Projections

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 to provide estimates for the full suite of greenhouse gases and the 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, published in the IPCC Special Report on Emission Scenarios (IPCC SRES November 2000). These scenarios provided input into the Third and Fourth Assessment Reports and were the basis for evaluating climatic and environmental consequences of different levels of future greenhouse gas emissions and for assessing alternative mitigation and adaptation strategies. These scenarios refer to the predictions made for future conditions mainly related to precipitation, sea level rise and temperature changes based on 'storylines' of the alternate greenhouse gas emissions. There are four storylines (A1, A2, B1 and B2) identifying alternate states of future economic and technological development that takes place over the next few decades as summarized in Table 10.

Table 10: Summary of IPCC SRES Scenarios

IPCC SRES Scenarios	
A1 World: Market Oriented Economy: Rapid economic growth. Population: Peaks in 2050 and then gradually declines. Governance: A convergent world - income and way of life converge between regions. Extensive social and cultural interactions worldwide. Technology: There are three subsets to the A1 family A1FI - fossil-fuels intensive. A1B - balanced on all energy sources. A1T - non-fossil energy sources.	A2 World: Divided World Economy: Regionally oriented, lowest per capita income Population: Continuously increasing population. Governance: independently operating, self-reliant nations Technology: Slower and more fragmented
B1 World: Convergent Economy: service and information based, lower growth than A1 Population: Same as A1. Governance: global solutions to economic, social and environmental stability Technology: clean and resource efficient technologies	B2 World: Local Solutions Economy: Intermediate levels of economic development Population: Continuously increasing population, but at a slower rate than in A2. Governance: local solutions to economic, social and environmental stability Technology: more rapid A2, less rapid more diverse A1/B1
Source: IPCC 4th Assessment Report (2007)	

Climate models are mathematic models used to simulate the behaviour of climate system. They incorporate information regarding climate processes, current climate variability and the response of the climate to the human-induced drivers. These models range from simple one dimensional models to complex three dimensional coupled models. The latter, known as Global Circulation Models (GCM), incorporate oceanic and atmospheric physics and dynamics and represent the general circulation of the planetary atmosphere or ocean. The GCMs are usually run at very course grid (about 3^0 X3^0) resolution whereas the processes that are of interest for studies such as this one, such as precipitation, are highly influenced by the local features namely orography and land use. These local characteristics are not properly represented at the coarse scale of GCM and contribute to prediction errors on the impact of climate change at the sub-grid scale. Therefore, these GCMs are strengthened with the incorporation of local factors and downscaled, in general with a grid resolution of about 0.5^0X0.5^0 or less. The downscaling can be of dynamic or statistical type. These models are referred to as Regional Climate Models (RCM) and improve the quality of climatic prediction for specific local areas.

A RCM is a model of the atmosphere and land surface which has high horizontal resolution and consequently covers a limited area of the earth's surface. A RCM cannot exist without a 'parent' GCM to provide the necessary inputs. The RCMs provide an opportunity to dynamically downscale global model simulations to superimpose the regional detail of specified region. RCM provide climate information with useful local detail including realistic extreme events and also they simulate current climate more realistically.

A regional climate model:

- Is comprehensive physical high resolution (~50km) climate model
- Covers a limited area of the globe
- Includes the atmosphere and land surface components of the climate system
- Contains representations of the key processes within the climate system (e.g., cloud, radiation, rainfall, soil hydrology)

Advantages of Regional climate models include

- highly resolved information
- physically based character
- many indicators
- Better representation of the mesocale and weather extremes than in GCMs.

Disadvantages of Regional climate models include

- computational expensiveness, particularly for long runs
- lack of two way nesting (feedback with the forcing GCM input)
- dependence on usually biased inputs from the forcing GCM
- errors in the GCM fields that could result in errors in the regional climate scenarios
- Availability of fewer scenarios.

Providing Regional Climates for Impact Studies (PRECIS) is an atmospheric and land surface model of limited area and high resolution which is locatable over any part of the globe. Dynamical flow, the atmospheric sulphur cycle, clouds and precipitation, radioactive processes, the land surface and the deep soil are all described and lateral boundary conditions (LBCs) are required at the limits of the model's domain. Information from every aspect may be diagnosed from within the model (Noguer et al., 1998[31]).

PRECIS can be applied easily to any area of the globe to generate detailed climate change predictions and is used for vulnerability and adaptation studies and climate research.

Regional Climate Scenarios for India Using PRECIS (AR4)

PRECIS is the Hadley Centre portable regional climate model, developed to run on a PC with a grid resolution of 0.44° x 0.44°. High-resolution limited area model is driven at its lateral and sea-surface boundaries by output from global coupled atmosphere-ocean (HadCM3) and global atmospheric (HadAM3) general circulation models. PRECIS captures important regional information on summer monsoon rainfall missing in its parent GCM simulations.

[31]Noguer M, Jones R, Murphy J (1998) Sources of systematic errors in the climatology of a regional climate model over Europe.ClimDyn 14:691–712

Indian RCM PRECIS has been configured for a domain extending from about 1.5°N to 38°N and 56°E to 103°E. IPCC SRES A1B Scenario[32]– Q14 Qump (Quantifying Uncertainty in Model Predictions[33]) for the time slices of present (1961–1990), mid-term (2021-2050) and end century (2071–2100) has been made available by IITM Pune.

Simulations from a seventeen-member perturbed physics ensemble (PPE) produced using HadCM3 under the Quantifying Uncertainty in Model Predictions (QUMP) project of Hadley Centre Met Office, UK have been used as LBCs for 138 year simulations of the regional climate model PRECIS. The QUMP simulations comprise 17 versions of the fully coupled version of HadCM3, one with the standard parameter setting and 16 versions in which 29 of the atmosphere component parameters are simultaneously perturbed (Collins et al. 2006[34]).

Having discussed the RCM scenarios that have been deployed so as to extract input to the hydrological model SWAT, for evaluating the impacts of climate change.

Climate change Data Extraction (AR4)

Data for many different indicators (Physical quantities, Rainfall, Temperature, Solar Radiation, Relative humidity, Wind speed) at a variety of different timescales; daily, monthly are used for the study area. All model data represent grid cell averages, i.e. an average quantity over a 2500 km^2 (50 km X 50 km) and are available in binary format.

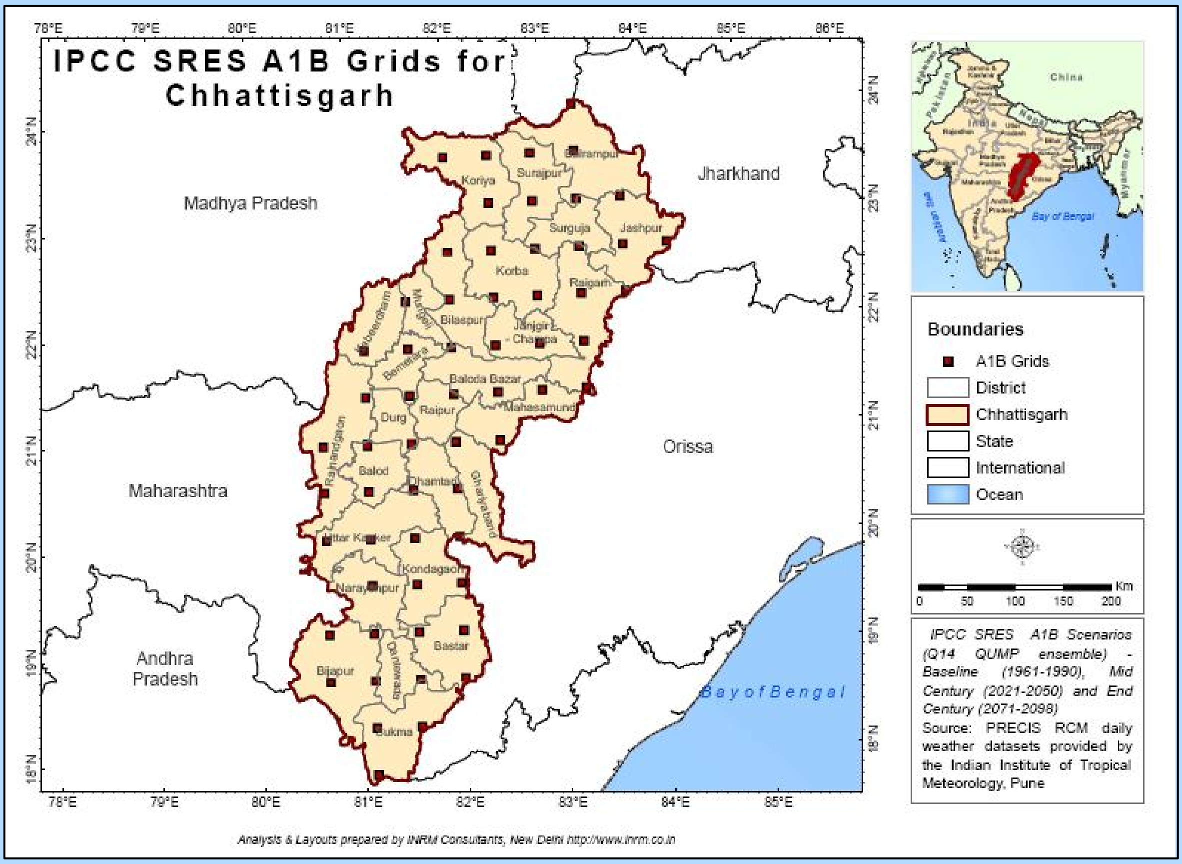
Special data extraction software is used to extract the relevant grids for the study areas. The RCM grids for Chhattisgarh are shown in Figure 16.

[32] PRECIS A1B, which is a mid path scenario, a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies, with the development balanced across energy sources

[33] The basic approach involves taking a single
model structure and making perturbations to the values of parameters in the model, based on the
discussions with scientists involved in the development of different parameterization schemes

[34] Collins, W.D., V. Ramaswamy, M.D. Schwarzkopf, Y. Sun, R.W. Portmann, Q. Fu, S.E.B. Casanova, J.-L. Dufresne, D.W. Fillmore, P.M.D. Forster, V.Y. Galin, L.K. Gohar, W.J. Ingram, D.P. Kratz, M.-P. Lefebvre, J. Li, P. Marquet, V. Oinas, Y. Tsushima, T. Uchiyama, and W.Y. Zhong, 2006: Radiative forcing by well-mixed greenhouse gases: Estimates from climate models in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). J. Geophys. Res., 111, D14317

Figure 16 : PRECIS Data grids of Chhattisgarh



Comparison of Observed and Simulated Temperature and Rainfall

A comparison of the simulated baseline temperature and rainfall was made to examine the model simulation capability. Figure 17 shows spatial distribution of temperature and rainfall at annual, monsoon (JJAS) and post monsoon (OND) seasons. It can be seen that simulated baseline reproduces the observed temperature statistics well.

Figure 17 : Comparison of Simulated Baseline and Observed Temperature and Rainfall for Chhattisgarh

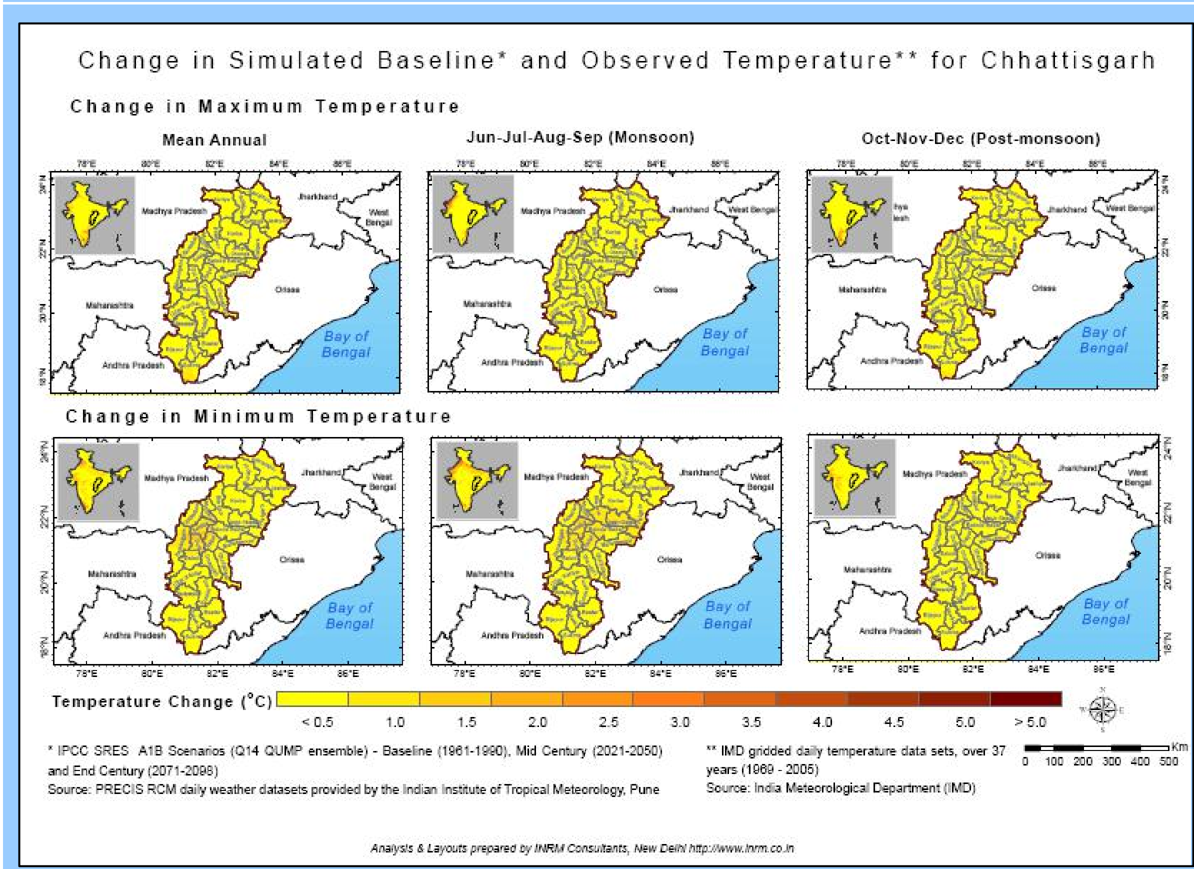
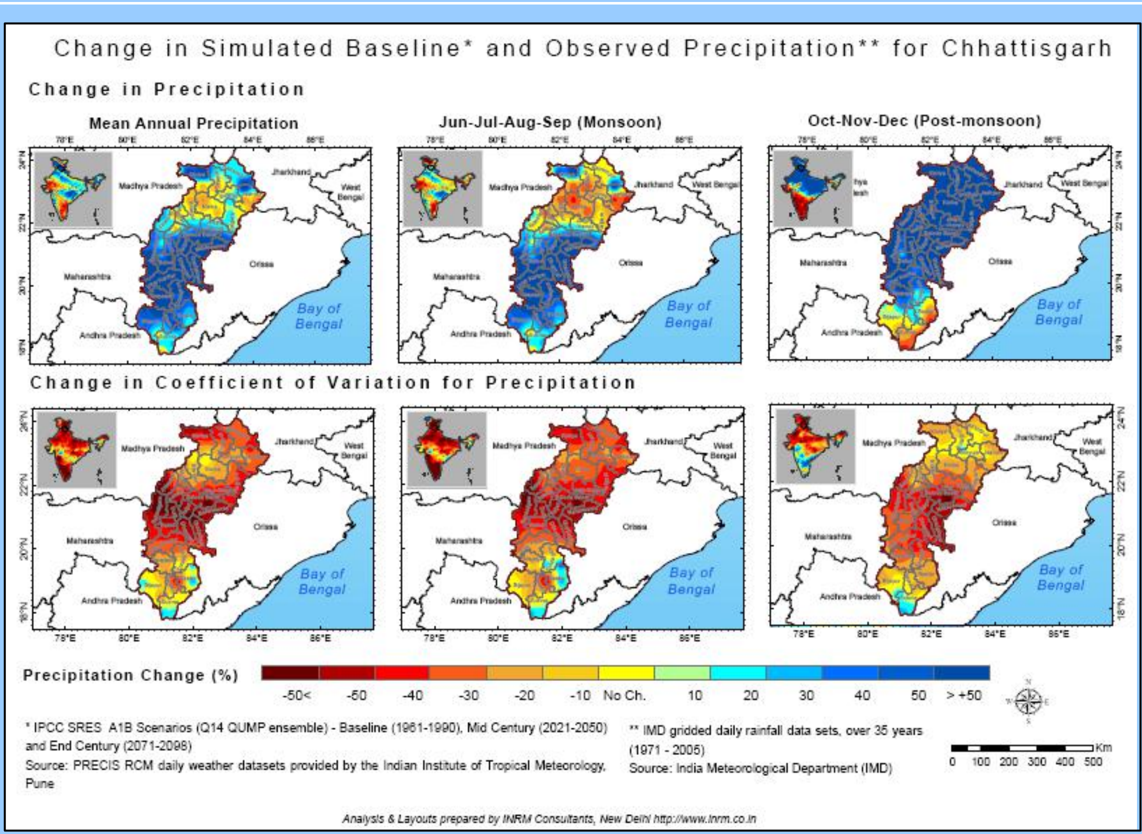
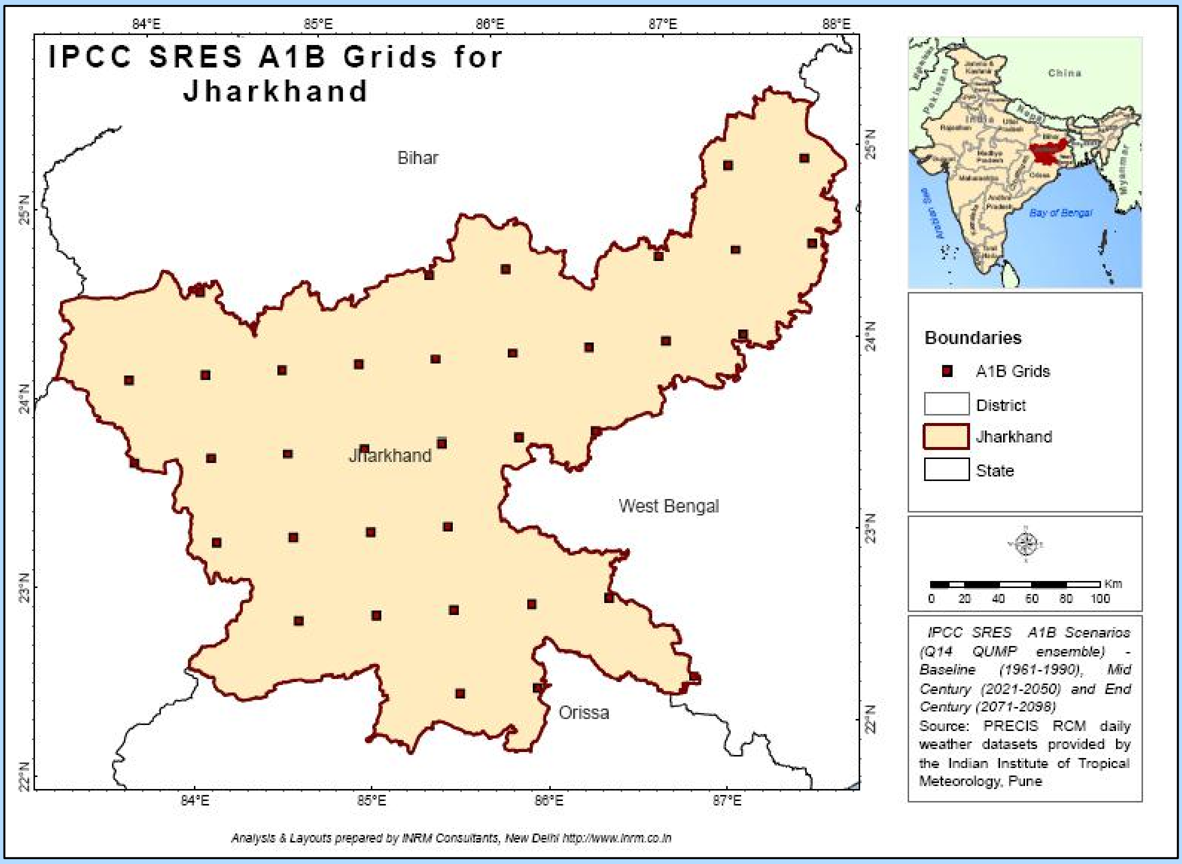


Figure 17 : Comparison of Simulated Baseline and Observed Temperature and Rainfall for Chhattisgarh



Simulated baseline annual rainfall shows volumetric difference by about 20 to 40% increase. In monsoon season, Northern districts of Chhattisgarh namely Bemetara, Mungeli, Bilaspur, Korba, Rajgarh, Surguja, Surajpur and Jashpur shows under simulation of rainfall in the baseline by about 20 to 40% as compared to IMD rainfall, whereas the rest of the districts shows no change or over simulation of rainfall in the baseline by 20 to 40% as compared to IMD rainfall. Baseline simulated rainfall show less inter annual variation than IMD rainfall.

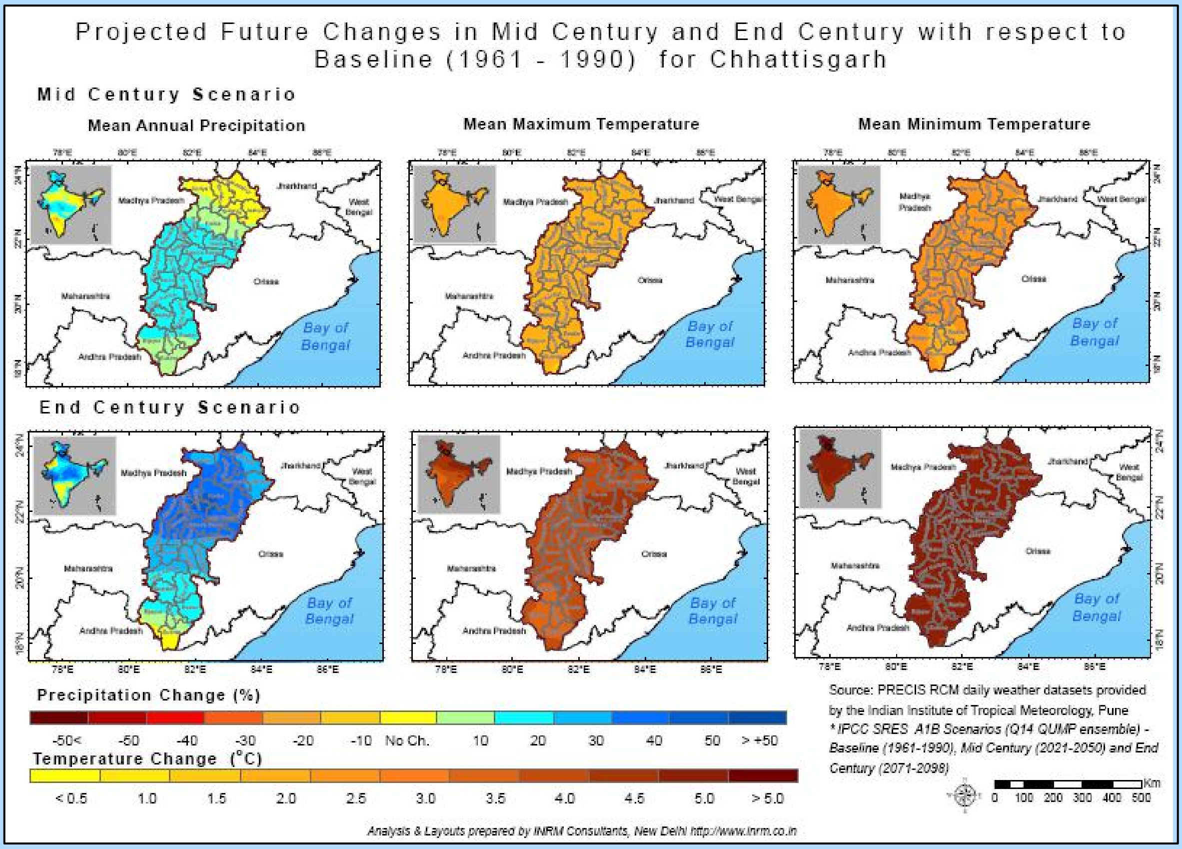
Figure 18 : PRECIS Data grids of Chhattisgarh



Analysis of the Climate Change Data (AR4)

The PRECIS data on precipitation, maximum and minimum temperature have been analysed for Chhattisgarh. Preliminary inferences on the variations of these entities have been presented in Figure 19. Annual maximum temperature is projected to increase by 1.8^{0}C and annual minimum temperature by 2.2^{0}C towards mid-century. The increase in annual maximum temperature is projected to be 3.8^{0}C and annual minimum temperature to be 4.8^{0}C towards end century respectively. Increase is projected for average annual rainfall by 11.2% and 24.7% respectively for mid and end century scenarios.

Figure 19 : Projected Changes in mean annual precipitation, and temperature in Chhattisgarh



PRECIS Temperature (AR4)

The HADCM3 simulations downscaled with PRECIS indicate an all-round warming over the Indian subcontinent associated with increasing greenhouse gas concentrations. Seasonal mean daily maximum and mean daily minimum temperatures from the PRECIS simulation of the A1B scenarios are given in Table 11.

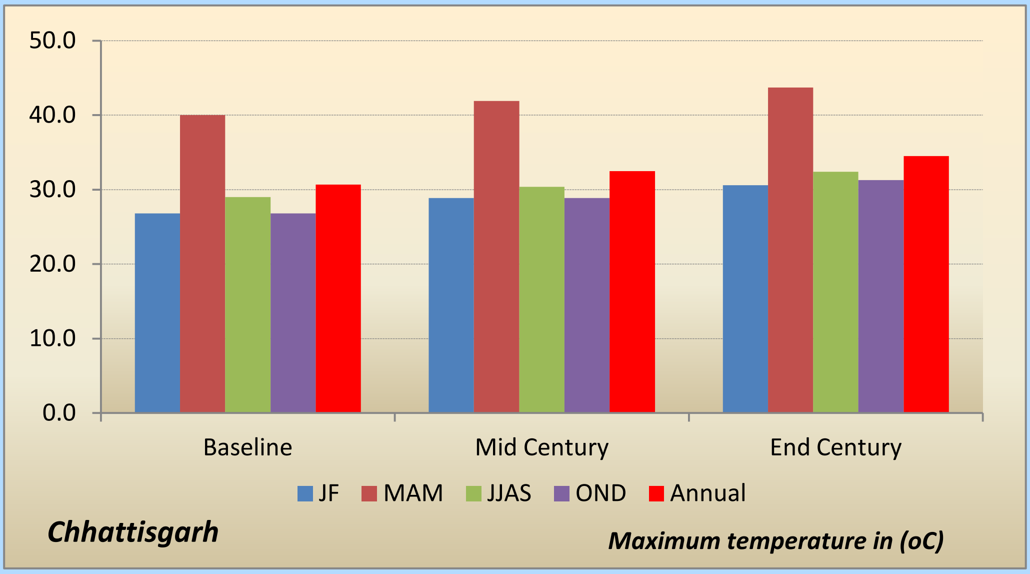
Table 11: Characteristics of simulated seasonal and annual temperature

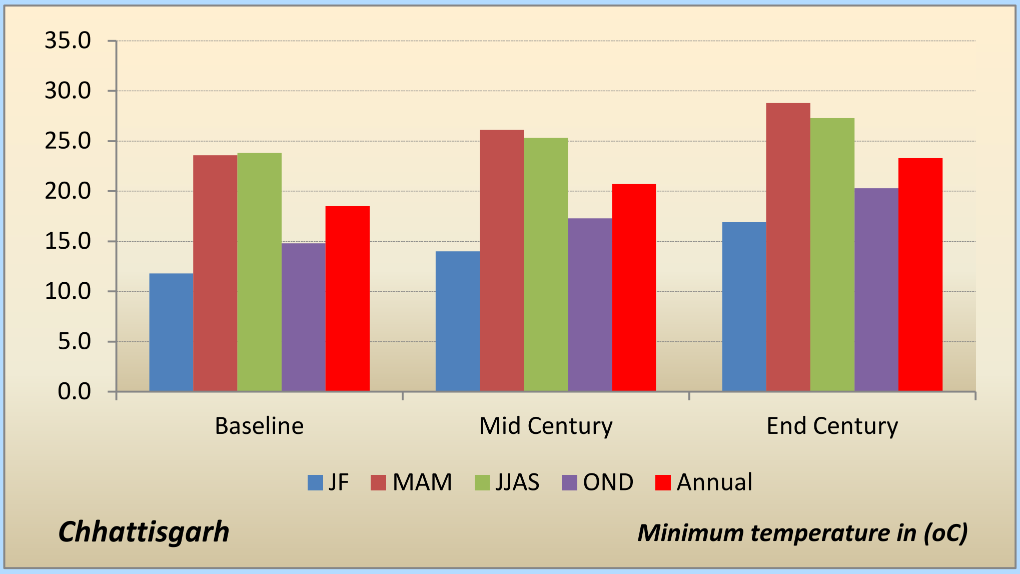
Temperature for IPCC SRES baseline and A1B scenario as simulated by PRECIS for Chhattisgarh						
Mean Daily Maximum Temperature (^{0}C)						
		JF	**MAM**	**JJAS**	**OND**	**Annual**
Chhattisgarh	1970s	26.8	40.0	29.0	26.8	30.7
Chhattisgarh	2050s	28.9	41.9	30.4	28.9	32.5
Chhattisgarh	2080s	30.6	43.7	32.4	31.3	34.5
Mean Daily Minimum Temperature (^{0}C)						
Chhattisgarh	1970s	11.8	23.6	23.8	14.8	18.5
Chhattisgarh	2050s	14.0	26.1	25.3	17.3	20.7
Chhattisgarh	2080s	16.9	28.8	27.3	20.3	23.3
Comparison of projected changes in temperatures for IPCC SRES scenario with respect to baseline for Chhattisgarh**						
Change in Mean Daily Maximum Temperature (^{0}C)						
		JF	**MAM**	**JJAS**	**OND**	**Annual**
Change from Baseline to Mid-term		2.1	1.9	1.4	2.1	1.8
Change from Baseline to End Century		3.8	3.7	3.4	4.5	3.8
Change in Mean Daily Minimum Temperature (^{0}C)						
Change from Baseline to Mid-term		2.2	2.5	1.5	2.5	2.2
Change from Baseline to End Century		5.1	5.2	3.5	5.5	4.8

*** Positive change indicates warming in Future and negative change indicates cooling in future*

Under the PRECISA1B scenario both maximum and minimum temperatures are projected to rise significantly. Mean annual maximum temperature increases by about1.8^{0}C by mid-century and by about 3.8^{0}C by end-century. Mean annual minimum temperature increases by about 2.2^{0}C by mid-century and by about 4.8^{0}C by end-century Increase in the monsoon season would be lower than in the dry seasons. Temperature changes are shown in Figure 20.

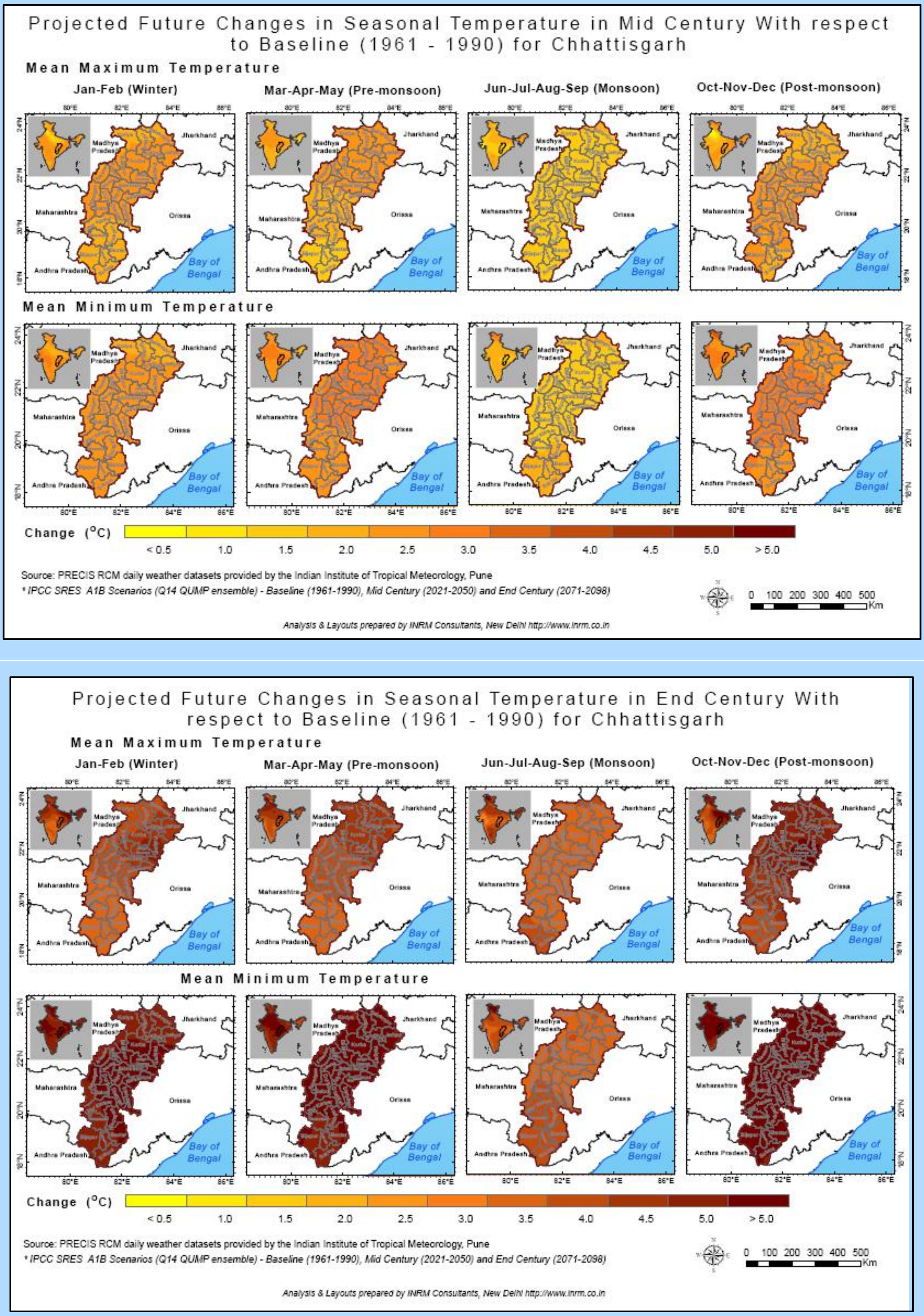
Figure 20 : Characteristics of simulated seasonal and annual temperature





Spatial variation in the change in the mean daily maximum and minimum temperature is shown in Figure 21. It can be seen from Figure 21 that the projected change in minimum temperature is higher than the change in maximum temperature in both mid and end century.

Figure 21 : Projected Changes in seasonal temperature in Chhattisgarh



PRECIS Precipitation (AR4)

Chhattisgarh receives most of its rain during the monsoon season, which starts in late June. The mean seasonal precipitation amounts simulated by PRECIS are as shown in Table 12. Data are presented for four seasonal periods: JF - January, February; MAM - March, April, May; JJAS - June, July, August, September; OND - October, November, December. Projected changes to mid and end-century is also presented.

Under the A1B scenario, rainfall is projected to increase. Mean annual rainfall increases by about 196 mm (11.2%) by mid-century and by about 432mm (24.7%) by end-century under the A1B scenario. Most of the increases occur in the monsoon period. There is a slight decline in JF rainfall towards mid-century under the A1B scenario. Mean monsoon rainfall increases by 156.3 mm by mid-century and by 302.8 mm by end century. Figure 22 shows the characteristics of rainfall for Chhattisgarh.

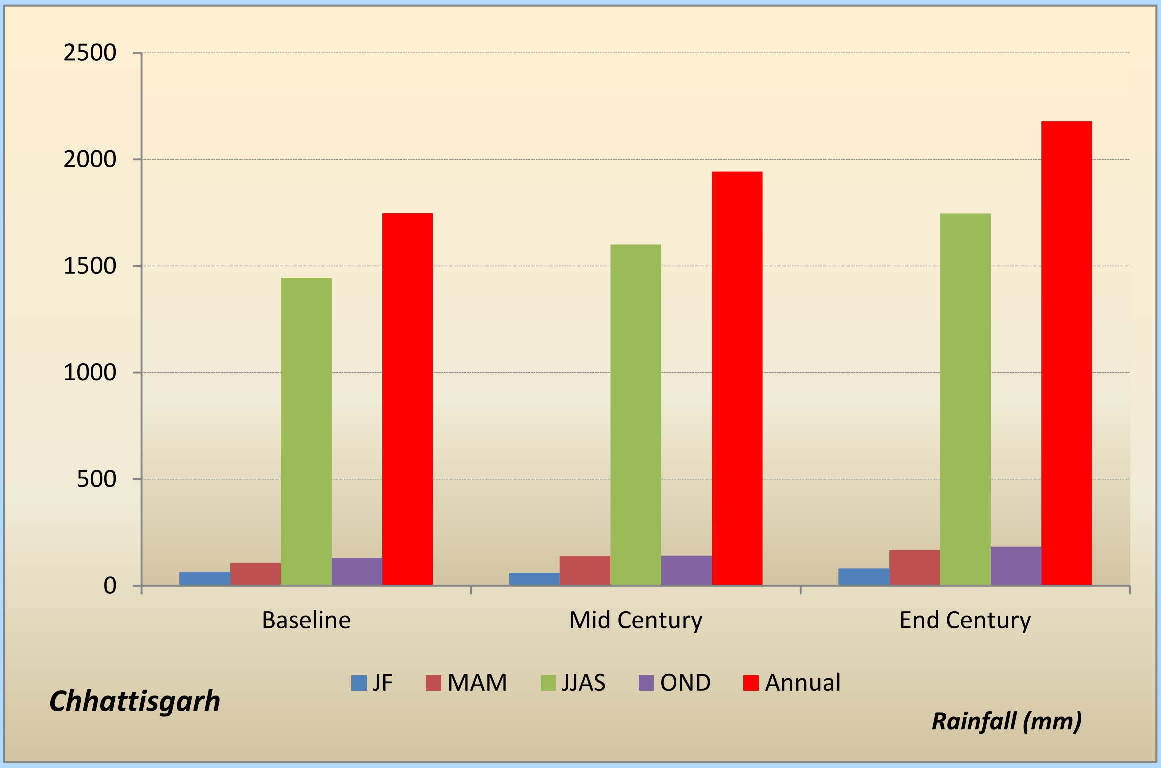
Table 12: Rainfall Statistics for Chhattisgarh

IPCC SRES baseline and A1B scenario as simulated by PRECIS for Chhattisgarh						
Rainfall (mm)						
		JF	**MAM**	**JJAS**	**OND**	**Annual**
Chhattisgarh	1970s	65.2	106.2	1443.9	131.7	1747.0
Chhattisgarh	2050s	61.0	139.3	1600.2	142.0	1942.5
Chhattisgarh	2080s	81.2	167.0	1746.7	183.9	2178.8
Comparison of projected changes in seasonal and annual rainfall (mm) for IPCC SRES scenario with respect to baseline for Chhattisgarh**						
Change in rainfall (%)						
Change from Baseline to Mid-term		-6.4	31.2	10.8	7.8	11.2
Change from Baseline to End Century		24.5	57.3	21	39.6	24.7

*** Positive change indicates increase in future and negative change indicates decrease in future*

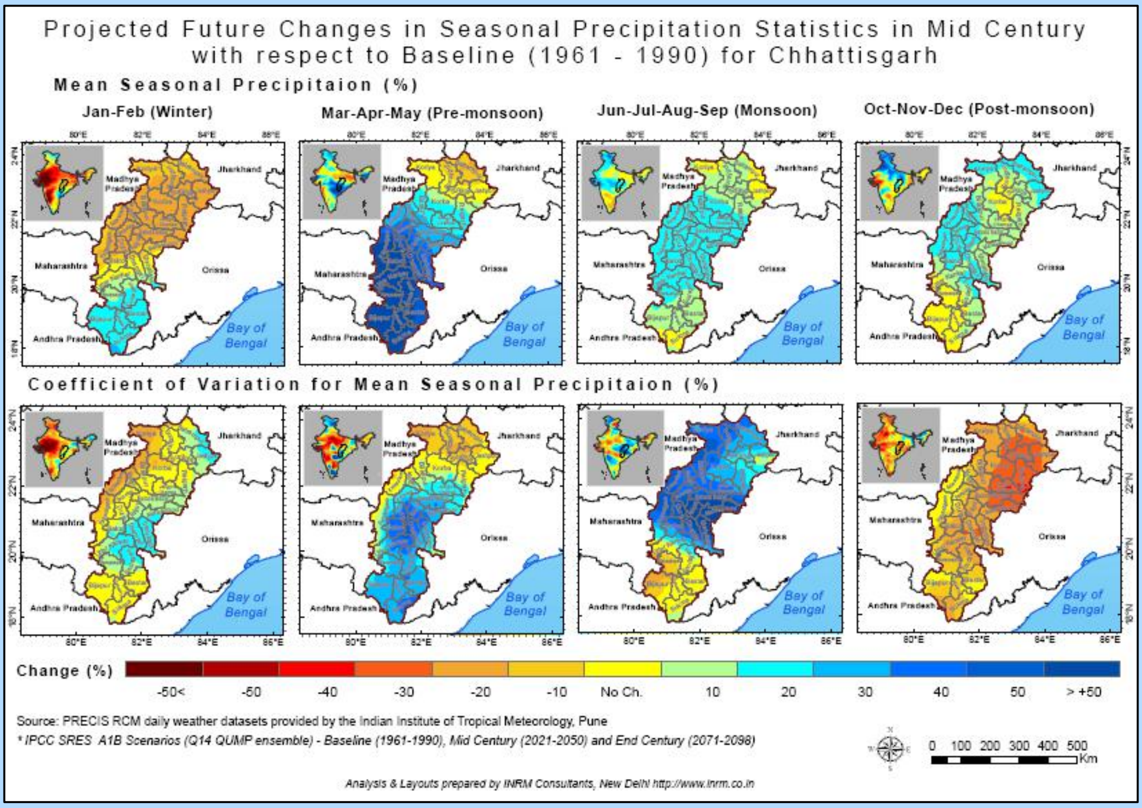
JF - January, February; MAM - March, April, May; JJAS - June, July, August, September; OND - October, November, December

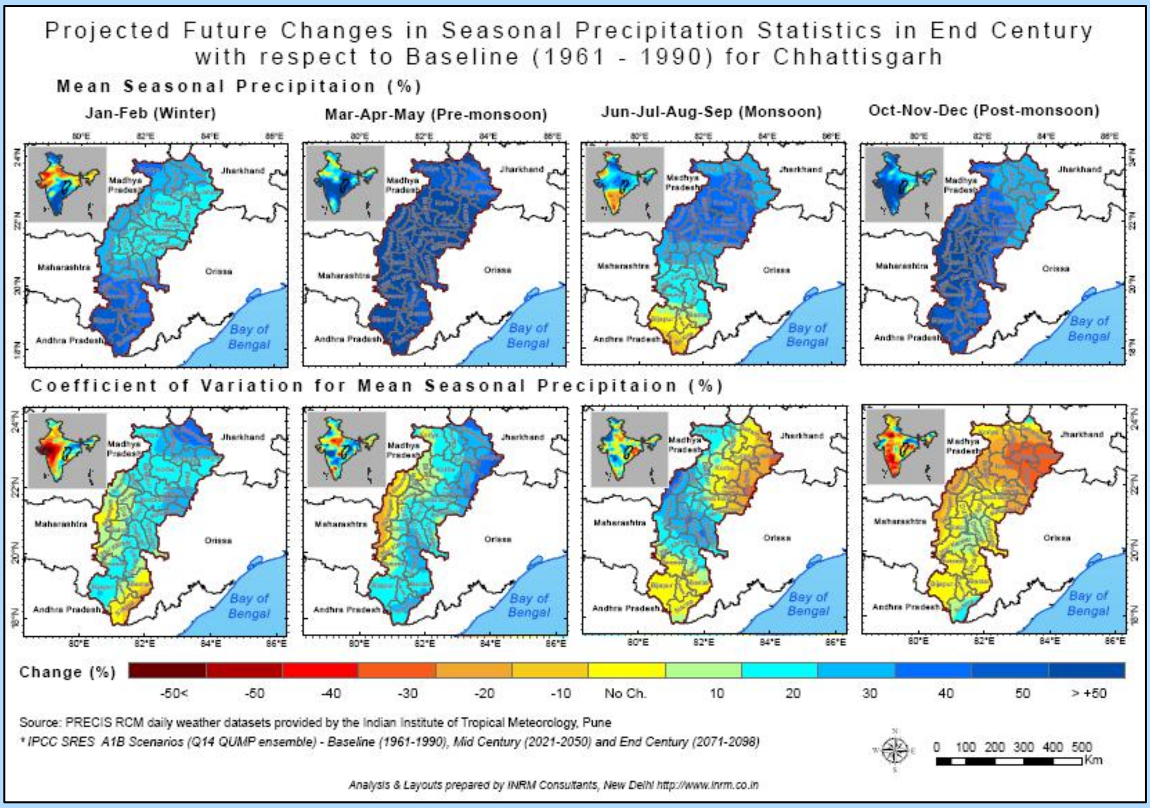
Figure 22 : Characteristics of simulated seasonal and annual rainfall and temperature



Spatial distribution of projected seasonal rainfall is depicted in Figure 23.

Figure 23 : Projected Change in seasonal precipitation in Chhattisgarh





It can be seen from Figure 23 that maximum changes in projected rainfall are noticed in pre monsoon and post monsoon seasons in the end century.

IPCC AR5 Projections

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)[35]. 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 radiative forcing values in the year 2100. Table 13gives the overview of four RCPs.

Table 13: Overview of Representative Concentration Pathways (RCPs) adopted by IPCC AR5

RCP	Description	IA Model	Publication – IA Model
RCP8.5	Rising radiative 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

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

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

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. There are three models namely, LMDzOR, SMHI-RCA4 and COSMO-CLM made available at 50km x 50km grid scale for South-Asian region on a daily time scale. For the present study only the SMHI-RCA4 model data which was available is used.

The scientific community has developed a set of new emission scenarios termed as Representative Concentration Pathways (http://www.iiasa.ac.at/web-apps/tnt/RcpDb/dsd?Action=htmlpage&page=welcome). In contrast to the SRES scenarios, RCPs represent pathways of radiative 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: RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5 – 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). The naming convention reflects socio-economic pathways that reach a specific radiative forcing by the year 2100. For example RCP 8.5 leads to a radiative forcing of 8.5 Wm-2 by 2100.

In this study, CORDEX-based mid-term (2030's, representing climatology over 2021-2050 climate change projections has been assessed for Chhattisgarh at the district-level. Projections have been made at a grid-spacing of 0.2°x0.2° resolution using single model (SMHI-RCA4) for RCP 4.5 (moderate emission scenario).

Climate change Data Extraction (AR5)

Both historic and climate projections were at 0.5°×0.5°. The data was further regridded to spatial scale of 0.2×0.2° resolution by using bilinear interpolation, thus, district-wise averages were obtained using appropriate weights (based on the area occupied) to all grids falling into a district.

Analysis of the Climate Change Data (AR5)

The CORDEX simulations with SMHI indicate an all-round warming over the Chhattisgarh. Seasonal mean daily maximum and mean daily minimum temperatures from the SMHI[36] simulation of the RCP 4.5 scenarios are given in Table 14.

[36]Rossby Centre CORDEX simulations

CORDEX Temperature - SMHI

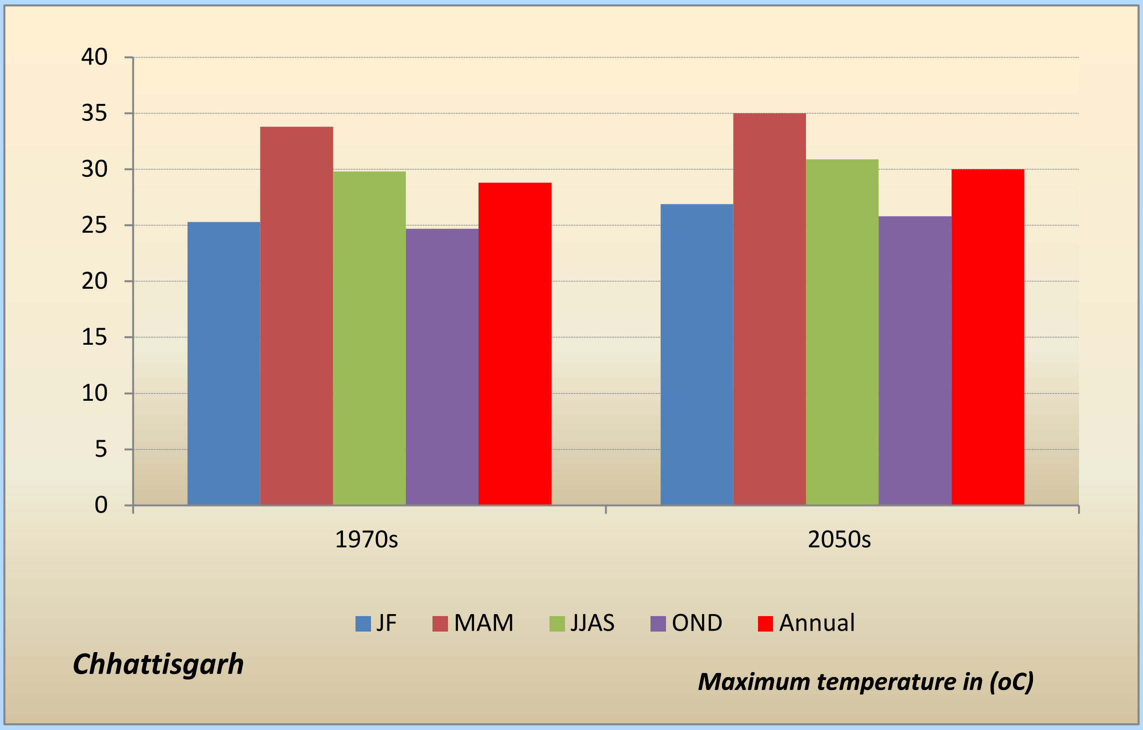
Table 14: Characteristics of simulated seasonal and annual temperature - AR5- RCP4.5 (CORDEX: SMHI)

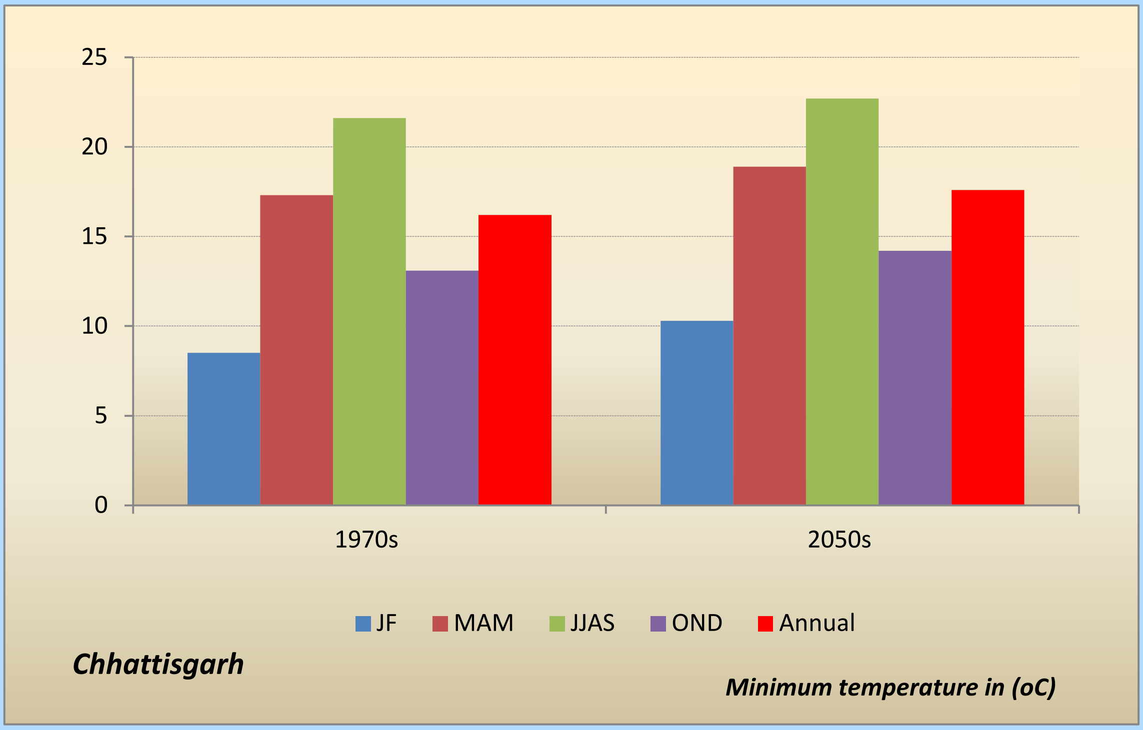
Temperature for IPCC AR5 baseline and RCP 4.5scenario as simulated by SMHI for Chhattisgarh						
Mean Daily Maximum Temperature (^{0}C)						
		JF	**MAM**	**JJAS**	**OND**	**Annual**
Chhattisgarh	1970s	25.3	33.8	29.8	24.7	28.8
Chhattisgarh	2050s	26.9	35.0	30.9	25.8	30.0
Mean Daily Minimum Temperature (^{0}C)						
Chhattisgarh	1970s	8.5	17.3	21.6	13.1	16.2
Chhattisgarh	2050s	10.3	18.9	22.7	14.2	17.6
Comparison of projected changes in temperatures for IPCC AR5 scenario with respect to baseline for Chhattisgarh**						
Change in Mean Daily Maximum Temperature (^{0}C)						
		JF	**MAM**	**JJAS**	**OND**	**Annual**
Change from Baseline to Mid-term		1.6	1.2	1.1	1.1	1.2
Change in Mean Daily Minimum Temperature (^{0}C)						
Change from Baseline to Mid-term		1.8	1.6	1.1	1.1	1.4

*** Positive change indicates warming in Future and negative change indicates cooling in future*

Under the IPCC RCP 4.5 scenario both maximum and minimum temperatures are projected to rise significantly. Mean annual maximum temperature increases by about 1.2^{0}C by mid-century. Mean annual minimum temperature increases by about 1.4^{0}C by mid-century. Increase in the monsoon season would be lower than in the dry seasons. Temperature changes are shown in Figure 24.

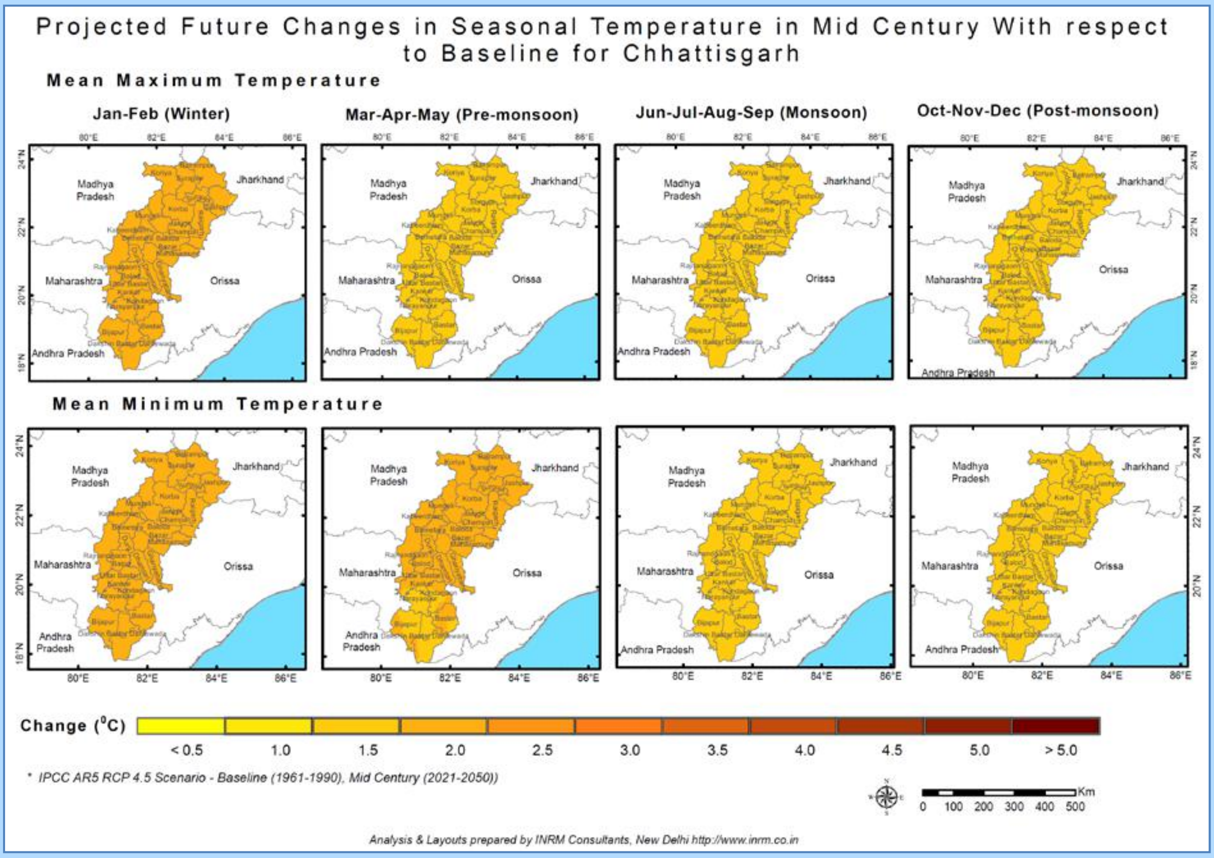
Figure 24 : Characteristics of simulated seasonal and annual temperature - Chhattisgarh





Spatial variation in the change in the mean daily maximum and minimum temperature is shown in Figure 25. It can be seen that the projected change in minimum temperature is higher than the change in maximum temperature in mid-term.

Figure 25 : Projected Changes in seasonal temperature in Chhattisgarh



CORDEX Precipitation - SMHI

Chhattisgarh receives most of its rain during the monsoon season, which starts in late June. The mean seasonal precipitation amounts simulated by PRECIS are as shown in Table 15. Data are presented for four seasonal periods: JF - January, February; MAM - March, April, May; JJAS - June, July, August, September; OND - October, November, December. Projected changes to mid and end-century is also presented.

Under the IPCC AR5 RCP 4.5 scenario, rainfall is projected to increase marginally in mid-century. Mean annual rainfall increases by about 83.6 mm (3.7%) by mid-century. .Most of the increases occur in the pre monsoon period. There is also a slight decline in JF rainfall towards mid-century. Mean monsoon rainfall increases by 49 mm by mid-century. Figure 26 shows the characteristics of rainfall for Chhattisgarh.

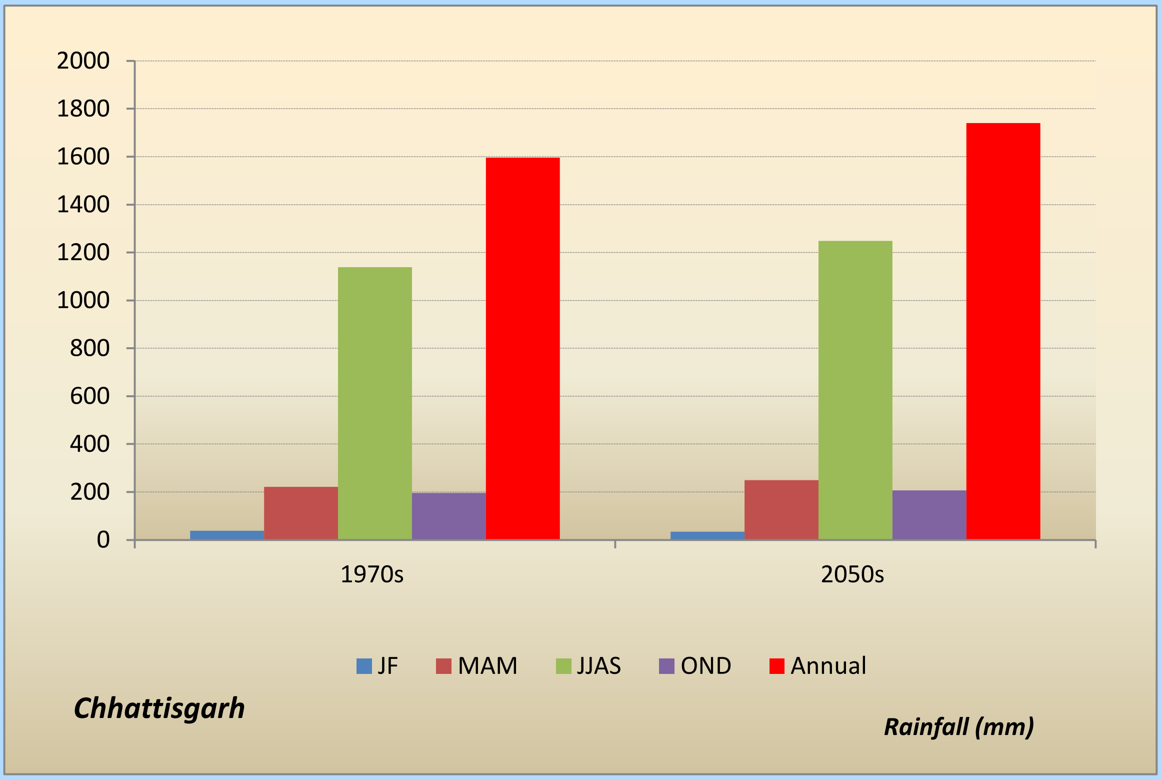
Table 15: Rainfall Statistics for Chhattisgarh

IPCC SRES baseline and IPCC AR5 RCP 4.5 scenario as simulated by SMHI for Chhattisgarh						
Rainfall (mm)						
		JF	MAM	JJAS	OND	Annual
Chhattisgarh	1970s	38.9	221.9	1139.3	195.8	1595.9
Chhattisgarh	2050s	34	250.2	1249	207.1	1740.4
Comparison of projected changes in seasonal and annual rainfall (mm) for IPCC SRES scenario with respect to baseline for Chhattisgarh**						
Change in rainfall (%)						
Change from Baseline to Mid-term		12.6	12.8	9.6	5.8	9.1

*** Positive change indicates increase in future and negative change indicates decrease in future*

JF - January, February; MAM - March, April, May; JJAS - June, July, August, September; OND - October, November, December

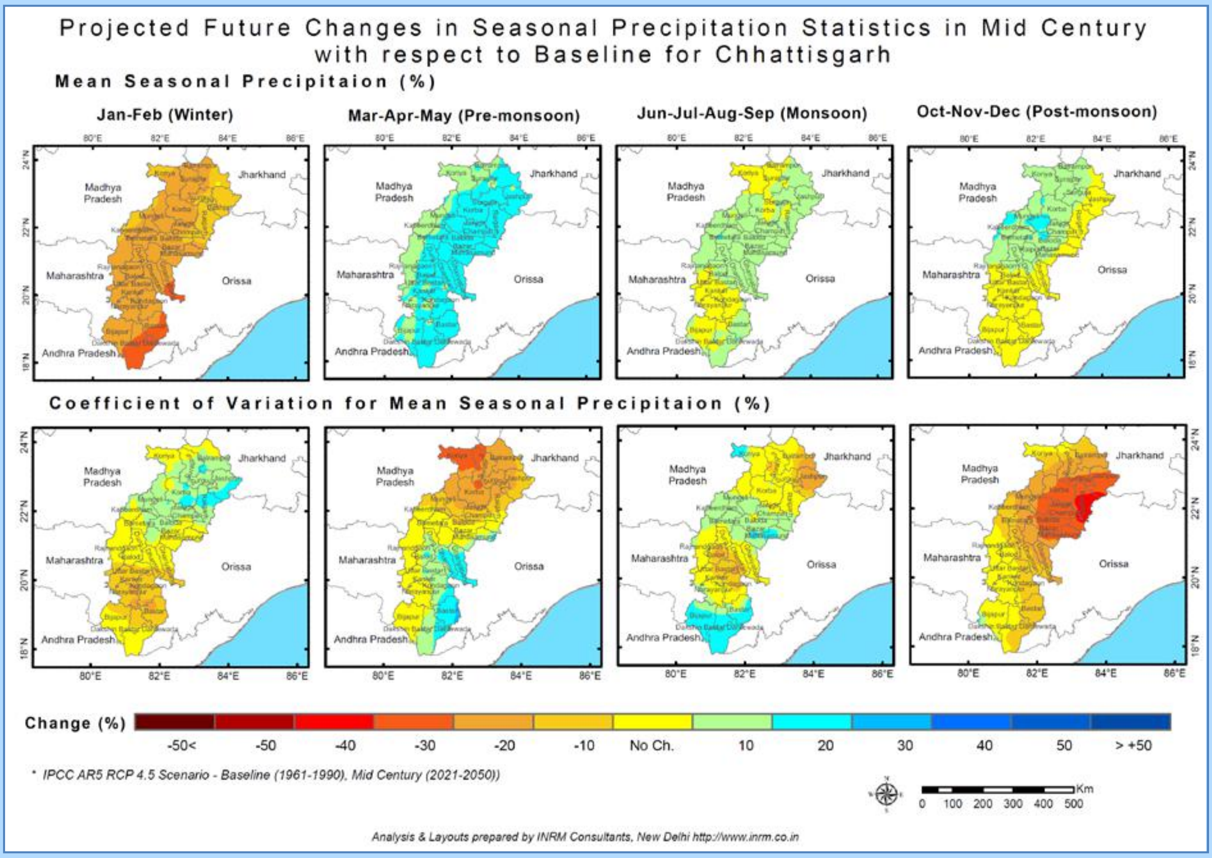
Figure 26 : Characteristics of simulated seasonal and annual rainfall and temperature



It can be seen from Figure 26 that in mid-century winter season's rainfall is projected to decline compared to the baseline. Maximum positive changes in projected rainfall are noticed in monsoon season.

Spatial distribution of projected seasonal rainfall is depicted in Figure 27.

Figure 27 : Projected Change in seasonal precipitation in Chhattisgarh



Climate Indices for extremes-AR4

A suite of climate change indices derived from daily data which focus primarily on extremes have been developed by Expert Team on Climate Change Detection and Indices (ETCCDI)[37]. A total of 21 indices are considered to be 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 vary from location to location (thresholds are typically defined as a percentile of the relevant data series). RClimDex (1.0)[38]which is designed to provide a user friendly interface to compute indices of climate extremes has been used to derive the relevant indices for Chhattisgarh. RClimDex calculates 10 precipitation and 11 temperature indices (Table 16) at annual and monthly time steps. 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

[37] http://www.clivar.org/organization/etccd
[38]http://cccma.seos.uvic.ca/ETCCDI/software.shtml

threshold are most suitable for spatial comparisons, because they sample same part of temperature/precipitation) distributions at each site[39].

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 xn is the largest, with n = total number of observations.

xi is the p_i^{th} 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^{0}C, gives the number of days where the maximum temperature is above 40^{0}C. 40^{0}C is an absolute threshold value and this may vary at different places (Shimla may be experiencing hot days when maximum temperature exceeds 30^{0}C, but for Churu it may be 45^{0}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 1961-1990.

Table 16: List of Climate Indices

Index	Descriptive Name	Definition	Units
Temperature indices calculated by RClimDex. TX is the daily maximum temperature; TN is daily minimum temperature; TG is daily mean temperature.			
TXx	Hottest day	Monthly highest TX	°C
TNx	Hottest night	Monthly highest TN	°C
TXn	Coolest day	Monthly lowest TX	°C
TNn	Coolest night	Monthly lowest TN	°C
TN10p	Cool night frequency	Percentage of days when TN<10th percentile of 1961-1990	%
TX10p	Cool day frequency	Percentage of days when TX<10th percentile of 1961-1990	%
TN90p	Hot night frequency	Percentage of days when TN>90th percentile of 1961-1990	%
TX90p	Hot day frequency	Percentage of days when TX>90th percentile of 1961-1990	%
WSDI	Warm spell	Annual count of days with at least 6 consecutive days when TX>90th percentile of 1961-1990	Days
CSDI	Cold spell	Annual count of days with at least 6 consecutive days when TN<10th percentile of 1961-1990	Days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	°C
Precipitation indices calculated by RClimDex. 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.			
PRCPTOT	Wet-day precipitation	Annual total precipitation from wet days	Mm
SDII	Simple daily intensity index	Average precipitation on wet days	mm/day

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

Index	Descriptive Name	Definition	Units
CDD	Consecutive dry days	Maximum number of consecutive dry days	Days
CWD	Consecutive wet days	Maximum number of consecutive wet days	Days
R10mm	Heavy precipitation days	Annual count of days when RR>=10	Days
R20mm	Very heavy precipitation days	Annual count of days when RR>=20	Days
R95p	Very wet day precipitation	Annual total precipitation when RR>95th percentile of 1961-90 daily rainfall	Mm
R99p	Extremely wet day precipitation	Annual total precipitation when RR>99th percentile of 1961-90 daily rainfall	Mm
RX1day	Max 1-day precipitation	Annual maximum 1-day precipitation	Mm
RX5day	Max 5-day precipitation	Annual maximum consecutive 5-day precipitation	Mm

Figure 28 : Characteristics of Hot Extremes - Warm days and Warm nights - Chhattisgarh

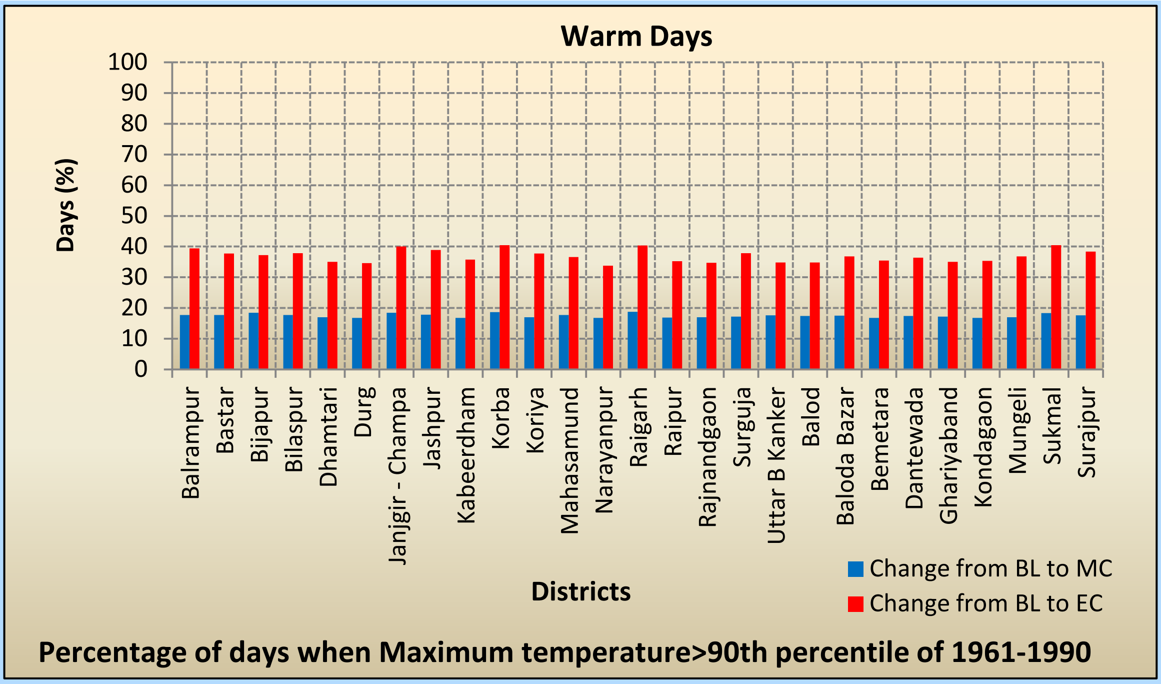


Figure 28 : Characteristics of Hot Extremes - Warm days and Warm nights - Chhattisgarh

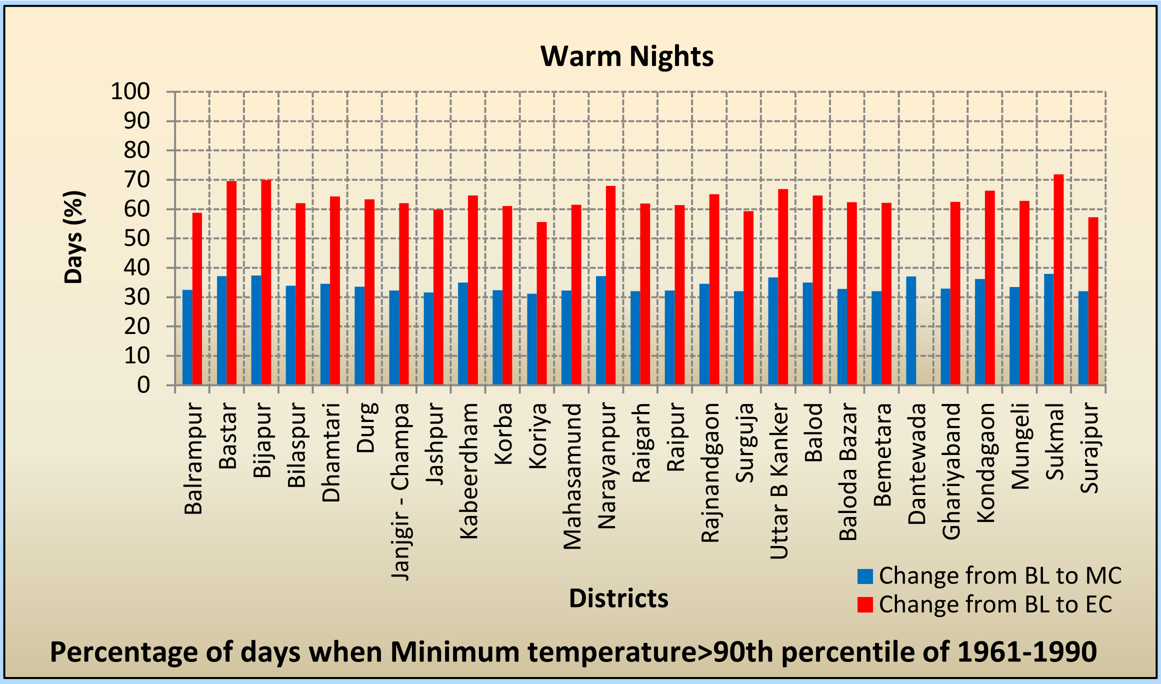
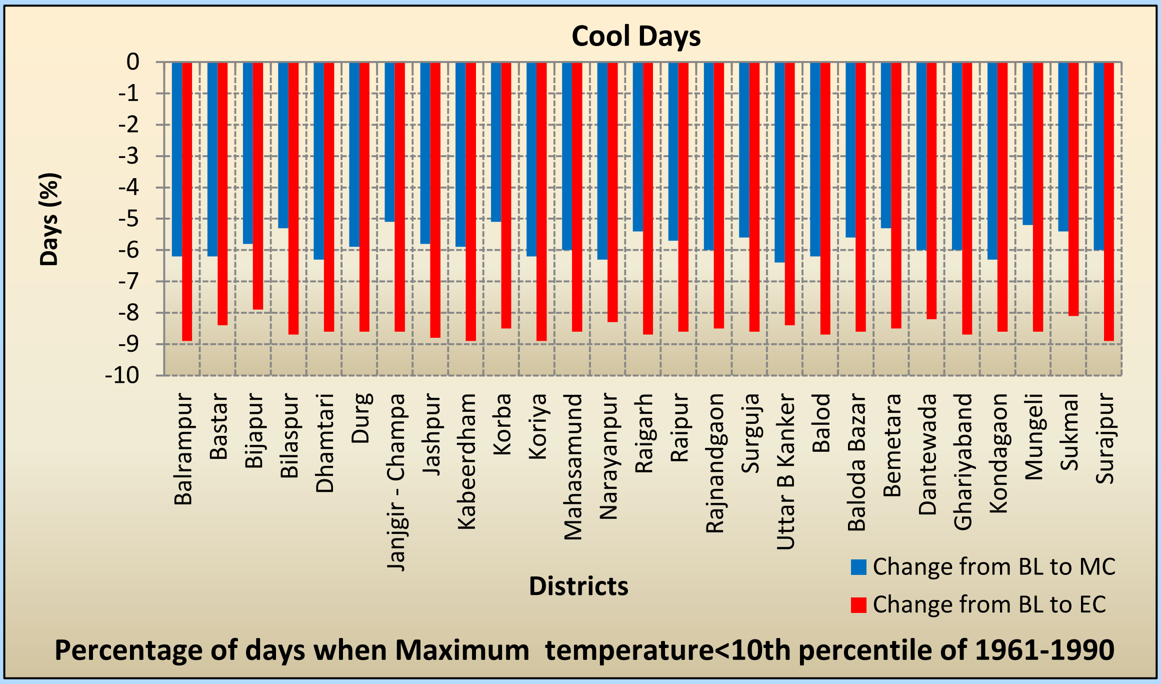


Figure 28 shows the characteristic of warm days and warm nights. From the figure it can be seen that percentage of warm days and warm nights is projected to increase for all the districts in MC and EC compared to the BL implying warming up. Towards the end century increase in warm days is more particularly for Janjgir-Champa, Korba, Raigarh and Sukmal districts and warm nights for Sukmal, Dantewada, Bastar and Bijapur compared to the other districts of Chhattisgarh. While for Narayanpur increase in warm days is the least relatively and for Koriya increase in warm nights is the least relatively compared to the baseline. It can be inferred that maximum of maximum and maximum of minimum temperatures is consistently increasing, indicating significant warming up over Chhattisgarh districts.

Figure 29 : Characteristics of Cold Extremes - Cool days and Cool nights - Chhattisgarh



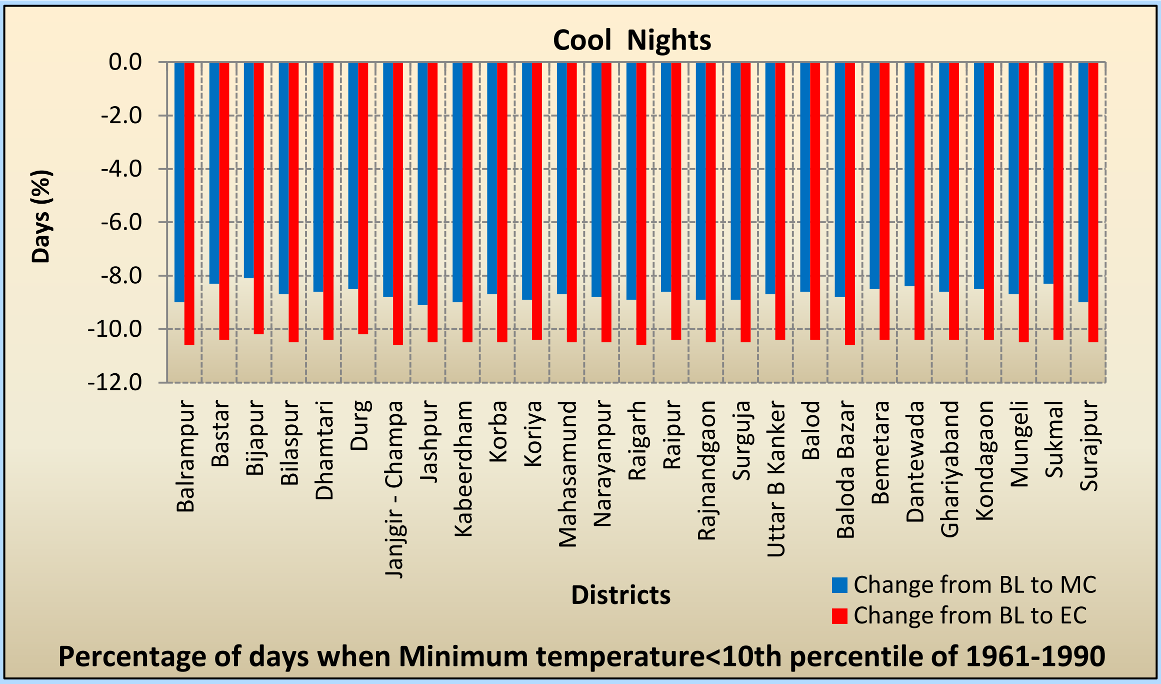
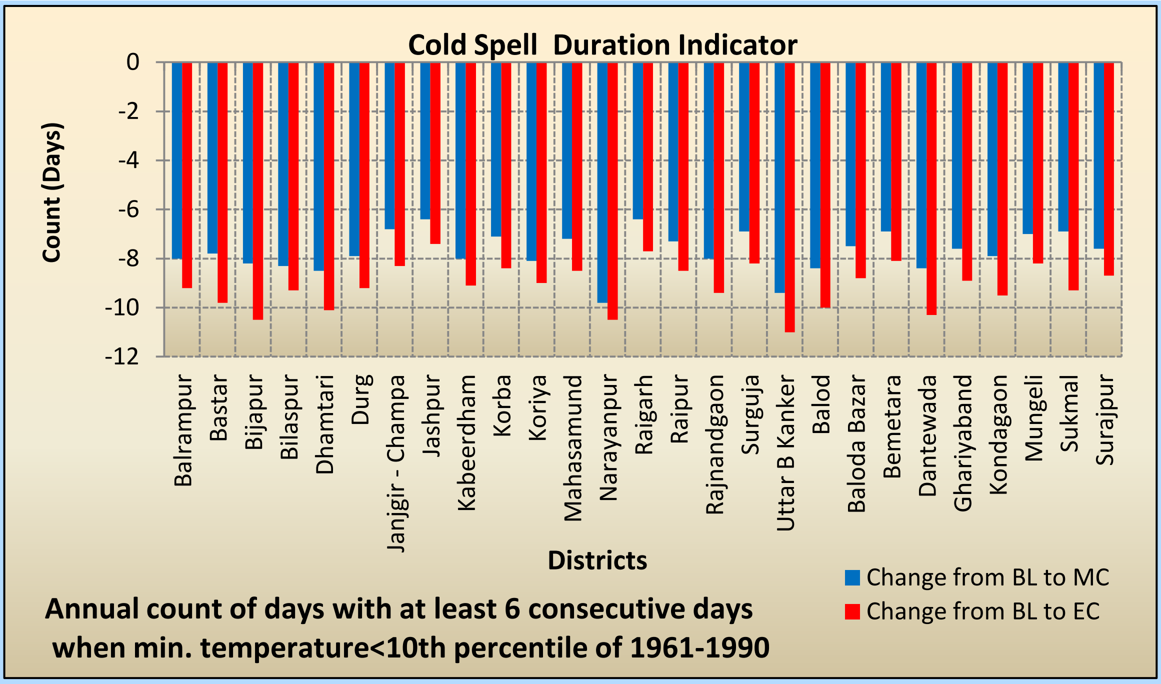


Figure 29 shows the characteristic of cool days and cool nights for Chhattisgarh districts. From the figure it can be seen that percentage of cool days and cool nights is projected to decrease for all the districts in MC and EC compared to the BL implying warming up.EC decrease is more than that of MC implies that EC would be warmer than MC. Towards the end century percentage decrease in cool days is more particularly for Balrampur, Kabeerdham, Koriya and Surajpur districts compared to the baseline thus they are expected to be the warmest compared to the other districts of Chhattisgarh.

It can be inferred that minimum of maximum and minimum of minimum temperatures is consistently increasing, indicating significant warming up over Chhattisgarh districts.

Figure 30 : Characteristics of Cold and Warm Spell duration - Chhattisgarh



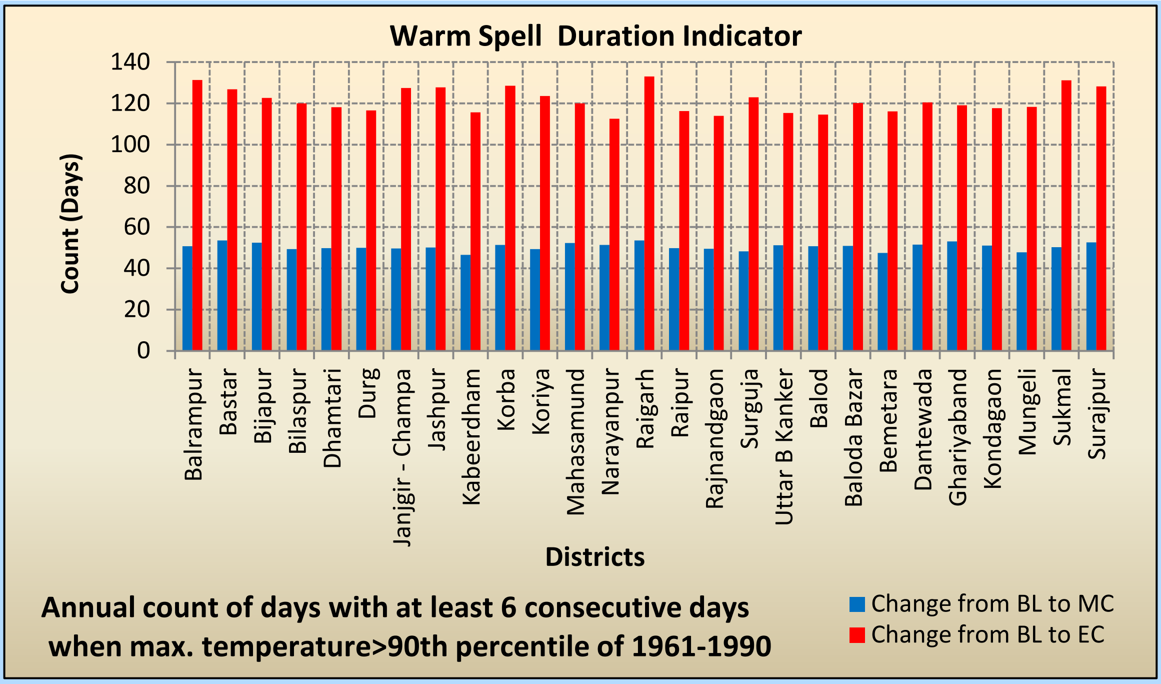
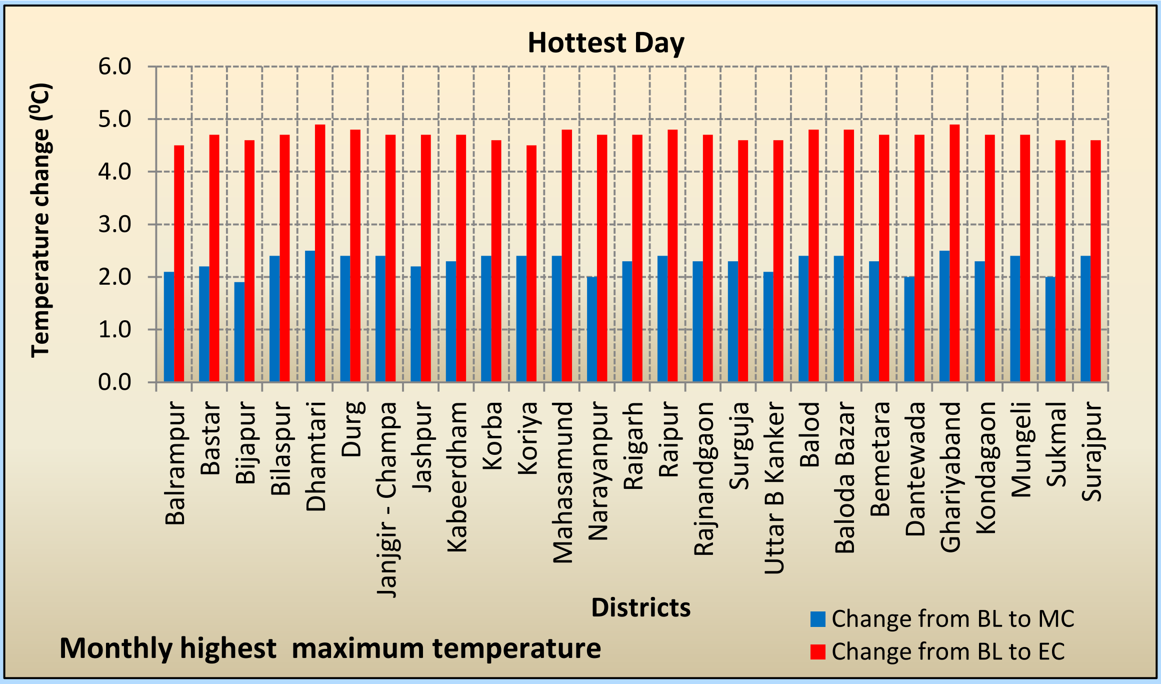


Figure 30 shows the characteristic of warm spell and cold spell duration indicator. From the figure it can be seen that cold spell duration indicator is projected to decrease and warm spell duration indicator is projected to increase for all the districts in MC and EC compared to the BL implying warming up over Chhattisgarh districts. Towards the end century Rajgarh, Balrampur, Sukmal and Surajpur are expected to have the highest change in warm spell duration days while Narayanpur and Rajnandgaon the least compared to the baseline. For cold spell duration days, Uttar Kanker, Narayanpur and Bijapur are expected to have the maximum decrease towards the end century compared to the baseline.

Figure 31 : Characteristics of Hottest day and Hottest night, Coolest day and Coolest night - Chhattisgarh



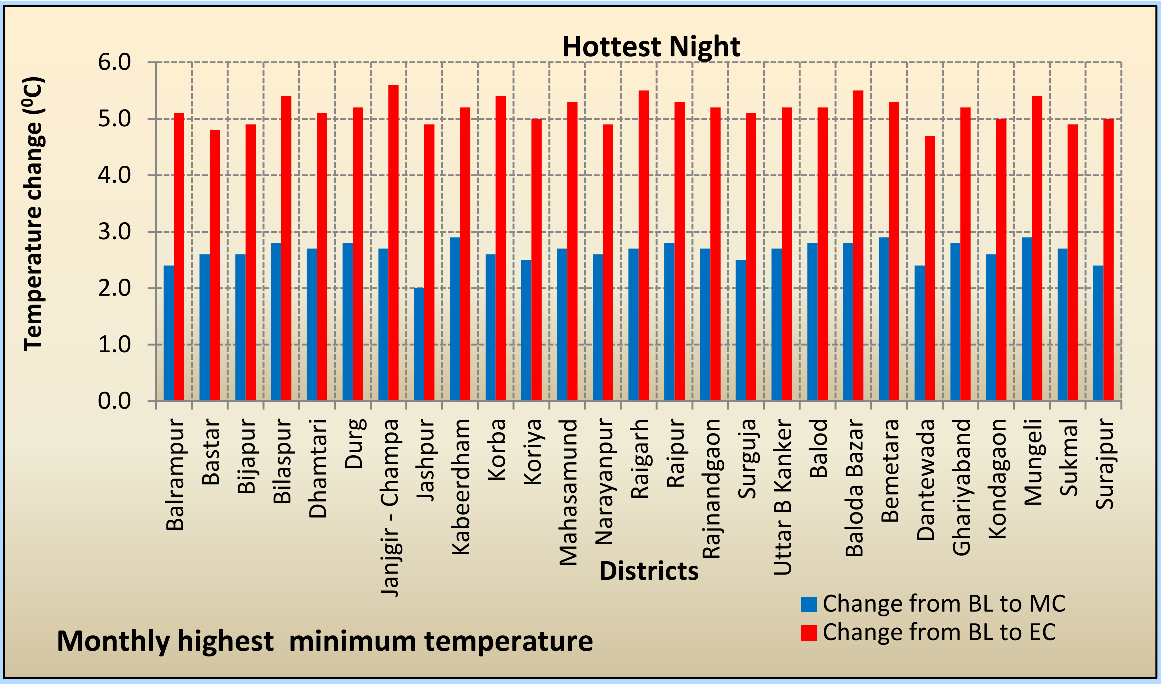


Figure 31 : Characteristics of Hottest day and Hottest night, Coolest day and Coolest night - Chhattisgarh

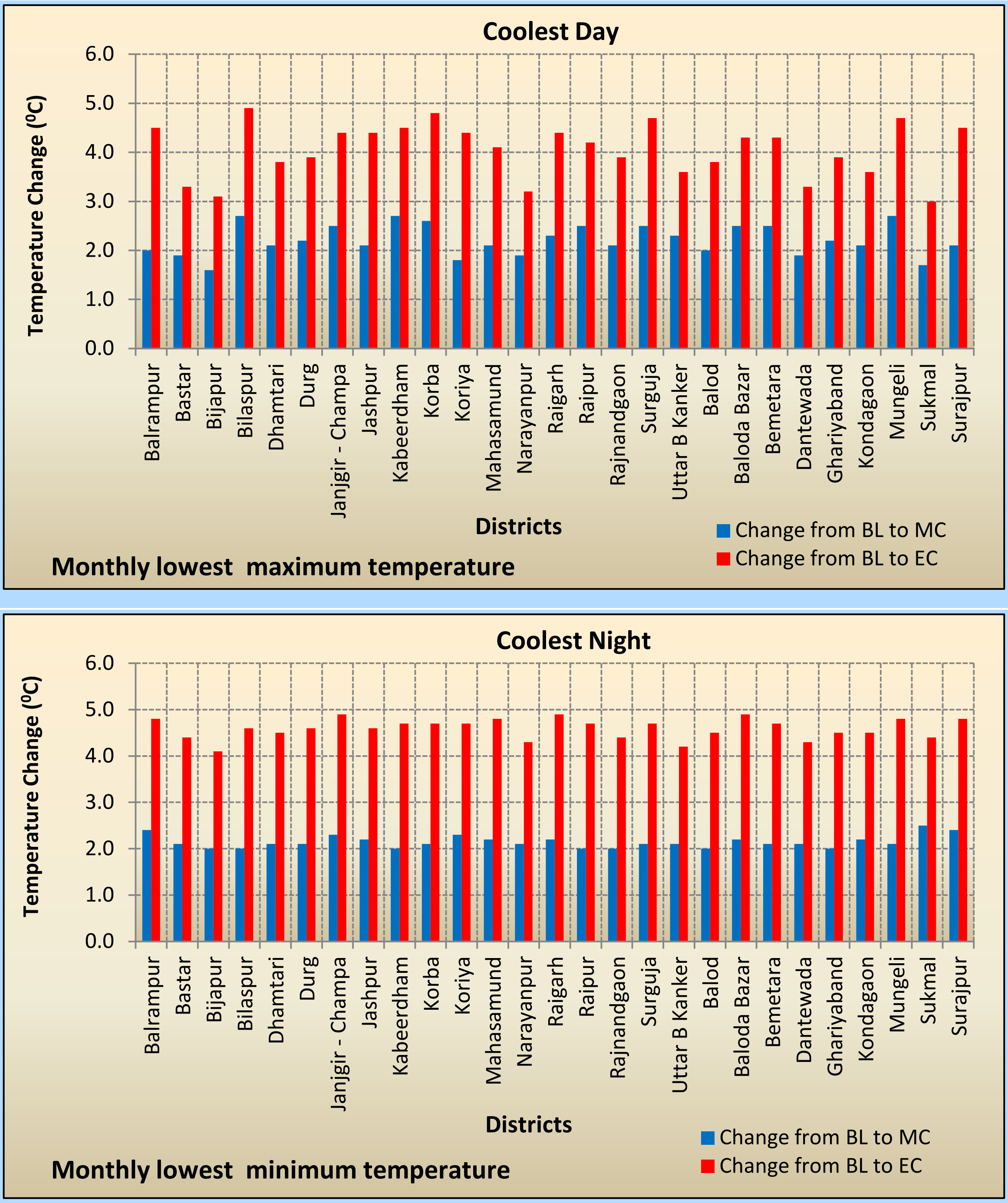


Figure 31 shows the characteristic of hottest day and hottest night, coolest day and coolest night. From the figure monthly highest maximum and minimum temperature and monthly lowest maximum and minimum temperature is projected to increase for all the districts in MC and EC compared to the BL implying warming up. Dhamtari and Ghariyaband of Chhattisgarh districts are expected to have the maximum increase in monthly highest maximum temperature in EC compared to the baseline. Jangir-Champa, Rajgarh and Balod Bazar are expected to have the maximum increase in monthly lowest and highest minimum temperature in the EC as compared to the baseline. Thus nights are expected to become the warmest for these districts in EC compared to the other districts.

Figure 32 : Characteristics of Diurnal temperature range - Chhattisgarh

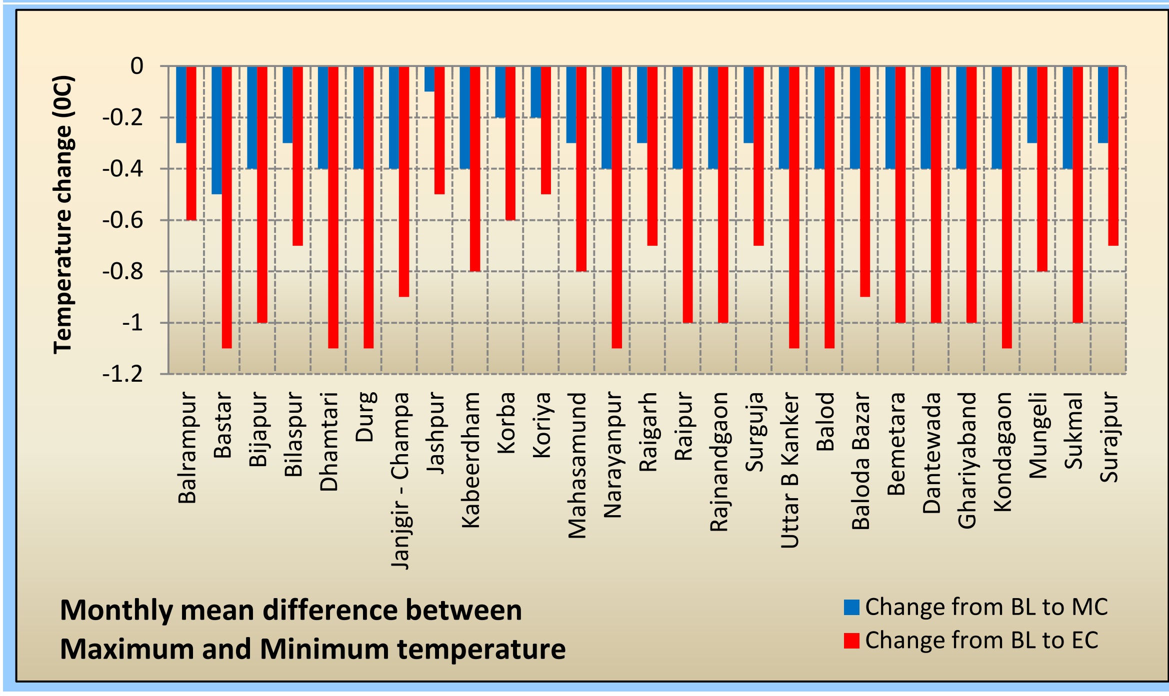
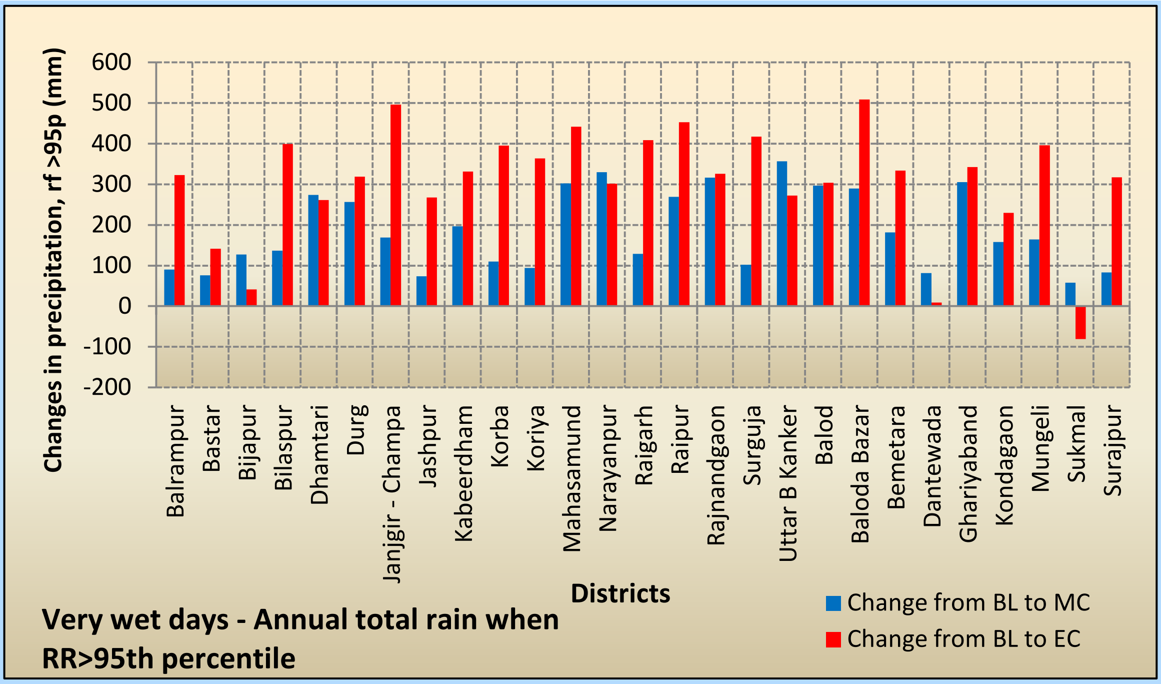


Figure 32 shows the characteristic of monthly difference between maximum and minimum temperature for Chhattisgarh districts. From the figure it can be seen that diurnal temperature change is projected to decrease for all the districts in MC and EC compared to the BL implying warming up.

Figure 33 : Characteristics of Precipitation Extremes –Very wet day and Extremely wet day precipitation - Chhattisgarh



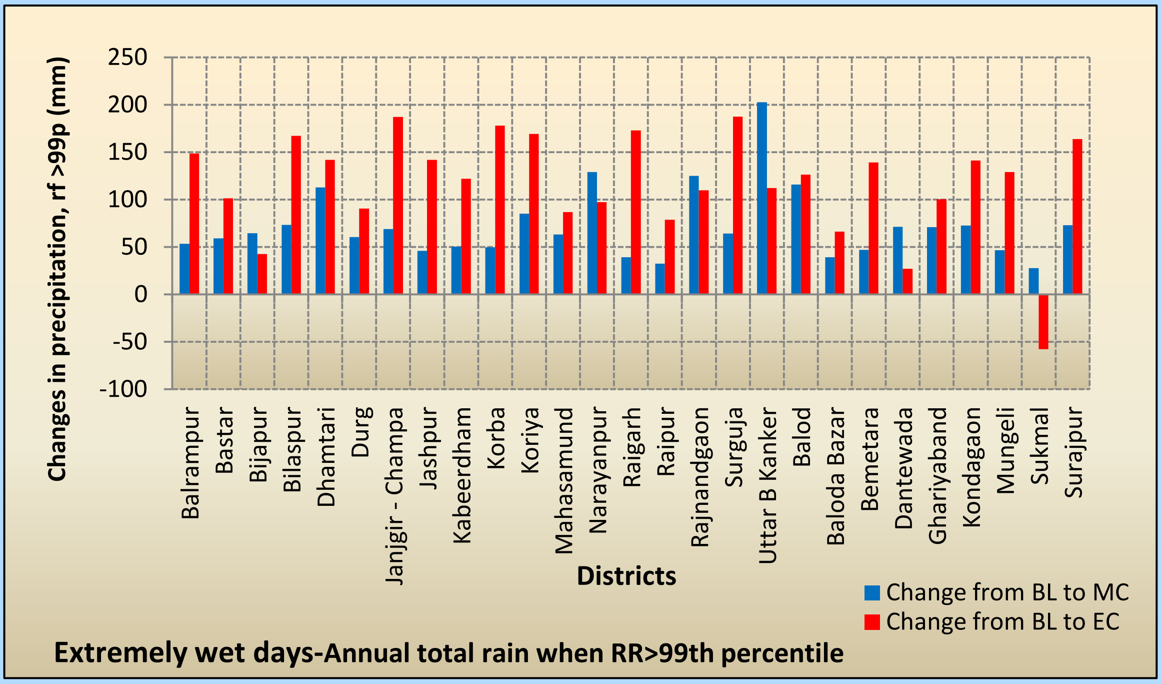
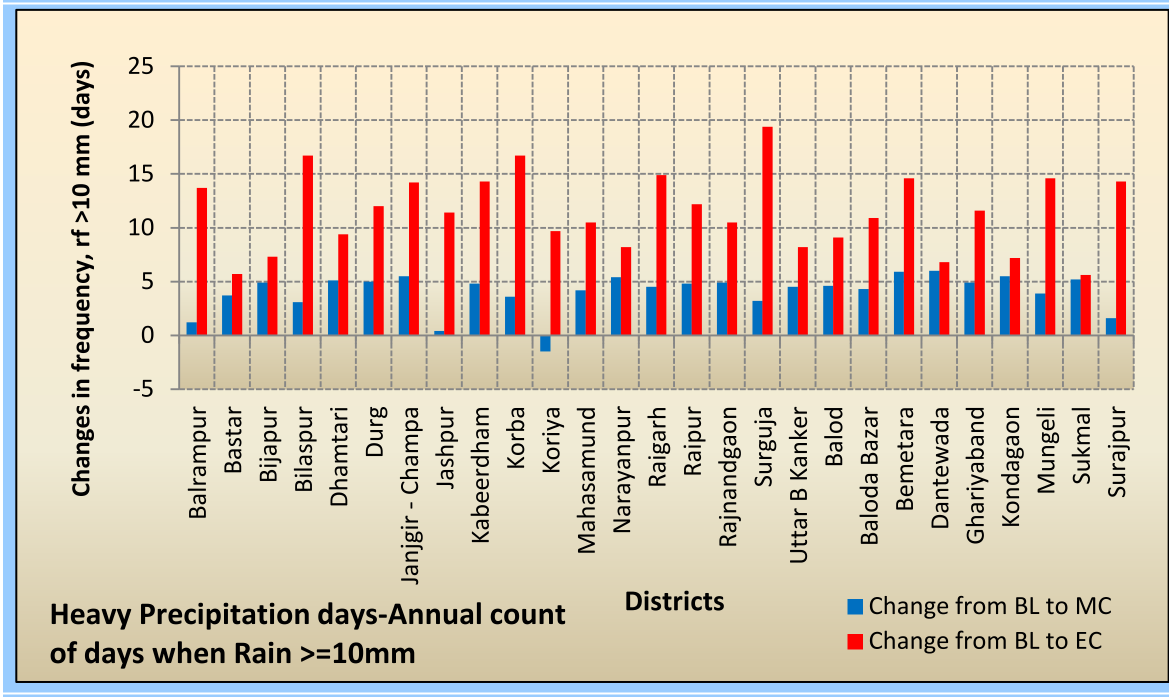


Figure 33 shows the characteristic of precipitation extremes. From the figure it can be seen that very wet and extremely wet day precipitation is projected to increase for all the districts in MC and EC except for Sukmal implying that rainfall and its intensity would increase in the future. But increase in very wet days is the maximum for Jangir-Champa and Baloda Bazar in end century compared to the baseline as can be seen from the figures.

Figure 34 : Characteristics of Precipitation Days–Heavy precipitation and very heavy precipitation days - Chhattisgarh



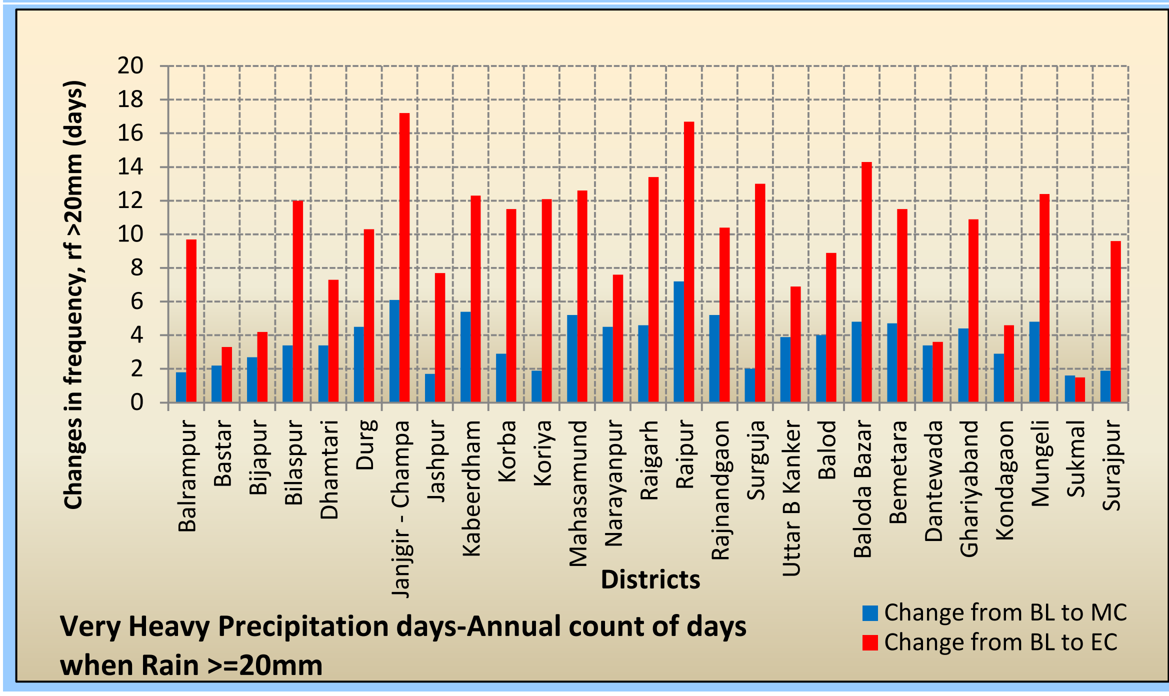
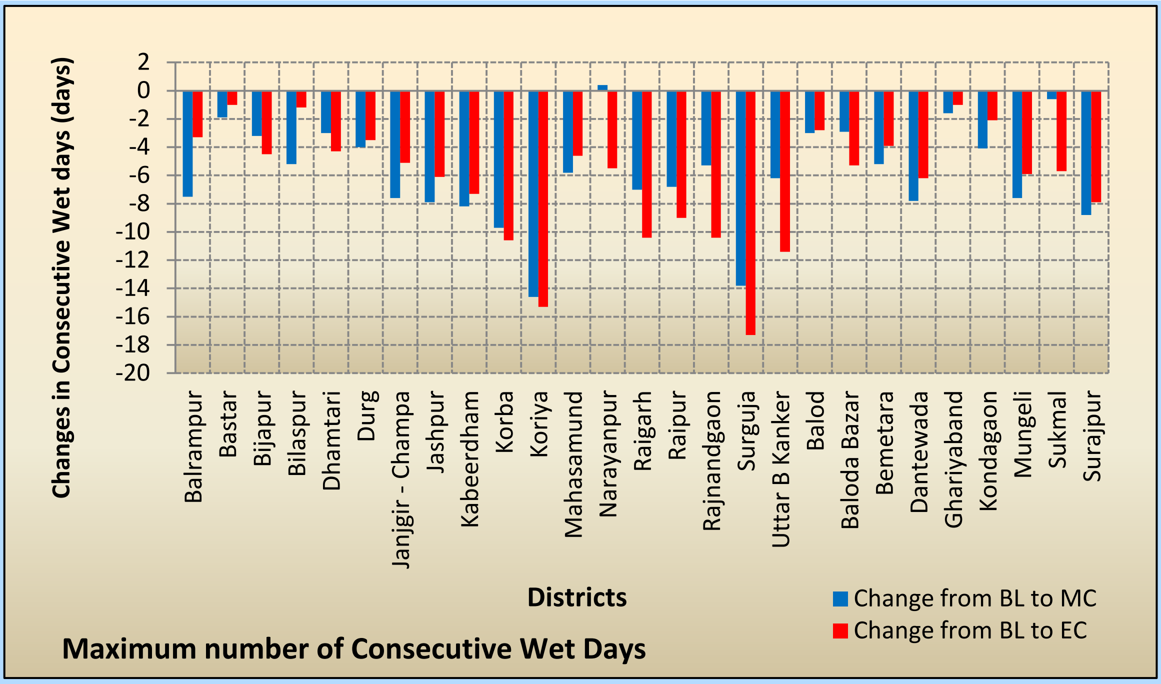


Figure 34 shows the characteristic of precipitation days. From the figure it can be seen that heavy and very heavy precipitation day is projected to increase for all the districts in MC and EC compared to the BL implying that count of heavy rainy days would increase in the future. Increase in count of very heavy precipitation days is expected to be the maximum for Jangir-Champa and Raipur of Chhattisgarh districts in end century compared to the baseline as can be seen from the figures.

Figure 35 : Characteristics of Precipitation Extremes - consecutive Dry and Wet days - Chhattisgarh



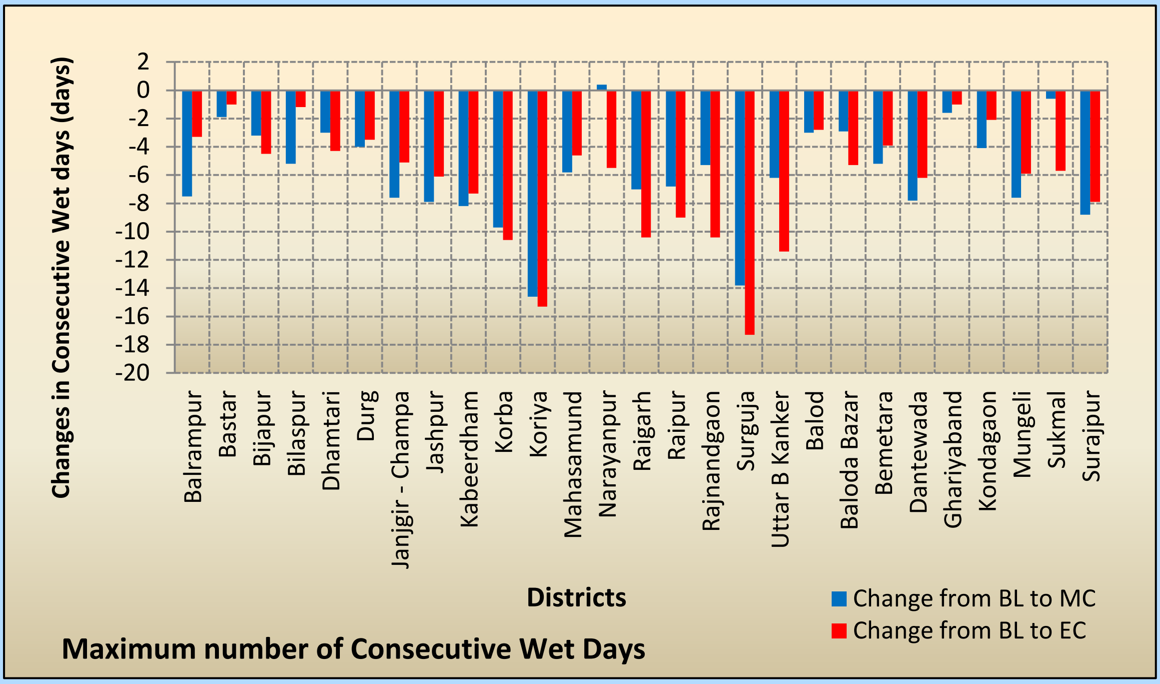
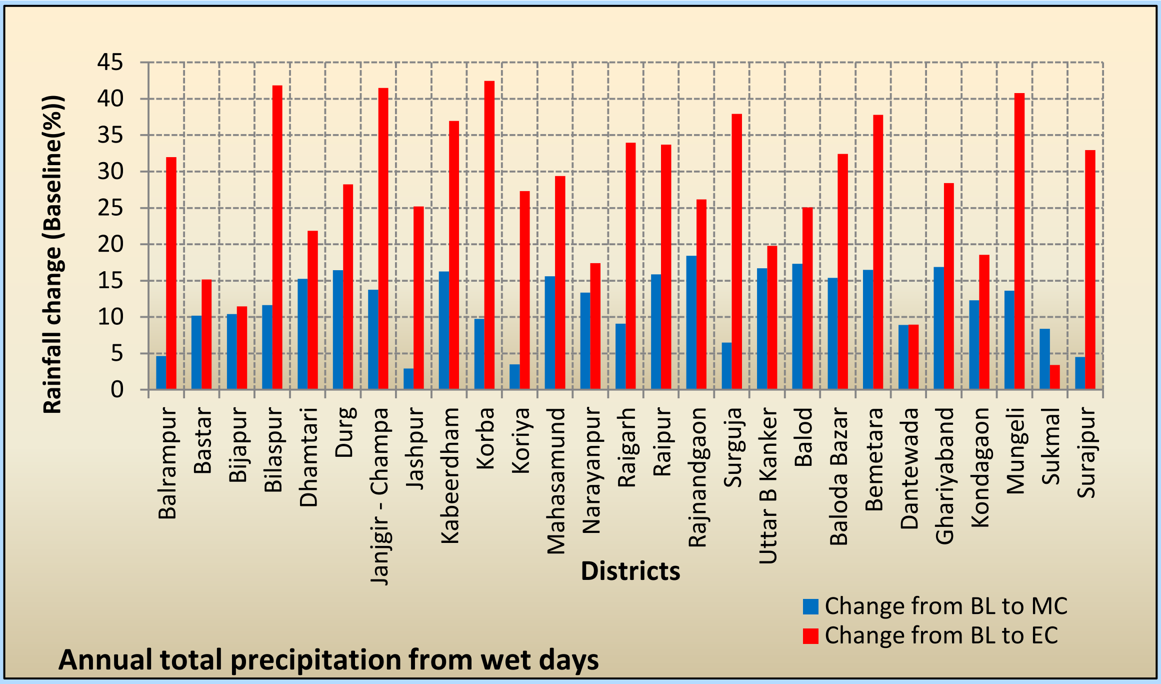


Figure 35 shows the characteristic of Consecutive Dry and Wet days. From the figure it can be seen maximum number of consecutive dry and wet days is declining in MC and EC compared to the baseline except for Bastar and Narayanpur in MC for which consecutive dry days and wet days is increasing respectively compared to the baseline.

Figure 36 : Characteristics of Annual Precipitation, Maximum 1 day and Maximum 5 day precipitation and Simple Daily Intensity Index - Chhattisgarh



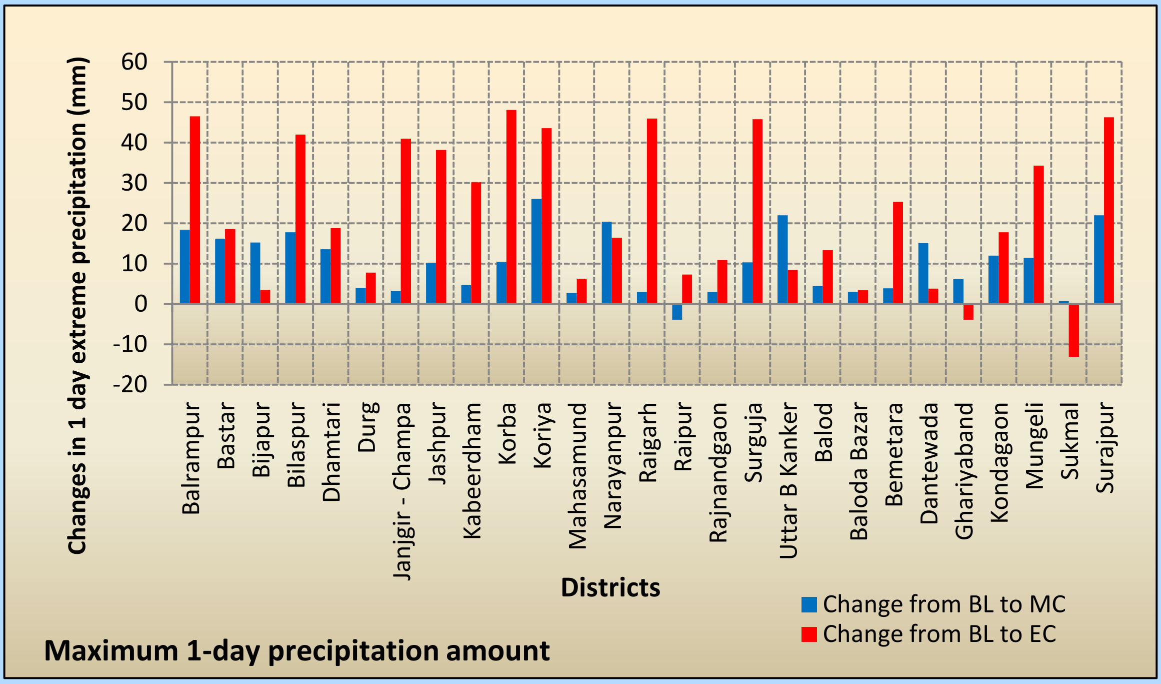


Figure 36 : Characteristics of Annual Precipitation, Maximum 1 day and Maximum 5 day precipitation and Simple Daily Intensity Index - Chhattisgarh

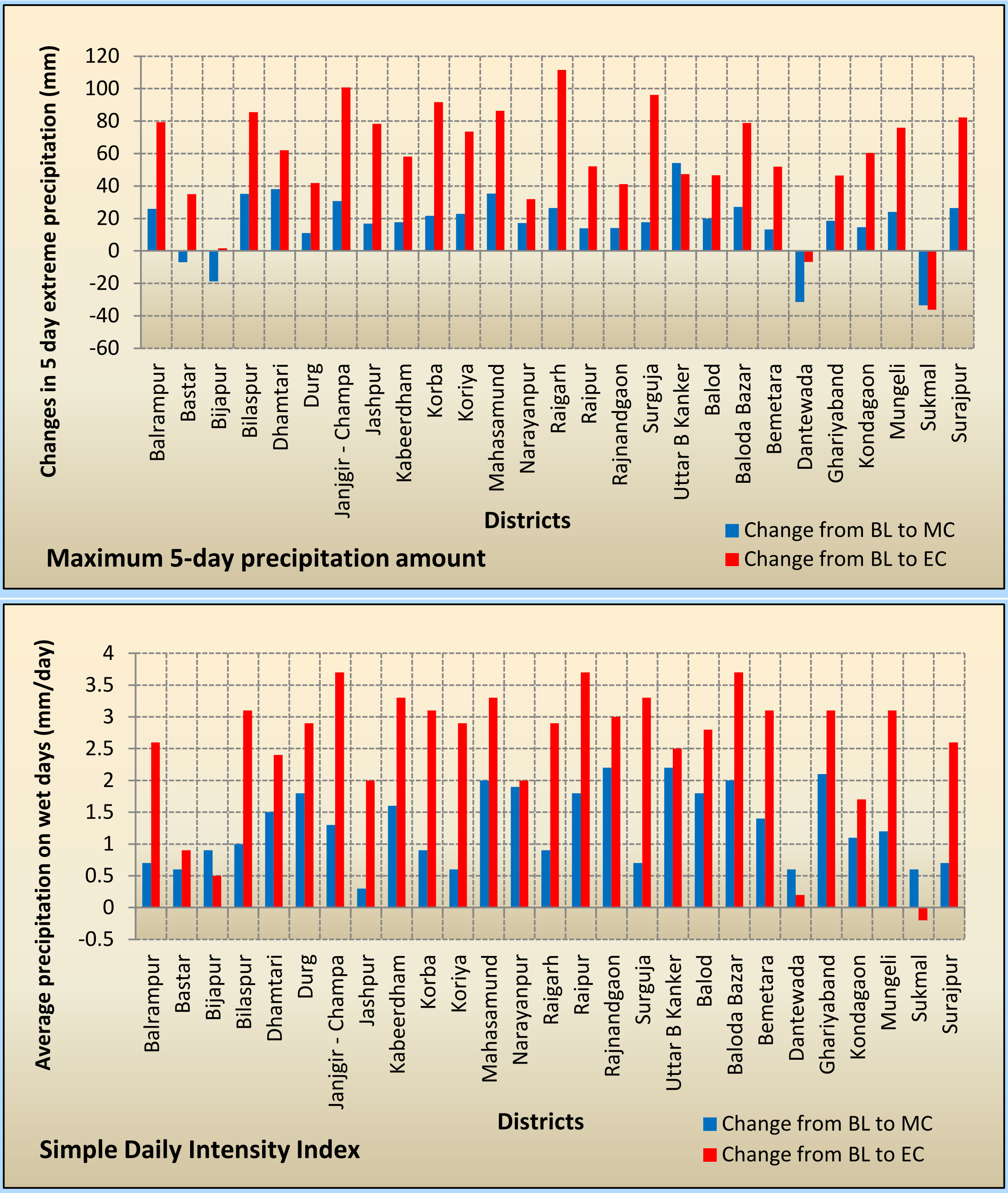


Figure 36 shows the characteristic of annual Precipitation, Maximum 1 day and Maximum 5 day precipitation and average precipitation on wet days. From the figure they are projected to increase for most of the districts in MC and EC compared to the BL implying that rainfall and its intensity would increase in the future. Towards end century increase in precipitation is projected to be the maximum for districts namely Bilaspur, Janjgir-Champa, Korba and Mungeli as compared to the baseline. 1 and 5 day extreme precipitation increase is projected to be the maximum for Janjgir-Champa, Korba, Bilaspur, Rajgarh and Surguja towards end century as can be seen from the figures.

Summary - AR4 Climate Extremes

Summary of the long term trends in observed seasonal precipitation and temperature over Chhattisgarh using IMD gridded rainfall and temperature at daily time scales is:

- ***Rainfall:*** Annual average rainfall for Chhattisgarh from 1971-2005 (35 years) is1287.6 mm. The mean south-west monsoon (June, July, August & September) rainfall (1141.5 mm) contributes 88.7% of annual rainfall. Contribution of pre-monsoon (March, April & May) rainfall and post-monsoon (October, November & December) rainfall in annual rainfall is 3.2% and 2.0% respectively.
- ***Rainy days:*** Average number of rainy days in Chhattisgarh during the south west monsoon is about 60 days for the period 1969-2005and varies from 47 days to 72 days. Average number of rainy days in the state during the post monsoon (winter) is about 6 days and varies from 4 days to 9 days.
- ***Temperature:*** Annual average maximum and minimum temperature for Chhattisgarh from 1969-2005 is 32.0^{0}C and 19.7^{0}C respectively. Seasonal average maximum temperature is higher during pre-monsoon season (37.6^{0}C) and ranges between 36.3^{0}C to 38.5^{0}C. Similarly seasonal average minimum temperature is lowest during winter period (13.2^{0}C) and ranges from 10.6^{0}C to 18.1^{0}C.

PRECIS simulations for future indicate an all-round warming over Chhattisgarh associated with increasing greenhouse gas concentrations.

- The mean minimum and maximum air temperature rise by mid-century is projected to be around 2.2°C and 1.8°C respectively. Change for the same towards end century is projected to be around 4.8°C and 3.8°C respectively. Increase in minimum temperature is projected to be marginally higher than the maximum temperature.
- Precipitation is projected to increase by about 11.2% and 24.7% towards mid-century and end Century respectively.

Climate extremes shows that minimum of maximum and minimum of minimum temperatures is consistently increasing in MC and EC compared to the BL, indicating significant warming up over the Chhattisgarh districts. Very wet and extremely wet day precipitation is projected to increase for all the districts in MC and EC compared to the BL implying that rainfall and its intensity would increase in the future.

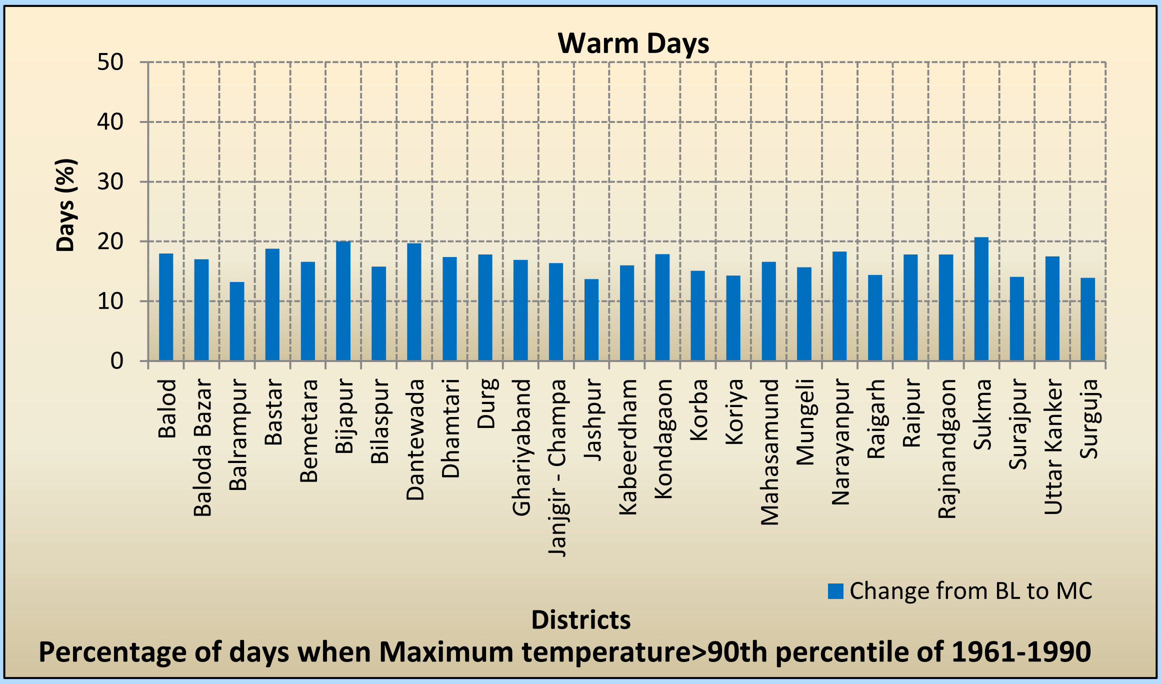
- Towards the end century increase in warm days is more particularly for Janjgir-Champa, Korba, Raigarh and Sukmal districts and warm nights for Sukmal, Dantewada, Bastar and Bijapur compared to the other districts of Chhattisgarh. While for Narayanpur increase in warm days is the least relatively and for Koriya increase in warm nights is the least relatively as compared to the baseline.

- Rajgarh, Balrampur, Sukmal and Surajpur are expected to have the highest change in warm spell duration days in EC while Narayanpur and Rajnandgaon the least compared to the baseline. For cold spell duration days, Uttar Kanker, Narayanpur and Bijapur are expected to have the maximum decrease towards the end century compared to the baseline.
- Towards the end century percentage decrease in cool days is more particularly for Balrampur, Kabeerdham, Koriya and Surajpur districts
- Dhamtari and Ghariyaband of Chhattisgarh districts are expected to have the maximum increase in monthly highest maximum temperature (hottest day) in EC compared to the baseline. Jangir-Champa, Rajgarh and Balod Bazar are expected to have the maximum increase in monthly lowest and highest minimum temperature (coolest and hottest night) in the EC as compared to the baseline. Thus nights are expected to become the warmest for these districts in EC compared to the other districts.
- Increase in precipitation is projected to be the maximum for districts namely Bilaspur, Janjgir-Champa, Korba and Mungeli in end century compared to the baseline.
- Very Wet and extremely wet day precipitation is projected to increase for all the districts in MC and EC except for Sukmal Very wet days is projected to increase the maximum for Jangir-Champa and Baloda Bazar districts of Chhattisgarh in EC compared to the BL.
- Increase in count of very heavy precipitation days is expected to be the maximum for Jangir-Champa and Raipur of Chhattisgarh districts in end century compared to the baseline
- 1 and 5 day extreme precipitation increase is projected to be the maximum for Janjgir-Champa, Korba, Bilaspur, Rajgarh and Surguja towards the end century.

Climate Indices for extremes-AR5

Same suite of climate change indices used in AR5 projections derived from the CORDEX model outputs - both historic (1961-1990) and climate projections (2021-2050) at 0.5°×0.5° have been assessed for Chhattisgarh at the district-level. Projections have been made at a grid-spacing of 0.2°x0.2° resolution using single model (SMHI-RCA4) for RCP 4.5 (moderate emission scenario) only due to data availability.

Figure 37 : Characteristics of Hot Extremes - Warm days and Warm nights - Chhattisgarh



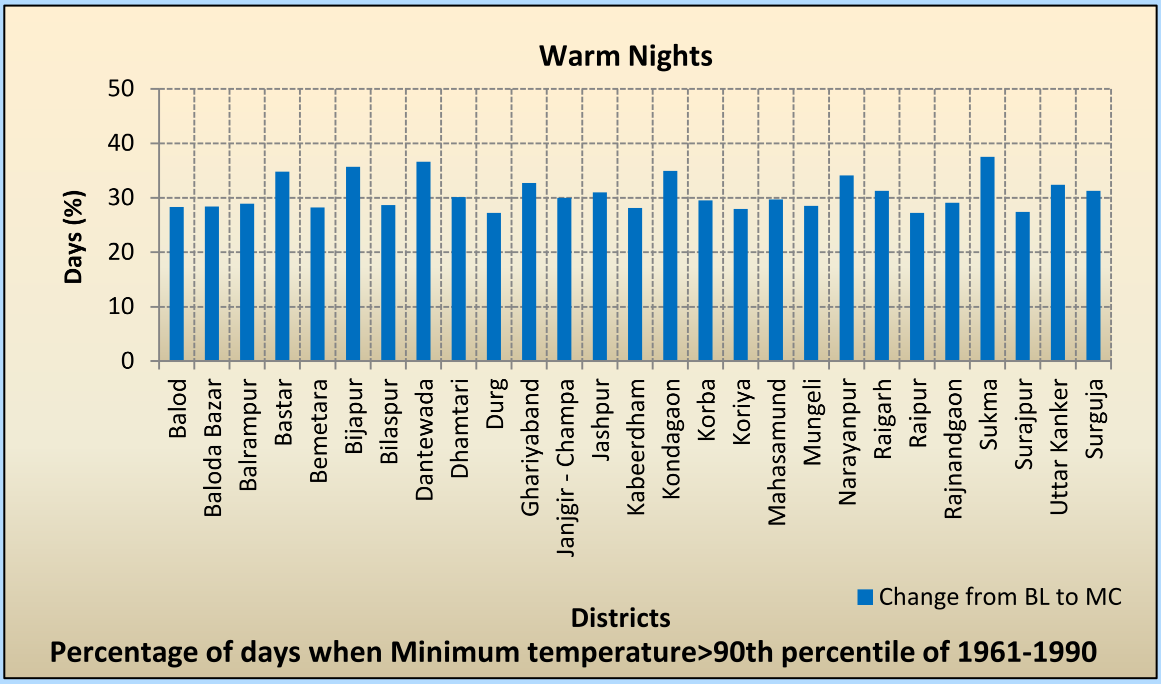
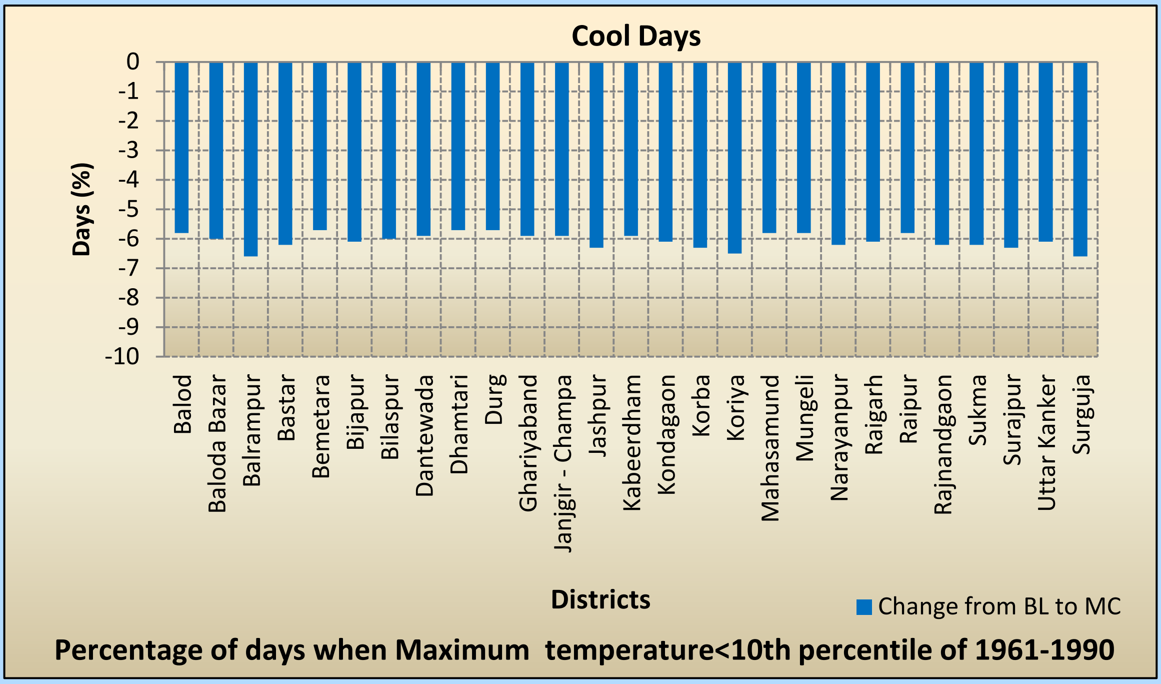


Figure 37 shows the characteristic of warm days and warm nights. From the figure it can be seen that percentage of warm days and warm nights is projected to increase for all the districts in the mid-term compared to the baseline implying warming up. Towards the mid-term increase in warm days and warm nights is more particularly for Sukma, Bijapur and Dantewada districts compared to the other districts of Chhattisgarh. While increase in warm days is the least relatively for Balrampur and increase in warm nights is the least relatively for Durg, Raipur and Surajpur compared to the baseline. It can be inferred that maximum of maximum and maximum of minimum temperatures is consistently increasing, indicating significant warming up over Chhattisgarh districts.

Figure 38 : Characteristics of Cold Extremes - Cool days and Cool nights - Chhattisgarh



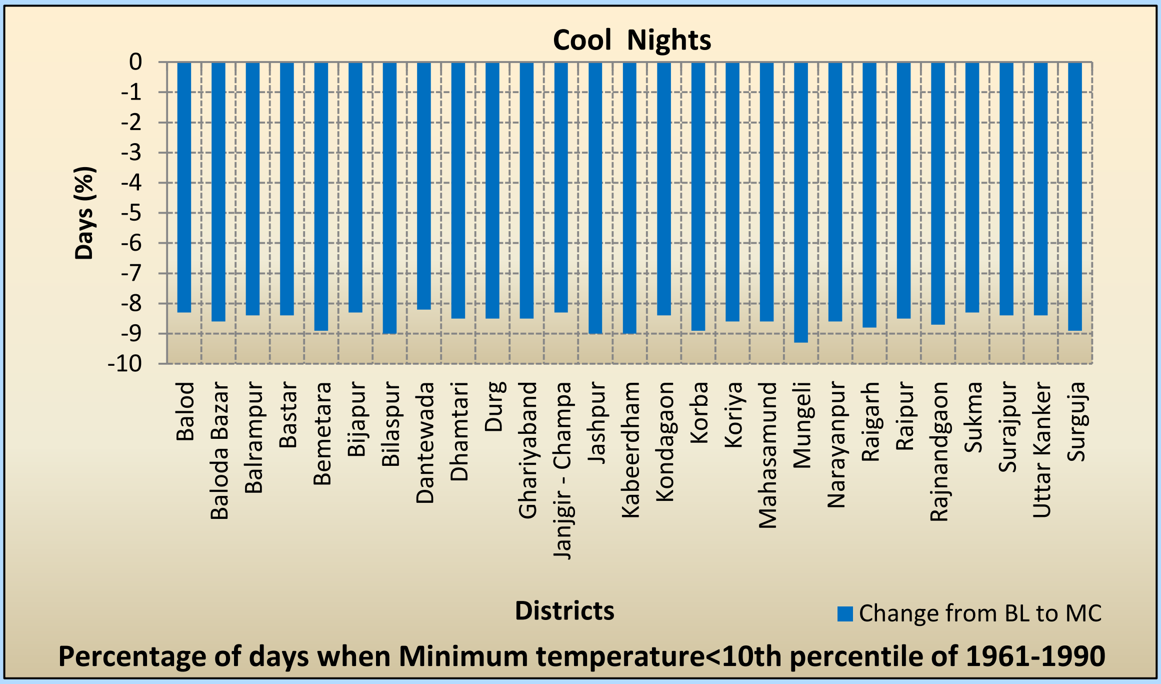


Figure 38 shows the characteristic of cool days and cool nights for Chhattisgarh districts. From the figure it can be seen that percentage of cool days and cool nights is projected to decrease for all the districts in MC compared to the BL implying warming up. Towards the mid-century percentage decrease in cool days is more particularly for Balrampur, Koriya and Surguja districts and cool nights for Mungeli compared to the baseline thus they are expected to be the warmest compared to the other districts of Chhattisgarh. It can be inferred that minimum of maximum and minimum of minimum temperatures is consistently increasing, indicating significant warming up over Chhattisgarh districts.

Figure 39 : Characteristics of Cold and Warm Spell duration - Chhattisgarh

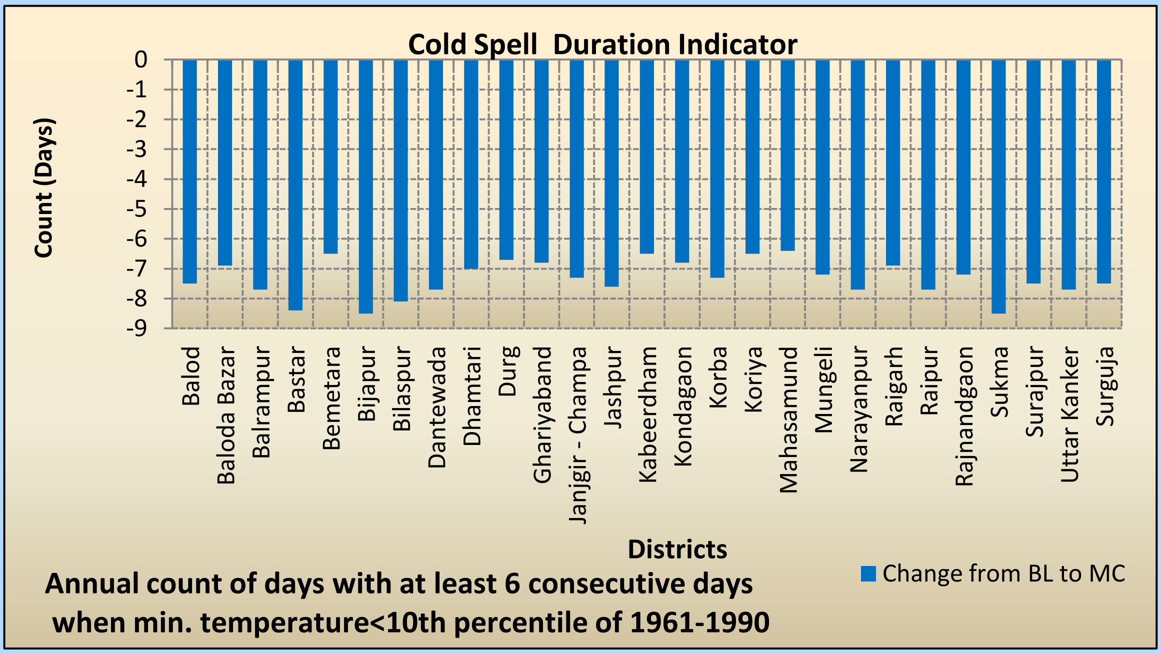


Figure 39 : Characteristics of Cold and Warm Spell duration - Chhattisgarh

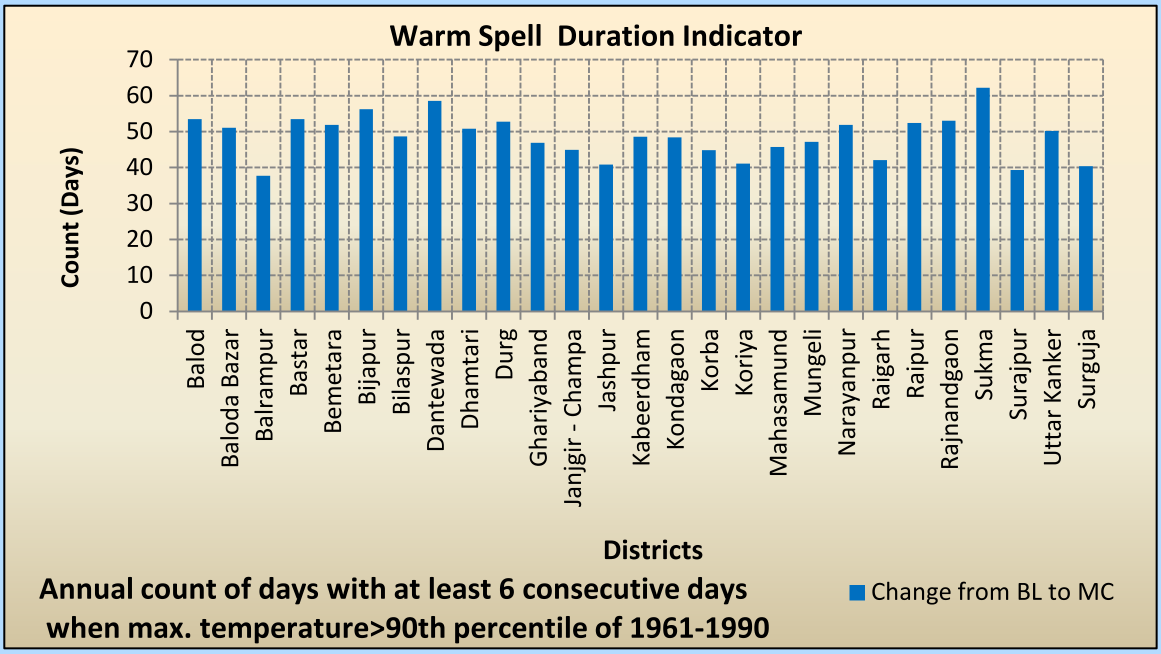
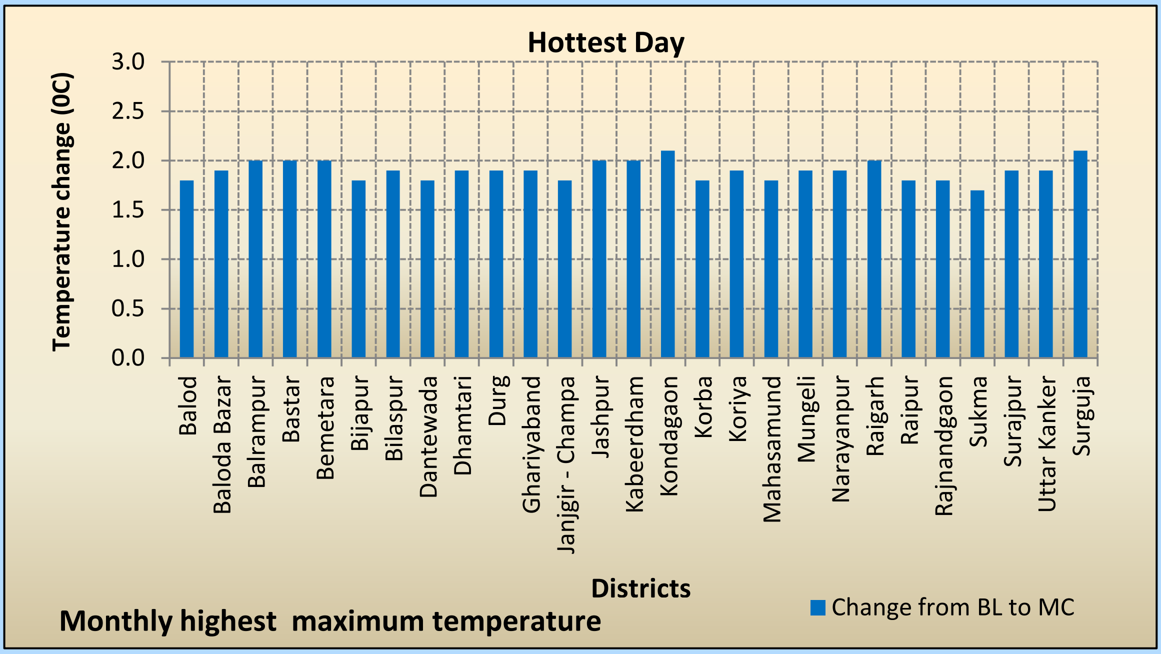


Figure 39 shows the characteristic of warm spell and cold spell duration indicator. From the figure it can be seen that cold spell duration indicator is projected to decrease and warm spell duration indicator is projected to increase for all the districts in MC compared to the BL implying warming up over Chhattisgarh districts. Towards the mid-century Sukma and Dantewada are expected to have the highest change in warm spell duration days while Balrampur and Surajpur the least compared to the baseline. For cold spell duration days, Bastar, Sukma and Bijapur are expected to have the maximum decrease towards the mid-century compared to the baseline.

Figure 40 : Characteristics of Hottest day and Hottest night, Coolest day and Coolest night - Chhattisgarh



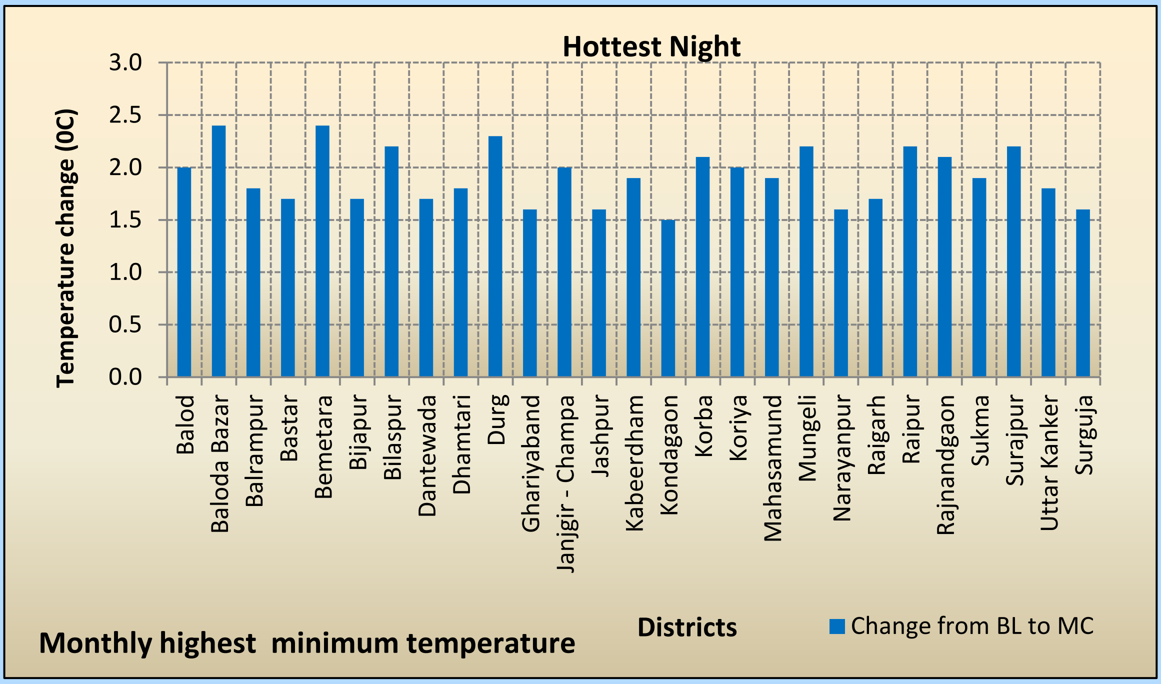


Figure 40 : Characteristics of Hottest day and Hottest night, Coolest day and Coolest night - Chhattisgarh

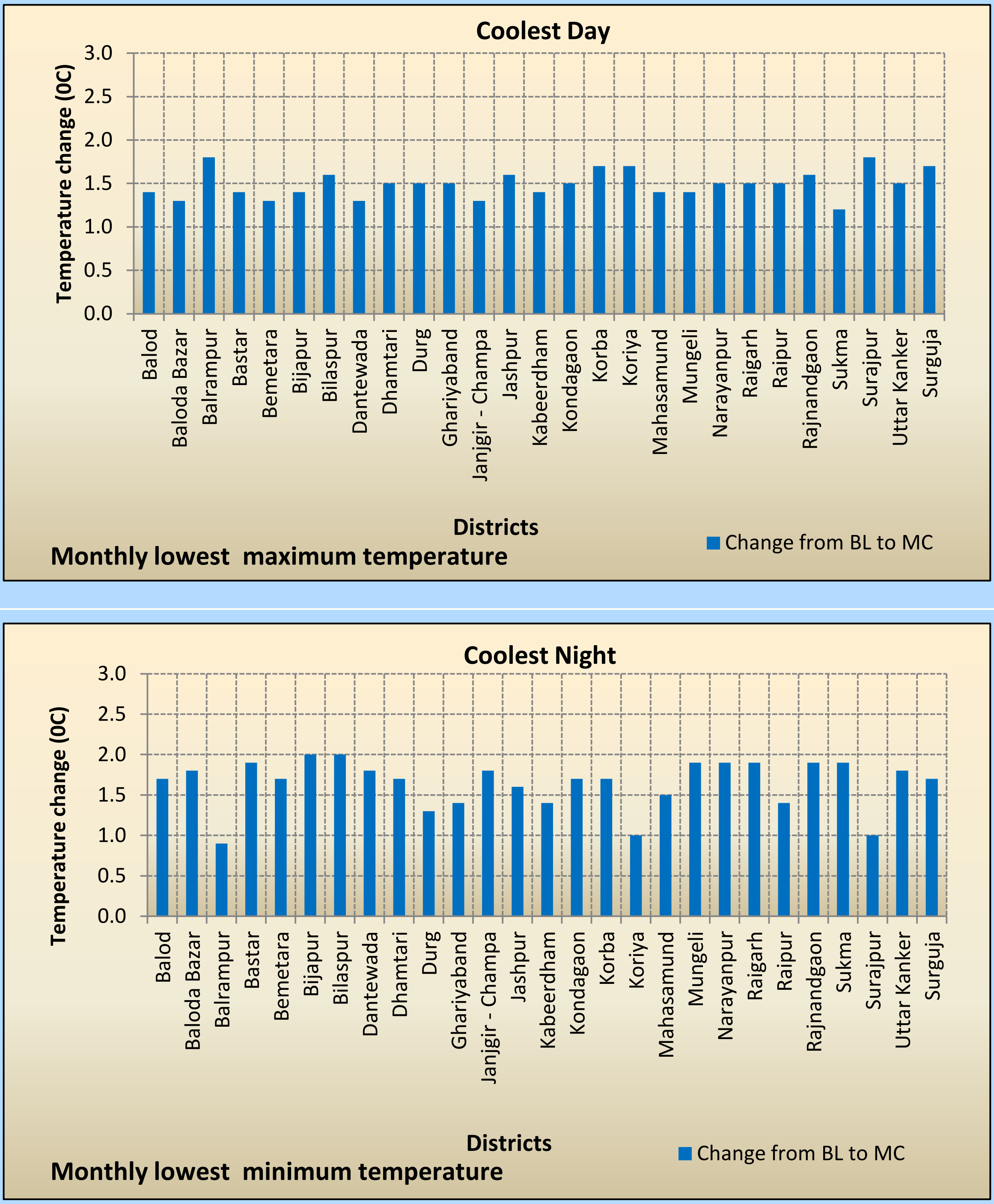


Figure 40 shows the characteristic of hottest day and hottest night, coolest day and coolest night for Chhattisgarh districts. From the figure monthly highest maximum and minimum temperature and monthly lowest maximum and minimum temperature is projected to increase for all the districts in MC compared to the BL implying warming up. Kondagaon and Surguja of Chhattisgarh districts are expected to have the maximum increase (2.1^{0}C) in monthly highest maximum temperature (hottest day) in MC compared to the baseline. . Thus days are expected to become the warmest for these districts in MC compared to the other districts.

Baloda Bazar, Bemetara and Durg are expected to have the maximum increase (2.4^{0}C) in monthly highest minimum temperature (hottest night) in the MC as compared to the baseline. Thus nights are expected to become the warmest for these districts in MC compared to the other districts.

Figure 41 : Characteristics of Diurnal temperature range - Chhattisgarh

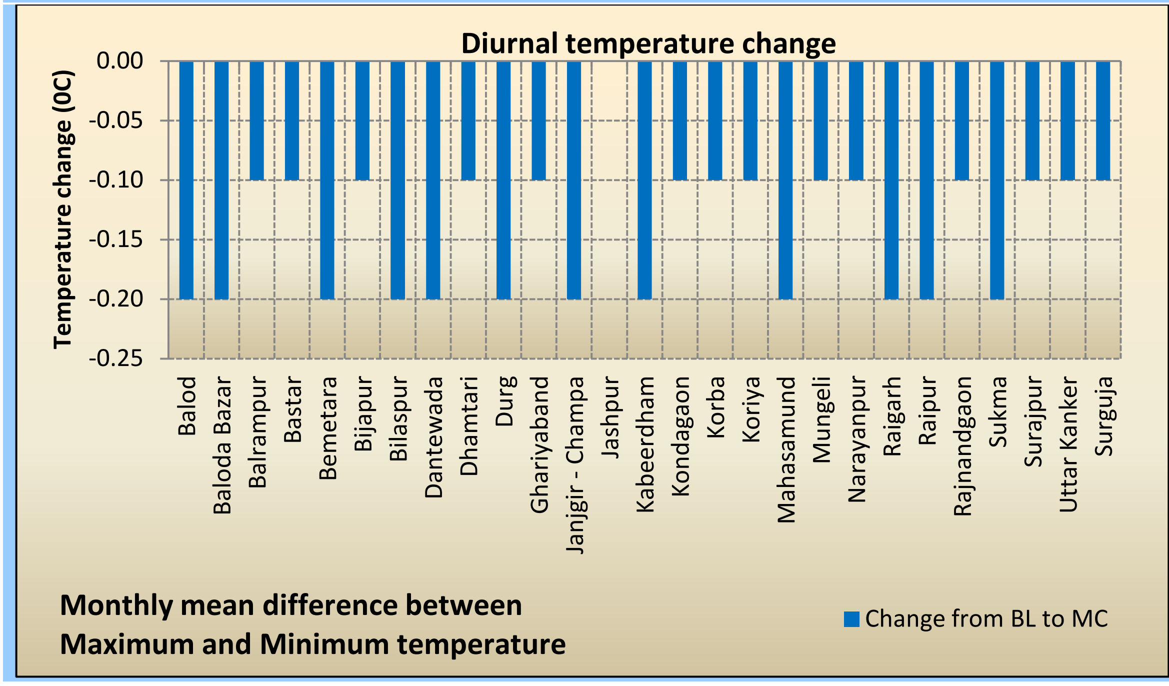
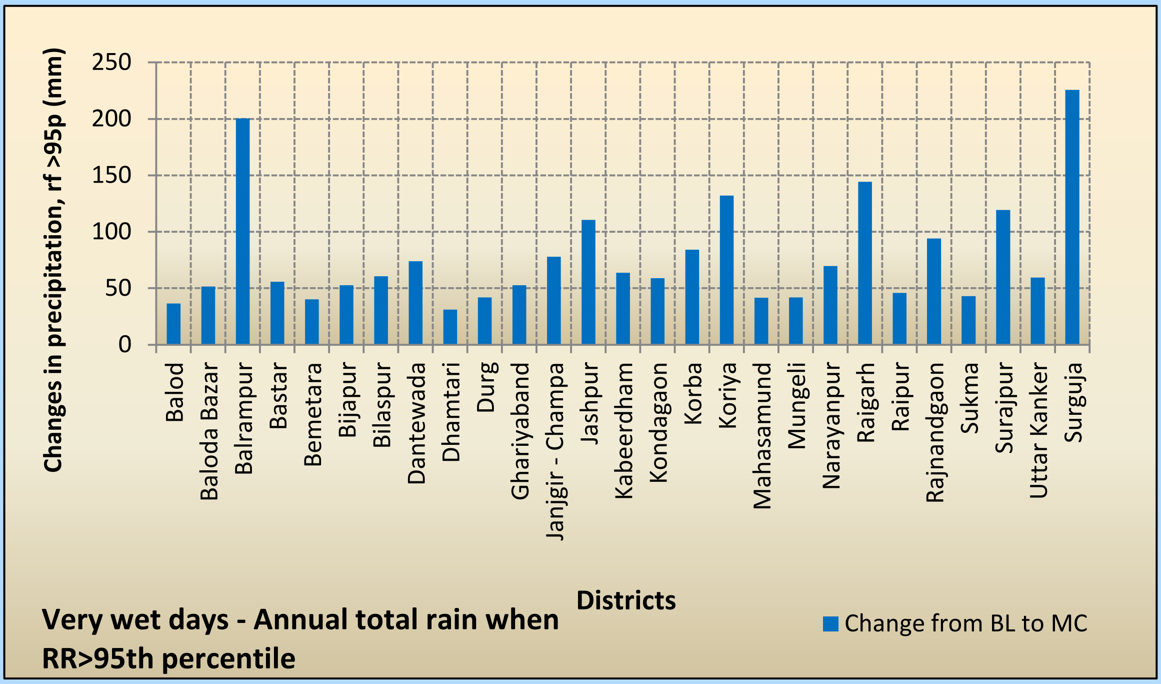


Figure 41 shows the characteristic of monthly difference between maximum and minimum temperature for Chhattisgarh districts. From the figure it can be seen that diurnal temperature change is projected to decrease for all the districts in MC compared to the BL implying warming up.

Figure 42 : Characteristics of Precipitation Extremes –Very wet day and Extremely wet day precipitation - Chhattisgarh



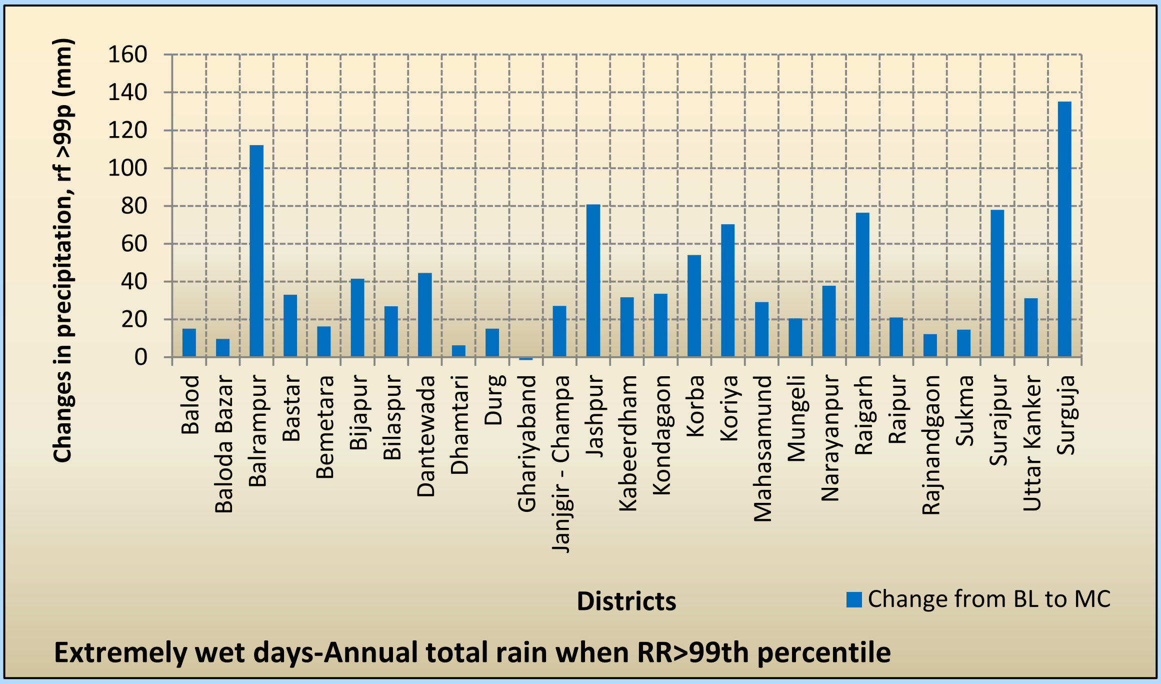
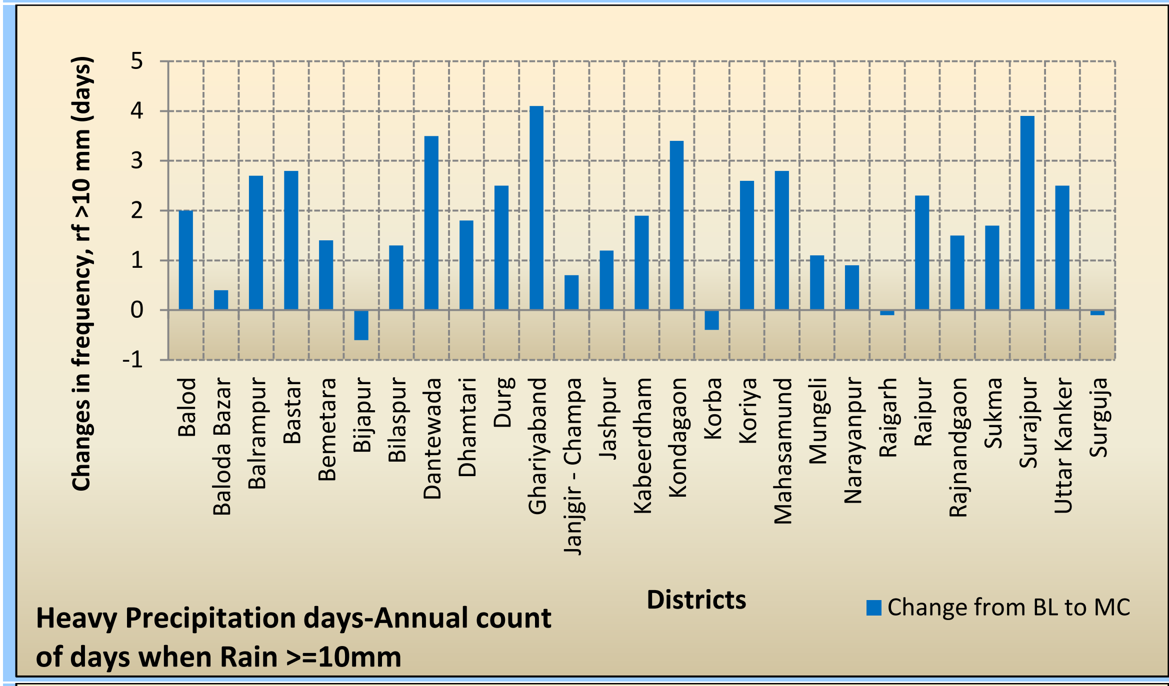


Figure 42 shows the characteristic of precipitation extremes. From the figure it can be seen that very wet and extremely wet day precipitation is projected to increase for all the districts of Chhattisgarh. Particularly the increase in very wet and extremely wet days is expected to be the maximum for Balrampur and Surguja in mid-term compared to the baseline as can be seen from the figures.

Figure 43 : Characteristics of Precipitation Days–Heavy precipitation and very heavy precipitation days - Chhattisgarh



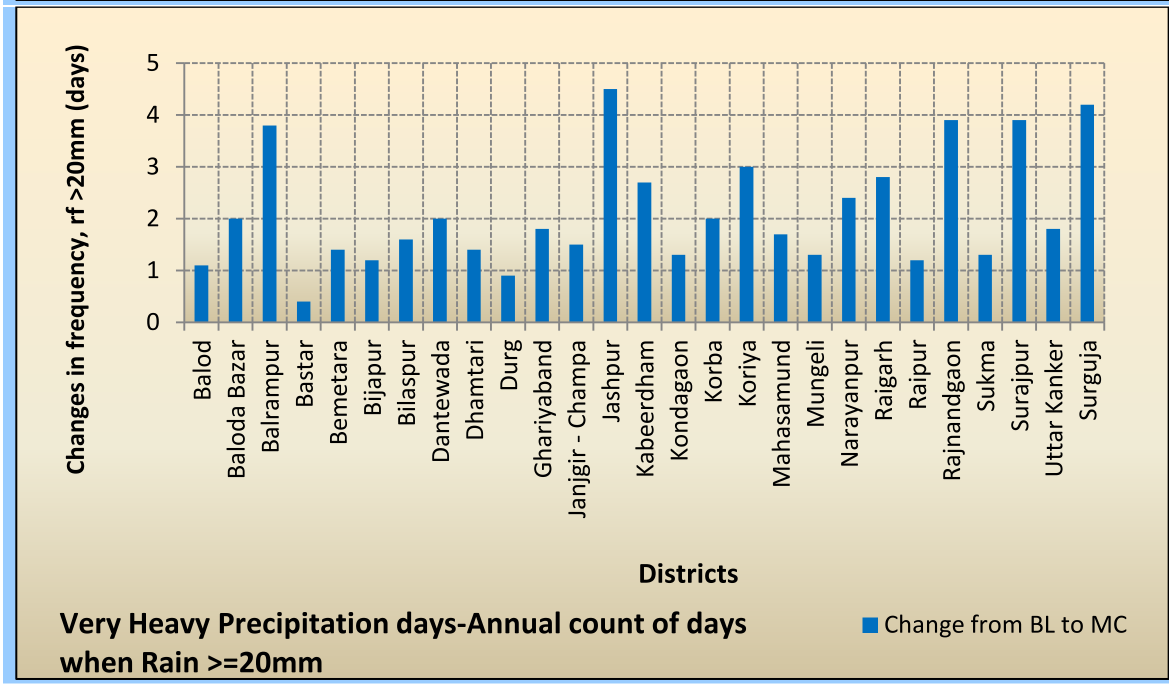
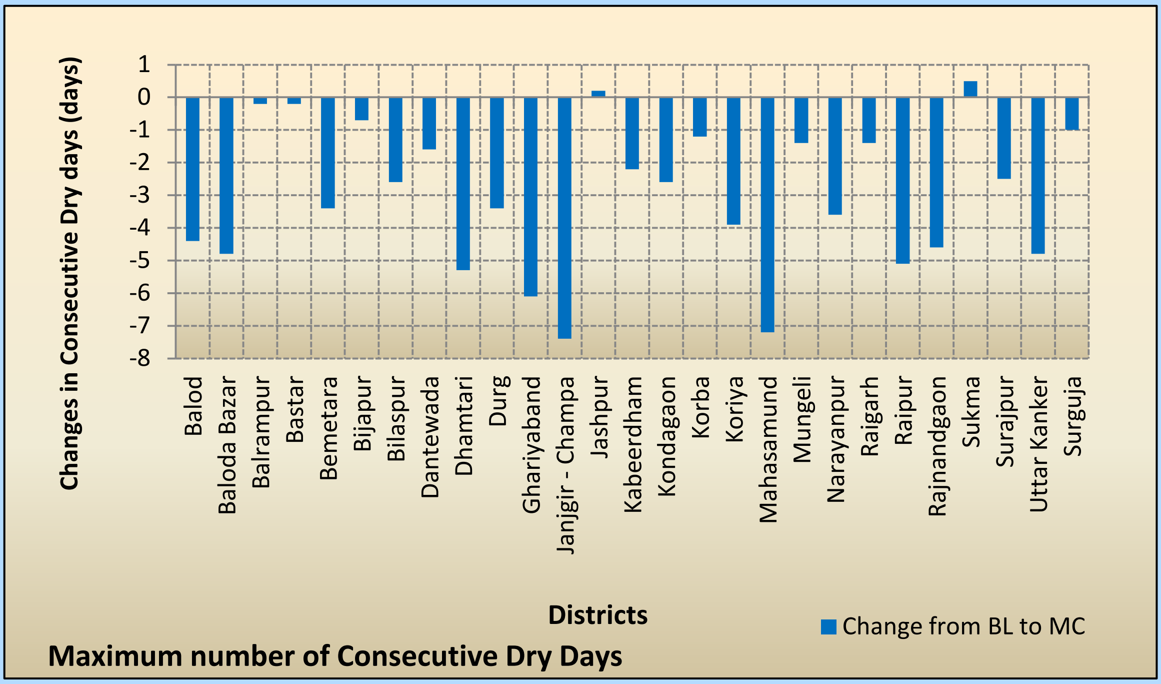


Figure 43 shows the characteristic of precipitation days. From the figure it can be seen that heavy precipitation day is projected to increase for all the districts in MC compared to the BL except for Bijapur, Korba, Raigarh and Surguja, while very heavy precipitation days is projected to increase for all the districts implying that count of heavy rainy days would increase in the future. Increase in count of very heavy precipitation days is expected to be the maximum for Jashpur and Surguja of Chhattisgarh districts in mid-term compared to the baseline as can be seen from the figures.

Figure 44 : Characteristics of Precipitation Extremes - consecutive Dry and Wet days - Chhattisgarh



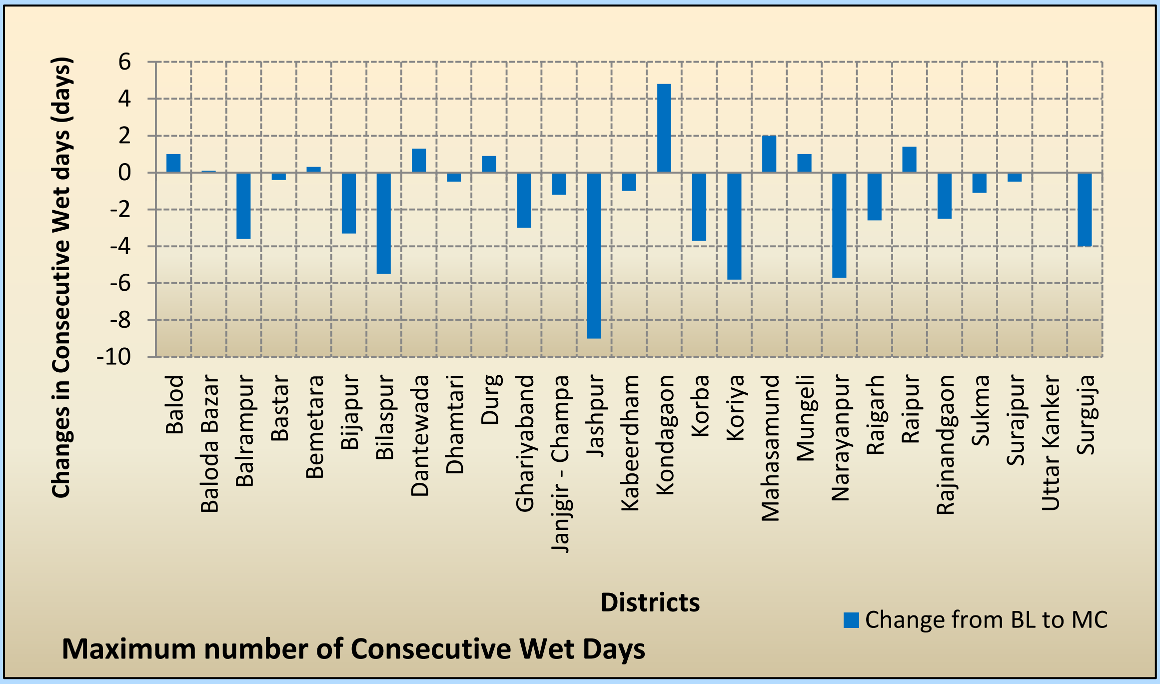
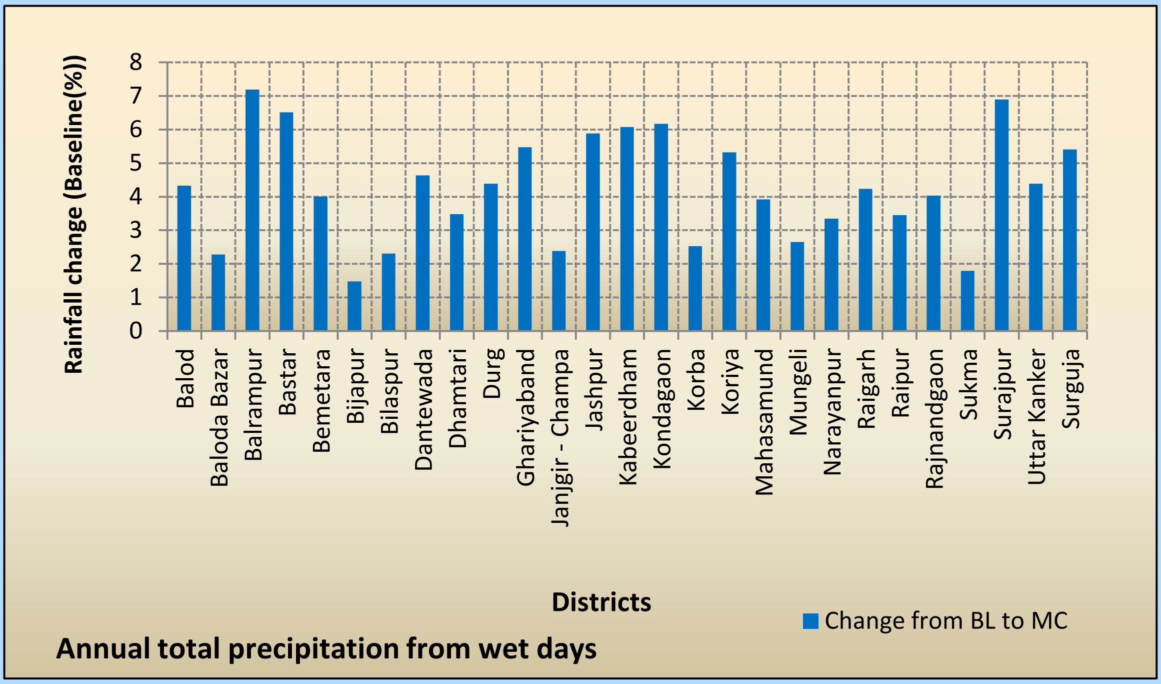


Figure 44 shows the characteristic of Consecutive Dry and Wet days. From the figure it can be seen maximum number of consecutive dry days is declining in MC compared to the baseline for all the districts except for Jashpur and Sukma for which it is increasing respectively compared to the baseline. Decline in consecutive wet days is expected to be the maximum for Jashpur.

Figure 45 : Characteristics of Annual Precipitation, Maximum 1 day and Maximum 5 day precipitation and Simple Daily Intensity Index - Chhattisgarh



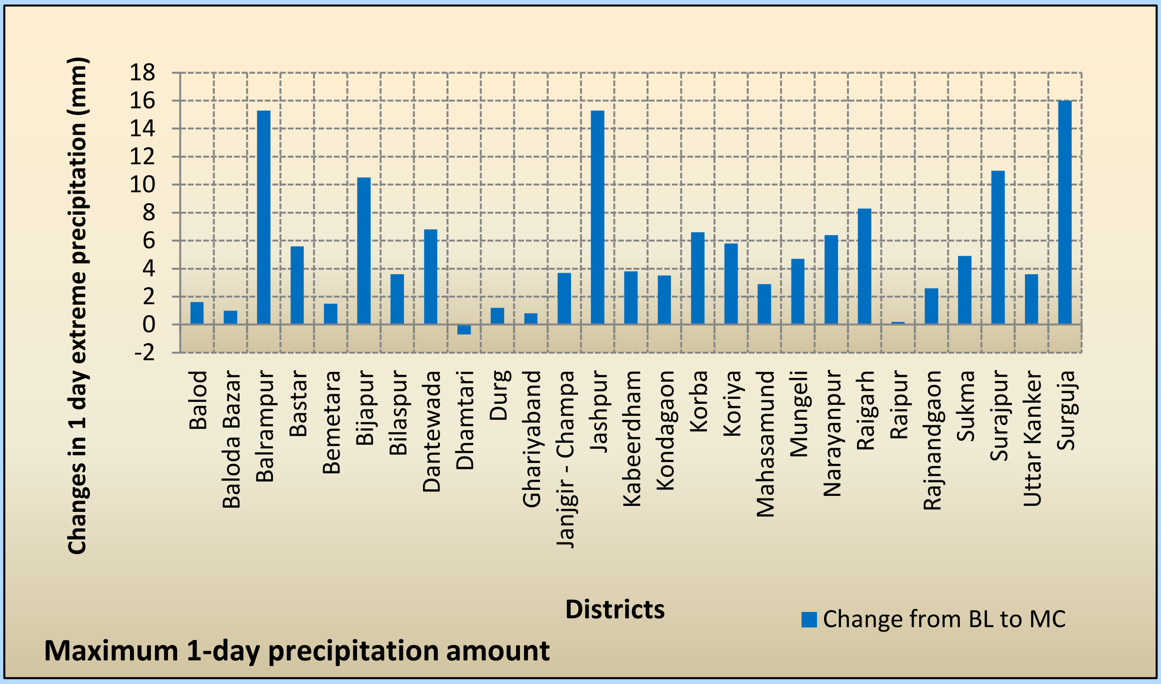
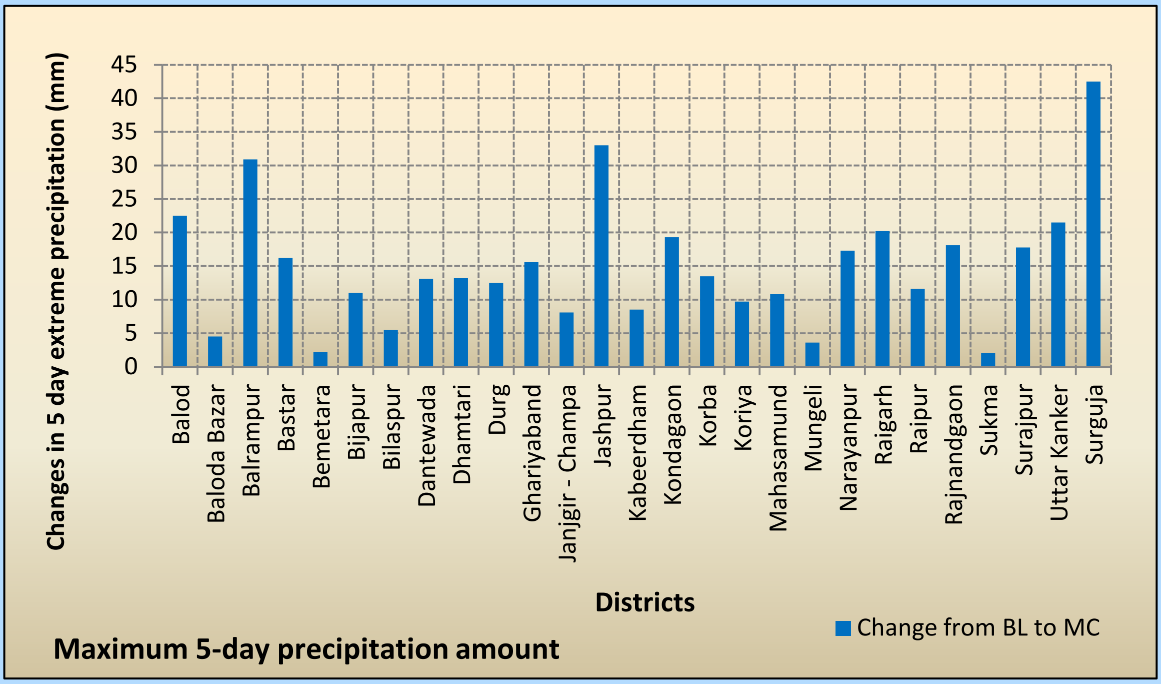


Figure 45 : Characteristics of Annual Precipitation, Maximum 1 day and Maximum 5 day precipitation and Simple Daily Intensity Index - Chhattisgarh



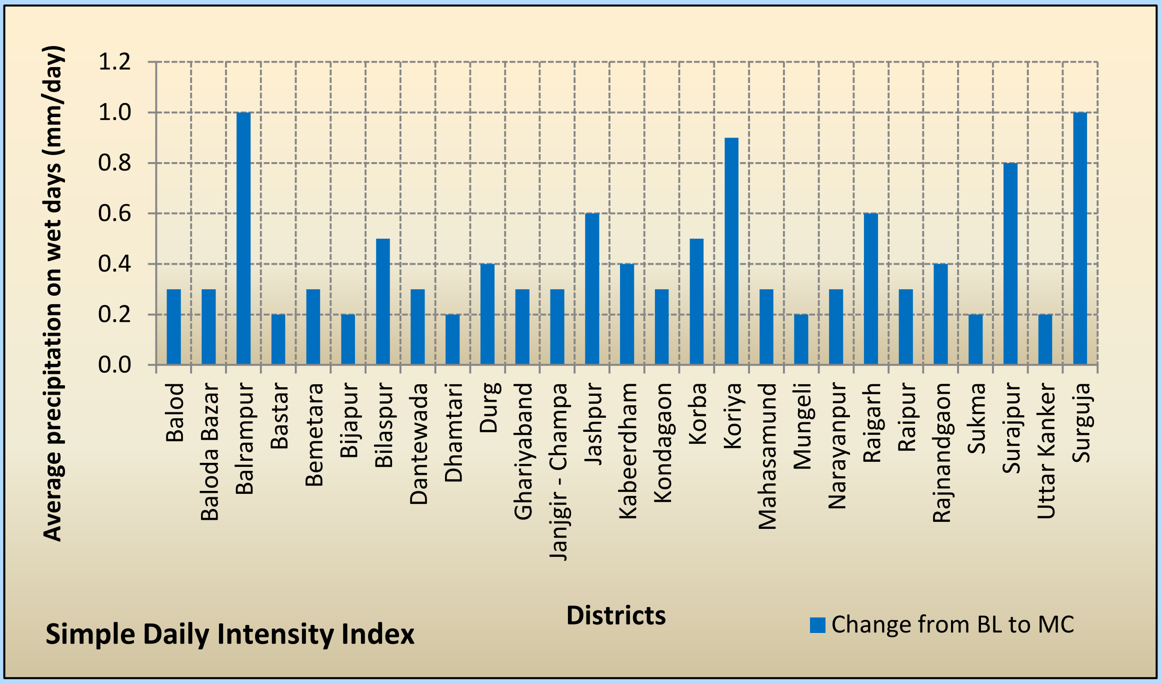


Figure 45 shows the characteristic of Annual Precipitation, Maximum 1 day and Maximum 5 day precipitation and average precipitation on wet days (Simple Daily Intensity Index). From the figure they are projected to increase for all the districts of Chhattisgarh in MC compared to the BL implying that rainfall and its intensity would increase in the future. Towards mid-century approximately 7%

increase (maximum) in precipitation compared to the baseline is projected for districts namely Balrampur and Surajpur.1 and 5 day extreme precipitation increase is projected to be the maximum for Balrampur, Jashpur and Surguja towards mid-term as can be seen from the figures.

Summary - AR5 Climate Extremes - Chhattisgarh

Climate extremes shows that minimum of maximum and minimum of minimum temperatures is consistently increasing in MC compared to the BL, indicating significant warming up over the Chhattisgarh districts. Very wet and extremely wet day precipitation is projected to increase for all the districts in MC compared to the BL implying that rainfall and its intensity would increase in the future.

- Towards the mid-term increase in warm days and warm nights is more particularly for Sukma, Bijapur and Dantewada districts compared to the other districts of Chhattisgarh. While increase in warm days is the least relatively for Balrampur and increase in warm nights is the least relatively for Durg, Raipur and Surajpur compared to the baseline.
- Towards the mid-century Sukma and Dantewada are expected to have the highest change in warm spell duration days while Balrampur and Surajpur the least compared to the baseline. For cold spell duration days, Bastar, Sukma and Bijapur are expected to have the maximum decrease towards the mid-century compared to the baseline.
- Towards the mid-century percentage decrease in cool days is more particularly for Balrampur, Koriya and Surguja districts and cool nights for Mungeli compared to the baseline thus they are expected to be the warmest compared to the other districts of Chhattisgarh.
- Kondagaon and Surguja of Chhattisgarh districts are expected to have the maximum increase (2.1^{0}C) in monthly highest maximum temperature (hottest day) in MC compared to the baseline. Baloda Bazar, Bemetara and Durg are expected to have the maximum increase (2.4^{0}C) in monthly highest minimum temperature (hottest night) in the MC as compared to the baseline.
- Percentage increase in precipitation is projected to be the maximum for districts namely Balrampur and Surajpur (approximately 7% increase) in mid-century compared to the baseline.
- Very Wet and extremely wet day precipitation is projected to increase for all the districts of Chhattisgarh. Particularly the increase is expected to be the maximum for Balrampur and Surguja in mid-term compared to the baseline.
- Increase in count of very heavy precipitation days is expected to be the maximum for Jashpur and Surguja of Chhattisgarh districts in mid-century compared to the baseline.
- 1 and 5 day extreme precipitation increase is projected to be the maximum for Balrampur, Jashpur and Surguja towards the mid-century.

Chapter 4

Climate Change - Sectoral Impact Assessment

Climate Change - Sectoral Impact Assessment

A brief summary of assessment of the impact of projected climate change on water, agriculture, forest and health sectors is presented here.

Impact of climate change on water resources of Chhattisgarh

Method and Models

In the arena of climate change impact assessment deployment of the simulation models is the only option since we are talking of the future which cannot be ascertained through observations. In the present study a hydrological model to simulate the climate change impact on water resources and agriculture has been used. A brief description of the SWAT hydrological model is given in the following paragraphs.

Soil and Water Assessment Tool (SWAT) Model

The Soil and Water Assessment Tool (SWAT) model (Arnold et al., 1998[40], Neitsch et al., 2002[41]) 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 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.

In SWAT, a watershed is divided into multiple sub-watersheds, which are then further subdivided into unique soil/land-use characteristics called hydrologic response units (HRUs). The water balance of each HRU in SWAT is represented by four storage volumes: snow, soil profile (0-2m), shallow aquifer (typically 2-20m), and deep aquifer (>20m). Flow generation, sediment yield, and non-point-source loadings from each HRU in a sub-watershed are summed, and the resulting loads are routed through channels, ponds, and/or reservoirs to the watershed outlet. Hydrologic processes are based on the following water balance equation:

[40]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

[41] 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.

$$SW_t = SW + \sum_{i=1}^{t}(R_{it} - Q_i - ET_i - P_i - QR_i)$$

where SW is the soil water content minus the wilting-point water content, and R, Q, ET, P, and QR are the daily amounts (in mm) of precipitation, runoff, evapotranspiration, percolation, and groundwater flow, respectively. The soil profile is subdivided into multiple layers that support soil water processes, including infiltration, evaporation, plant uptake, lateral flow, and percolation to lower layers. The soil percolation component of SWAT uses a storage routing technique to predict flow through each soil layer in the root zone. Downward flow occurs when field capacity of a soil layer is exceeded and the layer below is not saturated. Percolation from the bottom of the soil profile recharges the shallow aquifer. If the temperature in a particular layer is 0ºC or below, no percolation is allowed from that layer. Lateral subsurface flow in the soil profile is calculated simultaneously with percolation. The contribution of groundwater flow to the total stream flow is simulated by routing a shallow aquifer storage component to the stream (Arnold, Allen, and Bernhardt 1993[42]).

SWAT also simulates the nutrient dynamics. Sediment yield is calculated based on the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975[43]). The movement of nutrients, i.e. nitrogen and phosphorus is based on built in equations for their transformation from one form to the other. The total amounts of nitrates in runoff and subsurface flow is calculated from the volume of water in each pathway with the average concentration. Phosphorus however is assumed to be a relatively less mobile nutrient, with only the top 10 mm of soil considered in estimating the amount of soluble P removed in runoff. A loading function is used to estimate the phosphorus load bound to sediments (McElroy et al, 1976[44]). SWAT calculates the amount of algae, dissolved oxygen and carbonaceous biological oxygen demand (CBOD - the amount of oxygen required to decompose the organic matter transported in surface runoff) entering the main channel with surface runoff. CBOD loading function is based on a relationship given by Thomann and Mueller (1987)[45]

[42] Arnold, J.G., Allen, P.M, and Bernhardt, G.T. 1993. A comprehensive surface groundwater flow model. Journal of Hydrology, 142: 47-69

[43] Williams, J.R. 1975. Sediment routing for agricultural watersheds. Water Resources Bulletin, 11 (5): 965-974.

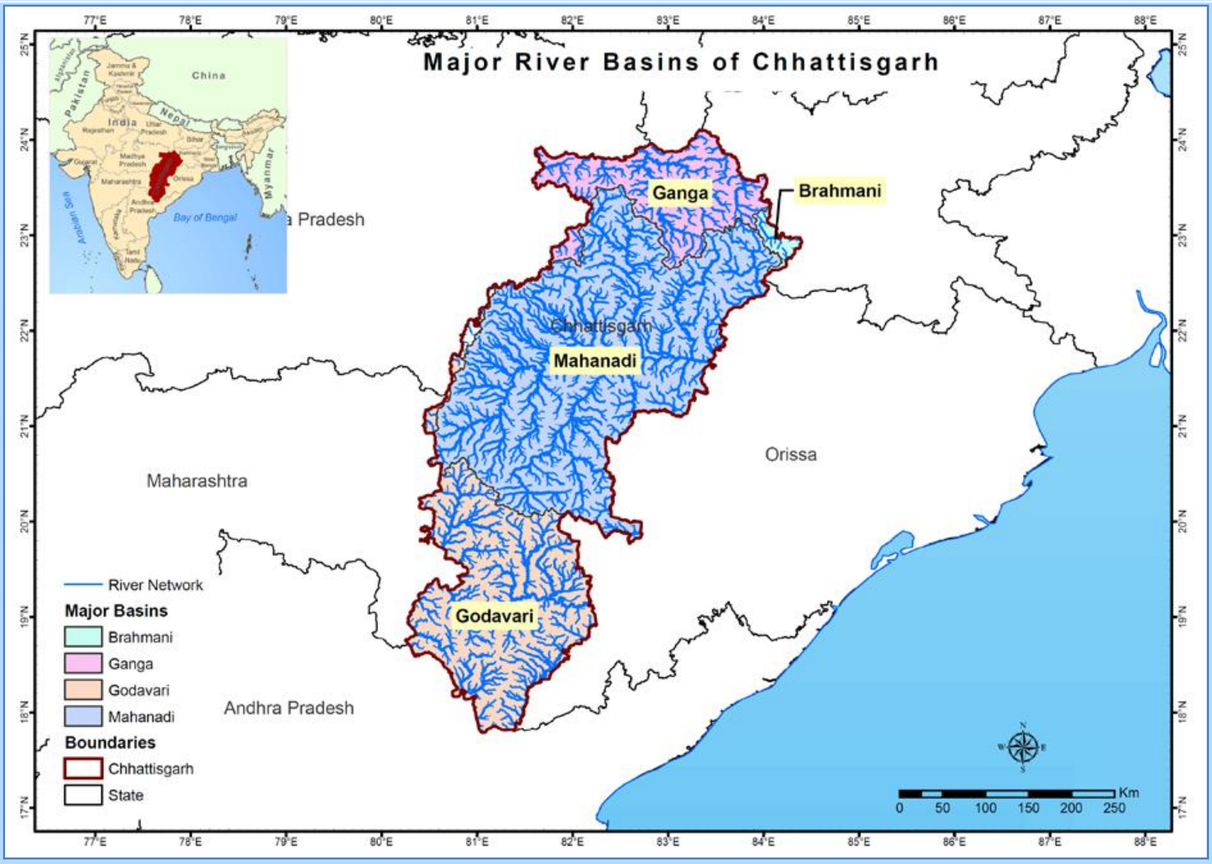
[44] McElroy, A.D., Chiu, S.Y. and Nebgen, J.W. 1976. Loading functions for assessment of water pollution from nonpoint sources. EPA document 600/2-76-151, USEPA, Athens, GA

[45]Thomann, R.V. and J.A. Mueller. 1987. Principles of surface water quality modelling and control. Harper & Row Publishers, New York

Development of hydrologic model for the river basins of Chhattisgarh

In the present analysis, the part of the Ganga, Brahmani, Godavari and Mahanadi river basin falling in the state of Chhattisgarh have been modelled. The study area is shown in Figure 46.

Figure 46 : River basins of Chhattisgarh



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 river systems falling in Chhattisgarh.

Data Used

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

- Digital Elevation Model: SRTM, of 90 m resolution[46]
- Drainage Network – Hydroshed[47]
- Soil maps and associated soil characteristics (source: FAO Global soil)[48]
- Land use: Global Map of Land Use/Land Cover Areas (GMLULCA), IWMI's Global Map of Irrigated Areas (GMIA) (source: IWMI) [49]

[46] http://srtm.csi.cgiar.org
[47] http://hydrosheds.cr.usgs.gov/
[48] http://www.lib.berkeley.edu/EART/fao.html
[49] http://www.iwmigiam.org/info/main/index.asp

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. These Weather data available as per following details are used

- Observed rainfall and temperature data IMD gridded Rainfall data (1971–2006)[50].
- Princeton University dataset constructed by combining a suite of global observation-based datasets with the NCEP/NCAR reanalysis[51]
- Climate Change: Global Climate Model outputs, IPCCAR5 CORDEX output from SMHI at a resolution of 0. 5° X 0.5° latitude by longitude grid points obtained from IITM Pune for Baseline (1961–1990, BL) , midterm (2021-2050 is considered as MC) for IPCC AR5 RCP 4.5 scenario

Water demand and abstraction data: In the absence of observed data, secondary information shall be used

- Current management/operation practices, existing irrigation as per crop demand taken from the landuse information

Model Performance

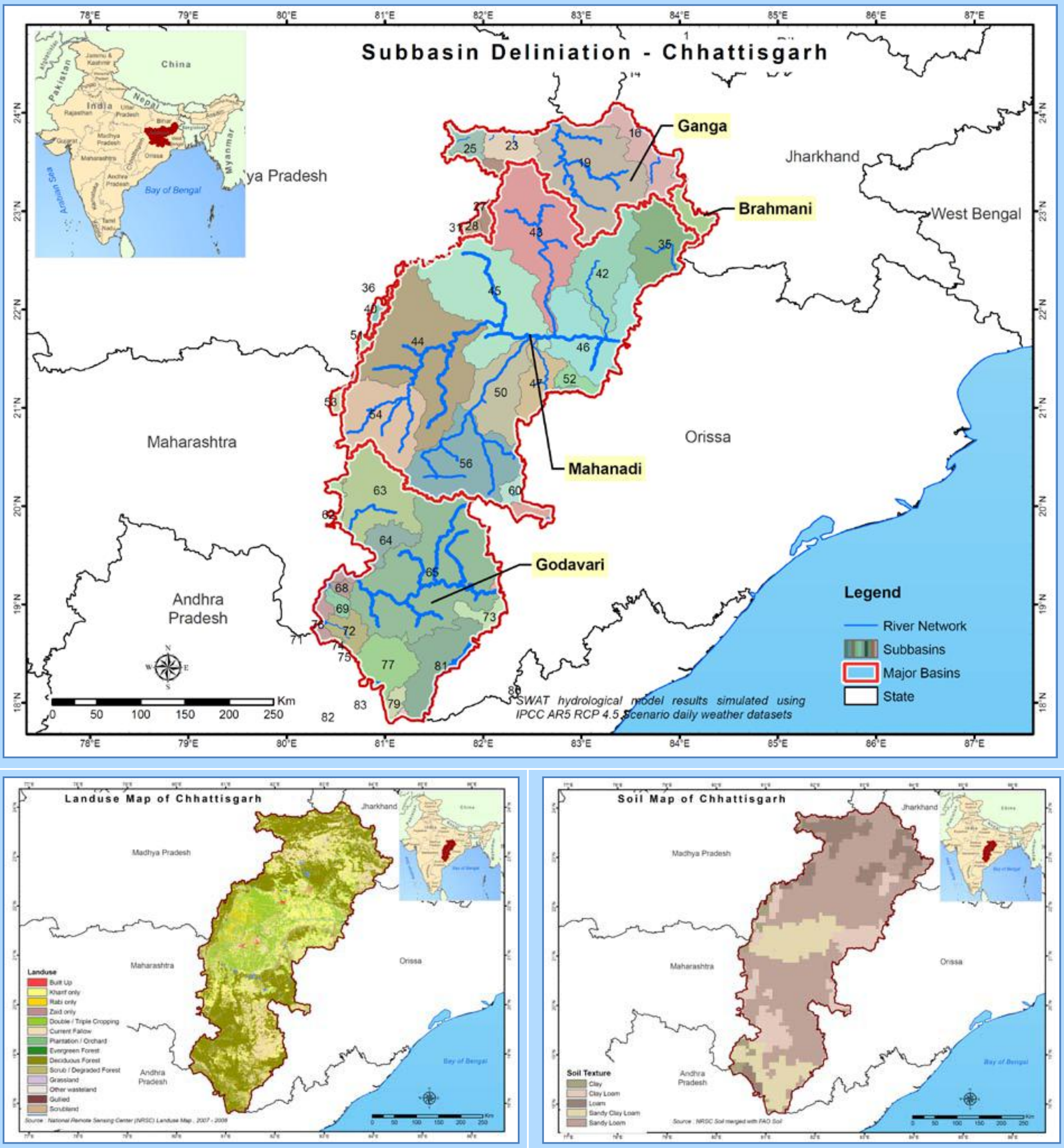
Statistical parameters namely regression coefficients (R^2) and Nash Sutcliffe coefficient (NS) are used to assess the model efficiency on monthly SWAT hydrologic stream flow predictions. Stream flow monitoring stations for which data is made available have been validated satisfactorily.

[50] http://www.chikyu.ac.jp/precip/products/index.html (IMD gridded data does not exist in the Nepal part, in order to maintain the uniformity of data sources, it is advisable that single source is used wherever possible, and that is the reason Aphrodite is chosen (source of Aphrodite anyway are from individual countrys' Met dept. repository))
[51] http://hydrology.princeton.edu/data/index.html

Mapping of River basins of Chhattisgarh

Automatic delineation of watersheds was done by using the DEM as input. The target outflow point is interactively selected. Figure 47 shows the subbasins delineated for Chhattisgarh.

Figure 47 : Sub basin delineation using DEM for the River basins of Chhattisgarh



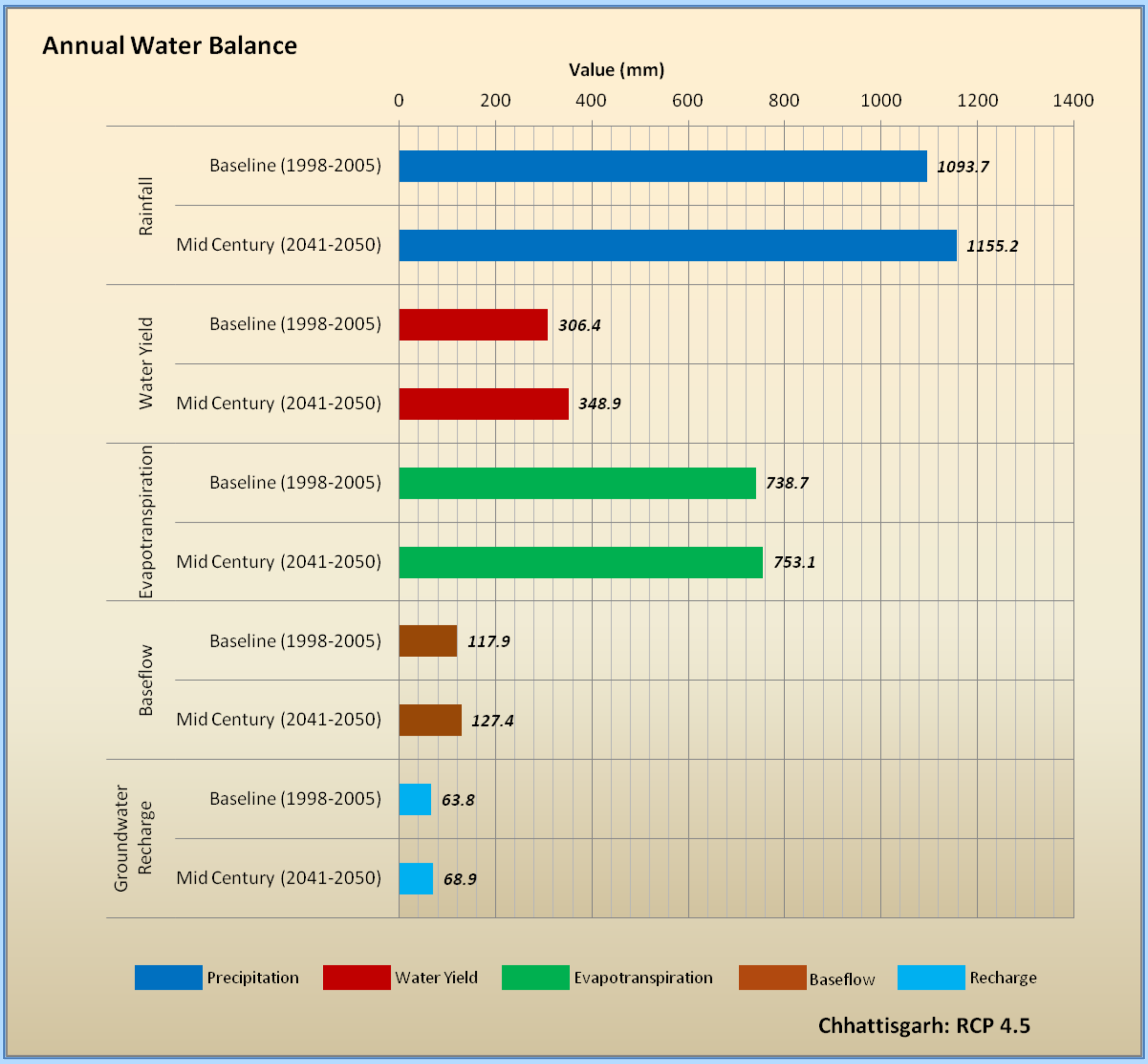
Impacts of Climate Change on Water Resources

The model has been run using climate scenarios for midterm (MC, 2021 – 2050) without changing the land use. The climate change simulations are run for RCP 4.5 scenario, for 2 time periods; Baseline and Mid-term.

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

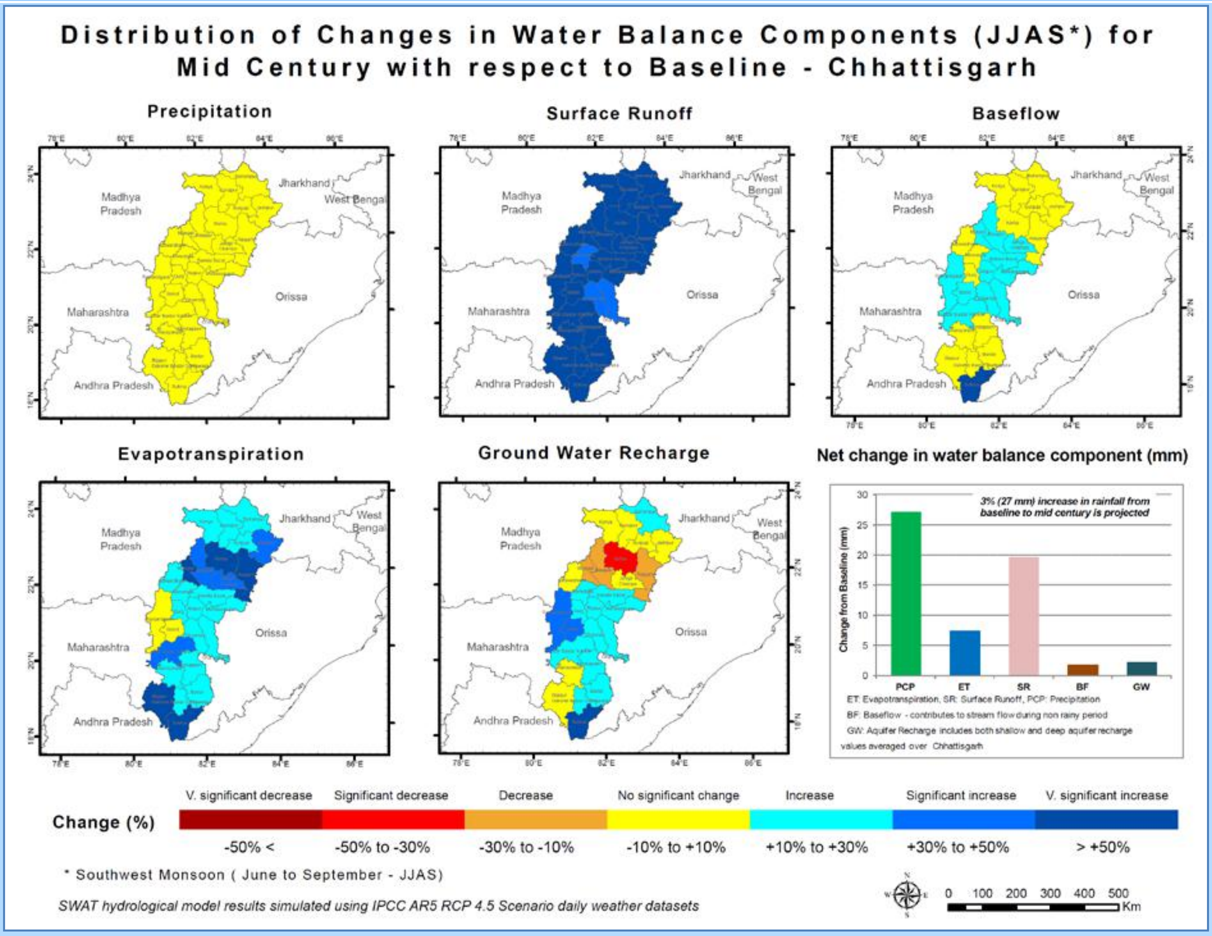
Figure 48 presents the snapshot long-term variability of the key water balance for Chhattisgarh. These components are expressed in terms of total annual depth of water in mm over the total watershed area. In other words, the total water yield is the equivalent depth in mm, of flow past the outlet of the watershed on average annual basis.

Figure 48 Annual water balance components for BL and MC climate scenarios (IPCC AR5 RCP 4.5) for the Chhattisgarh



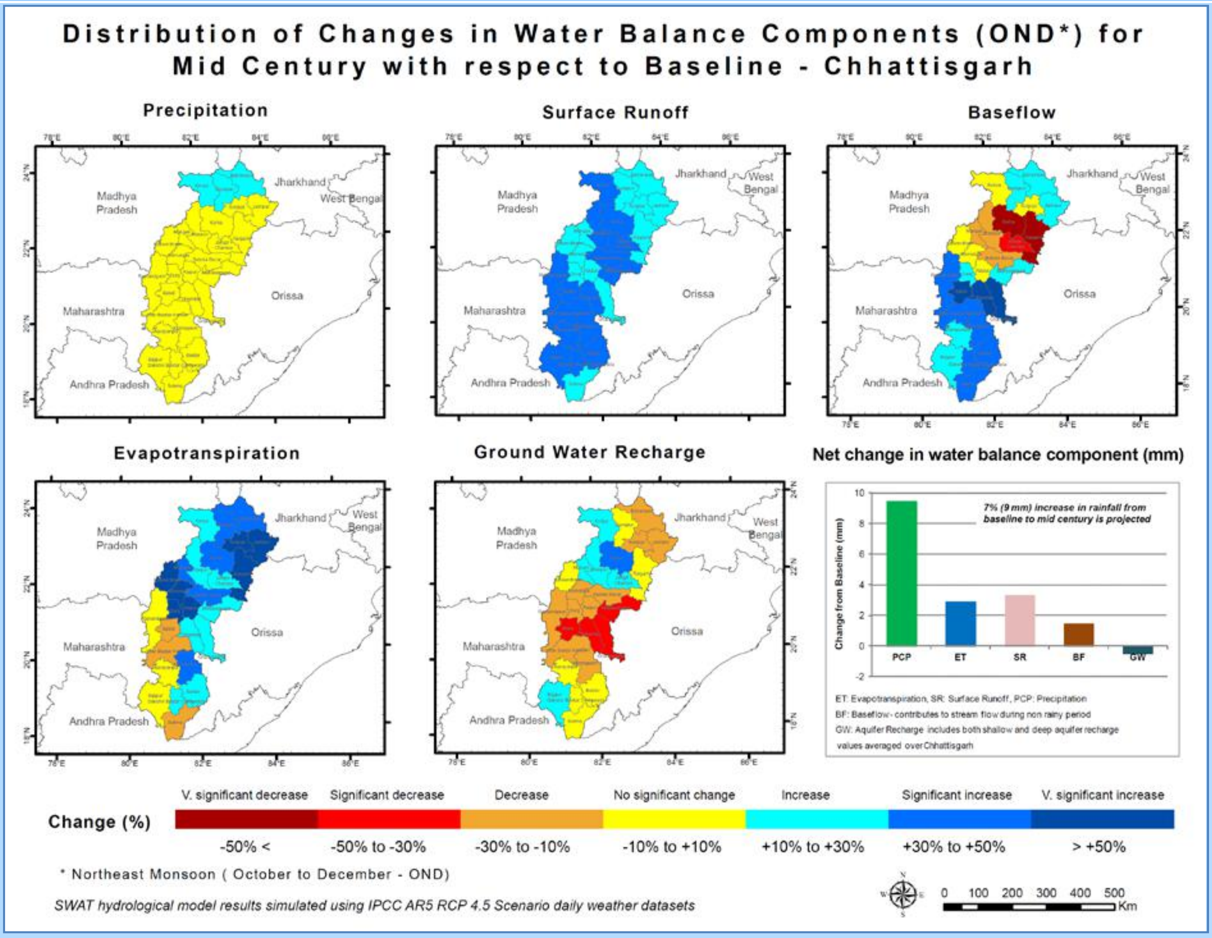
Analysis projects an increase in annual precipitation of about 5.6% (62 mm) by mid-term resulting in increase in runoff, thus contributing to the stream flow and 8% contribution to the ground water recharge. Evapotranspiration is projected to increase by 23%. During the monsoon months (JJAS) increase in precipitation is projected to be about 4.2%, 62% of this is contributed to the stream flow as surface runoff and the rest is contributed to the ground water recharge. There is projected increase in evapotranspiration. The indication is that in most part of Chhattisgarh surface runoff would be increased under the RCP4.5 midterm scenario (Figure 49).

Figure 49 : Change in water availability towards 2030s with respect to 1970s (IPCC AR5 RCO 4.5 scenario) in Chhattisgarh - Monsoon months (JJAS)



Similarly during the Rabi season (OND), precipitation is projected to increase by 9% resulting in increase in surface runoff and ground water recharge. Evapotranspiration is projected to increase marginally. Spatial variability in water balance components is more pronounced in the non monsoon months of October, November and December.

Figure 50 : Change in water availability towards 2030s with respect to 1970s (IPCC AR5 RCO 4.5 scenario) in Chhattisgarh - Non Monsoon months (OND)



Impact Assessment for Vulnerability Assessment

Outputs from hydrological modelling for baseline and midterm have been extracted and used in district vulnerability assessment. The following are the spatial and temporal impacts included in the assessment.

- Impact on annual water availability
    - Agriculture planning
- Impact on seasonal water availability
    - Irrigation water availability
- Installed power capacity
    - Impact on inter annual water availability
- Planning for water resources structure

    - Regional Variability of Water availability
    - Change in Cropping pattern
- Extreme events
    - Drought (Monsoon period) – reduced flows in dry seasons
    - Floods – higher flows during wet season

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 affecting 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[52]). 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[53]) 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 drought effect is proportional to the relative change in climate. For example, if a climate that usually has very slight deviation from the normal experiences a moderate dry period, the effect 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.

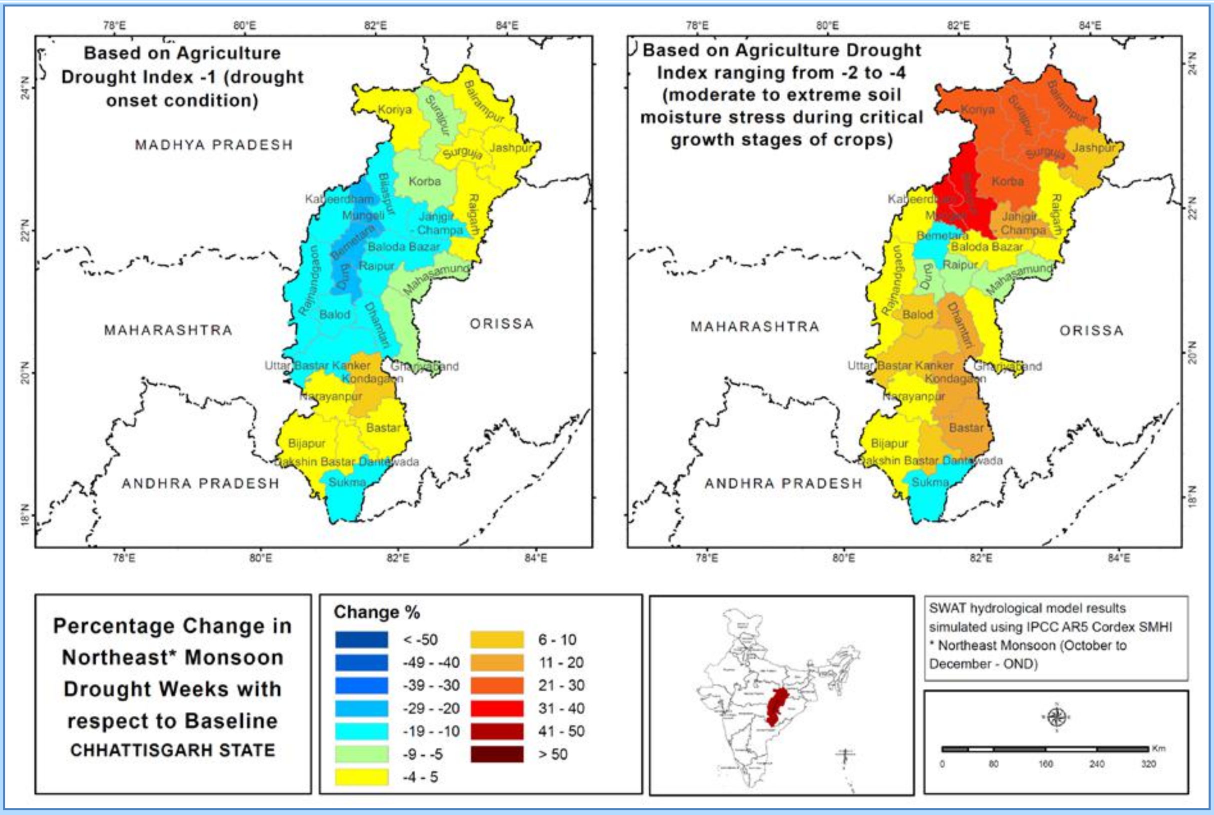
Soil Moisture Deficit Index (SMDI) was calculated from simulated soil moisture data for baseline (1961-1990) and MC (2021-2050) climate change scenarios. The change from current condition to mid-term shows improvement in the drought onset conditions (onset of drought) for Mid Century scenario under IPCC AR5 RCP 4.5. 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 Midcentury scenario in RCP 4.5 scenario.

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

[53]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

The spatial distribution of change in number of weeks (baseline to mid-term) 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 51. The hotspot areas can be recognised from the figure. For the mild to moderate and extreme drought condition maximum increase in drought weeks in midterm compared to the baseline is observed for North Western districts.

Figure 51: Change in Spatial distribution of Soil moisture deficit weeks for BL and MC scenarios(IPCC AR5 RCP 4.5) for Chhattisgarh – South West Monsoon (JJAS)



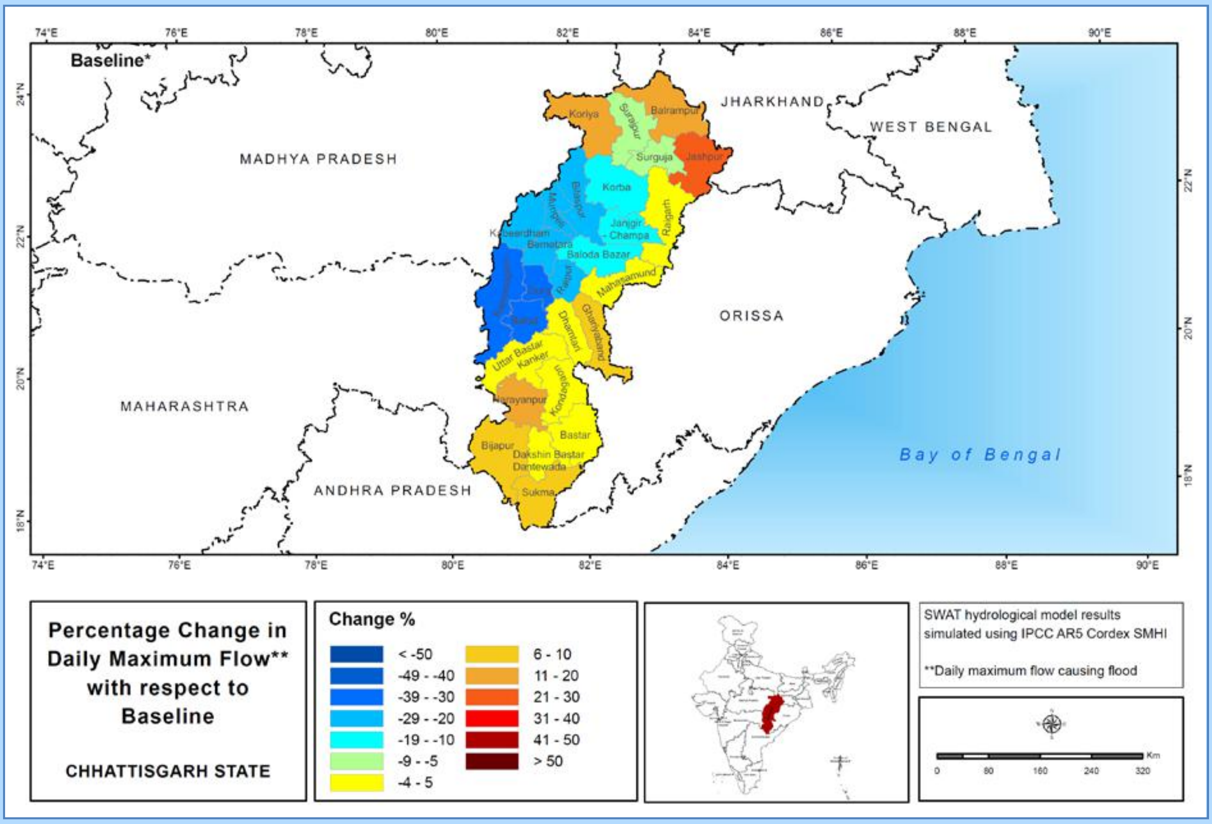
Flood Analysis

The vulnerability assessment with respect to the possible future floods 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 flow has been evaluated for river basins of Chhattisgarh for baseline (1961-1990)and MC (2021-2050) based on the simulated annual flows at various locations.

Average peak discharge at 99thpercentile

Figure 52 shows peak discharge equal to or exceeding at 1 % frequency from baseline to MC scenarios.

Figure 52: Spatial variation in Change in stream discharge at 99th percentile for BL and MC climate scenarios (IPCC AR5 RCP 4.5) for Chhattisgarh



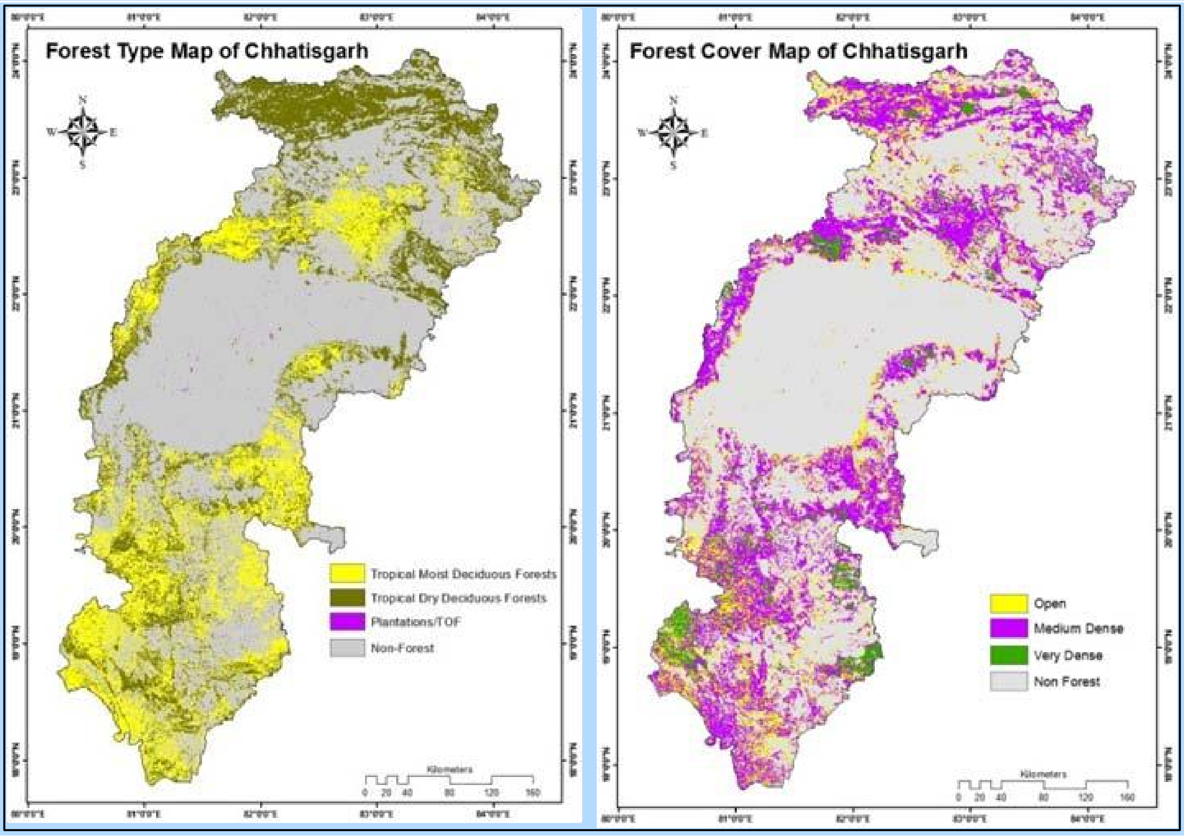
It can be seen from the figure that the magnitude of peak discharge marginally increases on the eastern part of Chhattisgarh and decreases in the north western part of Chhattisgarh in RCP 4.5 mid-term scenario as compared to the baseline.

Impact of climate change on forests of Chhattisgarh

The forest cover in the state based on interpretation of remote sensing data of Oct 2008-Jan 2009 is 55,674 km2 which is 41% of the state's geographical area (FSI, 2011). In terms of canopy density classes, the state has 4,163 km2 of very dense forests, 34,911 km2 of moderately dense forests and 16,600 km2 of open forests. The state has ten forest types (Figure 53) which belong to two forest type groups – Tropical Moist Deciduous and Tropical Dry Deciduous forests.

The consequences of climate-related changes in forest systems are categorized and predicted using two metrics "vulnerability" and "risk". Vulnerability is defined as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes" (Intergovernmental Panel on Climate Change 2007). Vulnerability is typically described to be a function of three overlapping elements: exposure, sensitivity, and adaptive capacity (Turner et al., 2003a).

Figure 53 : Forest type and forest density distribution map of Chhattisgarh



The impacts of climate change on forest ecosystems and the vulnerability of forests under 'current' climate scenario as well as under the 'future' climate scenario are presented. Based on these assessments the districts in Chhattisgarh are ranked in the order of forest vulnerability, separately under 'current' and 'future' climate scenarios.

Climate change could impact forest in many ways namely; changes or shifts in forest types, changes in net primary productivity (NPP) and occurrence of fire and pests. Vulnerability is defined as "the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes” (Intergovernmental Panel on Climate Change 2007). Vulnerability is typically described to be a function of three overlapping elements: exposure, sensitivity, and adaptive capacity according to IPCC.

Methods and Models

In this study the vulnerability is assessed under two scenarios namely, “current climate” and “climate change impacted”. In this section the methods and models used for assessing the climate change impacts and vulnerability are presented.

Approach and methods for vulnerability assessment under ‘current’ climate scenario

“Starting-point approach” to understand and assess vulnerability is adopted under ‘current’ climate scenario. Under this, the present internal state of forests is analyzed by using appropriate indicators to quantify the propensity of forests to suffer losses under future disturbances including climate change, which is communicated through a ‘vulnerability index’ value. The indicators which are likely to contribute to sensitivity or adaptive capacity are included for current vulnerability assessment. The indicators selected are described in Table 17, along with the weights. The steps adopted for this assessment include the following:

1. Considering the factors that determine vulnerability of forests and keeping in view the availability of spatial data, the following indicators to assess vulnerability assessment under 'current' climate were selected namely biological richness, disturbance index, canopy cover, forest dependence of communities and ground slope. Weights were assigned to each of these indicators using pair-wise comparison method (PCM) with a Consistency Ratio (CR) of 7.85%. A Consistency Ratio of <10% is acceptable. The vulnerability indicators are described in Table 1.
2. The entire area of the state was divided into over 3903 grids of 2.5’x2.5’ each. Out of these, 3352 grids are forested grids. Grids that do not have any area under forest cover were classified as non-forest grids.
3. The vulnerability index value for a grid was obtained as a weighted sum of the area-weighted vulnerability indicators values for that grid. To get the area-weighted vulnerability indicator values for each grid, sum of the products of proportion of forest area under different vulnerability classes were multiplied by the corresponding vulnerability-class values (vulnerability-class values of 3, 2 and 1 correspond to high, medium and low vulnerability).
4. The spatial profile of the vulnerability on the landscape was created by classifying the vulnerability values into 4 vulnerability classes namely low, medium, high and very high using the ArcGIS 10.2 Natural Breaks (Jenks Algorithm). District information was incorporated into each grid to get the district-wise vulnerability profile by overlaying the district map on the vulnerability map of Chhattisgarh.

Table 17: Details of indicator components, data source and weights assigned

Indicator	Indicator components	Indicator description	Source of data	Weights*
Biological	Species richness	Value of BR for a pixel (24x24 m2	IIRS database	**0.507**

Indicator	Indicator components	Indicator description	Source of data	Weights*
richness (BR)	Terrain complexity Ecosystem uniqueness Biological value Disturbance index	area) denotes status of biodiversity and potential to host biodiversity in a pixel; higher potential stands for higher resilience and lower vulnerability. DI as part of BR accounts for level of stress on biological richness.	used	
Disturbance index (DI)	Fragmentation Porosity Juxtaposition Interspersion Biotic interference	DI accounts for the change in spatial structural attributes of forests compared to undisturbed situation; under disturbed situation species are under new order and competition; forest resilience is adversely impacted.		**0.25**
Canopy cover (CC)	Canopy density	Change in canopy cover results in change of on-site conditions (exposure) of temperature, desiccation, wind speed, light and invasive species; loss of canopy cover enhances the exposure and sensitivity of forests and adversely impacts adaptive capacity thus adding to inherent vulnerability.	FSI database used	**0.137**
Slope (S)	Ground slope	Propensity to landslides, soil disturbance and erosion due to higher ground slope enhances inherent vulnerability of forests	Open access digital elevation data used	**0.035**
Forest dependence of rural communities (FD)	Rural population density per sq. km of forest area	Removal of leaf, fuel wood and other biomass impacts productivity and health of forests; seed removal impacts regeneration status; movement of people and cattle propagates disturbance and facilitates proliferation of invasive species and thereby adds to inherent vulnerability of forests.	Census of India 2011 and FSI data used	**0.071**

**Weights are assigned using Pair wise Comparison method (PCM) with a Consistency Ratio (CR) of 7.85%. CR of <10% is acceptable.*

Modeling of Impact of Climate Change on Forests

CMIP5 earth systems model (ESM) based climate projections are used for assessing the impact of climate change on forest ecosystems. Selection of ESMs for assessment of the impact of climate change on forests depends on the availability of the parameters from the ESM required for impact models. Even though there are nearly 40 ESMs (Chaturvedi et al, 2011), due to the climate data constraints, ensemble-climatology from only five ESMs (BCC-CSM1-1; IPSL-CM5A-LR; MIROC-5; MIROC_ESM and MIROC-ESM-CHEM), which best simulate temperature and precipitation over India, have been used for assessing the impacts of climate change. The climate change projections are developed for 4 representative concentration pathways (RCPs) scenarios namely; RCP2.6, RCP4.5, RCP6.0 and RCP8.5 Watts/m2. However, in the current study only 2 RCPs are used namely, 4.5 and

8.5. The present study is carried out for two time slices – short-term (2021-2050) and long-term (2070-2099).

DGVMs (Dynamic Global vegetation Models) are used to obtain future vegetation projections under projected climate change scenarios. A number of DGVMs are available to assess the impact of climate change on forest ecosystems. DGVMs simulate time-dependent changes in vegetation distribution and properties, and allow mapping of changes in ecosystem function and services. With the adoption of multiple DGVMs, reliability of projections of impacts has improved. Impact assessment is carried out using the Integrated Biosphere Simulator (IBIS) and Lund Postdam Jena (LPJ) models over the forests in Chhattisgarh state. Indian Institute of Science has validated these two models for Indian forest vegetation scenario. In case of LPJ DGVM, the approach has been to make vegetation projections using climatology from 17 climate models individually, one each time, and observe the agreement between (climate) models in simulation of vegetation shift in forest grids. The results of LPJ are considered robust when more than 11 of 17 (about 66%) models projected vegetation shift in a grid.

Methods for vulnerability assessment under 'future' climate scenario

The impact of climate change on forests under 'future' climate is assessed using DGVMs under future climatic conditions as projected by the climate models. The climate data requirements for the two vegetation models are; while LPJ requires only 3 variables namely, temperature, precipitation and cloudiness, the data requirement of IBIS is much stringent, as it requires 8 climate variables namely temperature, precipitation, cloudiness, relative humidity, temperature range, wet days, wind speed and deltaT (minimum temperature ever recorded at a particular location minus average temperature of the coldest month). A grid size of 0.5x0.5 degree is adopted to simulate climate as well as vegetation projections. Vulnerability assessment and ranking under climate change scenario is carried out, considering the combined effect of both the impacts of climate change and the current vulnerability of forests.

Assessment of Impact under future climate

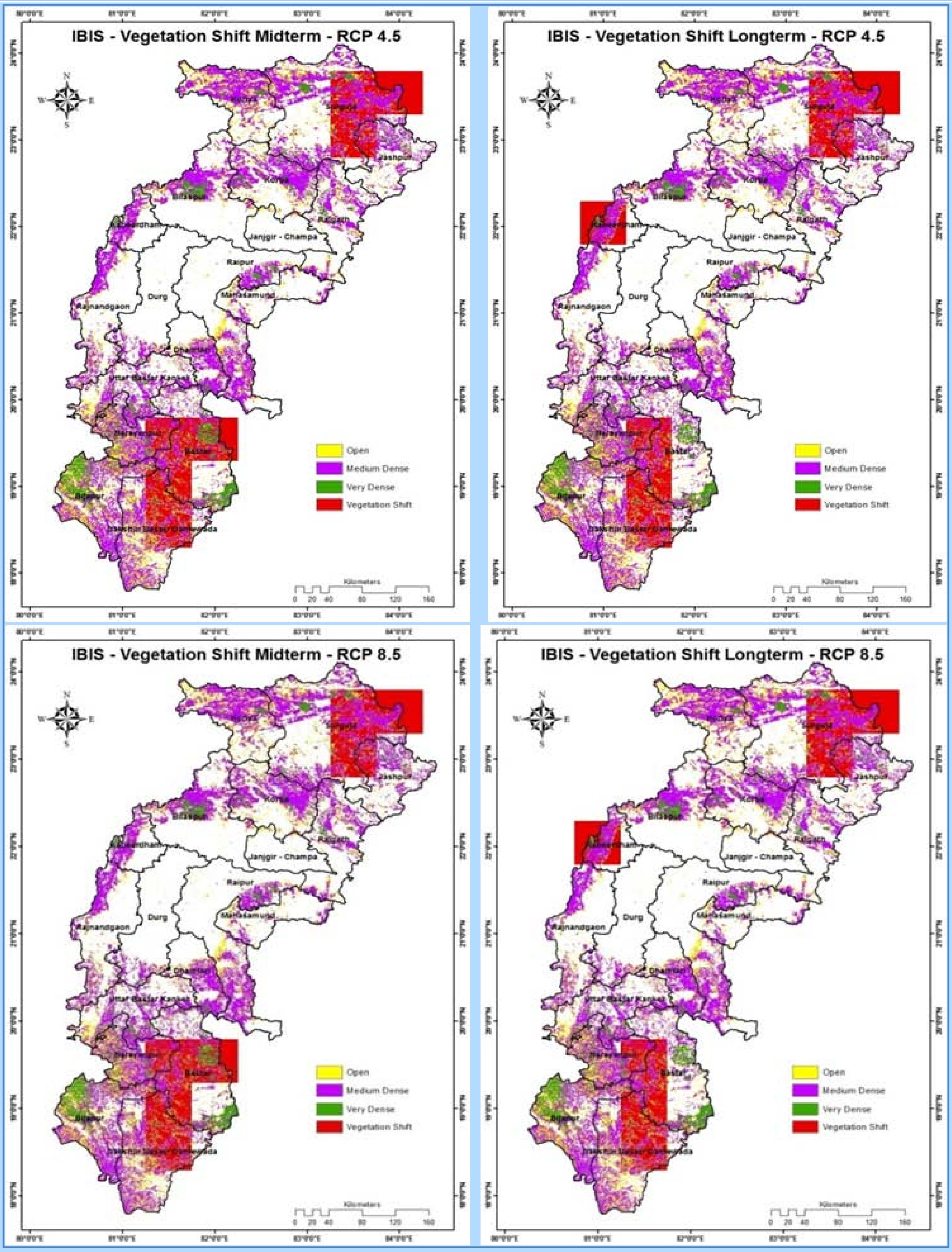
Impact of Climate Change

The impact of climate change on forests is assessed on the basis of vegetation shift projected by two DGVMs - LPJ and IBIS.

Impact according to IBIS

A spatial presentation of forests and districts undergoing change are presented in Figure 54. The DGVM-IBIS model outputs show that the forests in the districts of Surguja, Jashpur, Bastar, Dakshin Bastar Dantewada and Narayanpur are projected to be impacted by climate change in the short-term (2030s) under RCP 4.5 and 8.5. Further, the long-term projections show that Surguja, Jashpur, Bastar, Dakshin Bastar Dantewada and Narayanpur and Kabeerdham are projected to be vulnerable in the 2080s under RCP 4.5 and 8.5. The remaining districts in the central part are not projected to be impacted under future climate by 2030s or 2080s.

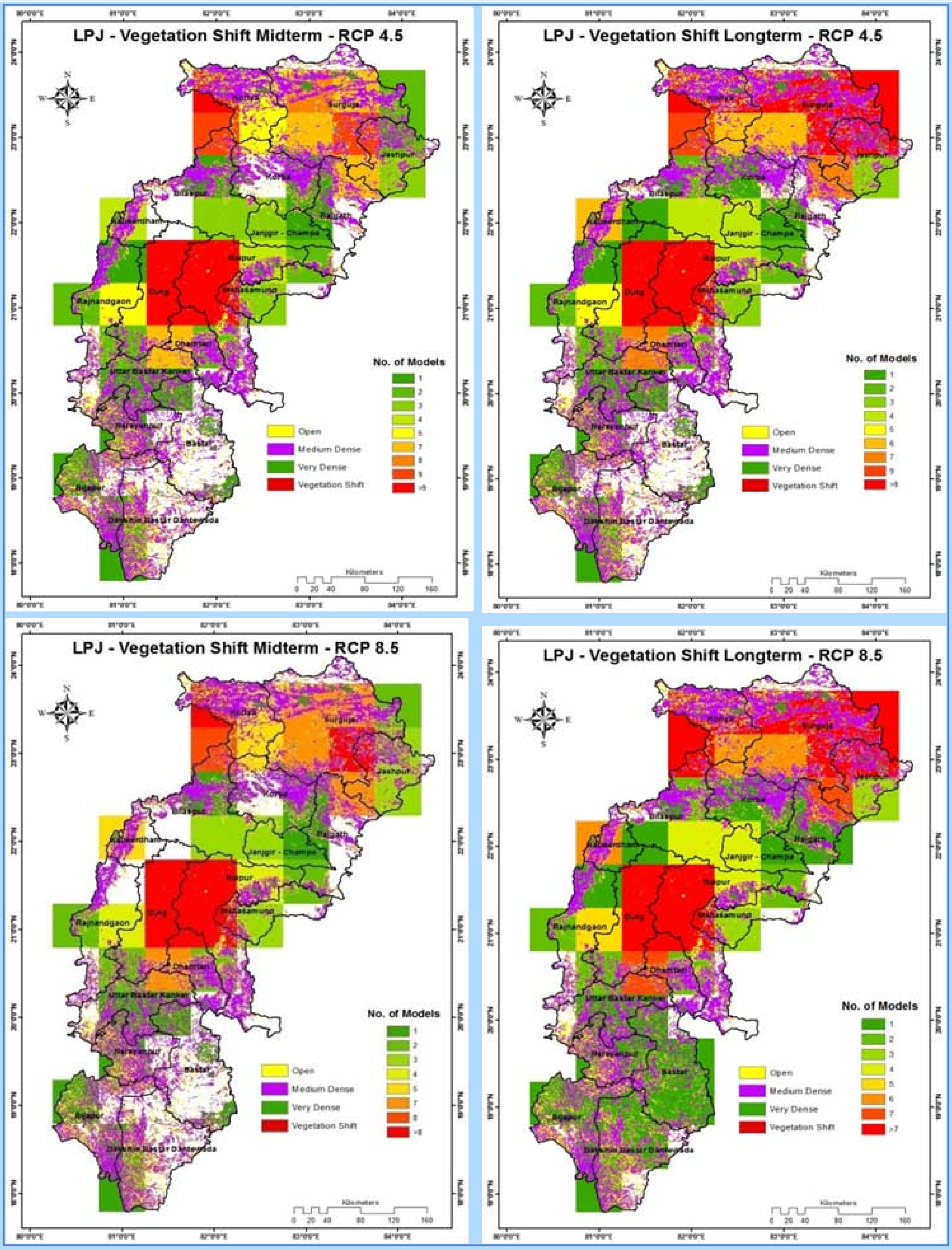
Figure 54 : Vegetation shift projected by IBIS dynamic vegetation model in mid- (2030s) and long-term (2080s) under RCP 4.5 and 8.5



Impact according to LPJ

A spatial presentation of forests and districts undergoing change are presented in Figure 55. As per DGVM-LPJ outputs, more than 66% of the models show that the forests in the districts of Durg, Raipur and Mahasamund are projected to be vulnerable in the mid-term RCP 4.5 and 8.5 while in the long-term under RCP 4.5 and 8.5 the districts of Surguja, Jashpur, Koriya, Bilapsur, Durg, Raipur and Mahasamund are projected to be vulnerable . Relatively more districts are impacted by climate change by 2080s under both RCP 4.5 and 8.5 compared to 2030s. The remaining districts that are in the southern side of the state are not projected to undergo change under future climate by 2030s or 2080s.

Figure 55 : Vegetation shift projected by LPJ dynamic vegetation model in mid- (2030s) and long-term (2080s) under RCP 4.5 and 8.5



Grids impacted according to both IBIS and LPJ

Adoption of multiple models improves the reliability of the projections of climate impacts. Forested grids or districts shown to be impacted by both the models are likely to be more robust. The model outputs show that the forests in the districts Surguja and Jashpur are projected to undergo shifts in forest type by both the vegetation models. This shows that the future climate will not be optimal for the existing vegetation and forest types, potentially leading to forest die-back. The existing forests may lose their biodiversity leading to loss of ecosystem services from the existing forest types. The two districts projected to be impacted by both the DGVMs are also those that are ranked 'high' and 'very high' on the vulnerability scale even under current climate.

Impact of climate change on Agriculture - Chhattisgarh

Impact of climate change on major crops of rice, wheat and maize has been modelled using crop system model DSSAT.

Methods and Models

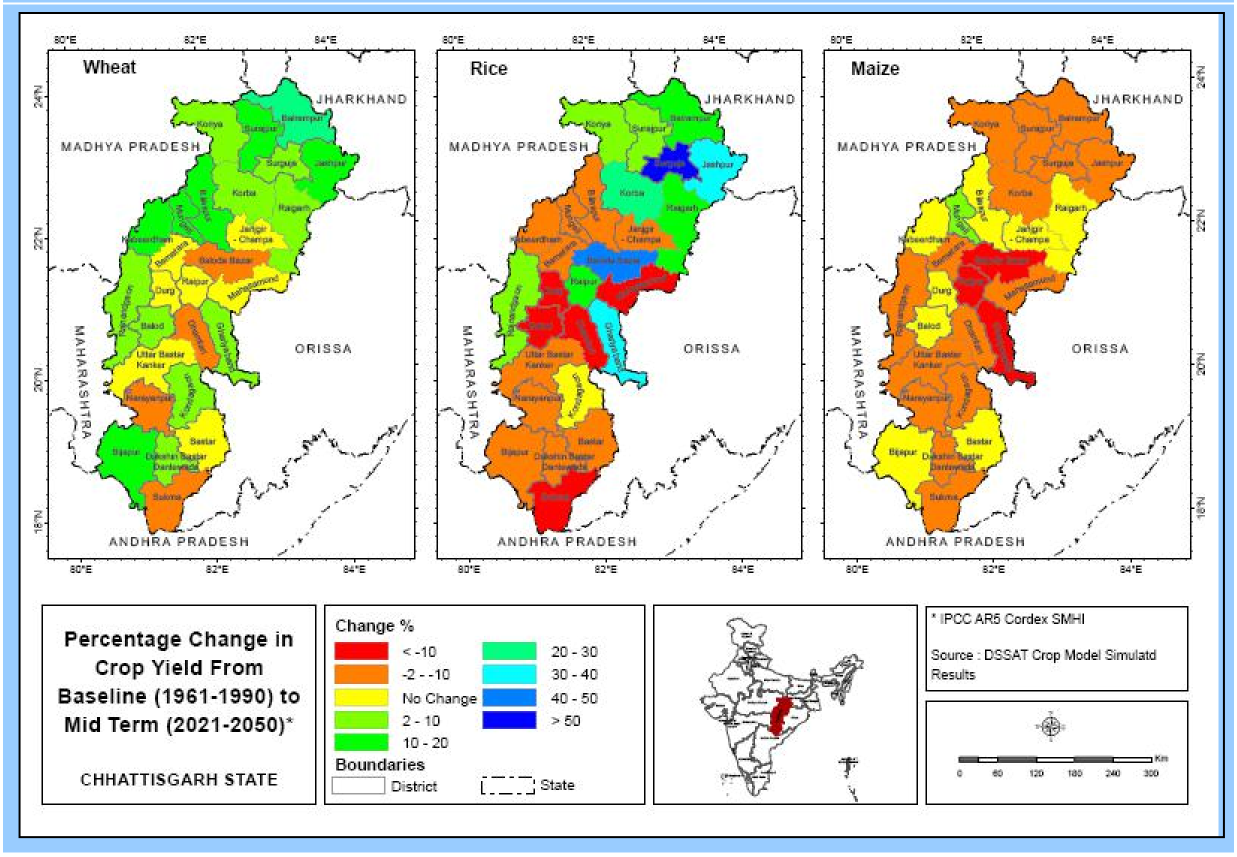
The DSSAT/CSM simulates growth, development and yield of a crop growing on a uniform area of land under prescribed or simulated management as well as the changes in soil water, carbon, and nitrogen that take place under the cropping system over time. The main factors affecting crop yield include air temperature, relative humidity, solar radiation, wind speed, water availability and atmospheric CO2 concentration. Increase in temperature adversely affects crop physiology and results in decreasing crop yields and grain quality. Increase in atmospheric concentration of carbon dioxide may lead to increase plant growth of certain crops.

Impact on agriculture may lead to

- Productivity - quantity and quality of crops
  - agricultural practices
  - changes of water use (irrigation)
- agricultural inputs such as herbicides, insecticides and fertilizers
  - environmental effects
  - soil drainage (leading to nitrogen leaching)
  - soil erosion
  - reduction of crop diversity
- Insects and Pests
  - insect, weed, and disease pests, beneficial organisms both above- and below-ground will be responding to climate change in different ways
  - climate change may likely to exacerbate problems with new invasive weed, insects and diseases

Crop yield projection for Chhattisgarh shows marginal increase in yield on average for wheat crop from baseline (1961-1990) to mid-term (2021-2050). Wheat crop yield is projected to increase by 6% on average. Rice yield is projected to decline for Southern districts while increase for Northern parts of Chhattisgarh. However in case of rainfed maize crop, yield .reduction is projected, decrease in yield is 6% on average from baseline to mid-term. Only Mungeli shows positive increase in maize yield in midterm (Figure 56). Figure 56 presents midterm variability in wheat, rice, and maize yield compared to the baseline for Chhattisgarh districts.

Figure 56: Change in crop yield from baseline (1961-1990) to midterm RCP 4.5 scenario (2021-2050)



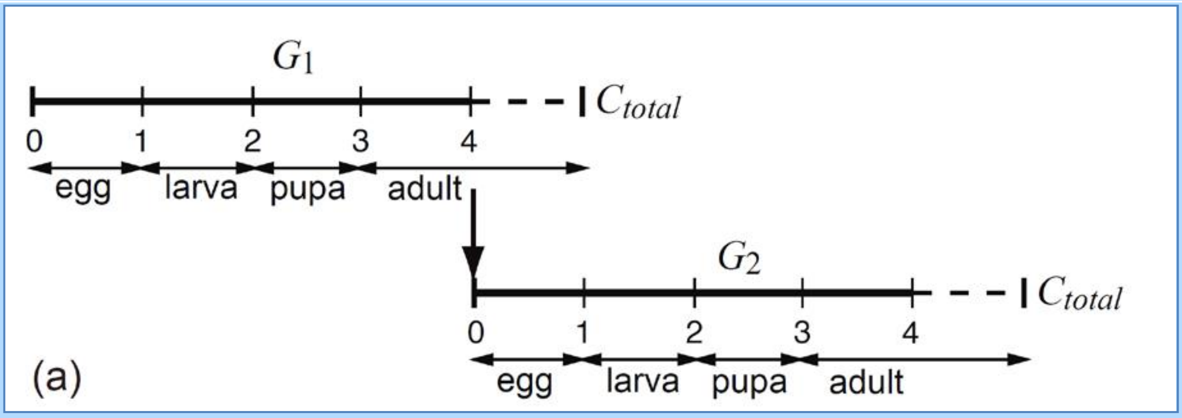
Impact of climate change on Human Health - Chhattisgarh

Impact on Malaria has been derived using hydrological model outputs. The malaria model is based on the life cycle of the mosquito and how it behaves with the changes in weather focusing on temperature conditions and soil moisture availability.

Methods and Models

Numbers ranging from 0 to 4 describe the progression of an egg through the mosquito life cycle to a mature adult (Figure 57).

Figure 57 : Conceptual Malaria Model



Numbers between 0 and 1 were attributed to embryonic development. Larval development was described using numbers between 1 and 2, and pupil development was described using numbers between 2 and 3. Values exceeding 3 were assigned following the emergence of adults. Numbers exceeding 4 were assigned when adult mosquitoes oviposited eggs. The alternation of generations was counted over a 1-year period (Gi), and the maximum number was described as the maximum number of generations (Gmax) to estimate the frequency of occurrence.

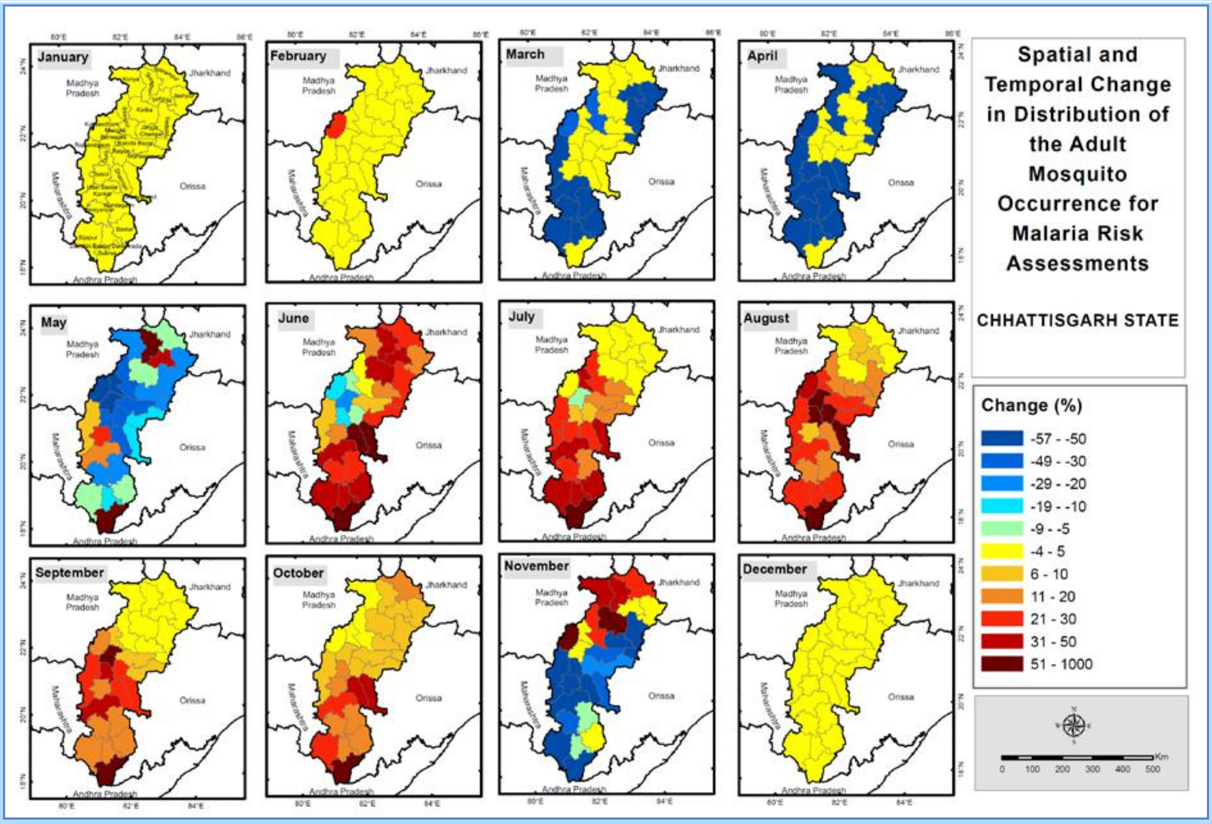
The daily growth of mosquitoes was calculated using the temperature-dependent developmental rate when appropriate soil moisture conditions were available to host the immature mosquito. This value of growth was accumulated at each day until the mature-adult stage when the mosquitoes were capable of laying eggs. The developmental rate was determined by the temperature of the habitat. This study used the mean air temperature to calculate development of the egg, larval, pupil, and adult mosquito stages.[54]

The temporal and geographic distribution of the malaria vector mosquito (Anopheles) at a district level has been modelled using the relationship between mosquito life history and climate conditions, focusing on temperature-dependent development of the mosquito. This model can be used to predict the distribution of the mosquito for malaria risk assessments under future scenarios involving climate change.

[54]Momoyo Kashiwada and Shunji Ohta, Modeling the Spatio-Temporal Distribution of the Anopheles Mosquito based on Life History and Surface Water Conditions The Open Ecology Journal, 2010, Volume 3

Figure 58 shows spatial and temporal distribution of malaria risk. Risk is projected to increase during the monsoon months and in October.

Figure 58 :Spatial and Temporal distribution of Malaria Risk



Chapter 5

District Vulnerability Profiles

District Vulnerability Profiles

Analysis and results - Composite Vulnerability Index (CVI)

The socio-economic and environmental indicators vary widely within the districts of Chhattisgarh. Composite Vulnerability Index (CVI) across the 27 districts of Chhattisgarh has been constructed using 73 indicators listed in Table 6. Principal Component Analysis was performed on the indicators to identify the initial Eigenvalues which is more than one and retained only factors with Eigenvalues greater than 1 (Kaiser, 1990[55]). 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. Thus, the most important variable in each component that best explains variance will be useful in explaining variability between observations (i.e. districts). A rank value 1 indicates that the district is least vulnerable to climate change and rank value 27 indicates that it is the most vulnerable. 27 districts are grouped into four categories, very high, high, moderate and low vulnerability according to their degree of vulnerability using cluster analysis. **Blue colour denotes Low (1), yellow denotes Moderate (2), red denotes High (3) and dark brown denotes Very High (4) vulnerability category in all the layouts.**

Baseline: Figure 59 shows cluster 4 (very high vulnerability) comprising of 3 districts namely, Jashpur, Bijapur and Narayanpur are the most vulnerable. The districts in this cluster are characterized by very low values of Composite Vulnerability Index (CVI) and hence are considered to be vulnerable to climate change. The districts in this cluster have also very high Composite Socioeconomic and Composite Environmental vulnerability as can be seen from Figure 60. They also have very high Social, Economic, Climate, Agriculture and Health sector vulnerabilities. It can also be seen from Figure 61(bar graph) that these districts are the most vulnerable to climate change since they have comparatively low adaptive capacity and show higher sensitivity and exposure to climate change with respect to the other districts. Bijapur and Narayanpur are located in the South West while Jashpur is located in the North East of Chhattisgarh.

The third cluster comprising of 9 districts namely Kabeerdham, Raigarh, Kondagaon, Bastar, Mahasamund, Janjgir-Champa, Koriya, Uttar Bastar Kanker and Korba are also vulnerable but are relatively less than the districts in the fourth cluster. The districts in this cluster have also very high Composite Environmental vulnerability as can be seen from Figure 60

Cluster 2 (depicted in yellow colour) made up of 8 districts namely Balrampur, Dhamtari, Rajnandgaon, Dantewada, Bilaspur, Surajpur, Surguja and Sukma have moderate vulnerability.

The first cluster (depicted in blue colour) made up of 7 districts namely; Mungeli, Baloda Bazar, Raipur, Durg, Ghariyaband, Bemetara and Balod have low vulnerability. The districts in these clusters by their high positive indices are less vulnerable to climate change because they have higher adaptive capacity (shown by blue colour in the graph) and show lower sensitivity and exposure (shown by colours red and green respectively in the graph) to climate change (Figure 61). The

[55] Kaiser, H. F. (1960). The application of electronic computers to factor analysis. Educational and Psychological Measurement, 20, 141-151.

districts in this cluster have also low Composite Socioeconomic and Composite Environmental vulnerability as can be seen from Figure 60. The lesser vulnerability of districts is associated with its relatively higher economic capacity, level of urbanization is high, its highest irrigation potential, high literacy rate, less exposure to extreme climatic events, and better access to drinking water, sanitation facilities, electricity, health, education and road infrastructure. The district ranking within each cluster can be seen from Figure 59.

Midterm RCP 4.5: Figure 59 shows the district vulnerability towards midterm scenario. No variability is seen in the districts in midterm compared to the baseline. They belong to the same clusters as can be seen from Figure 2. Though change in the relative ranking amongst the districts is observed from BL to midterm (Table 18).Thus the overall composite vulnerability of districts is projected relatively to be the same in midterm as baseline.

Table 18 gives the relative ranking of the districts for the baseline and midterm scenarios. A rank value 1 indicates that the district is least vulnerable to climate change and rank value 27 indicates that it is the most vulnerable. Spatial representation of district ranking is depicted in Figure 59.

Table 18: District wise Composite Vulnerability Index (CVI)-Index values, Ranks and Cluster code for baseline and midterm scenario

	Baseline			Midterm		
Districts	**CVI**	**Rank**	**Cluster code**	**CVI**	**Rank**	**Cluster code**
Balod	0.053	1	1	0.055	1	1
Bemetara	0.036	2	1	0.048	2	1
Ghariyaband	0.029	3	1	0.031	4	1
Durg	0.021	4	1	0.032	3	1
Raipur	0.019	5	1	0.031	4	1
Baloda Bazar	-0.005	6	1	0.007	6	1
Mungeli	-0.017	7	1	-0.007	7	1
Sukma	-0.050	8	2	-0.091	13	2
Surguja	-0.063	9	2	-0.070	11	2
Surajpur	-0.065	10	2	-0.067	10	2
Bilaspur	-0.080	11	2	-0.066	9	2
Dantewada	-0.081	12	2	-0.091	13	2
Rajnandgaon	-0.082	13	2	-0.076	12	2
Dhamtari	-0.085	14	2	-0.061	8	2
Balrampur	-0.088	15	2	-0.092	15	2
Korba	-0.131	16	3	-0.131	17	3
Uttar Bastar Kanker	-0.134	17	3	-0.140	18	3
Koriya	-0.138	18	3	-0.140	18	3
Janjgir - Champa	-0.142	19	3	-0.123	16	3
Mahasamund	-0.152	20	3	-0.151	20	3
Bastar	-0.155	21	3	-0.160	23	3
Kondagaon	-0.168	22	3	-0.151	20	3

	Baseline			Midterm		
Districts	CVI	Rank	Cluster code	CVI	Rank	Cluster code
Raigarh	-0.174	23	3	-0.156	22	3
Kabeerdham	-0.186	24	3	-0.179	24	3
Narayanpur	-0.218	25	4	-0.212	25	4
Bijapur	-0.249	26	4	-0.249	26	4
Jashpur	-0.273	27	4	-0.268	27	4

Figure 59 : Composite Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh for baseline and midterm(2021-2050)

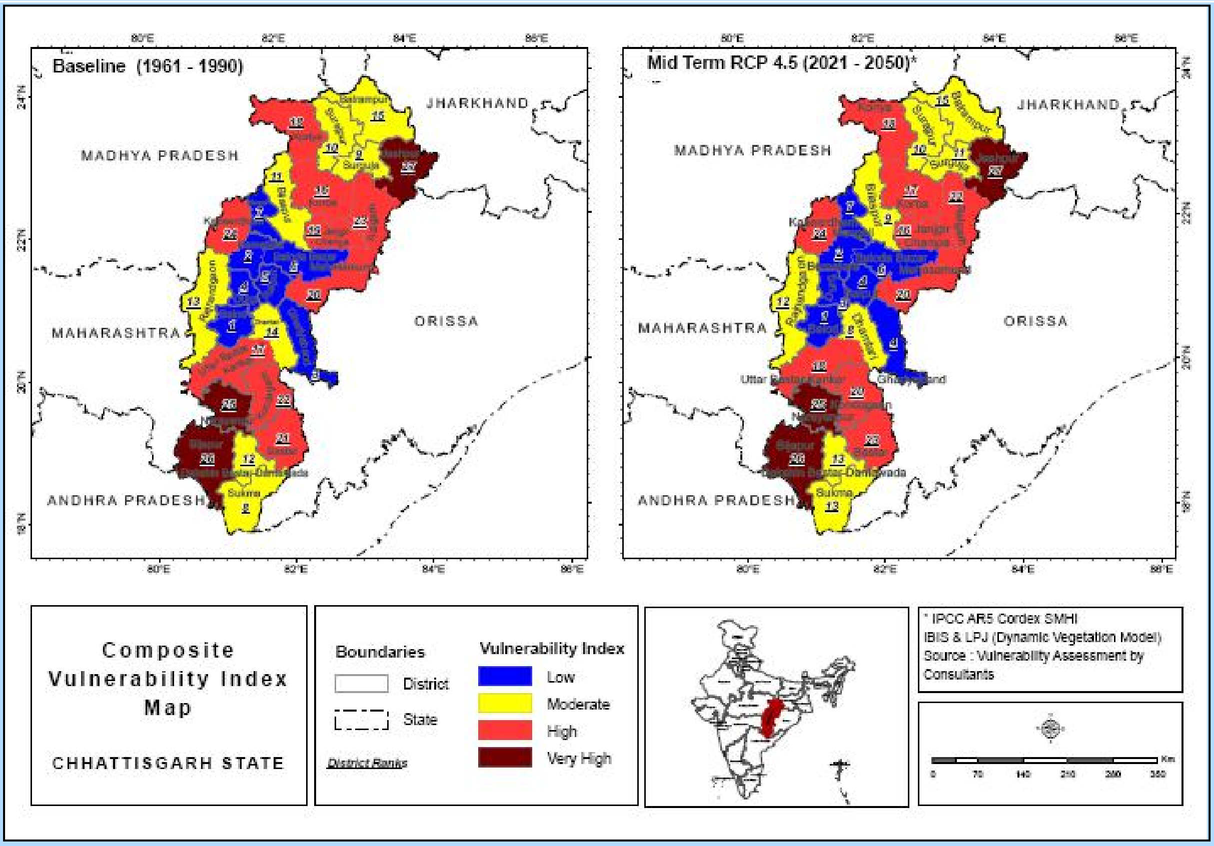


Figure 60 : Composite Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh along with sub-indices vulnerability cluster map

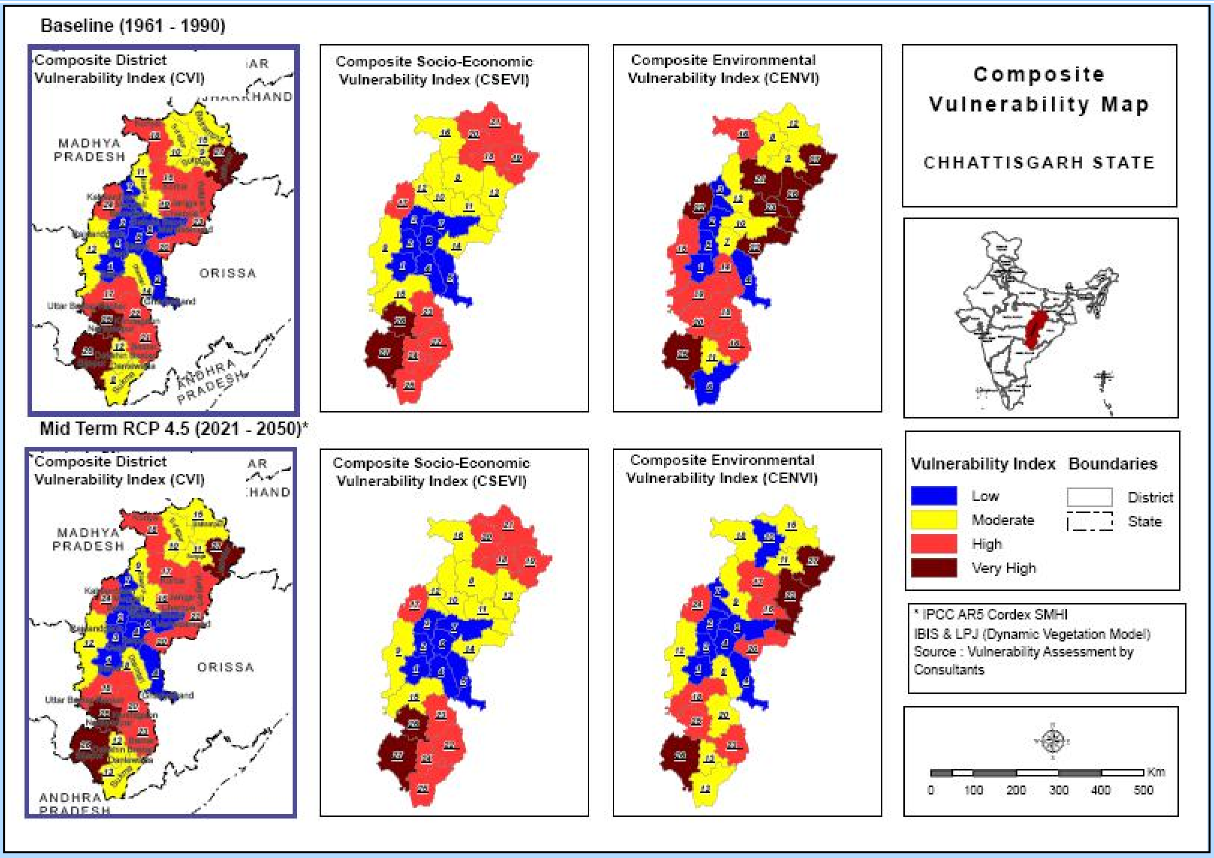
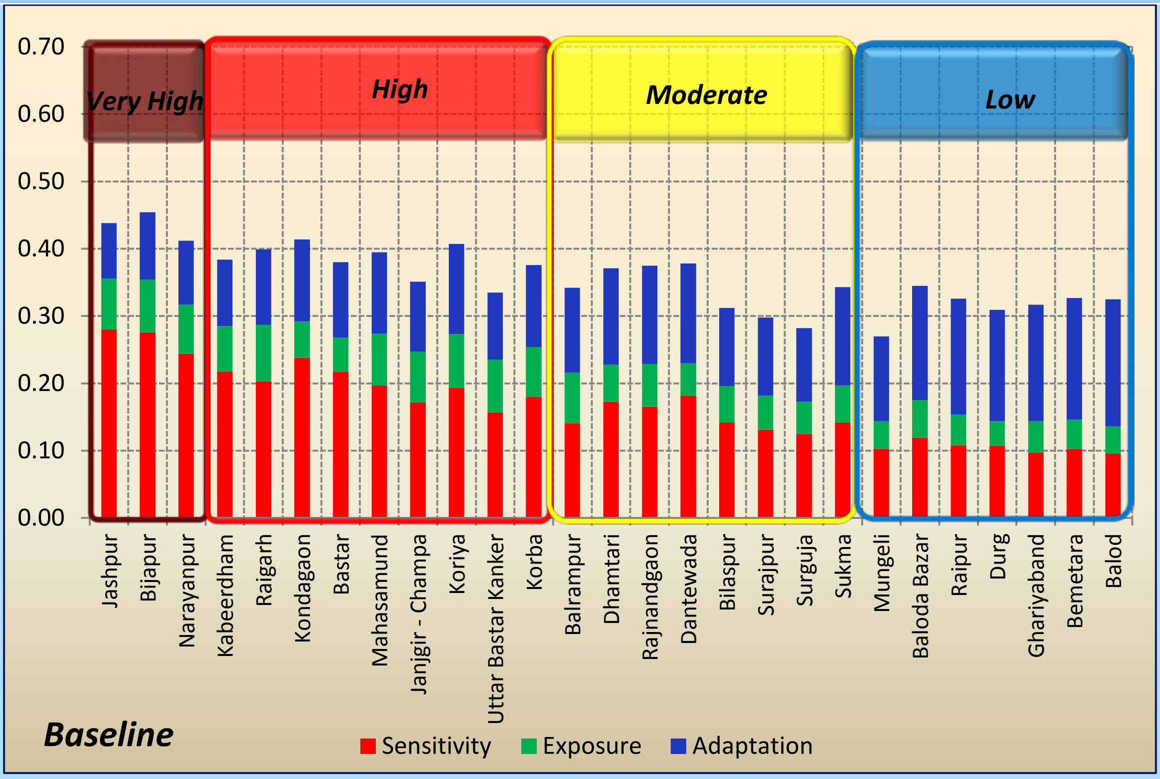


Figure 61 : Sub-Index values for Sensitivity, exposure and adaptive capacity showing district under low, moderate, high and very high vulnerability clusters (Composite)– baseline and midterm scenarios



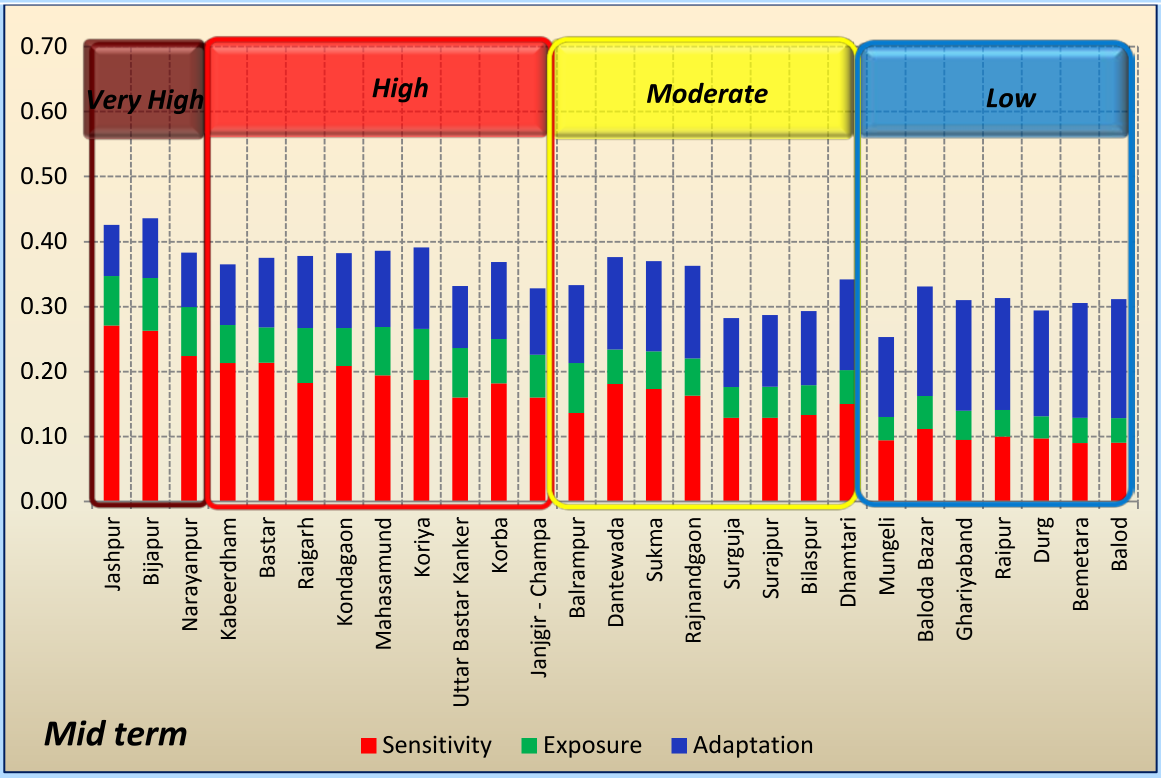


Figure 62 : Change in the number of districts under low, moderate, high and very high vulnerability clusters (CVI)– baseline and midterm scenarios

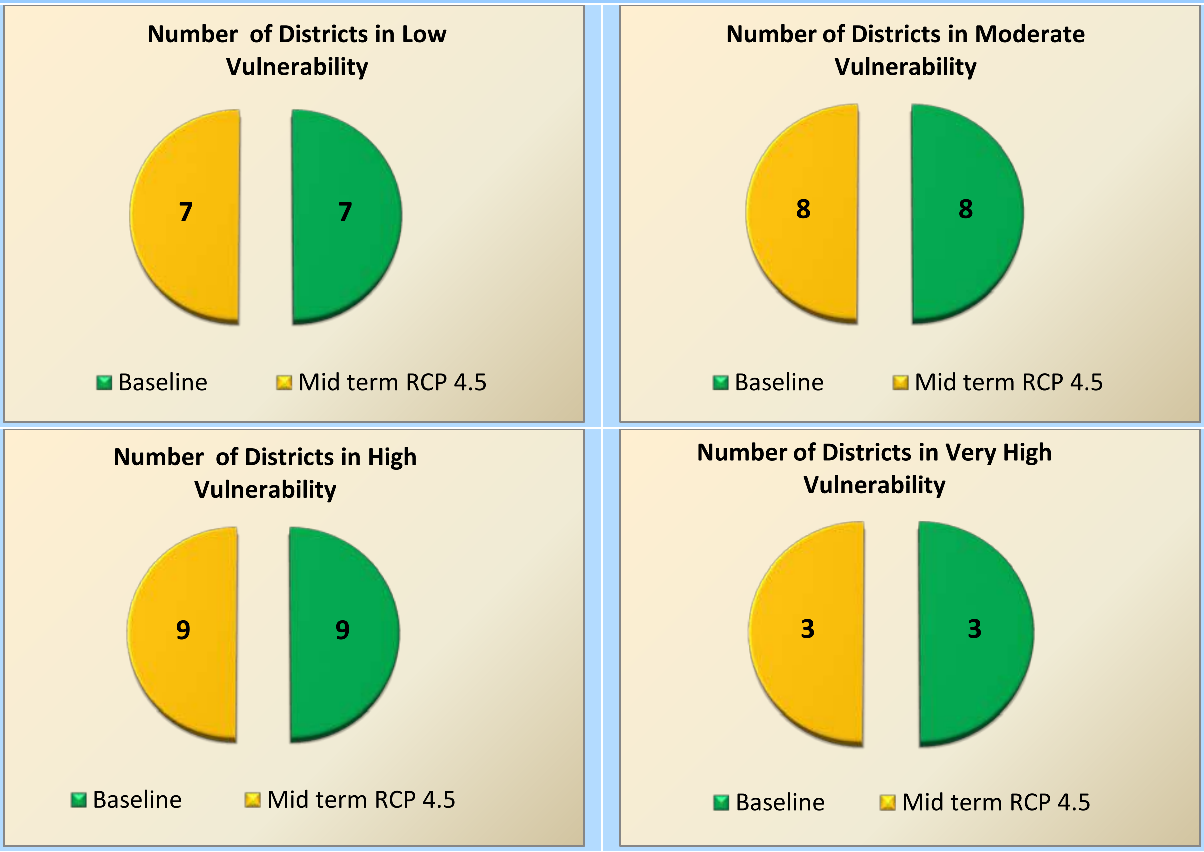


Figure 62 gives the number of districts falling in low, moderate, high and very high vulnerability category under baseline and midterm RCP 4.5 scenario. The green and yellow portions in the pie chart sum to 27 for baseline and midterm RCP 4.5 scenario respectively. There are no changes observed in the number of districts from baseline to midterm scenario for all 4 vulnerability categories-low, moderate, high and very high vulnerability cluster. Thus it can be inferred that composite vulnerability of districts is projected to remain the same towards midterm RCP 4.5 scenario compared to the baseline.

Significant Indicators

Principal Component Analysis performed also indicates the indicators which play significant role in explaining vulnerability among the districts. Amongst all the indicators considered in particular sector indicators with weights greater than the average weight of all indicators are considered as important in explaining vulnerability. Table 19 gives the list of significant indicators in order of their importance for each sector. These indicators can play important role in decision making in a goal to reduce vulnerability.

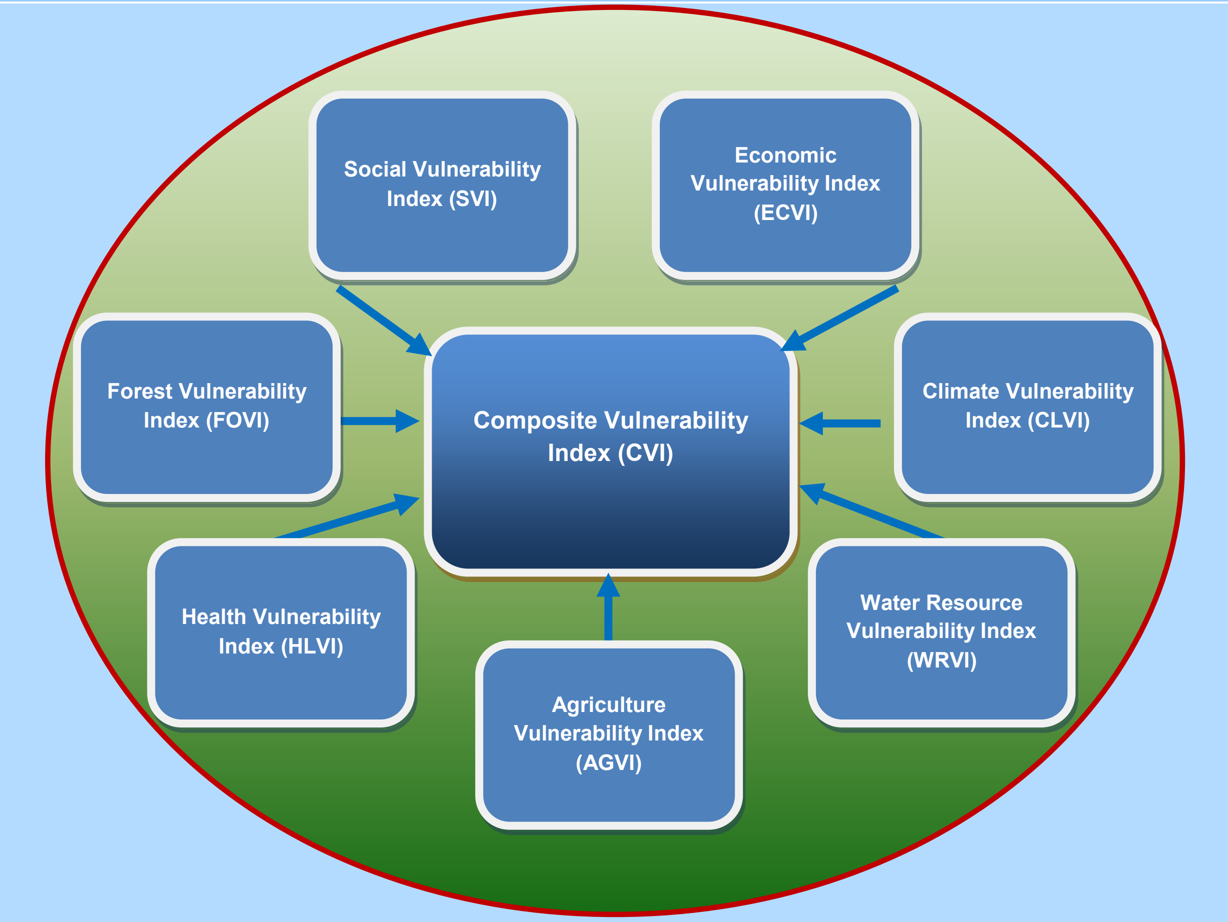
Table 19: Significant indicators explaining Composite vulnerability

Indicators	Conceptual Basis
Social	
Literacy Rate	Adaptive Capacity
Number of Primary, Upper Primary, Middle, Higher Secondary and Intermediate Schools Per Lakh of Population	Adaptive Capacity
Proportion of Child Population in the age group 0-6	Sensitive
Percentage of households with access to communication/transport	Adaptive Capacity
Percentage share of total households having electricity as main source of lighting	Adaptive Capacity
Percentage of rural households below poverty line	Sensitive
Percentage of Schedule Tribes and Scheduled Caste population	Sensitive
Percentage Share of Marginal Workers	Sensitive
Sex-ratio	Sensitive
Economic	
Percentage of Total Loan Advances to Total Deposits in Scheduled Commercial Banks	
Per Capita Income(NDDP) at current prices	Adaptive Capacity
Agriculture	
Crop diversity (number of crops grown)	Adaptive Capacity
Maize Production	
Percentage of Net Irrigated Area To Net Sown Area By Ground Water	Adaptive Capacity
Cropping intensity	Adaptive Capacity
Percentage Share of Agricultural And Cultivators to Main Workers	Sensitive
Net Area Sown as a percentage of the district Geographical Area	Sensitive
Wheat Production	Adaptive Capacity
Poultry Unit	Adaptive Capacity
Rice Production	
Forest	
Biological richness	Adaptive Capacity
Disturbance index	
Health	
Anopheles Mosquito Causing Malaria in September	Sensitive
Anopheles Mosquito Causing Malaria in October	Sensitive
Anopheles Mosquito Causing Malaria in August	Sensitive
Anopheles Mosquito Causing Malaria in July	Sensitive
Anopheles Mosquito Causing Malaria in June	Sensitive
Anopheles Mosquito Causing Malaria in November	Sensitive
Anopheles Mosquito Causing Malaria in May	
Water Resource	
Surface Water availability in North East Monsoon season	Adaptive Capacity
Ground Water availability in South West Monsoon season	Adaptive Capacity
Surface Water availability in South West Monsoon season	Adaptive Capacity
Crop water Stress(ET/PET) in South West Monsoon season	Sensitive
Climate	
Warm Spell Duration Indicator (Annual count of days with at least 6 consecutive days when maximum temperature>90th percentile)	
Cool Days - Cool nights- days when maximum temperature < 10th Percentile	Exposure
Warm nights- days when minimum temperature > 90th Percentile	Exposure
Warm Days - Cool nights- days when maximum temperature > 90th Percentile	Exposure
Cool nights- days when minimum temperature < 10th Percentile	Exposure
Cold Spell Duration Indicator (Annual count of days with at least 6 consecutive days when minimum temperature<10th percentile)	Exposure

Drill down Indices

To help the decision makers attempt is made to present the drill down version of the CVI (Composite Vulnerability Index) presented in the previous paragraphs. The drill down is performed sect orally along the same concept presented before. Sectoral Vulnerability Indices for Social (SVI), Economic (ECVI) individually and these combined as Composite Socio-economic Vulnerability Index (CSEVI), Climate (CLVI), Water (WRVI), Agriculture (AGVI), Forest (FOVI), Health (HLVI) and these five combined as Environmental Vulnerability Index (ENVI) have been derived, using the indicators shown in Table 6 using the relevant sector/sub-sector for arriving at the individual indices. This drill down exercise is to help the decision makers to prioritise the development activities in any chosen district by identifying the sector which makes that district vulnerable. Figure 63 depicts the relationship between the CVI and the sect oral vulnerability indices.

Figure 63 : Drill down Vulnerability Indices



Discussions on these sect oral indices are presented in the following paragraphs for the baseline and midterm RCP 4.5 scenarios.

Social Vulnerability Index (SVI)

Social Vulnerability Index (SVI) across the 27 districts of Chhattisgarh has been constructed using 17 social indicators listed in Table 6. Principal Component Analysis on these indicators and cluster analysis are performed to group the districts in four categories- very high, high, moderate and low according to their degree of vulnerability. Table 20 shows the relative ranks of the district along with the vulnerability groups (clusters) they fall into and their index values. Spatial representation of district ranking is depicted in Figure 64**.** In the absence of district wise impact on social sector due to climate change, no attempt was made to project the social indicators data.

Baseline: Cluster result shows (Figure 64) that 2 districts namely Bijapur and Narayanpur have very low values of Social Vulnerability Index (SVI) thus belong to very high vulnerable category (cluster 4) compared to the other districts of Chhattisgarh. It can also be seen from Figure 65 (bar graph) that these districts have comparatively low adaptive capacity (shown by blue colour in the graph) and show higher sensitivity (shown by colour red in the graph) to social indicators with respect to the other districts. It is low literacy rate, large proportion of child population, large percentage of rural households below poverty line, bad sanitation facilities, lack of access to electricity, households residing in kacchha houses, poor health infrastructure, low level of urbanization and high proportion of scheduled caste and scheduled tribes population which makes Bijapur and Narayanpur most vulnerable socially The districts in very high vulnerability cluster are located in the South West of Chhattisgarh as can be seen from Figure 64.

The third cluster (high vulnerability) comprising 8 districts are also vulnerable but are relatively less than the districts in the fourth cluster. These districts are located in South East and North East of Chhattisgarh state in Figure 64

The second cluster (moderate vulnerability) comprising of 7 districts namely Kabeerdham, Koriya, Raigarh, Mahasamund, Mungeli, Korba and Uttar Bastar Kanker have moderate vulnerability. The location of these districts can be seen in Figure 64 represented in yellow colour.

10 districts namely, Bilaspur, Baloda Bazar, Janjgir-Champa, Ghariyaband, Raipur, Rajnandgaon, Bemetara, Durg, Dhamtari and Balod are the least vulnerable districts (cluster 1) because they have high literacy rate, better access to drinking water, sanitation facilities and electricity, pucca houses, have access to proper transport and communication large number of medical institutions and level of urbanization is high compared to other districts. Thus districts in this cluster have higher adaptive and show lower sensitivity to social indicators with respect to the other districts. (Figure 65)

Table 20: District wise Social Vulnerability Index (SVI) –Values, Ranks and Cluster code for baseline

	Baseline		
Districts	SVI	Rank	Cluster code
Balod	0.193	1	1
Dhamtari	0.189	2	1
Durg	0.162	3	1
Bemetara	0.132	4	1
Rajnandgaon	0.113	5	1
Raipur	0.104	6	1
Ghariyaband	0.102	7	1
Janjgir - Champa	0.101	8	1

	Baseline		
Districts	SVI	Rank	Cluster code
Baloda Bazar	0.089	9	1
Bilaspur	0.081	10	1
Korba	0.053	11	2
Uttar Bastar Kanker	0.053	11	2
Mungeli	0.043	13	2
Mahasamund	0.039	14	2
Raigarh	0.037	15	2
Koriya	-0.016	16	2
Kabeerdham	-0.028	17	2
Jashpur	-0.081	18	3
Surguja	-0.123	19	3
Bastar	-0.130	20	3
Kondagaon	-0.145	21	3
Surajpur	-0.158	22	3
Dantewada	-0.162	23	3
Balrampur	-0.171	24	3
Sukma	-0.181	25	3
Narayanpur	-0.208	26	4
Bijapur	-0.254	27	4

Figure 64 : Social Vulnerability map showing low, moderate, high and very high cluster of districts in Chhattisgarh

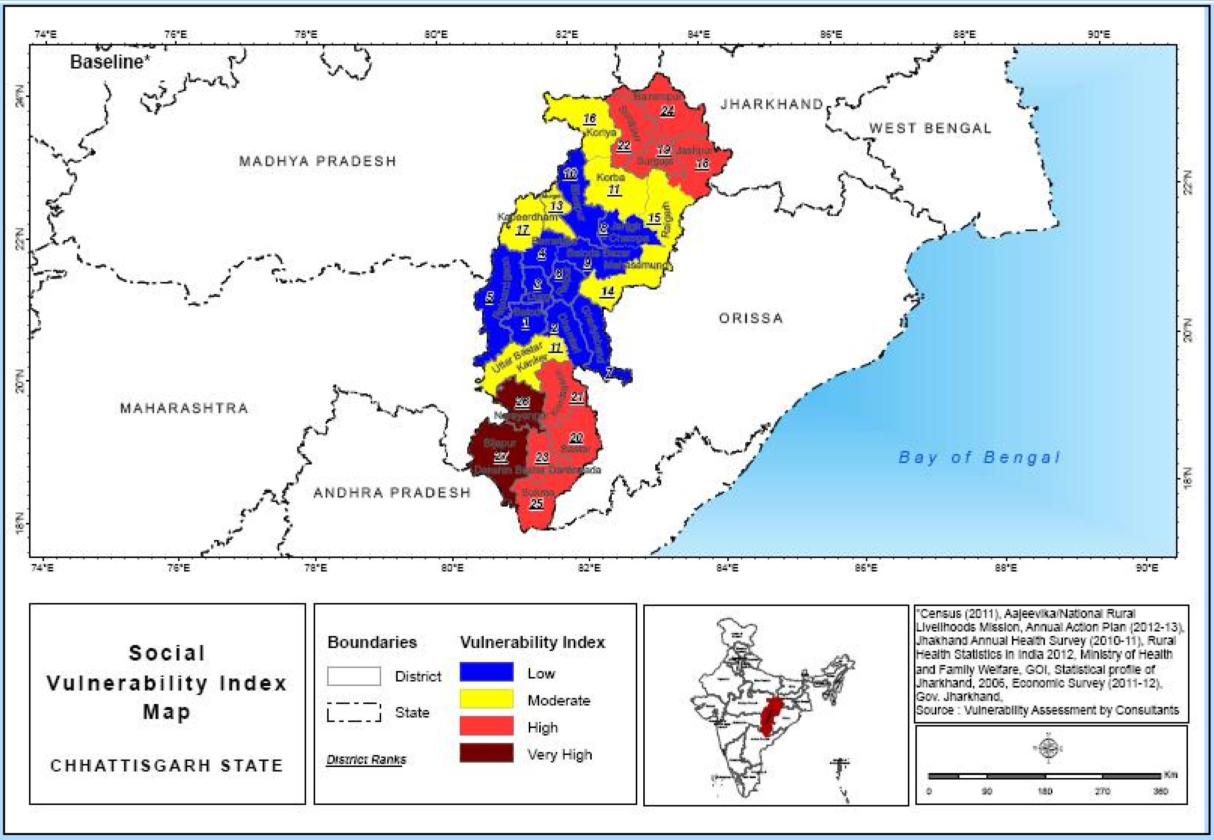
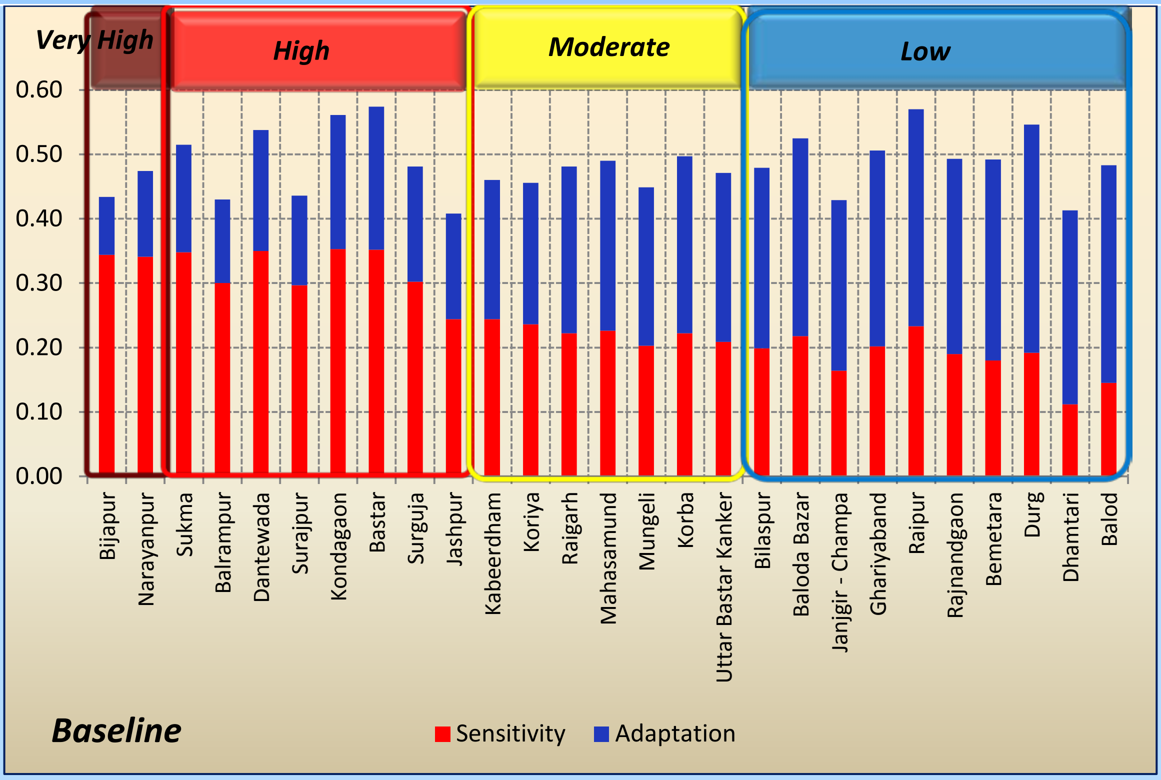


Figure 65 : Sub-Index values for Sensitivity, exposure and adaptive capacity showing district under low, moderate, high and very high vulnerability clusters (Social Vulnerability Index)– baseline



Economic Vulnerability Index (ECVI)

Economic Vulnerability Index (ECVI) across the 27 districts of Chhattisgarh has been constructed using 3 economic indicators listed in Table 6. Principal Component Analysis on these indicators and cluster analysis are performed to group the districts in four categories- very high, high, moderate and low according to their degree of vulnerability. Table 21 shows the relative ranks of the district along with the vulnerability groups (clusters) they fall into. Spatial representation of district ranking is depicted in Figure 66.In the absence of district wise impact on economic sector due to climate change, no attempt was made to project the economic indicators data.

Baseline: Cluster results show (Figure 66) that as many as 8 districts are the most vulnerable namely Narayanpur, Kabeerdham, Bijapur, Uttar Bastar Kanker, Janjgir - Champa, Jashpur, Bilaspur and Mungeli as can be seen from Figure 67 (bar graph) that they have the lowest Economic Vulnerability Index values as they have comparatively lowest adaptive capacity. It is low per capita income (NDDP), less number of banks and poor credit deposit ratio which makes Narayanpur and Kabeerdham most vulnerable. The districts in very high vulnerability cluster are located in the South West and North West regions of Chhattisgarh except Jashpur which is located in the North East as can be seen from Figure 66.

The third cluster (high vulnerability) comprising 14 districts are also vulnerable but are relatively less than the districts in the fourth cluster. The location of these districts can be seen in red colour in Figure 66

Districts in the moderate cluster, namely Balod, Bemetara, Durg, Korea, Dantewada and Sukma and in least vulnerability cluster namely Baloda Bazar, Ghariyaband and Raipur have higher adaptive capacity (high per capita income and access to credit) so highest Economic Vulnerability Index values (shown by blue colour line in the graph). (Figure 67)

Table 21: District wise Economic Vulnerability Index (ECVI) -Values, Ranks and Cluster code for baseline

	Baseline		
Districts	**ECVI**	**Rank**	**Cluster code**
Baloda Bazar	0.749	1	1
Ghariyaband	0.749	1	1
Raipur	0.749	1	1
Dantewada	0.569	4	2
Sukma	0.569	4	2
Korba	0.504	6	2
Balod	0.490	7	2
Bemetara	0.490	7	2
Durg	0.490	7	2
Raigarh	0.411	10	3
Balrampur	0.368	11	3
Surajpur	0.368	11	3
Surguja	0.368	11	3
Rajnandgaon	0.291	14	3
Mahasamund	0.278	15	3
Bastar	0.237	16	3
Dhamtari	0.237	16	3
Kondagaon	0.237	16	3
Koriya	0.226	19	3
Bilaspur	0.151	20	4
Mungeli	0.151	20	4
Jashpur	0.131	22	4
Janjgir - Champa	0.123	23	4
Uttar Bastar Kanker	0.122	24	4
Bijapur	0.096	25	4
Kabeerdham	0.090	26	4
Narayanpur	0.023	27	4

Figure 66 : Economic Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh

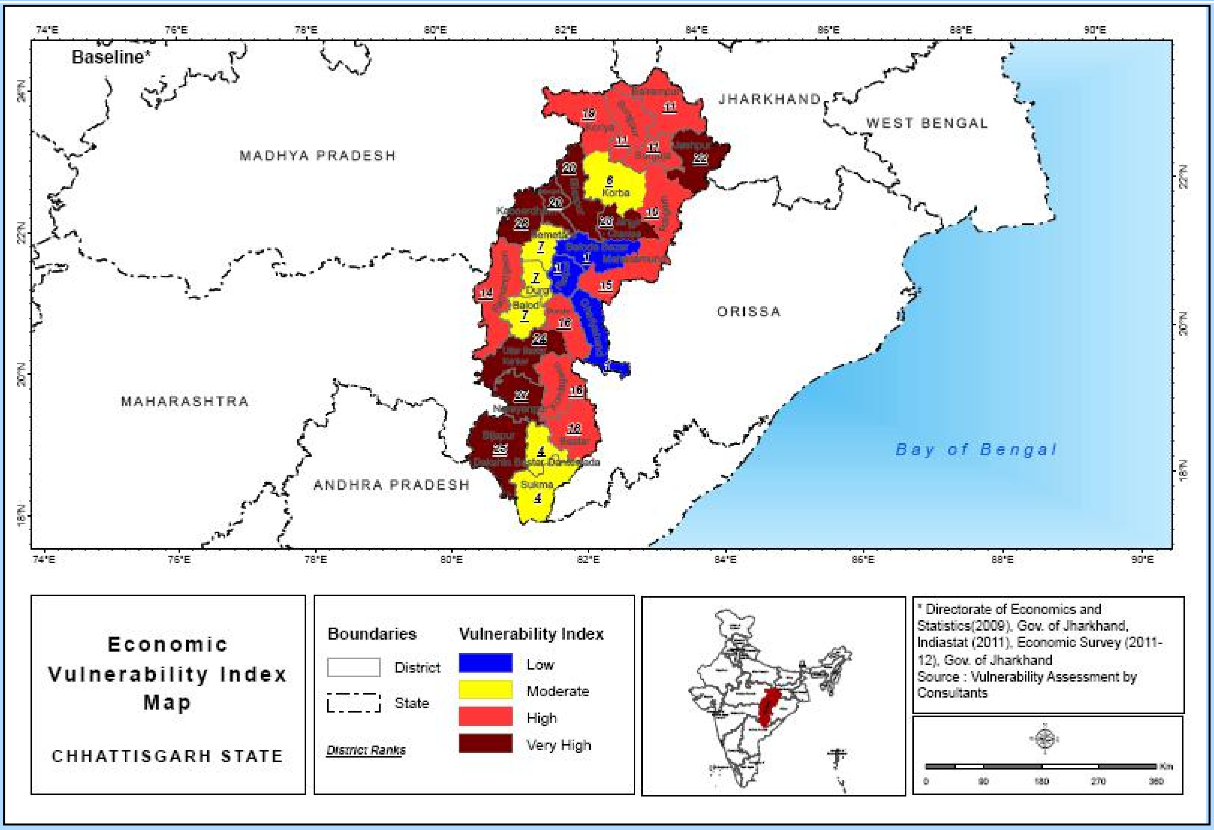
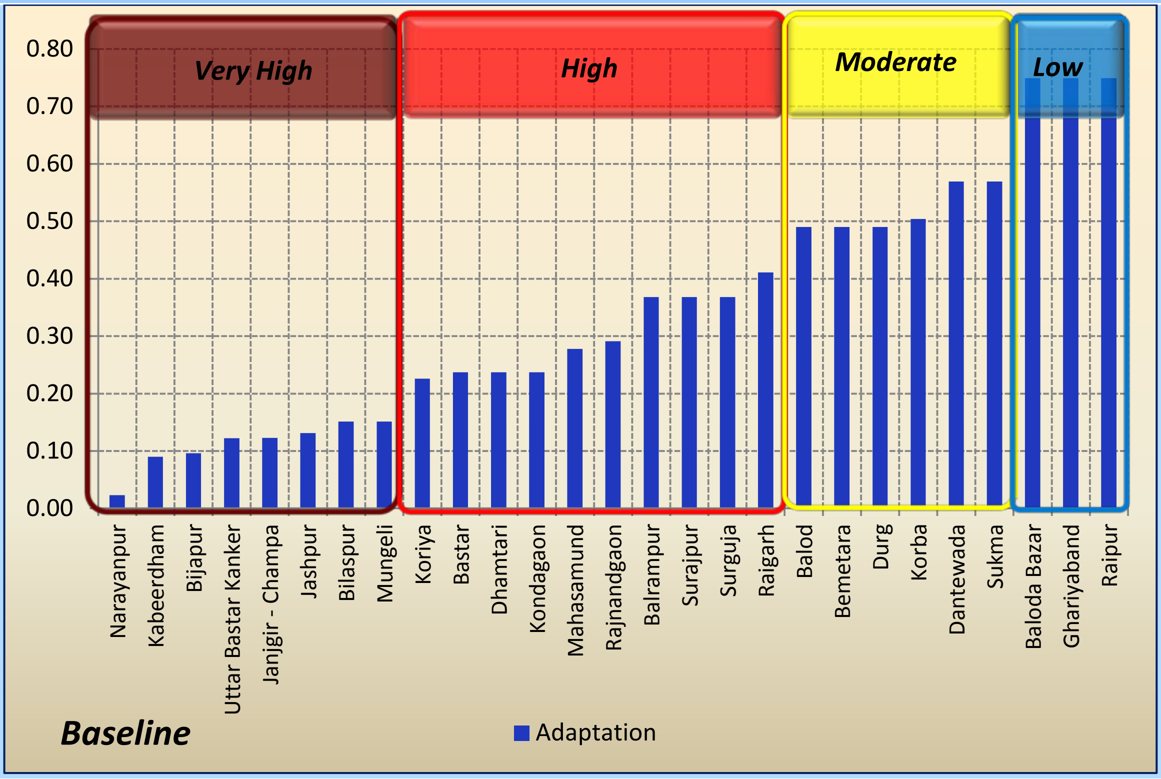


Figure 67 : Sub-Index values for Adaptive capacity showing district under low, moderate, high and very high vulnerability clusters (Economic Vulnerability Index)– baseline



Composite Socio Economic Vulnerability Index (CSEVI)

A Composite Socio Economic Vulnerability Index (CSEVI) is constructed using a matrix of 20indicators for 27 districts considering 17 social indicators and 3 economic indicators as mentioned in the previous paragraphs. Combination of social and economic indicators together brings out the disparity in the districts. Table 22 shows the relative ranks of the district along with the vulnerability groups (clusters) they fall into and their index values. Spatial representation of district ranking is depicted in Figure 68.

Baseline: Cluster results show (Figure 68) that 2 districts namely, Bijapur and Narayanpur have very high socio-economic vulnerability as these shows the lowest index values and can be seen from Figure 70 (bar graph) that these districts have comparatively low adaptive capacity and show higher sensitivity to socio economic indicators with respect to the other districts. The districts in very high vulnerable category also have very high social and economic vulnerability as highlighted before. These 2 districts show low index values with respect to both social and economic indices and these districts also shows lower values in the CSEVI (Figure 69)

The third cluster (high vulnerability) comprising 9 districts are also vulnerable but are relatively less than the districts in the fourth cluster. The second cluster (moderate vulnerability) comprising of 9 districts namely Koriya, Uttar Bastar Kanker, Mahasamund, Raigarh, Mungeli, Janjgir-Champa, Bilaspur, Rajnandgaon, and Korba have moderate vulnerability. The location of these districts can be seen in Figure 68 represented in yellow colour.

Baloda Bazar, Raipur, Ghariyaband, Dhamtari, Bemetara, Durg and Balod are the least vulnerable districts (cluster 1) as they have higher adaptive capacity (shown by blue colour in the graph) and show lower sensitivity to socio economic indicators (shown by colour red in the graph).These districts also have very low social and economic vulnerability as can be seen from Figure 69 except Dhamtari which has high economic vulnerability. The least vulnerable districts are located in the Eastern and Central regions of Chhattisgarh.

Table 22: District wise Composite Socio-Economic Vulnerability Index (CSEVI) - Values, Ranks and Cluster code for baseline

	Baseline		
Districts	**CSEVI**	**Rank**	**Cluster code**
Balod	0.240	1	1
Durg	0.205	2	1
Bemetara	0.177	3	1
Dhamtari	0.170	4	1
Ghariyaband	0.168	5	1
Raipur	0.156	6	1
Baloda Bazar	0.155	7	1
Korba	0.106	8	2
Rajnandgaon	0.094	9	2
Bilaspur	0.079	10	2
Janjgir - Champa	0.074	11	2
Mungeli	0.052	12	2
Raigarh	0.046	13	2
Mahasamund	0.025	14	2
Uttar Bastar Kanker	0.023	15	2
Koriya	0.000	16	2
Kabeerdham	-0.059	17	3
Surguja	-0.091	18	3
Jashpur	-0.098	19	3
Surajpur	-0.110	20	3
Balrampur	-0.121	21	3
Bastar	-0.138	22	3
Kondagaon	-0.149	23	3
Dantewada	-0.150	24	3
Sukma	-0.163	25	3
Narayanpur	-0.222	26	4
Bijapur	-0.252	27	4

Figure 68 : Composite Socio-Economic Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh

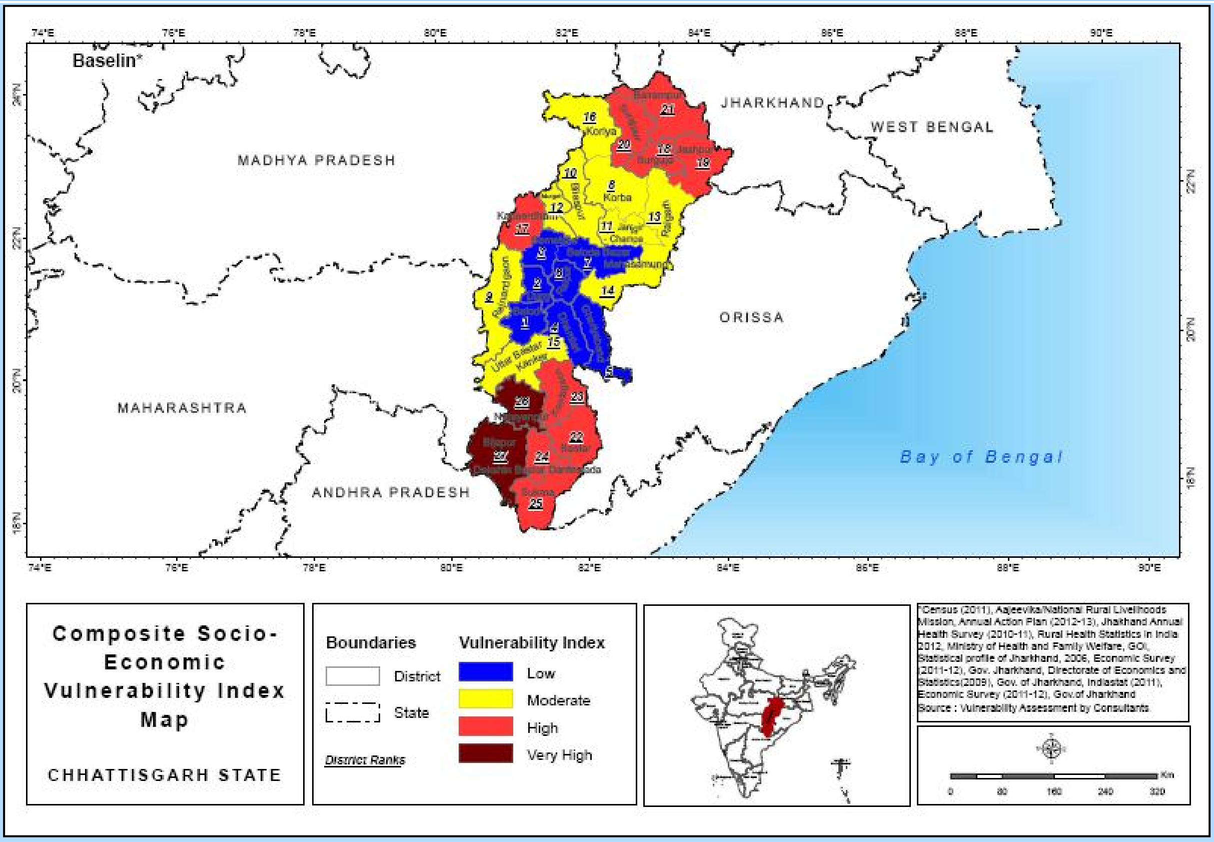


Figure 69 : Composite Socio-Economic Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh along with sub-indices vulnerability cluster map

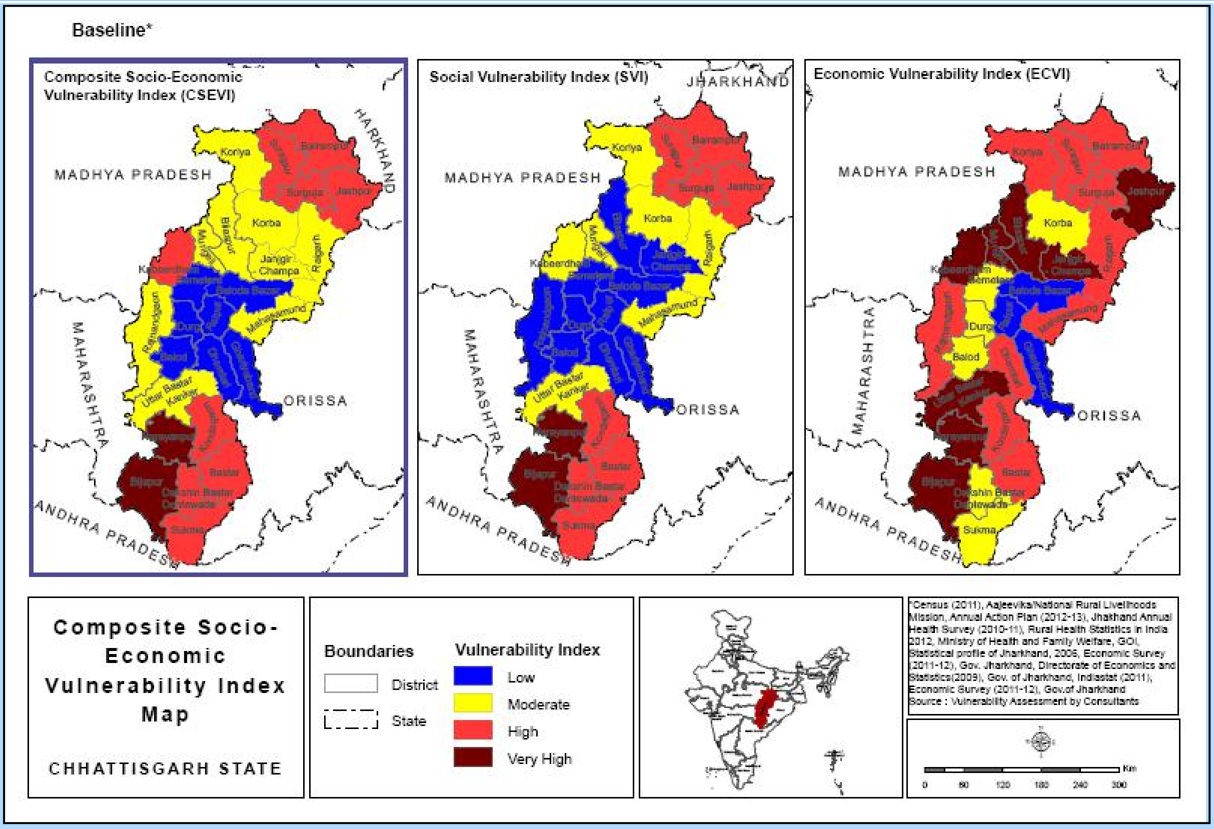
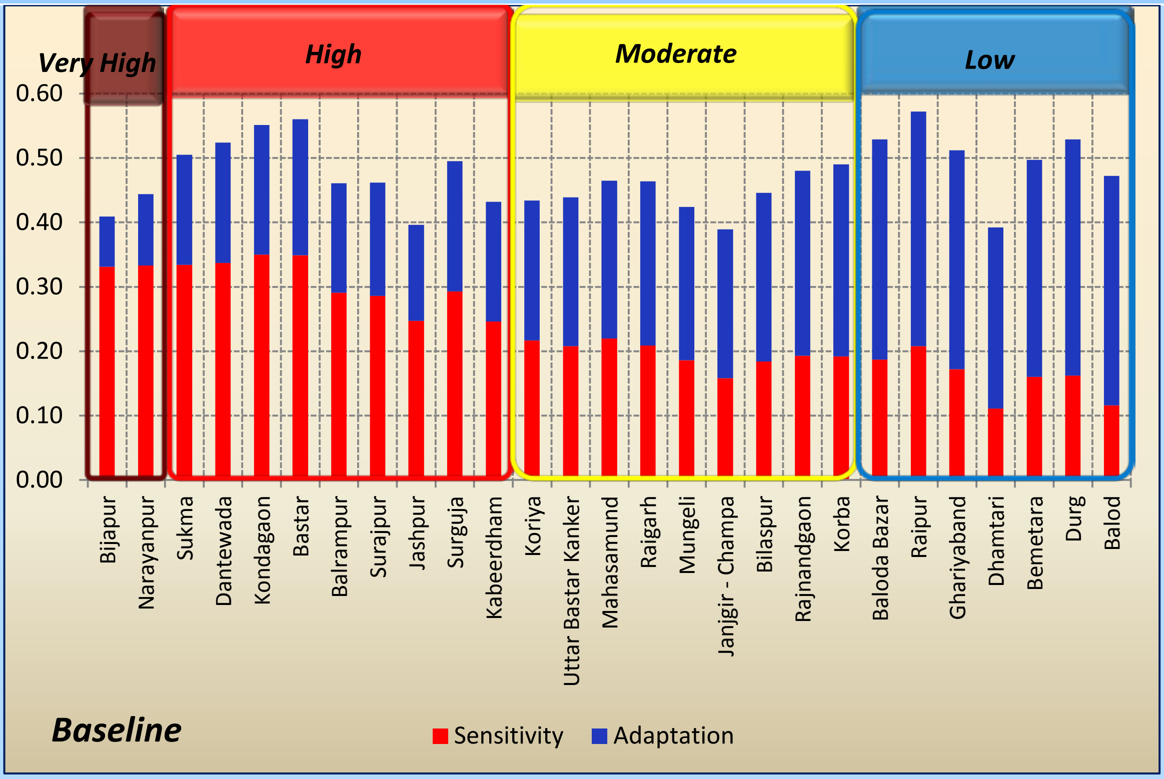


Figure 70 : Sub-Index values for Sensitivity, exposure and adaptive capacity showing district under low, moderate, high and very high vulnerability clusters (Composite Socio-Economic Vulnerability Index)– baseline



Agriculture Vulnerability Index (AGVI)

Agriculture Vulnerability Index (AGVI) for 27 districts of Chhattisgarh is constructed using 16 agriculture indicators listed in Table 6. Table 23 shows the relative ranks of the district along with the vulnerability groups (clusters) they fall into and their index values for baseline (BL) and midterm RCP 4.5 scenario. Spatial representation of district ranking is depicted in Figure 71.

Baseline: Cluster results show (Figure 71) 6 districts being located in North Eastern and South Western regions of Chhattisgarh have very highly agriculture vulnerability, namely, Jashpur, Janjgir - Champa, Korba, Surguja, Raigarh, and Uttar Bastar Kanker. It is low wheat and maize production per capita, larger proportion of wasteland, very less percentage of ground water and surface water irrigation to net sown area, greater share of agricultural and cultivators main workers to total main workers thus more dependence on agriculture income, etc which makes Jashpur and Janjgir-Champa most vulnerable in AGVI. It can also be seen from Figure 72. (Bar graph) that these districts thus have comparatively low adaptive capacity and show higher sensitivity to agriculture indicators.

The third cluster (high vulnerability) comprising 12 districts are also vulnerable but are relatively less than the districts in the fourth cluster. Sukma, Kabeerdham, Mungeli, Rajnandgaon, Dhamtari, Koriya and Ghariyaband have moderate vulnerability (yellow colour in Figure 71).

Balod and Bemetara are the least vulnerable districts due to higher adaptive capacity (shown by blue colour in the graph) and lesser sensitivity to agriculture vulnerability as can be seen from Figure 72.

It is high maize and rice production per capita, optimum ground water and surface water irrigation facilities, low wasteland, large crop diversity, high cropping intensity, large number of poultry units etc which makes Balod and Bemetara least vulnerable. They are located in the Western regions of Chhattisgarh.

Midterm RCP 4.5: Figure 71 shows the district agriculture vulnerability towards mid-term for RCP 4.5 scenario. It's seen that Kabeerdham's vulnerability has increased from baseline to midterm as Kabeerdham has come from moderate in BL to high vulnerability in midterm while Bijapur has come from high in BL to very high vulnerability in midterm. While rest of the districts show no change in cluster though changes in the relative ranking of the districts is observed.

Thus the overall Agriculture vulnerability of the Chhattisgarh districts is projected to increase slightly in the MC RCP 4.5 scenario compared to the baseline.

Table 23: District wise Agriculture Vulnerability Index (AGVI) - Values, Ranks and Cluster code for baseline (1961-1990) and midterm (2021-2050) RCP 4.5 scenario

	Baseline			Midterm		
Districts	**AGVI**	**Rank**	**Cluster code**	**AGVI**	**Rank**	**Cluster code**
Bemetara	0.301	1	1	0.273	1	1
Balod	0.295	2	1	0.264	2	1
Ghariyaband	0.139	3	2	0.121	3	2
Koriya	0.125	4	2	0.099	5	2
Dhamtari	0.122	5	2	0.111	4	2
Rajnandgaon	0.112	6	2	0.098	6	2
Mungeli	0.109	7	2	0.095	7	2
Kabeerdham	0.101	8	2	0.068	9	3
Sukma	0.096	9	2	0.067	10	3
Baloda Bazar	0.078	10	3	0.071	8	3
Balrampur	0.072	11	3	0.053	13	3
Durg	0.072	11	3	0.062	12	3
Raipur	0.070	13	3	0.067	10	3
Kondagaon	0.056	14	3	0.040	14	3
Narayanpur	0.046	15	3	0.035	15	3
Surajpur	0.045	16	3	0.025	18	3
Bastar	0.039	17	3	0.026	17	3
Dantewada	0.038	18	3	0.028	16	3
Mahasamund	0.034	19	3	0.019	20	3
Bilaspur	0.031	20	3	0.021	19	3
Bijapur	0.018	21	3	0.011	21	4
Uttar Bastar Kanker	0.006	22	4	-0.009	23	4
Raigarh	0.001	23	4	-0.002	22	4
Surguja	-0.006	24	4	-0.015	24	4
Korba	-0.014	25	4	-0.017	25	4

Districts	Baseline			Midterm		
	AGVI	Rank	Cluster code	AGVI	Rank	Cluster code
Janjgir - Champa	-0.023	26	4	-0.029	26	4
Jashpur	-0.035	27	4	-0.040	27	4

Figure 71 : Agriculture Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh

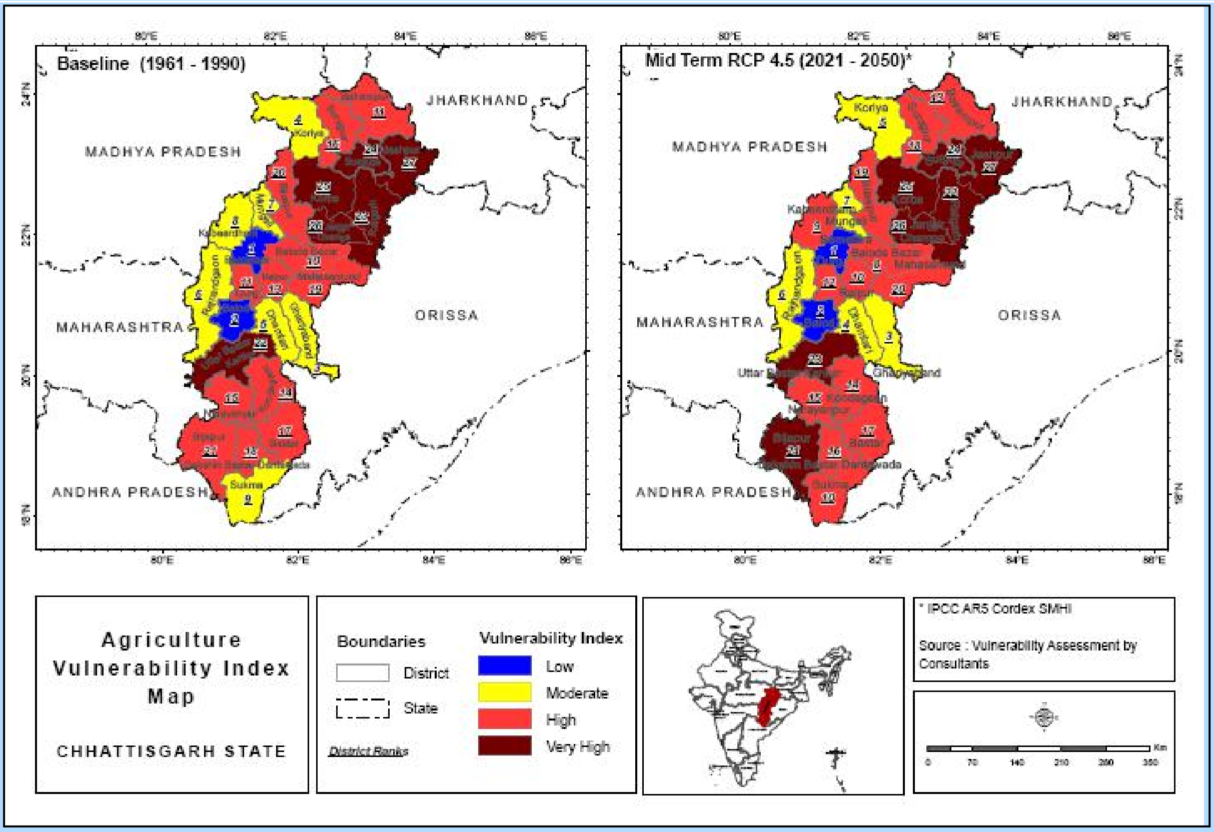
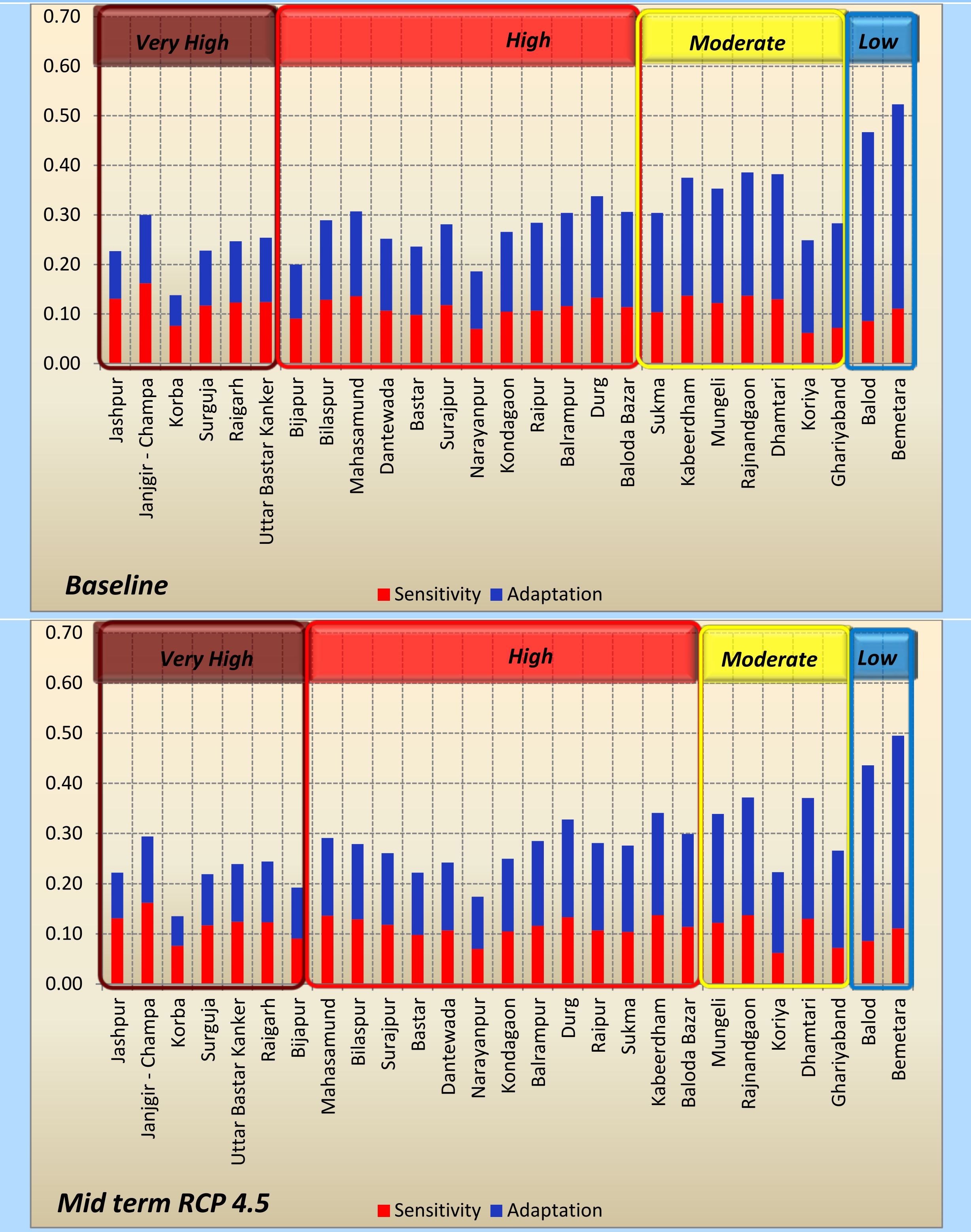


Figure 72 : Sub-Index values for Sensitivity, exposure and adaptive capacity showing district under low, moderate, high and very high vulnerability clusters (Agriculture Vulnerability Index)– baseline and midterm RCP 4.5 scenario



Forest Vulnerability Index (FOVI)

Forest Vulnerability Index (FOVI) for 27 districts of Chhattisgarh for baseline is constructed using 5 forest indicators listed in Table 6 and in Impact Chapter 4. Table 24 shows the relative ranks of the district along with the vulnerability groups (clusters) they fall into and their index values. Ranks of the new 9 districts formed in 2012 have been assumed to be the same as the parent district from which they are carved. Spatial representation of district ranking is depicted in Figure 73.

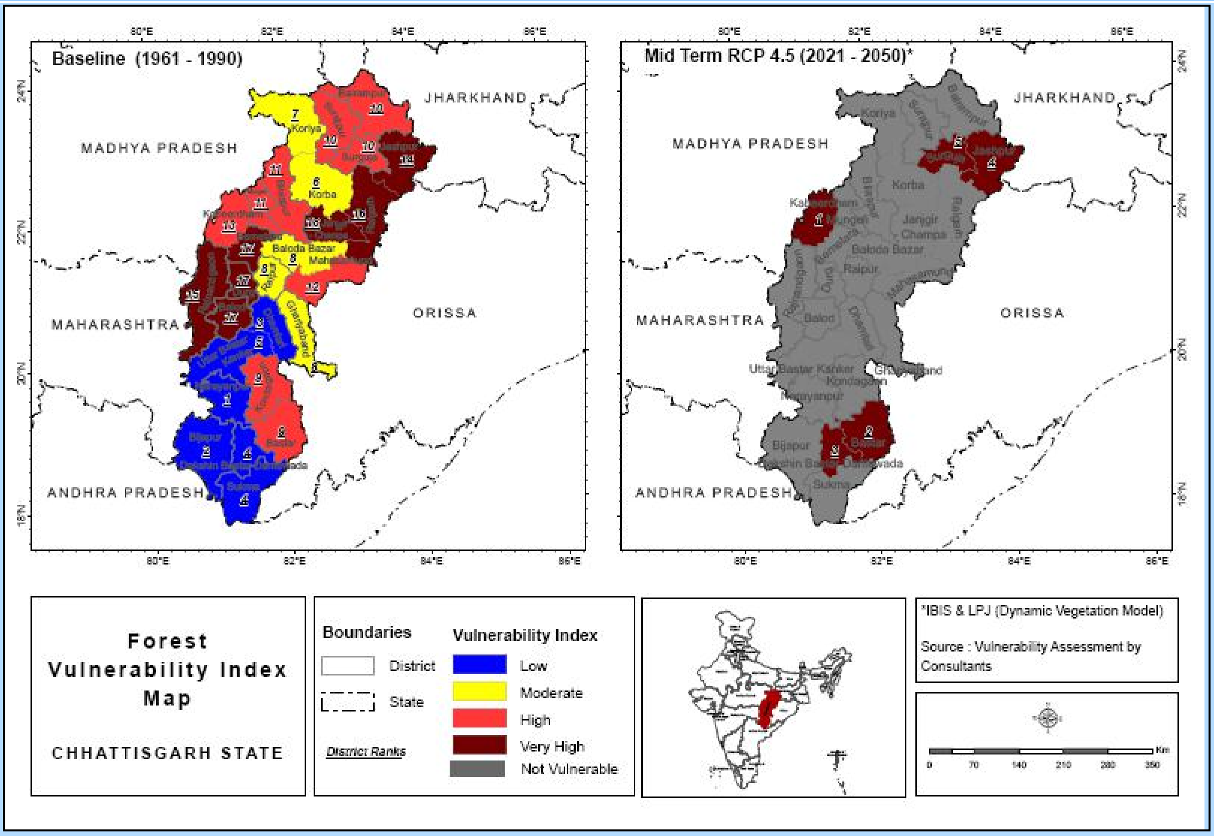
Baseline: In this Section, current vulnerability is assessed and presented at district level. Cluster analysis of vulnerability index (VI) values for the districts under current climate suggests the following clustering of districts in different vulnerability classes: Low –Dhamtari, Bijapur and Narayanpur; Moderate – Korba, Uttar Bastar, Dakshin Bastar, Raipur and Koriya; High – Kabeerdham, Mahasamund, Bilaspur, Surguja and Bastar; Very High –Janjgir-Champa, Durg, Raigarh, Rajnandgaon and Jashpur.

Table 24: District wise Forest Vulnerability Index (FOVI) - Values, Ranks and Cluster code for baseline (1961-1990)

	Baseline			
Districts	FOVI	Rank	Cluster code	Forest area in km2
Narayanpur	1.525	1	1	2707
Bijapur	1.544	2	1	5602
Dhamtari	1.652	3	1	2101
Dantewada	1.673	4	1	5631
Sukma	1.673	4	1	
Uttar Bastar Kanker	1.685	5	1	3541
Korba	1.762	6	2	3856
Koriya	1.812	7	2	4309
Baloda Bazar	1.840	8	2	
Ghariyaband	1.840	8	2	
Raipur	1.840	8	2	3158
Bastar	1.851	9	2	4812
Kondagaon	1.851	9	2	
Balrampur	1.861	10	2	
Surajpur	1.861	10	2	
Surguja	1.861	10	2	6404
Bilaspur	1.892	11	2	2661
Mungeli	1.892	11	2	
Mahasamund	1.894	12	2	1297
Kabeerdham	1.928	13	3	1370
Jashpur	1.943	14	3	2499
Rajnandgaon	1.951	15	3	2215
Raigarh	1.976	16	3	2360
Balod	2.093	17	4	

Districts	Baseline			
	FOVI	Rank	Cluster code	Forest area in km2
Bemetara	2.093	17	4	
Durg	2.093	17	4	961
Janjgir - Champa	2.165	18	4	242

Figure 73 : Forest Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh



Midterm RCP 4.5: Vulnerability assessment and ranking, considering the combined effect of both the impacts of climate change and the current vulnerability of forests is conducted to identify the most vulnerable districts under future climate. This ranking is a combined assessment of climate impacted districts, along with 5 indicators selected for estimating the current vulnerability. Table 3 presents the most vulnerable districts by 2030s under RCP 4.5. The focus here is more on the short-term (2030s) and on RCP 4.5, assuming the current emission trends will continue. The top five most vulnerable districts (Table 25) include Surguja, Jashpur, Dakshin Bastar, Bastar and Kabeerdham considering both climate impacts and current vulnerability. The districts Janjgir-Champa and Durg, although projected to be vulnerable are not ranked, as the forest area in these districts is very low. The remaining districts are not projected to be vulnerable. Spatial representation of district ranking is depicted in Figure 73.

Table 25: Vulnerability ranking of districts under future climate scenario in mid-term (2021-2050) under RCP 4.5

Districts	Future vulnerability ranking of districts	Geographical area (km^2)	Forest cover (km^2)
Surguja	5	15125	6404
Jashpur	4	5583	2499
Dakshin Bastar	3	9839	4812
Bastar	2	9581	4309
Kabeerdham	1	2969	1370

Water Resource Vulnerability Index (WRVI)

Water Resource Vulnerability Index (WRVI) across the 27 districts of Chhattisgarh is constructed using 8 water resources indicators listed in Table 6.Principal Component Analysis on these indicators and cluster analysis are performed to group the districts in four categories- very high, high, moderate and low according to their degree of vulnerability. Table 26 shows the relative ranks of the district along with the vulnerability groups (clusters) they fall into and their index values for baseline (BL) and midterm RCP 4.5.scenario.Spatial representation of district ranking is depicted in Figure 74.

Baseline: Cluster result shows (Figure 74) that 5 districts namely Kabeerdham, Bemetara, Durg, Raipur, Rajnandgaon have very low values of Water Resource Vulnerability Index (WRVI) thus belong to very high vulnerable category (cluster 4) compared to the other districts of Chhattisgarh. It is less surface water and ground water availability per capita in monsoon and non monsoon months, high crop water stress in North East Monsoon season which make these districts most vulnerable to climate change. It can also be seen from (Figure 75) (bar graph) that these districts thus have comparatively low adaptive capacity and show higher sensitivity and exposure to climate change. The location of districts in very high vulnerability cluster can be seen from Figure 74 in Western regions of Chhattisgarh.

The third cluster (high vulnerability) comprising 11 districts namely, Janjgir-Champa, Balod, Raigarh, Baloda Bazar, Bilaspur, Mungeli, Sukma, Mahasamund, Uttar Bastar Kanker, Korba and Dhamtari are also vulnerable but are relatively less than the districts in the fourth cluster. The location of these districts can be seen in red colour in Figure 74

The second cluster (moderate vulnerability) comprising of 8 districts has moderate vulnerability. The location of these districts can be seen in Figure 74 represented in yellow colour.

2 districts namely, Bijapur and Narayanpur are the least vulnerable districts (cluster 1) because they have the maximum availability of surface and ground water per capita and less crop water stress in South West Monsoon and North East Monsoon seasons compared to the other districts. Thus districts in this cluster have higher adaptive capacity (shown by blue colour in the graph) and show lower sensitivity and exposure (shown by colour red in the graph) to climate change (Figure 74).

Midterm RCP 4.5: Figure 4 shows the district vulnerability towards mid-term for RCP 4.5 scenario. No variability is seen in the districts in midterm compared to the baseline. They belong to the same clusters as can be seen from Figure 74. Though change in the relative ranking amongst the districts is observed from BL to midterm (Table 26).

Table 26: District wise Water Resources Vulnerability Index (WRVI) - Values, Ranks and Cluster code for baseline (1961-1990) and midterm (2021-2050) RCP 4.5 scenario

	Baseline			Midterm		
Districts	WRVI	Rank	Cluster code	WRVI	Rank	Cluster code
Narayanpur	0.458	1	1	0.299	1	1
Bijapur	0.406	2	1	0.268	2	1
Kondagaon	0.169	3	2	0.110	3	2
Dantewada	0.149	4	2	0.087	4	2
Balrampur	0.083	5	2	0.036	5	2
Koriya	0.076	6	2	-0.004	7	2
Surajpur	0.044	7	2	0.022	6	2
Bastar	0.001	8	2	-0.038	8	2
Surguja	-0.024	9	2	-0.038	8	2
Jashpur	-0.025	10	2	-0.064	11	2
Ghariyaband	-0.027	11	2	-0.052	10	2
Dhamtari	-0.090	12	3	-0.101	12	3
Korba	-0.100	13	3	-0.126	13	3
Uttar Bastar Kanker	-0.109	14	3	-0.134	14	3
Mahasamund	-0.133	15	3	-0.167	17	3
Sukma	-0.14	16	3	-0.173	19	3
Mungeli	-0.152	17	3	-0.159	15	3
Bilaspur	-0.158	18	3	-0.163	16	3
Baloda Bazar	-0.161	19	3	-0.170	18	3
Raigarh	-0.166	20	3	-0.201	21	3
Balod	-0.181	21	3	-0.198	20	3
Janjgir - Champa	-0.197	22	3	-0.203	22	3
Rajnandgaon	-0.223	23	4	-0.230	23	4
Raipur	-0.243	24	4	-0.235	24	4
Durg	-0.263	25	4	-0.253	25	4
Bemetara	-0.308	26	4	-0.282	26	4
Kabeerdham	-0.309	27	4	-0.283	27	4

Figure 74 : Water Resources Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh for baseline(1961-1990) and midterm (2021-2050) RCP 4.5 scenario

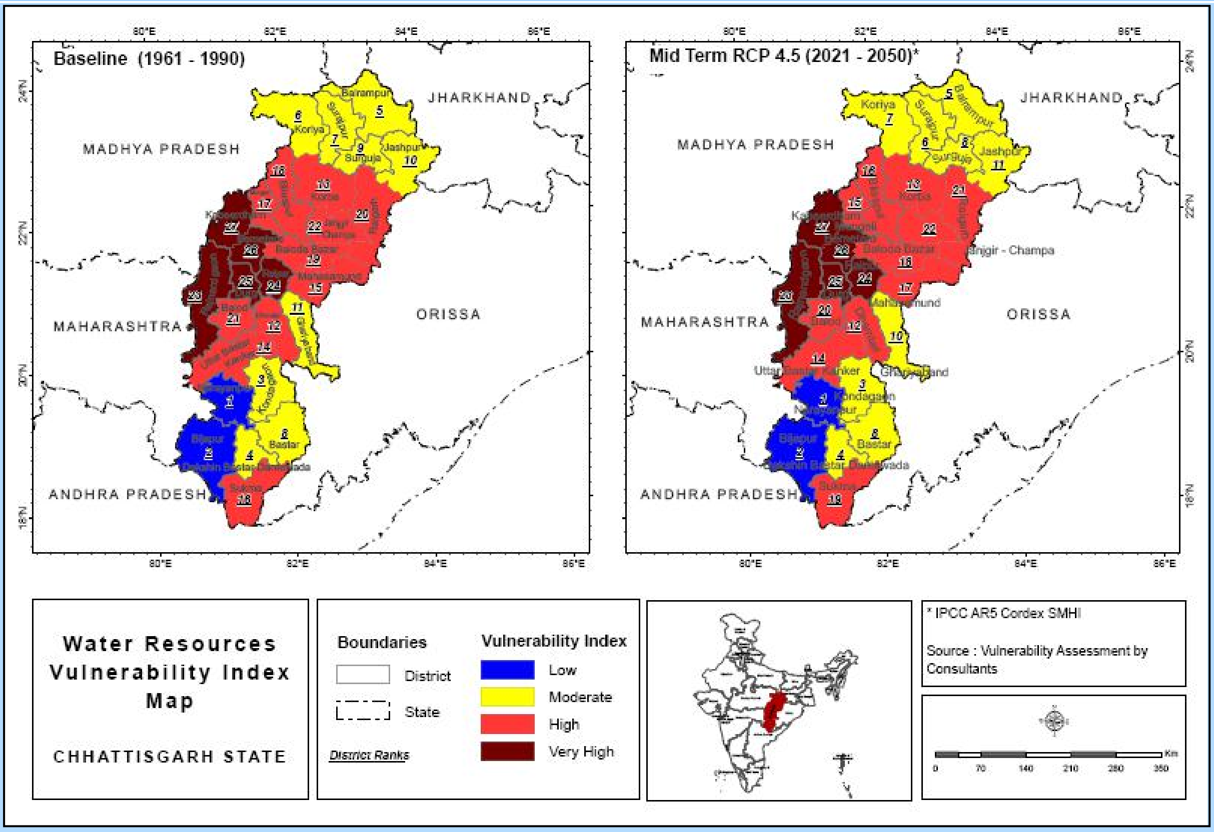
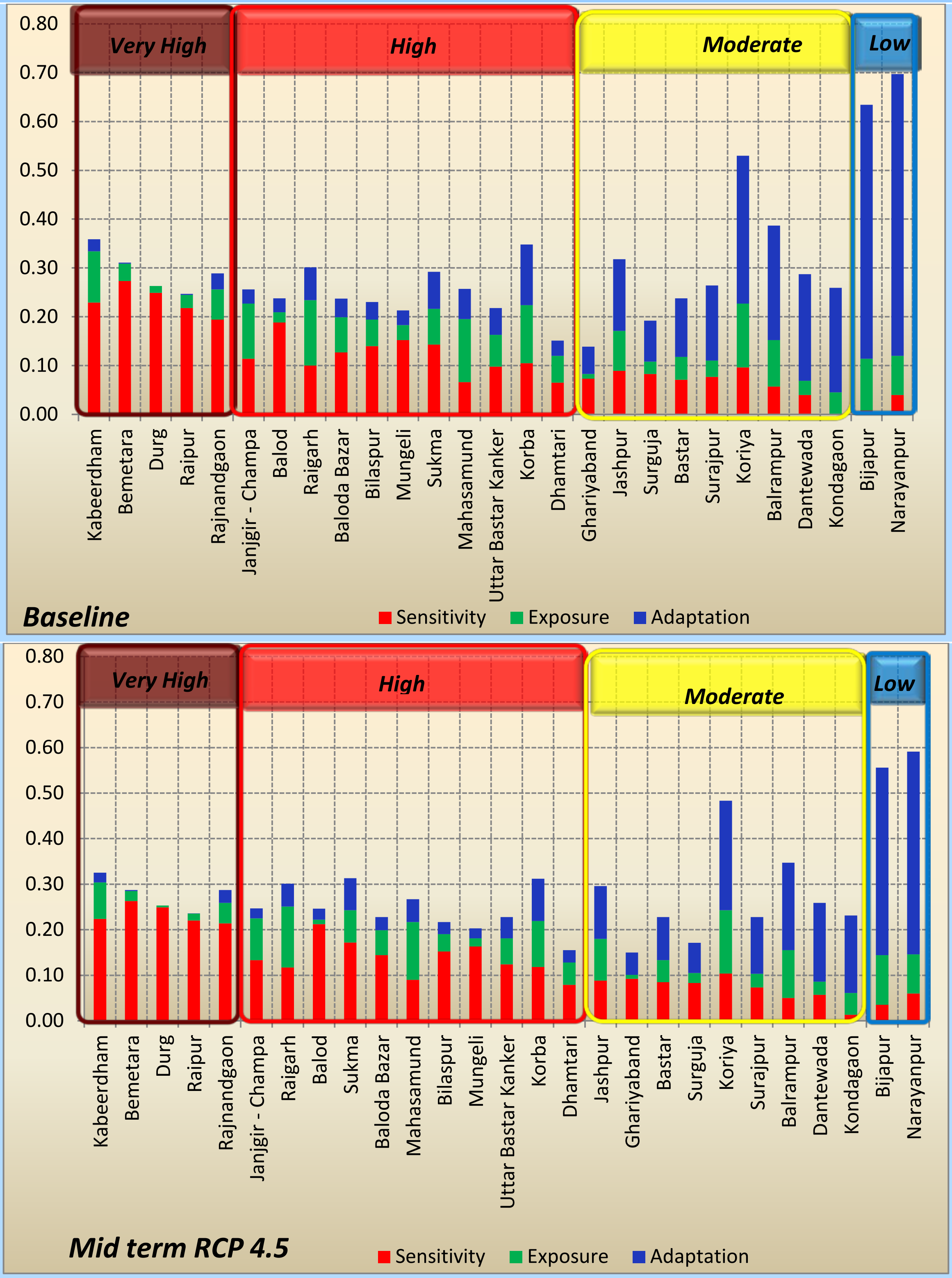


Figure 75 : Sub-Index values for Sensitivity, exposure and adaptive capacity showing district under low, moderate, high and very high vulnerability clusters (Water Resources Vulnerability Index)– baseline and midterm RCP 4.5 scenario



Climate Vulnerability Index (CLVI)

Climate Vulnerability Index (CLVI) across the 27 districts of Chhattisgarh is constructed using 11 climate indicators listed in Table 6. Principal Component Analysis on these indicators and cluster analysis are performed to group the districts in four categories- very high, high, moderate and low according to their degree of vulnerability. Table 27 shows the relative ranks of the district along with the vulnerability groups (clusters) they fall into and their index values for baseline (BL) and midterm RCP 4.5.Spatial representation of district ranking is depicted in Figure 76.

Baseline: Cluster result shows (Figure 76) that 6 districts namely have Uttar Bastar Kanker, Balrampur, Jashpur, Narayanpur, Raigarh and Bijapur very high vulnerability to current climate. These lie in the North East and South West of Chhattisgarh. It can be seen from Figure 77 (bar graph) that these 6 districts show greater exposure to extreme events with respect to the other districts thus have higher Climate Vulnerability Index values (indicated by green colouring the graph).

The third cluster (high vulnerability) comprising 10 districts namely, Ghariyaband, Koriya, Rajnandgaon, Janjgir - Champa, Mahasamund, Kondagaon, Surguja, Surajpur, Korba and Dantewada are also vulnerable but are relatively less than the districts in the fourth cluster.

The second cluster (moderate vulnerability) comprises of 7 districts have moderate vulnerability. The location of these districts can be seen in Figure 76 represented in yellow colour.

4 districts are in the low vulnerable category namely Balod, Mungeli, Bemetara and Durg because they have less exposure to extreme events due to climate change (Figure 77).

Midterm RCP 4.5: 4 districts which have now become moderately vulnerable compared to high vulnerability in the BL are Janjgir-Champa, Korba, Koriya and Surajpur. Similarly 3 districts which were in moderate cluster in BL namely Baloda Bazar, Bilaspur and Kabeerdham are now in least cluster in midterm as can be seen from the layout. Thus these districts vulnerability declined from baseline

Bastar, Dantewada, Kondagaon and Sukma's vulnerability has increased from baseline to midterm as can be seen in Figure 77. These districts climate vulnerability is expected to increase as their exposure to extreme climate events is expected to increase in midterm relative to the BL thus have greater Climate Index negative values in midterm (Figure 77).

Thus the overall Climate vulnerability of the Chhattisgarh districts is projected to increase for some districts in the MC RCP 4.5 scenario while decrease for others compared to the baseline

Table 27: District wise Climate Vulnerability Index (CLVI) - Values, Ranks and Cluster code for baseline (1961-1990) and midterm (2021-2050) RCP 4.5 scenario

	Baseline			Midterm		
Districts	CLVI	Rank	Cluster code	CLVI	Rank	Cluster code
Durg	-0.336	1	1	-0.331	3	1
Bemetara	-0.337	2	1	-0.326	2	1
Mungeli	-0.341	3	1	-0.315	1	1

Districts	Baseline			Midterm		
	CLVI	Rank	Cluster code	CLVI	Rank	Cluster code
Balod	-0.348	4	1	-0.340	4	1
Kabeerdham	-0.363	5	2	-0.350	6	1
Sukma	-0.374	6	2	-0.410	17	3
Baloda Bazar	-0.377	7	2	-0.354	7	1
Dhamtari	-0.384	8	2	-0.371	9	2
Raipur	-0.384	8	2	-0.365	8	2
Bilaspur	-0.385	10	2	-0.341	5	1
Bastar	-0.388	11	2	-0.408	15	3
Dantewada	-0.407	12	3	-0.454	21	4
Korba	-0.408	13	3	-0.377	10	2
Surajpur	-0.415	14	3	-0.382	11	2
Surguja	-0.416	15	3	-0.410	17	3
Kondagaon	-0.417	16	3	-0.441	20	4
Mahasamund	-0.423	17	3	-0.407	14	3
Janjgir - Champa	-0.426	18	3	-0.393	12	2
Rajnandgaon	-0.429	19	3	-0.409	16	3
Ghariyaband	-0.432	20	3	-0.410	17	3
Koriya	-0.432	20	3	-0.393	12	2
Bijapur	-0.467	22	4	-0.492	26	4
Raigarh	-0.468	23	4	-0.456	22	4
Narayanpur	-0.485	24	4	-0.486	25	4
Jashpur	-0.495	25	4	-0.464	23	4
Balrampur	-0.497	26	4	-0.470	24	4
Uttar Bastar Kanker	-0.545	27	4	-0.535	27	4

Figure 76 : Climate Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh for baseline(1961-1990) and midterm (2021-2050) RCP 4.5 scenario

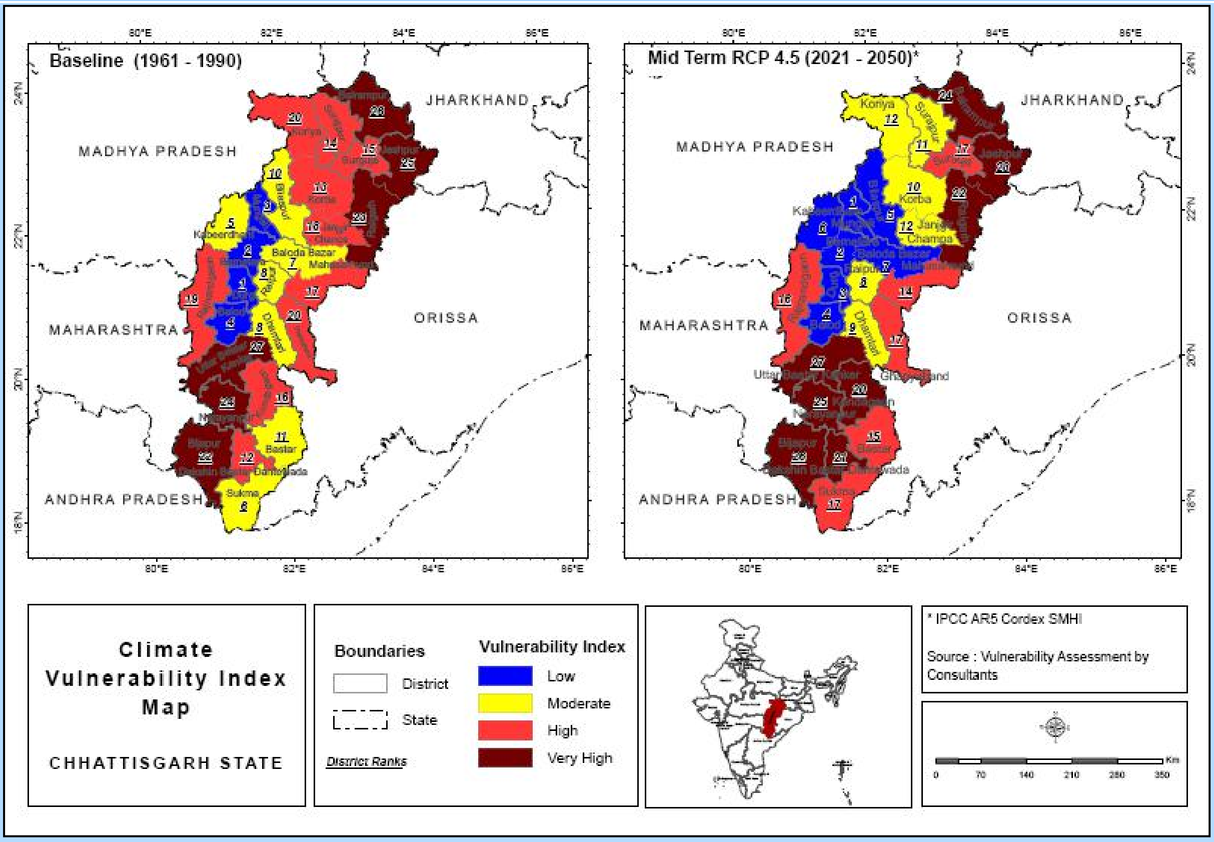
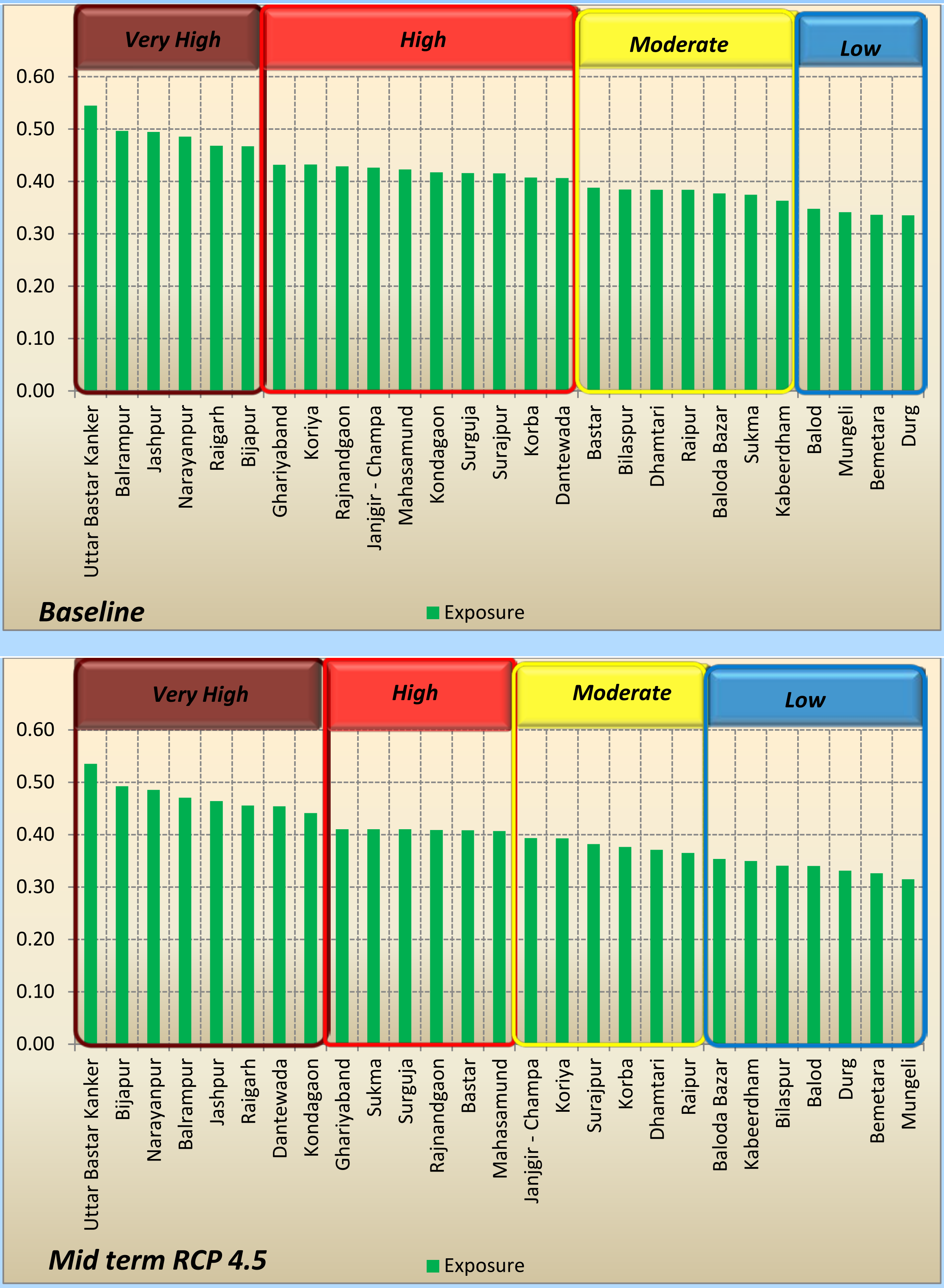


Figure 77 : Sub-Index values for Exposure showing district under low, moderate, high and very high vulnerability clusters (Climate Vulnerability Index) for baseline and midterm RCP 4.5 scenario



Health Vulnerability Index (HLVI)

Health Vulnerability Index (HLVI) across the 27 districts of Chhattisgarh is constructed using 14 health indicators listed in Table 6. Principal Component Analysis on these indicators and cluster analysis are performed to group the districts in four categories- very high, high, moderate, and low according to their degree of vulnerability. Table 28 shows the relative ranks of the district along with the vulnerability groups (clusters) they fall into and their index values for baseline (BL) and midterm RCP 4.5 scenario. Spatial representation of district ranking is depicted in Figure 78.

Baseline: Cluster result shows (Figure 78) that Jashpur and Bijapur are very highly vulnerable lying in North East and South West of Chhattisgarh respectively. It can be seen from Figure 79 (bar graph) that they have comparatively higher sensitivity to health indicators- with respect to the other districts (shown by colour red in the graph).It is high infant mortality rate, high diarrhoea cases, greater sensitivity to Anopheles Mosquito causing Malaria, which makes Jashpur and Bijapur most vulnerable.

The third cluster (high vulnerability) and second cluster (moderate vulnerability) comprises of 9 and 4districts respectively. The location of these districts can be seen in Figure 78

12 districts, Bilaspur, Balrampur, Surajpur, Baloda Bazar, Ghariyaband, Surguja, Sukma, Balod, Mungeli, Raipur, Bemetara and Durg are the least vulnerable districts because they have comparatively lesser sensitivity to Anopheles Mosquito causing Malaria thus have very low sensitivity to health indicators (Figure 79)

Midterm RCP 4.5: No variability is seen in the districts in midterm compared to the baseline. They belong to the same clusters as can be seen from Figure 78. Though change in the relative ranking amongst the districts is observed from BL to midterm (Table 28).

Table 28: District wise Health Vulnerability Index (HLVI) - Values, Ranks and Cluster code for baseline (1961-1990) and midterm (2021-2050) RCP 4.5 scenario

	Baseline			Midterm		
Districts	HLVI	Rank	Cluster code	HLVI	Rank	Cluster code
Durg	-0.032	1	1	-0.029	1	1
Bemetara	-0.037	2	1	-0.029	1	1
Raipur	-0.048	3	1	-0.047	3	1
Mungeli	-0.073	4	1	-0.071	4	1
Balod	-0.075	5	1	-0.082	5	1
Sukma	-0.107	6	1	-0.243	12	2
Surguja	-0.118	7	1	-0.124	6	1
Ghariyaband	-0.119	8	1	-0.135	7	1
Baloda Bazar	-0.135	9	1	-0.135	7	1
Surajpur	-0.152	10	1	-0.172	9	1
Balrampur	-0.192	11	1	-0.206	10	1
Bilaspur	-0.210	12	1	-0.210	11	1
Rajnandgaon	-0.266	13	2	-0.286	14	2

	Baseline			Midterm		
Districts	HLVI	Rank	Cluster code	HLVI	Rank	Cluster code
Dantewada	-0.281	14	2	-0.271	13	2
Uttar Bastar Kanker	-0.281	14	2	-0.318	15	2
Janjgir - Champa	-0.360	16	2	-0.349	16	2
Dhamtari	-0.395	17	3	-0.356	17	2
Korba	-0.396	18	3	-0.431	21	3
Bastar	-0.421	19	3	-0.414	18	3
Kabeerdham	-0.428	20	3	-0.422	20	3
Koriya	-0.458	21	3	-0.464	23	3
Raigarh	-0.461	22	3	-0.416	19	3
Mahasamund	-0.462	23	3	-0.477	24	3
Kondagaon	-0.517	24	3	-0.455	22	3
Narayanpur	-0.578	25	3	-0.543	25	3
Bijapur	-0.673	26	4	-0.662	26	4
Jashpur	-0.712	27	4	-0.696	27	4

Figure 78 : Health Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh- baseline and midterm RCP 4.5 scenario

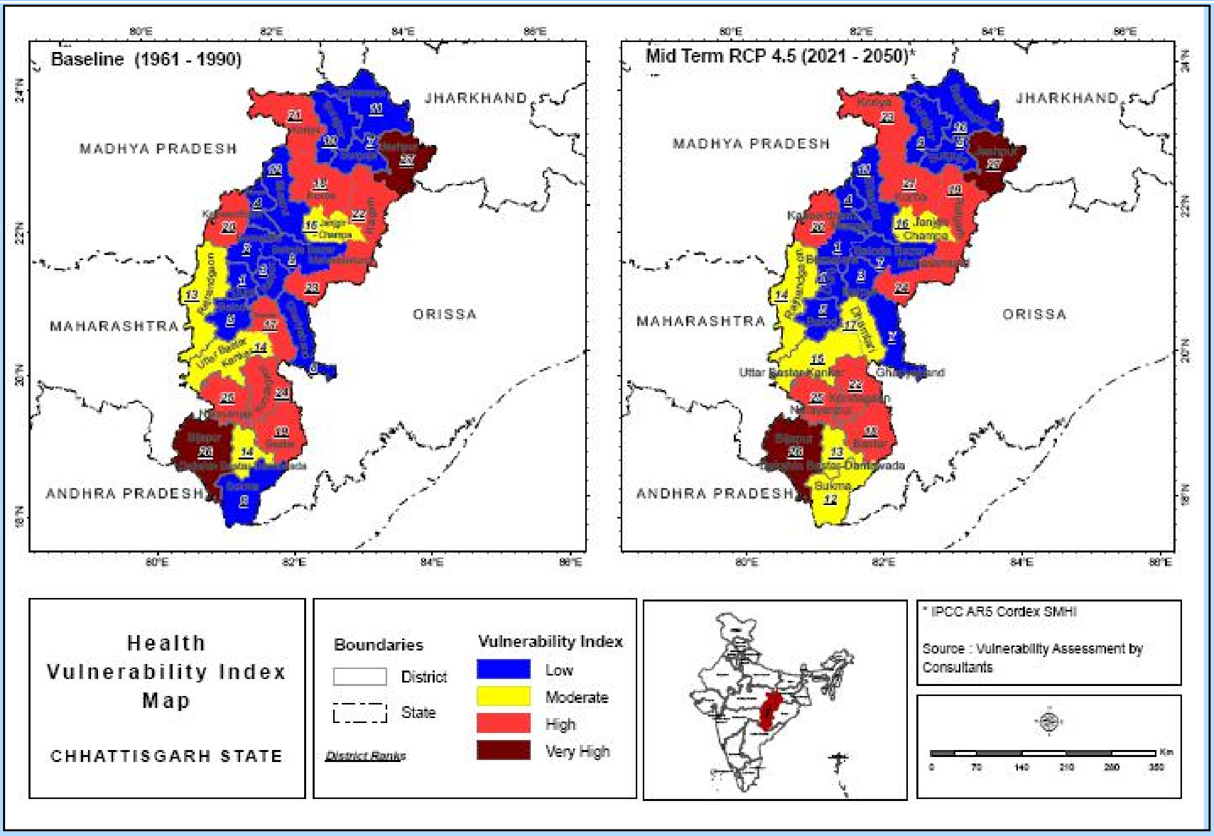
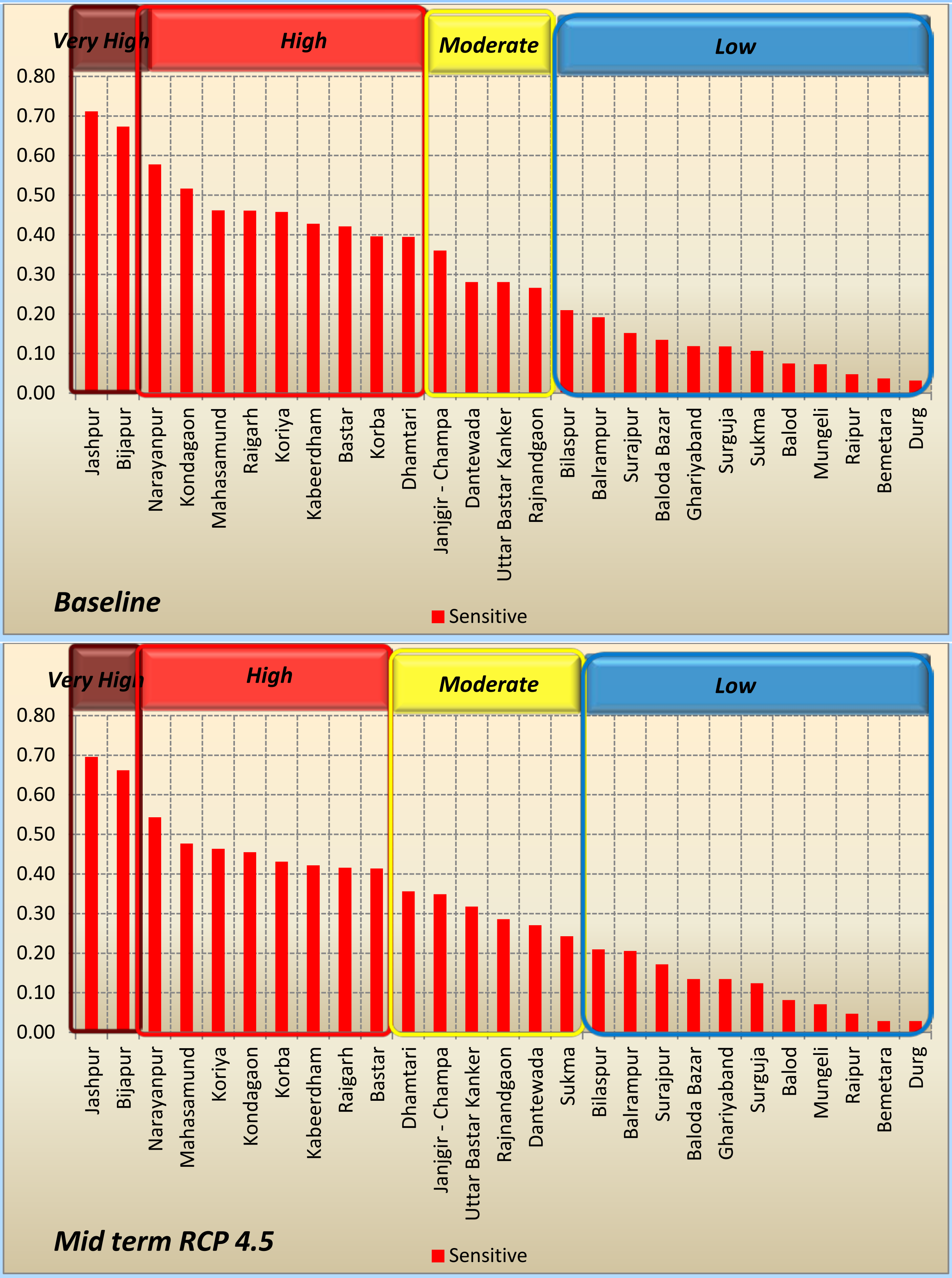


Figure 79 : Sub-Index values for Sensitivity, exposure and adaptive capacity showing district under low, moderate, high and very high vulnerability clusters (Health Vulnerability Index)– baseline and midterm RCP 4.5 scenario



Composite Environmental Vulnerability Index (CENVI)

Composite Environmental index (CENVI) is constructed using a matrix of 55indicators across 27 districts considering climate, water, agriculture and forest indicators listed in Table 6. This index gives the combined effect of all the environment indicators considered separately in the earlier paragraphs. Table 29 shows the relative ranks of the district along with the vulnerability groups (clusters) they fall into and their index values for baseline (BL) and midterm RCP 4.5 scenario. Spatial representation of district ranking is depicted in Figure 80.

Baseline: Cluster results show (Figure 80) that 7 districts namely, Jashpur, Raigarh, Bijapur, Janjgir-Champa, Mahasamund, Kabeerdham and Korba have very high environmental vulnerability as these shows the lowest index values and can be seen from Figure 82 (bar graph) that these districts have comparatively low adaptive capacity and show higher sensitivity and exposure to environmental indicators with respect to the other districts. The districts in very high vulnerable category also have very high climate, water resources, and health and agriculture sector vulnerabilities as highlighted before (Figure 81). These 7districts show low index values with respect to all climate, water resource, health and agriculture vulnerability indices and these districts also shows lower values in the CENVI.

The third cluster (high vulnerability) comprising 7 districts (Narayanpur, Uttar Bastar Kanker, Kondagaon, Bastar, Koriya, Rajnandgaon and Dhamtari) are also vulnerable but are relatively less than the districts in the fourth cluster. Koriya is located in the North West while others are located in South West of Chhattisgarh.

The second cluster (moderate vulnerability) comprising of 7 districts has moderate vulnerability. The location of these districts can be seen in Figure 80 represented in yellow colour.

6 districts namely Sukma, Durg, Ghariyaband, Mungeli, Bemetara and Balod are the least vulnerable districts (cluster 1) as they have higher adaptive capacity (shown by blue colour in the graph) and show lower sensitivity and exposure to environmental indicators (shown by colour red in the graph). These districts also have very low climate, health and agriculture vulnerability as highlighted before (Figure 81).

Midterm RCP 4.5: Figure 80 shows the district vulnerability towards mid-term for RCP 4.5 scenario. Now there are 3 districts in cluster 4 (very high vulnerable category) compared to 7 in the baseline. 4 districts which have now become highly vulnerable are Janjgir-Champa, Mahasamund, Kabeerdham and Korba compared to very high vulnerability (cluster 4) in the baseline. Kondagaon, Koriya, Rajnandgaon and Dhamtari have come from high to moderate vulnerability implying that their vulnerability declined relatively in midterm compared to baseline. Similarly Raipur and Baoda Bazar are least vulnerable districts now in midterm compared to moderate in baseline.

2 districts namely Sukma and Surajpur which were in low cluster in BL are now in moderate cluster in midterm as can be seen from the layout.

Thus the overall Composite Environmental vulnerability of the Chhattisgarh districts is projected to decrease in the MC RCP 4.5 scenario compared to the baseline.

Table 29: District wise Composite Environmental Vulnerability Index (CENVI) - Values, Ranks and Cluster code for baseline (1961-1990) and midterm (2021-2050) RCP 4.5 scenario

	Baseline			Midterm		
Districts	CENVI	Rank	Cluster code	CENVI	Rank	Cluster code
Balod	-0.114	1	1	-0.088	1	1
Bemetara	-0.125	2	1	-0.088	1	1
Mungeli	-0.139	3	1	-0.101	3	1
Ghariyaband	-0.147	4	1	-0.120	4	1
Durg	-0.159	5	1	-0.124	5	1
Sukma	-0.161	6	1	-0.191	13	2
Raipur	-0.173	7	2	-0.134	6	1
Surajpur	-0.178	8	2	-0.148	7	1
Surguja	-0.189	9	2	-0.175	10	2
Baloda Bazar	-0.19	10	2	-0.152	8	1
Dantewada	-0.193	11	2	-0.193	14	2
Balrampur	-0.203	12	2	-0.178	11	2
Bilaspur	-0.216	13	2	-0.172	9	2
Dhamtari	-0.232	14	3	-0.184	12	2
Rajnandgaon	-0.238	15	3	-0.205	15	2
Bastar	-0.249	16	3	-0.233	18	3
Koriya	-0.249	16	3	-0.223	17	2
Kondagaon	-0.253	18	3	-0.213	16	2
Uttar Bastar Kanker	-0.264	19	3	-0.242	21	3
Narayanpur	-0.269	20	3	-0.241	20	3
Korba	-0.277	21	4	-0.248	22	3
Kabeerdham	-0.284	22	4	-0.254	23	3
Janjgir - Champa	-0.287	23	4	-0.236	19	3
Mahasamund	-0.287	23	4	-0.261	24	3
Bijapur	-0.307	25	4	-0.289	26	4
Raigarh	-0.32	26	4	-0.277	25	4
Jashpur	-0.376	27	4	-0.345	27	4

Figure 80 : Composite Environmental Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh for baseline (1961-1990) and midterm (2021-2050) RCP 4.5 scenario

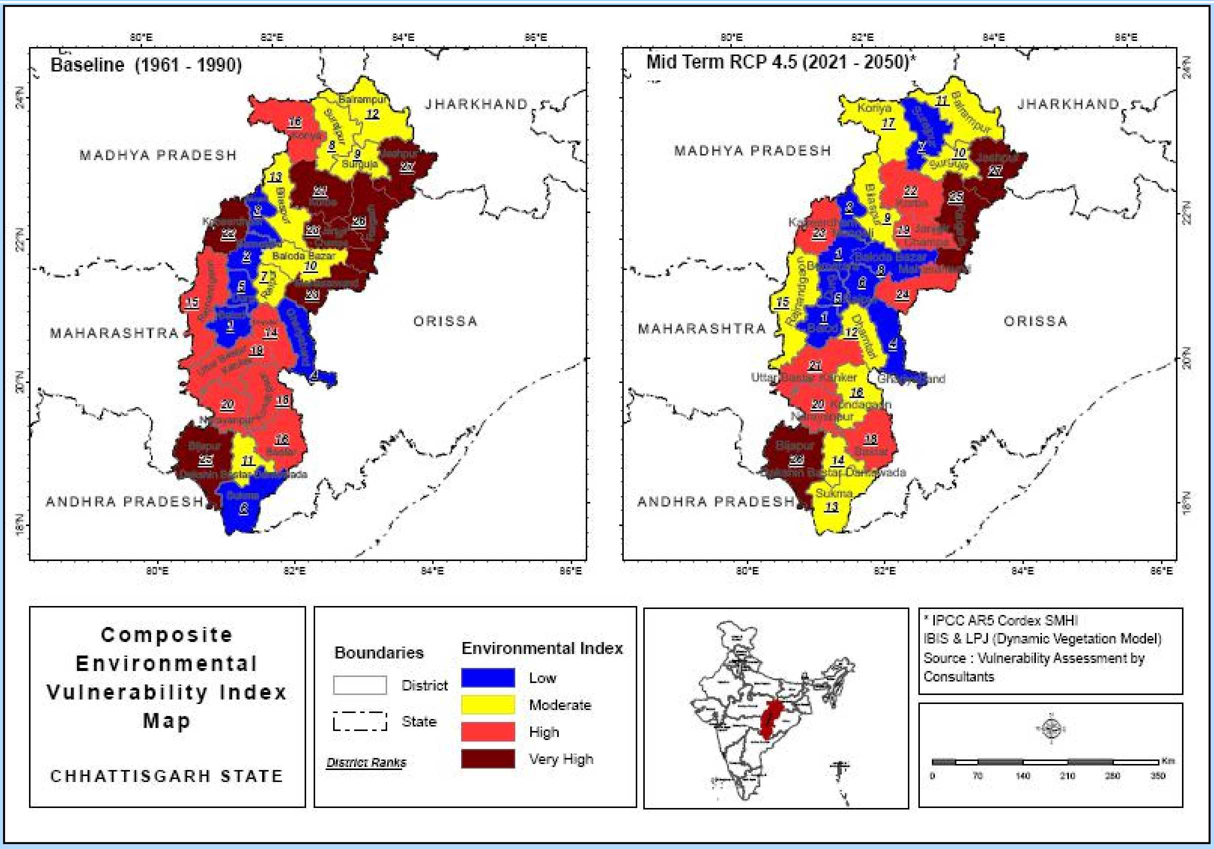


Figure 81 : Composite Environmental Vulnerability Index map showing low, moderate, high and very high cluster of districts in Chhattisgarh along with sub-indices vulnerability cluster map

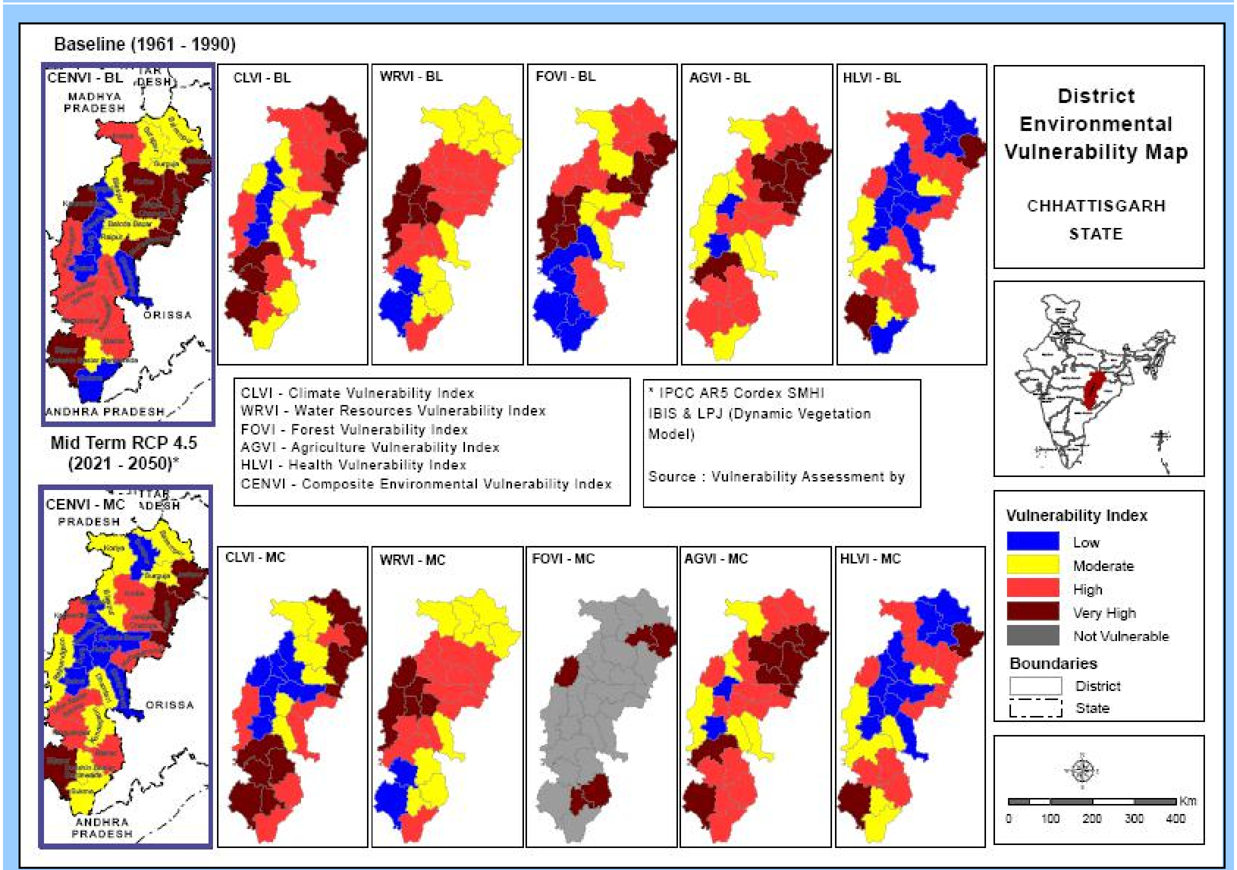
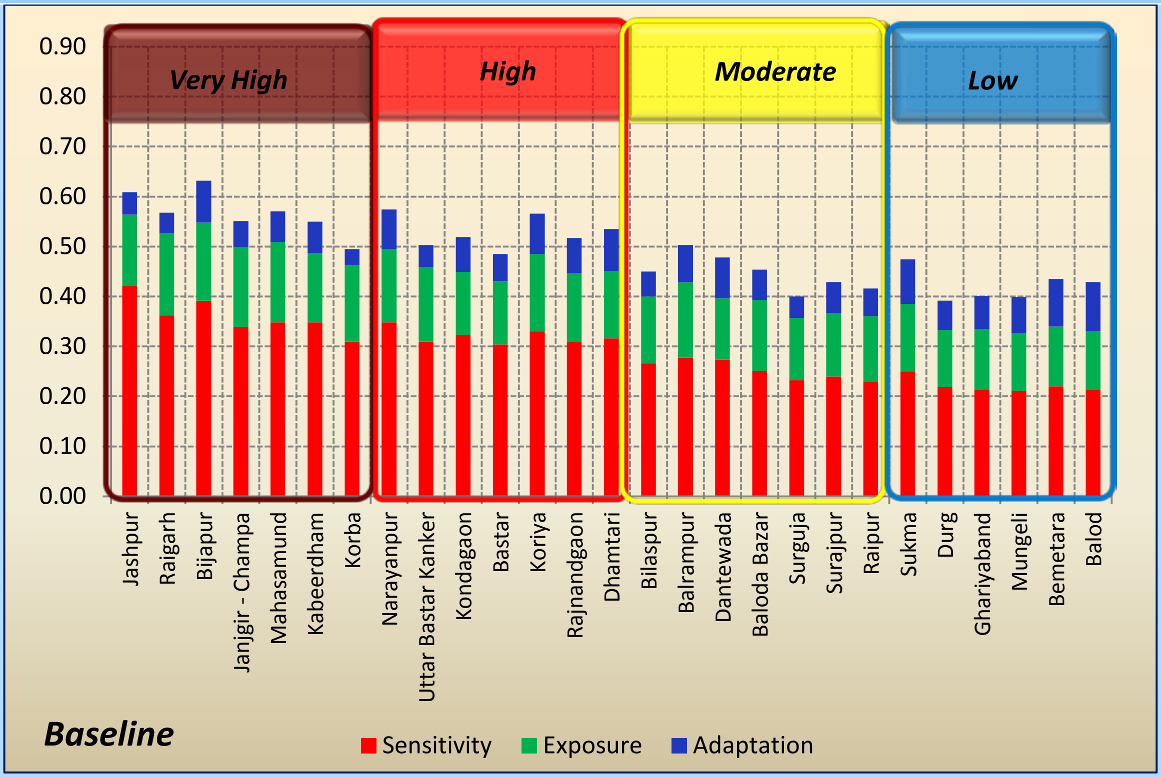


Figure 82 : Sub-Index values for Sensitivity, exposure and adaptive capacity showing district under low, moderate, high and very high vulnerability clusters (Composite Environmental Vulnerability Index)– baseline and midterm RCP 4.5 scenario



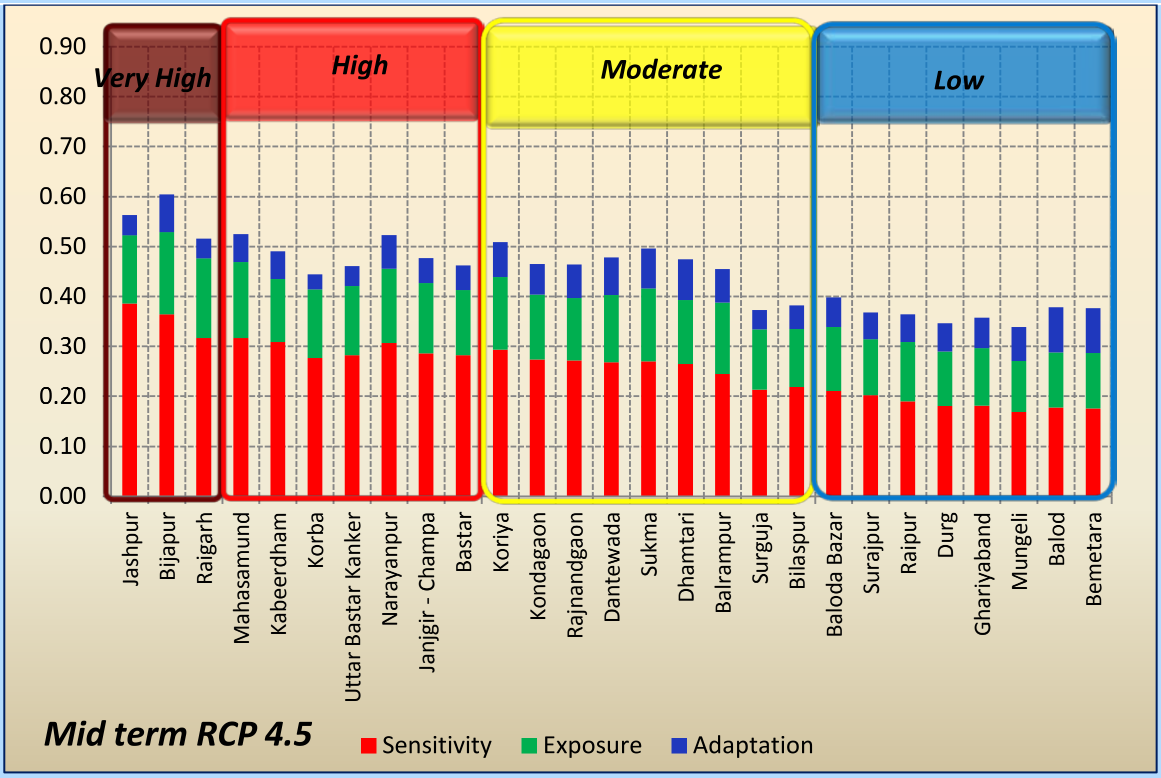


Figure 83 : Change in the number of districts under low, moderate, high and very high vulnerability clusters (CENVI)– baseline and midterm scenarios

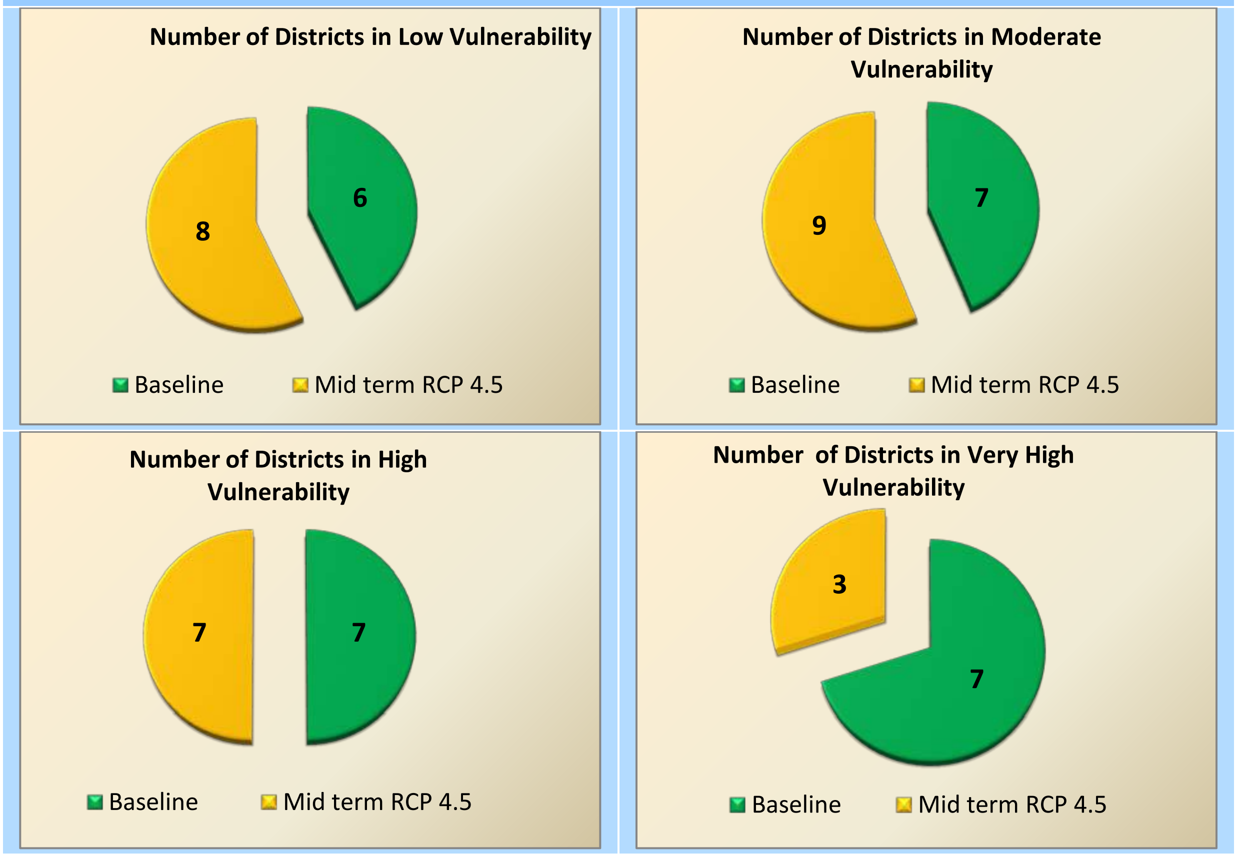


Figure 83 gives the number of districts falling in low, moderate, high and very high vulnerability category under baseline and midterm RCP 4.5 scenario. The green and yellow portions in the pie chart sum to 27 for baseline and midterm RCP 4.5 scenario respectively. There are 26% of districts (7 out of 27 districts) in moderate vulnerability cluster in the baseline which increases to 33% (9 districts)) in midterm. The percentage of districts in low vulnerable category also increases from 22% (2 districts) in the baseline to 30% (8 districts) in midterm as districts are moving from moderate clusters to low vulnerability clusters. While the percentage of districts in very vulnerable category decreases from 26% (7 districts) in the baseline to 11% (3 districts) in midterm as districts are moving from very high to high vulnerability clusters. Thus it can be inferred that composite environmental vulnerability (CENVI) of districts is projected to decrease towards midterm RCP 4.5 scenario compared to the baseline.

Chapter 6

Summary and Recommendations

Summary and Recommendations

Summary

Analysis based on the Composite Vulnerability Index (CVI) and drilled down indices of the districts for baseline and mid-term RCP 4.5 scenarios show that:

- Balod and Bemetara with ranks 1 and 2 respectively remains **least vulnerable** districts of Chhattisgarh for baseline and midterm RCP 4.5 scenario since:
  - They have higher adaptive capacity as compared to the other districts of the state which makes them well equipped to cope up with their exposure and/or sensitivity to climatic influences.
  - They have relatively higher economic capacity, level of urbanization is high, highest irrigation potential, high literacy rate, less exposure to extreme climatic events, and better access to drinking water, sanitation facilities, electricity, health, education and road infrastructure.
  - They have higher values with regards to both social and economic indices thus their socioeconomic vulnerability is also the least and also Composite Environmental vulnerability is low
- Mungeli, Baloda Bazar, Raipur, Durg, Ghariyaband, Bemetara and Balod remain low vulnerable districts in both baseline and midterm.
- In the baseline 3 districts namely Jashpur, Bijapur and Narayanpur are **very highly vulnerable**-cluster (4). to climate change since
  - They have very low values of Composite Vulnerability Index (CVI).
  - They have comparatively low adaptive capacity and show higher sensitivity and exposure to climate change with respect to the other districts.
  - They also have very high Social, Economic, Climate, Agriculture and Health sector vulnerabilities thus higher Composite Socioeconomic (CSEVI) and Composite Environmental vulnerability (CENVI).
  - Bijapur and Narayanpur are located in the South West while Jashpur is located in the North East of Chhattisgarh.
  - These districts remain highly vulnerable in midterm also.
- The overall composite vulnerability of districts is projected to be the same in midterm RCP 4.5 compared to the base scenario though change in the relative ranking amongst the districts is observed from BL to midterm.
  - There are no changes observed in the number of districts from baseline to midterm scenario for all 4 vulnerability categories-low, moderate, high and very high vulnerability cluster

Social Vulnerability Index (SVI) analysis results

- 2 districts namely Bijapur and Narayanpur are socially most vulnerable to climate change in the base period.
- It is low literacy rate, large proportion of child population, large percentage of rural households below poverty line, bad sanitation facilities, lack of access to electricity, households residing in kacchha houses, poor health infrastructure, low level of urbanization and high proportion of scheduled caste and scheduled tribes population which makes Bijapur and Narayanpur most vulnerable socially

- 10 districts namely, Bilaspur, Baloda Bazar, Janjgir-Champa, Ghariyaband, Raipur, Rajnandgaon, Bemetara, Durg, Dhamtari and Balod are the least vulnerable districts

Economic Vulnerability Index (ECVI)analysis results

- 8 districts are the most vulnerable namely Narayanpur, Kabeerdham, Bijapur, Uttar Bastar Kanker, Janjgir-Champa, Jashpur, Bilaspur and Mungeli in ECVI
- It is low per capita income (NDDP), less number of banks and poor credit deposit ratio which makes Narayanpur and Kabeerdham most vulnerable
- Baloda Bazar, Ghariyaband and Raipur are least vulnerable districts with rank 1.

Composite Socio Economic Vulnerability Index (CSEVI) analysis results

- 2 districts namely, Bijapur and Narayanpur have very high socio-economic vulnerability These 2 districts show low index values with respect to both social and economic indices and these districts also shows lower values in the CSEVI
- Baloda Bazar, Raipur, Ghariyaband, Dhamtari, Bemetara, Durg and Balod are the least vulnerable districts (cluster 1)

Agriculture Vulnerability Index (AGVI) analysis results

- 6 districts being located in North Eastern and South Western regions of Chhattisgarh have very highly agriculture vulnerability, namely, Jashpur, Janjgir-Champa, Korba, Surguja, Raigarh, and Uttar Bastar Kanker.
- It is low wheat and maize production per capita, larger proportion of wasteland, very less percentage of ground water and surface water irrigation to net sown area, greater share of agricultural and cultivators main workers to total main workers thus more dependence on agriculture income, etc which makes Jashpur and Janjgir-Champa most vulnerable in AGVI.
- Balod and Bemetara are the least vulnerable districts
- Overall Agriculture vulnerability of the Chhattisgarh districts is projected to increase slightly in the MC RCP 4.5 scenario compared to the baseline.

Forest Vulnerability Index (FOVI) analysis results

- Janjgir-Champa, Durg, Raigarh, Rajnandgaon and Jashpur have very highly forest sector vulnerability.
- Dhamtari, Bijapur and Narayanpur are least vulnerable districts in the baseline.
- The top five most vulnerable districts include Surguja, Jashpur, Dakshin Bastar, Bastar and Kabeerdham, considering both climate impacts (IBIS and LPJ)and current vulnerability

Water Resource Vulnerability Index (WRVI) analysis results

- 5 districts namely Kabeerdham, Bemetara, Durg, Raipur, Rajnandgaon have very low values of Water Resource Vulnerability Index (WRVI) thus belong to very high vulnerable category (cluster 4) compared to the other districts of Chhattisgarh
- It is less surface water and ground water availability per capita in monsoon and non monsoon months, high crop water stress in North East Monsoon season which make these districts most vulnerable to climate change.

  - 2 districts namely, Bijapur and Narayanpur are the least vulnerable districts
  - Overall Water Resource vulnerability of the Chhattisgarh districts is projected to be almost the same in the MC RCP 4.5 scenario compared to the baseline. Though change in the relative ranking amongst the districts is observed from BL to midterm.

Climate Vulnerability Index(CLVI) analysis results

  - 6 districts namely have Uttar Bastar Kanker, Balrampur, Jashpur, Narayanpur, Raigarh and Bijapur very high vulnerability to current climate since these 6 districts show greater exposure to extreme events with respect to the other districts.
  - 4 districts are in the low vulnerable category namely Balod, Mungeli, Bemetara and Durg.
  - the overall Climate vulnerability of the Chhattisgarh districts is projected to increase for some districts in the MC RCP 4.5 scenario while decrease for others compared to the baseline

Health Vulnerability Index(HLVI) analysis results

  - Jashpur and Bijapur are very highly vulnerable lying in North East and South West of Chhattisgarh.
  - It is high infant mortality rate, high diarrhoea cases and greater sensitivity to Anopheles Mosquito causing Malaria, which makes them most vulnerable
  - 12 districts, Bilaspur, Balrampur, Surajpur, Baloda Bazar, Ghariyaband, Surguja, Sukma, Balod, Mungeli, Raipur, Bemetara and Durg are the least vulnerable districts

Composite Environmental Vulnerability Index analysis results

  - Cluster results show that 7 districts namely, Jashpur, Raigarh, Bijapur, Janjgir-Champa, Mahasamund, Kabeerdham and Korba have very high composite environmental vulnerability. They also have very high climate, water resource, health and agriculture vulnerability
  - Sukma, Durg, Ghariyaband, Mungeli, Bemetara and Balod are the least vulnerable districts. These districts also have very low climate, health and agriculture vulnerability.
- Composite environmental vulnerability (CENVI) of districts is projected to decrease towards midterm RCP 4.5 scenario compared to the baseline.
  - There are 26% of districts (7 out of 27 districts) in moderate vulnerability cluster in the baseline which increases to 33% (9 districts)) in midterm. The percentage of districts in low vulnerable category also increases from 22% (2 districts) in the baseline to 30% (8 districts) in midterm as districts are moving from moderate clusters to low vulnerability clusters.
  - While the percentage of districts in very vulnerable category decreases from 26% (7 districts) in the baseline to 11% (3 districts) in midterm as districts are moving from very high to high vulnerability clusters.

CVI as one overall figure is good for easy comparison for a non-specialist or policy-makers; there is a trade-off between the component sub-indices when they are viewed in aggregated form. Therefore to add some depth to the overall assessment, drill down sub-indices is also provided to understand about the composition of vulnerability

Recommendations

The Composite Vulnerability Index (CVI) would be a useful for the policy makers of the state government to make changes at district level. By looking at the CVI ranks they can make out which district is the most vulnerable. Thus they would be able to bring suitable policies and actions for combating climate change impacts in that district. If the policy makers want to know the reasons as to why that district is vulnerable or the indicators which makes that district vulnerable, then they can look at the drilled down indices provided which would help them know the sectors or the indicators in the districts which are most impacted by climate change .

For Water experts of the State, Heads and ministries of Water Department WRVI (Water resources Index) would be useful as they can know the districts where they need to work on more than others, make more investment in the most vulnerable ones, and thus plan the overall investment in the state. Similarly for Agriculture, Health, Forest, Environment, Finance, Climate, and Socio Economic experts and Departmental heads of the State respective indices would be of help to plan investment, make necessary changes and policies in their respective departments.

Adaptation is not a one-time effort but an ongoing cycle of preparation, response, and revision Adaptation to global warming and climate change is a response to climate change that seeks to reduce the vulnerability of natural and human systems to climate change effects. Addressing the impacts and combating climate change assumes top priority in our country in the context of its influence on the poorest in the society. Large reductions in green house gas emissions are achievable if the right policies are put in place. Policies suggested to combat the effects of climate change in Chhattisgarh are:

- To develop price for GHG emissions like carbon taxes and emissions trading.
- To reduce subsidies that may indirectly increase GHGs such as those to energy or transport.
- Use of energy efficient equipments in buildings facilitate access to cleaner energy, use of renewable energy and propagate energy efficiency.
- Facilitate access to Clean Development Mechanism and carbon markets in the industries, renewable energy, forestry and municipal solid waste (MSW) sectors.
- Advocating climate-risk assessment as a requirement for all long-term infrastructure projects, as well as the exploration of new and innovative financial measures to promote income-diversification in rural areas.
- Investments in development infrastructure in terms of physical developments should be planned flexibly so that climate change impacts can be accommodated. For example, to make sure that school buildings and health facilities can cope with intense rain, and the expected higher temperatures.
- Greater support for agricultural research is recommended and extension to promote sustainable models of dry land farming.
- Improving access to resources and reducing poverty.
- Improving education and information by establishment of training programs for extension officers though Universities Training programs for farmers in water efficiency. Establish training hubs for dissemination of information on climate change.
- Plant trees to moderate temperature increases. Increase planting on non-forest land.

- Improving early warning systems and flood hazard mapping for storms.
- Improving water use efficiency and making changes to water allocation in the state.
- Support integrated water resources planning and management in river basins of the state.
- Focused attention and importance should be given to realize the full renewable energy potential of the state, i.e. hydro, solar, wind, biomass-based power plants and hybrid combinations (e.g. wind-solar) as well.
- Switching to energy-efficient lighting in all Government buildings need to be given an additional thrust.
- Increase reforestation and afforestation activities in degraded forest.
- Create new or strengthens existing institutions (e.g., establishing committees, identifying mechanisms for sharing information across institutional boundaries, training staff responsible or policy development).

The analysis of the pattern of vulnerability of districts in Chhattisgarh to climate change has shown that generally the South Western and North Eastern districts are more vulnerable to climate change than the other districts. This is explained by the greater exposure to drought and climate extremes as well as low levels of technology and socio-economic and infrastructure development. Vulnerability can result from environmental, social or economic issues. Hence a single policy for all of the districts would not be the solution. Rather, judicious and different combinations of policies for different districts could help them in moving closer to achieving sustainability. Nevertheless, this exercise can be regarded as a modest attempt to assess the preparedness of the districts of Chhattisgarh to cope up with the vulnerability issues and board the development pathway.

Without doubt, we have to change the way we live. Global Warming, Greenhouse Effect, Climate Change they are all happening right now. The rate of climate change is now so fast we are struggling to adapt our philosophies, economics, and lifestyle to slow it down. We must alter the way we live or we will suffer staggering consequences.

Potential Adaptation Measures to safeguard forests

The impacts of climate change on forest ecosystems and biodiversity are long-term and irreversible, requiring adaptation. Climate change impacts could include; forest die-back, loss or shift of biodiversity, increased occurrence of pests and fire and ultimately loss of ecosystem services and livelihoods. Further, there is a lag in the forest response to changing climate and long gestation periods are involved in adaptation responses. Thus there is a need to plan adaptation measures immediately to build resilience in forest ecosystems and forest dependent communities, to enable adaptation to projected changes in climate and enhanced vulnerability. However, currently there is no research on developing adaptation strategies in the forest sector. The Chhattisgarh Forest Department could integrate the components of the Greening India Mission to build resilience to projected climate change at species and ecosystem level and also build the resilience of forest dependent communities. The Government of India has formulated a large Greening India Mission aimed at mitigation and adaptation to enhance ecosystem services such as carbon sequestration and storage, biodiversity conservation and provision of biomass and NTFPs. The mission aims at responding to climate change by a combination of adaptation and mitigation measures, in particular adaptation of vulnerable species/ecosystems to the changing climate and adaptation of forest dependent communities. In the absence of dedicated research on developing adaptation strategies to build resilience in forest ecosystems, the forest department could adopt a set of 'win-win' adaptation strategies. There are no scientific studies to recommend specific adaptation measures suitable for different vulnerable forest types and regions. Some of the potential measures could include the following.

- Climate change considerations should be incorporated into Working Plans and forest management programmes of the forest department. Some of the potential 'win-win' adaptation measures to be adopted in the forest sector are presented below.
- Critical forest corridors should be identified in Chhattisgarh and regular afforestation activities should be integrated with the components of the Greening India Mission to revive these corridors and to promote migration of flora and fauna.
- Conservation of biodiversity of primary forests, as biodiversity rich forests is less vulnerable to climate change.
- Promotion of natural regeneration and mixed species planting in the afforestation programmes, particularly in the districts projected to be impacted by climate change in this study. There is a need to identify and incorporate temperature and pest tolerant tree species in the afforestation programmes.
- Effective fire prevention and management to cope with likely increased occurrence of fire and pests particularly in the deciduous forests of Chhattisgarh.
- Reduced forest fragmentation by conserving contiguous forest patches since contiguous forests facilitate migration of plant and animal species.
- Anticipatory planting of tree species across latitudinal and longitudinal gradient, in particular identify species from warmer districts and incorporate them in districts projected to become warmer.
- Research for development on temperature, pest and fire tolerant species and silviculture practices to cope with changing climate and its impacts is necessary.