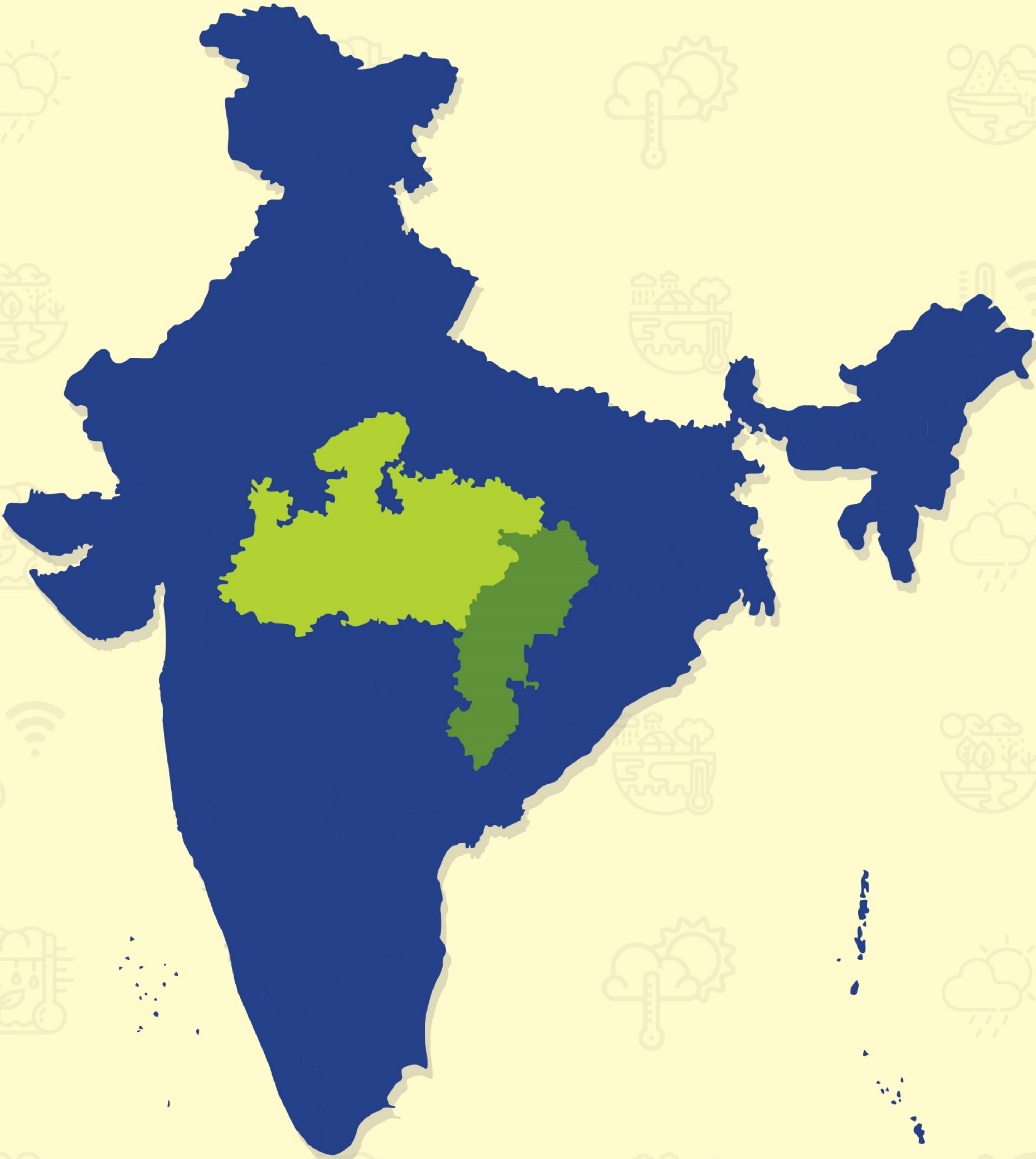
DISTRICT-LEVEL CHANGES IN CLIMATE:

HISTORICAL CLIMATE AND CLIMATE CHANGE PROJECTIONS FOR THE CENTRAL STATES OF INDIA



District-Level Changes in Climate: Historical Climate and Climate Change Projections for the Central States of India

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Executive Summary

Background and motivation: The impacts of climate variability, climate change, and extreme events are visible globally and in India. The Global Climate Risk Index 2021 ranks India seventh, considering the extent to which India has been affected by the impacts of weather-related loss events (storms, floods, heatwaves, etc.). The index signals that repercussions of escalating climate change are exacerbating and can no longer be ignored. The Government of India and state governments are committed to reducing the vulnerability of communities and ecosystems to climate change and building resilience to climate change risks. A good understanding of the historical climate trends and climate change projections at a district scale is essential in this endeavour as much of the decision-making, planning, and implementation happens at the district level.

Objective: This study analyses the historical climate and projects the temperature and rainfall of the two central Indian states: Chhattisgarh and Madhya Pradesh.

Methodology: Historical climate analysis and climate change projections have been made at a district level for the two central states of India. Historical climate analysis for the recent 30-year period (1991–2019) and climate change projections for the 2030s (2021–2050) have been made using the India Meteorological Department (IMD) data and CORDEX model outputs. Climate change projections for summer maximum and winter minimum temperatures, kharif season rainfall projections and rainfall variability (coefficient of variation), the occurrence of heavy rainfall events (51–100 mm/day and >100 mm/day), and rainfall deficient years (<20% of long period average rainfall) have been analysed under two representative concentration pathways (RCP): RCP 4.5 (medium emission) and RCP 8.5 (high emission) scenarios. The findings from this study on future climate in the 2030s are presented as change compared to the historical period for all the districts of central India.

Findings: Historically, temperature and rainfall have increased, and rainfall variability is high in the central Indian states. Climate change projections indicate an overall warming of both summer and winter minimum temperatures, an increase in the number of rainy days (>2.5 mm rainfall/day), and an increase in the number of heavy rainfall events across almost all the districts of central India. Rainfall variability shows mixed trends, and rainfall deficient years are projected to decline.

Temperature

Summer maximum and winter minimum temperatures are projected to increase in both the central Indian states by 1^{0}C to 2^{0}C.

Rainy days

The number of rainy days is projected to increase compared to the historical period in the 2030s in almost all the districts of central India. The increase is by 1 to 7 days in Chhattisgarh and 1 to 6 days in Madhya Pradesh under the RCP 4.5 scenario. The increase is by 1 to 9 days in Chhattisgarh and 1 to 6 days in Madhya Pradesh under the RCP 8.5 scenario.

Monsoon rainfall

Rainfall during the kharif (June to September) season is projected to increase in the 2030s in all the districts of central India compared to the historical period. The projected increase in the kharif season rainfall is by 1% to 23% under the RCP 4.5 scenario and 5% to 23% under the RCP 8.5 scenario. The rabi season rainfall is negligible in Madhya Pradesh; therefore, it has not been analysed. In Chhattisgarh, it is projected to increase by 5% to 40% under the RCP 4.5 scenario and 12% to 41% under the RCP 8.5 scenario.

Rainfall variability

The variability (coefficient of variation) of kharif and rabi season rainfall shows mixed trends in the 2030s across the districts of central India compared to the historical period. The variability of the kharif season rainfall is projected to largely increase in Chhattisgarh. In Madhya Pradesh, it is projected to largely decline under both climate scenarios. The variability of the rabi season rainfall is projected to decline across all the districts of Chhattisgarh under both climate scenarios.

Heavy rainfall events

An increase in high-intensity (51–100 mm/day) and very high-intensity (>100 mm/day) rainfall events is projected in the 2030s across all the districts of central India compared to the historical period. The increase in high-intensity rainfall events per annum is by one to two events under the RCP 4.5 scenario and one to three events under the RCP 8.5 scenario. The increase in very high-intensity rainfall events is largely by one to two events under the RCP 4.5 scenario and two to three events under the RCP 8.5 scenario.

Rainfall deficient years

A decline in rainfall deficient years is projected in the 2030s across many of the districts of central India compared to the historical period. The decline in rainfall deficient years is by 1 to 4 years out of the 30 years under both RCP 4.5 and RCP 8.5 scenarios in Chhattisgarh. In Madhya Pradesh, the decline is by one to four years under the RCP 4.5 scenario and 1 to 5 years under the RCP 8.5 scenario in a majority of the districts.

Discussion: It is evident from the study that in the future, climate in the districts of central India will be different from the historical climate. This has implications for water availability and management, agriculture, forest and biodiversity, and health and infrastructure. It also underpins the need for integrated strategies to combat multiple hazards, floods due to heavy rainfall or dry spells and droughts at other times. Historically, states have focused on drought planning and management, but a wetter future demands plans to integrate flood management.

Recommendations: The district-level climate change assessment for the central states of India provides an understanding of the historical climate and climate projections for the 2030s. States need to integrate this information into the State Action Plans on Climate Change, which are currently under revision. Additionally, states need to institute climate risk assessments. These assessments account for exposure and vulnerabilities in addition to the hazard mapping done in this study. Such climate risk mapping will help states buffer the loss and damage that are likely to incur from extreme climate events.

Contents

1. Introduction

Climate change results in higher temperatures, intense rainfalls, and an increase in the frequency of extreme weather events—floods, droughts, and heatwaves (IPCC, 2014). It has already impacted communities, livelihoods, and infrastructure and is projected to worsen in the coming years and decades.

The Intergovernmental Panel on Climate Change (IPCC; 2021) defines *climate* in a narrow sense as 'the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years.' *Climate variability* is defined by the IPCC as 'deviations of climate variables from a given mean state (including the occurrence of extremes, etc.) at all spatial and temporal scales beyond that of individual weather events.'

So far, the bulk of the efforts as well as investments have focused on mitigation to address climate risks. This is because mitigation is believed to have global benefits, while adaptation is seen to address local problems that need to be tackled by individual countries. India is already facing and is likely to face severe climate-related hazards, and given our vulnerabilities, the impacts may be dire. Adaptation has not received the same degree of attention as mitigation in India. Currently, India's adaptation initiatives are typically embedded in development programmes across a range of sectors. Adaptation needs to be addressed in a bottom-up manner, progressing from the local level to the national level. Adaptation strategies need to be implemented at the local, regional, and national levels because climate hazards and impacts vary in nature and severity across regions. Consequently, the capacity to manage and deal with incidents differ across populations, regions, and economic sectors. The lack of a comprehensive strategy and ground-level efforts is a serious drawback in the fight against climate change in India. Data on climate variability and change at different temporal and spatial scales would definitely aid in formulating implementable mitigation and adaptation measures.

Climate models are valuable tools as they provide the required information on changes in climate over different temporal and spatial scales.

1.1 Why model climate outputs?

Scientists use climate models to understand complex interactions between various components of the Earth system. These models are an extension of weather forecasting models, and they simulate the climate of our planet on decadal to centennial timescales. Specifically, they can project changes in average conditions over the coming decades for a region and help determine whether the predicted changes are climate variations or the result of imposed changes such as changes in land-use pattern and increase in greenhouse gases, aerosols, and land-use change. Climate models provide crucial information for the adaptation and mitigation of climate change. Simulations and predictions of climate models help us understand the consequences of not reducing emissions. They help us foresee what is at stake, what might be lost, and the cost of inaction when viewed from different regional and sectoral perspectives.

Climate models also inform climate adaptation strategies. Detailed, location-specific climate information can protect infrastructure by ensuring that it is robust enough to withstand climate change impacts in location, construction, and management.

1.2 The need for district-level climate model outputs

Climate data gathering at the district level is essential for risk planning, developing coping strategies, and adaptation. To frame climate change policies, data on the impacts of climate change across different spatial and temporal scales and sectors are needed. For assessing the impacts of climate change on a sector, for instance, on crops such as rice, wheat, maize, millet, and pulses, there is a need to consider the variations in climate and the multiplicity of conditions under which they are grown. This is because different approaches are adopted for growing a particular crop in different regions based on climate and traditional practices.

Similarly, assessing the impact of climate on health requires data on temperature and rainfall extremes, and fisheries requires data on rainfall, sea level, salinity, and so forth. The demand for climate information at different scales is multifold. Further, the State Action Plans on Climate Change are being revised. These require climate information to be presented and plans prepared, taking into consideration the projected changes in climate. In this context, data on district-level changes in temperature and precipitation find utility. They can be the basis for State Action Plans on Climate Change (SAPCC) and assessing climate risks and impacts on different sectors, regions, and communities. This directly feeds into the information needs for developing adaptation strategies.

This report is intended for the use of state- and district-level government officials, policymakers, and non-specialists. It therefore avoids extensive scientific and technical details and statistical analysis. The report presents critical information on changes in temperature and rainfall with the aim of sensitising and building awareness on climate change. The focus is on the short-term period (2021–2050) at a district level to aid decision-making in the short term, thus providing a valuable resource to the state- and district-level planners and development administrators.

2. Methodology

The study analyses historical climate information and projects climate for a future period using climate models. The data sources, models, climate scenarios, and methods are presented in this segment.

2.1. Historical climate analysis

Two key climate variables, temperature and rainfall, have been analysed. Gridded daily datasets for grids of 0.25° x 0.25° (~25 km X 25 km) for rainfall (Pai et al., 2014) and 1.0°x 1.0° (~100 km X 100 km) daily temperature datasets (Srivastava et al., 2009) for temperature from the Indian Meteorological Department (IMD) have been used. The present-day or historical data spans the 30-year period of 1990–2019.

Temperature has been analysed for the summer season (March to May) and the winter season (December to February). The occurrence of heatwaves has also been analysed for this 30-year period.

Heatwaves: Heatwaves—based on departure from the normal temperature—have been computed following the IMD's criteria[1]. The IMD declares a heatwave when the departure from the normal temperature is 4.5°C to 6.4°C. A severe heatwave is declared when the departure from the normal temperature is >6.4°C.

Rainfall has been analysed for the kharif season (June to September) and the rabi season (December to February). During these two seasons, the variability of rainfall has also been analysed by computing the coefficient of variation (CV). Additionally, the number of rainy days, heavy rainfall events, and rainfall deficient years have been analysed.

Rainy day: A *rainy day*, according to the IMD, is defined as any day receiving >2.5 mm rainfall.

Heavy rainfall events: Based on the amount of rainfall received per day (in mm) during the kharif season, heavy rainfall events have been analysed considering three categories:

- Low-intensity rainfall: Less than 50 mm/day
- High-intensity rainfall: 51–100 mm/day
- Very high-intensity rainfall: More than 100 mm/day

Rainfall deficient years: Considering the total quantum of rainfall received during the kharif season, rainfall deficient years have been analysed. Following the criterion defined by IMD[2]:

- Years that receive <20% of rainfall, compared to the long period average of rainfall during the kharif season, are categorised as rainfall deficient years.

[1]https://internal.imd.gov.in/section/nhac/dynamic/FAQ_heat_wave.pdf
[2]https://mausam.imd.gov.in/imd_latest/monsoonfaq.pdf

2.2. Climate change projections

Climate science is continuously advancing as groups involved in modelling worldwide are constantly updating and incorporating better spatial resolution, new physical processes, and biogeochemical cycles. The Coupled Model Intercomparison Projects (CMIP) is a forum where different modelling groups coordinate. The fifth assessment report (AR5) of the IPCC featured the fifth generation of CMIP—the CMIP5. In India, the high-resolution regional climate modelling work of CMIP5 is coordinated by the Centre for Climate Change Research (CCCR) at the Indian Institute of Tropical Meteorology, Pune.

CCCR provides high resolution downscaled projections for different climate scenarios under the Coordinated Regional Climate Downscaling Experiment (CORDEX) South Asia programme. The CORDEX regional models are driven by data from the atmosphere-ocean coupled general circulation model runs conducted under the CMIP5 (Taylor et al., 2012) for the representative concentration pathway (RCP) scenarios.

In this study, CORDEX model outputs were used for projecting temperature and rainfall at the district level. An ensemble mean from 15 bias-corrected CORDEX South Asia simulations were used for making climate change projections. The IPCC recommends the use of ensemble means for achieving more reliable and quantitative information on future climate compared to a single model run.

- Model resolution: 0.5° x 0.5° grid resolution (~50 km x 50 km)
- Time period: Short term (2021–2050), referred to as the 2030s
- Climate scenarios: Moderate emissions scenario (RCP 4.5) and high emissions scenario (RCP 8.5)

All data in this analysis were first re-gridded to a common 0.25° x 0.25° (~25 km x 25 km) resolution, which is the resolution of historical rainfall data from the IMD. Changes in temperature and rainfall during the projected period were computed as a difference between the model-simulated ensemble average of the projected 30-year period (2021–2050) and the 30-year historical period (1990–2019).

District-level averages of climatic variables were prepared using outputs from the re-gridded data. The mean value for a district was obtained by considering the mean of multiple grid points that might cover a district. Only grid points that fall fully within a district or those with at least 60% of the area falling within a district were considered for computing the mean. If a district fell within only one grid cell, then that single grid cell value was used for analysis. All the analyses were performed using these district means, using gridded (latitude–longitude) information of the districts.

Temperature projections: Both summer maximum (March to May) temperature, potentially causing heat stress, and winter minimum (December to February) temperature, critical for human comfort and winter crops, were analysed. The changes during the projected period (2021–2050) under the two climate scenarios, relative to the historical period (1990–2019), were analysed.

Heatwaves: As the incidence of heatwaves is typically limited to a few districts, the analysis of heatwaves was done for a few selected districts, using the historical record of heatwaves in a state. The criterion defined by the IMD, described in Section 2.1, was adopted, and the change during the projected period, relative to the historical period, was computed.

Rainfall projections: The number of rainy days, the magnitude of rainfall during the kharif and rabi seasons, heavy rainfall events, and rainfall deficient years were analysed, and changes, compared to the historical period (1990–2019), are presented. Rainfall variability was also computed for the projected period, and changes relative to the historical period are presented.

The projected climate (2021–2030) was compared with the historical climate (1990–2019) to estimate the magnitude of climate change. This is aligned with the World Meteorological Organization's approach—the use of 30-year averages for representing the climatology of the present-day (1990–2019) and short term (2021–2050)[3]. This is unlike the United Nations Framework Convention on Climate Change (UNFCCC) and IPCC reports, where a comparison of the projected climate is with pre-industrial periods.

2.3. Limitations of the study

In this report, we have provided climate change projections for RCP 4.5 (moderate emissions) and RCP 8.5 (high emissions) scenarios to provide a range of possibilities. The results presented in this report are likely to have some uncertainty due to the coarse resolution of the projected climate change data, which is derived from CORDEX data at 0.5° x 0.5° resolution. This resolution is inadequate for decision-making at a farm, village, or sub-watershed level but adequate for decision-making at the district level. Further, since we have not downscaled this data to a finer resolution, the sub-grid variability within the 0.5° x 0.5° resolution grid is not captured in the analysis, which is likely to introduce some uncertainty. However, the direction of changes in temperature, rainfall, and extreme events are largely in agreement with the literature at the global, South Asia, and national levels.

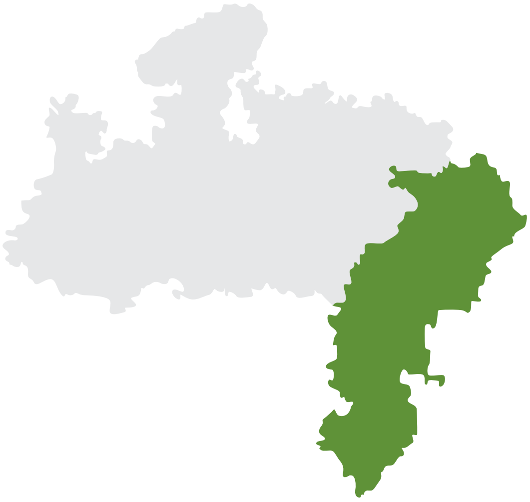
2.4. The organisation of the report

This report is for the central states of India: Chhattisgarh and Madhya Pradesh. The state chapters are organised as follows:

- Historical trends in temperature and rainfall
- Climate change projections at the district level, in the form of spatial maps and graphs
- Summary of projected changes in temperature and rainfall
- Key highlights at the district level of temperature, rainfall, and extreme events as tables in the Appendix

[3]https://public.wmo.int/en/media/news/new-two-tier-approach-%E2%80%9Cclimate-normals%E2%80%9D

3. Chhattisgarh



The state of Chhattisgarh has an area of 135,192 sq. km and a population of 25.55 million, which is predominantly rural according to 2011 Census. It is bordered by Madhya Pradesh in the north-west, Uttar Pradesh in the north, Jharkhand in the north-east, Maharashtra in the south-west, Telangana in the south, and Odisha in the south-east. The northern and southern regions of the state are hilly. The central region is a fertile plain. About 46% of the state is covered by forests, and roughly three-fourths is under agriculture. The state has 27 districts, and a tropical hot and humid climate, with average annual rainfall varying from 1,100 mm to 1,700 mm and the temperatures ranging between 11°C and a scorching 47°C. The state has thermal power plants in Bilaspur and Korba districts and several dams for hydropower generation and irrigation.

Chhattisgarh is prone to loss and damages caused by several natural hazards. The majority of the state (more than 80%) is drought-prone, with five districts exhibiting a high probability of drought occurrence (Baloda Bazar, Bemetara, Mungeli, Kabirdham, and Raipur). Similarly, 17 out of the 27 districts have moderate to high flood proneness because of very high-intensity rainfall distributed over a short period of time. According to the Vulnerability Atlas of India 2019, about 18.6% of the state is at moderate risk for earthquakes. The four districts of Sukma, Raigarh, Bastar, and Bijapur have reported residual impacts of cyclonic storms occurring in the Bay of Bengal. Furthermore, such storms are accompanied by lightning, which has resulted in more than 1,000 fatalities over a period of 5 years (2011–2015). Heatwaves are also a common occurrence, with temperatures soaring over 45°C in the summer months.

These characteristics make Chhattisgarh climate-sensitive, underpinning the need for climate information. Climate data could serve as the basis for hazard mapping and risk assessment of various regions, sectors, and communities to ensure climate-proof development.

3.1. Historical climate

Temperature and seasonal rainfall—kharif and rabi—at the district level for the historical period spanning 1990–2019 are presented in subsequent sections.

3.1.1. Trends in temperature

Chhattisgarh recorded a moderate warming of 0.31°C to 0.62°C in the summer maximum temperature and 0.1°C to 0.32°C in the winter minimum temperature during the historical period. Figure 3-1 presents the mean summer maximum and winter minimum temperatures in Chhattisgarh during the historical period.

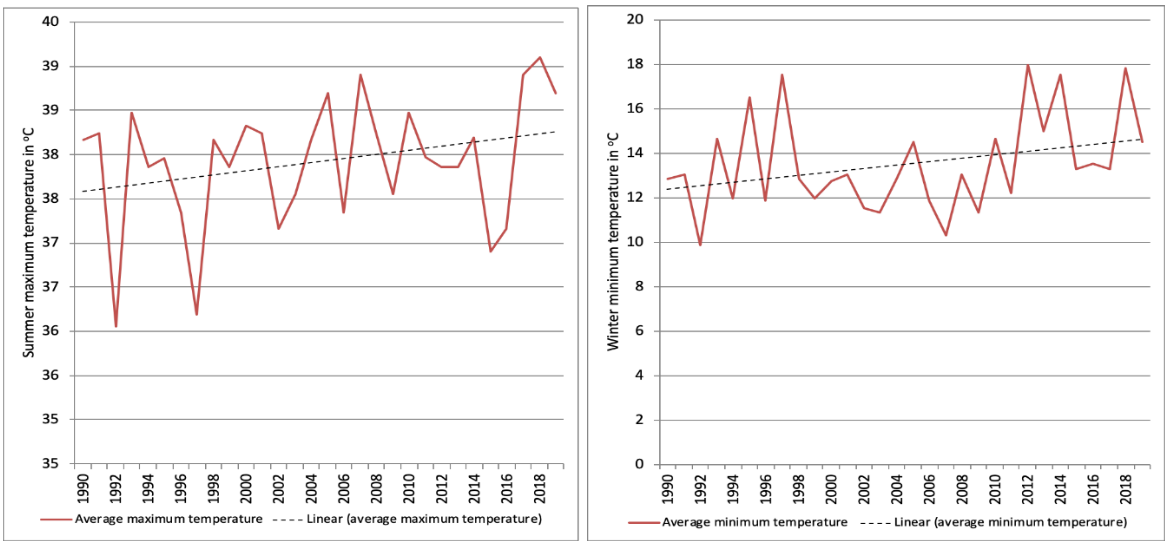


Figure 3-1: Mean summer maximum and winter minimum temperatures in Chhattisgarh during the historical period (1990–2019)

3.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual rainfall, in the range of 5% to 15%, was recorded in a majority of the districts. In the kharif season, which is the main monsoon season, an increase in rainfall >10% and up to 20% was recorded in the eastern and northern districts of the state. Likewise, an increase in the rabi season rainfall was recorded, with an increase in the range of 1% to 10%, in a majority of the districts. Figure 3-2 presents the mean annual rainfall in Chhattisgarh during the historical period.

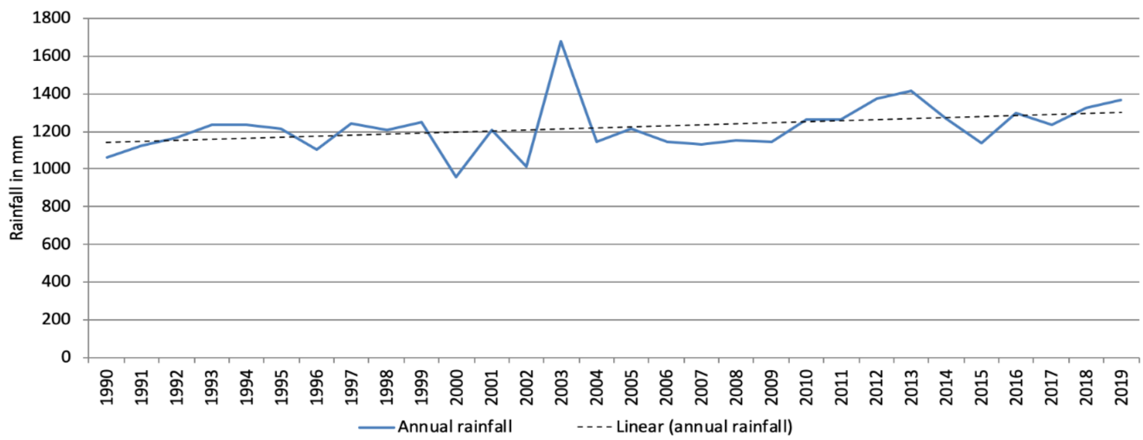


Figure 3-2: Mean annual rainfall in Chhattisgarh during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 16% in Dhamtari, Korba, Mungeli, and Narayanpur to 31% in Balrampur (Figure 3-3). The rabi season rainfall variability was in the range of 57% to >100%, indicating complete failure in some districts (Figure 3-3). However, it is important to note that rainfall during the rabi season is not significant in Chhattisgarh.

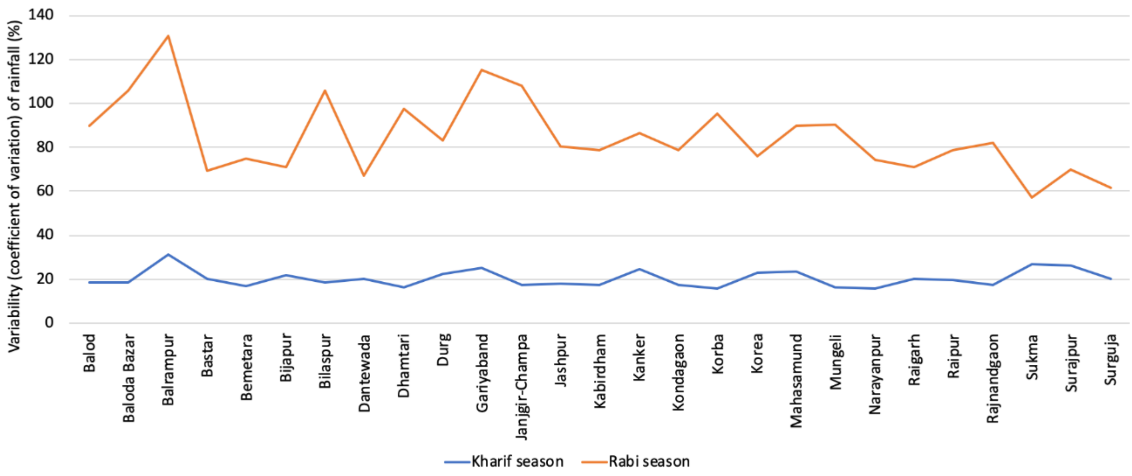


Figure 3-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

3.2. Climate change projections

Temperature and rainfall have been projected for the 2030s under two representative concentration pathways (RCP)—RCP 4.5 (medium emission) and RCP 8.5 (high emission) scenarios. For details on the scenarios and models, refer to Section 2.2.

3.2.1. Temperature projections

The projected changes in the summer maximum and winter minimum temperatures for all the districts of Chhattisgarh are presented in **Error! Reference source not found.**.

The summary of projected changes between 2021–2050 and 1990–2019 is as follows:

Climate scenarios	Summer maximum	Winter minimum
RCP 4.5	Increases by 1^{0}C to 1.5^{0}C	Increases by 1^{0}C to 2^{0}C
RCP 8.5	Increases by 1^{0}C to 2^{0}C	Increases by 1^{0}C to 2^{0}C

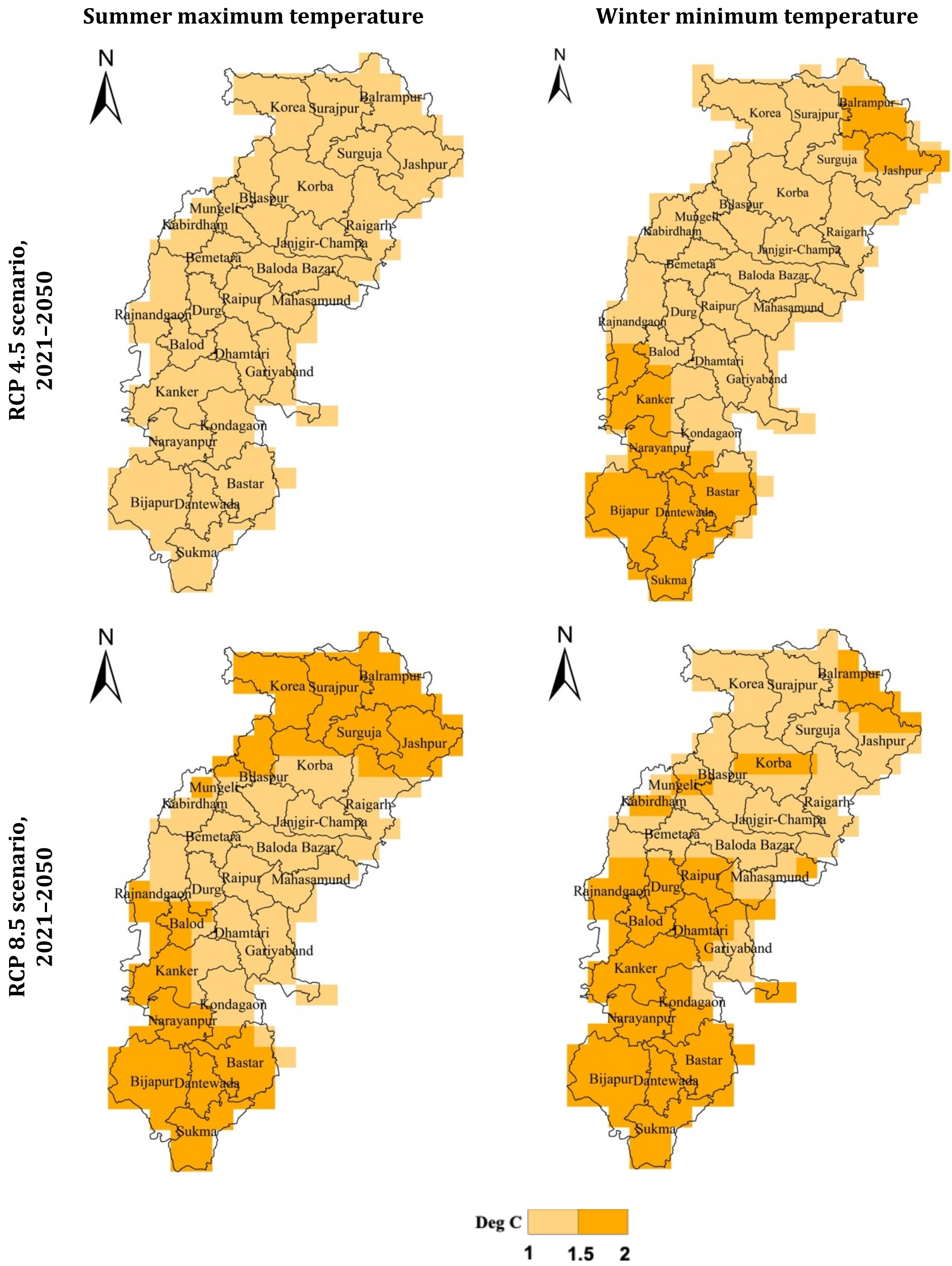


Figure 3-4: Projected changes in summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019). The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

3.2.1.1 Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 1, a heatwave analysis of the Raipur district was conducted.

The analysis of temperature during the projected period of the 2030s shows that there would only be decline in the number of heatwaves (departure from the normal temperature is 4.5°C to 6.4°C) and a decline in the number of severe heatwaves (departure from the normal temperature is >6.4°C), as categorised by the India Meteorological Department (IMD) under both RCP 4.5 and RCP 8.5 scenarios (Figure 3-).

- 'Heatwaves' are projected to decline by approximately 21% under both RCP 4.5 and RCP 8.5 scenarios.
- 'Severe Heatwaves' are projected to increase by 33% and 39% under RCP 4.5 and RCP 8.5 scenarios, respectively.

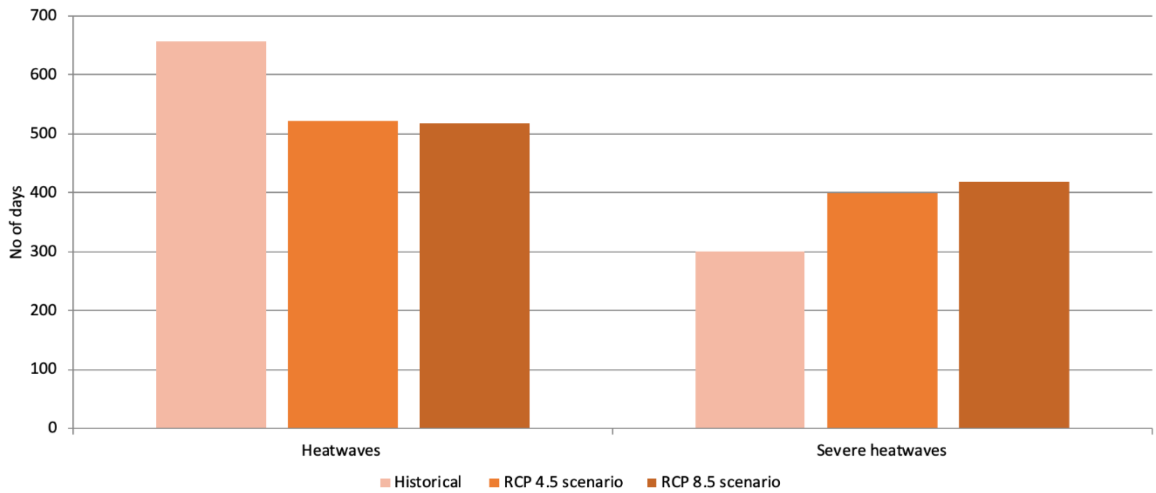


Figure 3-5: The number of heatwaves during the historical (1990–2019) and projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

3.2.2 Rainfall projections

3.2.2.1. Number of rainy days

According to the IMD, a *rainy day* is defined as a day with rainfall of 2.5 mm or more. Analysis of rainy days under historical and projected periods shows that there will be an increase in the number of rainy days during the projected period in all the districts (Figure 3-). The number of rainy days during the historical period and the projected 2030s under both RCP 4.5 and 8.5 scenarios is presented in Appendix 3-3. The total number of rainy days that ranged from 1373 to 2221 days over the 30-year period under the historical period increases to 1574 to 2259 days under the RCP 4.5 scenario and 1590 to 2295 days under the RCP 8.5 scenario during the projected 2030s. The increase per annum is as follows:

RCP 4.5 scenario: Increases by 1 to 7 days annually in all the districts, except Balod
RCP 8.5 scenario: Increases by 1 to 9 days in all the districts, with an increase of 5 or more days per annum in eight districts—Baloda Bazar, Balrampur, Bastar, Bijapur, Kondagaon, Korea, Janjgir-Champa, and Jashpur.

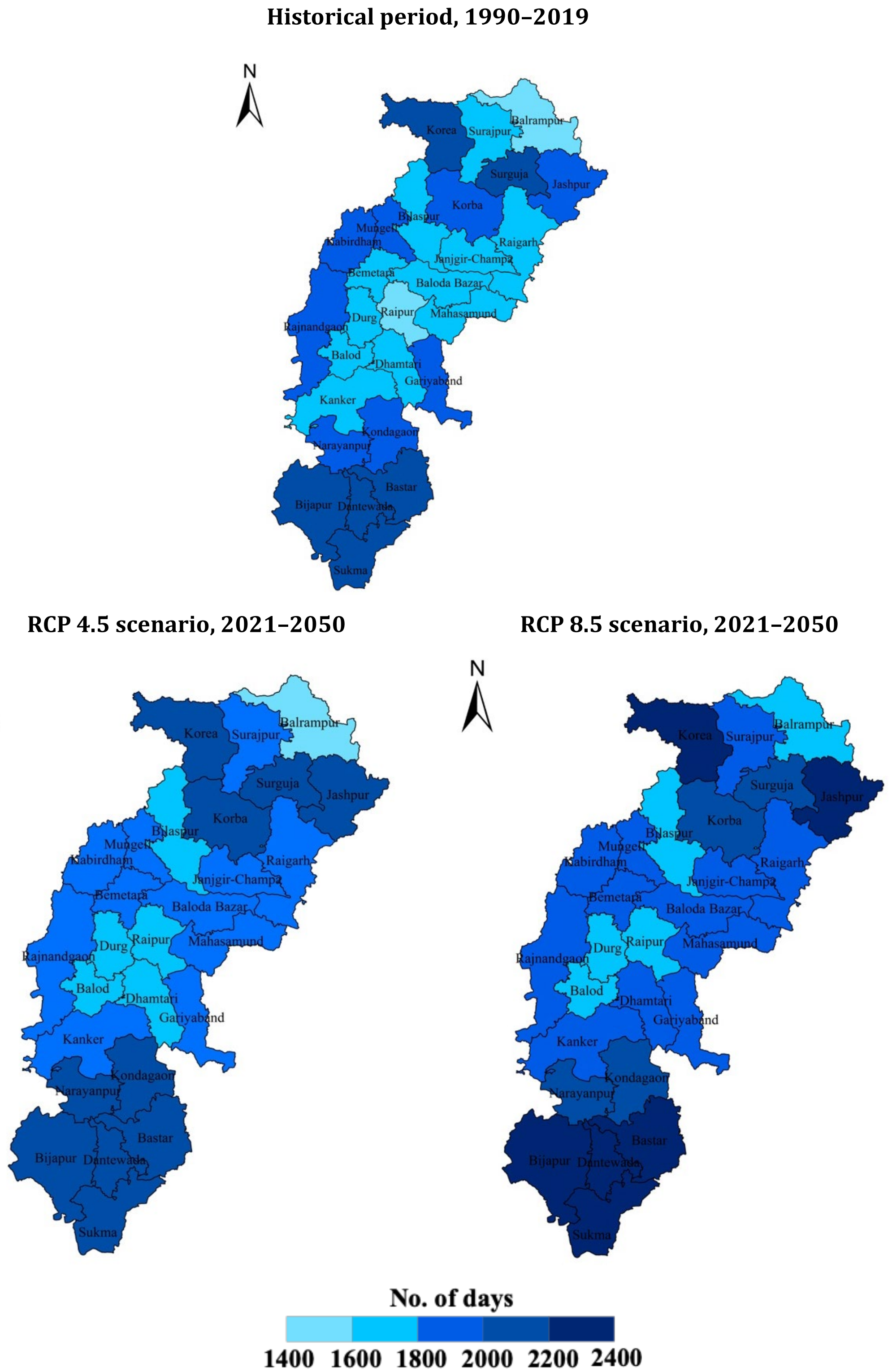


Figure 3-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

3.2.2.2. Mean rainfall and rainfall variability during the kharif season

The kharif season rainfall is projected to increase in all the districts under both climate scenarios. Figure 3- presents district-wise changes in the kharif season rainfall, and Figure 3- presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 5% in Bastar to 23% in Korba	Increases in 19 districts by 1% to 13% and declines in eight districts by 1% to 6%
RCP 8.5	Increases in all the districts, from 10% in Sukma to 23% in Korba	Increases in 19 districts by 1% to 10% and declines in eight districts by 1% to 9%

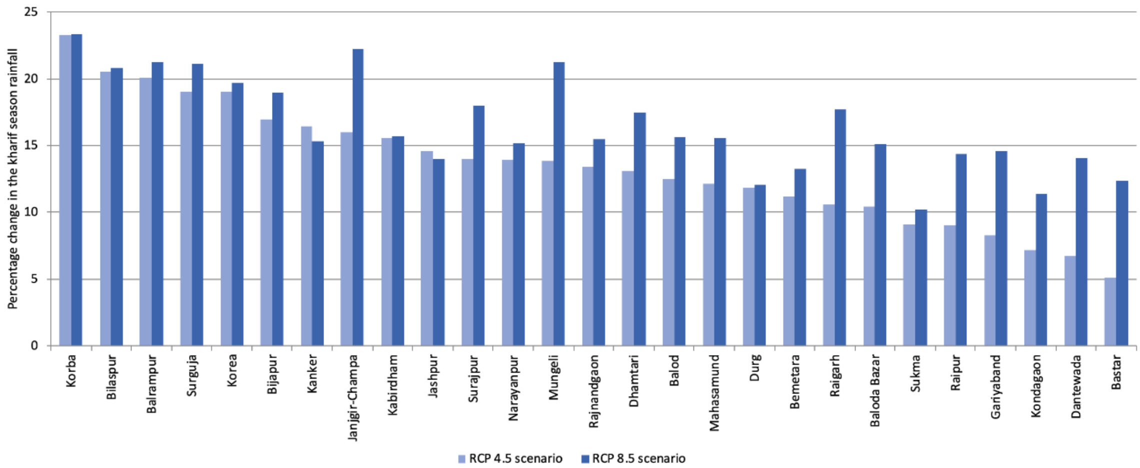


Figure 3-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

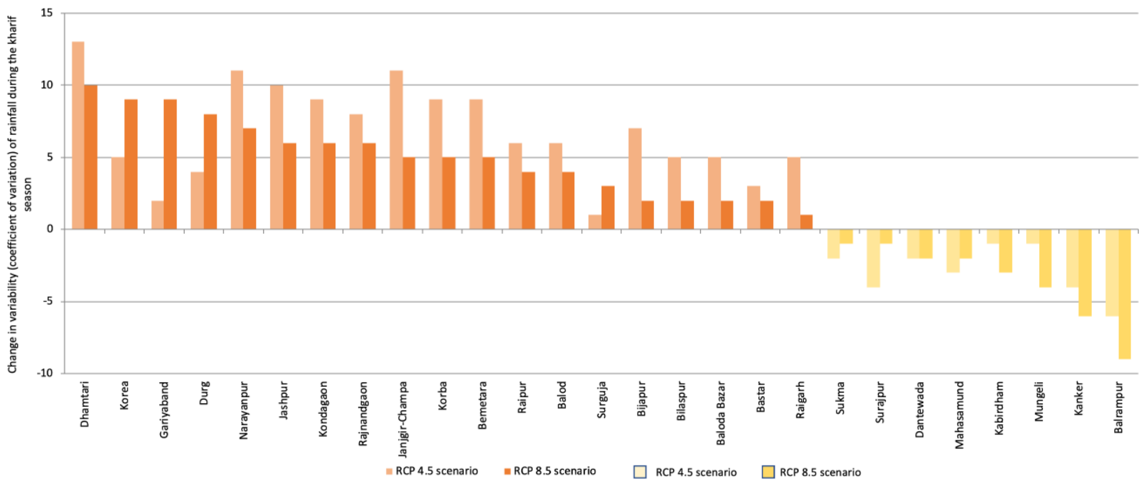


Figure 3-8: Projected changes in the variability of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

3.2.2.3. Mean rainfall and rainfall variability during the rabi season

The rabi season rainfall is projected to increase in all the districts under both climate scenarios. Figure 3 presents district-wise changes in the rabi season rainfall, and Figure 3- presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 5% in Dhamtari to 40% in Kondagaon	Declines in all the districts by 4% to 54%
RCP 8.5	Increases in all the districts, from 12% in Bijapur to 41% in Gariyaband	Declines in all the districts by 3% to 59%

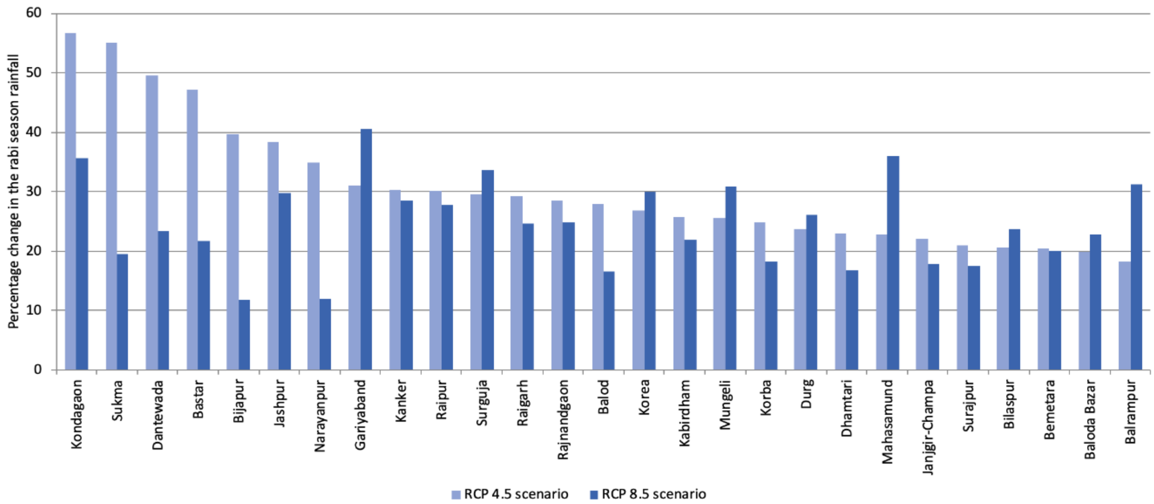


Figure 3-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

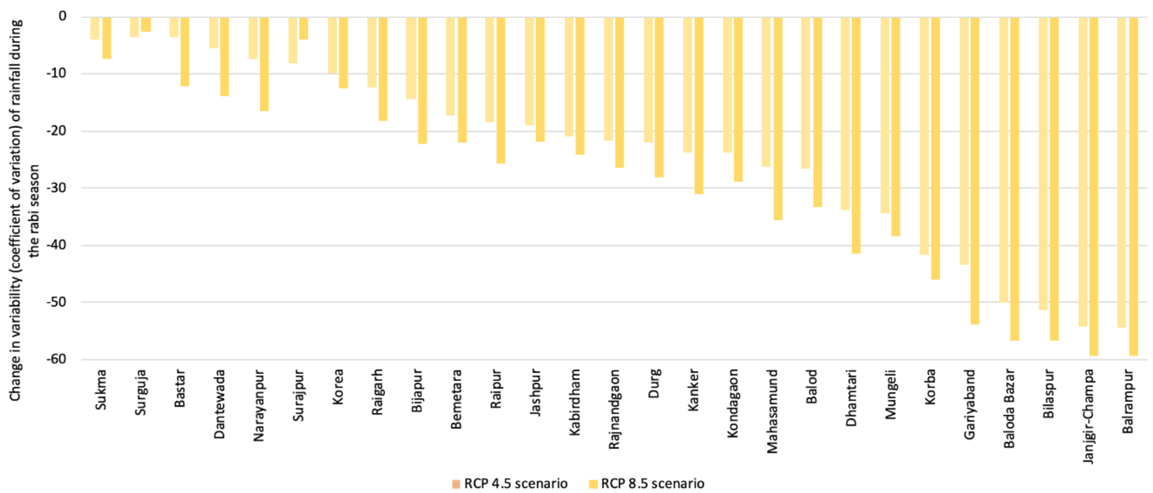


Figure 3-10: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

3.3 Heavy rainfall events and rainfall deficient years

Rainfall during the kharif season was analysed by considering the intensity of rainfall under three categories: <50 mm/day; 51–100 mm/day, termed 'High' intensity; and >100 mm/day, termed 'Very High' intensity. The number of such events was computed for the historical period and projected 2030s under the two climate scenarios, and the change was computed for all the districts of Chhattisgarh.

High-intensity rainfall events (Figure 3-11)

The total number of high-intensity rainfall events increases from 59 to 128 days during the historical period (1990–2019) to 92 to 148 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 103 to 175 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: An increase in high-intensity rainfall events by one event is projected in all the districts of Chhattisgarh.

RCP 8.5 scenario: An increase in high-intensity rainfall events by one to two events is projected in all the districts of Chhattisgarh. An increase by two events is projected for Balrampur, Bilaspur, Dantewada, Kabirdham, Kondagaon, Korba, Kanker, Mahasamund, Rajnandgaon, Surguja, and others.

Very high-intensity rainfall events (Figure 3-12)

The total number of very high-intensity rainfall events increases from 5 to 50 days during the historical period (1990–2019) to 34 to 64 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 45 to 88 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: An increase in very high-intensity rainfall events by one event is projected in all the districts of Chhattisgarh.

RCP 8.5 scenario: An increase in very high-intensity rainfall events by one to two events is projected in all the districts of Chhattisgarh. An increase per annum by two events is projected for Balod, Bilaspur, Dantewada, Jashpur, Kondagaon, Korba, Korea, Mahasamund, Mungeli, Rajnandgaon, and a few other districts.

Rainfall deficient years (Figure 3-13)

Rainfall deficient years computed considering the rainfall during the kharif season are projected to decline in all the districts of Chhattisgarh under both climate scenarios. The number of rainfall deficient years declines from 6 to 12 years during the historical period to 5 to 11 years under the RCP 4.5 scenario and 5 to 12 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: A decline is projected in 21 districts by 1 to 4 years. Of the 21 districts, in 13 districts, including Bastar, Kondagaon, Raipur, Rajnandgaon, Durg, Janjgir-Champa, Mahasamund, Mungeli, Kanker, and Sukma, a decline by 3 to 5 years is projected. No change is projected in the remaining districts.

RCP 8.5 scenario: A decline is projected in 11 districts by 1 to 4 years. Of the 11 districts, in five districts—Balrampur, Kondagaon, Janjgir-Champa, Mahasamund, and Kanker—a decline by 3 to 4 years is projected. No change is projected in the remaining districts.

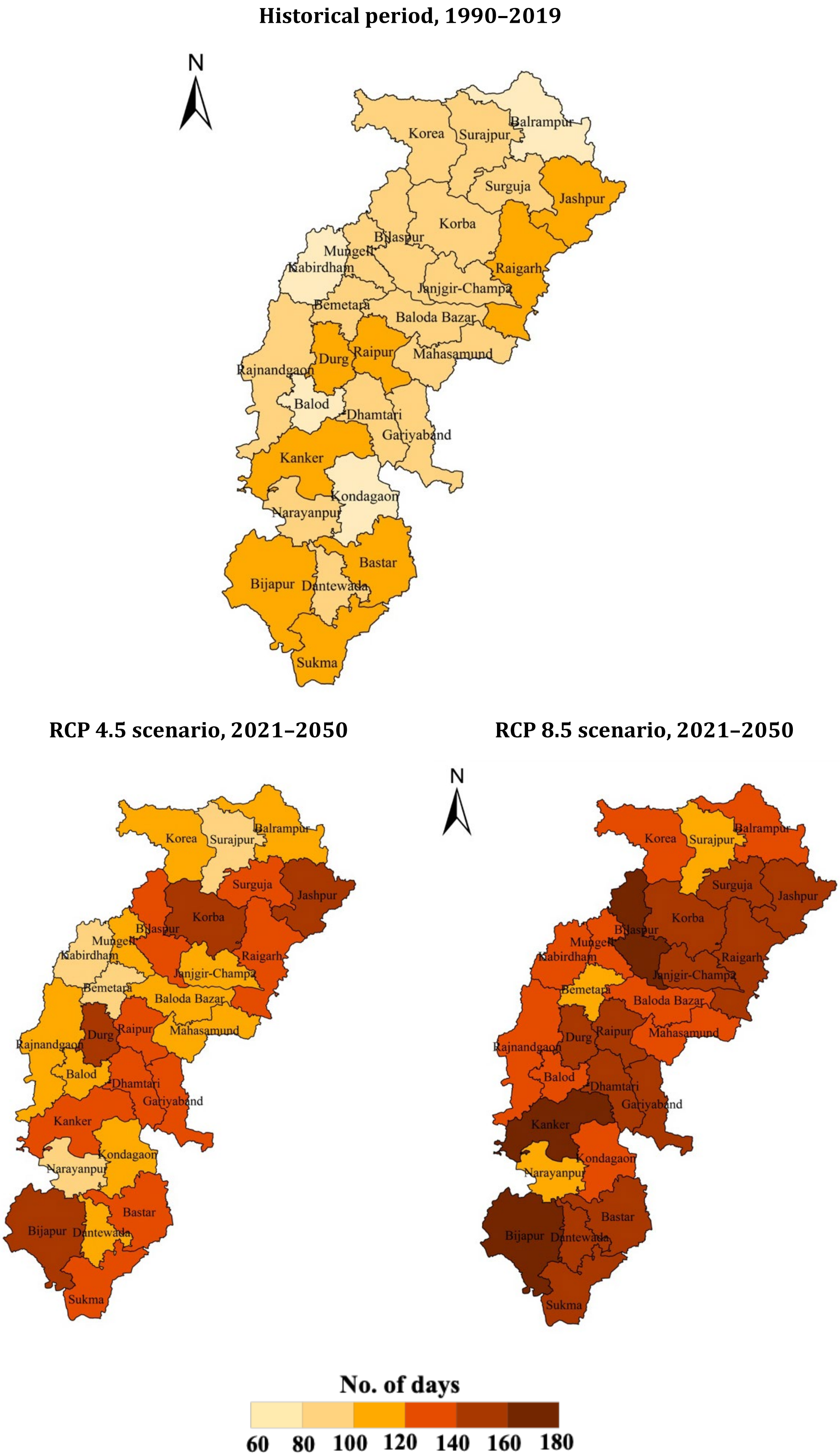


Figure 3-11: The number of high-intensity rainfall events during historical (1990–2019) and projected periods (the 2030s) under RCP 4.5 and RCP 8.5 scenarios

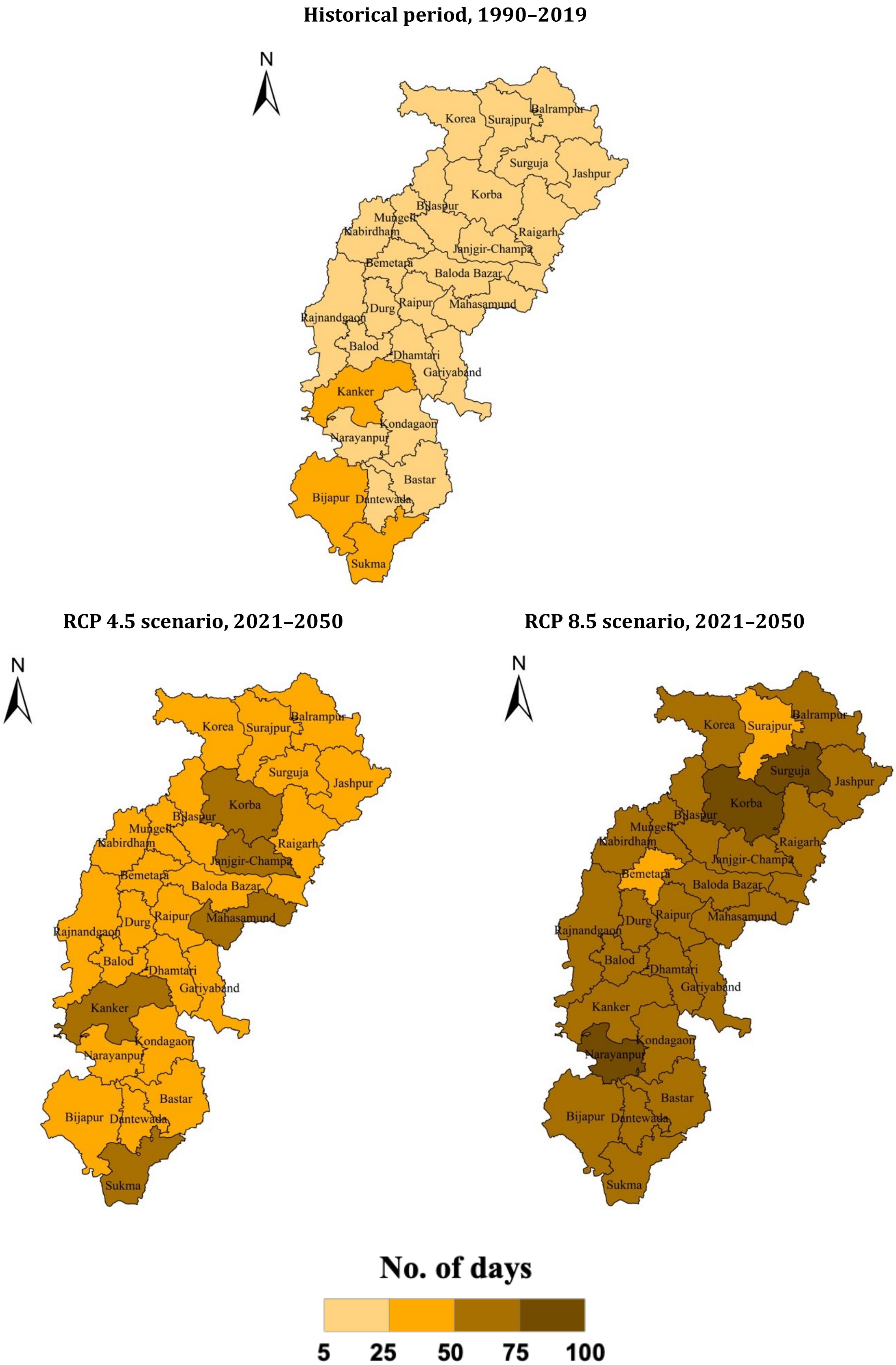


Figure 3-12: The number of very high-intensity rainfall events during historical (1990–2019) and projected periods (the 2030s) under RCP 4.5 and RCP 8.5 scenarios

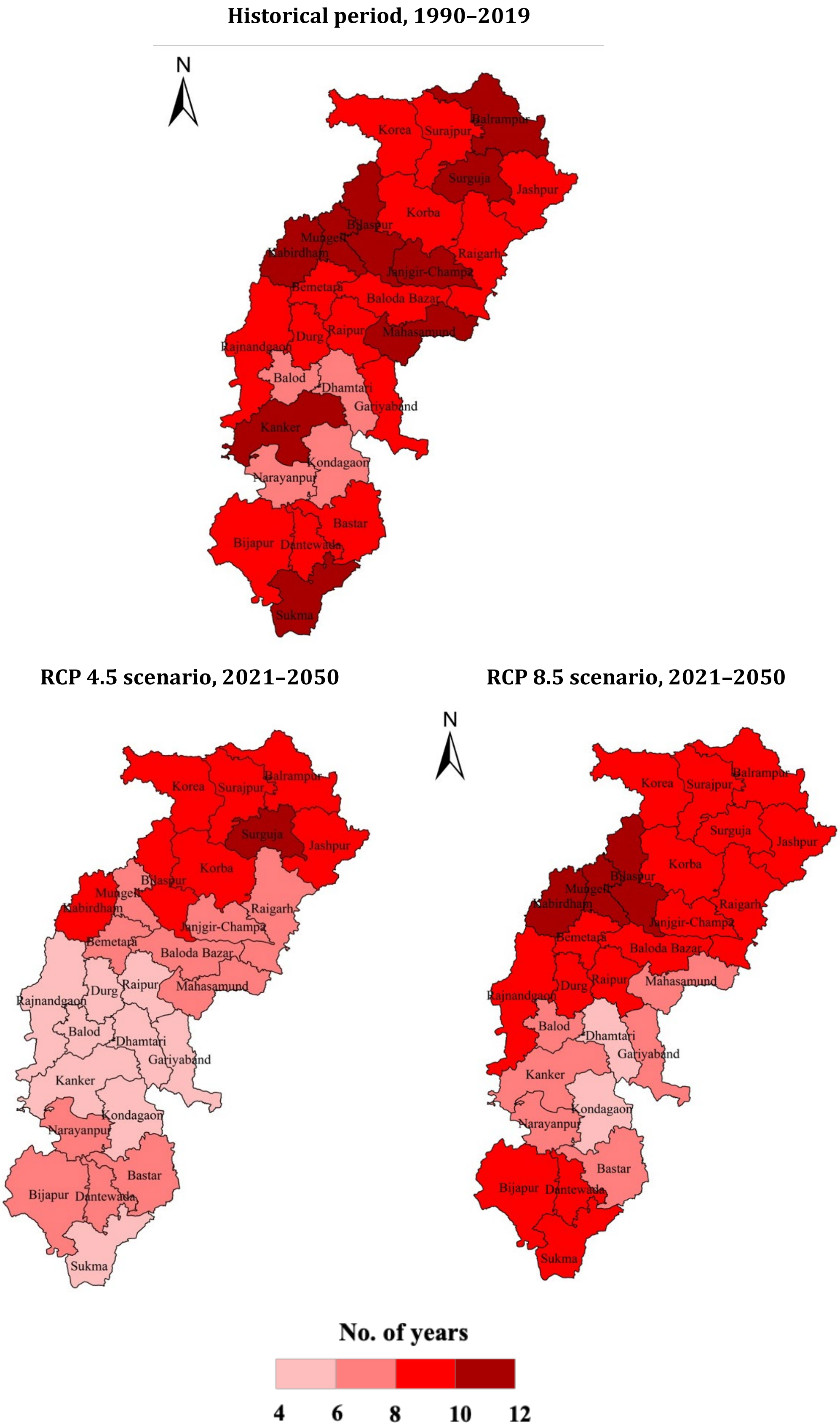


Figure 3-13: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

3.4. The summary of projected changes in the climate for Chhattisgarh

The temperature is projected to increase in the short term (2021–2050) in all the districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 3-1).

- The summer maximum temperature is projected to warm by 1°C to 1.5°C under the RCP 4.5 scenario and 1°C to 2°C under the RCP 8.5 scenario. Likewise, the winter minimum temperature is also projected to warm by 1°C to 2 °C under both RCP 4.5 and RCP 8.5 scenarios.

Rainfall is projected to increase in the short term (2021–2050) in all the districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 3-2).

There is a notable increase in rainfall of 20% or more in the northern districts of Surguja, Balrampur, and Bilaspur.

Rainfall variability during the kharif season is projected to increase in most districts but is projected to decline in a few districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019).

- The projected increase in rainfall variability is ≥10% in the Dhamtari, Narayanpur, Jashpur, and Janjgir-Champa districts. The decline in variability is projected in the Dantewada, Kabirdham, Mahasamund, Mungeli, Kanker, Balrampur, Sukma, and Surajpur districts.

The number of rainy days is projected to increase in all the districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 3-3).

- The increase annually during the projected 2030s (2021–2050) is in the range of 1 to 7 days under the RCP 4.5 scenario and 1 to 9 days under the RCP 8.5 scenario.
- The increase is >5 days per annum in Kondagaon, Balrampur, and Baloda Bazar under both scenarios. In Bastar, Bijapur, Jashpur, Korea, and Janjgir-Champa, an increase of >5 days per annum is projected under only the RCP 8.5 scenario.

An increase in the occurrence of heavy rainfall events is projected in all the districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 3-4).

- The increase per annum is by one to two events, with an increase by two events projected in Rajnandgaon, Mahasamund, Korba, Kondagaon, Bilaspur, Dantewada, and a few other districts under both climate scenarios.

Rainfall deficient years are projected to largely decline under both RCP 4.5 and RCP 8.5 scenarios in a majority of the districts by 1 to 5 years compared to the historical period (1990–2019; Appendix 3-4).

Appendix

Appendix 3-1: Changes in temperature under climate scenarios

Districts	Change in temperature (^{o}C) during the 2030s (2021–2050) compared to the historical period (1990–2019)			
	Summer maximum temperature		Winter minimum temperature	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Balod	1.2	1.7	1.3	1.9
Baloda Bazar	1.2	1.4	1.1	1.2
Balrampur	1.0	1.6	1.2	1.7
Bastar	1.3	1.6	1.6	1.9
Bemetara	1.1	1.3	1.4	1.5
Bijapur	1.3	1.7	1.6	1.8
Bilaspur	1.3	1.6	1.2	1.7
Dantewada	1.6	1.7	1.6	1.9
Dhamtari	1.4	1.6	1.3	1.7
Durg	1.3	1.4	1.1	1.4
Gariyaband	1.4	1.6	1.2	1.7
Janjgir-Champa	1.1	1.3	1.3	1.6
Jashpur	1.2	1.7	1.6	1.8
Kabirdham	1.1	1.6	1.2	1.4
Kanker	1.1	1.7	1.6	1.7
Kondagaon	1.2	1.6	1.6	1.8
Korba	1.3	1.4	1.2	1.3
Korea	1.2	1.4	1.3	1.7
Mahasamund	1.1	1.4	1.3	1.8
Mungeli	1.3	1.6	1.3	1.5
Narayanpur	1.2	1.7	1.6	1.7
Raigarh	1.2	1.4	1.3	1.7
Raipur	1.2	1.5	1.2	1.4
Rajnandgaon	1.3	1.7	1.3	1.4
Sukma	1.3	1.8	1.7	1.9
Surajpur	1.1	1.4	1.2	1.5
Surguja	1.3	1.7	1.4	1.6

Appendix 3-2: Changes in rainfall under climate scenarios

Districts	Changes in rainfall (%) during the 2030s (2021–2050) compared to the historical period (1990–2019)					
	Annual rainfall		Kharif season rainfall		Rabi season rainfall	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Balod	14	17	13	16	11	17
Baloda Bazar	12	17	10	15	19	23
Balrampur	20	18	20	21	31	31
Bastar	4	11	5	12	12	22
Bemtara	12	13	11	13	9	20
Bijapur	16	16	17	19	8	12
Bilaspur	21	24	20	21	11	24
Dantewada	10	13	7	14	16	23
Dhamtari	14	16	13	17	5	17
Durg	13	14	12	12	14	26
Gariyaband	8	13	8	15	31	41
Janjgir-Champa	17	21	16	22	13	18
Jashpur	20	20	15	14	35	30
Kabirdham	14	16	16	16	12	22
Kanker	16	16	16	15	23	28
Kondagaon	9	12	7	11	40	36
Korba	20	22	23	23	14	18
Korea	21	20	19	20	26	30
Mahasamund	9	13	12	16	24	36
Mungeli	13	18	14	21	21	31
Narayanpur	13	16	14	15	8	12
Raigarh	11	15	11	18	19	25
Raipur	12	14	9	14	18	28
Rajnandgaon	17	15	13	15	16	25
Sukma	10	11	9	10	13	19
Surajpur	14	17	14	18	11	18
Surguja	18	18	19	21	23	34

Appendix 3-3: The total number of rainy days (>2.5 cm/day) during the historical period (1990–2019) and the projected 2030s (2021–2050)

Districts	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Balod	1632	1641	1767
Baloda Bazar	1613	1837	1878
Balrampur	1373	1574	1590
Bastar	2125	2258	2295
Bemetara	1776	1867	1890
Bijapur	2055	2153	2264
Bilaspur	1687	1729	1777
Dantewada	2221	2259	2241
Dhamtari	1661	1738	1801
Durg	1616	1635	1755
Gariyaband	1846	1954	1984
Janjgir-Champa	1771	1826	1959
Jashpur	2000	2134	2210
Kabirdham	1869	1925	1951
Kanker	1778	1837	1810
Kondagaon	1969	2159	2183
Korba	1987	2028	2115
Korea	2015	2102	2205
Mahasamund	1781	1933	1941
Mungeli	1819	1876	1906
Narayanpur	1950	2038	2092
Raigarh	1788	1843	1901
Raipur	1592	1629	1755
Rajnandgaon	1832	1880	1914
Sukma	2091	2125	2223
Surajpur	1784	1835	1801
Surguja	2001	2021	2098

Appendix 3-4: Extreme events under historical (1990–2019) and projected short-term (2021–2050) periods. The numbers indicate the total number of days with either high- or very high-intensity rainfall over a 30-year period and the number of rainfall deficient years over a 30-year period.

Districts	High-intensity rainfall events			Very high-intensity rainfall events			Rainfall deficient years		
	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5
Balod	78	114	134	11	46	64	7	6	7
Baloda Bazar	96	105	123	22	43	56	10	8	10
Balrampur	80	105	132	10	45	58	12	9	9
Bastar	106	135	146	19	40	57	10	7	8
Bemetara	86	97	112	11	35	45	10	8	10
Bijapur	128	148	166	35	49	69	10	7	9
Bilaspur	100	123	167	17	48	67	11	9	11
Dantewada	100	120	149	18	46	68	9	7	9
Dhamtari	97	123	147	22	45	60	6	6	6
Durg	103	143	158	16	49	56	10	6	10
Gariyaband	83	121	145	17	46	57	9	6	8
Janjgir-Champa	88	109	144	22	54	65	12	8	9
Jashpur	108	148	156	16	47	66	10	10	10
Kabirdham	59	92	133	5	39	60	12	10	12
Kanker	111	134	175	50	64	75	11	6	7
Kondagaon	59	109	133	5	43	67	8	5	5
Korba	94	143	160	18	58	78	10	10	10
Korea	88	109	129	8	40	68	10	10	9
Mahasamund	84	103	134	17	60	65	11	7	8
Mungeli	82	104	123	5	34	65	12	8	12
Narayanpur	83	97	103	23	47	88	8	7	8
Raigarh	105	123	147	18	46	61	9	7	9
Raipur	106	133	147	25	45	67	9	6	9
Rajnandgaon	87	103	134	9	40	65	9	6	9
Sukma	104	133	146	26	54	67	11	6	10
Surajpur	88	97	120	13	40	50	10	10	10
Surguja	100	134	156	19	43	87	11	11	9

4. Madhya Pradesh

The state of Madhya Pradesh covers an area of 3,08,250 sq. km and is bordered by the states of Uttar Pradesh to the north-east, Chhattisgarh to the south-east, Maharashtra to the south, Gujarat to the south-west, and Rajasthan to the north-west. According to Census 2011, Madhya Pradesh has a population of 72.59 million. There are 52 districts in Madhya Pradesh[4]. A majority of the state's rural population's main source of livelihood is agriculture. The total area under agriculture is 15.8 Mha, of which 4.19 Mha alone is the irrigated area. There are several thermal, hydro, solar, and wind power plants in the state. These characteristics make Madhya Pradesh climate-sensitive, underpinning the need for climate information. Climate data could serve as the basis for climate hazard mapping and risk assessment of various regions, sectors, and communities to ensure climate-proof development.

4.1 Historical climate

Temperature and seasonal rainfall—kharif and rabi—at the district level for the historical period spanning 1990–2019 are presented in the subsequent sections.

4.1.1. Trends in temperature

Madhya Pradesh recorded a moderate warming of 0.30°C to 0.71°C in the summer maximum temperature and 0.34°C to 0.68°C in the winter minimum temperature during the historical period. Figure 4-1 presents the mean summer maximum and winter minimum temperatures in Madhya Pradesh during the historical period.

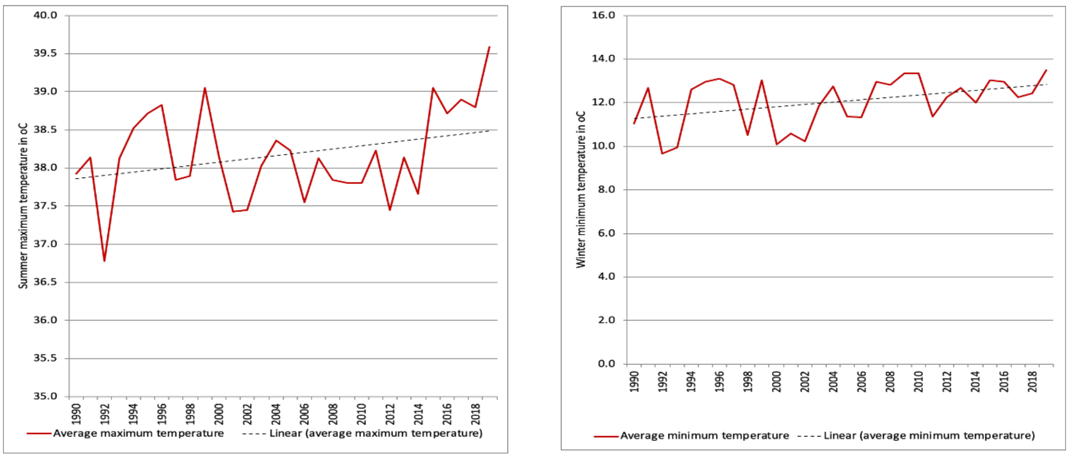


Figure 4-1: Mean summer maximum and winter minimum temperatures in Madhya Pradesh during the historical period (1990–2019)

[4]The current analysis is for 51 of the 52 districts, excluding Niwari district formed from Tikamgarh.

4.1.2. Trends in temperature

An increasing trend in the annual and kharif season rainfall—which is the main monsoon season—was recorded in the districts of Madhya Pradesh. The increase in the annual rainfall was in the range of 5% to 10% while the increase in the kharif season rainfall was marginal, by up to 5% in the eastern districts and 5% to 10% in the western districts. Figure 4-2 presents the mean annual rainfall in Madhya Pradesh during the historical period.

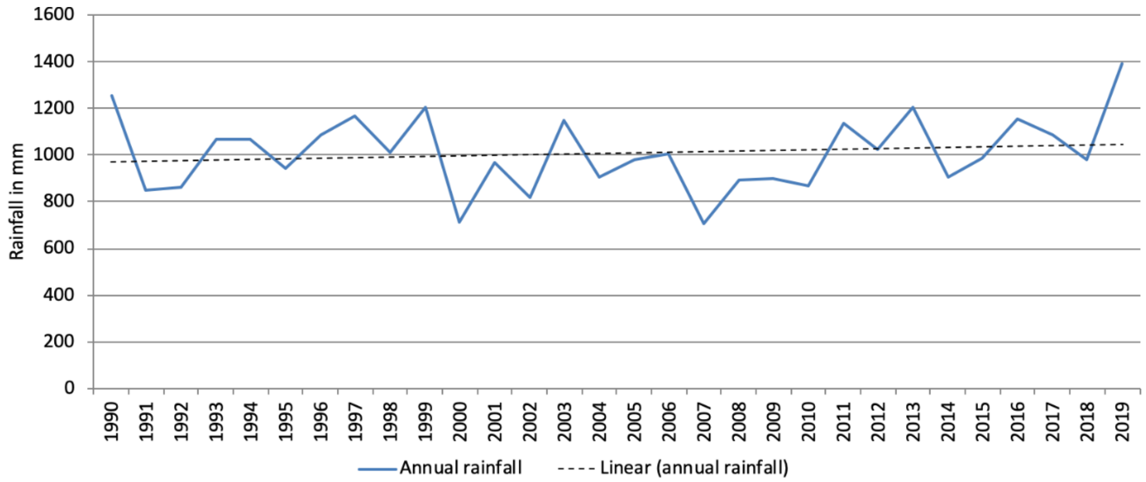


Figure 4-2: Mean annual rainfall in Madhya Pradesh during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 15% in Anuppur to 40% in Khandwa and Balaghat (Figure 4-3). The rabi season rainfall is insignificant and extremely variable in Madhya Pradesh (Figure 4-3).

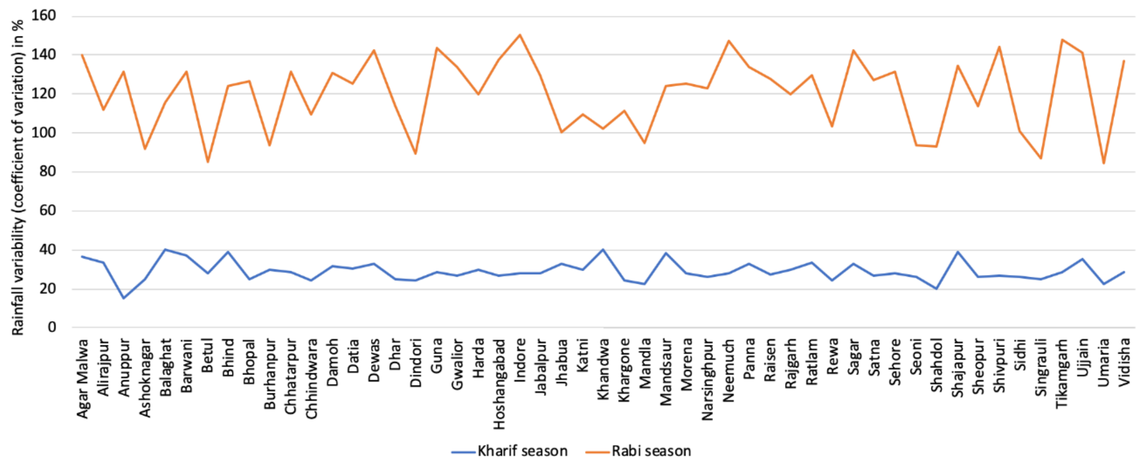


Figure 4-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

4.2 Climate change projections

Temperature and rainfall have been projected for the 2030s under two representative concentration pathways (RCP)—RCP 4.5 (medium emission) and RCP 8.5 (high emission) scenarios. For details on the scenarios and models, refer to Section 2.2.

4.2.1 Temperature projections

The projected changes in summer maximum and winter minimum temperatures for all the districts of Madhya Pradesh are presented in Figure 4-4.

The summary of projected changes between 2021–2050 and 1990–2019 is as follows:

Climate scenarios	Summer maximum	Winter minimum
RCP 4.5	Increases by 1^{0}C to 2^{0}C	Increases by 1^{0}C to 2^{0}C
RCP 8.5	Increases by 1^{0}C to 2^{0}C	Increases by 1.5^{0}C to 2^{0}C

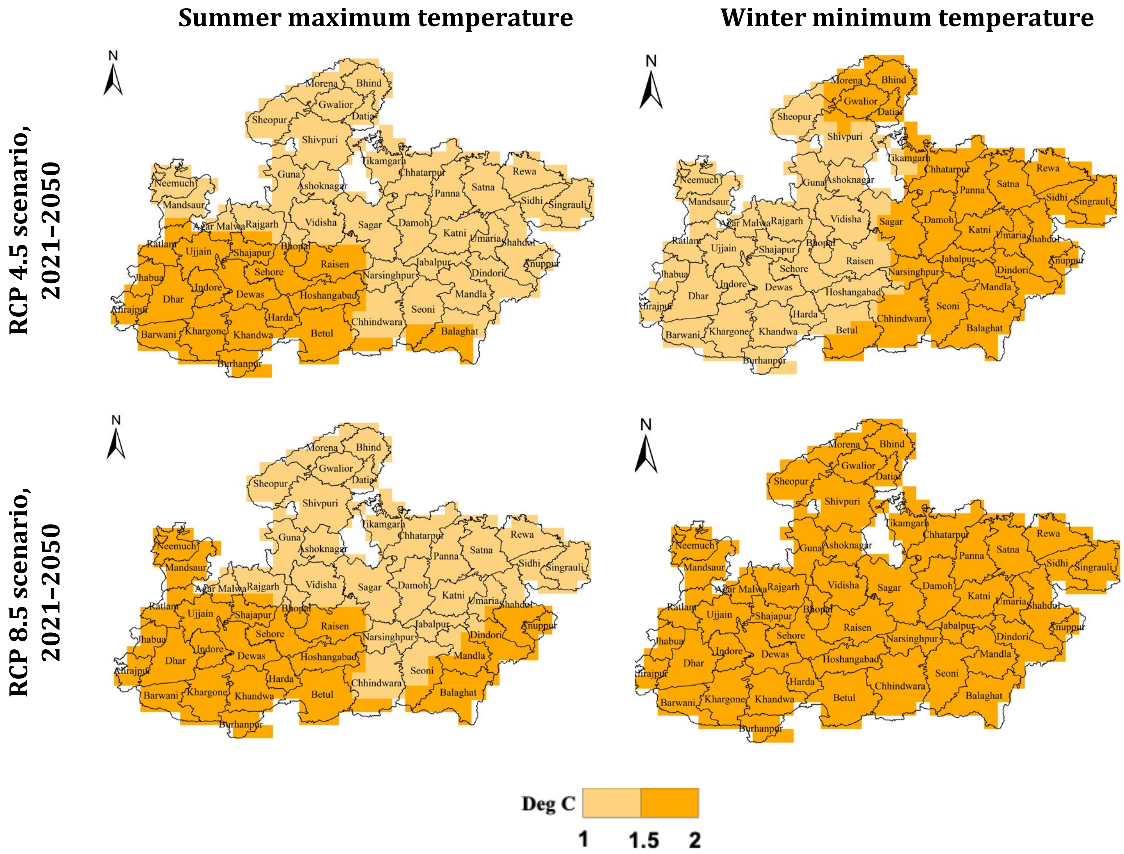


Figure 4-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

4.2.1.1 Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 1, a heatwave analysis of the Khargone district was conducted. In the district, heatwave incidences have consistently increased over the decades during the historical period.

The analysis of temperature during the projected period of the 2030s shows that there would an increase in the number of heatwaves (departure from the normal temperature is 4.5°C to 6.4°C) and severe heatwaves (departure from the normal temperature is >6.4°C), as categorised by the India Meteorological Department (IMD). Severe heatwaves are projected to double under both RCP 4.5 and RCP 8.5 scenarios (Figure 3-).

Figure 4-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

4.2.2 Rainfall projections

4.2.2.1 Number of rainy days

According to the IMD, a *rainy day* is defined as a day with rainfall of 2.5 mm or more. The analysis of rainy days under historical and projected periods shows that there will be an increase in the number of rainy days during the projected period in all the districts (Figure 3-). The number of rainy days during the historical period and the projected 2030s under both RCP 4.5 and 8.5 scenarios is presented in Appendix 4-3. The total number of rainy days that ranged from 1103 to 1930 days over the 30-year historical period increases to 1156 to 2011 days under the RCP 4.5 scenario and 1181 to 2056 days under the RCP 8.5 scenario during the projected 2030s. The increase per annum is as follows:

RCP 4.5 scenario: Projected to increase by 1 to 6 days annually in all the districts. The increase is by 6 days in Dindori and Damoh; 5 days in Singrauli, Chhatarpur, and Shajapur; 4 days in Burhanpur, Harda, Sagar, Gwalior, Agar Malwa, Anuppur, Rewa, Shahdol, and Panna; 3 days in 15 districts; 2 days in 16 districts; and 1 day in six districts.

RCP 8.5 scenario: Projected to increase by 1 to 6 days annually in all the districts. The increase is by 6 days in Dindori, Shajapur, and Bhopal; 5 days in Rewa, Shahdol, Damoh, Sagar, Agar Malwa, and Singrauli; 4 days in Dhar, Indore, Hoshangabad, Alirajpur, Panna, Satna, Anuppur, Chhatarpur, and Gwalior; 3 days in 23 districts, 2 days in nine districts; and 1 day in Chhindwara district.

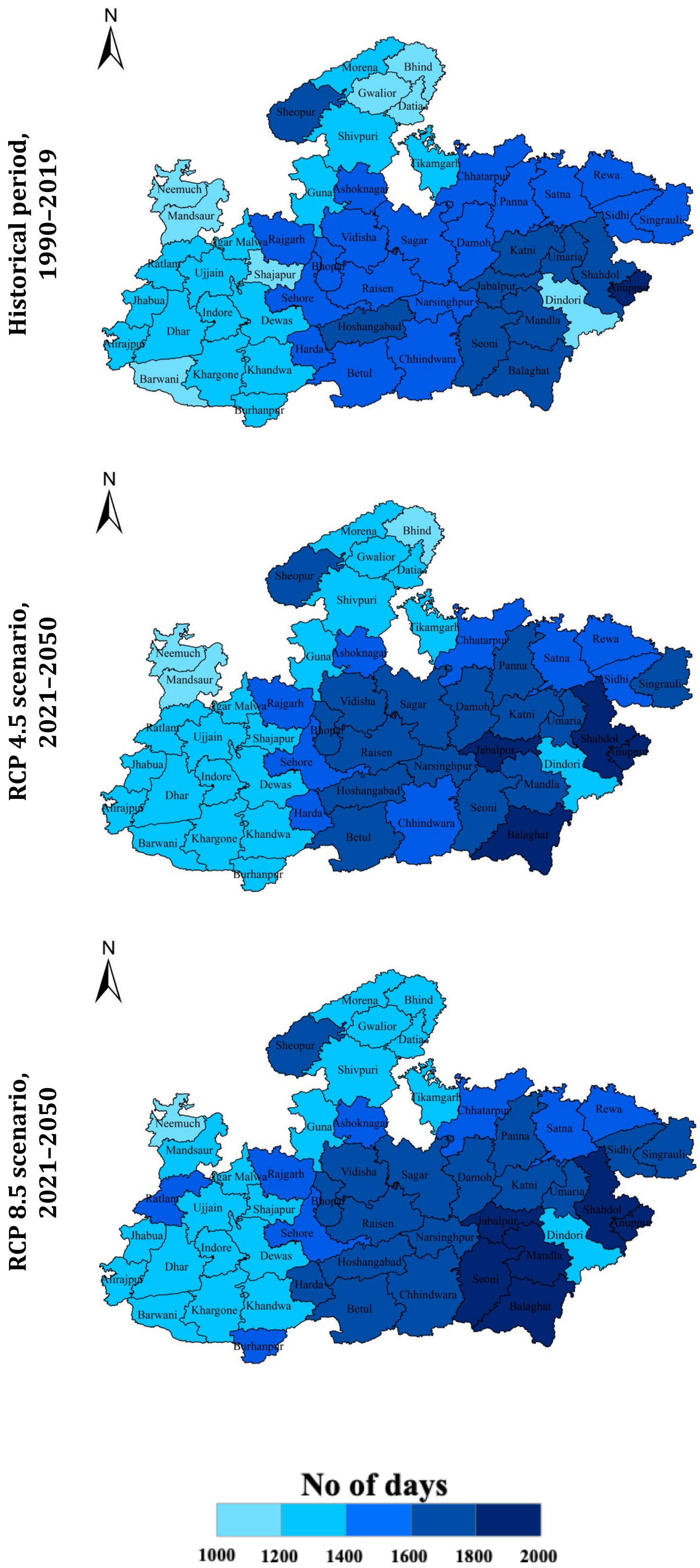


Figure 4-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

4.2.2.2 Mean rainfall and rainfall variability during the kharif season

The kharif season rainfall is projected to increase in all the districts under both climate scenarios. Figure 3- presents district-wise changes in the kharif season rainfall, and Figure 3- presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 1% in Anuppur to 20% in Mandla	Increases in six districts by 1% to 11%, declines in 43 districts by 1% to 15%, and no change in Rewa and Singrauli
RCP 8.5	Increases in all the districts, from 5% in Anuppur and Mandsaur to 23% in Ujjain and Mandla	Increases in six districts by 3% to 6% and declines in 45 districts by 1% to 14%

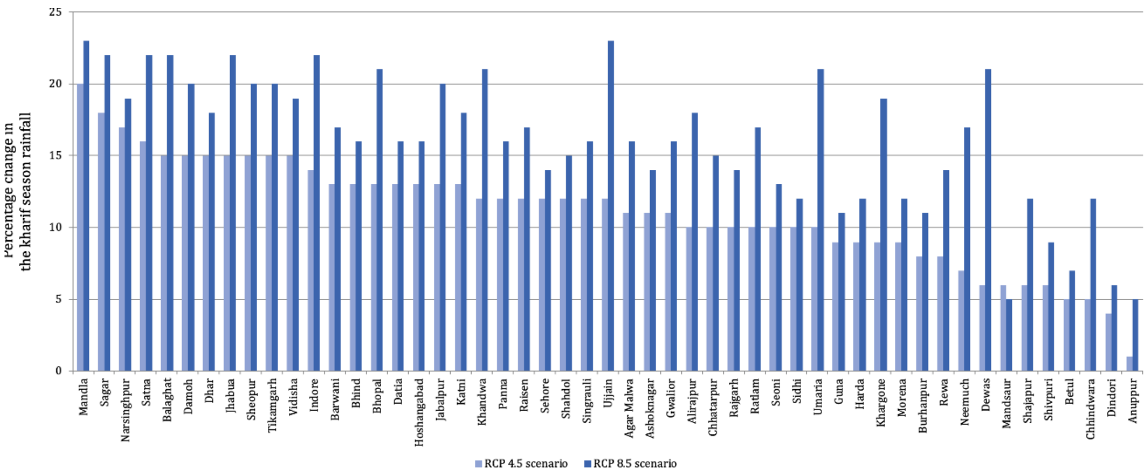


Figure 4-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

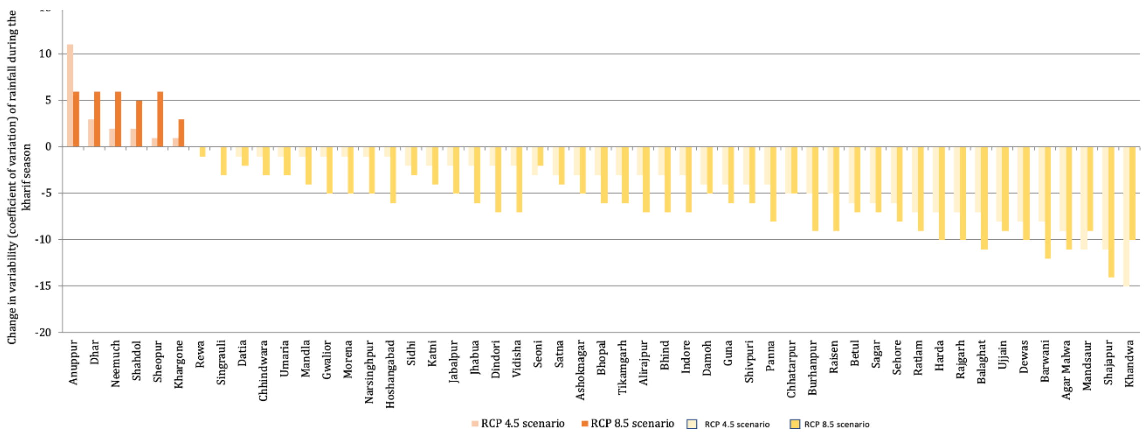


Figure 4-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

4.3 Heavy rainfall events and rainfall deficient years

Rainfall during the kharif season was analysed by considering the intensity of rainfall under three categories: <50 mm/day; 51–100 mm/day, termed 'High' intensity; and >100 mm/day, termed 'Very High' intensity. The number of such events was computed for the historical period and the projected 2030s under the two climate scenarios, and the change was computed for all the districts of Madhya Pradesh.

High-intensity rainfall events (Figure 4-9)

The total number of high-intensity rainfall events increases from 32 to 125 days during the historical period (1990–2019) to 78 to 187 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 101 to 200 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: The projected increase per annum is by one to two events. The increase is by two events in Balaghat, Burhanpur, Bhind, Chhindwara, Gwalior, Seoni, Satna, Shahdol, and Vidisha and one event in the remaining districts.

RCP 8.5 scenario: The projected increase per annum is by one to three events. The increase is by three events in 20 districts including Balaghat, Sheopur, Sidhi, Panna, Satna, Gwalior, Rewa, Chhindwara, Seoni, Shahdol, and others; two events in 29 districts; and one event in Chhatarpur and Dindori districts.

Very high-intensity rainfall events (Figure 4-10)

The total number of very high-intensity rainfall events increases from 4 to 38 days during the historical period (1990–2019) to 35 to 89 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 67 to 112 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: The projected increase per annum is by one to two events. The increase is by two events in 17 districts including Bhopal, Bhind, Vidisha, Sagar, Neemuch, Singrauli, Gwalior, Mandla, Seoni, Satna, and others; and one event in the remaining 34 districts.

RCP 8.5 scenario: The projected increase per annum is by two to three events. The increase is by three events in 13 districts, including Tikamgarh, Shahdol, Umaria, Damoh, Sagar, Vidisha, Seoni, Chhindwara, Sheopur, Gwalior, and others; and two events in the remaining 38 districts.

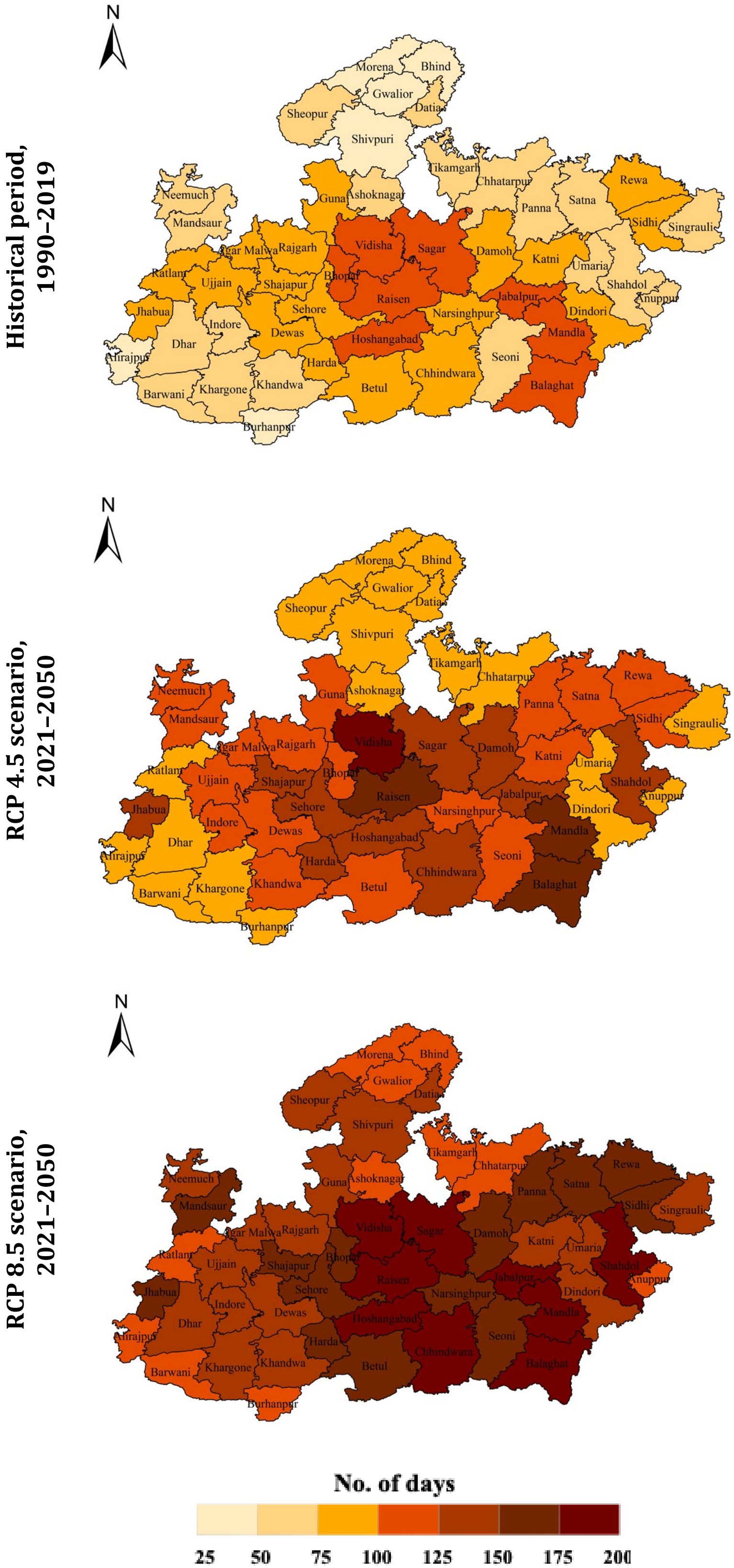


Figure 4-9: The total number of high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

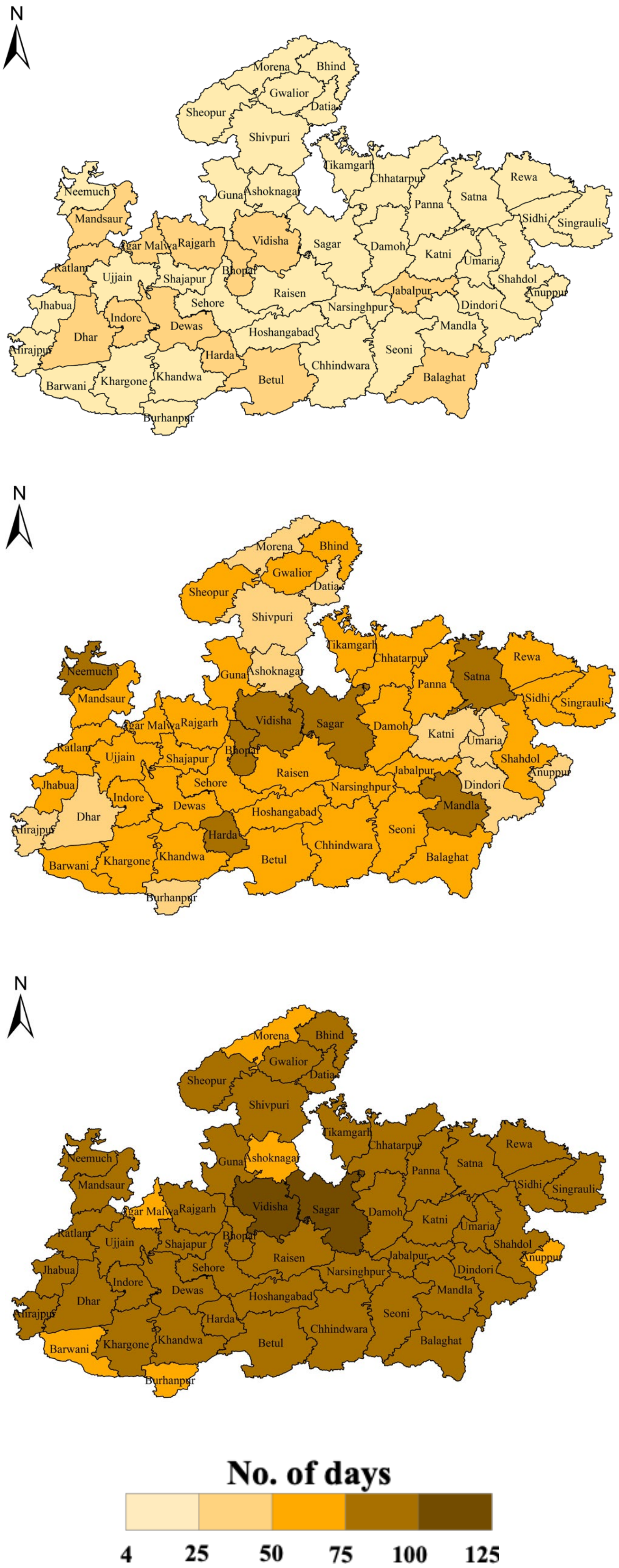


Figure 4-10: The total number of very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

Rainfall deficient years (Figure 4-11)

Rainfall deficient years, computed considering the rainfall during the kharif season, is projected to decline in a majority of the districts of Madhya Pradesh under both climate scenarios. The number of rainfall deficient years declines from 8 to 17 years during the historical 30-year period to 8 to 15 years under the RCP 4.5 scenario and 7 to 14 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: The projected decline is by 1 to 4 years in 38 districts. In the remaining districts, no change is projected.

RCP 8.5 scenario: The projected decline is by 1 to 5 years in 48 districts. No change is projected in Harda, Rewa, and Anuppur.

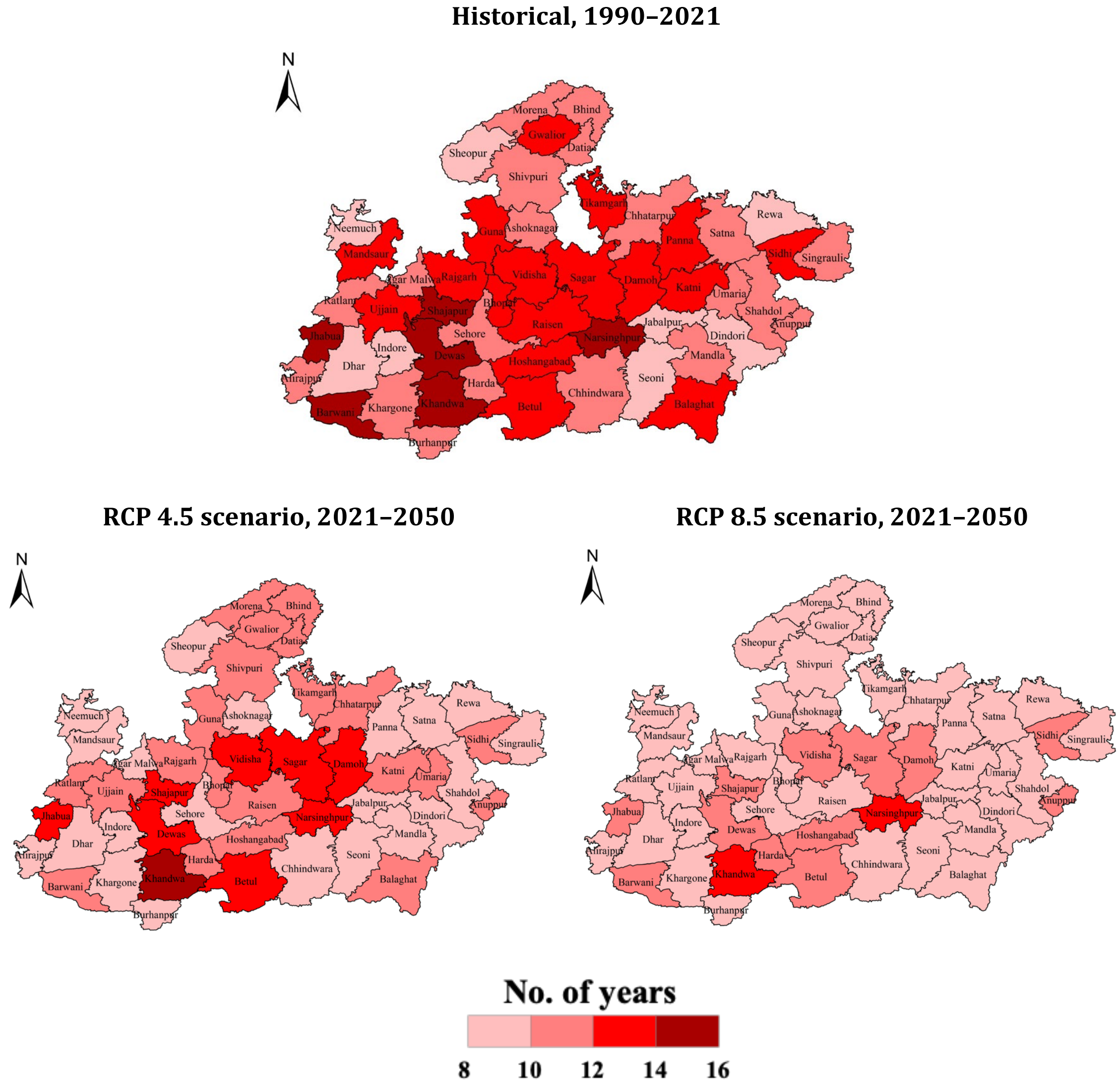


Figure 4-11: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

4.4 The summary of projected changes in the climate for Madhya Pradesh

The temperature is projected to increase in the short term (2021–2050) in all the districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 4-1).

- A higher warming of summer maximum temperature is projected in the south-western districts of Barwani, Betul, Harda, Neemuch, and a few others.
- A higher warming of winter minimum temperature is projected in the eastern districts under the RCP 4.5 scenario, and a warming of 1.5^{0}C to 2^{0}C is projected in all the districts under the RCP 8.5 scenario.

Rainfall is projected to increase in the short term (2021–2050) in all the districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 3-2).

A notable increase in rainfall is projected in the eastern districts of Madhya Pradesh under both RCP 4.5 and RCP 8.5 scenarios.

Rainfall variability during the kharif season is projected to decline in most districts but increase in a few districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019).

- A ≥10% increase in rainfall variability is projected in three districts under the RCP 4.5 scenario and in 10 districts under the RCP 8.5 scenario.

The number of rainy days is projected to increase in all the districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 4-3:).

- The increase annually during the projected 2030s (2021–2050) is in the range of 1 to 6 days under both RCP 4.5 and RCP 8.5 scenarios.

Heavy rainfall events are projected to increase, largely in the range of one to two events annually, under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 4-4).

- Heavy rainfall events are projected to increase in the range of one to six events annually under both scenarios.

Rainfall deficient years are projected to decline in the range of 1 to 2 years under the RCP 4.5 scenario and 1 to 3 years under the RCP 8.5 scenario compared to the historical period (1990–2019; Appendix 4-4).

Appendix

Appendix 4-1: Changes in temperature under climate scenarios

Districts	Changes in temperature (°C) during the 2030s (2021–2050) compared to the historical period (1990–2019)			
	Summer maximum temperature		Winter minimum temperature	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Agar Malwa	1.4	1.8	1.5	1.9
Alirajpur	1.6	1.9	1.3	1.6
Anuppur	1.2	1.6	1.6	1.8
Ashoknagar	1.2	1.4	1.5	1.9
Balaghat	1.6	1.7	1.6	1.8
Barwani	1.6	1.8	1.3	1.7
Betul	1.6	1.7	1.6	1.8
Bhind	1.3	1.5	1.6	1.8
Bhopal	1.4	1.6	1.1	1.6
Burhanpur	1.6	1.8	1.4	1.7
Chhatarpur	1.2	1.4	1.6	1.7
Chhindwara	1.6	1.8	1.5	1.8
Damoh	1.1	1.3	1.6	1.7
Datia	1.2	1.5	1.6	1.8
Dewas	1.6	1.8	1.3	1.7
Dhar	1.6	1.9	1.3	1.6
Dindori	1.3	1.8	1.6	1.7
Guna	1.1	1.4	1.3	1.6
Gwalior	1.2	1.5	1.6	1.9
Harda	1.0	1.3	1.3	1.7
Hoshangabad	1.3	1.5	1.6	1.8
Indore	1.6	1.8	1.2	1.6
Jabalpur	1.2	1.5	1.7	1.9
Jhabua	1.6	1.7	1.4	1.8
Katni	1.2	1.4	1.6	1.9
Khandwa	1.6	1.7	1.2	1.4
Khargone	1.7	1.9	1.3	1.5
Mandla	1.6	1.8	1.6	1.8
Mandsaur	1.7	1.9	1.3	1.8
Morena	1.2	1.4	1.7	1.9
Narsinghpur	1.2	1.5	1.6	1.8
Neemuch	1.3	1.6	1.3	1.7

Districts	Changes in temperature (°C) during the 2030s (2021–2050) compared to the historical period (1990–2019)			
	Summer maximum temperature		Winter minimum temperature	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Panna	1.2	1.5	1.6	1.9
Raisen	1.1	1.3	1.6	1.8
Rajgarh	1.2	1.5	1.2	1.7
Ratlam	1.6	1.7	1.3	1.7
Rewa	1.1	1.4	1.6	1.9
Sagar	1.2	1.3	1.7	1.9
Satna	1.1	1.4	1.6	1.7
Sehore	1.2	1.6	1.2	1.7
Seoni	1.4	1.7	1.6	1.8
Shahdol	1.3	1.6	1.7	1.9
Shajapur	1.4	1.8	1.3	1.7
Sheopur	1.3	1.5	1.3	1.8
Shivpuri	1.1	1.4	1.6	1.7
Sidhi	1.2	1.4	1.7	1.9
Singrauli	1.3	1.5	1.5	1.9
Tikamgarh	1.4	1.5	1.6	1.8
Ujjain	1.6	1.9	1.3	1.7
Umaria	1.3	1.6	1.6	1.8
Vidisha	1.1	1.4	1.6	2.0

Appendix 4-2: Changes in rainfall under climate scenarios

Districts	Changes in rainfall (%) during the 2030s (2021–2050) compared to the historical period (1990–2019)					
	Annual rainfall		Kharif season rainfall		Rabi season rainfall	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Agar Malwa	10	15	11	16	9	30
Alirajpur	18	25	10	18	3	26
Anuppur	1	5	1	5	10	23
Ashoknagar	13	15	11	14	13	34
Balaghat	16	25	15	22	8	28
Barwani	12	21	13	17	11	39
Betul	8	12	5	7	8	32
Bhind	13	14	13	16	16	34
Bhopal	14	19	13	21	7	36
Burhanpur	12	14	8	11	10	32
Chhatarpur	11	16	10	15	14	40
Chhindwara	8	12	5	12	4	21
Damoh	12	19	15	20	4	24
Datia	15	18	13	16	13	52
Dewas	10	12	6	21	27	71
Dhar	19	24	15	18	2	40
Dindori	4	11	4	6	44	72
Guna	12	13	9	11	24	63
Gwalior	10	13	11	16	6	45
Harda	37	43	9	12	13	32
Hoshangabad	13	17	13	16	2	33
Indore	14	19	14	22	8	25
Jabalpur	11	17	13	20	5	27
Jhabua	14	21	15	22	7	23
Katni	13	24	13	18	20	39
Khandwa	14	23	12	21	8	20
Khargone	13	23	9	19	20	54
Mandla	21	29	20	23	4	20
Mandsaur	8	11	6	5	4	27
Morena	10	15	9	12	9	32
Narsinghpur	16	20	17	19	9	34

Districts	Changes in rainfall (%) during the 2030s (2021–2050) compared to the historical period (1990–2019)					
	Annual rainfall		Kharif season rainfall		Rabi season rainfall	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Neemuch	10	20	7	17	10	12
Panna	12	19	12	16	20	38
Raisen	12	15	12	17	10	27
Rajgarh	11	13	10	14	8	41
Ratlam	11	18	10	17	1	21
Rewa	8	11	8	14	3	26
Sagar	15	21	18	22	3	42
Satna	13	20	16	22	8	31
Sehore	23	29	12	14	11	36
Seoni	21	25	10	13	10	36
Shahdol	12	16	12	15	6	35
Shajapur	9	15	6	12	19	54
Sheopur	4	9	15	20	12	43
Shivpuri	7	9	6	9	7	23
Sidhi	8	10	10	12	9	29
Singrauli	11	12	12	16	10	68
Tikamgarh	20	24	15	20	37	60
Ujjain	12	21	12	23	14	26
Umaria	12	22	10	21	9	34
Vidisha	15	18	15	19	13	48

Appendix 4-3: The total number of rainy days (>2.5 cm/day) during the historical period (1990–2019) and the projected 2030s (2021–2050)

	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Agar Malwa	1243	1324	1389
Alirajpur	1234	1289	1346
Anuppur	1930	2011	2056
Ashoknagar	1456	1512	1549
Balaghat	1765	1834	1862
Barwani	1160	1212	1253
Betul	1585	1623	1668
Bhind	1136	1190	1223
Bhopal	1563	1623	1737
Burhanpur	1308	1378	1410
Chhatarpur	1473	1578	1600
Chhindwara	1566	1589	1608
Damoh	1568	1679	1716
Datia	1195	1244	1278
Dewas	1225	1267	1295
Dhar	1291	1343	1396
Dindori	1113	1232	1289
Guna	1314	1378	1400
Gwalior	1167	1245	1294
Harda	1515	1590	1616
Hoshangabad	1655	1723	1766
Indore	1266	1303	1376
Jabalpur	1781	1823	1881
Jhabua	1202	1233	1289
Katni	1666	1710	1741
Khandwa	1209	1234	1273
Khargone	1291	1345	1372
Mandla	1732	1789	1816
Mandsaur	1161	1190	1231
Morena	1213	1277	1310
Narsinghpur	1585	1623	1659
Neemuch	1103	1156	1181
Panna	1600	1689	1719
Raisen	1589	1611	1663

	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Rajgarh	1437	1478	1503
Ratlam	1349	1398	1434
Rewa	1437	1521	1588
Sagar	1535	1611	1678
Satna	1467	1512	1592
Sehore	1496	1534	1582
Seoni	1737	1789	1812
Shahdol	1744	1832	1899
Shajapur	1115	1214	1289
Sheopur	1602	1644	1695
Shivpuri	1239	1289	1325
Sidhi	1563	1599	1624
Singrauli	1573	1681	1726
Tikamgarh	1283	1323	1367
Ujjain	1247	1260	1294
Umaria	1688	1712	1787
Vidisha	1590	1623	1663

Appendix 4-4: Extreme events under historical (1990–2019) and projected short-term (2021–2050) periods. The numbers indicate the total nuber of days with either high- or very high-intensity rainfall over a 30-year period and the number of rainfall deficient years over a 30-year period.

Districts	High-intensity rainfall events			Very high-intensity rainfall events			Rainfall deficient years		
	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5
Agar Malwa	86	121	142	27	63	74	11	10	9
Alirajpur	50	87	112	18	46	88	12	10	9
Anuppur	75	98	123	11	38	69	11	12	11
Ashoknagar	63	97	125	10	42	72	12	8	8
Balaghat	107	156	189	37	68	93	13	11	10
Barwani	65	92	123	13	57	75	15	12	11
Betul	90	125	163	30	63	82	14	13	11
Bhind	32	79	101	5	56	78	11	11	9
Bhopal	102	124	167	27	78	96	13	12	10
Burhanpur	44	89	110	10	43	67	11	9	8
Chhatarpur	69	85	112	15	56	78	12	11	10
Chhindwara	84	133	180	12	57	92	12	10	9
Damoh	93	126	168	21	68	99	14	14	12
Datia	58	98	134	7	43	76	12	11	10
Dewas	76	112	146	30	67	93	15	13	11
Dhar	64	89	132	27	47	87	10	9	8
Dindori	92	97	134	14	45	87	8	8	7
Guna	82	110	145	20	56	88	14	11	9
Gwalior	35	89	123	11	67	94	13	12	10
Harda	90	130	167	34	76	89	11	11	11
Hoshangabad	109	147	177	19	56	89	14	12	11
Indore	75	108	141	26	68	93	10	10	9
Jabalpur	110	143	178	31	56	80	10	9	9
Jhabua	89	132	167	21	68	90	15	13	12
Katni	81	114	147	13	46	87	14	12	10
Khandwa	69	103	145	25	56	88	17	15	14
Khargone	62	97	132	19	55	78	11	10	9
Mandla	116	156	178	21	78	90	11	10	9
Mandsaur	75	114	157	29	58	80	14	10	10
Morena	38	78	103	4	35	69	11	11	10
Narsinghpur	90	124	156	22	67	78	16	14	13
Neemuch	74	102	145	23	78	90	10	9	8
Panna	73	117	156	13	54	89	13	10	8
Raisen	122	151	178	24	68	92	14	12	10
Rajgarh	94	102	145	27	58	88	14	11	10
Ratlam	76	95	123	38	64	90	12	12	10
Rewa	77	113	167	18	66	90	10	10	10
Sagar	116	143	178	23	78	101	13	13	11
Satna	70	123	155	20	89	94	12	9	7
Sehore	97	134	161	23	56	93	12	9	9
Seoni	70	121	167	15	72	94	10	8	7
Shahdol	74	134	178	16	56	93	11	9	8
Shajapur	88	132	165	24	72	97	15	14	11
Sheopur	61	86	144	6	54	86	10	10	9
Shivpuri	50	86	132	14	44	87	12	11	10
Sidhi	85	125	168	18	62	93	14	12	11
Singrauli	54	82	128	9	64	93	11	10	9
Tikamgarh	72	97	121	16	56	93	13	11	10
Ujjain	92	120	146	25	62	89	13	11	9
Umaria	55	90	132	9	37	87	11	11	9
Vidisha	125	187	200	33	84	112	13	13	11

Conclusion

A moderate warming of summer maximum and winter minimum temperatures and an increase in rainfall were recorded during the historical period of 1991–2019 in both the central states.

Climate projections for the central states at the district level for the period 2021–2050 (the 2030s) indicate a warmer and wetter future, with increase in extreme events, particularly heavy rainfalls that are more frequent and more intense. These projections are largely in agreement with the literature available at the global, South Asia, and national levels. The findings are particularly consistent with national-level projections of climate by the Ministry of Earth Sciences.

The projected changes in climate in the various districts of the southern states of India could have the following implications:

Water: Climate change is affecting and could affect where, when, and how much water is available. Rising temperatures, changing precipitation patterns, and increasing heavy rainfall events could affect the amount of water in rivers, lakes, and streams and the amount of water replenished into the ground. This has implications for water management for irrigation and drinking purposes. Historically, the focus has been on managing droughts. The climate projections make it clear that flood management strategies should be integrated with drought management strategies for strengthening adaptation measures and building resilience.

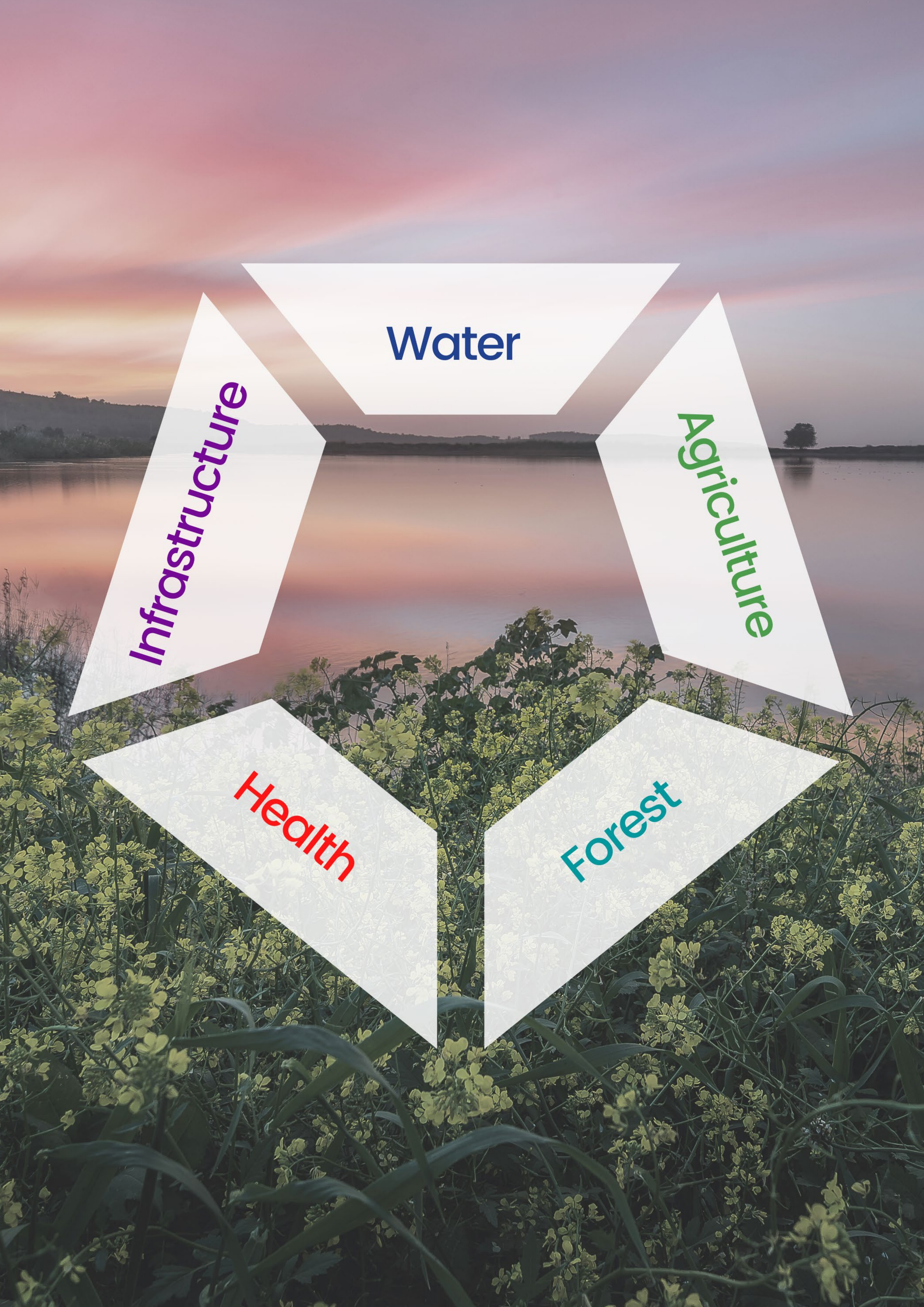
Agriculture: Agriculture crops require specific conditions to thrive and have specific temperature and water requirements. Higher temperatures projected in the various districts of the southern states can adversely impact crop growth and production. When coupled with increasing rainfall, this could promote the growth of invasive species and pests and their spread to newer areas. Projected heavy rainfall events could damage crops, leading to crop loss and adverse impacts on farm incomes and livelihoods. Climate change could thus increase the strain on agriculture systems through changes in the distribution and magnitude of rainfall, warming of temperature, and the frequency of heavy rainfall events.

Forest and wildlife: Changes in climate could affect both forests and wildlife, as well as the entire ecosystem. The projected increase in heavy rainfall events could lead to a higher incidence of pests and diseases. On the other hand, higher summer temperatures could increase the biomass fuel load in forests, leading to forest fires.

Health: Projections of a warmer and wetter future in the districts of the southern states have health implications. These implications could be both direct (thermal stress due to high summer temperatures and death, injury, or mental stress caused by forced migration due to climate- or weather-related disasters such as floods, droughts, and storms) as well as indirect (through changes in the ranges of disease vectors such as mosquitoes and rodents, changes in the availability and quality of water, air quality, and food availability and quality).

Infrastructure: Projected high summer temperatures and an increase in heavy rainfall events have implications for energy supply and management. The performance of power infrastructure assets and the assets themselves are likely to be adversely impacted under high temperature and heavy rainfall conditions. While the increase in the summer maximum temperature, extended dry spells, and water shortage are key risks to thermal power plants, heavy rainfall events could cause material damage to solar and wind power plants. Other infrastructure such as communication networks, transport, bridges, roads, and railways could also be damaged due to high temperature and heavy rainfall events.

To cope with the changes in climate and their multiplying effects on social and economic inequities, it is vital that we build capacities that ensure the use of climate information and the flow of critical climate data to planners and decision-makers. This work is an effort in that direction. Further analysis considering specific sectors and their exposure and vulnerabilities at a state level can help states identify climate risks and integrate them into the planning and implementation of future projects and programmes, as well as formulate adaptation or resilience-building strategies for existing infrastructure. Building climate resilience—the ability to anticipate, absorb, accommodate, and recover from the effects of a potentially hazardous event—has several benefits. Delaying actions needed for resilience even by 10 years could almost double the costs.


Water
Agriculture
Forest
Health
Infrastructure

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