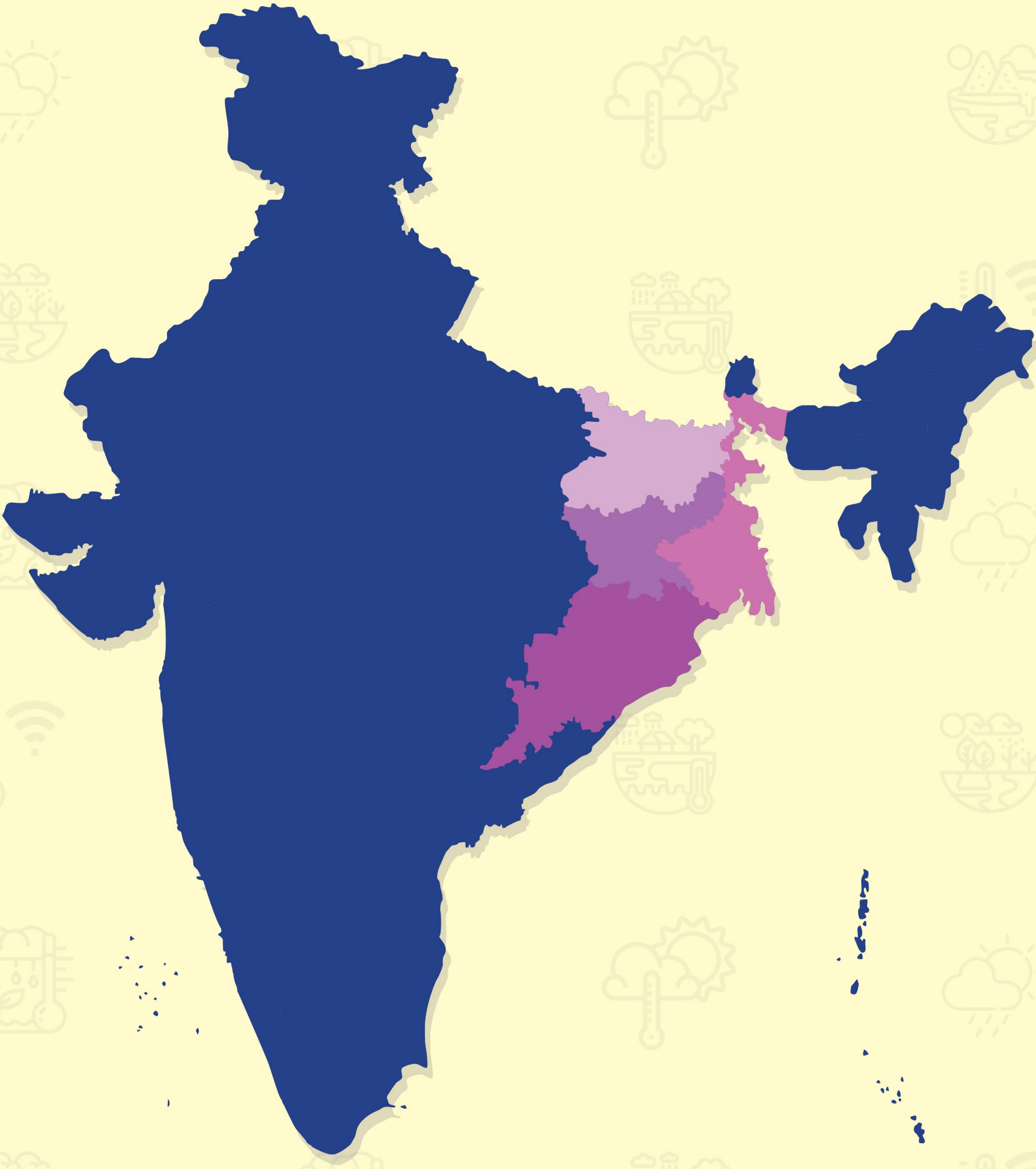
DISTRICT-LEVEL CHANGES IN CLIMATE:
HISTORICAL CLIMATE AND CLIMATE CHANGE PROJECTIONS FOR THE EASTERN STATES OF INDIA



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

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CSTEP

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(*The author list provided assumes no particular order as every individual contributed to the successful execution of the project.*)

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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 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 four eastern states of India: Bihar, Jharkhand, Odisha, and West Bengal.

Methodology: Historical climate analysis and climate change projections have been made at a district level for all the eastern 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, 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 eastern India.

Findings: Historically, temperature and rainfall have increased, and rainfall variability is high across all the eastern 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 the eastern states. Rainfall variability and rainfall deficient years are projected to predominantly decline in a majority of the districts of the eastern states.

Temperature

Summer maximum and the winter minimum temperatures are projected to increase by 1°C to 2°C in the districts of eastern India compared to the historical temperatures under the high emission RCP 8.5 scenario.

Rainy days

The number of rainy days is projected to increase in the 2030s in all the districts of eastern India compared to the historical period. The increase is by 1 to 11 days under the RCP 4.5 scenario, with the maximum increase projected in West Bengal and a minimum increase projected in Odisha. The increase is by 1 to 15 days under the RCP 8.5 scenario, with the maximum increase projected in West Bengal.

Monsoon rainfall

Rainfall during kharif (June to September) and rabi (October to December) seasons is projected to increase in the 2030s in almost all the districts of eastern India compared to the historical period. The projected increase in the kharif season rainfall is by 1% to 46% under the RCP 4.5 scenario and 6% to 36% under the RCP 8.5 scenario. The rabi season rainfall is projected to increase by 2% to 55% under the RCP 4.5 scenario and 2% to 85% under the RCP 8.5 scenario.

Rainfall variability

The variability (coefficient of variation) of both kharif and rabi season rainfall shows mixed trends in the 2030s across the districts of eastern India compared to the historical period. However, the decline in rainfall variability is more than the increase in all the states during kharif and rabi seasons.

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 a majority of the districts of eastern India compared to the historical period. The increase in high-intensity rainfall events per annum is by one to three events under the RCP 4.5 scenario and one to four events under the RCP 8.5 scenario.

Rainfall deficient years

A decline in rainfall deficient years is projected in the 2030s across a majority of the districts of eastern India compared to the historical period. The decline in rainfall deficient years is by 1 to 6 years out of 30 years under both RCP 4.5 and RCP 8.5 scenarios. The highest decline in rainfall deficient years is projected in Odisha.

Discussion: It is evident from the study that in the future, climate in the districts of eastern India will be different from the historical climate. This has implications for water availability and management, agriculture, forest and biodiversity, health, and infrastructure. It 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 eastern states 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.

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

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

[2]https://mausam.imd.gov.in/imd_latest/monsoonfaq.pdf

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.

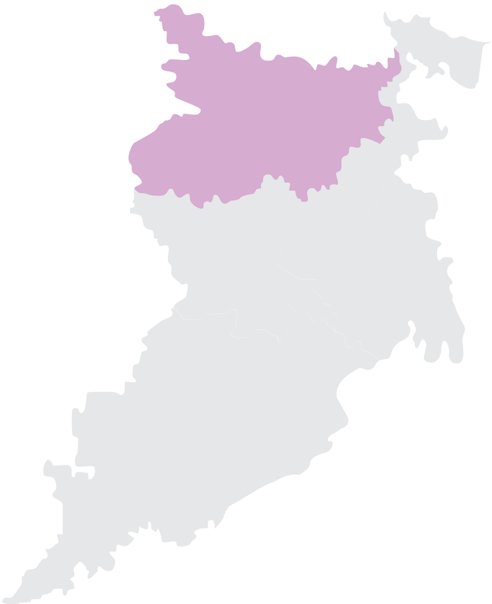
2.4. The organisation of the report

This report is for the four eastern states of India: Bihar, Jharkhand, Odisha, and West Bengal. 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. Bihar



Bihar is a land-locked state bordered by West Bengal in the east, Uttar Pradesh in the west, and Jharkhand in the south. In the north, Bihar shares its boundary with Nepal. It has a geographical area of 94,163 sq. km and a population of 100.38 million, according to Census 2011. Of the total population, close to 88% live in rural areas. Bihar has 38 districts rich in natural resources, such as perennial rivers and fertile lands. It is largely an agrarian state, and the major crops are paddy, wheat, lentils, sugarcane, and jute.

More than 70% of the state is flood-prone and 30% is drought-prone, exposing over a 100 million people to the vagaries of climate. Almost 80 million people are exposed to floods, of which 68% are women and children and almost 12% are below the poverty line, making them severely vulnerable to the impacts of floods. Almost 28 million people are exposed to droughts, of which 9.5% are extremely vulnerable, given their inherent poverty.

These characteristics make Bihar 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.

3.1. Historical climate

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

3.1.1. Trends in temperature

Bihar has recorded a moderate warming of 0.12°C to 0.46°C in the summer maximum temperature and 0.32°C to 0.53°C in the winter minimum temperature during the historical period. Figure 3-1 presents the mean summer maximum and winter minimum temperatures in Bihar during the historical period.

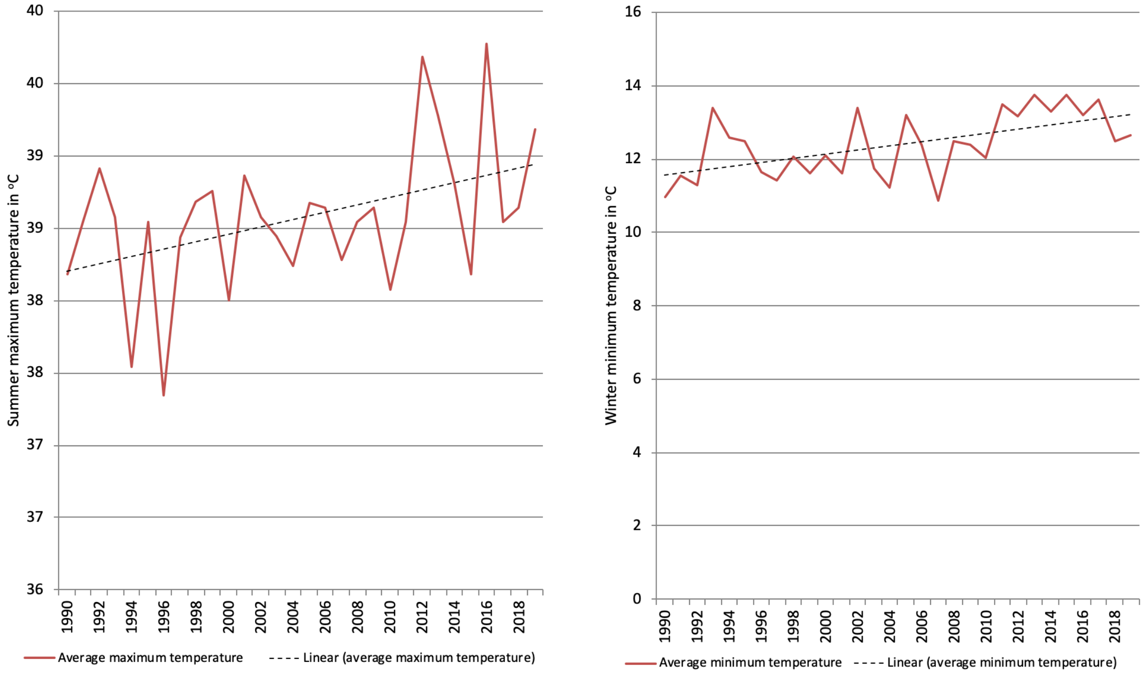


Figure 3-1: Mean summer maximum and winter minimum temperatures in Bihar during the historical period (1990–2019)

3.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and kharif season rainfall, the main monsoon season, was recorded across the districts of Bihar. The increase in the annual and kharif season rainfall was largely in the range of 5% to 10% in a majority of the districts. A higher increase in rainfall (10% to 15%) was recorded in the western districts of Bihar during the historical period. Figure 3-2 presents the mean annual rainfall in Bihar during the historical period.

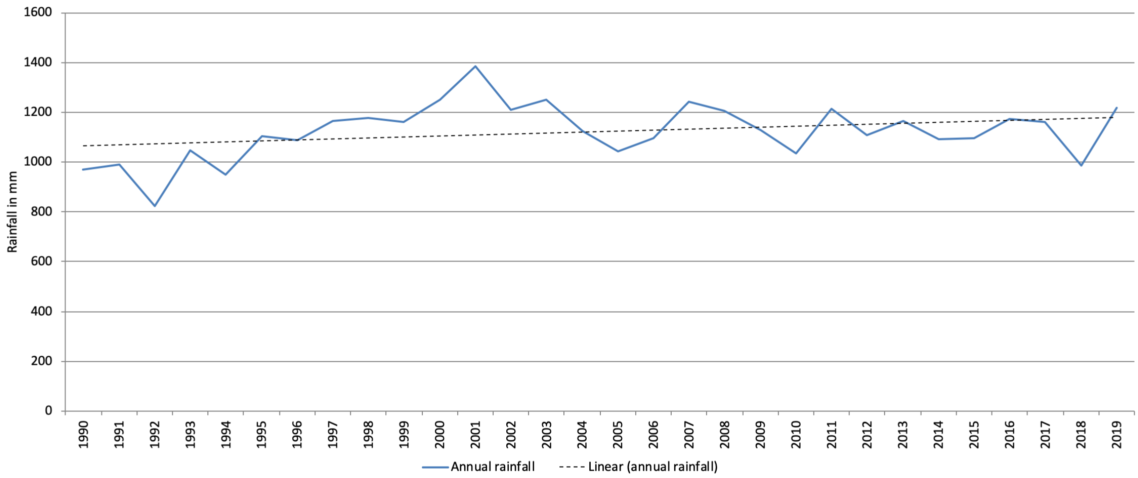


Figure 3-2: Mean annual rainfall in Bihar during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 19% in Saharsa to 40% in Samastipur (Figure 3-3). The rabi season rainfall variability was in the range of 70% in Begusarai to >100% in 15 of the 38 districts, indicating a complete failure of rainfall during the historical period (Figure 3-3).

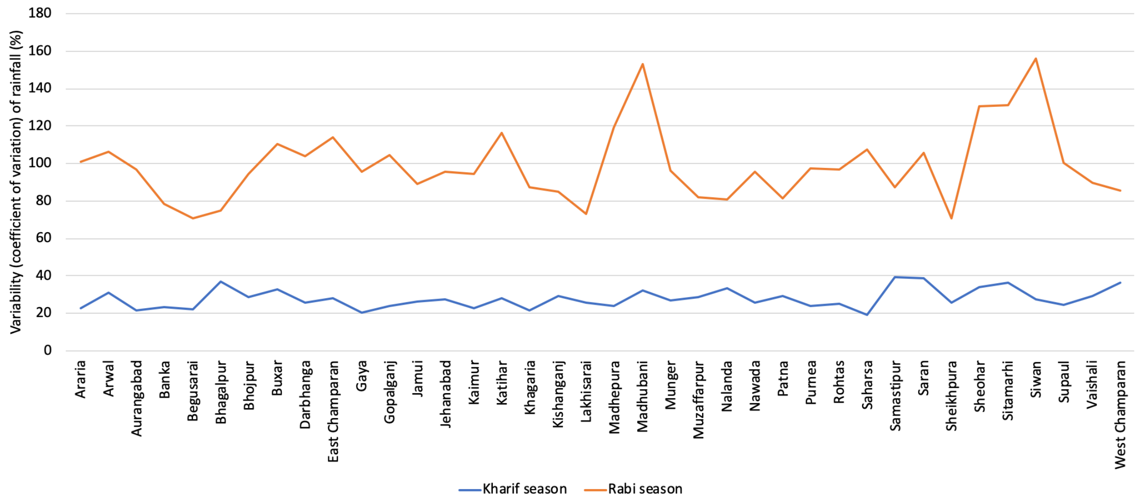


Figure 3-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

3.2. Climate change projections

Temperature and rainfall are 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 summer maximum and winter minimum temperatures for all the districts of Bihar are presented in Figure 3-4.

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°C to 1.5°C	Increases by 1°C to 1.5°C
RCP 8.5	Increases by 1°C to 2°C	Increases by 1°C to 2°C

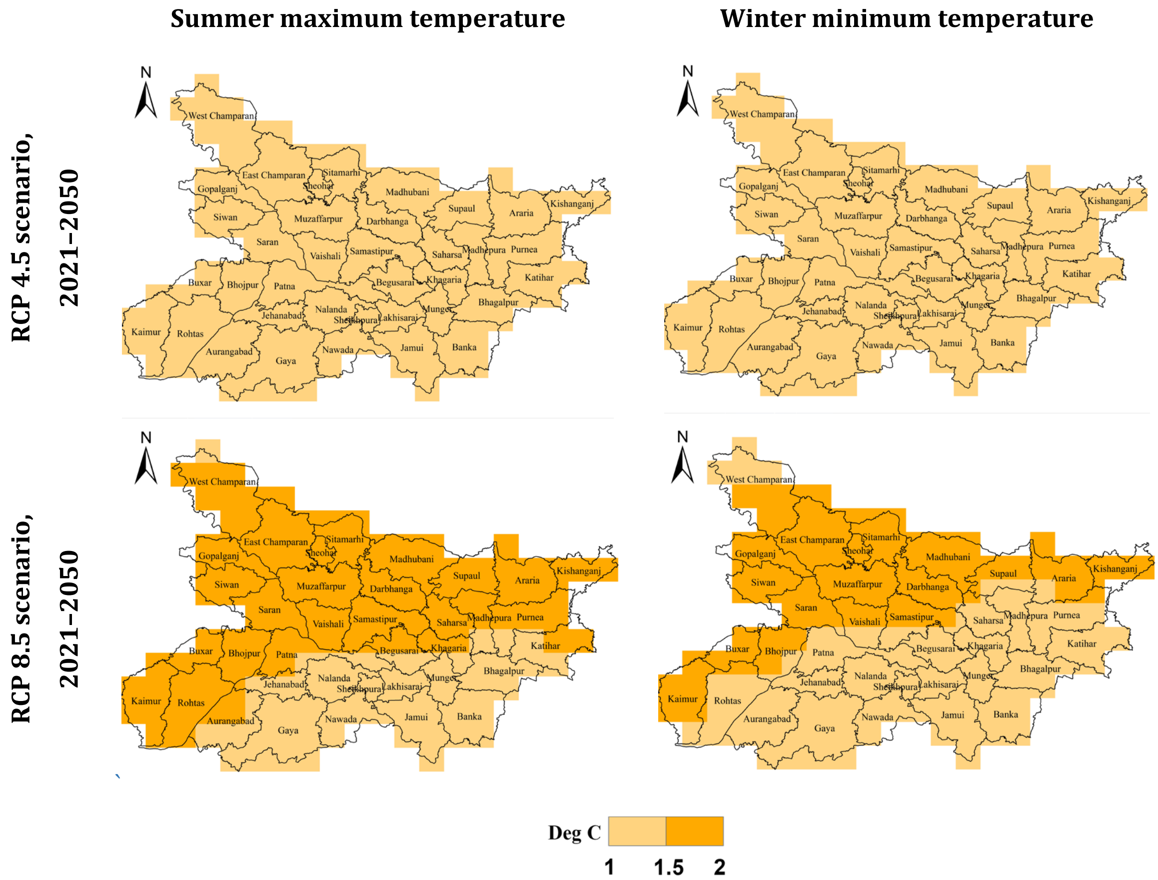


Figure 3-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

3.2.2. Rainfall projections

3.2.2.1. Number of rainy days

According to the India Meteorological Department (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 3-5). 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 1255 to 2240 days over the 30-year historical period increases to 1348 to 2281 days under the RCP 4.5 scenario and 1369 to 2306 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 Purnea. The maximum increase annually is by 7 days in Aurangabad; 6 days in Muzaffarpur, Nawada, and Sitamarhi; 5 days in Sheikhpura, Katihar, Buxar, Siwan, East Champaran, Begusarai, Araria, Darbhanga, Kaimur, and Sheohar; and 1 to 4 days in the remaining districts.

RCP 8.5 scenario: Increases by 2 to 5 days annually in all the districts. The maximum increase annually is by 5 days in Siwan, Begusarai, Madhubani, Lakhisarai, Buxar, Samastipur, Nawada, Sitamarhi, East Champaran, Muzaffarpur, Sheohar, and Aurangabad and 1 to 4 days in the remaining districts.

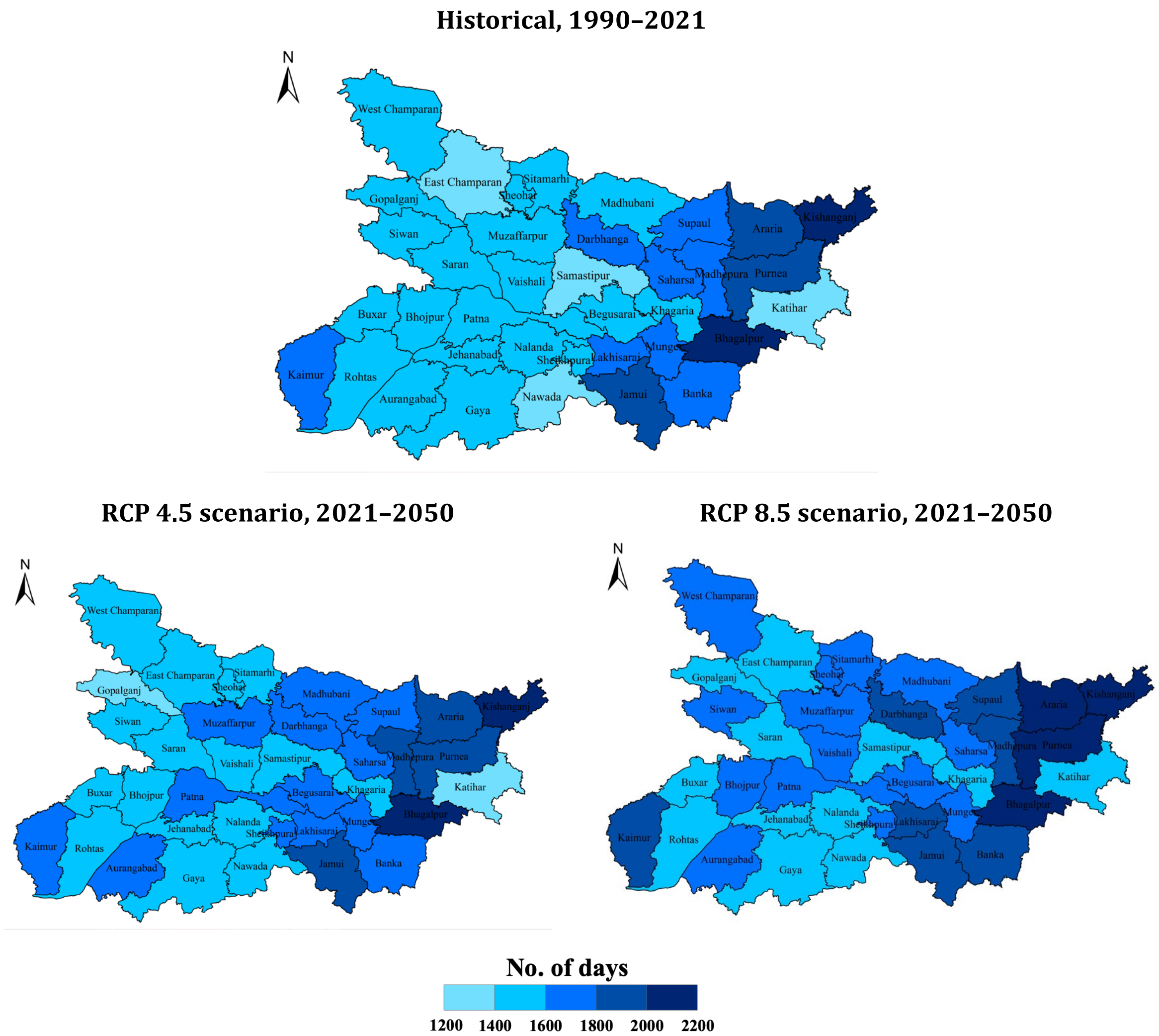


Figure 3-5: The total number of rainy days during the historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

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 3-6 presents district-wise changes in the kharif season rainfall, and Figure 3-7 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 7% in Araria, Kishanganj, and Katihar to 19% in Rohtas	Declines in 27 districts by 5% to 11%, increases in nine districts by 1% to 5% and no change in two districts
RCP 8.5	Increases in all the districts, from12% in Araria to 24% in West Champaran	Declines in 29 districts by 9% to 13% and increase in nine districts by 3% to 9%

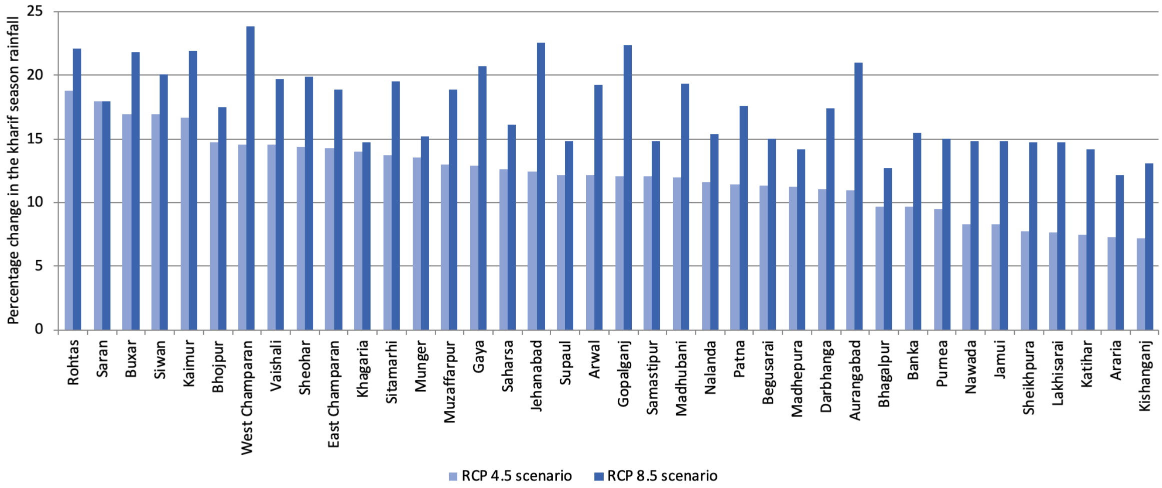


Figure 3-6: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

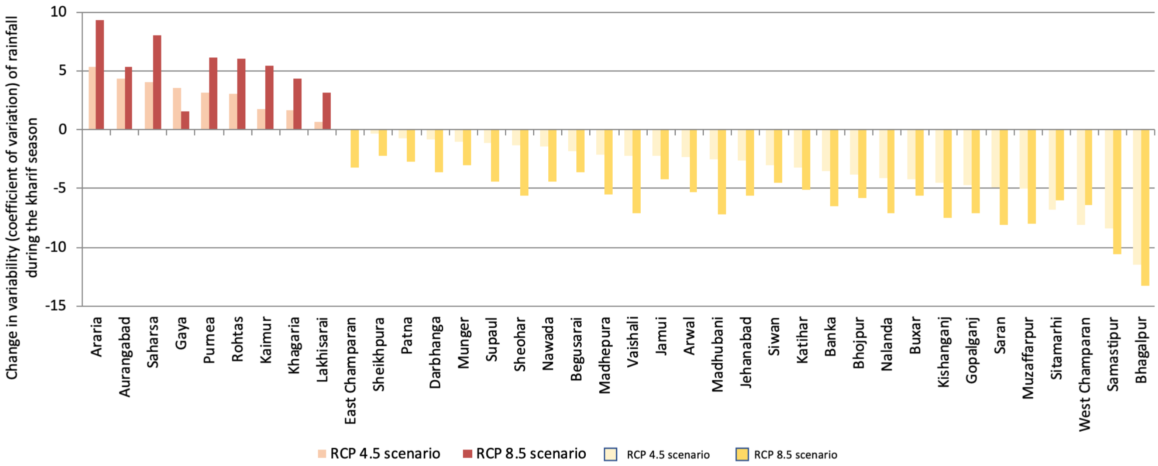


Figure 3-7: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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 3-8 presents district-wise changes in the rabi season rainfall, and Figure 3-9 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 7% in Muzaffarpur to 55% in the Bhojpur district	Declines in all the 38 districts by 3% to 74%.
RCP 8.5	Increases in all the districts, from 19% in Madhepura to 85% in West Champaran	Declines in all the 38 districts by 1% to 70%.

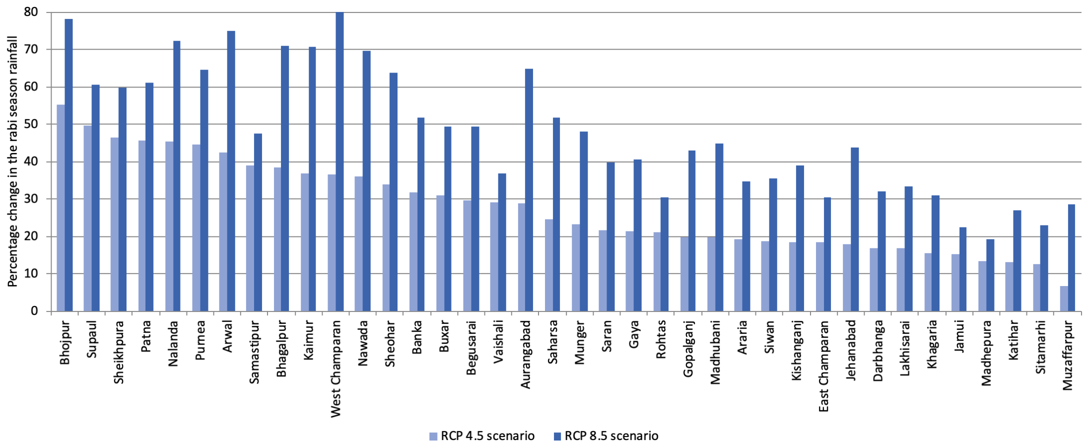


Figure 3-8: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

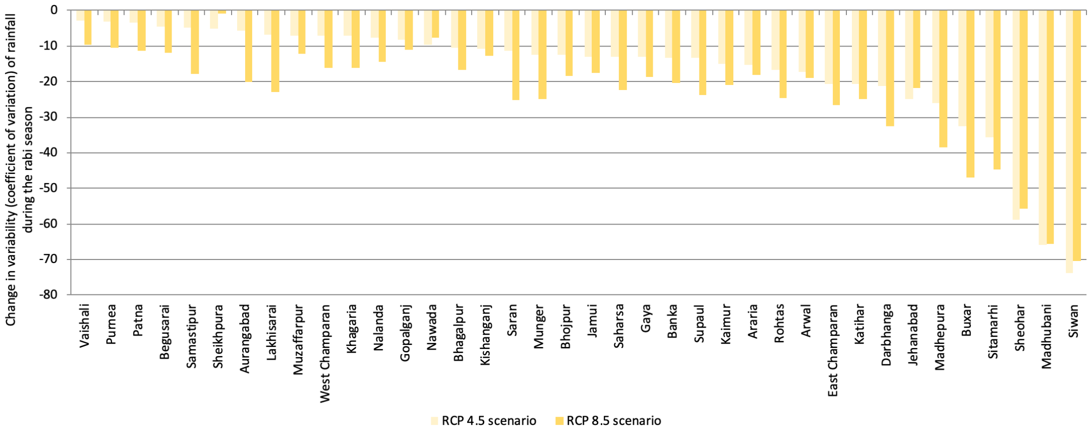


Figure 3-9: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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 Bihar.

High-intensity rainfall events (Figure 3-10)

The total number of high-intensity rainfall events increases from 61 to 226 days during the historical period (1990–2019) to 78 to 266 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 97 to 280 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 is projected in all the districts of Bihar. The projected increase per annum is by one to two events in all the districts.

RCP 8.5 scenario: An increase in high-intensity rainfall events is projected in all the districts of Bihar. The projected increase per annum is by one to three additional events.

Very high-intensity rainfall events (Figure 3-11)

The total number of very high-intensity rainfall events increases from 7 to 61 days during the historical period (1990–2019) to 22 to 80 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 47 to 98 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 two events in Lakhisarai and Madhepura districts. In the remaining 36 districts, the increase is by one additional event per annum.

RCP 8.5 scenario: The projected increase per annum is by two events in 26 districts, including Kishanganj, Muzaffarpur, Buxar, Saran, Bhagalpur, Samastipur, Banka, and Gaya. In the remaining districts—Vaishali, Nawada, Araria, Khagaria, Madhubani, Kaimur, West Champaran, Aurangabad, Begusarai, Nalanda, Katihar, and Jehanabad—the increase is by one additional event per annum.

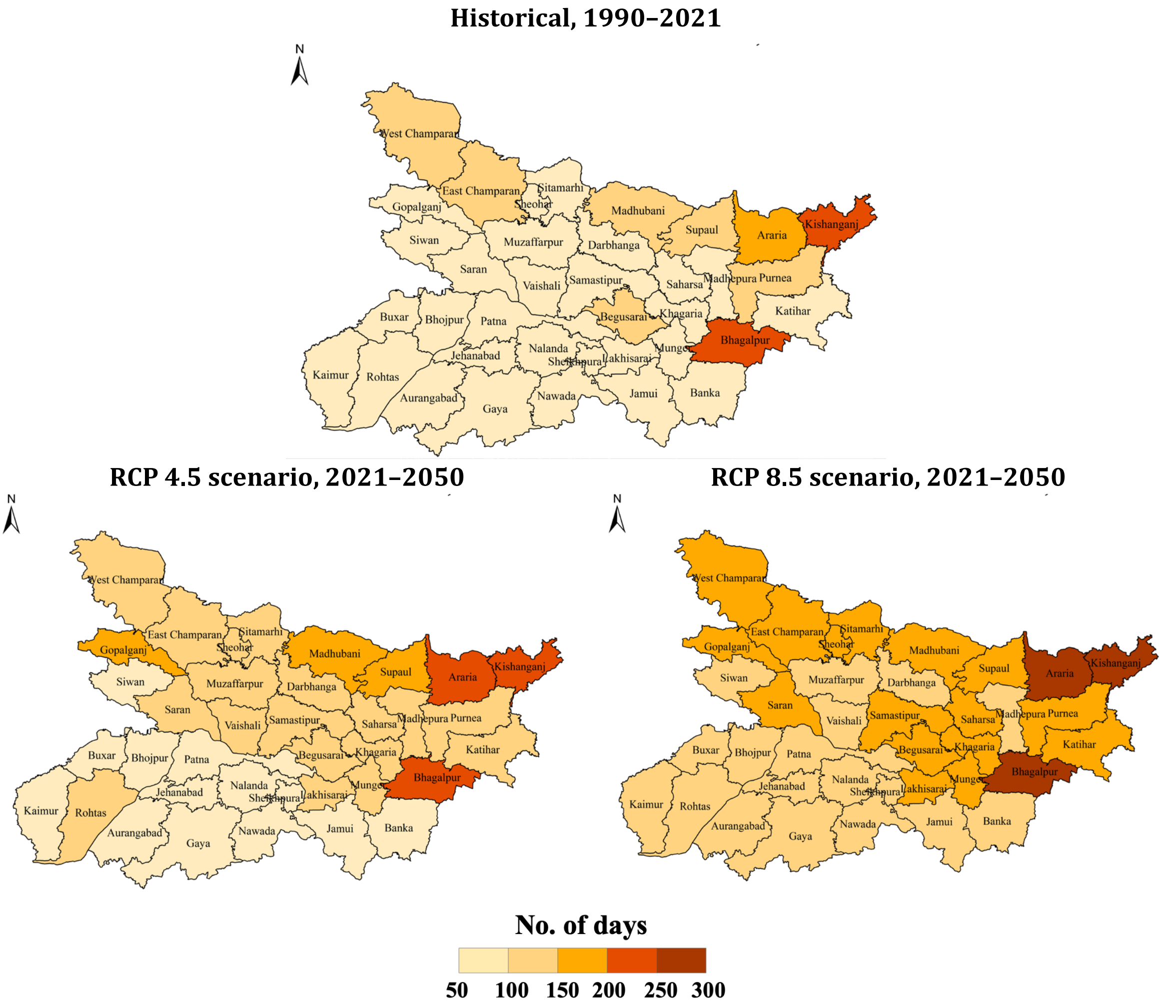


Figure 3-10: The total number of high-intensity rainfall events over a 30-year period during historical (1990–2019) and projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

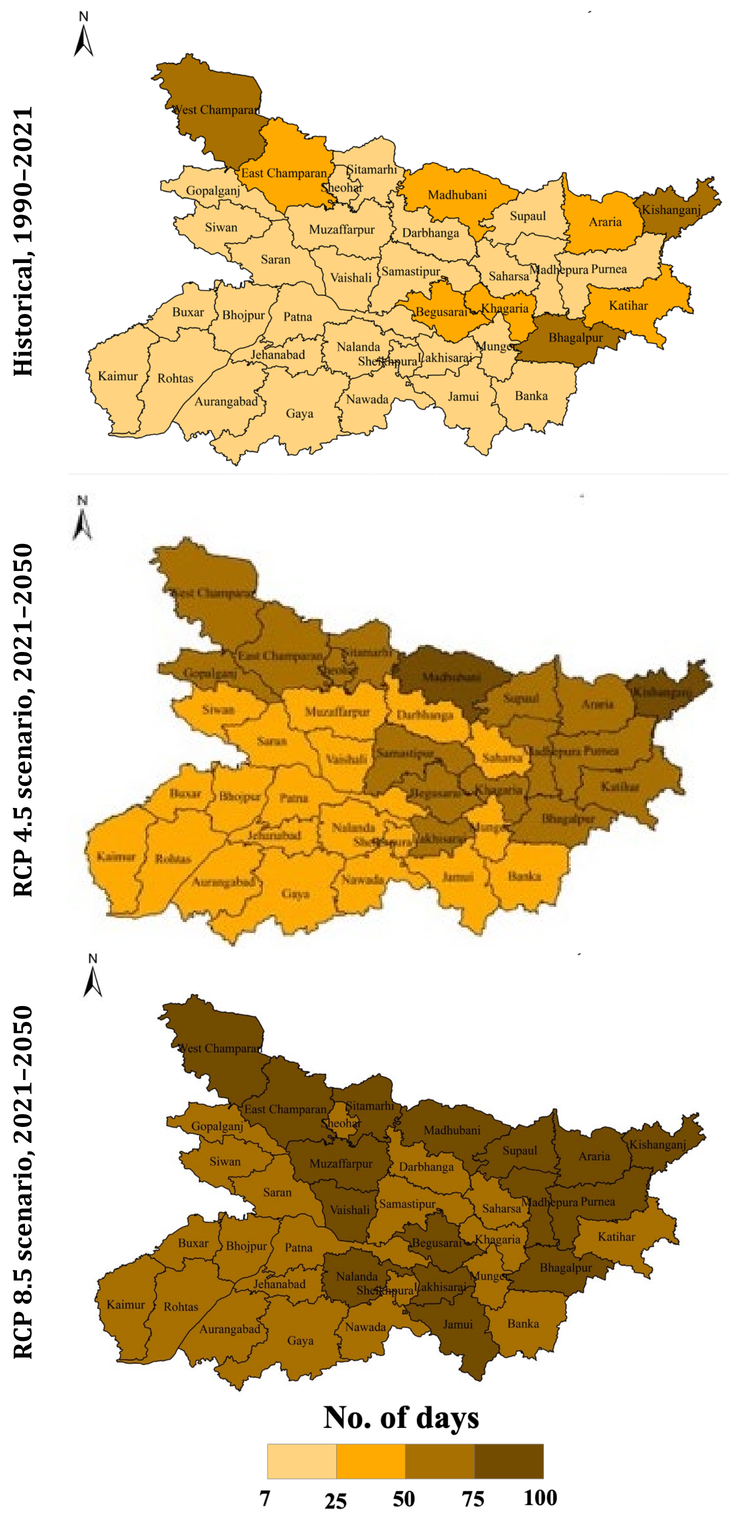


Figure 3-11: The total number of very high-intensity rainfall events over a 30-year period during historical (1990–2019) and projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

Rainfall deficient years (Figure 3-12)

Rainfall deficient years computed by considering the rainfall during the kharif season are projected to decline in a majority of the districts under both climate scenarios. The number of rainfall deficient years declines from 8 to 15 years during the historical 30-year period to 7 to 13 years under the RCP 4.5 scenario and 6 to 12 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: There is a projected decline in 23 districts, by 1 to 4 years, and no change is projected in the remaining 15 districts, including Araria, Banka, Bhagalpur, Gaya, Jamui, Katihar, Kaimur, Lakhisarai, Madhubani, Purnea, Rohtas, and Vaishali.

RCP 8.5 scenario: There is a projected decline in 35 of the 38 districts by 1 to 5 years, and no change is projected in the Araria, East Champaran, and Saharsa districts.

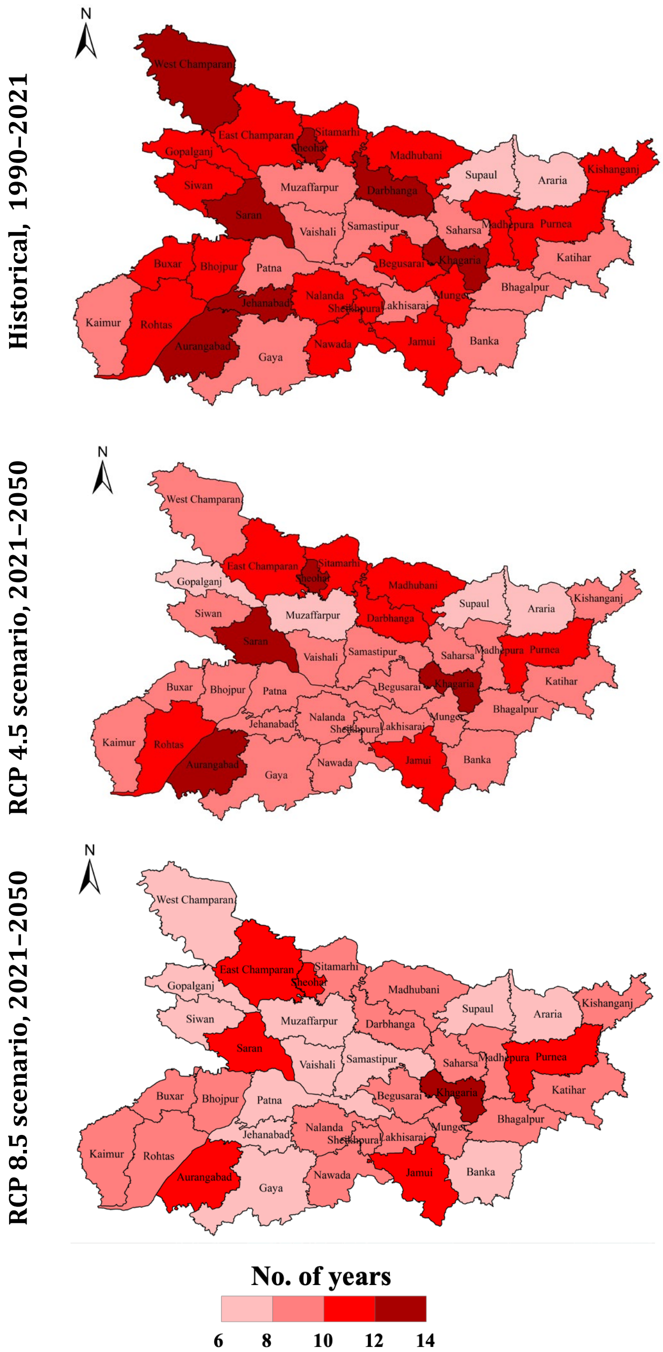


Figure 3-12: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

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

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

- Summer maximum and winter minimum temperatures are projected to warm by 1°C to 1.5°C uniformly across all the districts under the RCP 4.5 scenario and 1°C to 2 °C under the RCP 8.5 scenario.

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

- There will be a notable increase in rainfall particularly in the eastern districts under RCP 4.5 and RCP 8.5 scenarios.

Rainfall variability is projected to decline marginally in all the districts during kharif and rabi seasons in all the districts.

- A decline in rainfall variability during the kharif season is projected under both climate scenarios in Araria, Aurangabad, Gaya, Kaimur, Khagaria, Lakhisarai, Purnea, Rohtas, and Saharsa districts.

The number of rainy days is projected to increase in all the districts under both climate scenarios (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 2 to 5 days under the RCP 8.5 scenario.

An increase in the occurrence of heavy rainfall events is projected in the range of one to two events annually under both RCP 4.5 and RCP 8.5 scenarios (Appendix 3-4).

- There is a larger increase particularly in the eastern districts of Bihar.

Rainfall deficient years are projected to decline under RCP 4.5 and RCP 8.5 scenarios (Appendix 3-4).

Appendix

Appendix 3-1: 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
Araria	1.4	1.6	1.5	1.8
Arwal	1.2	1.7	1.3	1.6
Aurangabad	1.4	1.6	1.2	1.7
Banka	1.2	1.5	1.3	1.5
Begusarai	1.2	1.4	1.3	1.5
Bhagalpur	1.1	1.4	1.2	1.5
Bhojpur	1.3	1.5	1.4	1.7
Buxar	1.4	1.8	1.4	1.6
Darbhanga	1.4	1.7	1.2	1.5
East Champaran	1.3	1.5	1.4	1.5
Gaya	1.4	1.8	1.2	1.5
Gopalganj	1.2	1.6	1.4	1.7
Jamui	1.4	1.5	1.3	1.5
Jehanabad	1.3	1.6	1.5	1.8
Kaimur	1.3	1.6	1.2	1.7
Katihar	1.1	1.4	1.3	1.5
Khagaria	1.2	1.5	1.1	1.4
Kishanganj	1.3	1.7	1.4	1.9
Lakhisarai	1.1	1.4	1.2	1.5
Madhepura	1.2	1.5	1.1	1.3
Madhubani	1.3	1.9	1.3	1.8
Munger	1.2	1.4	1.2	1.5
Muzaffarpur	1.3	1.7	1.3	1.9
Nalanda	1.4	1.7	1.2	1.5
Nawada	1.3	1.6	1.4	1.5
Patna	1.3	1.6	1.2	1.6
Purnea	1.0	1.5	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
Rohtas	1.3	1.7	1.4	1.8
Saharsa	1.1	1.5	1.2	1.4
Samastipur	1.3	1.6	1.1	1.5
Saran	1.4	1.7	1.2	1.8
Sheikhpura	1.4	1.7	1.2	1.5
Sheohar	1.5	1.7	1.1	1.4
Sitamarhi	1.4	1.8	1.2	1.4
Siwan	1.2	1.7	1.4	1.9
Supaul	1.3	1.6	1.3	1.8
Vaishali	1.4	1.9	1.4	1.8
West Champaran	1.2	1.7	1.2	1.5

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
Araria	7	13	7	12	19	35
Arwal	14	19	12	19	42	75
Aurangabad	13	19	11	21	29	65
Banka	8	13	10	15	32	52
Begusarai	14	15	11	15	30	49
Bhagalpur	5	12	7	14	13	27
Bhojpur	10	13	10	13	38	71
Buxar	18	21	15	18	55	78
Darbhanga	17	19	17	22	31	50
East Champaran	14	18	11	17	17	32
Gaya	15	19	13	21	21	41
Gopalganj	11	16	12	22	20	43
Jamui	7	14	8	15	15	22
Jehanabad	13	19	12	23	18	44
Kaimur	16	20	17	22	37	71
Katihar	13	15	14	15	16	31
Khagaria	6	12	7	13	18	39
Kishanganj	7	14	8	15	17	33
Lakhisarai	13	14	11	14	14	19
Madhepura	13	17	12	19	20	45
Madhubani	10	14	14	15	23	48
Munger	14	20	13	19	7	29
Muzaffarpur	12	16	12	15	46	72
Nalanda	10	16	8	15	36	70
Nawada	12	15	15	24	37	85
Patna	12	20	11	18	46	61
Purnea	12	17	14	19	18	30
Rohtas	7	12	10	15	45	64
Saharsa	17	20	19	22	21	30

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
Samastipur	11	14	13	16	25	52
Saran	13	14	12	15	39	48
Sheikhpura	18	20	18	18	22	40
Sheohar	8	12	8	15	46	60
Sitamarhi	15	19	14	20	34	64
Siwan	14	19	14	19	13	23
Supaul	17	20	17	20	19	36
Vaishali	13	15	12	15	50	61
West Champaran	15	18	15	20	29	37

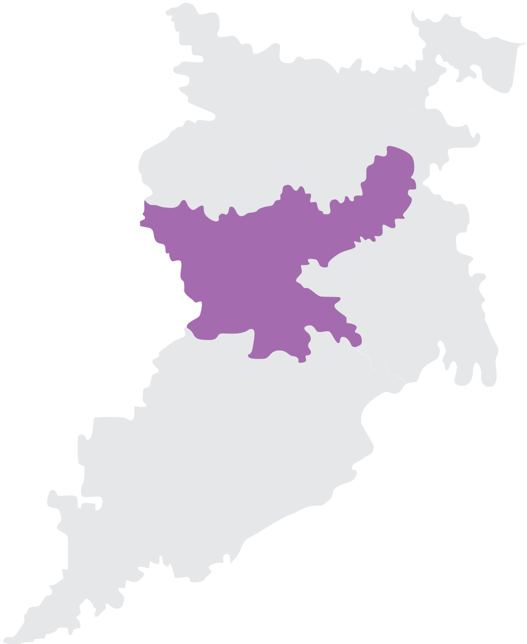
Appendix 3-3: The total number of rainy days (>2.5 cm/day) during the historical period (1990–2019) and the projected 2030s (2021–2050)

Districts	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Araria	1877	1980	2011
Arwal	1399	1467	1497
Aurangabad	1559	1690	1716
Banka	1773	1783	1828
Begusarai	1589	1691	1727
Bhagalpur	2196	2273	2291
Bhojpur	1528	1571	1650
Buxar	1454	1549	1596
Darbhanga	1695	1798	1812
East Champaran	1388	1486	1538
Gaya	1503	1513	1572
Gopalganj	1407	1450	1493
Jamui	1884	1921	1997
Jehanabad	1482	1562	1597
Kaimur	1690	1797	1825
Katihar	1255	1348	1369
Khagaria	1475	1560	1597
Kishanganj	2240	2281	2306
Lakhisarai	1681	1756	1822
Madhepura	1755	1812	1867
Madhubani	1555	1632	1695
Munger	1662	1741	1796
Muzaffarpur	1559	1673	1715
Nalanda	1408	1476	1506
Nawada	1359	1484	1505
Patna	1586	1666	1694
Purnea	1956	1965	2027
Rohtas	1487	1561	1599
Saharsa	1626	1699	1741
Samastipur	1355	1437	1501
Saran	1409	1458	1507
Sheikhpura	1586	1677	1692
Sheohar	1487	1595	1644
Sitamarhi	1476	1589	1623
Siwan	1492	1589	1630
Supaul	1734	1799	1823
Vaishali	1530	1583	1624
West Champaran	1511	1600	1640

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 deficient rainfall 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
Araria	197	231	268	50	68	79	8	8	8
Arwal	72	89	101	14	45	67	14	13	11
Aurangabad	70	89	110	7	38	47	8	7	6
Banka	87	94	119	18	45	68	10	10	8
Begusarai	72	78	97	17	45	60	11	10	10
Bhagalpur	226	266	280	54	73	90	11	10	9
Bhojpur	79	98	123	9	40	66	11	10	9
Buxar	77	83	115	10	48	56	12	10	10
Darbhanga	84	105	133	13	39	68	13	12	10
East Champaran	117	145	160	26	68	78	12	12	12
Gaya	61	97	136	7	41	72	9	9	8
Gopalganj	94	155	167	23	55	72	11	8	8
Jamui	73	96	112	15	46	78	12	12	11
Jehanabad	67	97	123	13	50	73	13	9	8
Kaimur	123	148	167	34	64	78	10	10	9
Katihar	91	136	155	26	58	70	10	10	9
Khagaria	96	127	163	30	53	66	14	14	13
Kishanganj	219	250	270	61	76	92	12	10	9
Lakhisarai	93	130	158	20	57	90	10	10	8
Madhepura	96	111	147	16	66	87	11	10	9
Madhubani	117	167	190	33	80	98	12	12	11
Munger	92	122	159	22	37	56	11	10	9
Muzaffarpur	76	106	134	11	42	78	10	8	7
Nalanda	72	89	109	7	36	76	12	10	9
Nawada	61	90	132	12	31	56	12	10	9
Patna	81	90	121	9	28	48	10	9	8
Purnea	120	150	177	23	54	78	12	12	11
Rohtas	79	106	145	10	37	68	11	11	10
Saharsa	87	120	151	21	48	70	9	9	9
Samastipur	98	136	167	25	51	72	10	9	8
Saran	91	130	168	15	42	67	15	13	11
Sheikhpura	67	90	112	12	42	67	12	10	9
Sheohar	85	130	168	16	52	70	13	13	12
Sitamarhi	81	133	157	14	56	80	12	11	10
Siwan	87	99	136	7	22	60	11	9	8
Supaul	136	165	170	25	60	76	8	7	7
Vaishali	83	112	145	18	42	78	9	9	8
West Champaran	112	134	170	53	70	77	14	12	10

4. Jharkhand



The state of Jharkhand has a geographic area of 79,714 sq. km and a population of 32.99 million, which is predominantly rural, according to Census 2011. The state is bordered by Bihar in the north, Uttar Pradesh in the north-west, Chhattisgarh in the west, Odisha in the south, and West Bengal in the east. Jharkhand has 24 districts, and its climate ranges from dry semi-humid to humid semi-arid, with an average annual rainfall of about 900 mm and temperature varying between 4°C and 47°C. Although 54.5% of the state's area is arable, only 17.37% is under cultivation, out of which 92% is rainfed. Agriculture and allied activities remain the main source of income for almost 80% of the workforce even though productivity levels are low and variable due to heavy dependence on rainfall. This has resulted in almost 77% of Jharkhand living in poverty. Livestock and dairy, in particular, play an important role in augmenting rural incomes and empowering women. According to the 19th Livestock Census (2012), the state has a total livestock population of 18.05 million.

Jharkhand is prone to several natural hazards, including droughts, heatwaves, cyclones, floods, earthquakes, and forest fires. An increasing trend in the frequency of occurrence of droughts and heatwaves has been recorded across the state. According to the Vulnerability Atlas of India (2019), about 4% of the state's area is at high risk and 52% of the area is at moderate risk of damage by earthquakes. The state is also prone to damage caused by cyclonic storms, with about 1% of the state exposed to very high wind speeds (50 m/s to 55 m/s) and more than 25% to high wind speeds of 47 m/s. In the recent past, flash floods have become a common occurrence in 11 districts with the erosion of embankments, catchment area encroachment, and an influx of people into flood-prone regions. As the state's forests are mostly dry deciduous, they are prone to fires in the summer months.

These characteristics make Jharkhand climate-sensitive, underpinning the need for climate information. Climate data could serve as a 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

Jharkhand recorded a moderate warming of 0.1^{0}C to 0.48^{0}C in the summer maximum temperature and a higher warming in the range of 0.33^{0}C to 0.54^{0}C in the winter minimum temperature during the historical period. Figure 4-1 presents the mean summer maximum and winter minimum temperatures in Jharkhand during the historical period.

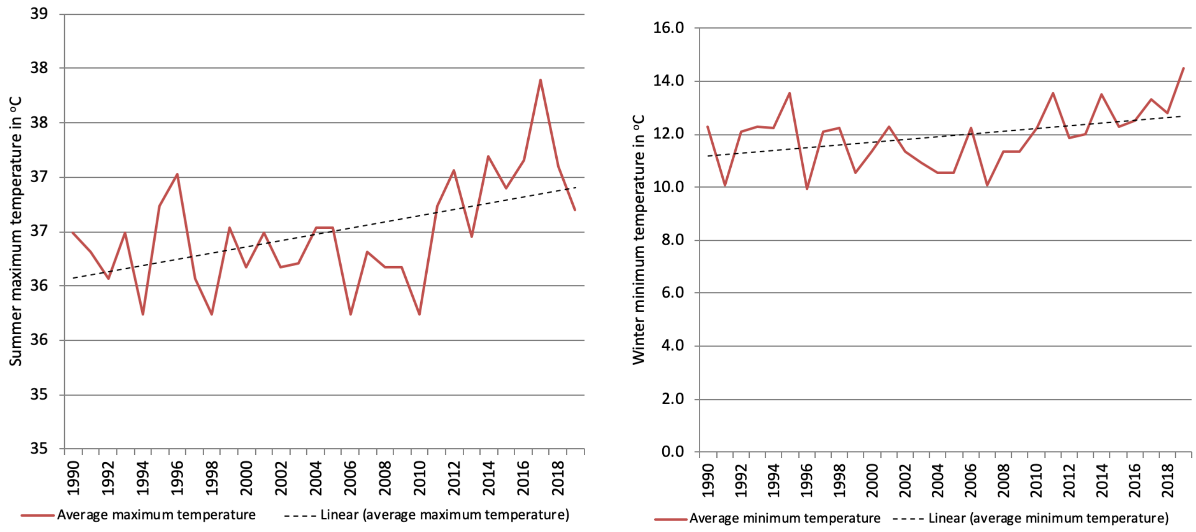


Figure 4-1: Mean summer maximum and winter minimum temperatures in Jharkhand during the historical period (1990–2019)

4.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and the kharif season rainfall was recorded during the historical period. Figure 4-2 presents the mean annual rainfall in Jharkhand during the historical period.

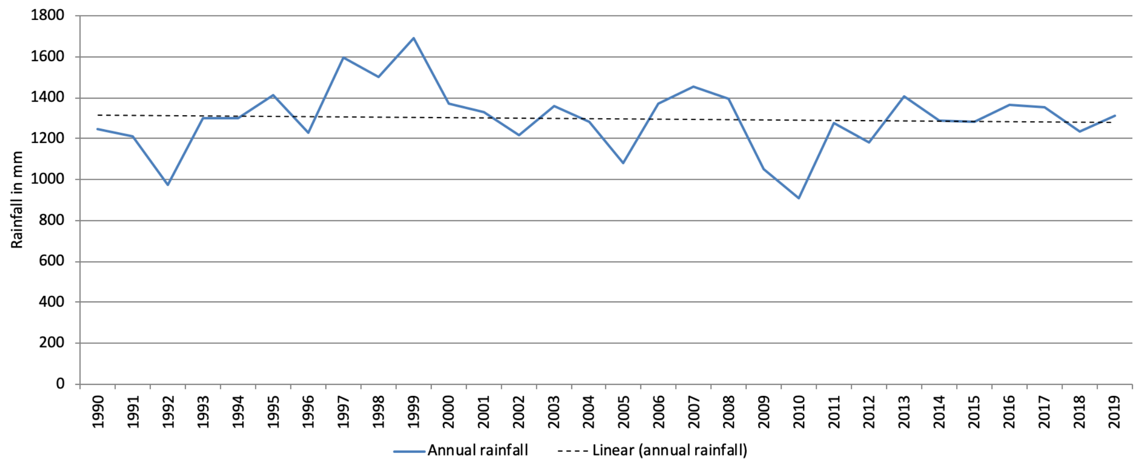


Figure 4-2: Mean annual rainfall in Jharkhand during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 17% in Godda to 35% in Seraikela-Kharsawan. During this period, the rabi season rainfall variability ranged from 63% in Simdega to >100% in a majority of the districts—an indication of total failure of rainfall during the season (Figure 4-3).

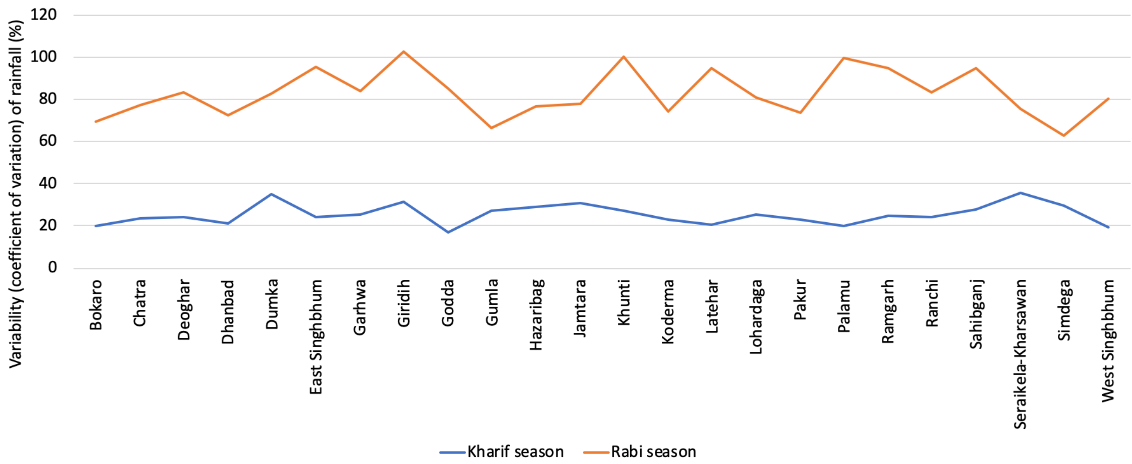


Figure 4-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

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 the summer maximum and winter minimum temperatures for all the districts of Jharkhand 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 1⁰C to 2⁰C	Increases by 1⁰C to 2⁰C
RCP 8.5	Increases by 1⁰C to 2⁰C, with a greater number of districts experiencing warming	Increases by 1⁰C to 2⁰C, with a greater number of districts experiencing warming

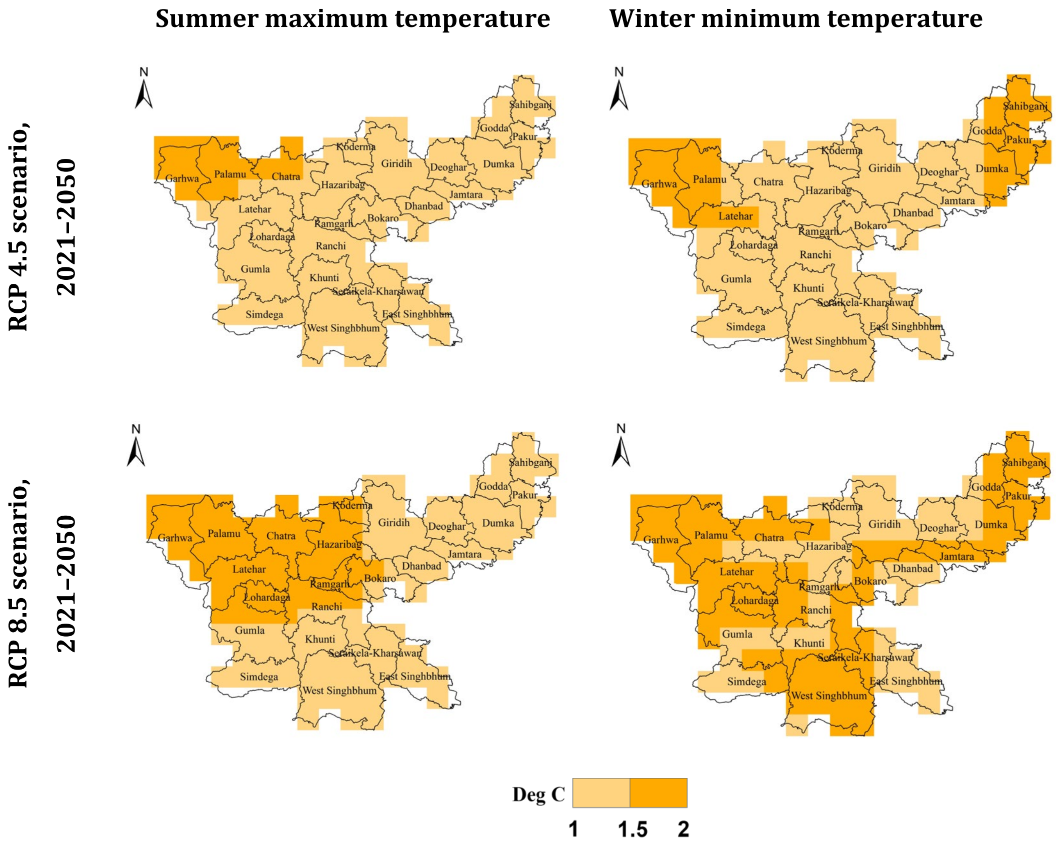


Figure 4-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

4.2.1.1. Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 1, a heatwave analysis of the East Singhbhum 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 be an increase in the number of heatwaves (departure from the normal temperature is 4.5°C to 6.4°C) as well as 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 4-5) compared to the historical period (1990–2019). While heatwaves are projected to increase marginally, severe heatwaves are projected to treble under both RCP 4.5 and RCP 8.5 scenarios.

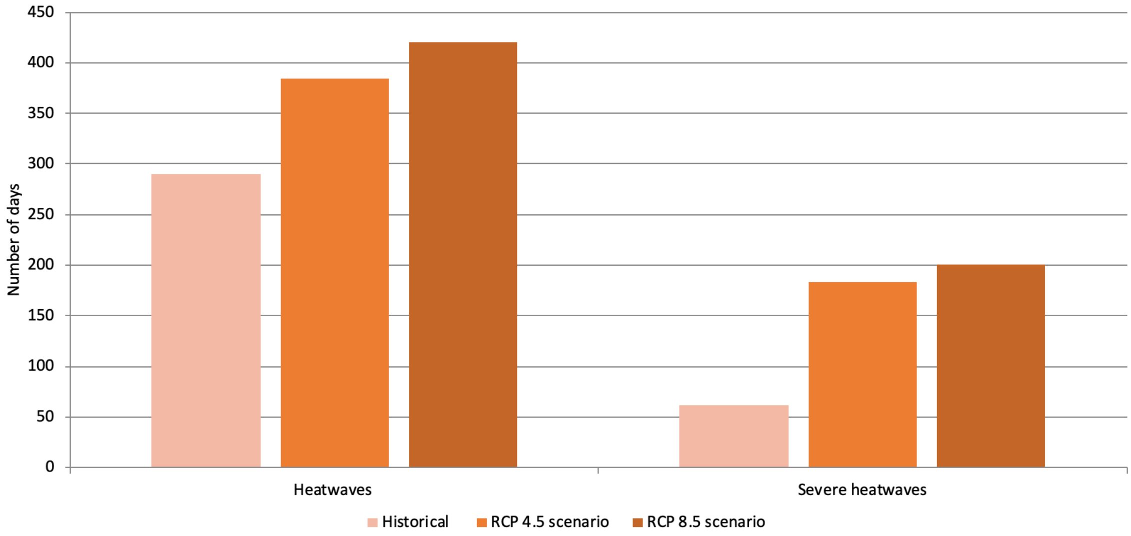


Figure 4-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

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 4-6). 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 1528 to 2196 days over the 30-year historical period increases to 1590 to 2234 days under the RCP 4.5 scenario and 1634 to 2290 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 2 to 5 days annually in all the districts. The increase is by 5 days in Seraikela-Kharsawan and Koderma; 4 days in Garhwa, Pakur, Hazaribag, Dhanbad, Ramgarh, East Singhbhum, Jamtara, Ranchi, and Dumka; 3 days in Gumla, Palamu, Latehar, Bokaro, and West Singhbhum; and 2 days in the remaining districts.

RCP 8.5 scenario: Projected to increase by 1 to 5 days annually in all the districts. The increase is by 5 days in Seraikela-Kharsawan, Koderma, Garhwa, and Pakur; 4 days in Hazaribag, Chatra, Dhanbad, West Singhbhum, East Singhbhum, Jamtara, Bokaro, Dumka, Palamu, and Deoghar; 3 days in Gumla, Khunti, Latehar, Ramgarh, Ranchi, Sahibganj, Giridih, Simdega, and Lohardaga; and 1 day in Godda.

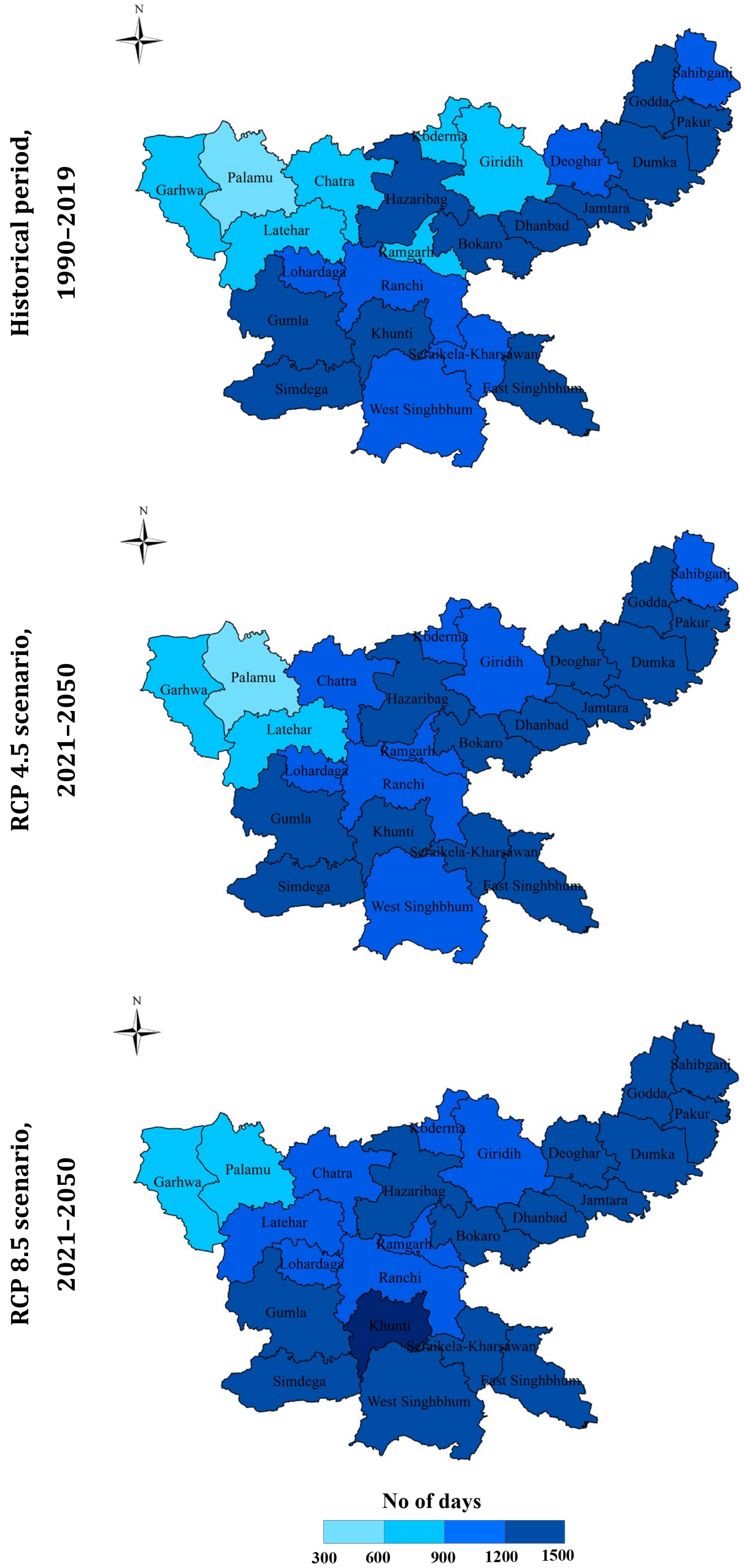


Figure 4-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

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 4-7 presents district-wise changes in the kharif season rainfall, and Figure 4-8 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 Ramgarh to 46% in Pakur	Declines in 12 districts by 1% to 11%, increases in six districts by 1% to 9%, and no change in six districts
RCP 8.5	Increases in all the districts, from 6% in Palamu to 36% in Khunti and Sahibganj	Declines in 18 districts by 2% to 13%, increases in four districts by 2% to 7%, and no change in Ranchi and Pakur

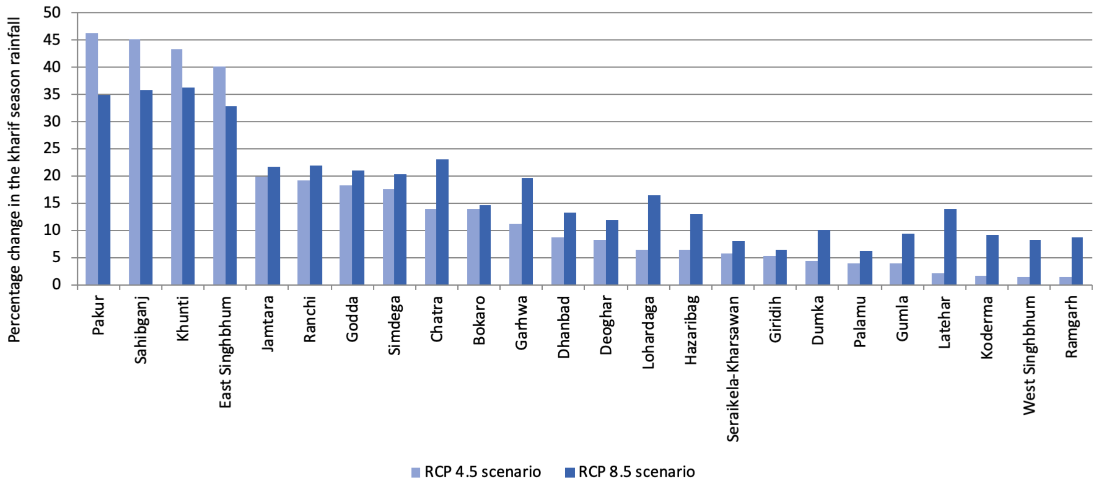


Figure 4-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

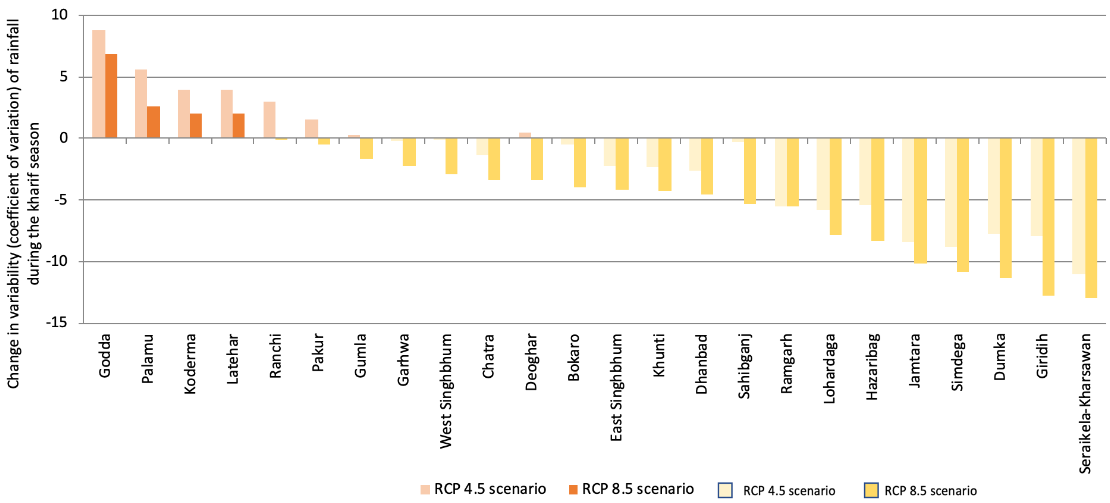


Figure 4-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

4.2.2.3. 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 4-9 presents district-wise changes in the rabi season rainfall, and Figure 4-10 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 3% in Lohardaga to 26% in Bokaro	Declines in all the districts by 7% to 45%
RCP 8.5	Increases in all the districts, from 2% in West Singhbhum to 36% in Ramgarh	Declines in all the districts by 10% to 47%

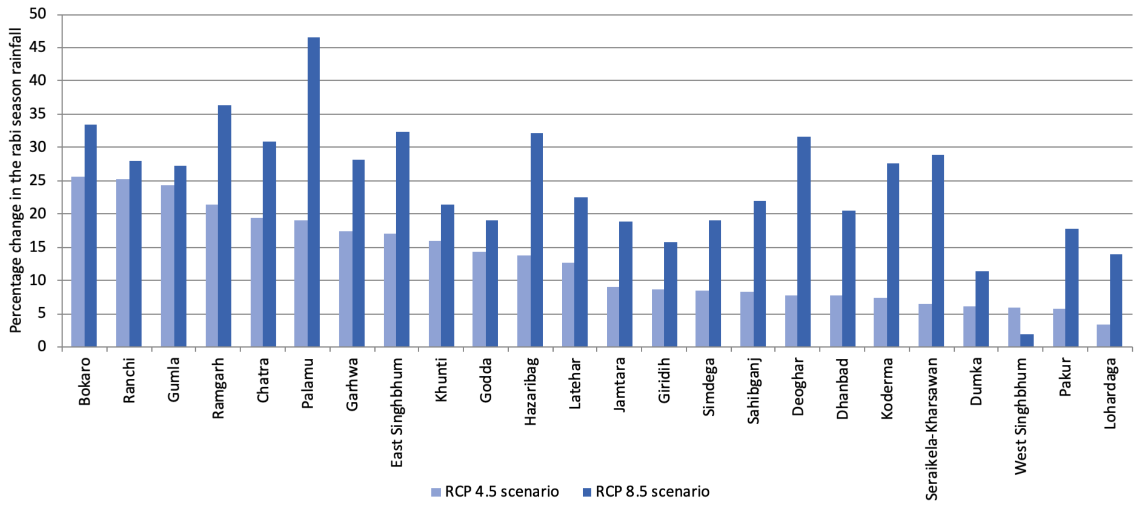


Figure 4-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

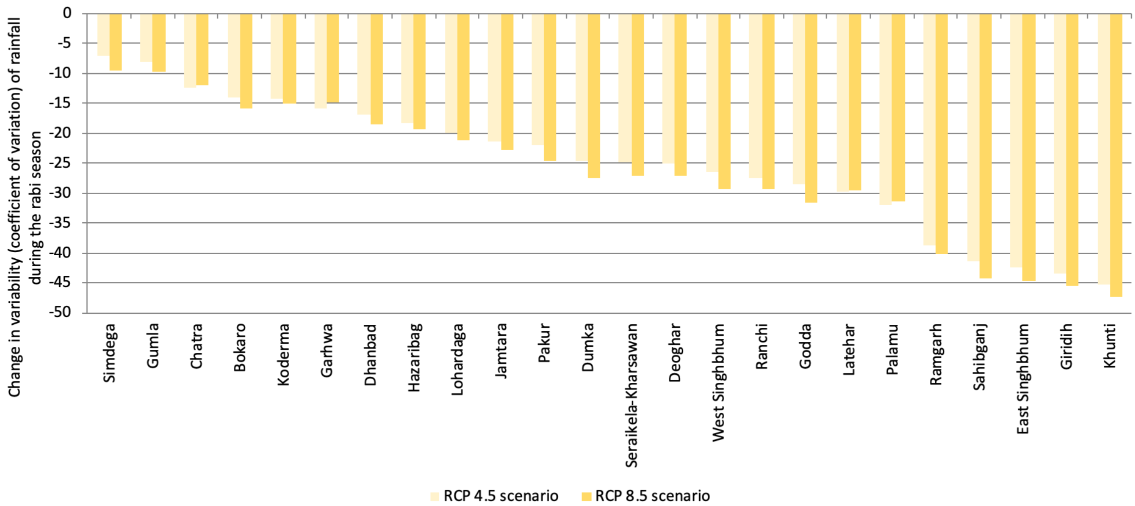


Figure 4-10: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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 Jharkhand.

High-intensity rainfall events (Figure 4-11)

The total number of high-intensity rainfall events increases from 44 to 95 days during the historical period (1990–2019) to 78 to 132 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 97 to 156 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 Gumla and Simdega. In the remaining districts, the projected increase is marginal, by one event per annum.

RCP 8.5 scenario: The projected increase per annum is by one to three events. The increase is by three events in Gumla, Godda, and Ranchi; two events in 18 districts, including Khunti, Simdega, Lohardaga, East Singhbhum, Giridih, Koderma, Seraikela-Kharsawan, Jamtara, Latehar, and Ramgarh. In Deoghar, West Singhbhum, and Bokaro districts, the projected increase is marginal, by one event per annum.

Very-high intensity rainfall events (Figure 4-11)

The total number of very high-intensity rainfall events increases from 4 to 23 days during the historical period (1990–2019) to 35 to 68 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 64 to 89 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 Sahibganj, Hazaribag, Ramgarh, and Giridih. In the remaining districts, the projected increase is marginal, by one event per annum.

RCP 8.5 scenario: Very high-intensity rainfall events are projected to increase per annum by two to three events. The increase is by three events in Hazaribag. In the remaining districts, the projected increase is by two events per annum.

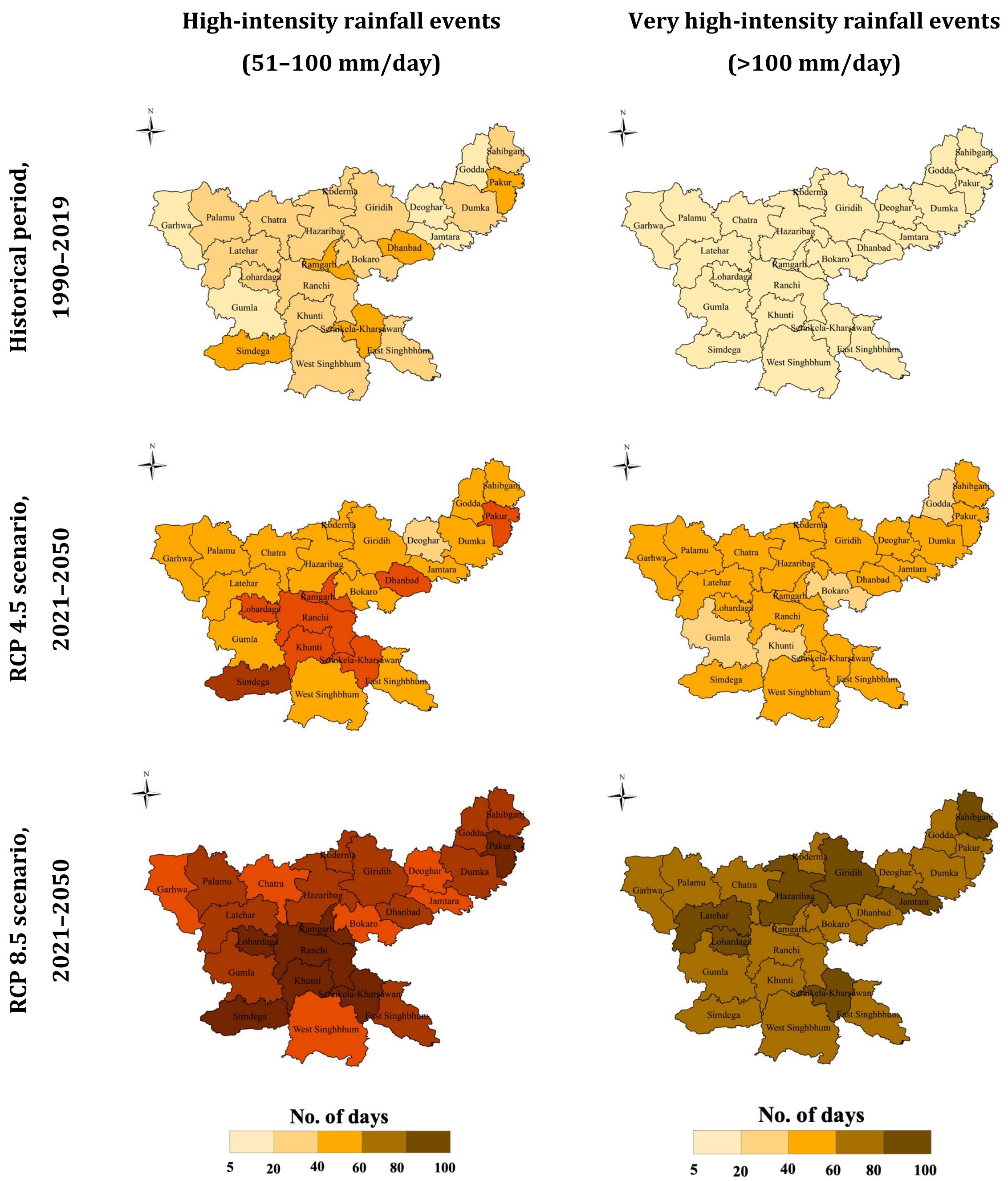


Figure 4-11: The total number of high-intensity and very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

Rainfall deficient years (Figure 4-12)

Rainfall deficient years, computed considering the rainfall during the kharif season, are projected to decline in a majority of the districts (Figure 4-12). The number of rainfall deficient years declines from 7 to 14 years during the historical 30-year period to 7 to 12 years under the RCP 4.5 scenario and 6 to 11 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: Rainfall deficient years are projected to decline in 16 districts, including Sahibganj, Ranchi, Seraikela-Kharsawan, Pakur, Jamtara, East Singhbhum, Godda, Hazaribag, Dhanbad, Dumka, and others by 1 to 3 years. No change is projected in the remaining districts.

RCP 8.5 scenario: Rainfall deficient years are projected to decline in all the districts by 1 to 3 years, except Palamu.

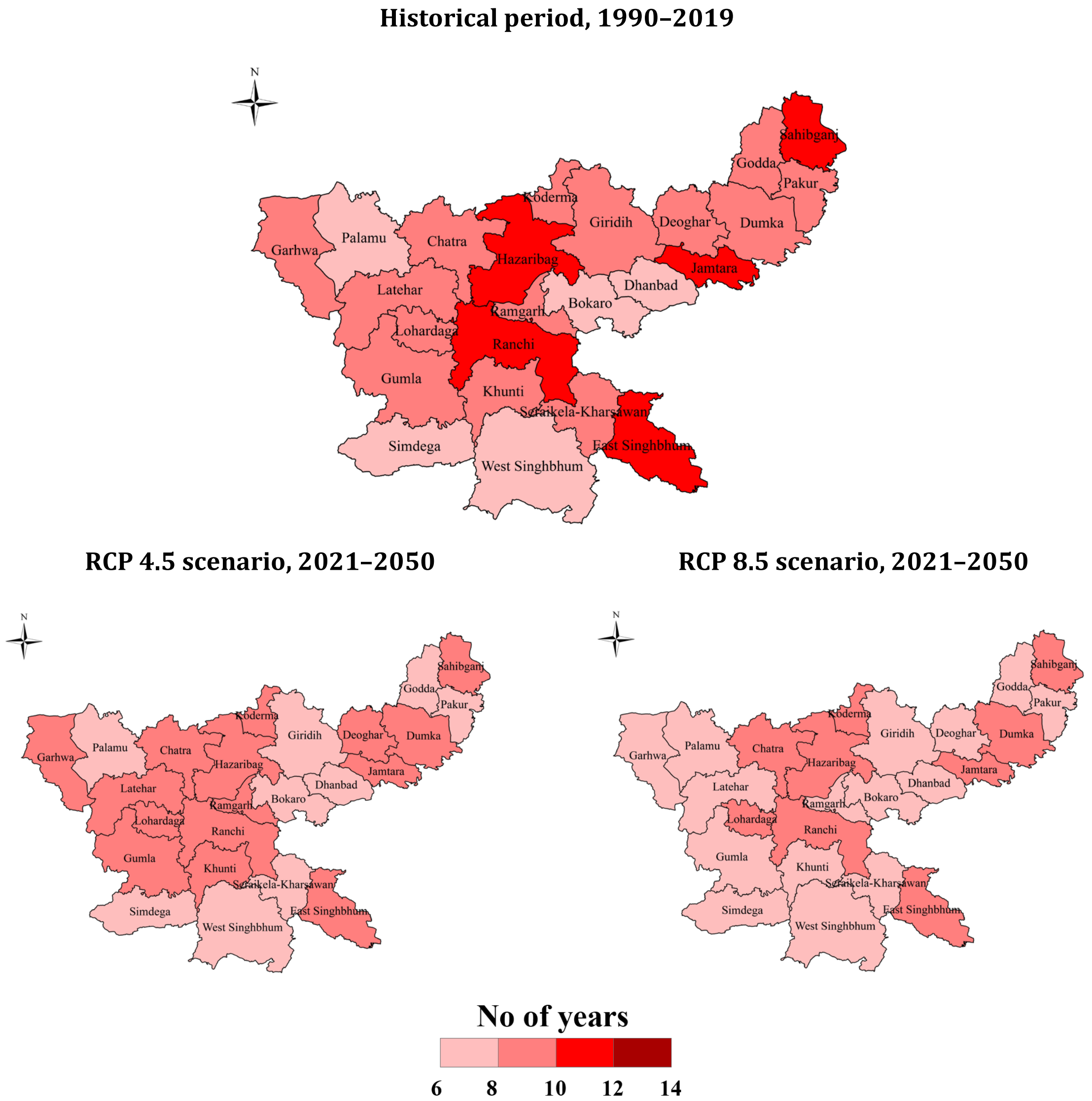


Figure 4-12: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

4.4. The summary of projected changes in the climate for Jharkhand

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

- The summer maximum and winter minimum temperatures are 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 RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 4-2).

- There is a notable increase in rainfall of >30% in Pakur, Sahibganj, Khunti, and East Singhbhum under RCP 4.5 and RCP 8.5 scenarios.

Rainfall variability during the kharif season is projected to largely decline under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019).

- A >10% decline in variability is projected for the Seraikela-Kharsawan district under both climate scenarios. In Simdega, Dumka, and Giridih, a >10% decline is projected only under the RCP 8.5 scenario.

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

- The increase is in the range of 2 to 5 days under the RCP 4.5 scenario and 1 to 5 days under the RCP 8.5 scenario.

Heavy rainfall events are projected to increase in all the districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 4-4).

- High-intensity rainfall events are projected to increase annually by one to two events and one to three events under RCP 4.5 and RCP 8.5 scenarios, respectively.
- Very high-intensity rainfall events are projected to increase annually by one to two events and two to three events under RCP 4.5 and RCP 8.5 scenarios, respectively.

Rainfall deficient years are projected to largely decline under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019) in a majority of the districts by 1 to 3 years (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
Bokaro	1.3	1.7	1.1	1.5
Chatra	1.3	1.7	1.2	1.6
Deoghar	1.2	1.4	1.2	1.6
Dhanbad	1.3	1.5	1.3	1.6
Dumka	1.2	1.4	1.2	1.5
East Singhbhum	1.3	1.5	1.1	1.4
Garhwa	1.3	1.8	1.4	1.9
Giridih	1.2	1.5	1.3	1.6
Godda	1.1	1.3	1.4	1.9
Gumla	1.1	1.4	1.3	1.7
Hazaribag	1.3	1.7	1.3	1.5
Jamtara	1.2	2.4	1.3	1.6
Khunti	1.4	1.5	1.3	1.8
Koderma	1.3	1.6	1.4	1.6
Latehar	1.3	1.8	1.2	1.7
Lohardaga	1.4	1.9	1.2	1.5
Pakur	1.3	1.5	1.4	1.6
Palamu	1.3	1.8	1.4	1.9
Ramgarh	1.4	1.7	1.2	1.5
Ranchi	1.2	1.5	1.3	1.8
Sahibganj	1.1	1.4	1.3	1.7
Seraikela-Kharsawan	1.2	1.5	1.3	1.7
Simdega	1.3	1.7	1.4	1.7
West Singhbhum	1.3	1.5	1.4	1.9

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
Bokaro	11	14	14	15	26	33
Chatra	13	21	14	23	19	31
Deoghar	8	14	8	12	8	32
Dhanbad	8	12	9	13	8	20
Dumka	6	11	4	10	6	11
East Singhbhum	56	41	40	33	17	32
Garhwa	2	10	11	20	17	28
Giridih	-2	3	5	7	9	16
Godda	20	21	18	21	14	19
Gumla	9	18	4	9	24	27
Hazaribag	1	8	6	13	14	32
Jamtara	20	23	20	22	9	19
Khunti	50	38	43	36	16	21
Koderma	1	6	2	9	7	28
Latehar	-2	10	2	14	13	22
Lohardaga	1	11	7	17	3	14
Pakur	62	42	46	35	6	18
Palamu	-21	-8	4	6	19	47
Ramgarh	-6	2	1	9	21	36
Ranchi	17	19	19	22	25	28
Sahibganj	38	30	45	36	8	22
Seraikela-Kharsawan	-15	-10	6	8	6	29
Simdega	3	15	18	20	9	19
West Singhbhum	7	16	2	8	-13	-4

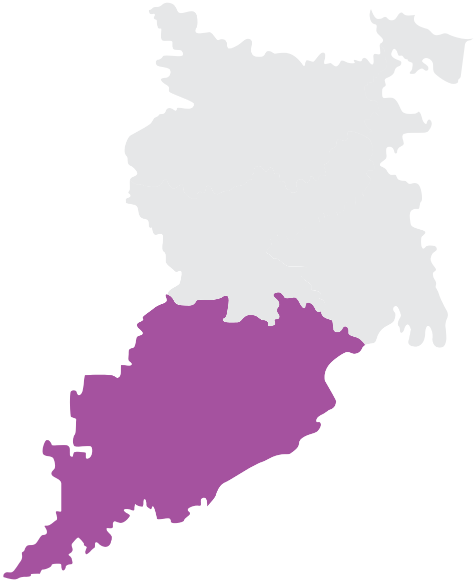
Appendix 4-3: The total number of rainy days (>2.5 cm/day) during the historical period (1990–2019) and the projected 2030s (2021–2050)

Districts	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Bokaro	2035	2093	2149
Chatra	1766	1812	1899
Deoghar	1971	2015	2077
Dhanbad	2007	2083	2132
Dumka	2007	2077	2132
East Singhbhum	2071	2145	2178
Garhwa	1641	1729	1788
Giridih	1785	1816	1870
Godda	2060	2103	2088
Gumla	2060	2123	2163
Hazaribag	2010	2087	2144
Jamtara	2071	2145	2199
Khunti	2196	2234	2290
Koderma	1746	1851	1890
Latehar	1732	1792	1823
Lohardaga	1889	1923	1966
Pakur	2053	2134	2189
Palamu	1528	1590	1634
Ramgarh	1800	1876	1890
Ranchi	1906	1978	1994
Sahibganj	1943	1985	2028
Seraikela-Kharsawan	1948	2041	2097
Simdega	2110	2158	2190
West Singhbhum	1943	2000	2067

Appendix 4-4: 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 scenario	RCP 8.5 scenario	Historical	RCP 4.5 scenario	RCP 8.5 scenario	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Bokaro	79	85	106	11	40	65	7	7	6
Chatra	62	82	112	11	44	68	12	11	11
Deoghar	56	78	97	12	46	75	10	10	9
Dhanbad	84	112	132	8	46	80	8	7	7
Dumka	76	94	124	23	56	70	12	11	10
East Singhbhum	66	89	134	12	54	78	13	10	11
Garhwa	60	89	107	14	54	70	10	10	9
Giridih	68	91	133	13	58	82	10	9	9
Godda	44	85	124	6	35	70	10	9	8
Gumla	44	91	136	6	40	74	10	10	9
Hazaribag	68	92	122	7	56	84	13	11	10
Jamtara	59	85	117	12	49	83	13	11	10
Khunti	79	103	152	4	37	64	10	10	9
Koderma	64	90	128	13	52	78	12	11	10
Latehar	79	97	137	16	54	89	10	10	9
Lohardaga	77	102	146	17	56	88	12	11	10
Pakur	86	110	142	9	48	67	11	9	8
Palamu	68	85	123	11	50	73	8	8	8
Ramgarh	85	120	141	7	56	77	10	10	9
Ranchi	72	110	148	9	48	73	14	12	11
Sahibganj	67	91	121	14	68	84	14	12	11
Seraikela-Kharsawan	95	110	156	16	56	89	11	9	8
Simdega	86	132	156	12	47	77	9	8	7
West Singhbhum	67	89	106	14	55	79	8	7	7

5. Odisha



The state of Odisha is bound by the states of Jharkhand and West Bengal to the north and north-east, the Bay of Bengal to the east, the states of Andhra Pradesh and Telangana to the south, and Chhattisgarh to the west. The geographic area of Odisha is 1,55,710 sq. km., and the population according to Census 2011 is 41,974,218. There are 30 districts in Odisha. The state has 480 km of vulnerable coastline, which is prone to cyclones and coastal erosion. It is rich in mineral resources, and therefore, there is a predominance of mineral-based industries that are both energy- and water-intensive. About 38% of the state's geographical area is covered by forests. The state has 10% of the country's water resources.

Odisha has a total agricultural area of 4.9 Mha, out of which the irrigated area is only 1.24 Mha. Agriculture is thus largely rainfed. Climate change is a major concern for the state of Odisha as it is vulnerable to climate variations and change. Fishing is an important sector. There are thermal power plants in Sambalpur, Jharsuguda, Dhenkanal, and a few other districts. There are several dams and solar power plants in the various districts of Odisha.

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

5.1. 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.

5.1.1. Trends in temperature

Odisha has recorded a moderate warming of 0.10°C to 0.52°C in the summer maximum temperature and 0.17°C to 0.51°C in the winter minimum temperature during the historical period. Figure 5-1 presents the mean summer maximum and winter minimum temperatures in Odisha during the historical period.

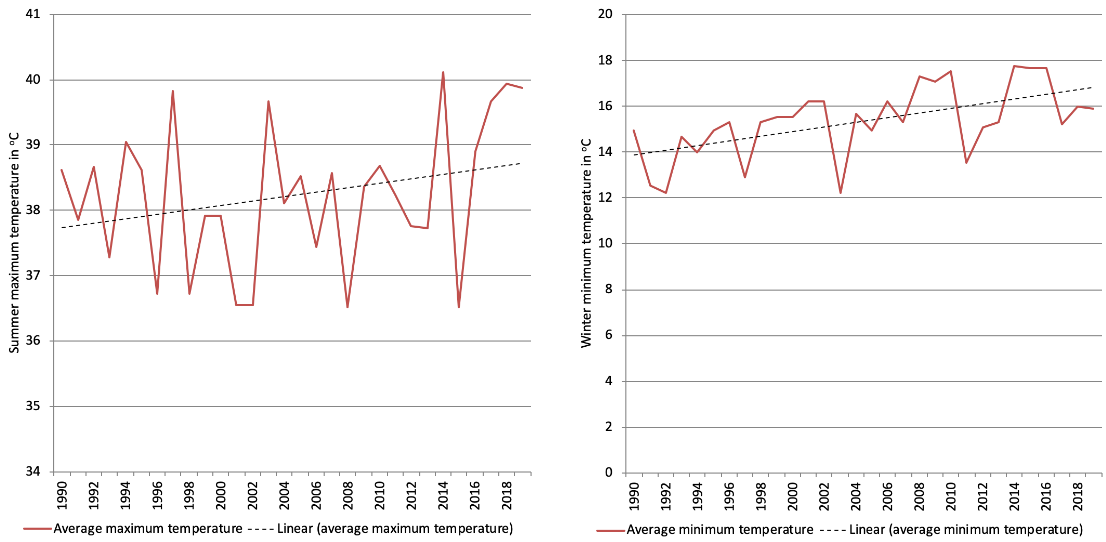


Figure 5-1: Mean summer maximum and winter minimum temperatures in Odisha during the historical period (1990–2019)

5.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and kharif season rainfall—which is the main monsoon season—was recorded during the historical period. The increase in the annual and kharif season rainfall was largely by about 10% in a majority of the districts. A higher increase in the kharif season rainfall, in the range of 10% to 15%, was recorded in parts of Koraput, Malkangiri, Bargarh, and Kendrapara. Figure 5-2 presents the mean annual rainfall in Odisha during the historical period.

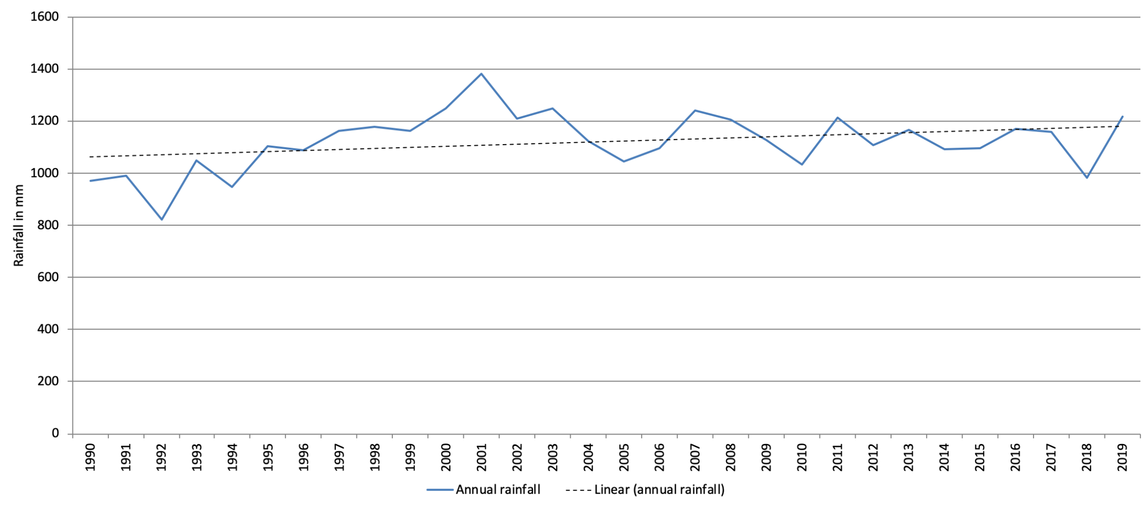


Figure 5-2: Mean annual rainfall in Odisha during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 18% in Gajapati and Nayagarh to 39% in Malkangiri (Figure 5-3). The rabi season rainfall variability ranged from 54% in Malkangiri to >100% in Nuapada and Balangir (Figure 5-3)—indicating a complete failure of rainfall during the rabi season.

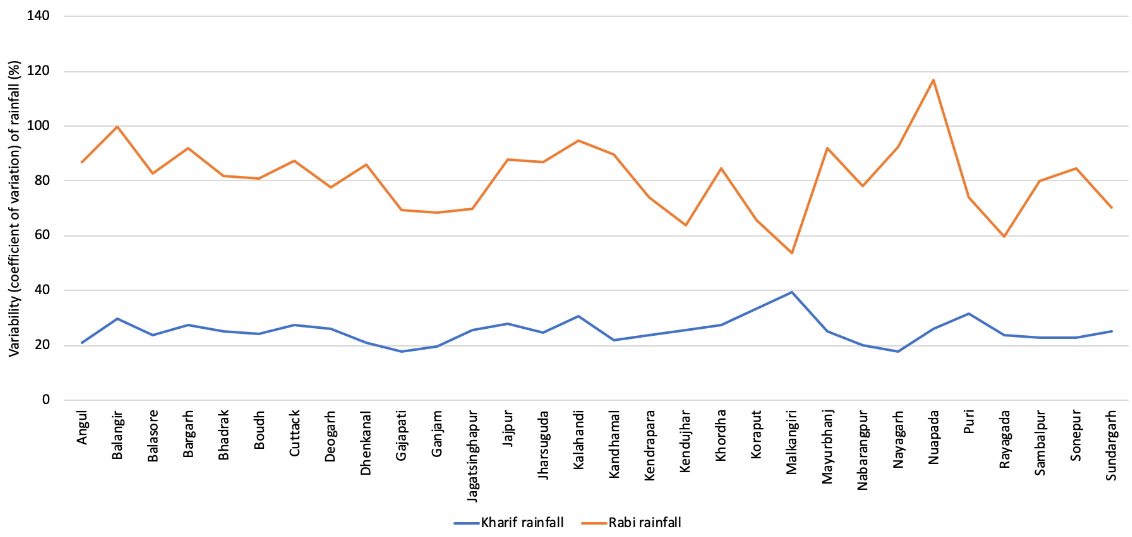


Figure 5-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

5.2. 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.

5.2.1. Temperature projections

The projected changes in the summer maximum and winter minimum temperatures for all the districts of Odisha are presented in Figure 5-4.

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 1^0C to 1.5^0C	Increases by 1^0C to 1.5^0C
RCP 8.5	Increases by 1^0C to 2^0C	Increases by 1^0C to 2^0C

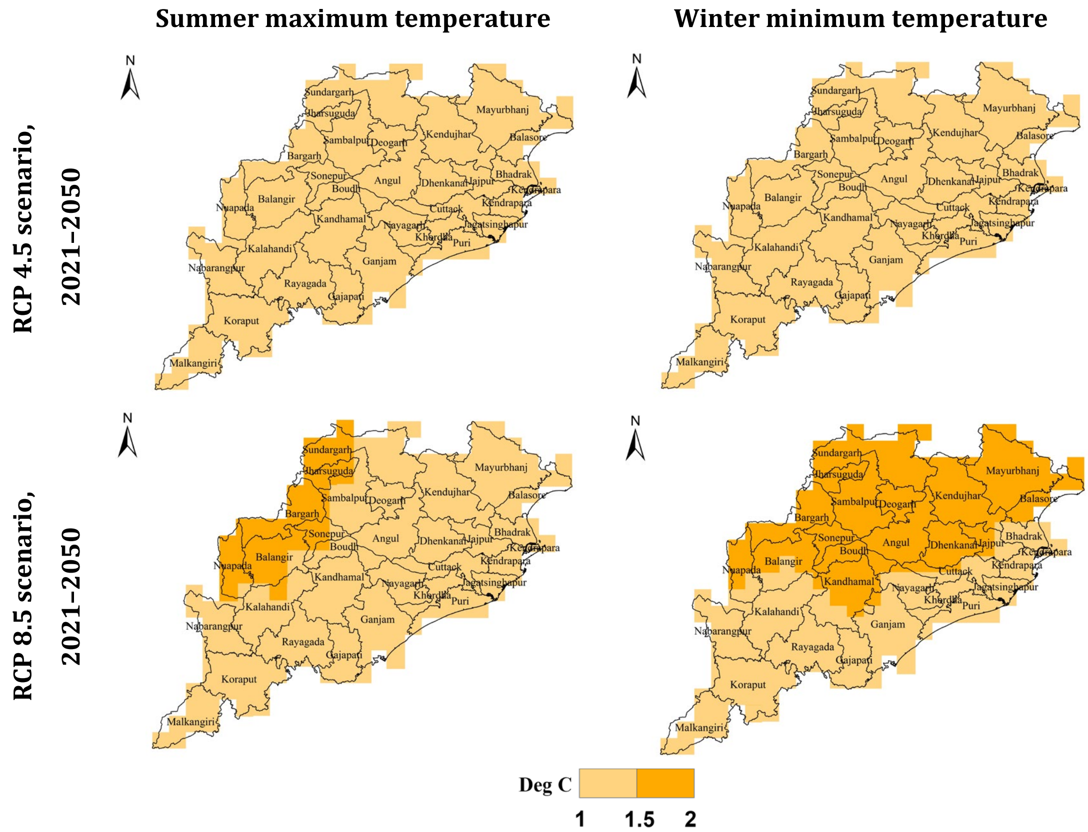


Figure 5-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

5.2.1.1. Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 1, a heatwave analysis of the Sambalpur 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 only be decline in the number of heatwaves (departure from the normal temperature is 4.5°C to 6.4°C) but severe heatwaves (departure from the normal temperature is >6.4°C), as categorised by the India Meteorological Department (IMD), will nearly double under both RCP 4.5 and RCP 8.5 scenarios (Figure 5-5).

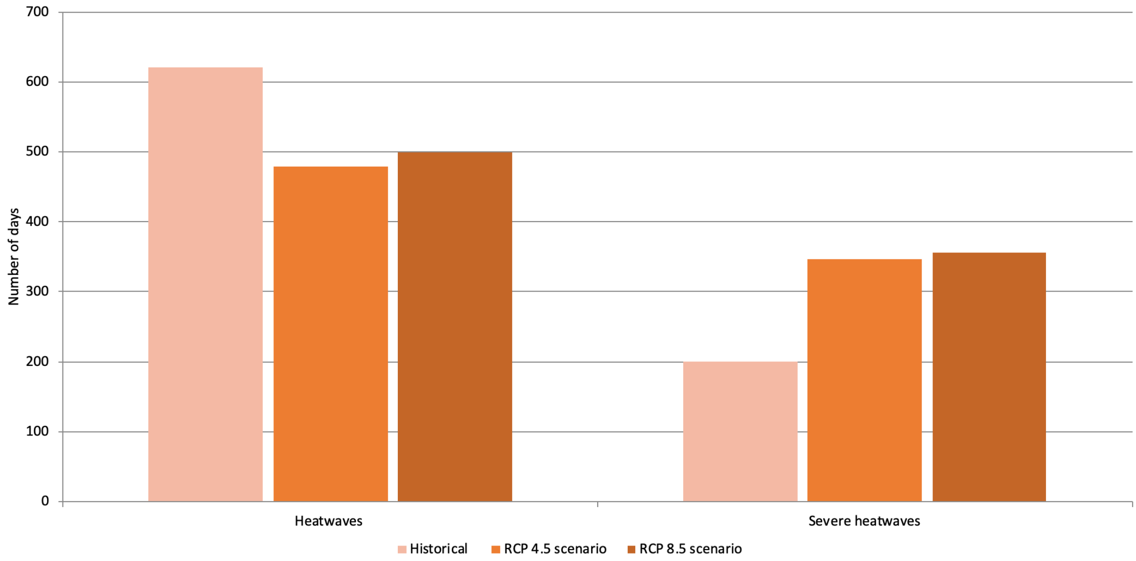


Figure 5-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

5.2.2. Rainfall projections

5.2.2.1. 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 5-6). 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 5-3. The total number of rainy days that ranged from 1398 to 2101 days over the 30-year historical period increases to 1459 to 2158 days under the RCP 4.5 scenario and 1612 to 2194 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 4 days annually in all the districts. The increase is by 4 days in Jharsuguda and Balangir; 3 days in Angul, Nuapada, Sambalpur, Sonepur, and Sundargarh; 2 days in 12 districts, and 1 day in the remaining districts.

RCP 8.5 scenario: Projected to increase by 2 to 7 days annually in all the districts. The increase is by 7 days in Puri; 6 days in Jharsuguda; 5 days in Angul, Bargarh, Balangir, Sonepur, and Sundargarh; 4 days in 12 districts, including Dhenkanal, Jajpur, Gajapati, Ganjam, Sambalpur, Koraput, and Kalahandi; 3 days in nine districts; and 2 days in the remaining districts

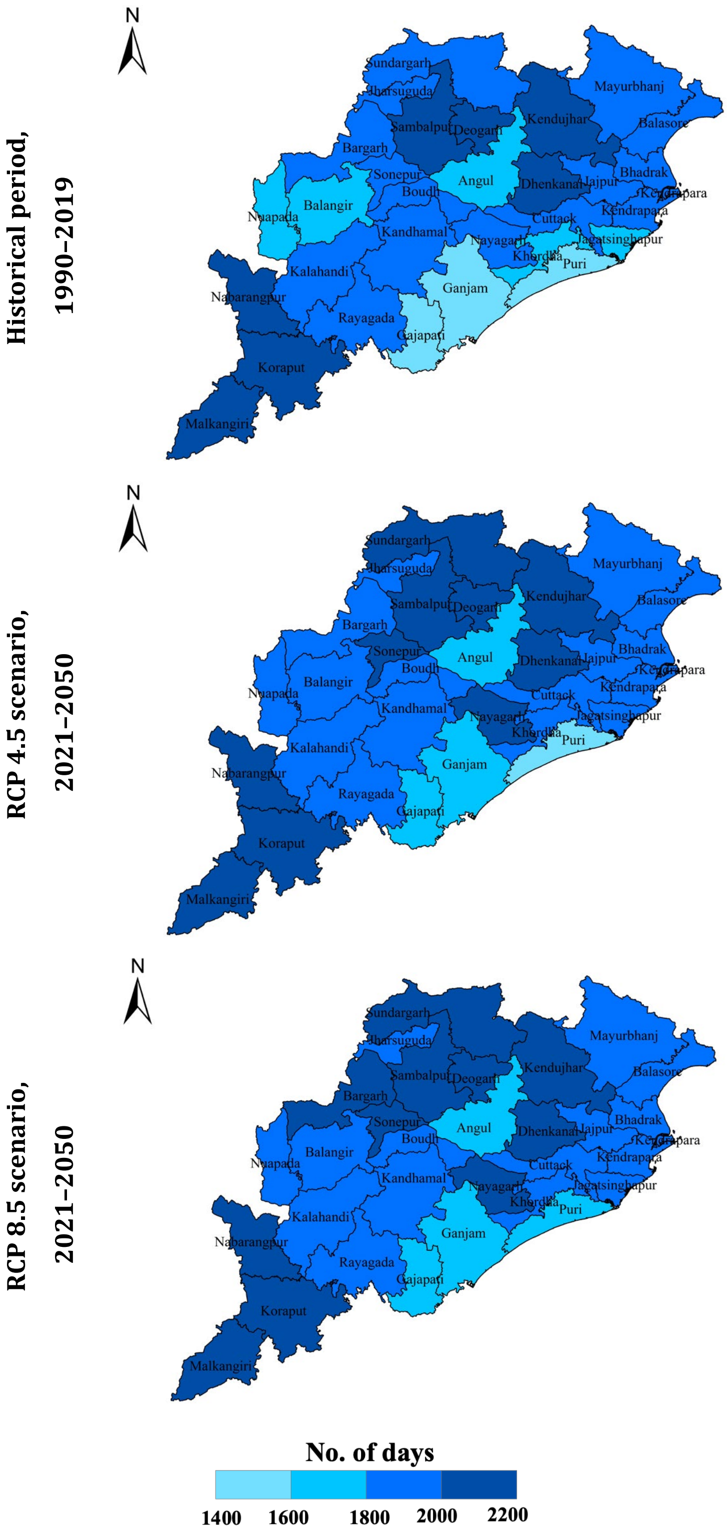


Figure 5-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

5.2.2.2. 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 5-7 presents district-wise changes in the kharif season rainfall, and Figure 5-8 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 4% in Nabarangpur and Malkangiri to 16% in Sundargarh and Kendujhar	Increases in nine districts by about 1% to 6% and declines in 21 districts by 1% to 5%
RCP 8.5	Increases in all the districts, from 11% in Nuapada, Puri, and Jaipur to 20% in Sonepur	Increases in five districts by 4% to 14% and declines in 25 districts by 1% to 8%

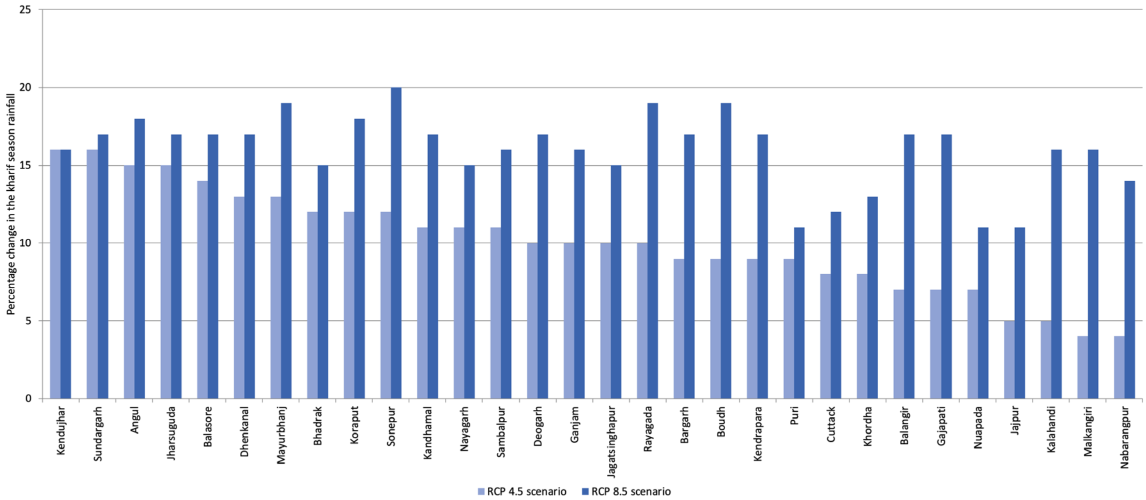


Figure 5-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

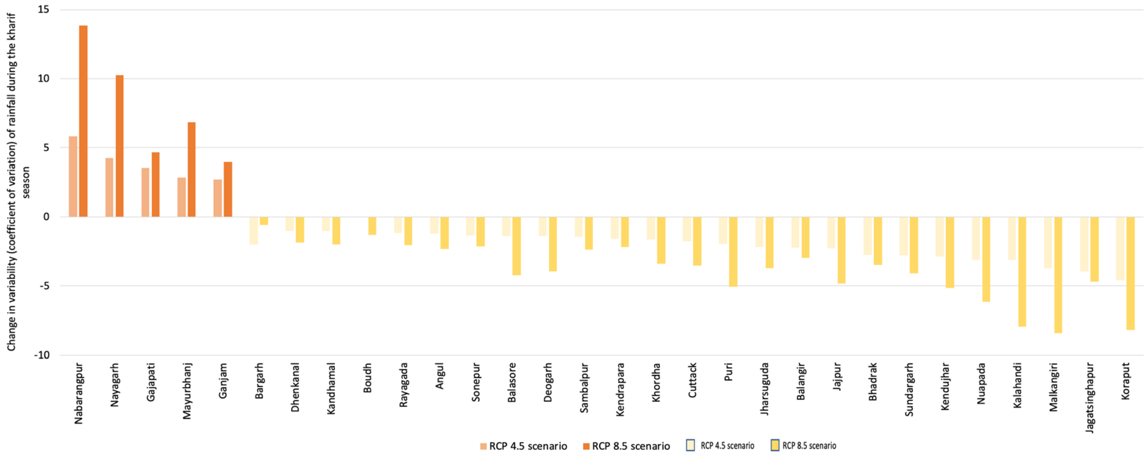


Figure 5-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

5.2.2.3. 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 5-9 presents district-wise changes in the rabi season rainfall, and Figure 5-10 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 2% in Jaipur to 30% in Bargarh	Declines in all the districts by 2% to 29%
RCP 8.5	Increase in all the districts, from 14% in Puri to 45% in Kalahandi	Declines in all the districts by 4% to 47%

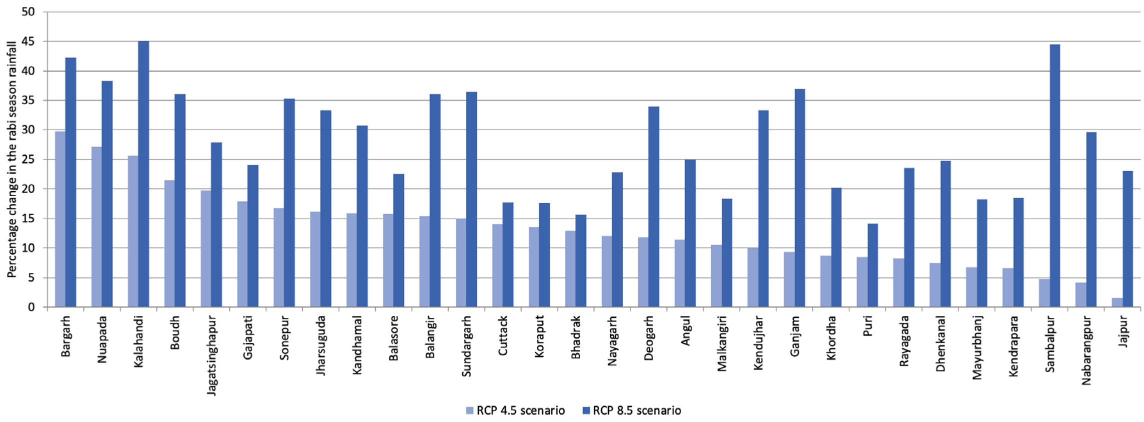


Figure 5-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

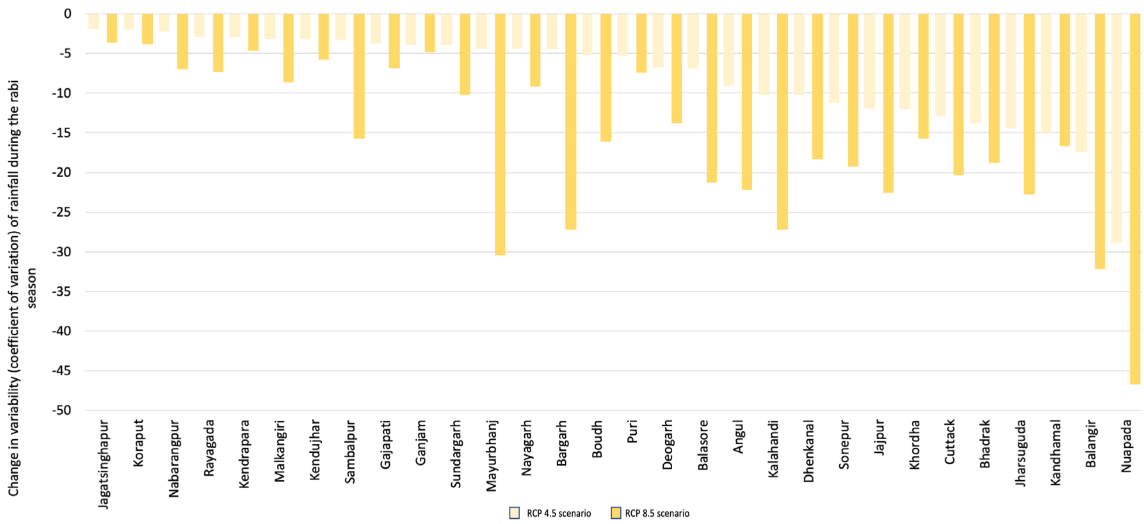


Figure 5-10: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

5.3. 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 Odisha.

High-intensity rainfall events (Figure 5-11)

The total number of high-intensity rainfall events increases from 49 to 133 days during the historical period (1990–2019) to 89 to 172 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 103 to 192 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 in all the districts of Odisha, except Balasore where no change is projected. The increase is by two events in Sonepur, Kandhamal, and Kendrapara and one event in the remaining 26 districts.

RCP 8.5 scenario: The projected increase per annum is by one to three events in all the districts of Odisha. The increase is by three events in Sonepur, Kandhamal, Boudh, Kalahandi, and Kendrapara; two events in 23 districts; and one event in Koraput and Nayagarh.

Very high-intensity rainfall events (Figure 5-11)

The total number of very high-intensity rainfall events increases from 7 to 49 days during the historical period (1990–2019) to 36 to 76 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 66 to 90 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 in all the districts of Odisha, except Jagatsinghapur and Balasore. The increase is by two events in Kendrapara, and by one event in the remaining 27 districts.

RCP 8.5 scenario: The projected increase per annum is by one to two events in all the districts of Odisha. The increase is by two events in 28 districts and one event in Balasore and Bargarh districts.

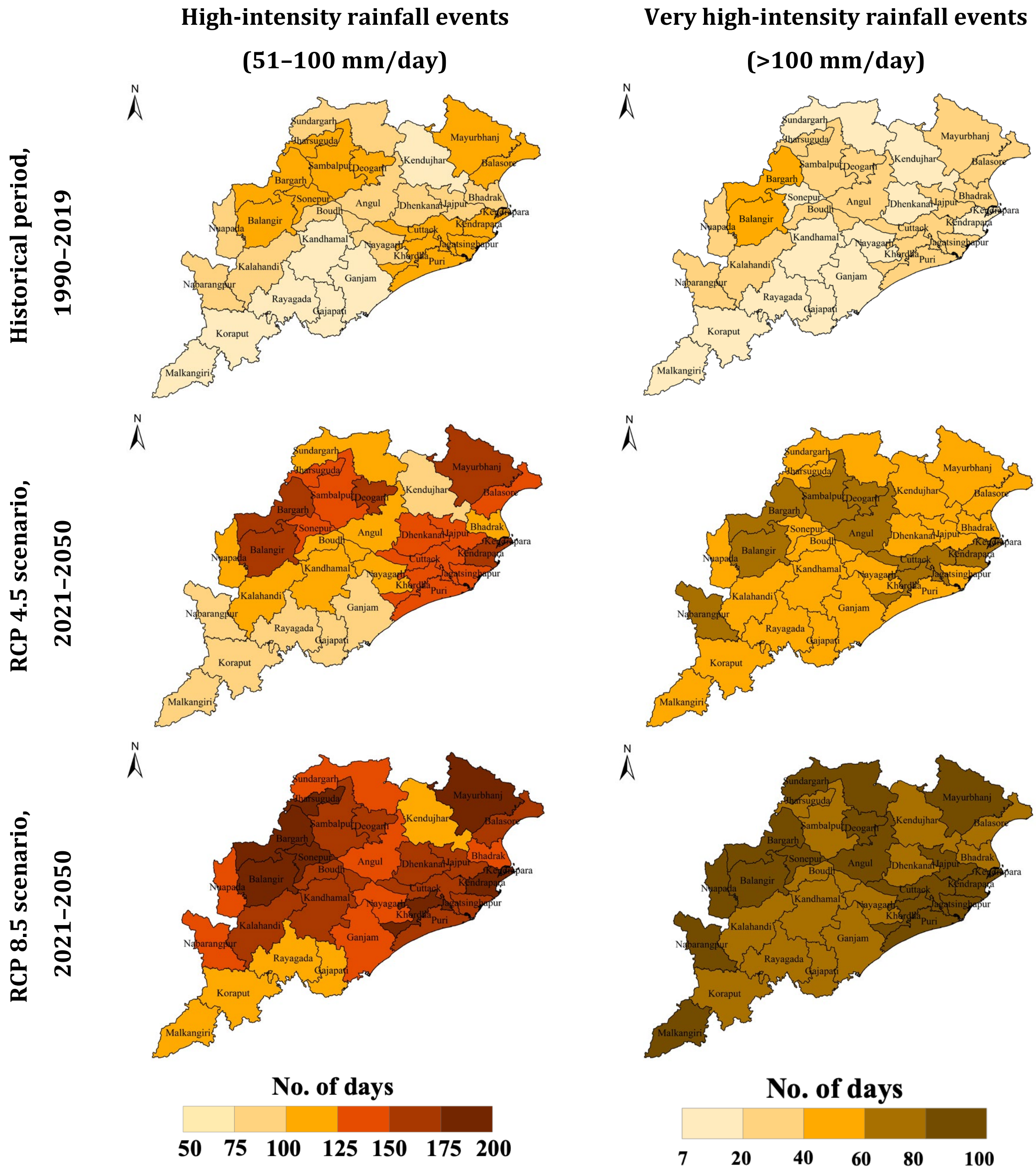


Figure 5-11: The number of high- and very high-intensity rainfall events during historical (1990–2019) and projected periods (the 2030s) under RCP 4.5 and RCP 8.5 scenarios

Rainfall deficient years (Figure 5-12)

Rainfall deficient years, computed considering rainfall during the kharif season, are projected to decline in a majority of the districts. The number of rainfall deficient years declines from 9 to 17 years during the historical 30-year period to 7 to 14 years under the RCP 4.5 scenario and 7 to 13 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: The projected decline is by 1 to 5 years in 19 districts, and no change is projected in the remaining 11 districts.

RCP 8.5 scenario: The projected decline is by 1 to 6 years in 28 districts, and no change is projected in Sonepur and Dhenkanal.

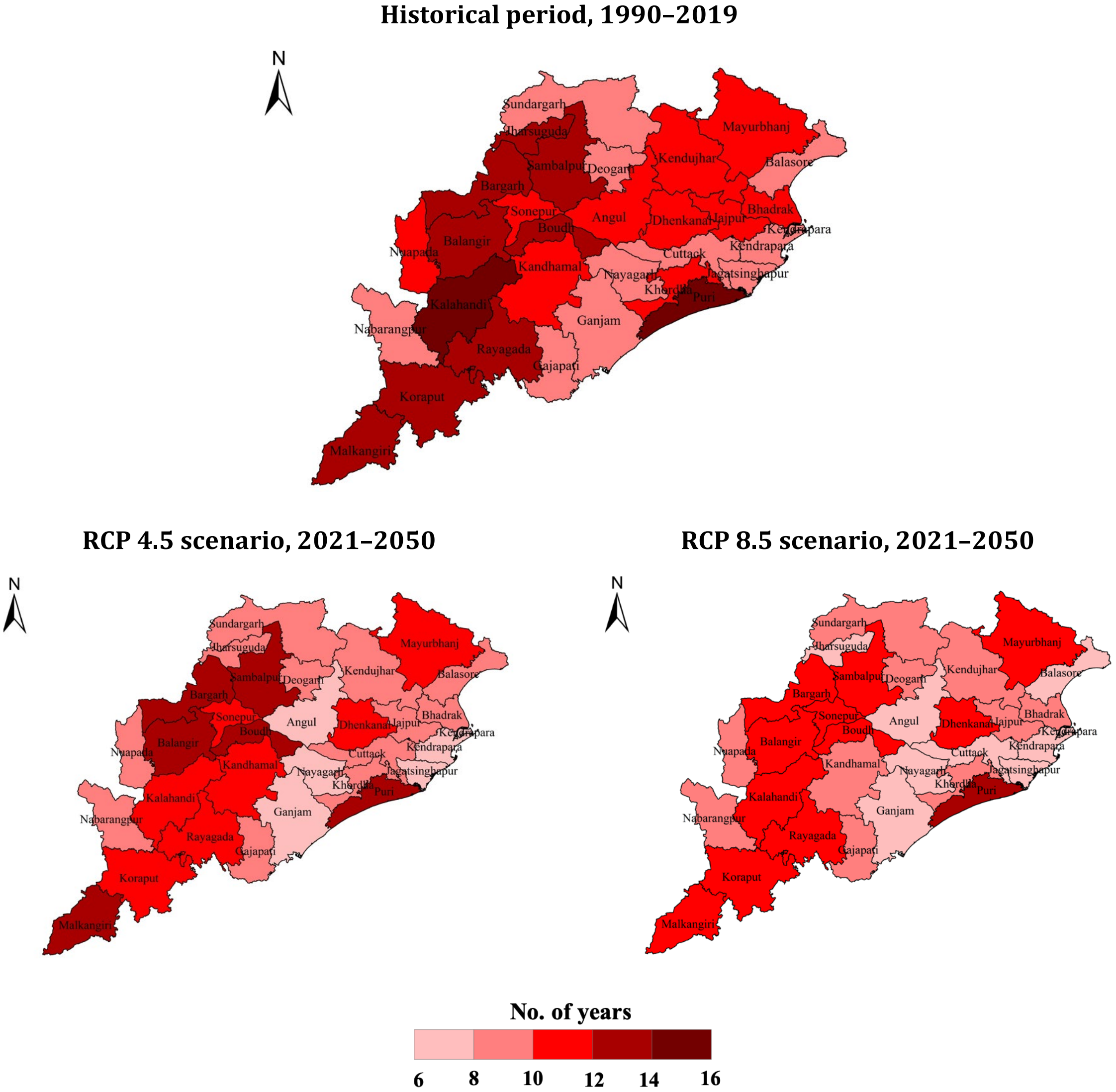


Figure 5-12: The number of rainfall deficient years during historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

5.4. The summary of projected changes in the climate for Odisha

The temperature is projected to increase in the short term (2021–2050) in all the districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 5-1).

- Summer maximum temperature is projected to be higher in the north-western districts of Balangir, Jharsuguda, Nuapada, and Sonepur under the RCP 8.5 scenario.
- Winter minimum temperature is projected to be higher in all the northern districts under the RCP 8.5 scenario.

Rainfall is projected to increase in the short term (2021–2050) in all the districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 5-2).

- There is a notable increase in rainfall particularly in the northernmost and southernmost districts under RCP 4.5 and RCP 8.5 scenarios.

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

- The projected increase in rainfall variability is >5% in only Nabarangpur under the RCP 4.5 scenario and Nabarangpur, Nayagarh, and Mayurbhanj districts under the RCP 8.5 scenario.

The number of rainy days is projected to increase in all the districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 5-3).

- The increase annually during the projected 2030s (2021–2050) is in the range of 1 to 4 days under the RCP 4.5 scenario and 2 to 7 days under the RCP 8.5 scenario.

An increase in the occurrence of heavy rainfall events is projected, in the range of one to two events annually, under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 5-4).

- Heavy rainfall events are projected to increase in all the districts. The increase is larger particularly in the northern districts of Odisha

Rainfall deficient years are projected to decline in the range of 1 to 5 years under the RCP 4.5 scenario and 1 to 6 years under the RCP 8.5 scenario compared to the historical period (1990–2019; Appendix 5-4).

Appendix

Appendix 5-1: 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
Angul	1.2	1.6	1.4	1.7
Balangir	1.5	1.7	1.5	1.8
Balasore	1.2	1.3	1.3	1.8
Bargarh	1.4	1.7	1.5	1.8
Bhadrak	1.4	1.6	1.4	1.8
Boudh	1.3	1.6	1.4	1.9
Cuttack	1.2	1.5	1.3	1.7
Deogarh	1.4	1.8	1.3	1.7
Dhenkanal	1.3	1.5	1.2	1.8
Gajapati	1.2	1.5	1.3	1.5
Ganjam	1.3	1.5	1.2	1.5
Jagatsinghapur	1.3	1.5	1.3	1.5
Jajpur	1.2	1.5	1.3	1.6
Jharsuguda	1.4	1.7	1.4	1.8
Kalahandi	1.3	1.7	1.3	1.6
Kandhamal	1.2	1.5	1.5	1.7
Kendrapara	1.0	1.4	1.3	1.5
Kendujhar	1.2	1.5	1.4	1.7
Khordha	1.1	1.3	1.2	1.5
Koraput	1.3	1.5	1.3	1.5
Malkangiri	1.4	1.5	1.2	1.5
Mayurbhanj	1.3	1.5	1.4	1.7
Nabarangpur	1.1	1.4	1.4	1.6
Nayagarh	1.2	1.5	1.5	1.8
Nuapada	1.4	1.8	1.3	1.7
Puri	1.2	1.6	1.4	1.8
Rayagada	1.2	1.5	1.3	1.8
Sambalpur	1.3	1.7	1.4	1.7
Sonepur	1.2	1.6	1.4	1.9
Sundargarh	1.4	1.8	1.5	1.6

Appendix 5-2: 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
Angul	15	16	15	18	11	25
Balangir	5	13	7	17	15	36
Balasore	6	10	14	17	16	23
Bargarh	6	10	9	17	30	42
Bhadrak	11	15	12	15	13	16
Boudh	10	18	9	19	21	36
Cuttack	10	15	8	12	14	18
Deogarh	9	15	10	17	12	34
Dhenkanal	7	11	13	17	8	25
Gajapati	8	16	7	17	18	24
Ganjam	7	17	10	16	9	37
Jagatsinghapur	11	14	10	15	20	28
Jajpur	7	11	5	11	2	23
Jharsuguda	15	15	15	17	16	33
Kalahandi	4	16	5	16	26	45
Kandhamal	12	18	11	17	16	31
Kendrapara	6	11	9	17	7	19
Kendujhar	15	17	16	16	10	33
Khordha	2	6	8	13	9	20
Koraput	11	15	12	18	14	18
Malkangiri	7	16	4	16	11	18
Mayurbhanj	5	7	13	19	7	18
Nabarangpur	5	14	4	14	4	30
Nayagarh	11	15	11	15	12	23
Nuapada	7	13	7	11	27	38
Puri	9	14	9	11	8	14
Rayagada	6	15	10	19	8	24
Sambalpur	16	23	11	16	5	44
Sonepur	9	19	12	20	17	35
Sundargarh	16	17	16	17	15	36

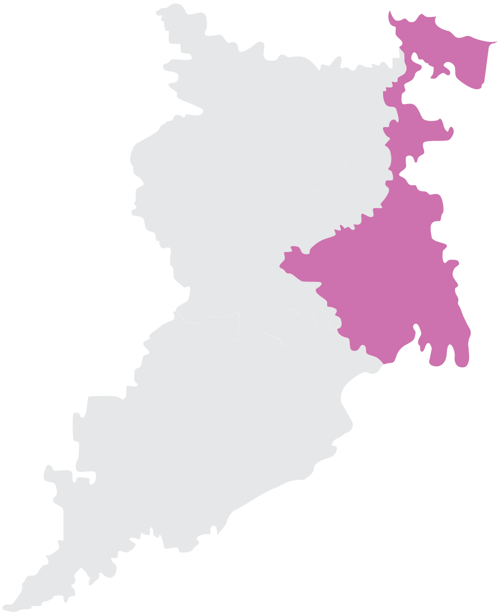
Appendix 5-3: The total number of rainy days (>2.5 cm/day) during the historical period (1990–2019) and the projected 2030s (2021–2050)

	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Angul	1609	1712	1766
Balasore	1926	1987	2015
Bargarh	1922	1984	2085
Bhadrak	1908	1923	1994
Balangir	1729	1846	1890
Boudh	1823	1862	1918
Cuttack	1900	1956	1991
Deogarh	2094	2134	2170
Dhenkanal	2074	2108	2194
Gajapati	1585	1619	1701
Ganjam	1580	1628	1692
Jagatsinghapur	1785	1812	1867
Jajpur	1884	1958	1993
Jharsuguda	1808	1923	1985
Kalahandi	1868	1938	1989
Kandhamal	1912	1977	2018
Kendrapara	1902	1932	1968
Kendujhar	2010	2055	2100
Khordha	1800	1857	1923
Koraput	2033	2060	2138
Malkangiri	2046	2080	2112
Mayurbhanj	1905	1955	2020
Nabarangpur	2101	2158	2191
Nayagarh	1972	2057	2098
Nuapada	1759	1848	1893
Puri	1398	1459	1612
Rayagada	1824	1860	1908
Sambalpur	2009	2095	2140
Sonepur	1949	2051	2088
Sundargarh	1951	2035	2091

Appendix 5-4: 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
Angul	87	110	132	27	67	82	11	8	7
Balangir	131	167	192	41	66	86	14	13	12
Balasore	121	132	167	37	47	66	10	9	8
Bargarh	133	172	190	49	76	84	13	13	12
Bhadrak	88	108	144	24	55	78	12	10	10
Boudh	83	122	167	33	54	80	13	13	12
Cuttack	109	144	167	31	67	88	10	9	8
Deogarh	113	151	172	30	66	89	10	10	9
Dhenkanal	96	131	168	16	48	79	11	11	11
Gajapati	50	89	103	10	46	78	10	10	9
Ganjam	62	92	134	12	36	73	9	7	7
Jagatsinghapur	119	145	171	26	40	81	10	8	8
Jajpur	90	131	163	24	52	88	11	9	9
Jharsuguda	110	142	179	30	51	78	14	9	8
Kalahandi	83	105	166	33	60	78	17	12	11
Kandhamal	73	120	156	17	40	78	12	12	10
Kendrapara	103	167	185	18	63	84	10	7	7
Kendujhar	63	92	123	18	48	77	12	10	10
Khordha	109	143	187	32	67	86	11	10	9
Koraput	67	89	105	18	44	78	14	12	11
Malkangiri	67	91	125	17	42	89	14	13	11
Mayurbhanj	121	165	185	26	56	90	12	12	11
Nabarangpur	77	96	134	30	67	83	10	10	9
Nayagarh	87	107	130	16	43	80	9	8	7
Nuapada	79	110	142	25	52	85	11	10	9
Puri	101	130	167	33	59	88	15	14	13
Rayagada	49	90	116	7	40	75	13	12	11
Sambalpur	102	142	160	30	62	78	13	13	12
Sonepur	101	146	190	20	55	87	12	12	12
Sundargarh	87	120	143	17	42	87	10	10	9

6. West Bengal



West Bengal is a state in eastern India situated between the Himalayas and the Bay of Bengal. It is bordered by Sikkim and Bhutan in the north, Assam in the north-east, Bangladesh in the east, the Bay of Bengal in the south, Odisha in the south-west, Jharkhand and Bihar in the west, and Nepal in the north-west. The geographic area of West Bengal is 88,750 sq. km, and the population according to Census 2011 is 91,347,736. There are 23 districts in West Bengal.

The area under agriculture in West Bengal is 5.5 Mha, of which the irrigated area is 2.98 Mha. The Sundarbans delta of West Bengal has the largest mangrove forest in the world. The state has several ports, thermal power plants, and dams. The state has a 1,076 km long coastline and contributes to 12.62% of the country’s marine fish production.

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

6.1. 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.

6.1.1. Trends in temperature

West Bengal recorded a moderate warming of 0.13°C to 0.6°C in the summer maximum temperature and 0.19°C to 0.6°C in the winter minimum temperature during the historical period. Figure 6-1 presents the mean summer maximum and winter minimum temperatures in West Bengal during the historical period.

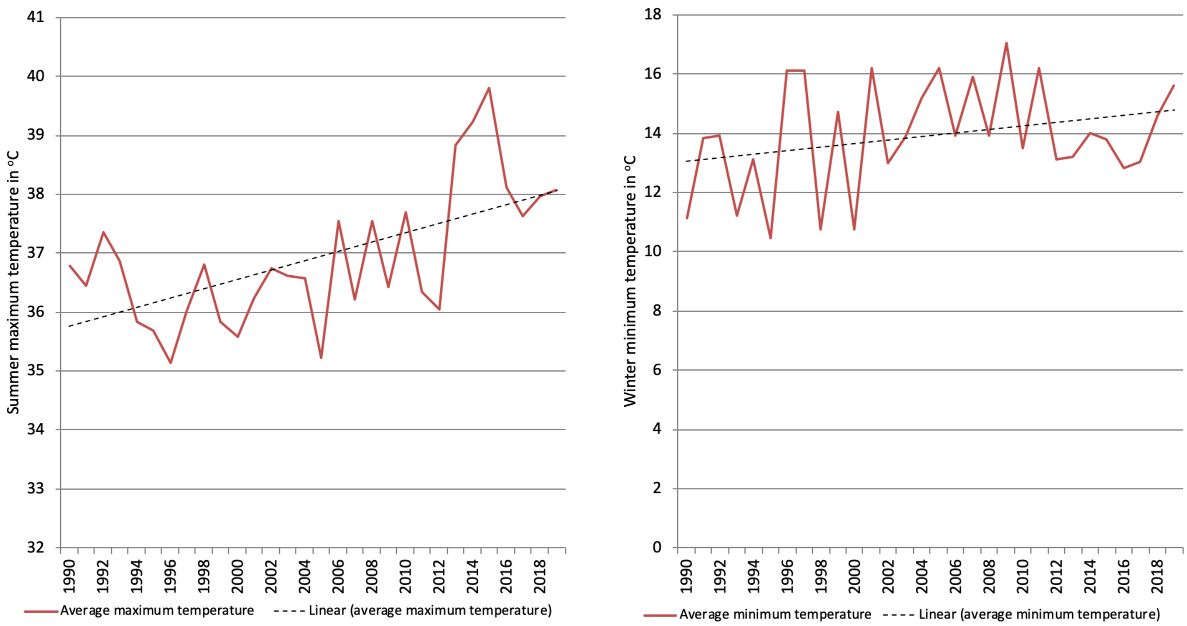


Figure 6-1: Mean summer maximum and winter minimum temperatures in West Bengal during the historical period (1990–2019)

6.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and kharif season rainfall, which is the main monsoon season, was recorded across the districts of West Bengal. The increase in the annual and kharif season rainfall was in the range of 5% to 10% in a majority of the districts. A higher increase in the kharif season rainfall in the range of 10% to 15% was recorded in a few of the northern districts. Figure 6-2 presents the mean annual rainfall in West Bengal during the historical period.

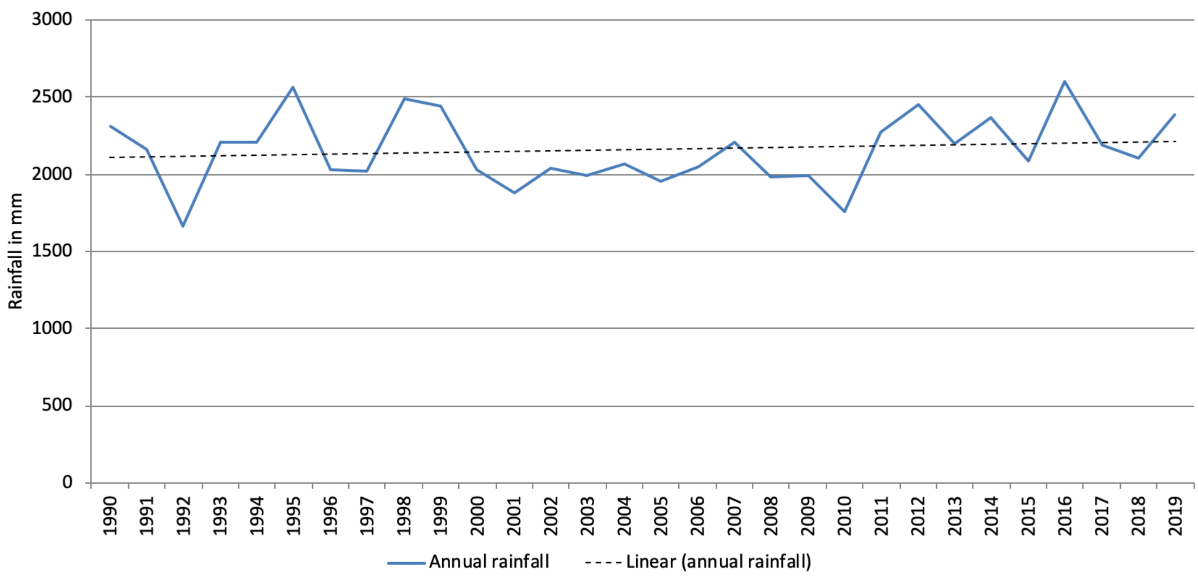


Figure 6-2: Mean annual rainfall in West Bengal during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 18% in Kalimpong to 47% in Dakshin Dinajpur (Figure 6-3). The rabi season rainfall variability was in the range of 55% in Murshidabad to 81% in Uttar Dinajpur during the historical period (Figure 6-3).

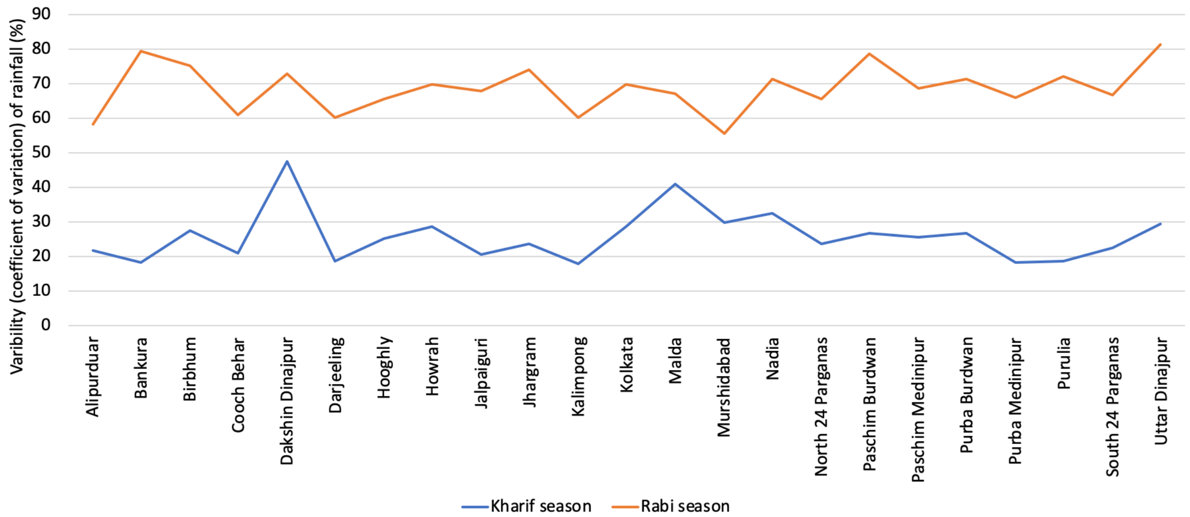


Figure 6-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

6.2. 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.

6.2.1. Temperature projections

The projected changes in summer maximum and winter minimum temperatures for all the districts of West Bengal are presented in Figure 6-4.

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 1^0C to 1.5^0C	Increases by 1^0C to 1.5^0C
RCP 8.5	Increases by 1^0C to 2^0C	Increases by 1^0C to 2^0C

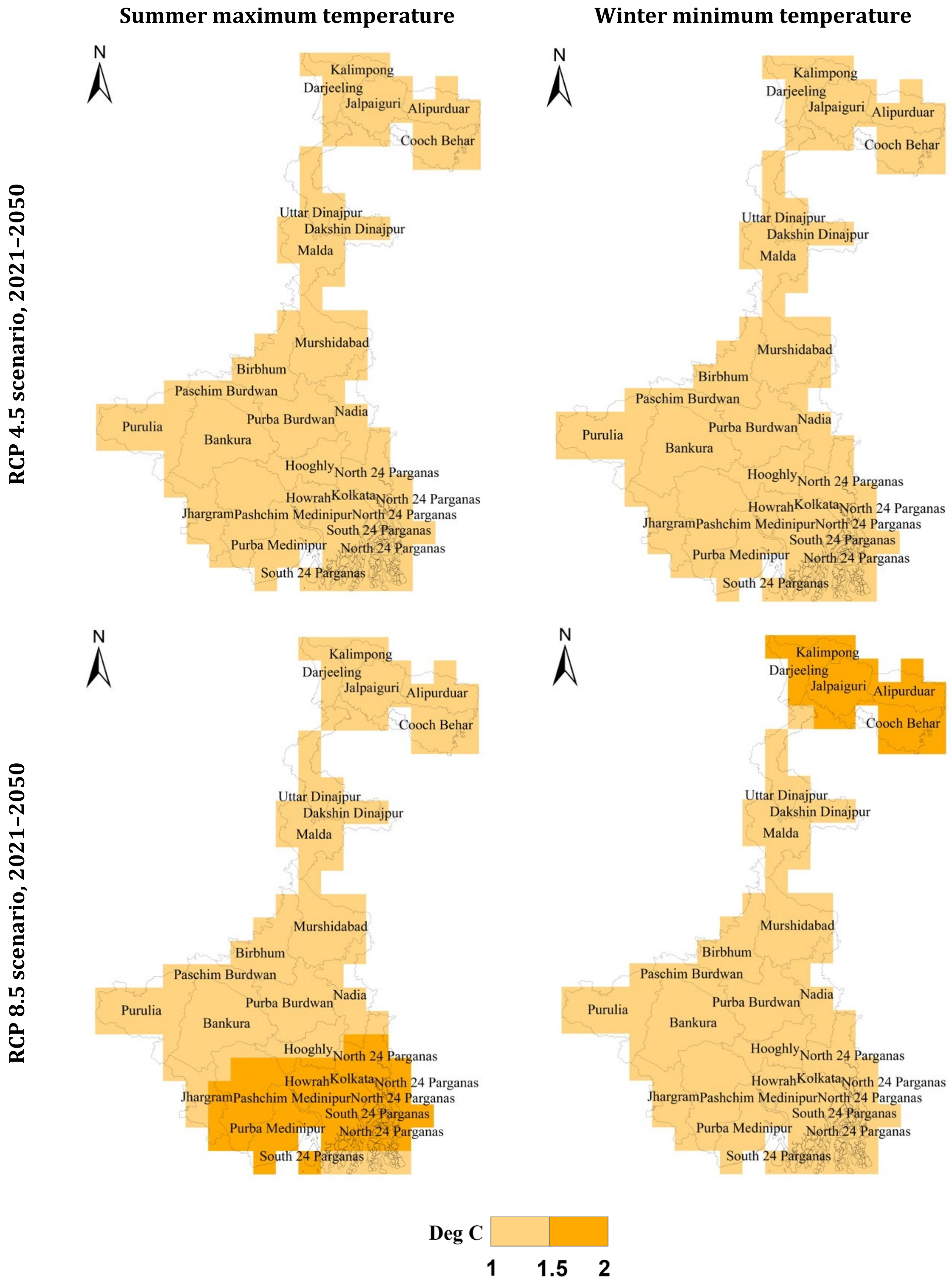


Figure 6-4: Projected changes in summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

6.2.1.1. Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 1, a heatwave analysis of the Birbhum 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 be 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).

While the heatwaves are projected to increase marginally, severe heatwaves are projected to treble and quadruple under RCP 4.5 and RCP 8.5 scenarios, respectively (Figure 6-5).

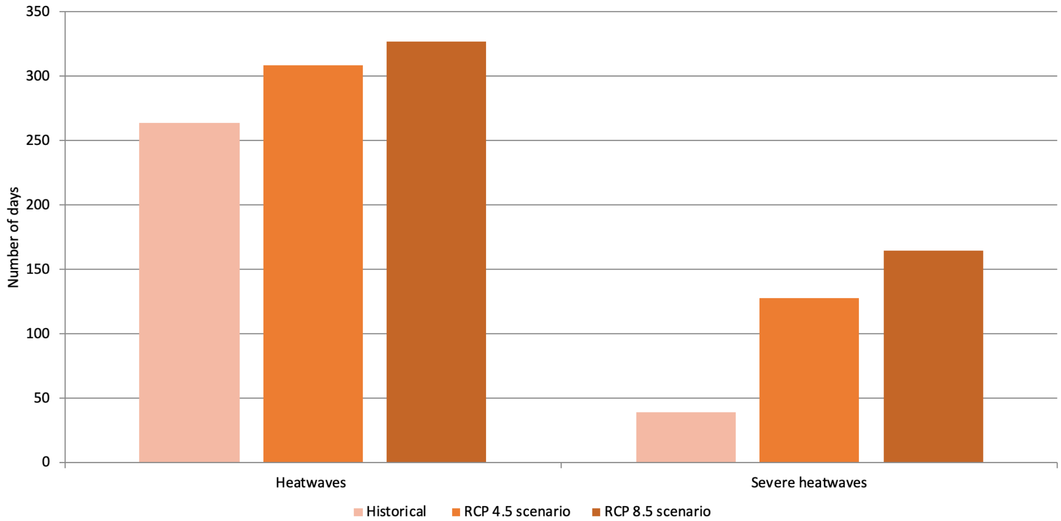


Figure 6-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

6.2.2. Rainfall projections

6.2.2.1. 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 6-6). 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 6-1. The total number of rainy days that ranged from 1529 to 2988 days over the 30-year historical period increases to 1864 to 3099 days under the RCP 4.5 scenario and 1966 to 3123 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 11 days with an increase of 11 days per annum in Dakshin Dinajpur, 9 days in Howrah, 8 days in Bankura, 6 days in Uttar Dinajpur, 5 days in Jalpaiguri and Murshidabad, and 1 to 4 days in the remaining districts

RCP 8.5 scenario: Projected to increase by 2 to 15 days annually, with an increase of 15 days in Dakshin Dinajpur, 1 day in Howrah, 10 days in Bankura, 9 days in North 24 Parganas, 8 days in Nadia, and 2 to 7 days in the remaining districts.

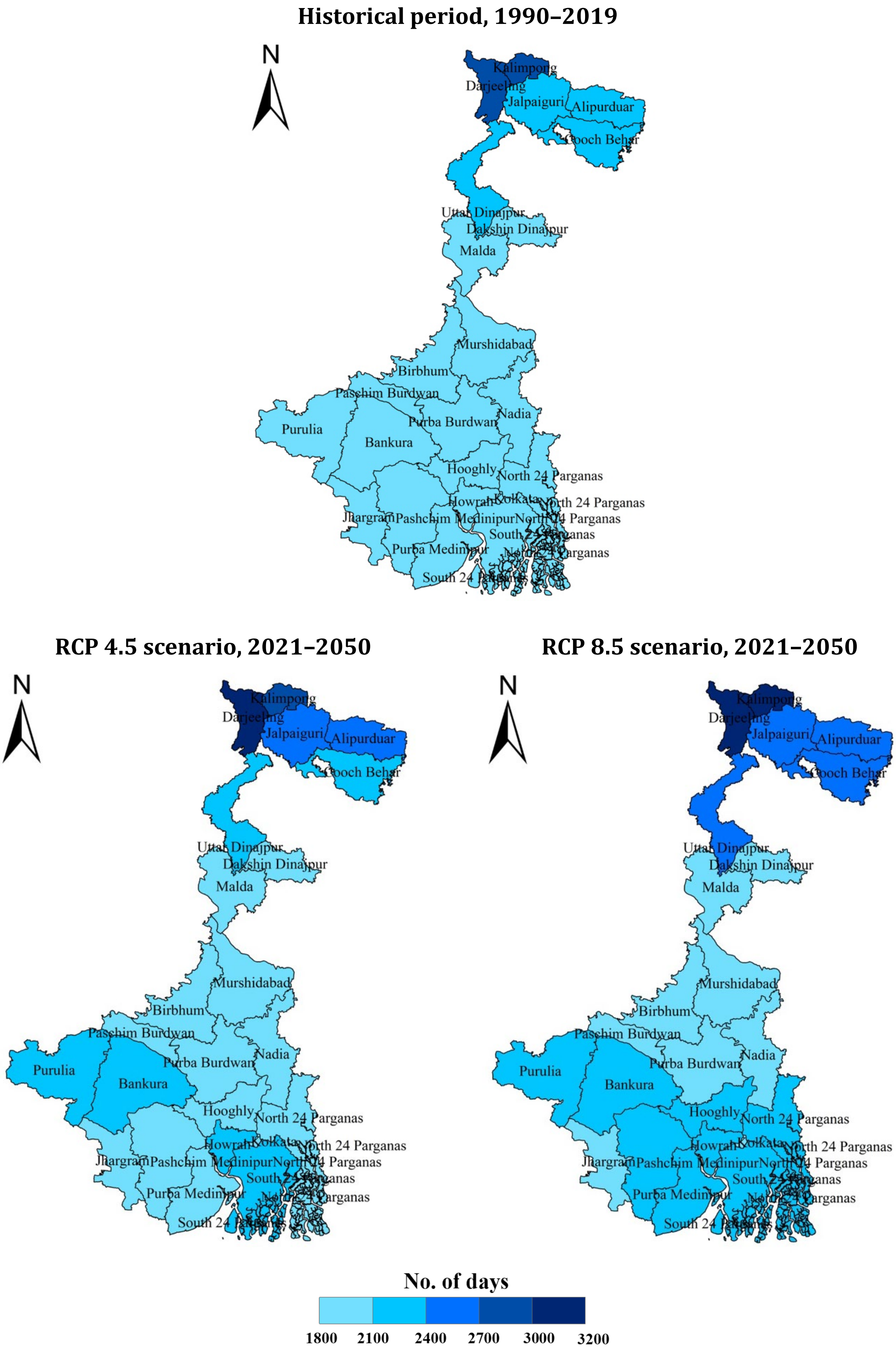


Figure 6-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

6.2.2.2. 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 6-7 presents district-wise changes in the kharif season rainfall, and Figure 6-8 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 2% in Kalimpong to 26% in Dakshin Dinajpur	Increases in six districts by 0.1% to 3% and declines in 17 districts by 0.5% to 19%
RCP 8.5	Increases in all the districts, from 9% in Darjeeling and Kalimpong to 28% in Dakshin Dinajpur	Increases in four districts by 3% to 5% and declines in 19 districts by 1% to 20%

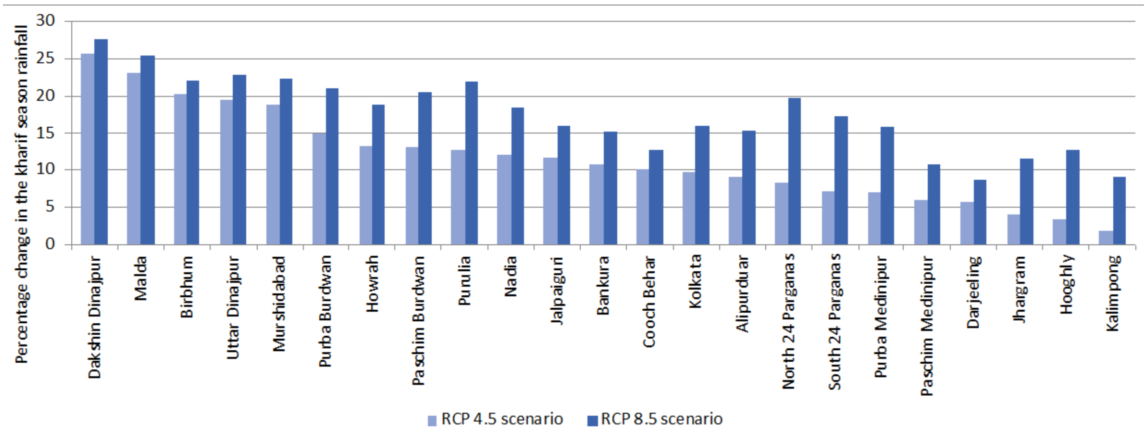


Figure 6-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

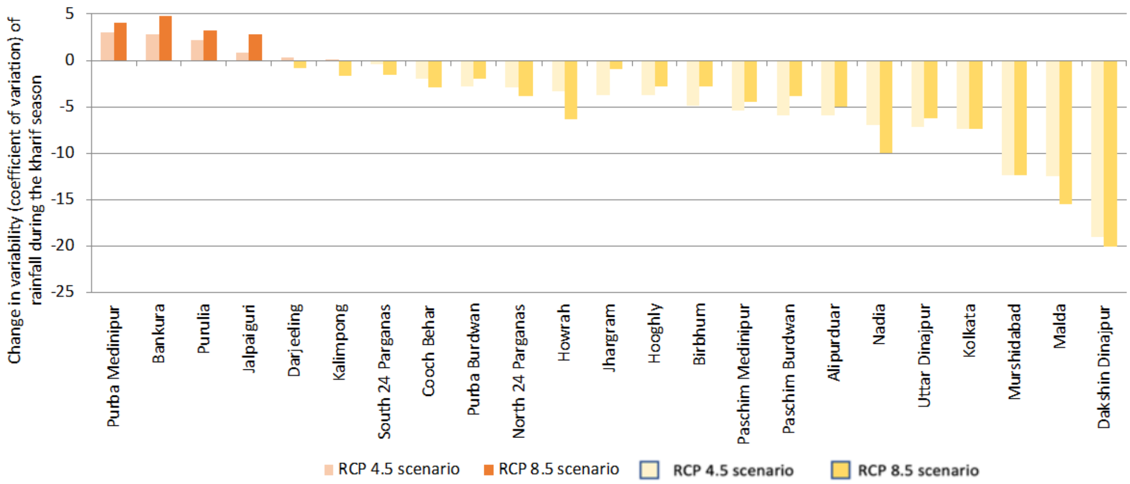


Figure 6-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

6.2.2.3. 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 6-9 presents district-wise changes in the rabi season rainfall, and Figure 6-10 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 3% in Alipurduar, South 24 Parganas, North 24 Parganas, and Purba Medinipur districts to 17% in Kolkata	Increases in three districts by 2% to 6% and declines in 20 districts by 2% to 24%
RCP 8.5	Increases in all the districts, from 7% in North 24 Parganas, Howrah, and Purba Medinipur to 41% in Malda	Increases in three districts by 4% to 8% and declines in 20 districts by 1% to 23%

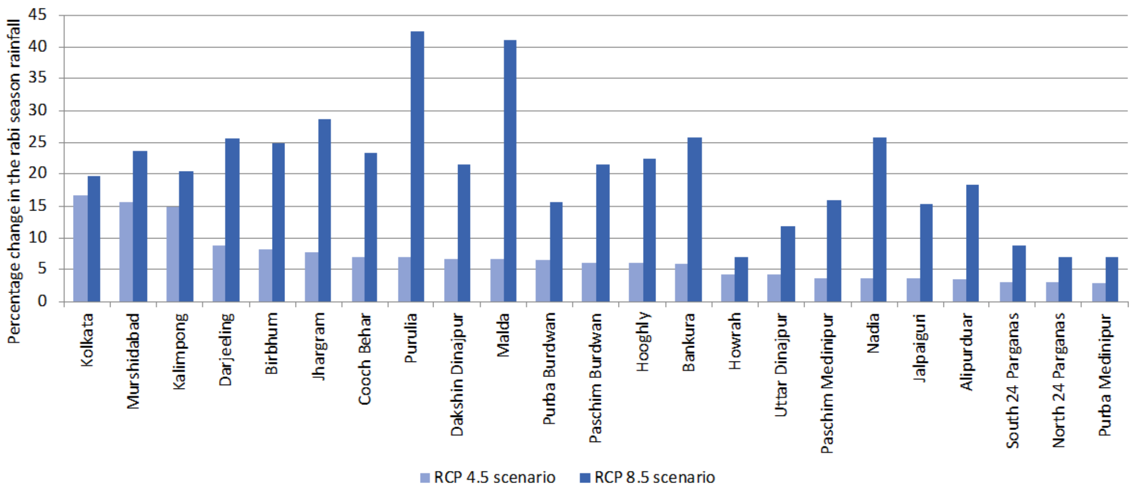


Figure 6-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

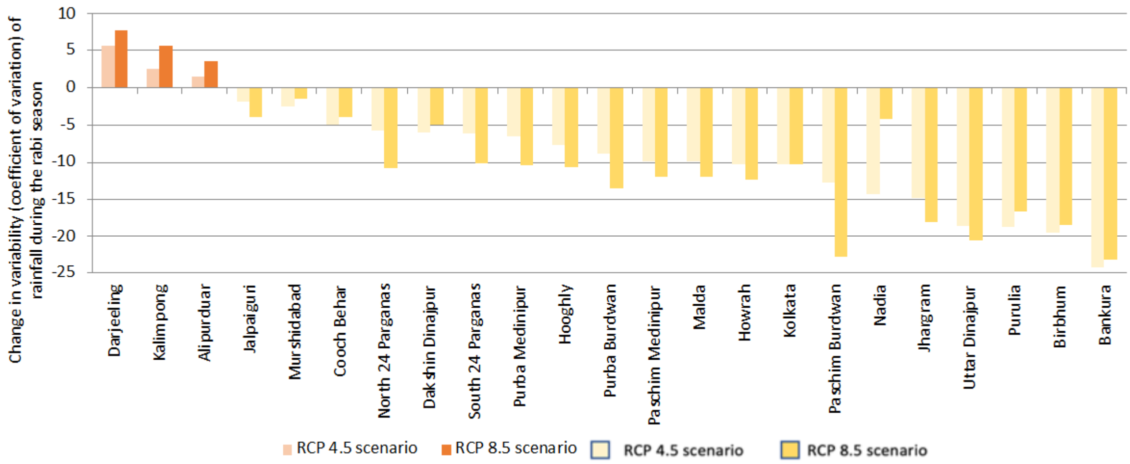


Figure 6-10: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

6.3. 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, termed 'Low' intensity; 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 for the 2030s under the two climate scenarios, and the change was computed for all the districts of West Bengal.

High-intensity rainfall events (Figure 6-11)

The total number of high-intensity rainfall events increases from 57 to 356 days during the historical period (1990–2019) to 90 to 396 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 112 to 408 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 three events in all the districts of West Bengal, except Darjeeling. The increase is by three events in Kolkata and Uttar Dinajpur; two events in Alipurduar, Cooch Behar, Dakshin Dinajpur, Howrah, Murshidabad, Paschim Medinipur, Purba Medinipur, and Purulia; and one event in 12 districts. No change is projected in Darjeeling.

RCP 8.5 scenario: The projected increase per annum is by one to four events in all the districts of West Bengal. The increase is by four events in Cooch Behar, Murshidabad, and Dakshin Dinajpur districts; three events in 12 districts including Alipurduar, Hooghly, Howrah, Jalpaiguri, Kolkata, Malda, North 24 Parganas, Uttar Dinajpur, Purulia, Paschim Medinipur, and two other districts; two events in Bankura, Birbhum, Jhargram, Nadia, Purba Medinipur, and South 24 Parganas; and one event in Darjeeling and Kalimpong.

Very high-intensity rainfall events (Figure 6-12)

The total number of very high-intensity rainfall events increases from 10 to 206 days during the historical period (1990–2019) to 45 to 231 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 76 to 220 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 in all the districts of West Bengal, except Cooch Behar. The increase is by two events in 15 districts including Jhargram, Maldah, Murshidabad, Kolkata, Howrah, Hooghly, Nadia, North 24 Parganas, South 24 Parganas, Purulia, and five other districts and one event in Uttar Dinajpur, Kalimpong, Jalpaiguri, Darjeeling, Birbhum, Bankura, and Alipurduar. No change is projected in Cooch Behar.

RCP 8.5 scenario: The projected increase per annum is by one to three events in all the districts of West Bengal, except Alipurduar. The increase is by three events in Birbhum, Jhargram, Kolkata, Murshidabad, Hooghly, Purulia, Jalpaiguri, South 24 Parganas, North 24 Parganas, Purba Burdwan, and Paschim Burdwan; two events in Bankura, Dakshin Dinajpur, Darjeeling, Howrah, Kalimpong, Maldah, Nadia, Paschim Medinipur, Purba Medinipur, and Uttar Dinajpur; and one event in Cooch Behar. No change is projected in Alipurduar.

Rainfall deficient years (Figure 6-13)

Rainfall deficient years, computed by considering the rainfall during the kharif season, are projected to decline in all the districts of West Bengal under both climate scenarios. The number of rainfall deficient years declines from 8 to 14 years during the historical 30-year period to 6 to 12 years under the RCP 4.5 scenario and 6 to 13 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: The projected decline is by 1 to 4 years (over a 30-year period) in 17 districts. No changes are projected for six districts. The projected decline is by 4 years in Birbhum, 3 years in Paschim Medinipur and Maldah, and 1 to 2 years in 14 districts. No changes are projected for Alipurduar, Cooch Behar, Dakshin Dinajpur, North 24 Parganas, Purulia, and South 24 Parganas.

RCP 8.5 scenario: The projected decline is by 1 to 4 years (over a 30-year period) in 17 districts. No changes are projected for Kolkata and Purulia districts. The projected decline is by 4 years in Uttar Dinajpur, Malda, Paschim Medinipur, and Birbhum; 3 years in Cooch Behar, Nadia, Jhargram, Paschim Burdwan, and Purba Burdwan; and 1 to 2 years in 11 districts.

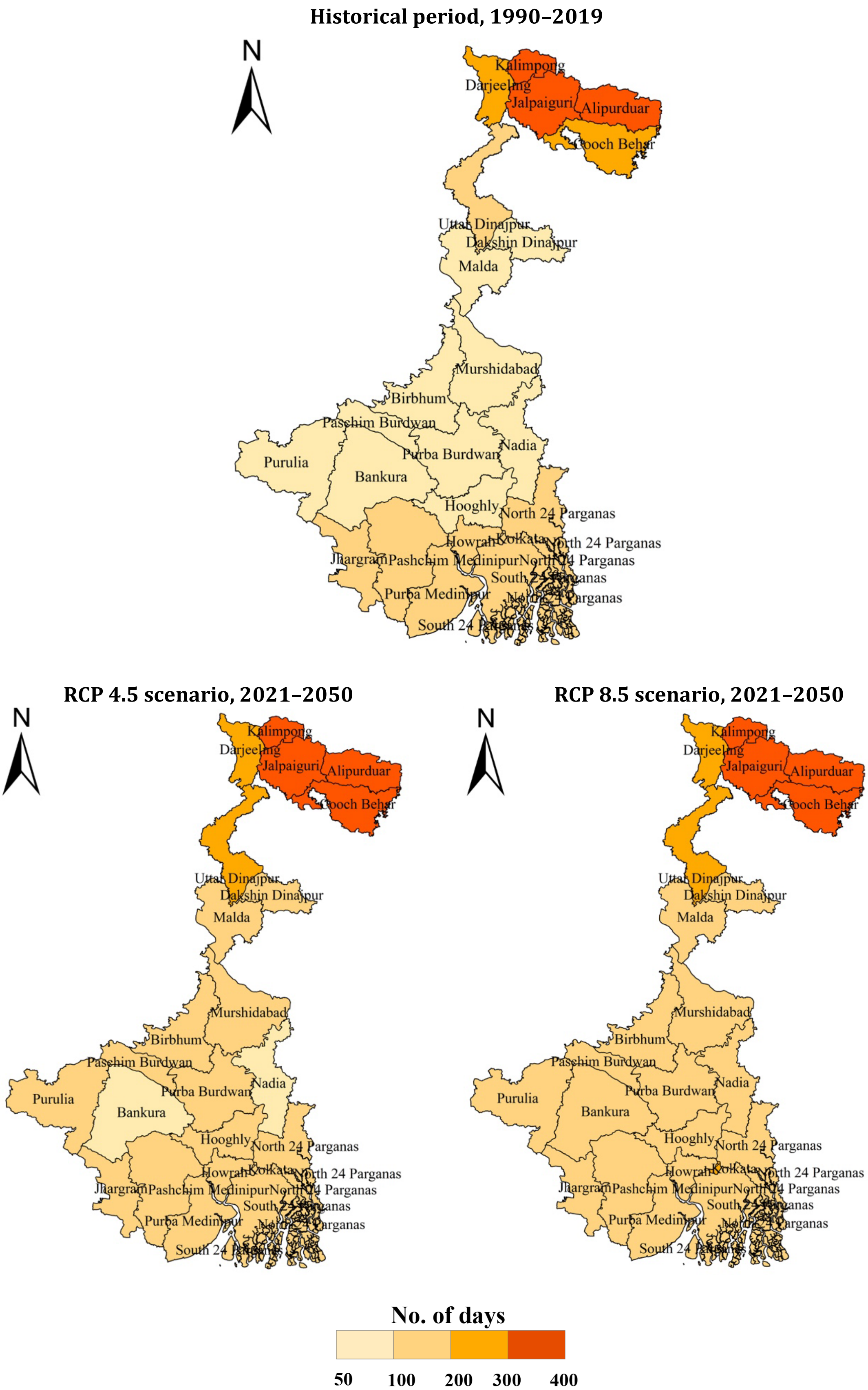


Figure 6-11: The total number of high-intensity events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

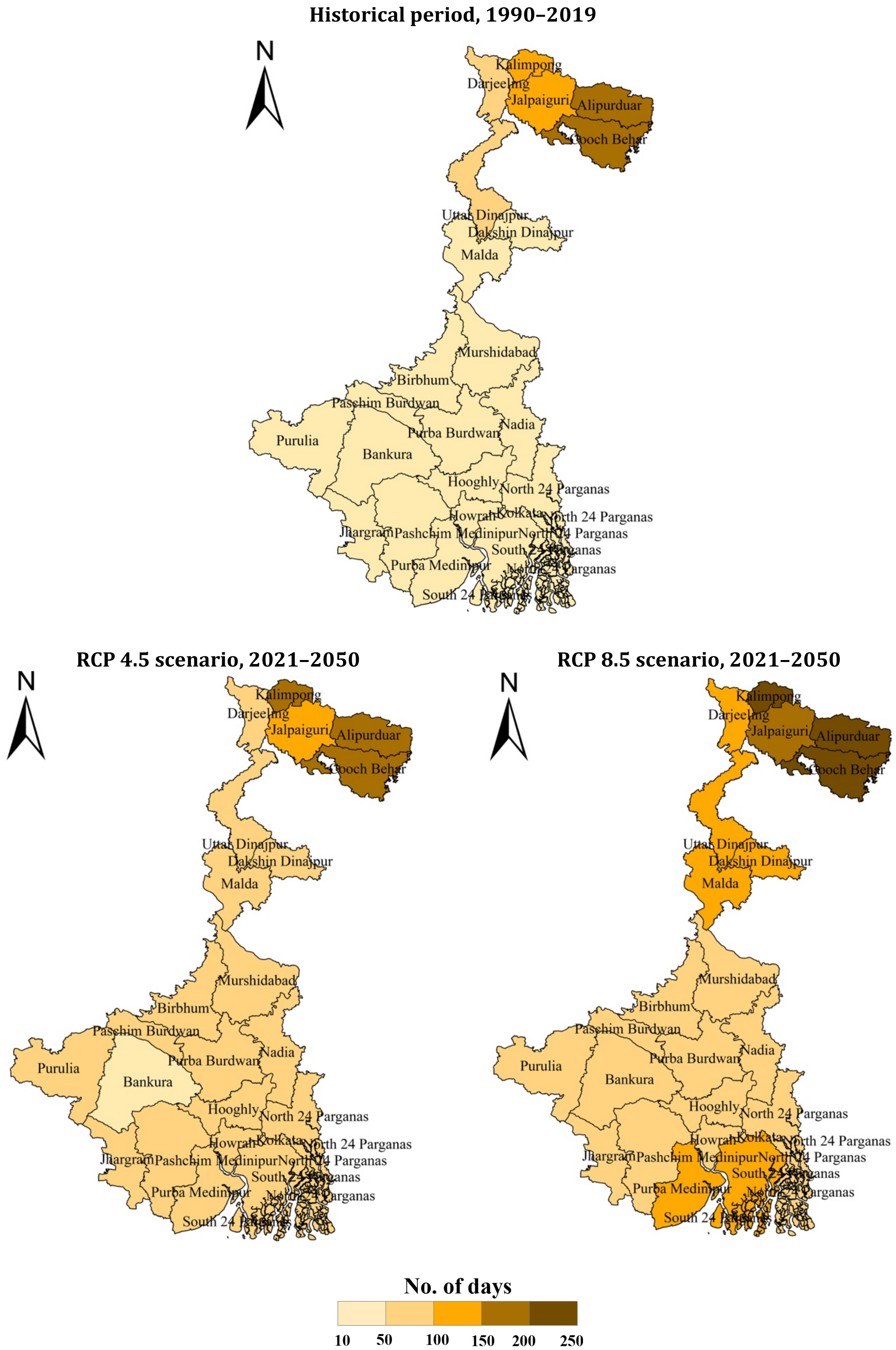


Figure 6-12: The total number of very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

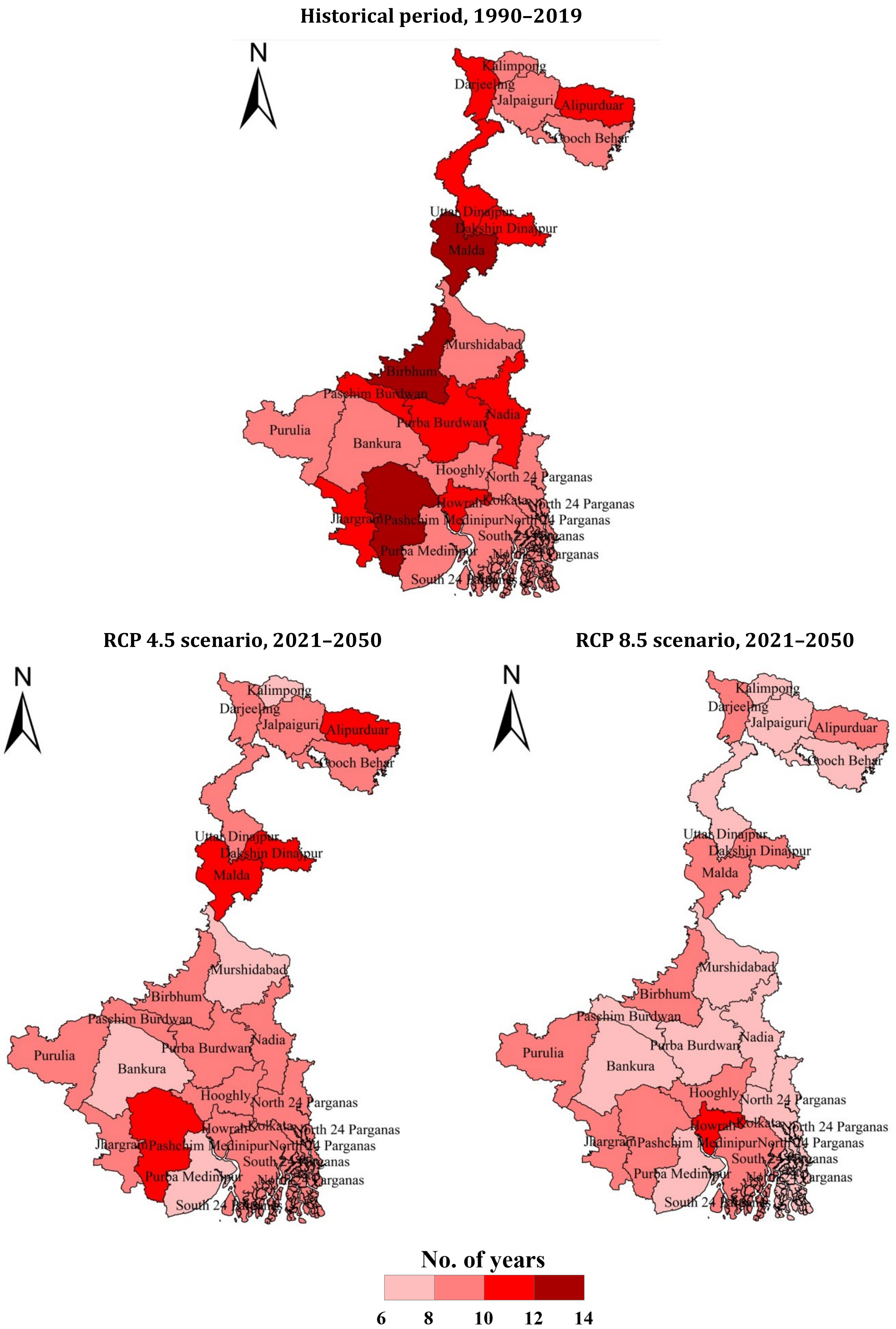


Figure 6-13: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

6.4. The summary of projected changes in the climate for West Bengal

The temperature is projected to increase in the short term (2021–2050) in all the districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 6-1).

- Under the RCP 4.5 scenario, the warming of both summer maximum and winter minimum temperatures is uniform and ranges from 1°C to 1.5°C across all the districts.
- Under the RCP 8.5 scenario, the warming of summer maximum temperature is projected to be higher in the southern-most districts, while the winter minimum temperature is projected to be higher in the northern-most districts.

Rainfall is projected to increase in the short term (2021–2050) in all the districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 6-2).

- Notable increase in rainfall by >20% in three districts under the RCP 4.5 scenario and eight districts under the RCP 8.5 scenario

Rainfall variability during the kharif season is projected to decline in a majority of the districts but increase marginally in four districts under both climate scenarios.

- The projected decline in rainfall variability is >10% in Murshidabad, Malda, and Dakshin Dinajpur districts under RCP 4.5 and RCP 8.5 scenarios.

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 6-3).

- The increase annually during the projected 2030s (2021–2050) is in the range of 1 to 17 days and 2 to 15 days per annum under RCP 4.5 and RCP 8.5 scenarios, respectively.

Heavy rainfall events are projected to increase in all the districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 6-4).

- There is a larger increase particularly in the northern districts of West Bengal.

Rainfall deficient years are projected to decline in all the districts under the RCP 8.5 scenario and in 10 of the 13 districts under the RCP 4.5 scenario compared to the historical period (1990–2019; Appendix 6-4).

- Decline in rainfall deficient years is projected to be 1 to 4 years under both the scenarios.

Appendix

Appendix 6-1: Changes in temperature under climate scenarios

Districts	Change 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
Alipurduar	1.2	1.4	1.2	1.7
Bankura	1.1	1.3	1.1	1.3
Birbhum	1.0	1.5	1.2	1.4
Cooch Behar	1.3	1.4	1.3	1.8
Dakshin Dinajpur	1.2	1.5	1.2	1.4
Darjeeling	1.3	1.5	1.1	1.8
Hooghly	1.2	1.4	1.0	1.3
Howrah	1.1	1.4	1.0	1.2
Jalpaiguri	1.2	1.5	1.3	1.7
Jhargram	1.1	1.3	1.2	1.5
Kalimpong	1.2	1.5	1.4	1.8
Kolkata	1.3	1.5	1.1	1.5
Malda	1.1	1.5	1.1	1.2
Murshidabad	1.2	1.4	1.3	1.4
Nadia	1.0	1.4	1.2	1.4
North 24 Parganas	1.3	1.7	1.1	1.3
Paschim Burdwan	1.2	1.4	1.2	1.4
Paschim Medinipur	1.3	1.6	1.1	1.4
Purba Burdwan	1.2	1.5	1.2	1.4
Purba Medinipur	1.4	1.6	1.0	1.5
Purulia	1.2	1.5	1.2	1.5
South 24 Parganas	1.4	1.8	1.1	1.4
Uttar Dinajpur	1.4	1.5	1.2	1.7

Appendix 6-2: Changes in rainfall under climate scenarios

Districts	Change (%) 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
Alipurduar	9	13	9	15	3	18
Bankura	6	11	11	15	6	26
Birbhum	16	17	20	22	8	25
Cooch Behar	8	12	10	13	7	23
Dakshin Dinajpur	22	24	26	28	7	22
Darjeeling	7	7	6	9	9	26
Hooghly	5	13	3	13	6	22
Howrah	7	16	13	19	4	7
Jalpaiguri	11	15	12	16	4	15
Jhargram	4	7	4	12	8	29
Kalimpong	4	8	2	9	15	20
Kolkata	7	15	10	16	17	20
Malda	22	23	23	25	7	41
Murshidabad	17	18	19	22	16	24
Nadia	10	14	12	18	4	26
North 24 Parganas	10	14	8	20	3	7
Paschim Burdwan	12	18	13	21	6	22
Paschim Medinipur	5	11	6	11	4	16
Purba Burdwan	13	19	15	21	7	16
Purba Medinipur	6	15	7	16	3	7
Purulia	6	15	13	22	7	42
South 24 Parganas	8	14	7	17	3	9
Uttar Dinajpur	18	19	19	23	4	12

Appendix 6-3: 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
Alipurduar	2289	2406	2489
Bankura	2026	2262	2321
Birbhum	1835	1937	2012
Cooch Behar	2323	2397	2499
Dakshin Dinajpur	1529	1864	1990
Darjeeling	2988	3099	3123
Hooghly	1989	2076	2112
Howrah	1912	2176	2234
Jalpaiguri	2398	2543	2590
Jhargram	1908	1954	1990
Kalimpong	2962	2973	3012
Kolkata	1912	1976	1966
Malda	1800	1934	1973
Murshidabad	1902	2047	2073
Nadia	1871	1959	2099
North 24 Parganas	2030	2076	2312
Paschim Burdwan	1845	1937	1989
Paschim Medinipur	2001	2095	2131
Purba Burdwan	1845	1900	2001
Purba Medinipur	1982	2081	2134
Purulia	2042	2155	2167
South 24 Parganas	2059	2139	2196
Uttar Dinajpur	2219	2390	2412

Appendix 6-4: 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
Alipurduar	323	396	408	206	231	213	11	11	10
Bankura	59	90	112	12	45	76	8	6	6
Birbhum	85	101	134	14	56	89	13	9	9
Cooch Behar	287	350	398	176	190	220	10	10	7
Dakshin Dinajpur	73	132	189	34	89	107	12	12	10
Darjeeling	258	267	290	55	75	101	11	10	9
Hooghly	81	124	156	10	67	89	10	9	9
Howrah	110	167	189	11	69	80	12	10	13
Jalpaiguri	311	348	390	113	145	190	10	9	8
Jhargram	106	134	167	17	78	95	12	10	9
Kalimpong	356	380	400	140	178	201	8	7	6
Kolkata	110	189	201	11	76	93	11	10	11
Malda	100	134	189	28	89	102	14	11	10
Murshidabad	74	130	189	12	60	95	9	8	7
Nadia	57	99	126	14	67	80	11	10	8
North 24 Parganas	112	144	189	17	68	95	9	9	7
Paschim Burdwan	78	112	178	15	71	97	11	9	8
Paschim Medinipur	101	167	191	23	70	94	14	11	10
Purba Burdwan	78	112	178	15	78	96	11	9	8
Purba Medinipur	129	178	199	35	86	102	9	8	7
Puruliya	67	112	166	17	67	92	9	9	9
South 24 Parganas	129	145	199	20	86	102	10	10	9
Uttar Dinajpur	197	278	292	61	92	114	12	10	8

7. 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 all the eastern states.

Climate projections for the eastern states at the district level for the period 2021–2050 (the 2030s) indicate a warmer and wetter future, with an 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 eastern 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. In Eastern India—particularly Bihar, Odisha, and West Bengal, which are flood-prone[4]—the conditions will likely get worse with climate change. These states have also witnessed droughts in the past. Therefore, it is important to integrate flood management with drought management strategies to ensure losses are reduced and effective adaptation occurs.

Agriculture: Agriculture crops require specific conditions to thrive and have specific temperature and water requirements. Higher temperatures projected in the various districts of the eastern 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 eastern states could have 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) implications for health.

[4]https://www.mapsofindia.com/top-ten/geography/india-flood.html

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.

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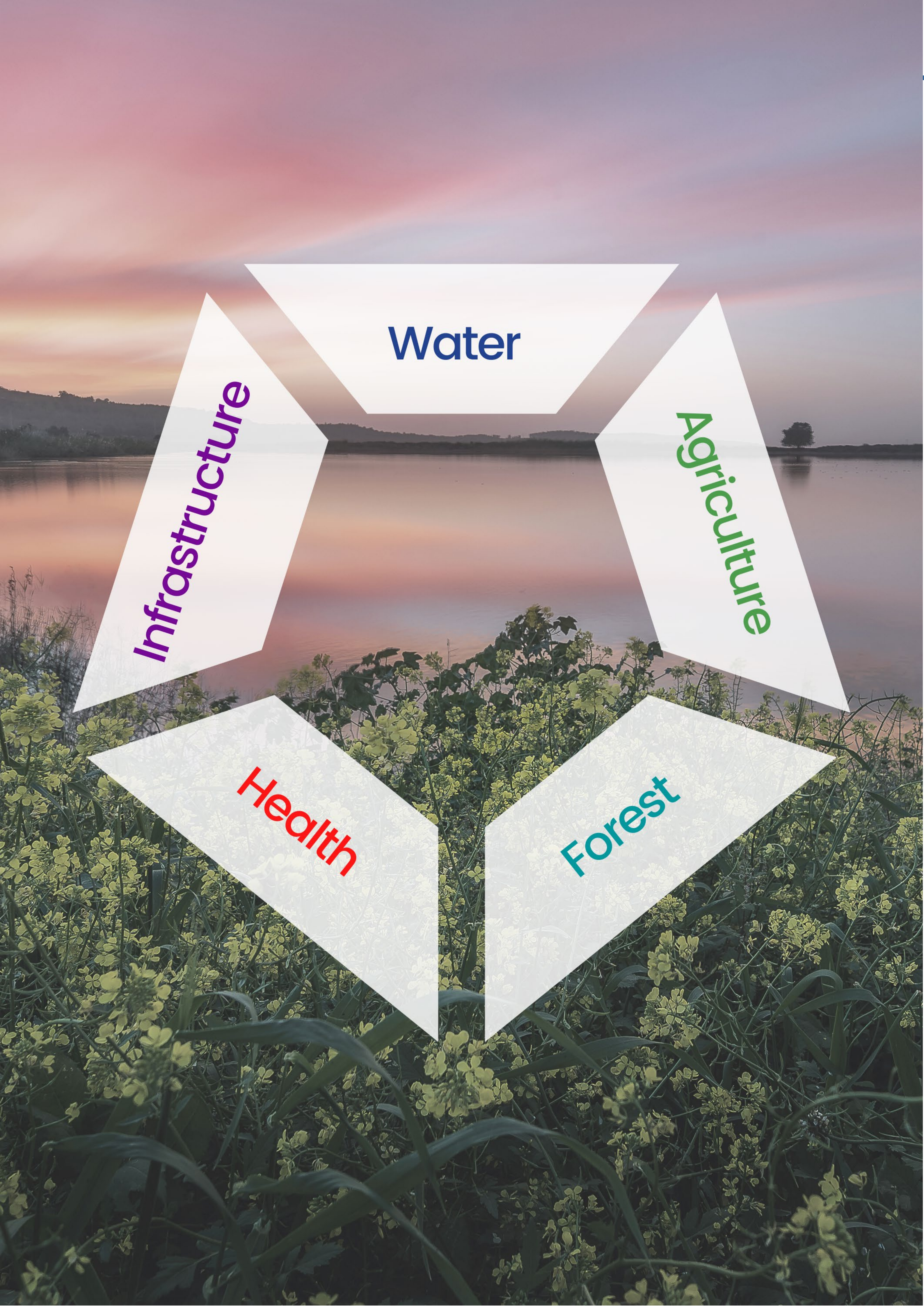
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