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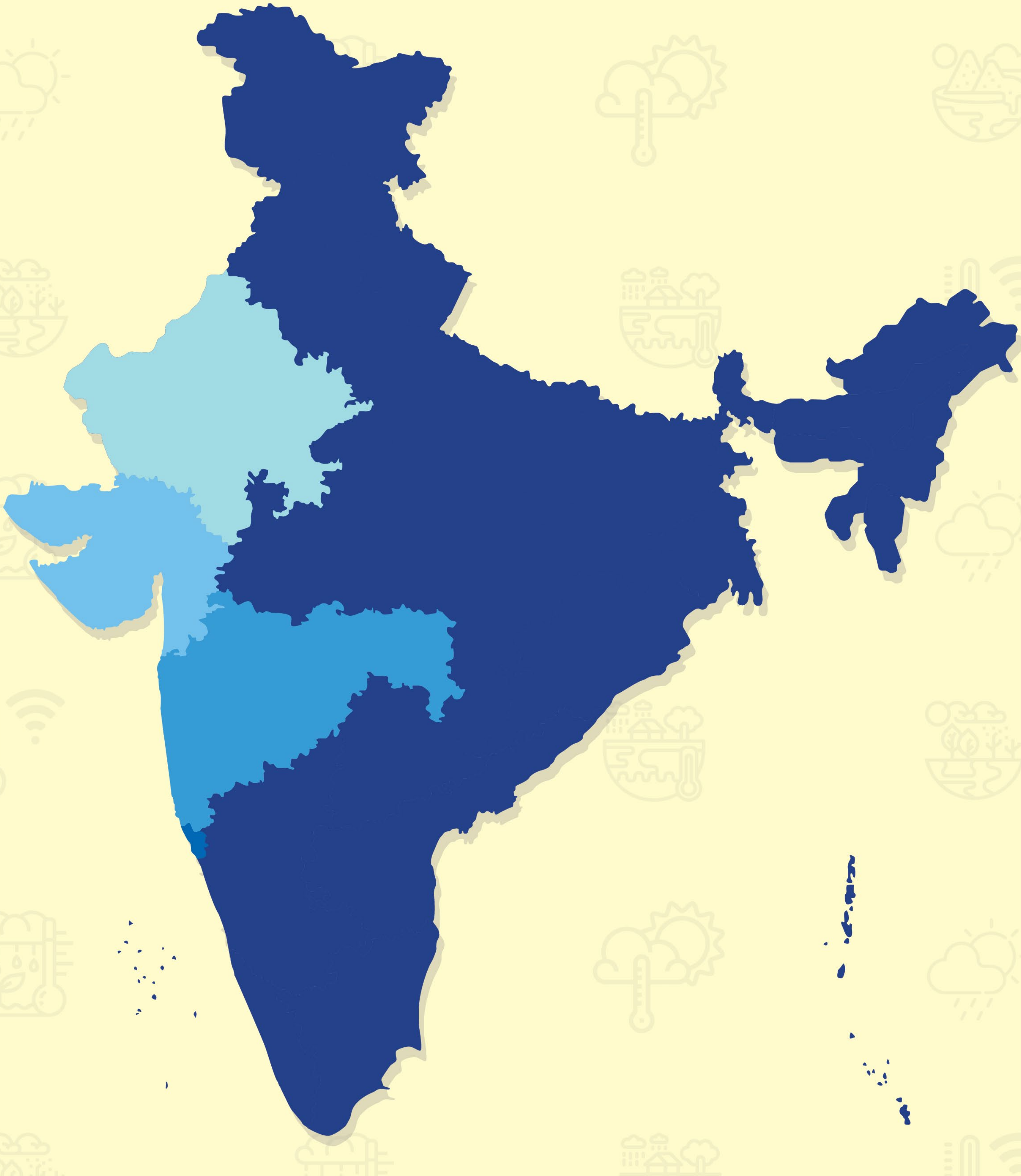
DISTRICT-LEVEL CHANGES IN CLIMATE:

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



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

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CSTEP

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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 western states of India: Goa, Gujarat, Maharashtra, and Rajasthan.

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

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

Temperature

Summer maximum and the winter minimum temperatures are projected to increase by 1^{0}C to 2^{0}C in the districts of western India compared to the historical temperatures.

Rainy days

The number of rainy days is projected to increase in the 2030s in almost all the districts of western India compared to the historical period. The increase is by 1 to 24 days under the RCP 4.5 scenario, with the maximum increase projected in Rajasthan and a minimum increase projected in Maharashtra. The increase is by 3 to 22 days under the RCP 8.5 scenario, with the maximum increase projected in Goa.

Monsoon rainfall

Rainfall during kharif (June to September) and rabi (October to December) seasons are projected to increase in the 2030s in almost all the districts of western India compared to the historical period. The projected increase in the kharif season rainfall is by 1% to 33% under the RCP 4.5 scenario and 3% to 34% under the RCP 8.5 scenario. The rabi season rainfall is projected to increase by 3% to 57% under the RCP 4.5 scenario and 13% to 81% 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 western 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 western India compared to the historical period. The increase in high-intensity rainfall events per annum is by one to five events under the RCP 4.5 scenario and one to eight events under the RCP 8.5 scenario.

Rainfall deficient years

A decline in rainfall deficient years is projected in the 2030s across almost all the districts of western India compared to the historical period. The decline in rainfall deficient years is by 1 to 8 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 Gujarat followed by Maharashtra.

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

Recommendations: The district-level climate change assessment for the western 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.

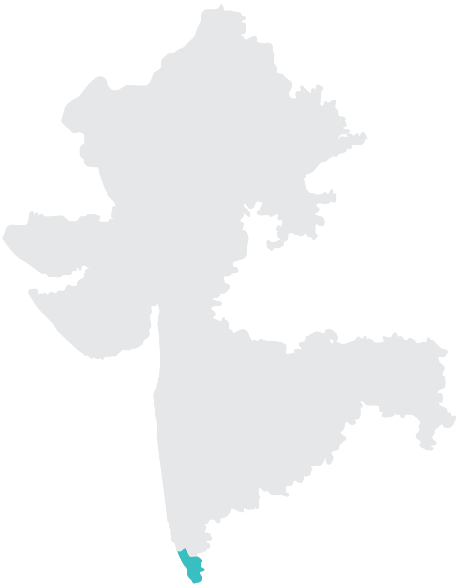
2.4. The organisation of the report

This report is for the four western states of India: Goa, Gujarat, Maharashtra, and Rajasthan. 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. Goa



Goa is one of the smallest states in India. It is situated along the Konkan coast and has only two districts: North Goa and South Goa. It is bound by Maharashtra on the north, Karnataka on the east and south, and the Arabian Sea on the west. Goa has a 160 km long coastline, spans an area of 3,700 sq. km, and has a population of 1.46 million according to Census 2011. It has a tropical monsoon climate with an average annual rainfall of 3,800 mm, received mostly during the south-west monsoon, and an average annual temperature ranging from 16°C to 37°C. The Western Ghats and coastal plains are the two distinct physiographic regions of Goa. About 35% of the state is covered by biodiversity-rich forests as it is in the Western Ghats region. Approximately 36% of the state's area is under agriculture, with a majority under paddy cultivation. The remaining area is under cash crops such as cashew, mango, jackfruit, bananas, and pineapple.

Flooding and inundations caused by excessive rain are the main natural hazards in Goa. The state is categorised as a Moderate Damage Risk Zone in terms of earthquakes. The hilly parts of the state are also plagued by landslides, with some regions becoming perennial hazard zones during the monsoons.

These characteristics make Goa climate-sensitive, underpinning the need for climate information in development planning. Climate data can 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 are presented in the subsequent sections.

3.1.1. Trends in temperature

Goa recorded a moderate warming of 0.1^{0}C to 0.65^{0}C in the summer maximum temperature and 0.24^{0}C to 0.45^{0}C in the winter minimum temperature during the historical period. Figure 3-1 presents the mean summer maximum and winter minimum temperatures in Goa during the historical period.

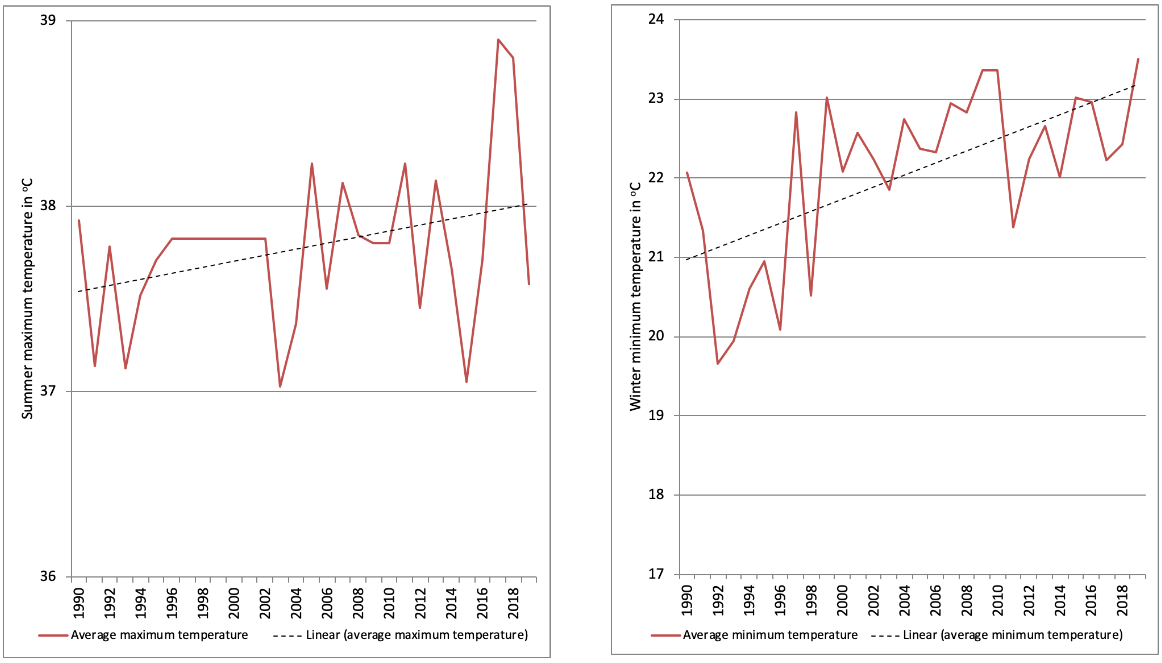


Figure 3-1: Mean summer maximum and winter minimum temperatures in Goa during the historical period (1990–2019)

3.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and kharif season rainfall was recorded in the two districts, and the increase was by 5% and 20%, respectively, during the historical period. The variability of rainfall during this period was 30% and 53% in North Goa and 37% and 68% in South Goa during the kharif and rabi seasons, respectively. Figure 3-2 presents the mean annual rainfall in Goa during the historical period.

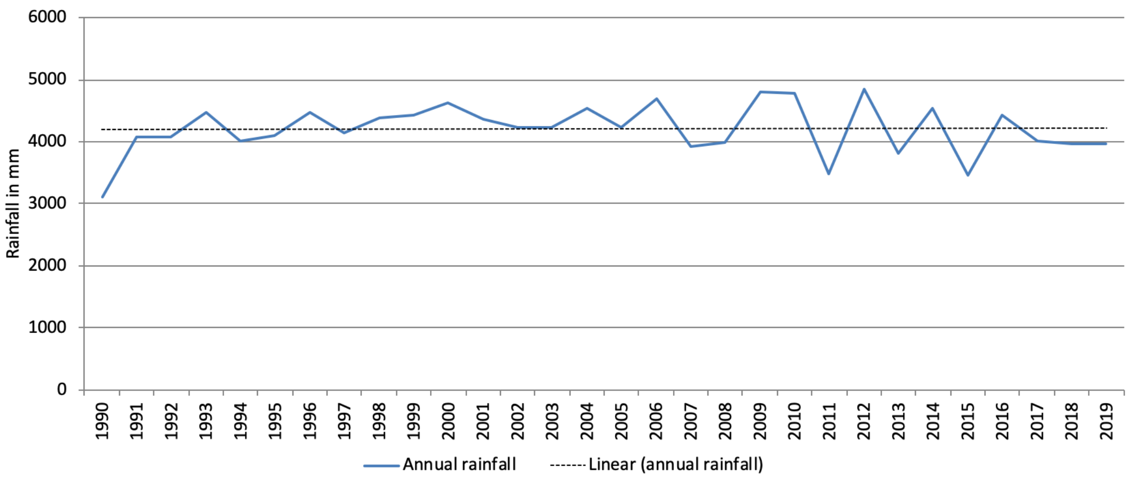


Figure 3-2: Mean annual rainfall in Goa during the historical period (1990–2019)

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 the summer maximum and winter minimum temperatures for the two districts of Goa are presented in Figure 3-3.

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

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

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 in both North and South Goa districts during the projected 2030s (Figure 3-4). 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 was 3053 and 3114 days in North Goa and South Goa, respectively, during the 30-year historical period. This is projected to increase to 3325 and 3435 days under the RCP 4.5 scenario and 3412 and 3458 days under the RCP 8.5 scenario in North Goa and South Goa, respectively. The increase per annum is as follows:

RCP 4.5 scenario: Projected to double in both the districts

RCP 8.5 scenario: Projected to quadruple in North Goa and increase by five times in South Goa under the RCP 8.5 scenario compared to the historical period

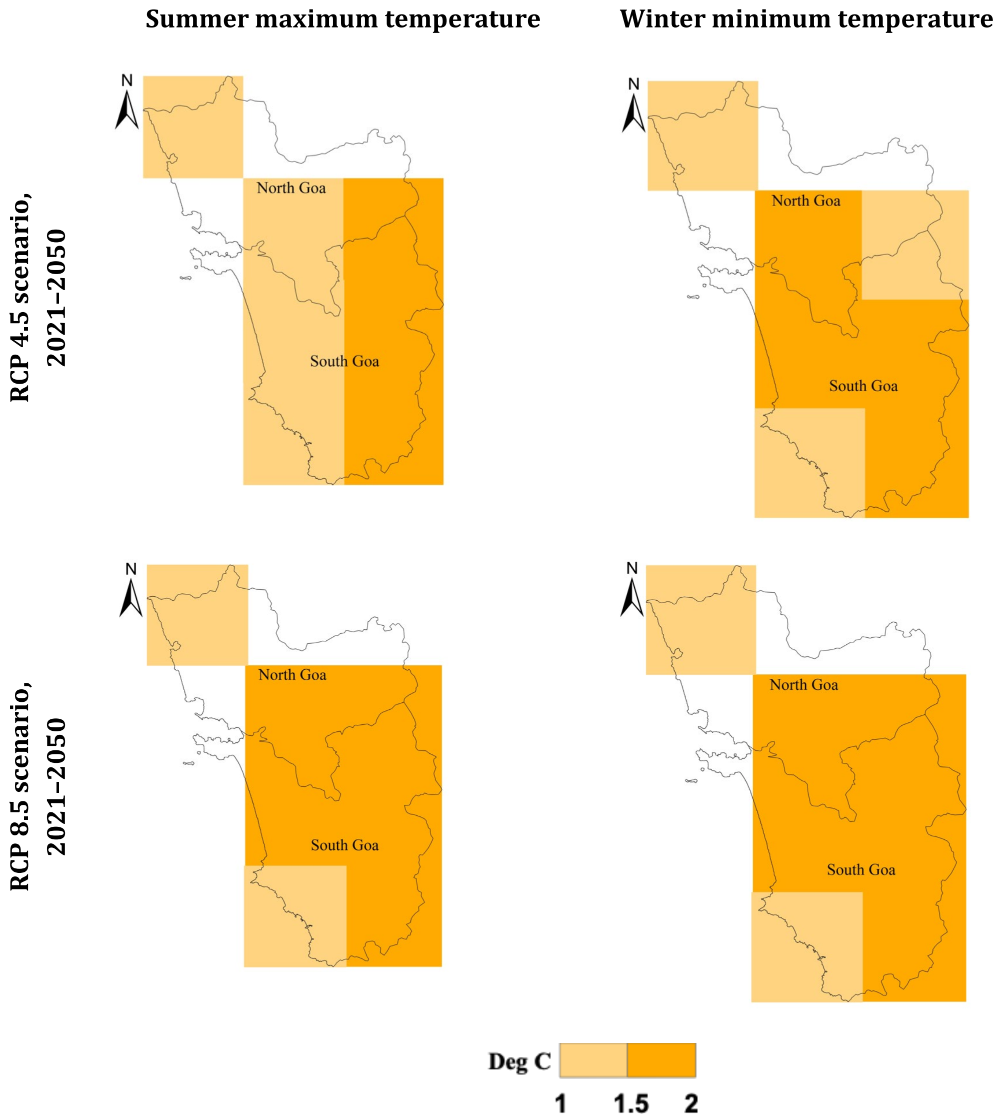


Figure 3-3: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

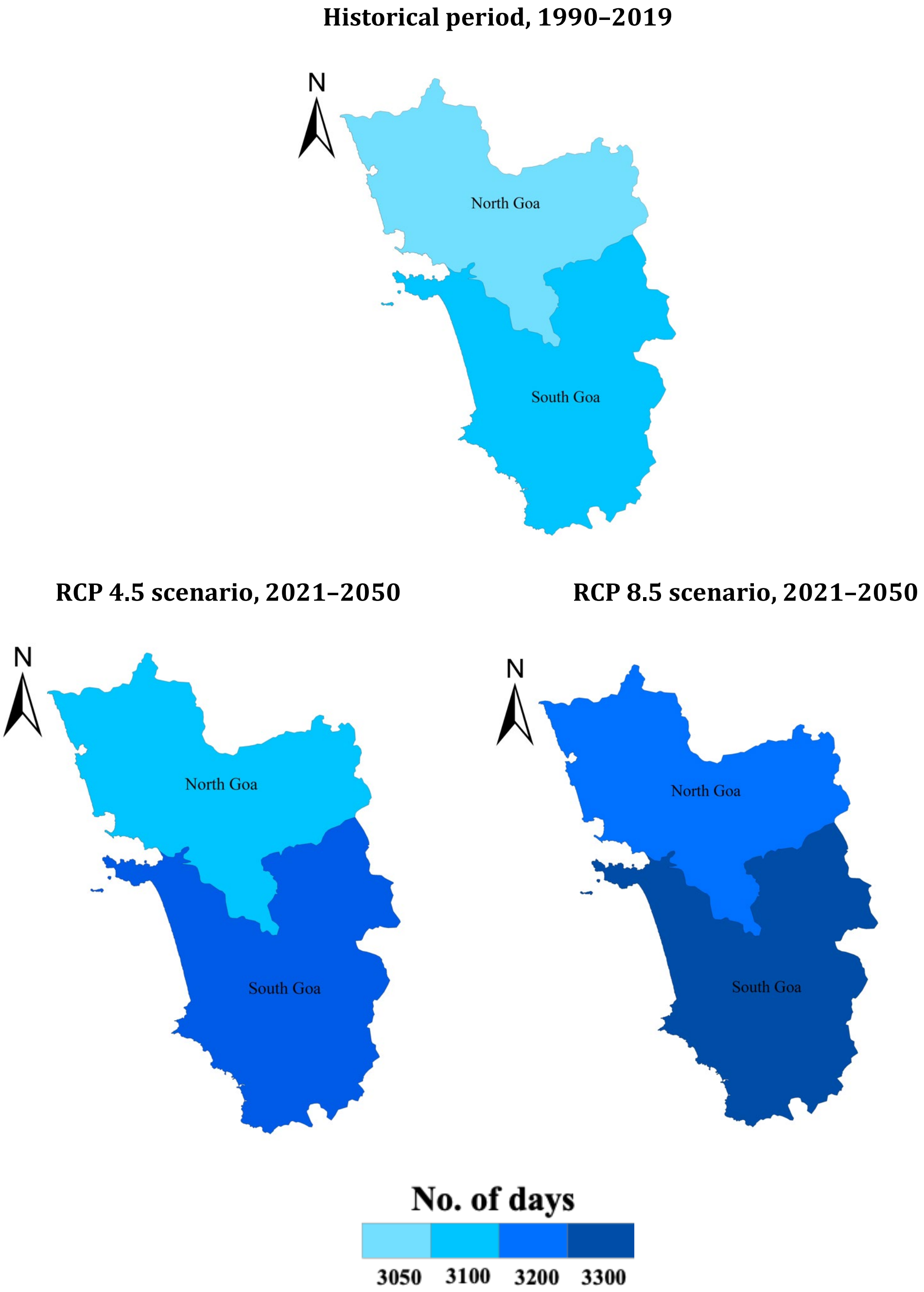
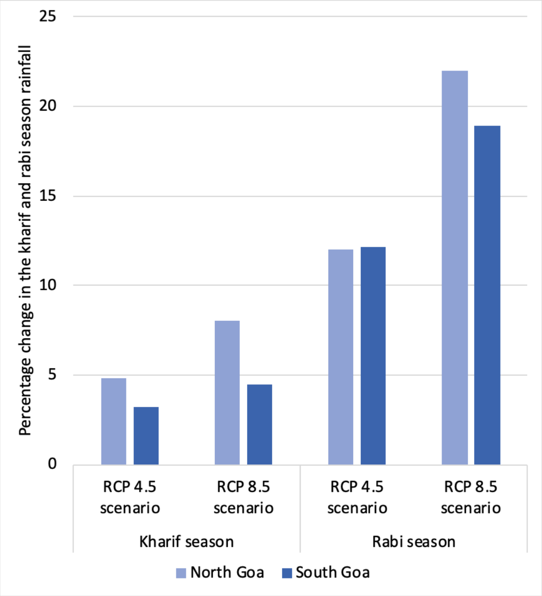


Figure 3-4: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

3.2.2.2. Mean rainfall and rainfall variability during the kharif and rabi seasons

The kharif season rainfall is projected to increase in both districts under both climate scenarios. Figure 3-5 presents district-wise changes in the kharif and rabi season rainfall and changes in the variability (coefficient of variation) of rainfall under both climate scenarios for the kharif and rabi seasons.

Season	Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
Kharif	RCP 4.5	Increases in North Goa by 5% and South Goa by 3%	Declines in North Goa by 4% and South Goa by 3%
	RCP 8.5	Increases in North Goa by 8% and South Goa by 5%	Declines in both North and South Goa by 5%
Rabi	RCP 4.5	Increases in both North and South Goa by 12%	Declines in North Goa by 3% and South Goa by 17%
	RCP 8.5	Increases in North Goa by 22% and South Goa by 19%	Declines in North Goa by 11% and South Goa by 28%



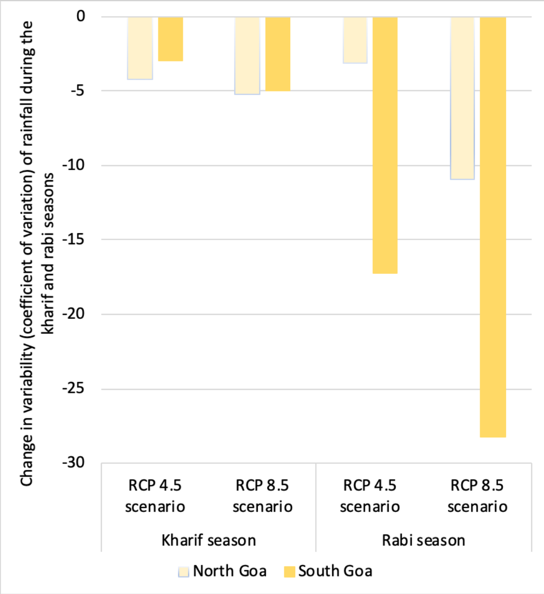


Figure 3-5: Projected percentage change in the magnitude and variability (coefficient of variation) of the kharif and rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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 the projected 2030s under the two climate scenarios, and the change was computed for both districts of Goa.

High-intensity rainfall events (Figure 3-6)

The total number of high-intensity rainfall events increases from 585 and 633 days during the historical period (1990–2019) to 631 to 760 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 655 to 805 days under the RCP 8.5 scenario in South Goa and North Goa, respectively. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: An increase in high-intensity rainfall events by four and two events per annum is projected in North and South Goa, respectively.

RCP 8.5 scenario: An increase in high-intensity rainfall events by six and two events per annum is projected in North and South Goa, respectively.

Very high-intensity rainfall events (Figure 3-6)

The total number of very high-intensity rainfall events increases from 270 and 321 days during the historical period (1990–2019) to 335 and 376 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 375 and 410 days under the RCP 8.5 scenario in South Goa and North Goa, respectively. 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 both North Goa and South Goa.

RCP 8.5 scenario: The projected increase per annum is by three and four events in North Goa and South Goa, respectively.

Rainfall deficient years (Figure 3-7).

Rainfall deficient years, computed considering the rainfall during the kharif season, are projected to decline in both districts under both climate scenarios. The number of rainfall deficient years declines from 10 and 14 years during the historical 30-year period to 9 and 13 years under the RCP 4.5 scenario and 9 and 11 years under the RCP 8.5 scenario during the projected period in South Goa and North Goa, respectively.

RCP 4.5 scenario: The projected decline is by one event in both North Goa and South Goa.

RCP 8.5 scenario: The projected decline is by one and three events in North Goa and South Goa, respectively.

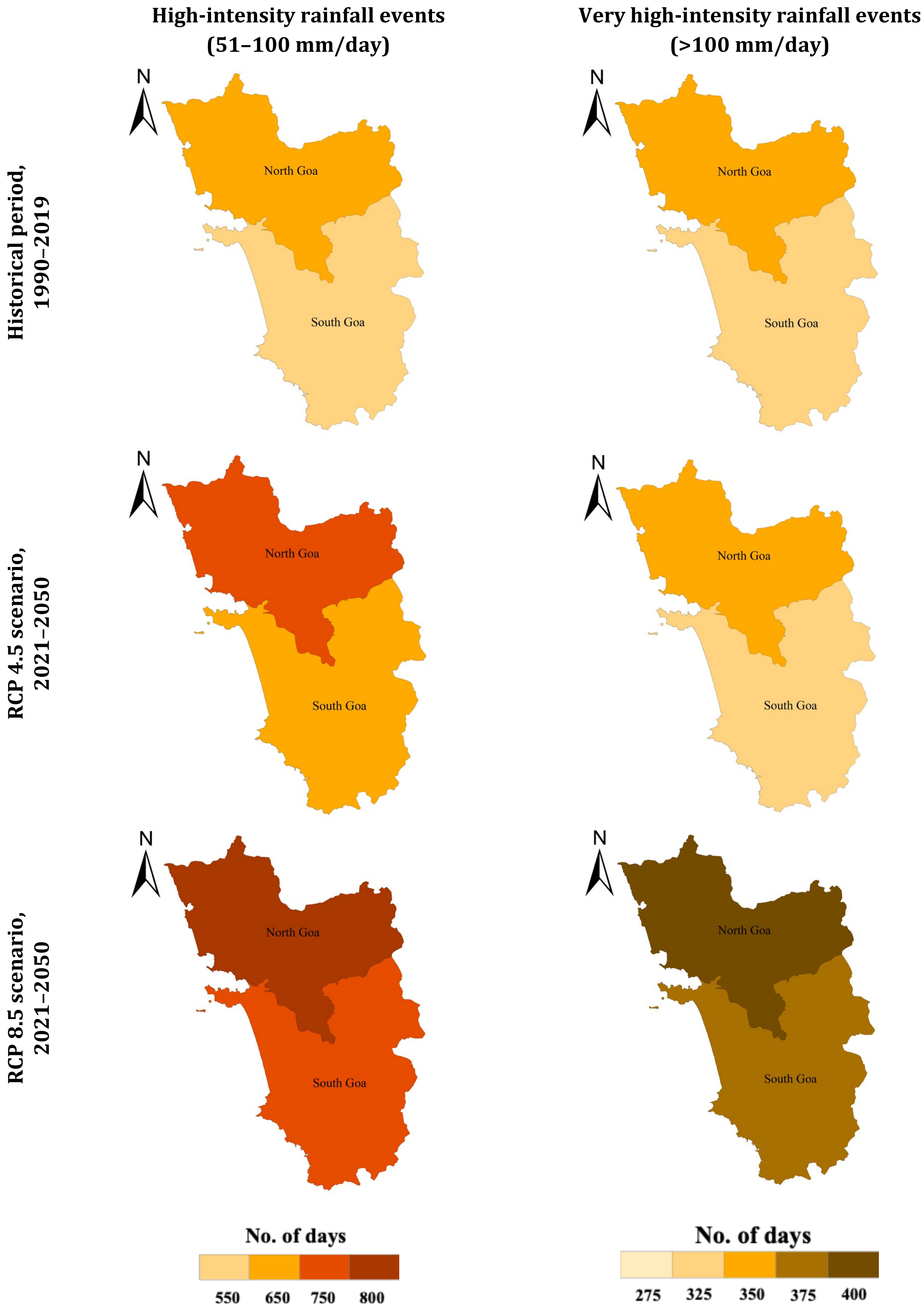


Figure 3-6: The total number of high-intensity and very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

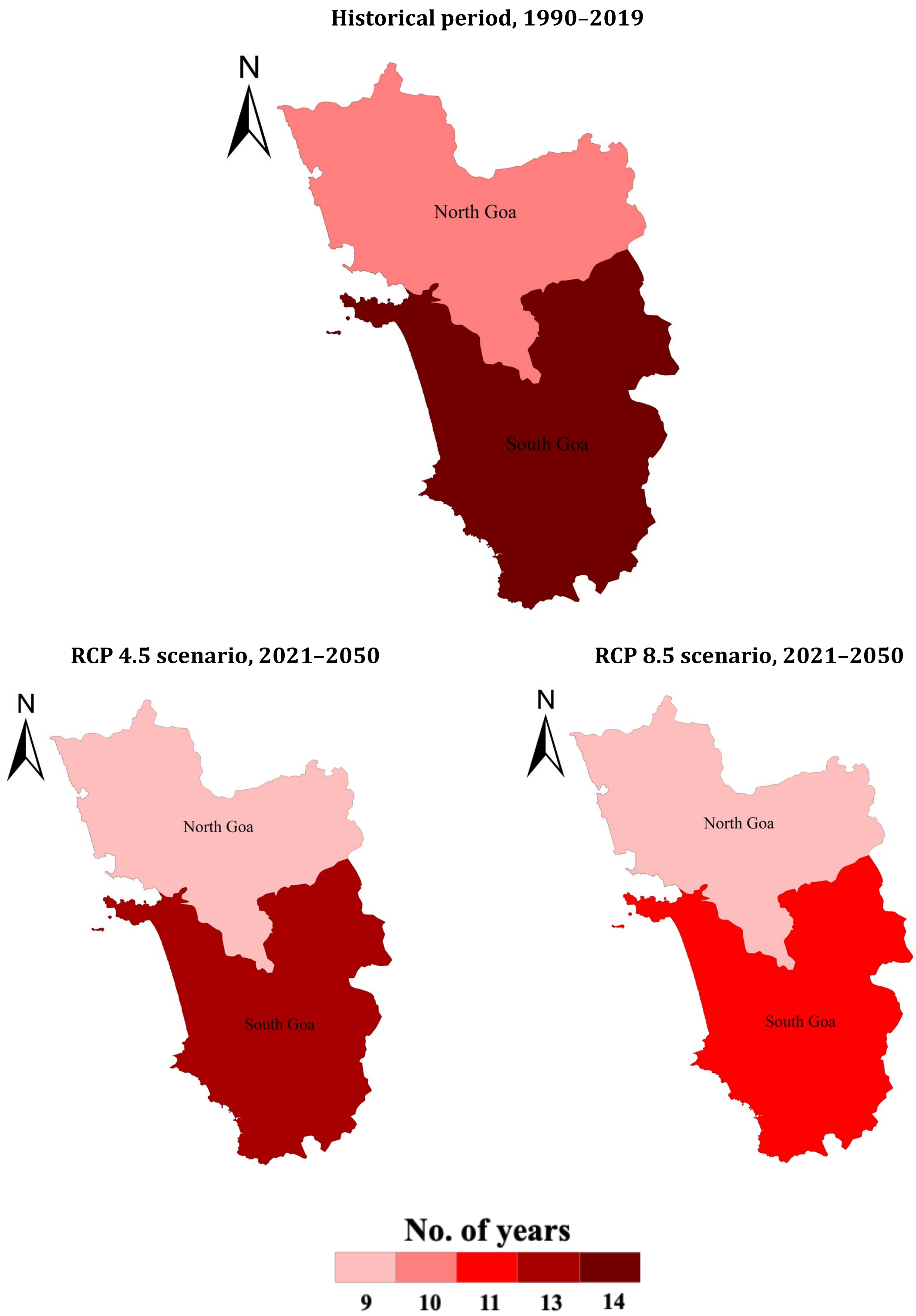


Figure 3-7: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

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

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

- Both summer maximum and winter minimum temperatures are projected to warm by 1°C to 2°C across North Goa and South Goa 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 3-2).

Rainfall variability is projected to decline in both districts during kharif and rabi seasons under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019).

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

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

Rainfall deficient years are projected to decline in both districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; 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
North Goa	1.2	1.8	1.0	1.7
South Goa	1.6	1.9	1.0	2.0

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
North Goa	16	18	5	8	12	22
South Goa	14	18	3	5	12	19

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
North Goa	3053	3125	3162
South Goa	3114	3180	3258

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

Districts	High-intensity rainfall events			Very high-intensity rainfall events			Rainfall deficient years		
	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5
North Goa	633	760	805	321	376	410	10	9	9
South Goa	585	631	655	270	335	375	14	13	11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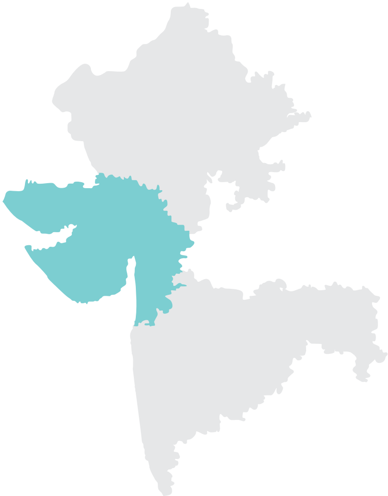
4. Gujarat



The state of Gujarat has an area of 196,024 sq. km and a population of 60.44 million according to Census 2011. It is the westernmost state of the country and has the longest coastline (1,663 km). It is bordered by Pakistan in the north, Rajasthan in the north and the north-east, Madhya Pradesh in the east, and Maharashtra and Dadra and Nagar Haveli in the south. Gujarat has 33 districts, and the climate ranges from arid and semi-arid to humid. The mean temperature is between 25°C and 28°C, and the average annual rainfall is from 800 mm to 1,000 mm. The state receives most of the rainfall (95%) during the south-west monsoons. More than half of Gujarat (54%) is under agriculture and only about 10% has forest cover.

Owing to its geo-climatic, geological, and physical features, Gujarat is vulnerable to all major natural hazards, namely droughts, floods, cyclones, earthquakes, and tsunamis. 18.3% of the state is classified as very high damage risk zone for earthquakes, with 13.4% considered as high damage risk zone, and 67.4% as moderate damage risk zone. More than half the state (54%) is at risk of damage because of high-intensity cyclones, with wind speeds ranging between 47 m/s and 55 m/s. Because of the heavy dependence on the monsoons for replenishment of water sources, failures of monsoons have led to acute water and food scarcity across the state—particularly in the arid to semi-arid regions that do not have alternative sources of irrigation. Groundwater exploitation and falling water tables have added further stress on crops and water supplies. According to the Vulnerability Atlas of India 2019, about 7.9% of the state is flood-prone. Because of its long coastline, Gujarat is also prone to tsunamis. In the summer, the maximum temperature can go up to 45°C, leading to severe heatwaves.

These characteristics make Gujarat climate-sensitive, underpinning the need for climate information in development planning. 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

Gujarat recorded a warming of 0.5^{0}C to 0.9^{0}C in the summer maximum temperature and 0.05^{0}C to 0.2^{0}C in the winter minimum temperature during the historical period. Figure 4-1 presents the mean summer maximum and winter minimum temperatures in Gujarat during the historical period.

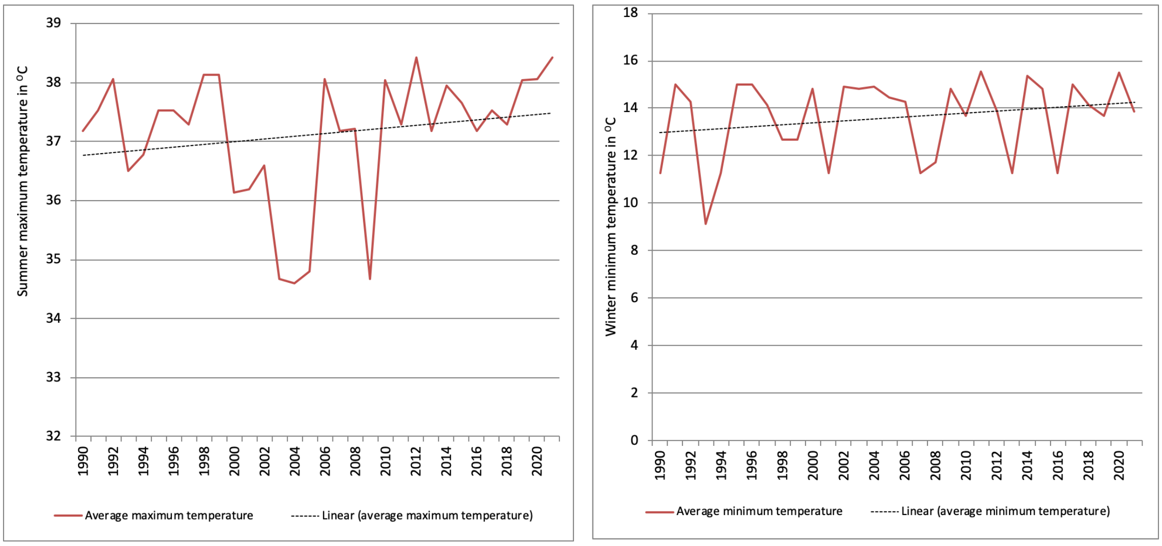


Figure 4-1: Mean summer maximum and winter minimum temperatures in Gujarat during the historical period (1990–2019)

4.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and the kharif season rainfall of up to 10% was recorded in a majority of the districts except for parts of the south-eastern districts, where a 10% to 15% increase in annual rainfall was recorded. Figure 4-2 presents the mean annual rainfall in Gujarat during the historical period.

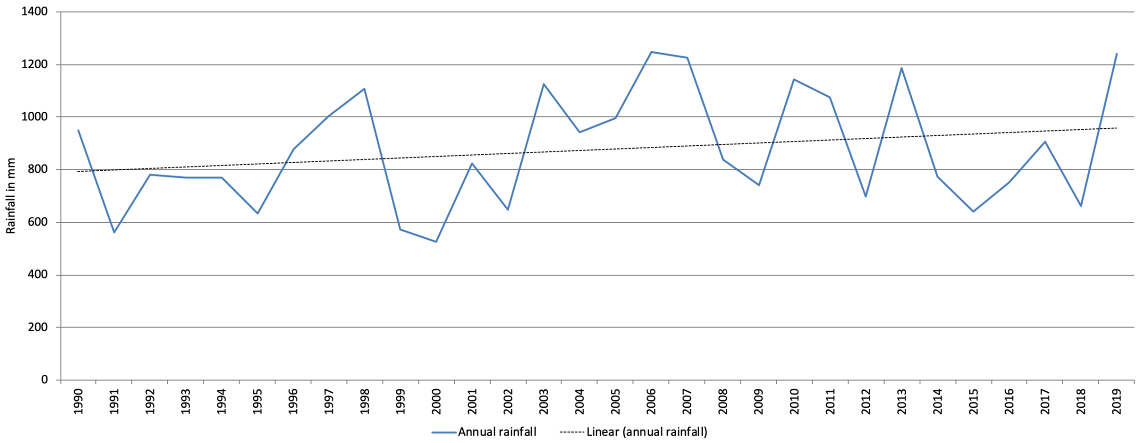


Figure 4-2: Mean annual rainfall in Gujarat during the historical period (1990–2019)

The kharif season rainfall variability (the coefficient of variation) ranged from 20% in Surat and Valsad to 66% in the Kachchh district (Figure 4-3). During this period, the rabi season rainfall variability was >100% in all the districts—an indication of the total failure of rainfall during the season (Figure 4-3).

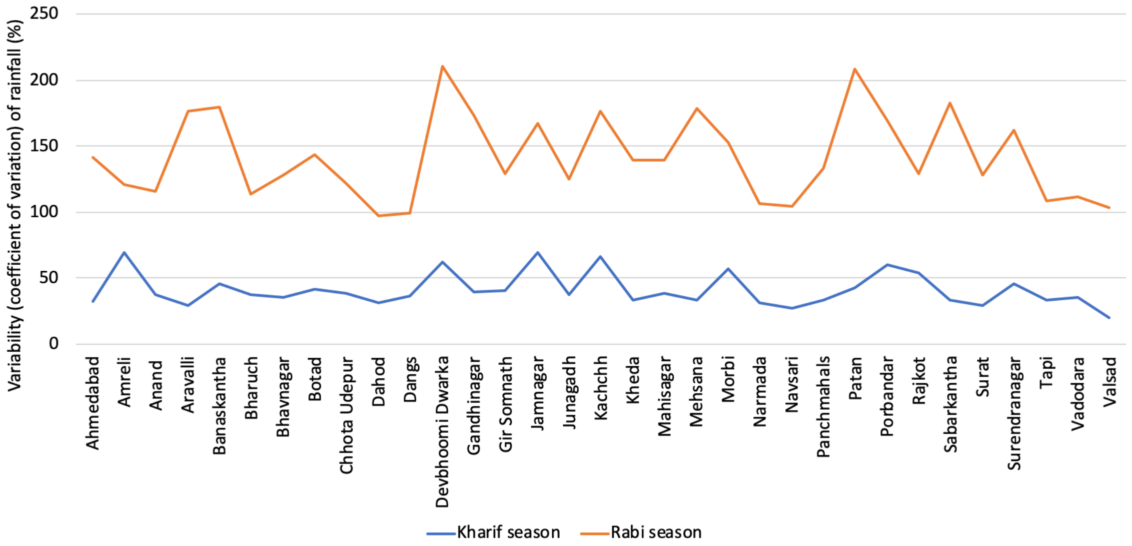


Figure 4-3: The kharif and rabi season rainfall variability during the historical period (1990–2019)

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 Gujarat are presented in Figure 4-4.

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

Climate scenarios	Summer maximum	Winter minimum
RCP 4.5	Increases by 1^0C to 2^0C	Increases by 1^0C to 2^0C
RCP 8.5	Increases by 1^0C to 2^0C, with a greater number of districts experiencing warming	Increases by 1^0C to 2^0C, with a greater number of districts experiencing warming

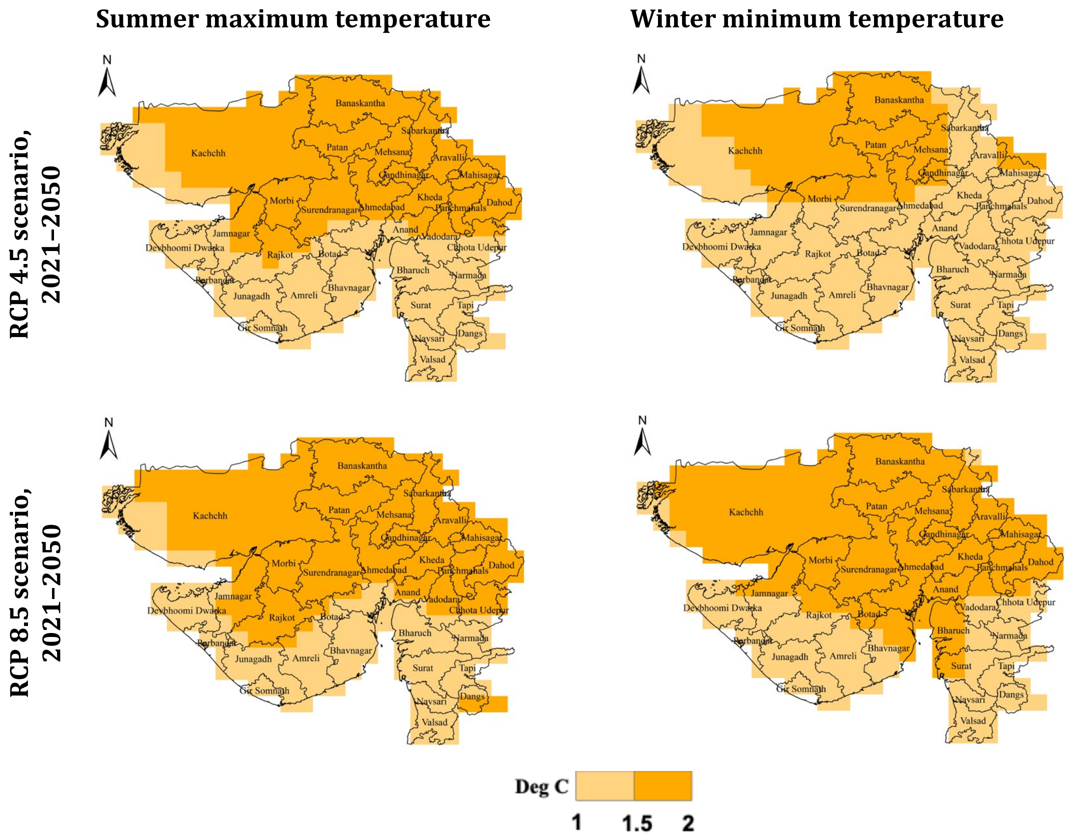


Figure 4-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019). The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

4.2.1.1. Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 1, a heatwave analysis of the Ahmedabad 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), under both RCP 4.5 and RCP 8.5 scenarios (Figure 4-5) relative to the historical period (1990–2019).

- Heatwaves are projected to double under both RCP 4.5 and RCP 8.5 scenarios in the 2030s.
- Severe heatwaves are projected to increase by five and seven times under RCP 4.5 and RCP 8.5 scenarios, respectively, in the 2030s.

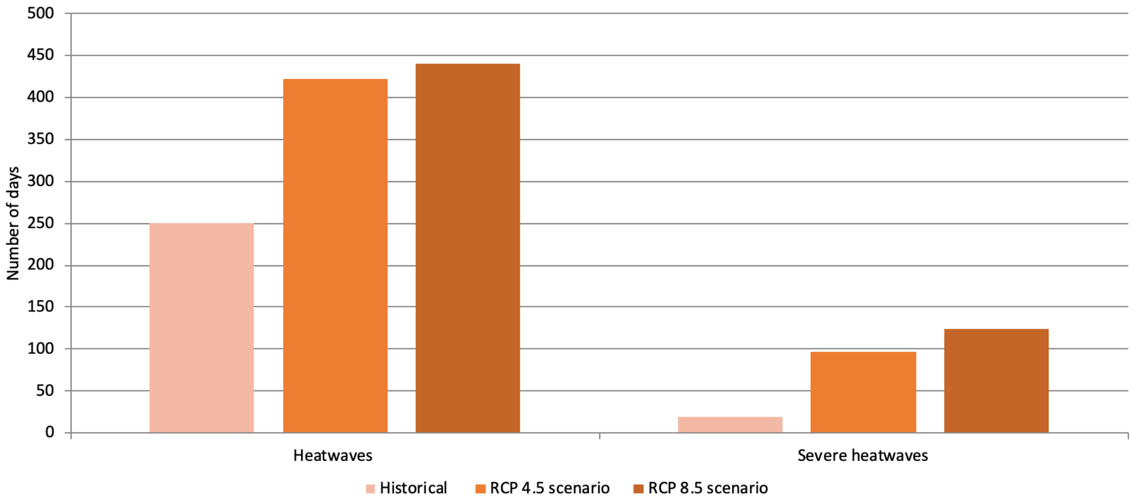


Figure 4-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

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 489 to 2115 days over the 30-year historical period increases to 626 to 2267 days under the RCP 4.5 scenario and 843 to 2290 days under the RCP 8.5 scenario during the projected 2030s. The increase per annum is as follows:

RCP 4.5 scenario: Increases by 2 to 15 days annually in all the districts, with >10 additional days projected for Bhavnagar, Patan, and Porbandar districts

RCP 8.5 scenario: Increases by 3 to 15 days in all the districts, with >10 additional days per annum projected for Kachchh, Bhavnagar, Patan, and Porbandar districts

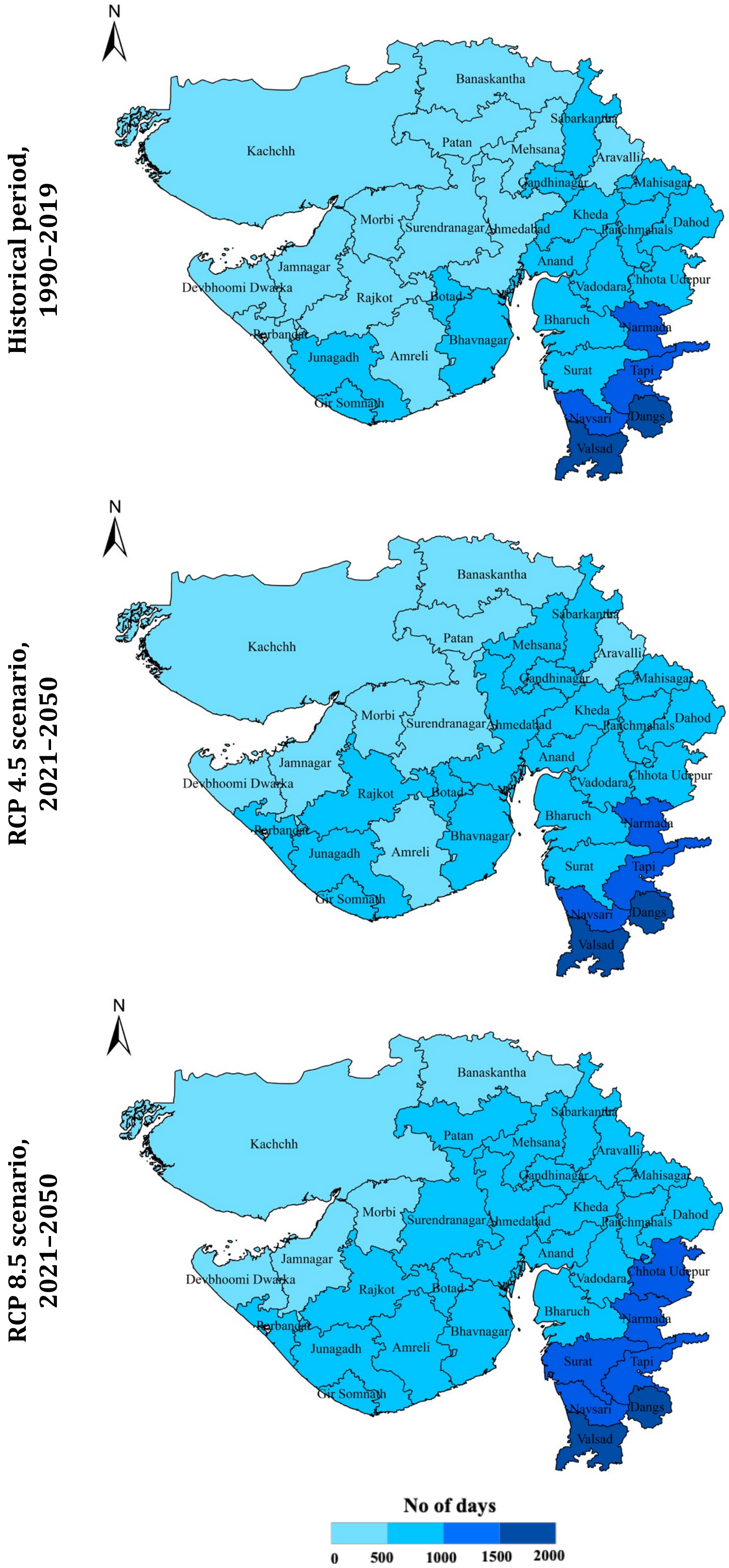


Figure 4-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

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, except Banaskantha, from 3% in Surendranagar to 33% in Dangs	Declines in 25 districts by 1% to 21%, increases in six districts by 1% to 8%, with no change in Mehsana and Ahmedabad
RCP 8.5	Increases in all the districts, from 6% in Surendranagar to 32% in Porbandar	Declines in 30 districts by 1% to 27% and increases in Valsad, Surat, and Aravalli by 3% to 5%

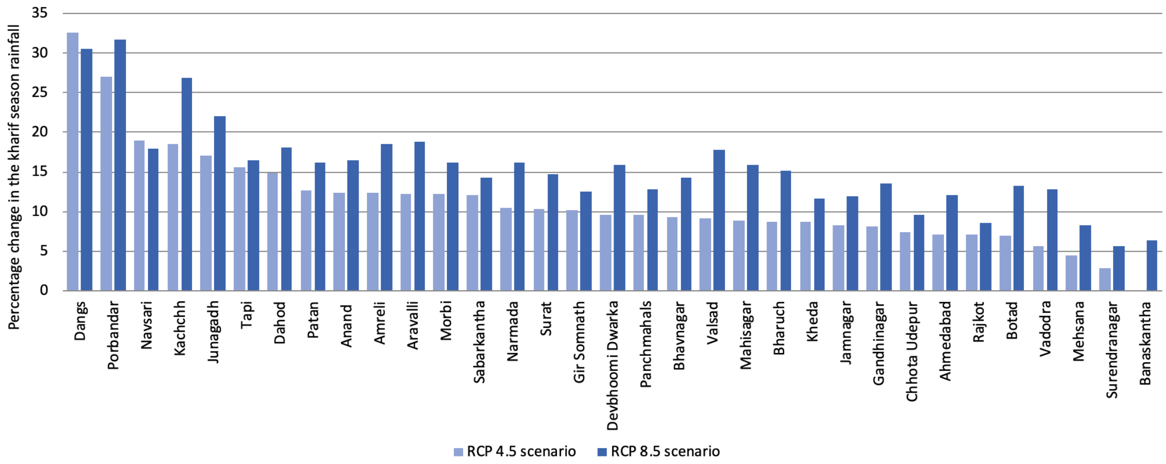


Figure 4-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

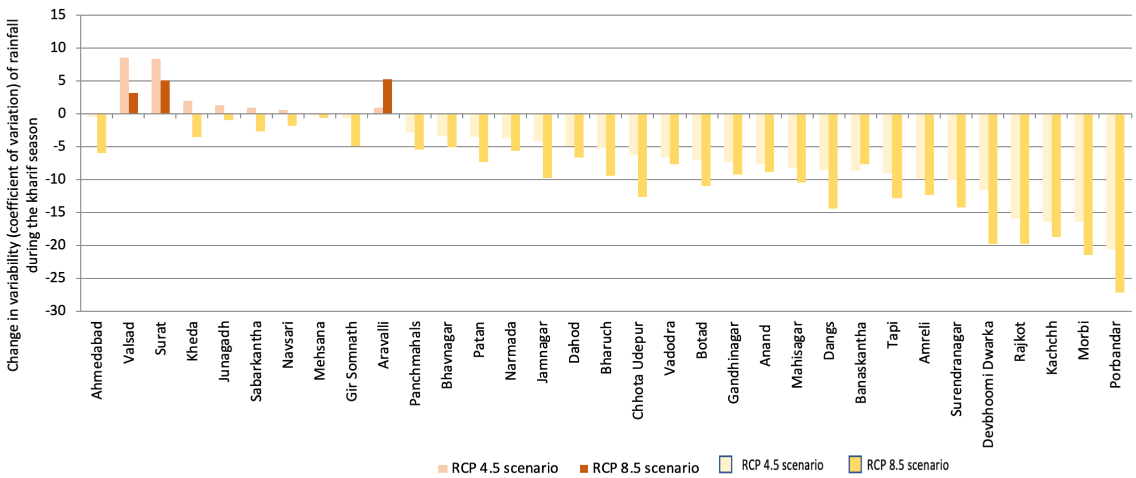


Figure 4-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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 5% in Valsad to 57% in Surendranagar	Declines in 31 of the 33 districts by 1% to 99% with no change in Anand and Bharuch
RCP 8.5	Increases in all the districts, from 14% in Valsad to 65% in Surendranagar	Declines in all the districts by 3% to 99%

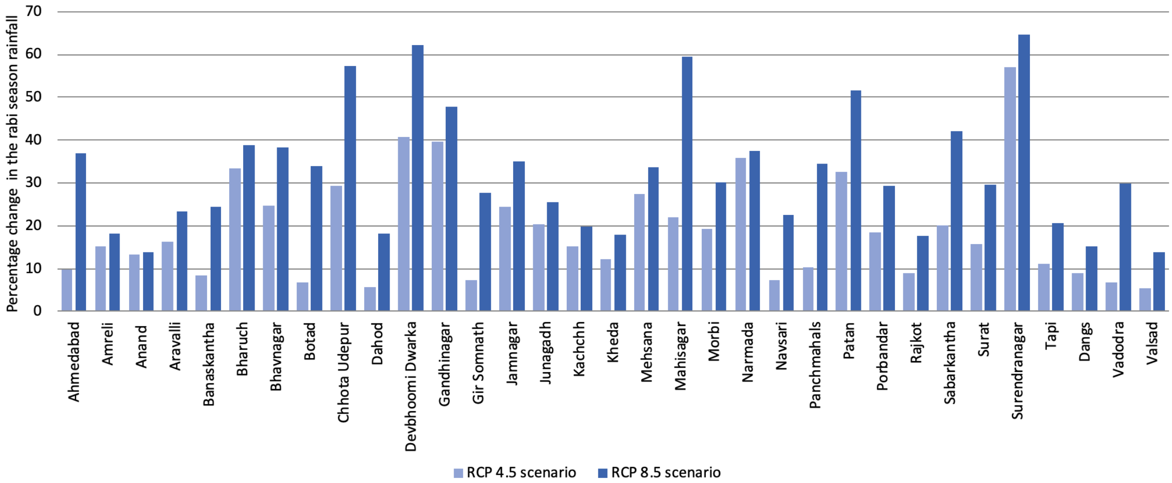


Figure 4-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

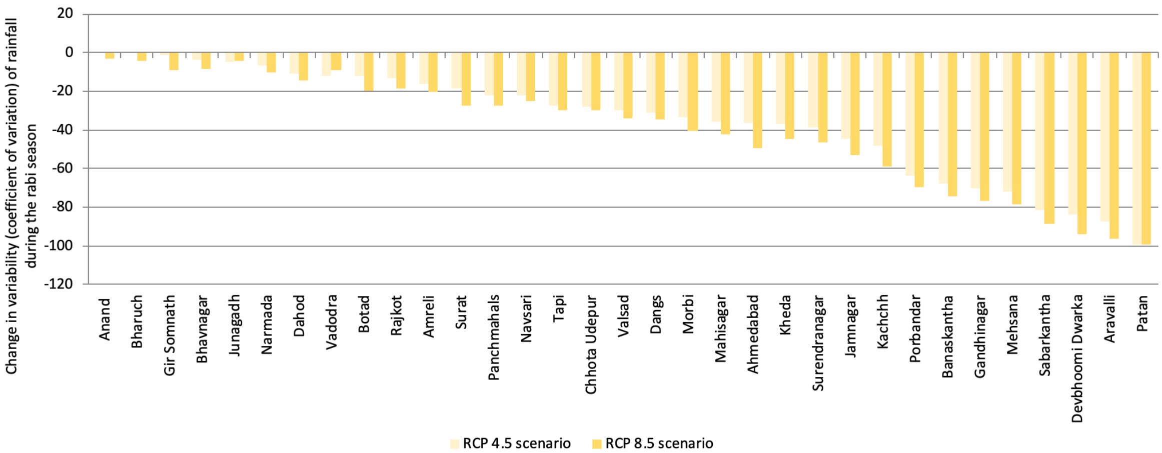


Figure 4-10: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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 projected 2030s under the two climate scenarios, and the change was computed for all the districts of Gujarat.

High-intensity rainfall events (Figure 4-11)

The total number of high-intensity rainfall events increases from 35 to 217 days during the historical period (1990–2019) to 78 to 223 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 90 to 230 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 Aravalli, Banaskantha, and Porbandar. 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 Patan and Kachchh, two events in 20 districts—including Anand, Aravalli, Bharuch, Bhavnagar, Junagadh, Gandhinagar, Mehsana, Panchmahals, Porbandar, and Sabarkantha—and one event in the remaining 11 districts.

Very high-intensity rainfall events (Figure 4-12)

The total number of very high-intensity rainfall events increases from 6 to 111 days during the historical period (1990–2019) to 32 to 135 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 45 to 143 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 Gir Somnath. In the remaining 32 districts, the increase is by one event per annum.

RCP 8.5 scenario: The projected increase per annum is by one to two events. The increase is by two events in Aravalli, Bhavnagar, Dahod, Morbi, Narmada, Patan, Porbandar, Surendranagar, Dangs, and Vadodara. In the remaining 23 districts, the increase is by one event per annum.

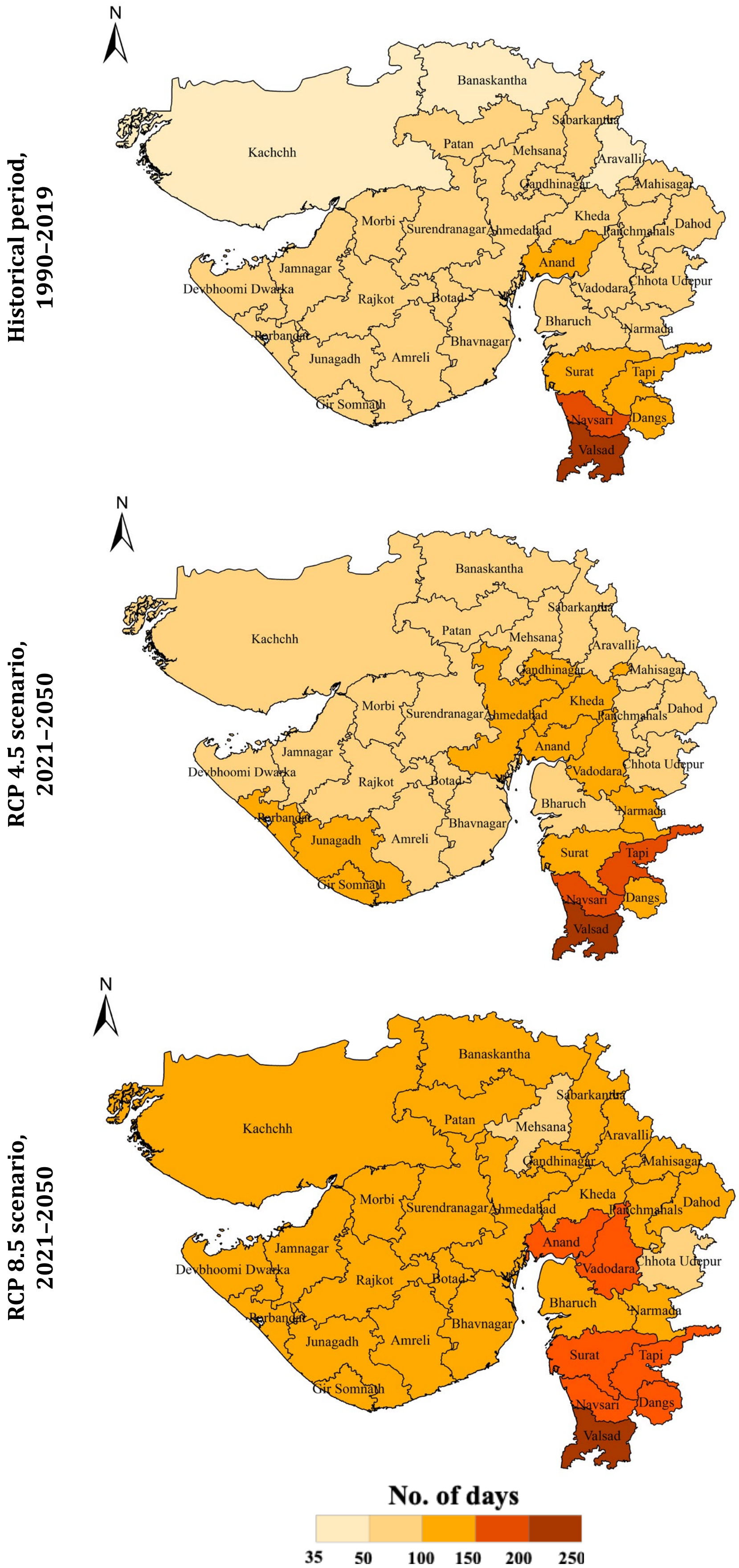


Figure 4-11: The total number of high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

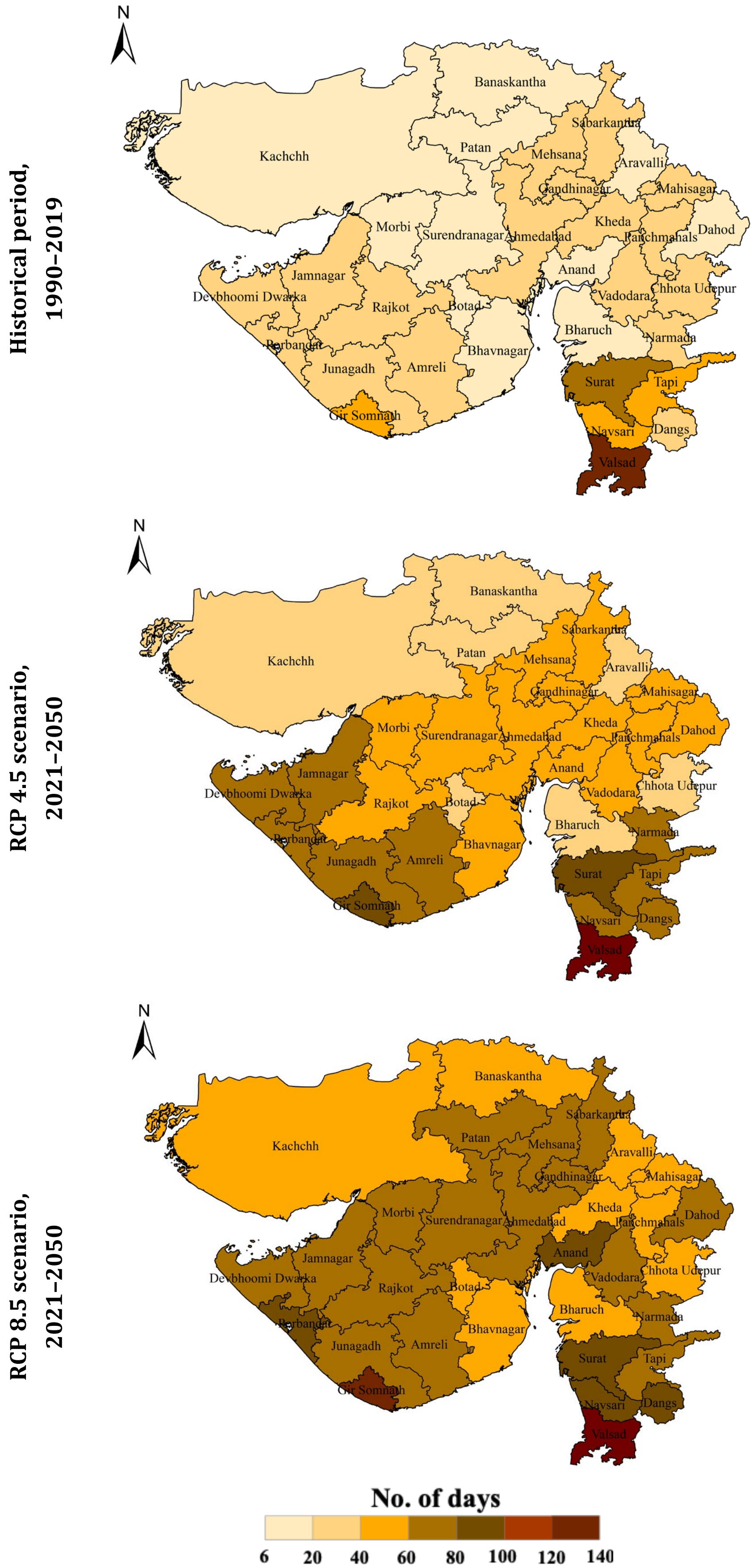


Figure 4-12: The total number of very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

Rainfall deficient years (Figure 4-13)

Rainfall deficient years, computed considering the rainfall during the kharif season, are projected to decline in almost all the districts of Gujarat under both climate scenarios. The number of rainfall deficient years declines from 10 to 17 years during the historical 30-year period to 9 to 16 years under the RCP 4.5 scenario and 8 to 15 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: The projected decline is by 1 to 8 years in 27 districts and there is a marginal increase in Surat. No change is projected in Chhota Udepur, Panchmahals, Valsad, Surendranagar, and Aravalli.

RCP 8.5 scenario: The projected decline in 28 districts is by 1 to 8 years. No change is projected in Surat, Chhota Udepur, Panchmahals, Valsad, and Junagadh.

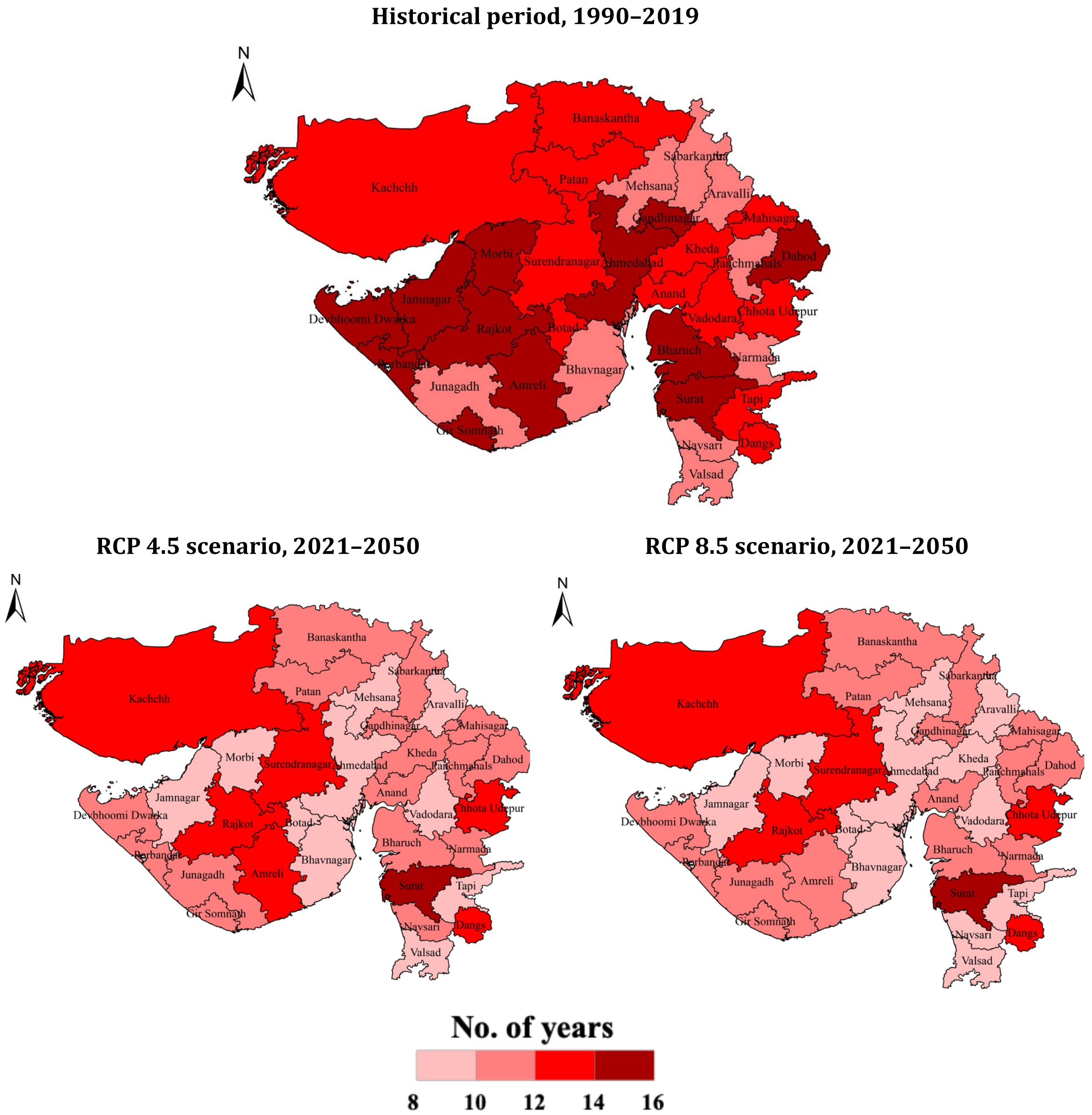


Figure 4-13: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

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

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

- 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 both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 4-2).

- Notable increase in rainfall in Dangs, Porbandar, Kachchh, Junagadh, and Tapi

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

- >10% and >20% decline in variability projected for Devbhoomi Dwarka, Rajkot, Kachchh, Morbi, and Porbandar under RCP 4.5 and RCP 8.5 scenarios, respectively

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

- The increase is in the range of 1 to 10 days under the RCP 4.5 scenario and 3 to 15 days under the RCP 8.5 scenario.

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

- 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 by one to two events annually under both climate scenarios.

Rainfall deficient years are projected to largely decline under both RCP 4.5 and RCP 8.5 scenarios in a majority of the districts by 1 to 8 years compared to the historical period (1990–2019; Appendix 4-4).

Appendix

Appendix 4-1: Changes in temperature under climate scenarios

Districts	Changes in temperature (°C) during the 2030s (2021–2050) compared to the historical period (1990–2019)			
	Summer maximum temperature		Winter minimum temperature	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Ahmedabad	1.5	1.9	1.6	1.7
Amreli	1.1	1.4	1.2	1.6
Anand	1.6	1.9	1.6	1.9
Aravalli	1.5	1.8	1.3	1.7
Banaskantha	1.6	1.8	1.4	1.8
Bharuch	1.4	1.8	1.3	1.6
Bhavnagar	1.2	1.6	1.2	1.4
Botad	1.5	1.6	1.3	1.7
Chhota Udepur	1.6	1.8	1.3	1.8
Dahod	1.6	1.7	1.2	1.6
Dangs	1.3	1.5	1.3	1.6
Devbhoomi Dwarka	1.2	1.3	1.1	1.4
Gandhinagar	1.6	1.6	1.6	1.8
Gir Somnath	1.2	1.5	1.2	1.4
Jamnagar	1.2	1.5	1.1	1.3
Junagadh	1.1	1.3	1.3	1.5
Kachchh	1.3	1.7	1.5	1.6
Kheda	1.5	1.7	1.6	1.7
Mehsana	1.5	1.6	1.6	1.8
Mahisagar	1.6	1.7	1.3	1.5
Morbi	1.6	1.8	1.5	1.7
Narmada	1.6	1.9	1.4	1.8
Navsari	1.2	1.5	1.3	1.5
Panchmahals	1.6	1.7	1.5	1.8
Patan	1.5	1.8	1.6	1.8
Porbandar	1.1	1.2	1.1	1.4
Rajkot	1.5	1.7	1.6	1.7
Sabarkantha	1.6	1.8	1.4	1.6
Surat	1.3	1.6	1.3	1.7
Surendranagar	1.5	1.8	1.6	1.7
Tapi	1.3	1.7	1.3	1.8
Vadodara	1.5	1.9	1.3	1.8
Valsad	1.3	1.4	1.2	1.4

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
Ahmedabad	8	14	7	12	10	37
Amreli	10	17	12	19	15	18
Anand	11	17	12	17	13	14
Aravalli	58	67	12	19	16	23
Banaskantha	1	3	0	6	8	24
Bharuch	6	14	9	15	33	39
Bhavnagar	9	20	9	14	25	38
Botad	7	14	7	13	7	34
Chhota Udepur	9	14	7	10	29	57
Dahod	14	16	15	18	6	18
Dangs	28	29	33	31	9	15
Devbhoomi Dwarka	12	14	10	16	41	62
Gandhinagar	8	12	8	14	40	48
Gir Somnath	5	14	10	12	7	28
Jamnagar	7	12	8	12	25	35
Junagadh	17	22	17	22	20	26
Kachchh	19	22	18	27	15	20
Kheda	7	13	9	12	12	-88
Mehsana	6	9	5	8	27	34
Mahisagar	7	15	9	16	22	59
Morbi	11	14	12	16	19	30
Narmada	11	11	10	16	36	38
Navsari	17	18	19	18	7	23
Panchmahals	6	14	10	13	10	34
Patan	12	18	13	16	32	51
Porbandar	26	33	27	32	19	29
Rajkot	6	10	7	9	9	18
Sabarkantha	6	10	12	14	20	42
Surat	9	21	10	15	16	30
Surendranagar	4	7	3	6	57	65
Tapi	14	18	16	16	0	21
Vadodara	6	15	6	13	7	30
Valsad	10	17	9	18	5	14

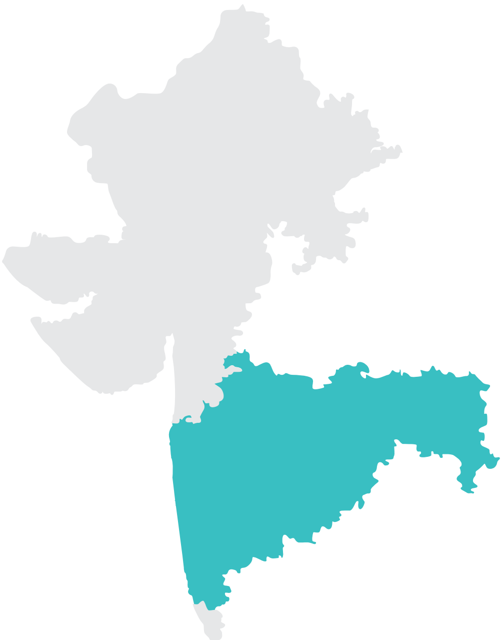
Appendix 4-3: The total number of rainy days (>2.5 cm/day) during the historical period (1990–2019) and the projected 2030s (2021–2050)

Districts	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Ahmadabad	989	1023	1133
Amreli	909	978	1102
Anand	1214	1389	1440
Aravalli	872	929	1042
Banaskantha	702	867	912
Bharuch	1271	1365	1434
Bhavnagar	1031	1268	1358
Botad	1002	1135	1233
Chhota Udepur	1385	1482	1530
Dahod	1213	1380	1441
Dangs	2039	2133	2207
Devbhoomi Dwarka	658	848	921
Gandhinagar	1072	1190	1192
Gir Somnath	1095	1244	1345
Jamnagar	679	877	980
Junagadh	1074	1156	1208
Kachchh	489	626	843
Kheda	1067	1108	1253
Mehsana	913	1016	1180
Mahisagar	1151	1235	1328
Morbi	792	841	983
Narmada	1574	1638	1705
Navsari	1693	1769	1842
Panchmahals	1093	1183	1252
Patan	733	947	1082
Porbandar	717	1009	1173
Rajkot	949	1037	1102
Sabarkantha	1106	1204	1373
Surat	1351	1457	1592
Surendranagar	853	961	1061
Tapi	1780	1838	1882
Vadodara	1275	1321	1401
Valsad	2115	2267	2290

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	RCP 8.5	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5
Ahmedabad	23	105	130	23	43	67	15	10	10
Amreli	31	98	102	31	65	72	16	13	12
Anand	18	135	167	18	42	88	14	11	11
Aravalli	6	86	102	6	33	60	10	10	8
Banaskantha	16	98	106	16	40	56	13	11	12
Bharuch	20	93	123	20	39	56	15	12	11
Bhavnagar	13	84	121	13	51	60	12	10	10
Botad	12	97	123	12	38	58	14	10	10
Chhota Udepur	24	78	90	24	40	56	13	13	13
Dahod	15	91	114	15	42	61	15	11	12
Dangs	37	148	167	37	61	92	14	14	13
Devbhoomi Dwarka	28	98	117	28	63	70	15	11	11
Gandhinagar	25	104	127	25	45	65	15	11	12
Gir Somnath	41	127	134	41	88	101	15	11	12
Jamnagar	30	94	114	30	62	80	16	10	10
Junagadh	40	122	143	40	67	79	12	11	12
Kachchh	17	94	124	17	35	45	14	13	13
Kheda	29	110	120	29	43	56	13	11	10
Mahisagar	25	92	105	25	43	52	14	12	12
Mehsana	24	78	99	24	50	65	12	10	10
Morbi	20	93	111	20	41	67	17	9	9
Narmada	32	122	146	32	66	78	12	11	11
Navsari	52	170	182	52	69	89	12	11	9
Panchmahals	39	94	123	39	46	47	12	12	12
Patan	14	98	130	14	32	66	14	11	11
Porbandar	32	107	127	32	67	89	16	11	11
Rajkot	26	97	109	26	49	62	16	14	13
Sabarkantha	29	97	125	29	58	67	12	11	11
Surat	67	134	168	67	89	92	15	16	15
Surendranagar	14	96	133	14	44	68	14	14	13
Tapi	46	165	170	46	65	80	14	10	9
Vadodara	23	134	165	23	42	68	13	10	9
Valsad	111	223	230	111	135	143	10	10	10

5. Maharashtra



Maharashtra accounts for 9.4% of the total geographical area of India and is the third largest state. It covers an area of 3,07,713 sq. km and has a population of 112.37 million according to Census 2011. There are 36 districts in Maharashtra. The state is divided into five main regions: Vidarbha (north-eastern region), Marathwada (south-central region), Khandesh (north-western region), Northern Maharashtra, and Western Maharashtra (Konkan). The Western Ghats is a prominent biodiversity resource of the state and forms an important climatic divide. It forms one of the three watersheds of the state from which originate several important rivers, including Godavari and Krishna. A wide variation in the distribution of rainfall is seen across the state. The Marathwada region of Maharashtra is a drought-prone area and is generally characterised by extreme aridity, hot climate, and acute deficiency in water availability.

The total area under agriculture in Maharashtra is 19.8 Mha, of which about 3 Mha is groundwater-irrigated. The state's coastline is indented and approximately 720 km long and spread across the coastal districts of Mumbai, Raigad, Ratnagiri, Sindhudurg, and Thane. Maharashtra accounts for 5% share in the country's fish production. The state has two major ports, several thermal power plants, hydroelectric projects, wind power plants, and large solar power plants.

These characteristics make Maharashtra 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

Maharashtra recorded a moderate warming of 0.25°C to 0.42°C in the summer maximum temperature and 0.3°C to 0.55°C in the winter minimum temperature during the historical period. Figure 5-1 presents the mean summer maximum and winter minimum temperatures in Maharashtra during the historical period.

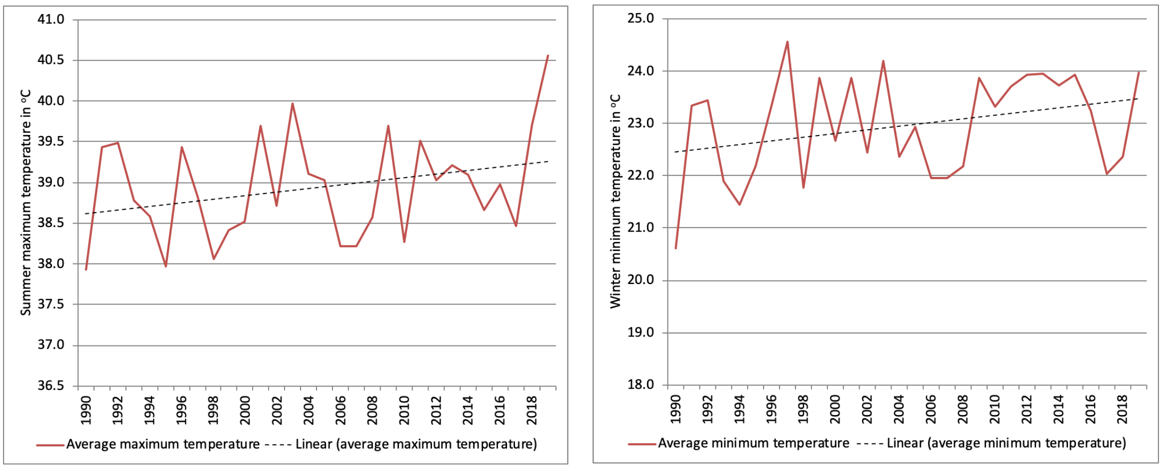


Figure 5-1: Mean summer maximum and winter minimum temperatures in Maharashtra during the historical period (1990–2019)

5.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual rainfall in the range of 10% to 20% was recorded in a majority of the districts. During the kharif season, which is the main monsoon season, a 10% to 25% increase in rainfall was recorded in a majority of the districts. Figure 5-2 presents the mean annual rainfall in Maharashtra during the historical period.

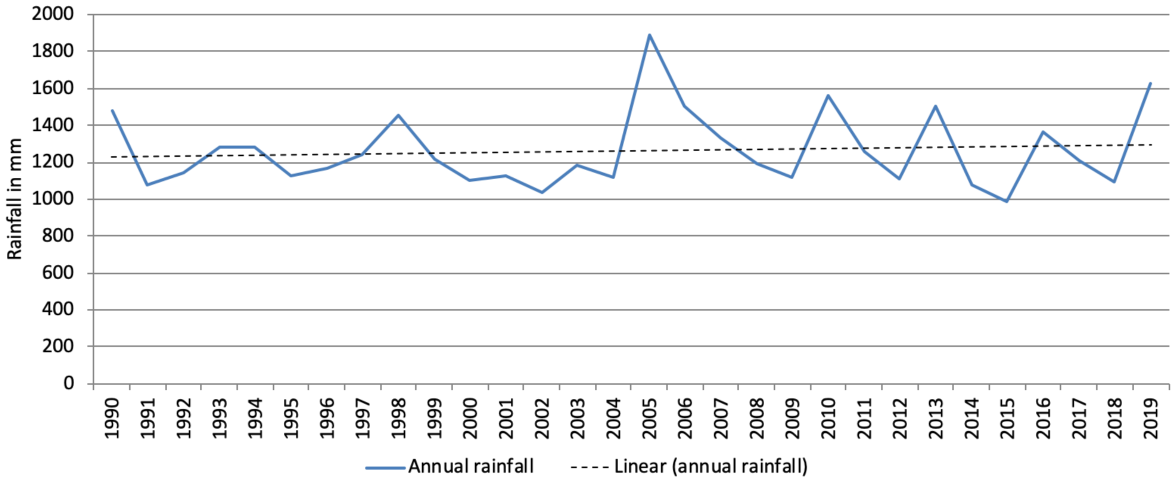


Figure 5-2: Mean annual rainfall in Maharashtra during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 19% in Mumbai Suburban to 67% in Nashik (Figure 5-3). The rabi season rainfall variability was in the range of 57% in Kolhapur to 94% in Jalgaon during the same period (Figure 5-3).

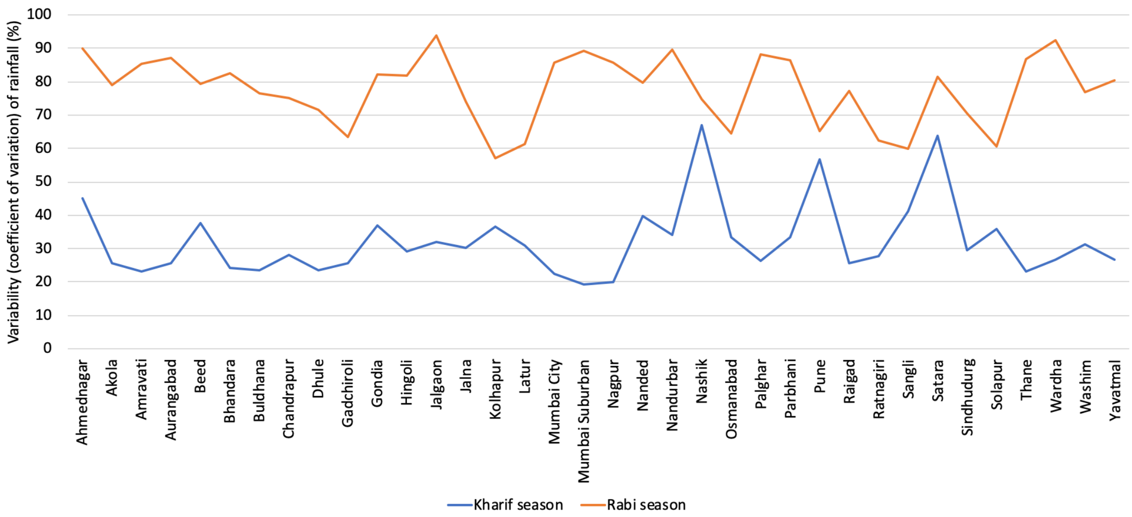


Figure 5-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

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

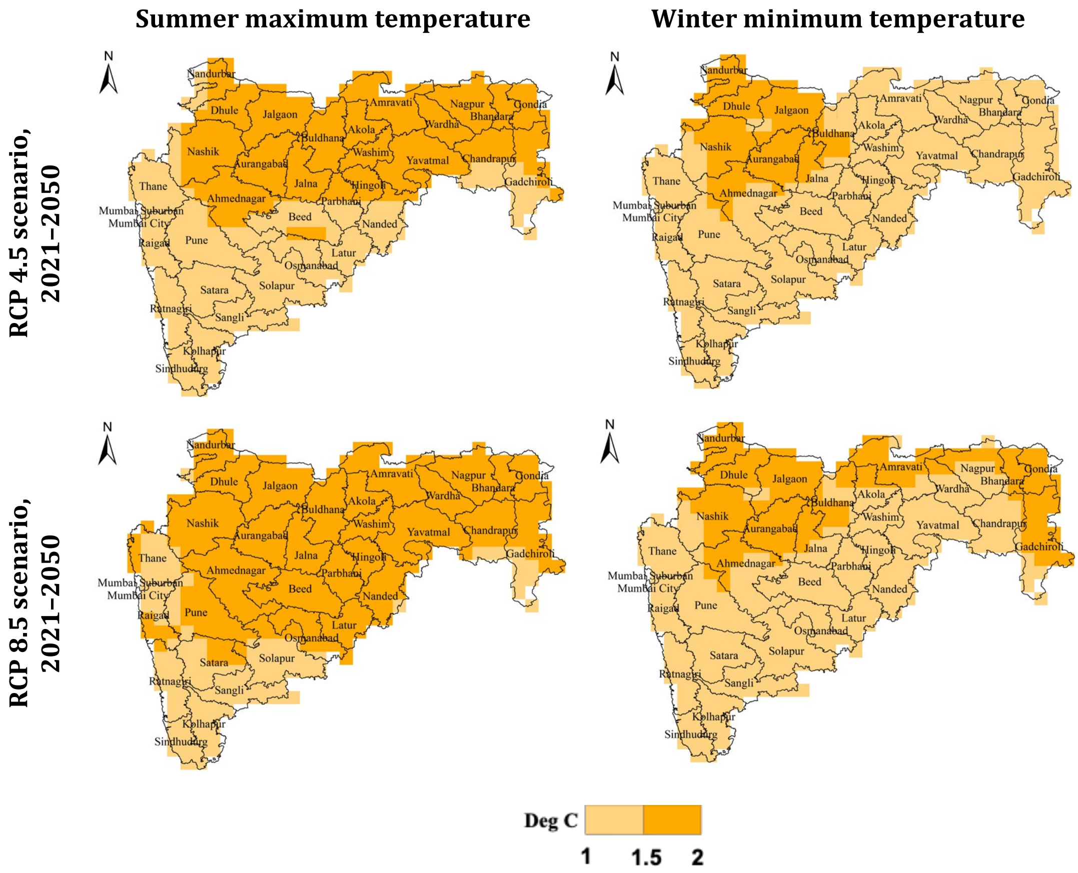


Figure 5-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

5.2.1.1. Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 1, a heatwave analysis of the Chandrapur 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 a decline in 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 increase under both RCP 4.5 and RCP 8.5 scenarios (Figure 5-5). A doubling of severe heatwave days, compared to the historical period, is projected under both RCP 4.5 and RCP 8.5 scenarios in Chandrapur district.

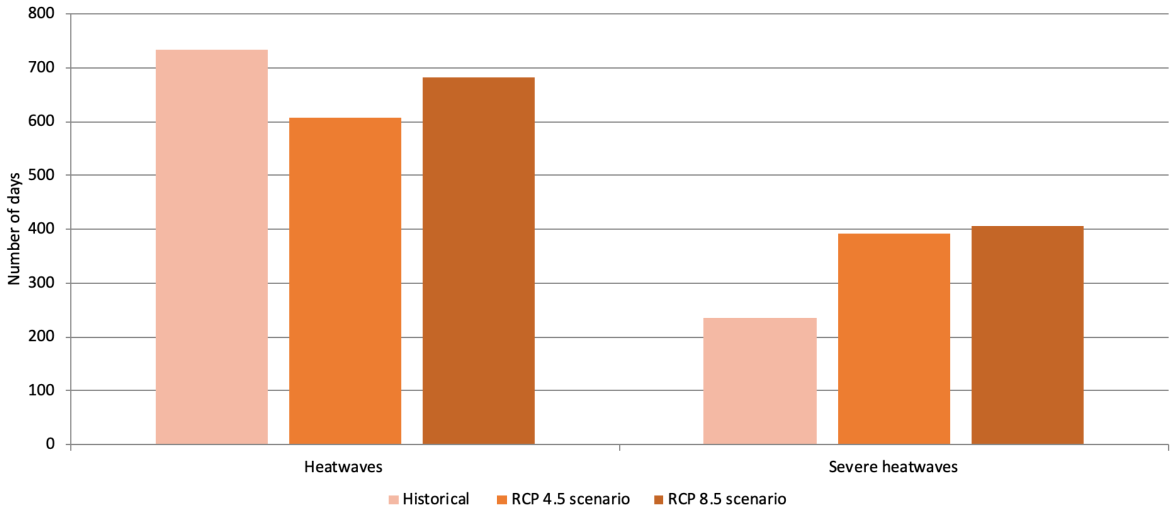


Figure 5-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

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 953 to 2864 days over the 30-year historical period increases to 1088 to 2930 days under the RCP 4.5 scenario and 1123 to 2980 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 9 days annually in all the districts, except Yavatmal. The increase is by 9 days in Washim; 8 days in Jalna; 7 days in Chandrapur and Ahmednagar; 6 days in Satara and Nandurbar; and 2 to 5 days in the remaining districts.

RCP 8.5 scenario: Projected to increase by 2 to 8 days annually in all the districts. The increase is by 8 days in Washim; 7 days in Mumbai Suburban; 6 days in Ahmednagar, Chandrapur, Gadchiroli, Jalna, and Satara; 5 days in Akola, Buldhana, Nandurbar, Osmanabad, Pune, Sangli, and Wardha; and 2 to 4 days in the remaining districts.

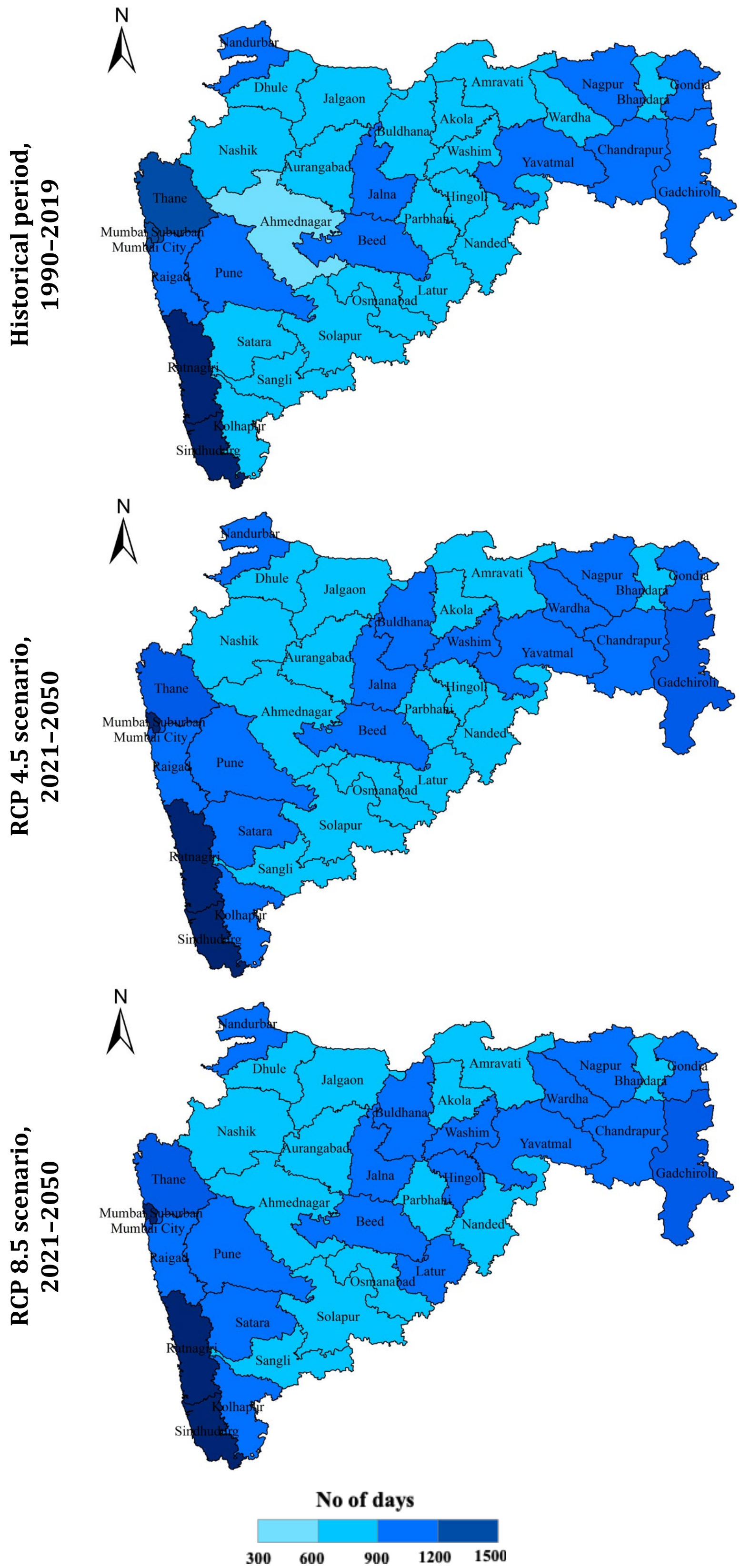


Figure 5-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

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 of rainfall (coefficient of variation) 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 Gondia to 29% in Pune	Declines in 17 districts by about 1% to 29% and increases in 19 districts by about 1% to 14%
RCP 8.5	Increases in all the districts, from 3% in Gondia to 34% in Pune	Declines in 25 districts by about 1% to 32% and increases in 11 districts by about 1% to 11%

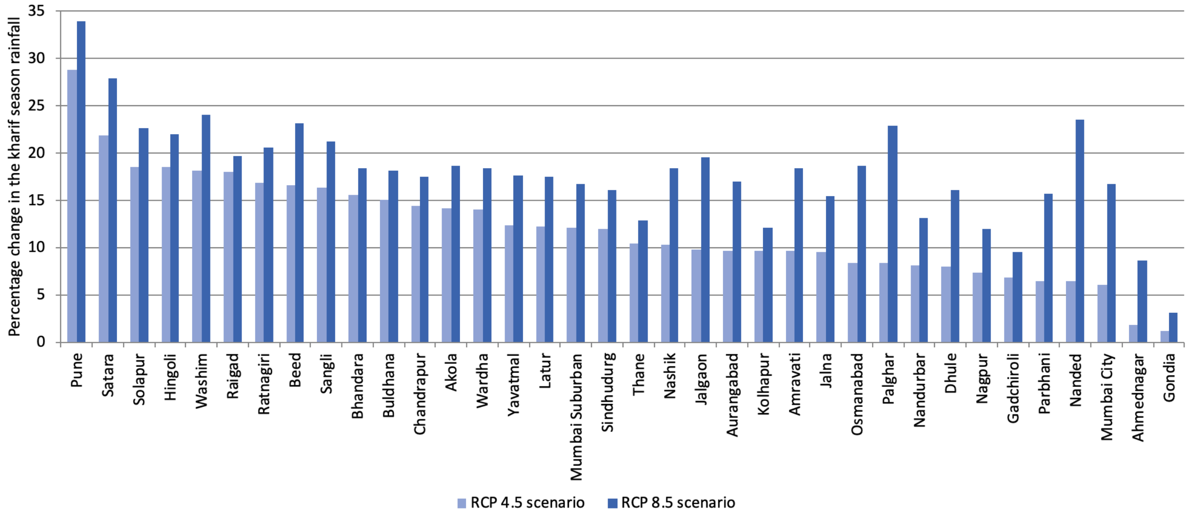


Figure 5-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

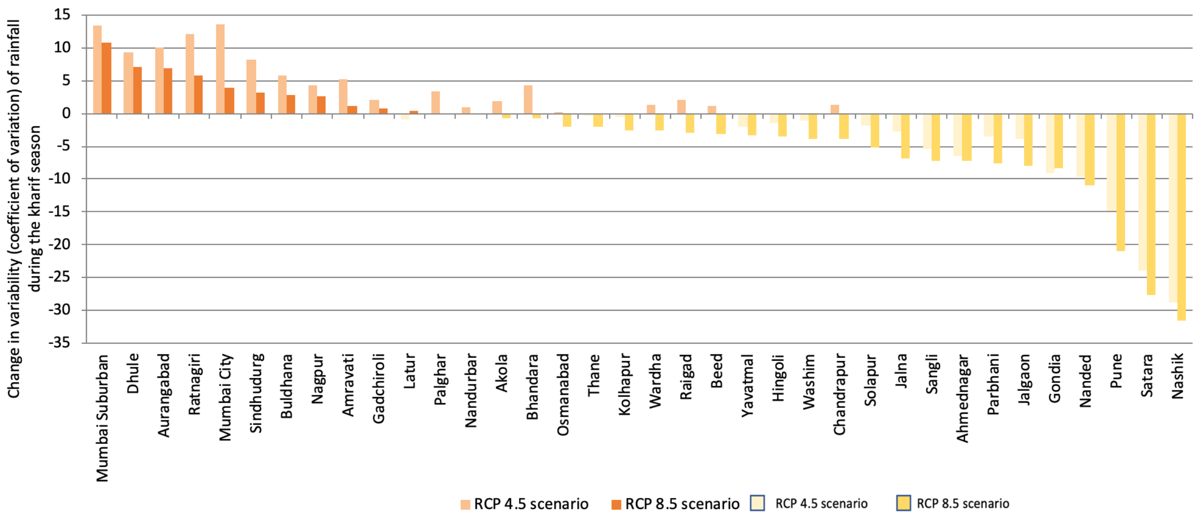


Figure 5-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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 3% in Dhule to 57% in Nandurbar	Declines in 33 districts by about 1% to 28% and increases in three districts by 2% to 9%
RCP 8.5	Increases in all the districts, from 13% in Buldhana and Hingoli to 81% in Nandurbar	Declines in all the districts by 2.5% to 38%

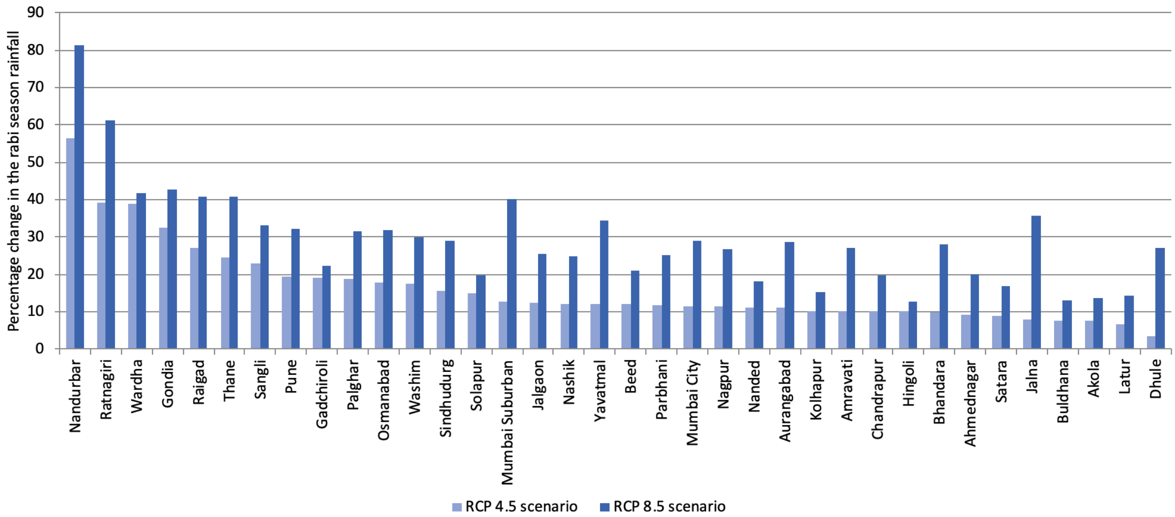


Figure 5-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

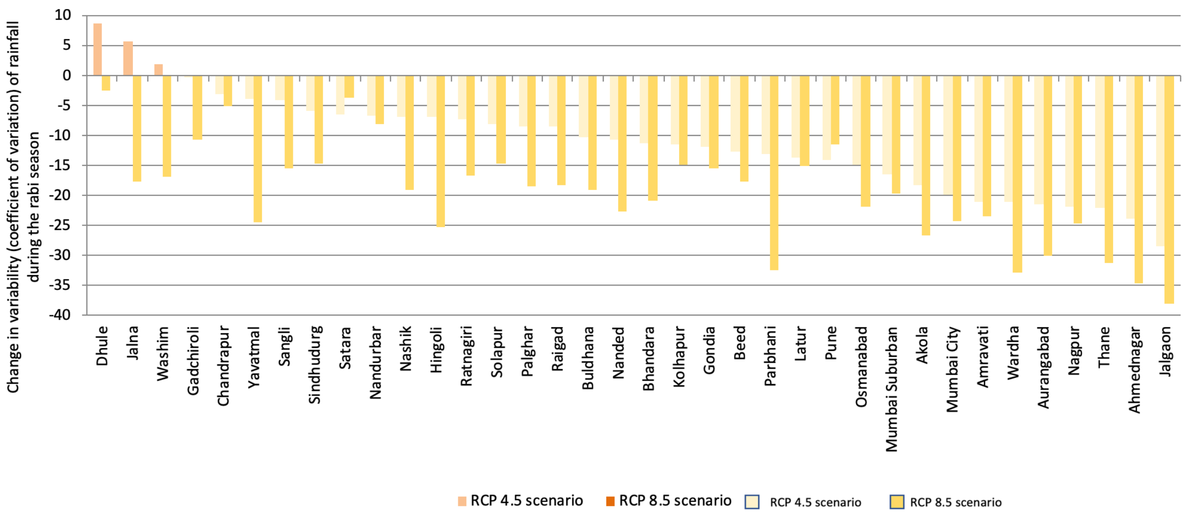


Figure 5-10: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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 Maharashtra.

High-intensity rainfall events (Figure 5-11)

The total number of high-intensity rainfall events increases from 17 to 422 days during the historical period (1990–2019) to 82 to 567 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 106 to 650 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 five events in all the districts, except Bhandara, where no change is projected. The increase is by five events in Sindhudurg; four in Buldhana; three in Hingoli, Latur, Beed, Solapur, and Aurangabad; two in 20 districts; and one in the remaining eight districts.

RCP 8.5 scenario: The projected increase per annum is by two to eight events in all the districts, except Bhandara, where no change is projected. The increase is by eight events in Sindhudurg; five in Buldhana and Hingoli; four in Ahmednagar, Aurangabad, Kolhapur, Latur, Nanded, Parbhani, Sangli, Solapur, and Washim; three in 15 districts; and two in the remaining eight districts.

Very high-intensity rainfall events (Figure 5-12)

The total number of very high-intensity rainfall events increases from 1 to 147 days during the historical period (1990–2019) to 23 to 166 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 41 to 196 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. The increase is by two events in Buldhana, Hingoli, Kolhapur, Nashik, Raigad, Sangli, and Satara and one event in the remaining districts.

RCP 8.5 scenario: The projected increase per annum is by one to three events in all the districts. The increase is by three events in 12 districts, including Hingoli, Nanded, Nashik, Osmanabad, Parbhani, Raigad, Sangli, Kolhapur, Nagpur, Washim, Wardha, and Mumbai City; two in 16 districts; and one in eight districts.

Rainfall deficient years (Figure 5-13)

Rainfall deficient years, computed considering the rainfall during the kharif season, are projected to decline in a majority of the districts. The number of rainfall deficient years declines from 8 to 24 years during the historical 30-year period to 5 to 19 years under the RCP 4.5 scenario and 4 to 17 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: Rainfall deficient years are projected to decline by 1 year in seven districts; 2 years in nine districts; 3 years in five districts; 4 years in Dhule, Satara, and Sindhudurg; and 5 years in Ahmednagar and Sindhudurg districts. No change is projected in the remaining districts compared to the historical period.

RCP 8.5 scenario: Rainfall deficient years are projected to decline by 1 year in six districts; 2 years in six districts; 3 years in nine districts; 4 years in six districts; 5 years in Pune, Sangli, and Dhule; 6 years in Satara, Ratnagiri, and Sindhudurg; and 7 years in Ahmednagar district. No change is projected in the remaining districts compared to the historical period.

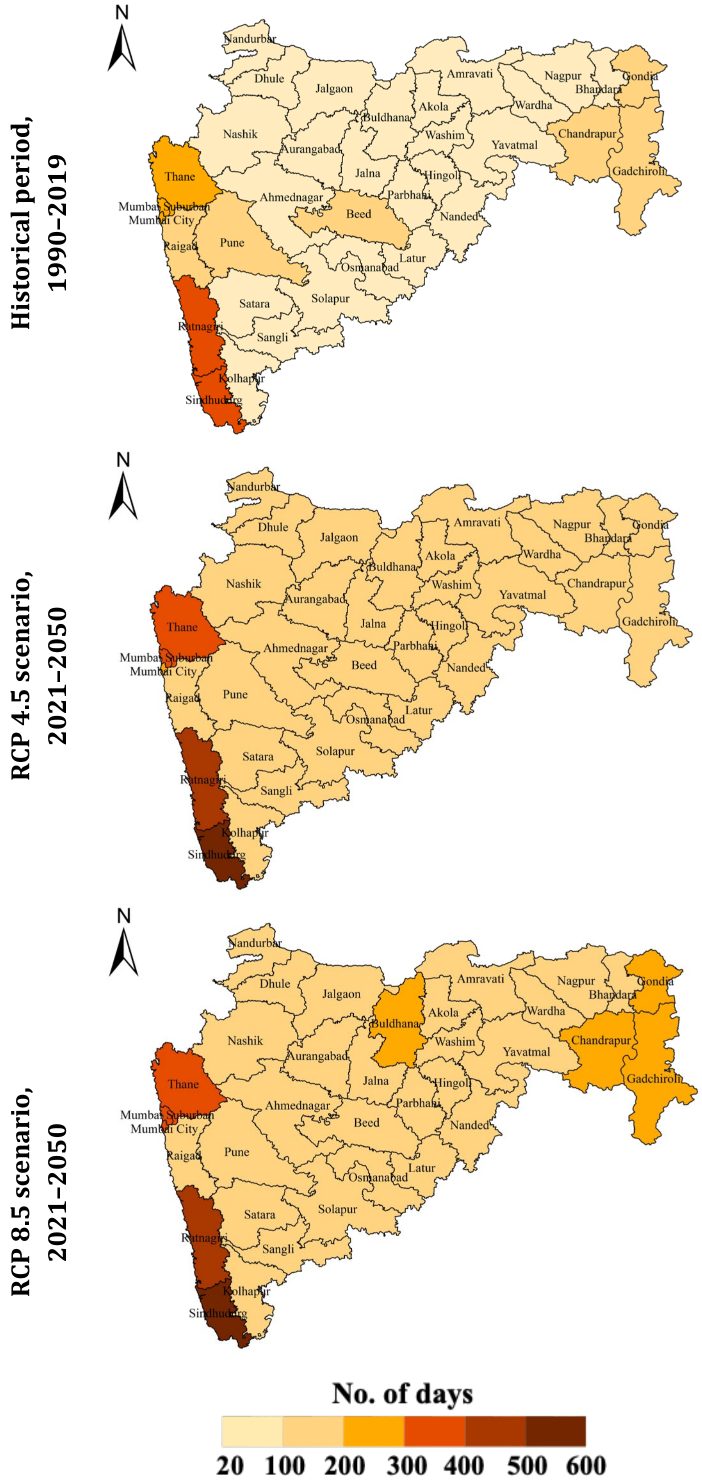


Figure 5-11: The total number of high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

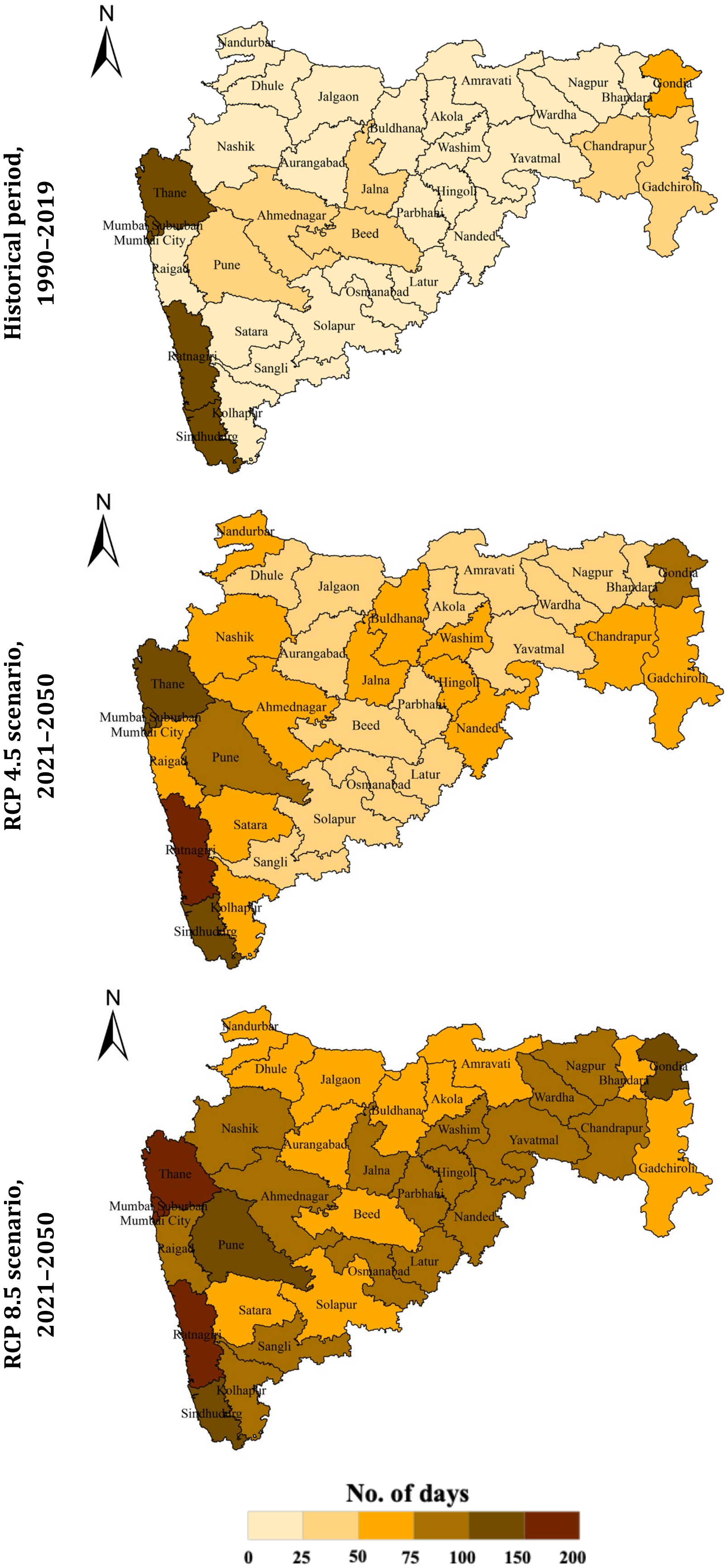


Figure 5-12: The total number of very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

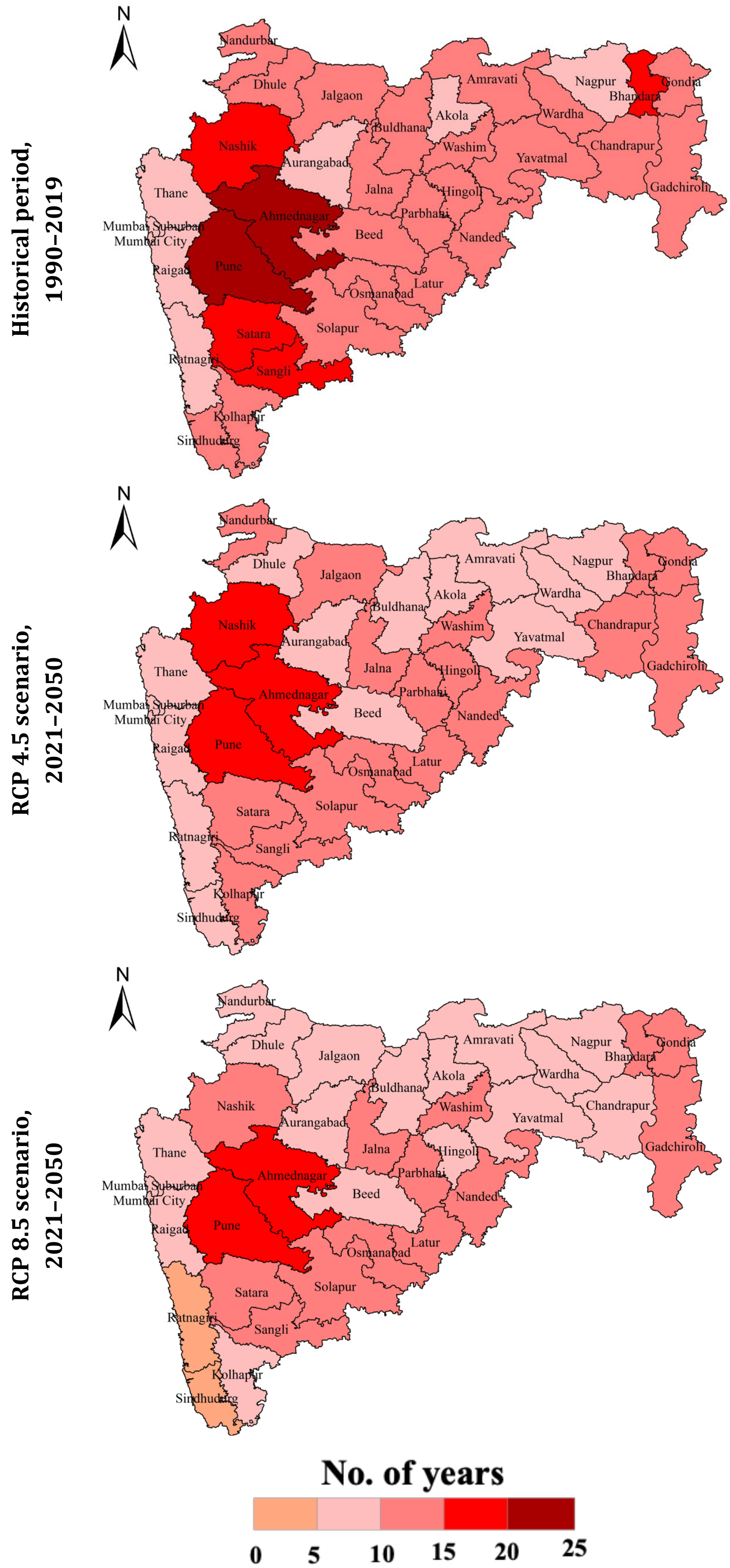


Figure 5-13: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

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

Temperature 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 5-1).

- Both summer maximum and winter minimum temperatures are projected to increase in the range of 1^0C to 2^0C in all the districts.

Rainfall 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 5-2).

- A >15% increase in rainfall is projected in 10 districts including Ratnagiri, Satara, Pune, Solapur, Sangli, and so forth.

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

- A ≥10% increase in rainfall variability is projected in Aurangabad, Ratnagiri, Mumbai City, and Mumbai Suburban under both climate 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 5-3).

- The increase is projected to be by 2 to 9 days per annum under the RCP 4.5 scenario and 2 to 8 days per annum under the RCP 8.5 scenario.
- The increase is >5 days per annum in the Satara, Ahmednagar, Chandrapur, Jalna, and Washim districts under both climate scenarios.

Heavy rainfall events are 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 5-4).

- High-intensity rainfall events are projected to increase by one to nine events per annum under the RCP 4.5 scenario and two to eight events under the RCP 8.5 scenario.
- Very high rainfall events are projected to increase by one to five events under the RCP 4.5 scenario and one to nine events under the RCP 8.5 scenario.

Rainfall deficient years are projected to decline in a majority of the districts under both RCP 4.5 and RCP 8.5 scenarios 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
Ahmednagar	1.0	2.0	1.1	2.1
Akola	1.3	2.5	1.2	3.0
Amravati	1.6	2.9	1.2	2.0
Aurangabad	1.1	2.1	1.4	2.3
Beed	1.2	1.6	1.2	2.1
Bhandara	2.0	2.6	1.1	2.4
Buldhana	1.4	2.3	1.6	2.8
Chandrapur	0.8	1.2	1.5	2.4
Dhule	1.1	2.2	1.9	2.8
Gadchiroli	0.2	1.1	0.6	1.1
Gondia	1.1	2.1	2.3	3.3
Hingoli	1.2	2.2	1.8	2.5
Jalgaon	1.3	2.5	2.9	3.5
Jalna	1.3	2.7	1.1	2.6
Kolhapur	0.5	0.7	1.1	2.0
Latur	1.4	1.8	1.0	1.6
Mumbai City	0.2	0.8	0.1	0.6
Mumbai Suburban	0.2	0.8	0.1	0.6
Nagpur	1.1	2.2	1.6	2.8
Nanded	1.0	2.0	1.1	2.4
Nandurbar	1.6	2.5	2.0	3.6
Nashik	1.3	2.4	2.6	3.4
Osmanabad	1.4	1.8	1.3	1.9
Palghar	0.4	1.2	0.7	0.9
Parbhani	1.2	1.4	0.3	1.1
Pune	1.1	1.7	1.3	2.1
Raigad	0.3	0.8	0.2	1.0
Ratnagiri	0.3	0.9	0.5	1.0
Sangli	0.6	1.1	1.3	2.0
Satara	0.6	1.0	0.9	1.6
Sindhudurg	0.5	0.8	0.2	0.6
Solapur	0.4	1.6	1.0	1.7
Thane	0.6	1.0	0.1	1.0
Wardha	1.1	2.1	1.1	2.1
Washim	1.2	2.3	1.3	2.4
Yavatmal	1.1	1.7	1.2	2.2

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
Ahmednagar	8	15	2	9	9	20
Akola	17	21	14	19	8	14
Amravati	12	18	10	18	10	27
Aurangabad	11	18	10	17	11	29
Beed	11	21	17	23	12	21
Bhandara	17	20	16	18	10	28
Buldhana	14	18	15	18	8	13
Chandrapur	14	17	14	18	10	20
Dhule	11	16	8	16	3	27
Gadchiroli	10	16	7	10	19	22
Gondia	2	4	1	3	33	43
Hingoli	12	18	19	22	10	13
Jalgaon	9	16	10	20	13	25
Jalna	8	14	10	15	8	36
Kolhapur	10	12	10	12	10	15
Latur	11	17	12	18	7	14
Mumbai City	3	12	6	17	12	29
Mumbai Suburban	3	9	12	17	13	40
Nagpur	8	11	7	12	11	27
Nanded	13	19	6	24	11	18
Nandurbar	7	14	8	13	57	81
Nashik	15	16	10	18	12	25
Osmanabad	9	18	8	19	18	32
Palghar	1	13	8	23	19	31
Parbhani	13	21	6	16	12	25
Pune	25	29	29	34	20	32
Raigad	0	5	18	20	27	41
Ratnagiri	17	20	17	21	39	61
Sangli	12	24	16	21	23	33
Satara	19	24	22	28	9	17
Sindhudurg	14	15	12	16	16	29
Solapur	15	19	19	23	15	20
Thane	11	14	10	13	25	41
Wardha	19	22	14	18	39	42
Washim	18	21	18	24	18	30
Yavatmal	17	19	12	18	12	34

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
Ahmednagar	953	1088	1123
Akola	1271	1342	1423
Amravati	1364	1431	1478
Aurangabad	1194	1231	1290
Beed	1166	1233	1267
Bhandara	1659	1721	1756
Buldhana	1375	1466	1512
Chandrapur	1608	1752	1788
Dhule	1267	1321	1390
Gadchiroli	1939	2001	2132
Gondia	1692	1733	1799
Hingoli	1412	1490	1532
Jalgaon	1272	1321	1390
Jalna	1620	1783	1811
Kolhapur	1474	1534	1590
Latur	1436	1490	1521
Mumbai City	2315	2390	2445
Mumbai Suburban	2455	2521	2655
Nagpur	1592	1671	1701
Nanded	1283	1321	1389
Nandurbar	1561	1671	1712
Nashik	1395	1434	1490
Osmanabad	1245	1321	1390
Palghar	2360	2412	2456
Parbhani	1305	1390	1432
Pune	1581	1678	1732
Raigad	1788	1876	1912
Ratnagiri	2845	2921	2960
Sangli	1075	1134	1231
Satara	1398	1521	1589
Sindhudurg	2864	2930	2980
Solapur	1269	1345	1390
Thane	2334	2390	2431
Wardha	1437	1523	1598
Washim	1446	1623	1689
Yavatmal	1535	1544	1590

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
Ahmednagar	65	107	182	38	70	87	24	19	17
Akola	64	112	125	8	42	55	9	10	8
Amravati	52	102	133	10	23	41	12	9	9
Aurangabad	46	121	177	3	42	68	10	9	8
Beed	20	99	106	9	35	48	16	15	13
Bhandara	111	112	120	30	34	63	11	10	9
Buldhana	47	152	202	12	61	75	12	10	8
Chandrapur	114	180	212	36	55	85	12	12	10
Dhule	31	92	133	2	32	68	14	10	9
Gadchiroli	138	174	208	32	64	72	15	13	12
Gondia	169	196	224	70	93	107	13	13	11
Hingoli	52	142	192	13	71	95	14	12	10
Jalgaon	36	91	112	8	43	71	12	11	10
Jalna	90	131	175	31	70	91	14	13	11
Kolhapur	21	82	129	5	62	96	14	12	10
Latur	34	120	147	5	45	78	13	13	12
Mumbai City	250	295	311	119	145	196	8	8	8
Mumbai Suburban	266	313	364	122	140	170	10	10	9
Nagpur	77	101	134	18	41	97	8	7	6
Nanded	51	111	165	18	53	95	15	13	12
Nandurbar	68	115	134	12	56	72	13	11	10
Nashik	50	95	146	14	69	90	18	16	14
Osmanabad	37	98	120	3	34	88	15	13	12
Palghar	226	267	288	116	156	189	11	11	10
Parbhani	68	127	195	13	44	89	12	13	11
Pune	110	156	168	50	87	120	22	19	17
Raigad	105	134	195	18	73	96	9	10	8
Ratnagiri	392	443	493	147	166	171	10	5	4
Sangli	17	90	134	3	48	94	16	13	11
Satara	55	99	133	8	60	75	18	14	12
Sindhudurg	422	567	650	133	136	150	11	7	5
Solapur	26	103	156	1	36	72	11	13	11
Thane	286	332	367	121	144	162	10	7	7
Wardha	77	136	175	20	44	98	12	10	8
Washim	55	129	166	16	59	95	14	13	11
Yavatmal	69	130	152	18	48	78	11	8	7

6. Rajasthan

Rajasthan, situated in the north-western part of India, is one of the most drought-prone states of India. The geographic area of Rajasthan is 3,42,240 sq. km, spanning 33 districts, and the population according to Census 2011 is 68.5 million. The state receives poor rainfall and faces severe water scarcity. It is dominated by arid and semi-arid climates. Geographically, deserts in the state constitute a large share of the land mass. Rajasthan is divided into 10 agro-climatic zones spanning arid western to flood-prone eastern regions.

The area under agriculture in Rajasthan is about 21 Mha, of which 3.98 Mha is irrigated by groundwater and 1.52 Mha by canals. The state has thermal power plants in the districts of Bikaner, Baran, Sri Ganganagar, and Kota; solar parks in Bikaner, Jaisalmer, Jodhpur, and so forth; and a wind park in Jaisalmer.

These characteristics make Rajasthan 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.

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 the subsequent sections.

6.1.1. Trends in temperature

Rajasthan recorded a moderate warming of 0.27°C to 0.53°C in the summer maximum temperature and 0.13°C to 0.34°C in the winter minimum temperature during the historical period. Figure 6-1 presents the mean summer maximum and winter minimum temperatures in Rajasthan during the historical period.

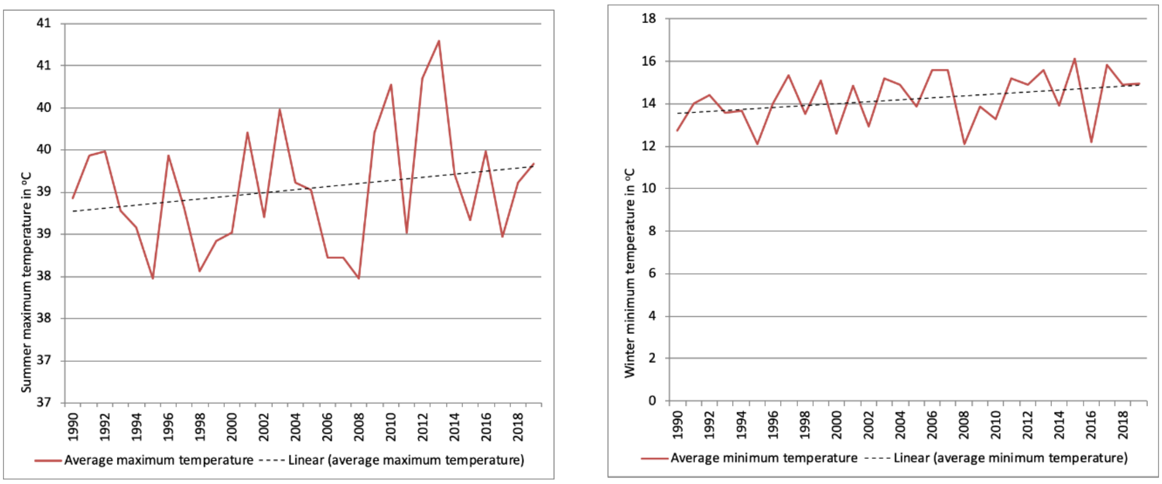


Figure 6-1: Mean summer maximum and winter minimum temperatures in Rajasthan during the historical period (1990–2019)

6.1.2. Trends in rainfall and rainfall variability

Rajasthan receives a bulk of its rainfall from June to September. During the historical period, an increasing trend in the annual rainfall, up to 15%, was recorded in Rajasthan. Likewise, an increase in rainfall during the kharif season was recorded, with up to 15% increase recorded in some of the eastern districts. Figure 6-2 presents the mean annual rainfall in Rajasthan during the historical period.

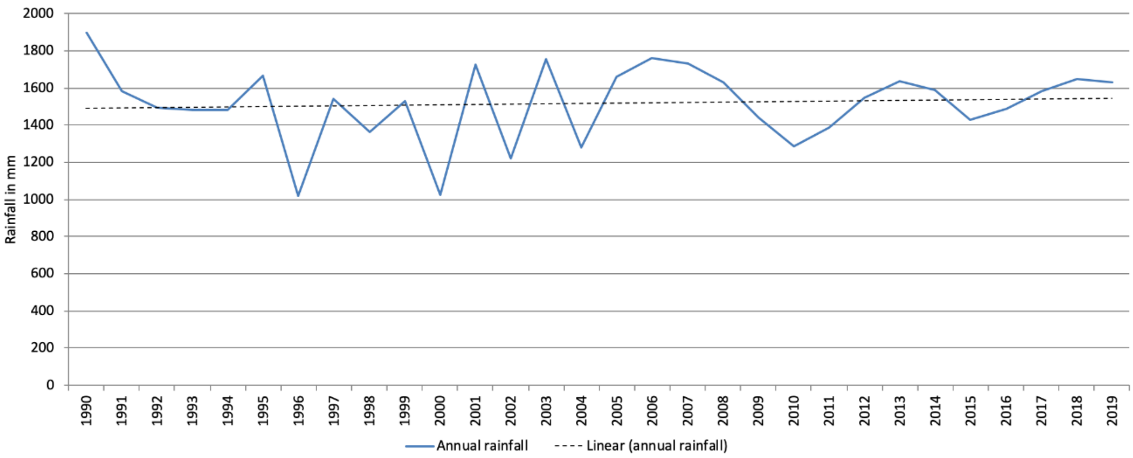


Figure 6-2: Mean annual rainfall in Rajasthan during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) was generally high in different districts, ranging from 26% in Pratapgarh to 72% in Hanumangarh during the historical period (Figure 6-3).

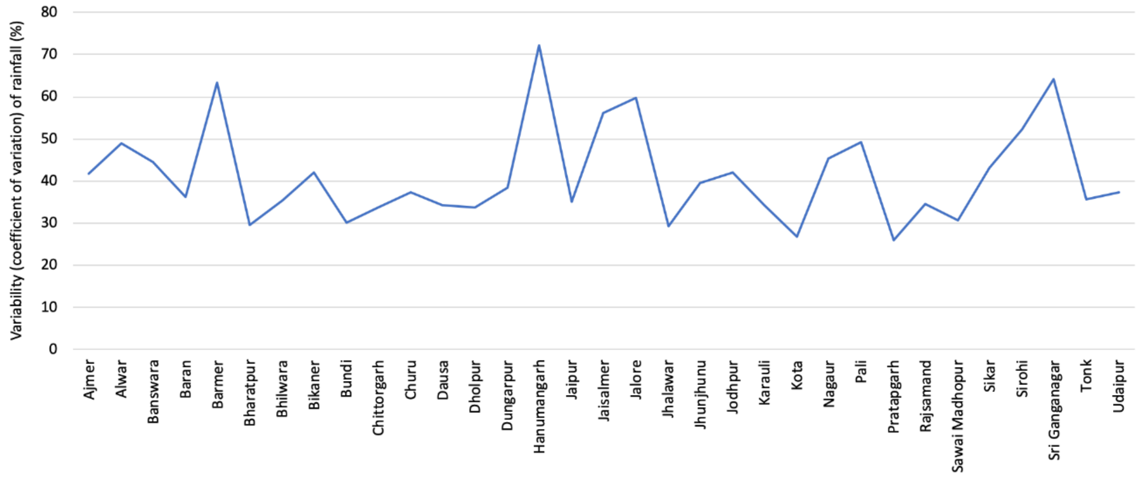


Figure 6-3: Mean annual rainfall in Rajasthan during the historical period (1990–2019)

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 the summer maximum and winter minimum temperatures for all the districts of Rajasthan 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 up to 1.5^{0}C	Increases up to 1.5^{0}C
RCP 8.5	Increases up to 2^{0}C	Increases up to 1.5^{0}C

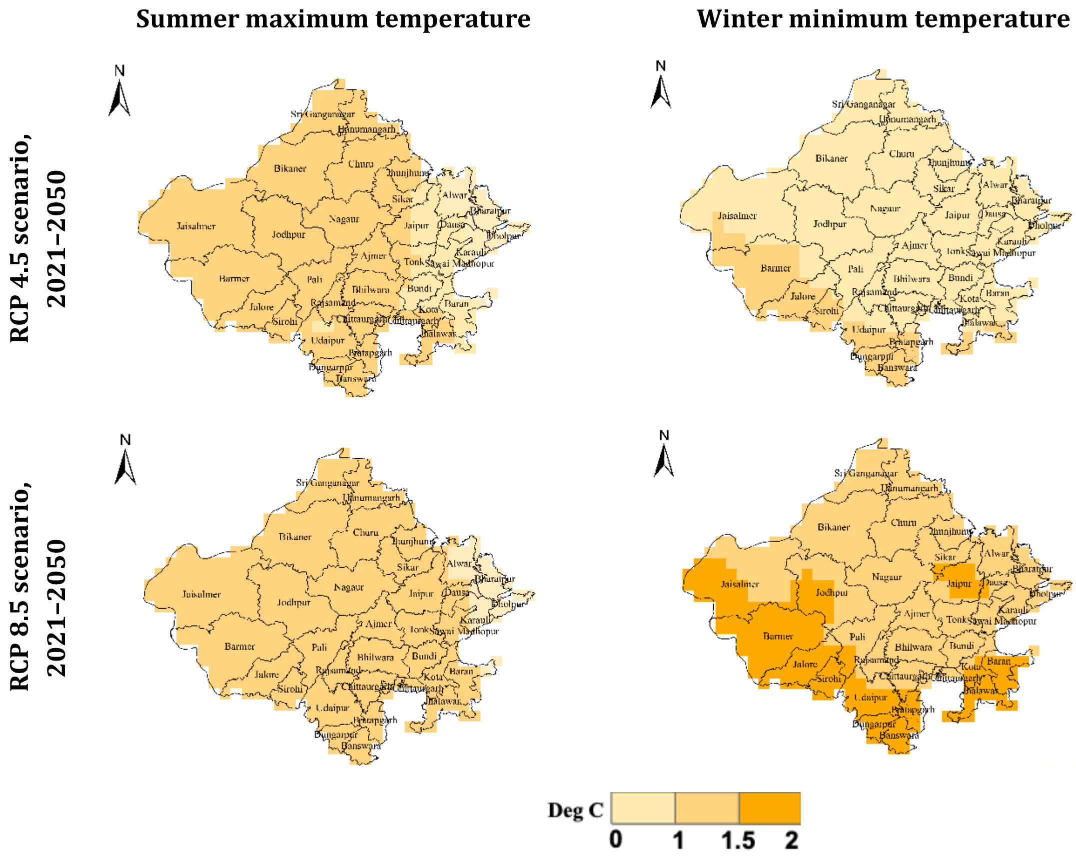


Figure 6-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

6.2.1.1. Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 1, a heatwave analysis of the Bikaner 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 a further 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), under both RCP 4.5 and RCP 8.5 scenarios (Figure 6-5) compared to the historical period (1990–2019).

- Heatwaves are projected to increase by 1% and 14% under RCP 4.5 and RCP 8.5 scenarios, respectively.
- Severe heatwaves are projected to increase by 38% and 36% under RCP 4.5 and RCP 8.5 scenarios, respectively.

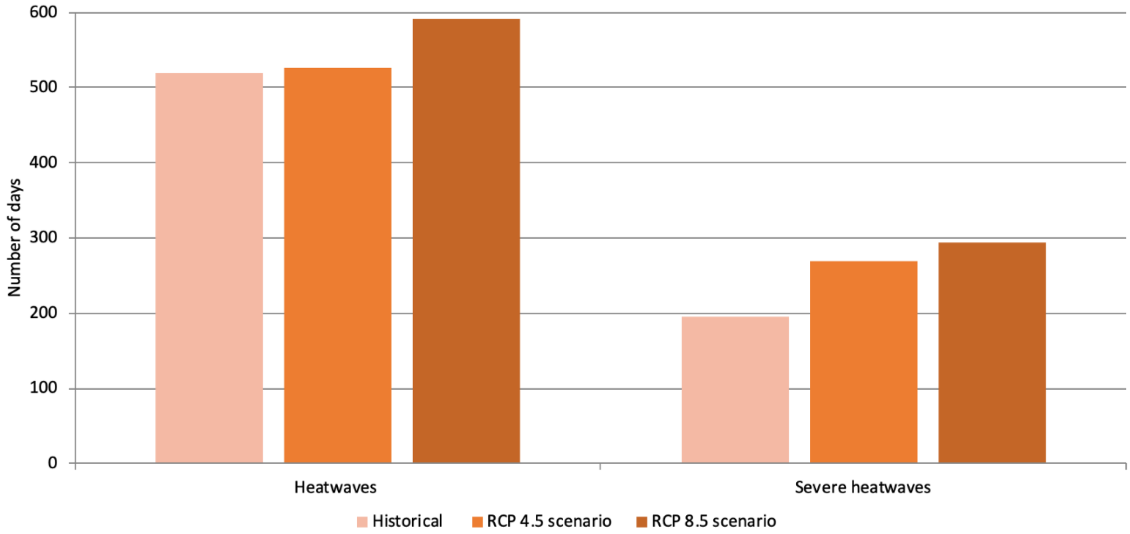


Figure 6-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

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 6-3. The total number of rainy days that ranged from 307 to 1227 days over the 30-year historical period increases to 390 to 1312 days under the RCP 4.5 scenario and 470 to 1412 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 24 days annually in all the districts, except Udaipur and Sikar, where no change is projected. The increase is by 24 days in Jalore; 21 days in Jaisalmer; 6 days in Jhalawar, Dausa, and Barmer; 5 days in Pali and Jodhpur; 3 days in Ajmer, Bharatpur, Bhilwara, Nagaur, Banswara, Sri Ganganagar, Tonk, and Dholpur; and 1 to 2 days in the remaining districts.

RCP 8.5 scenario: Projected to increase by 1 to 15 days annually in all the districts, except Dausa. The increase is by >10 days in Jodhpur, Jalore, and Rajsamand; 8 days in Hanumangarh; 7 days in Barmer; 6 days in Bikaner and Sri Ganganagar; 5 days in Dungarpur, Pali, Jaipur, Sirohi, Churu, Nagaur, Banswara, and Alwar; and 1 to 4 days in the remaining districts.

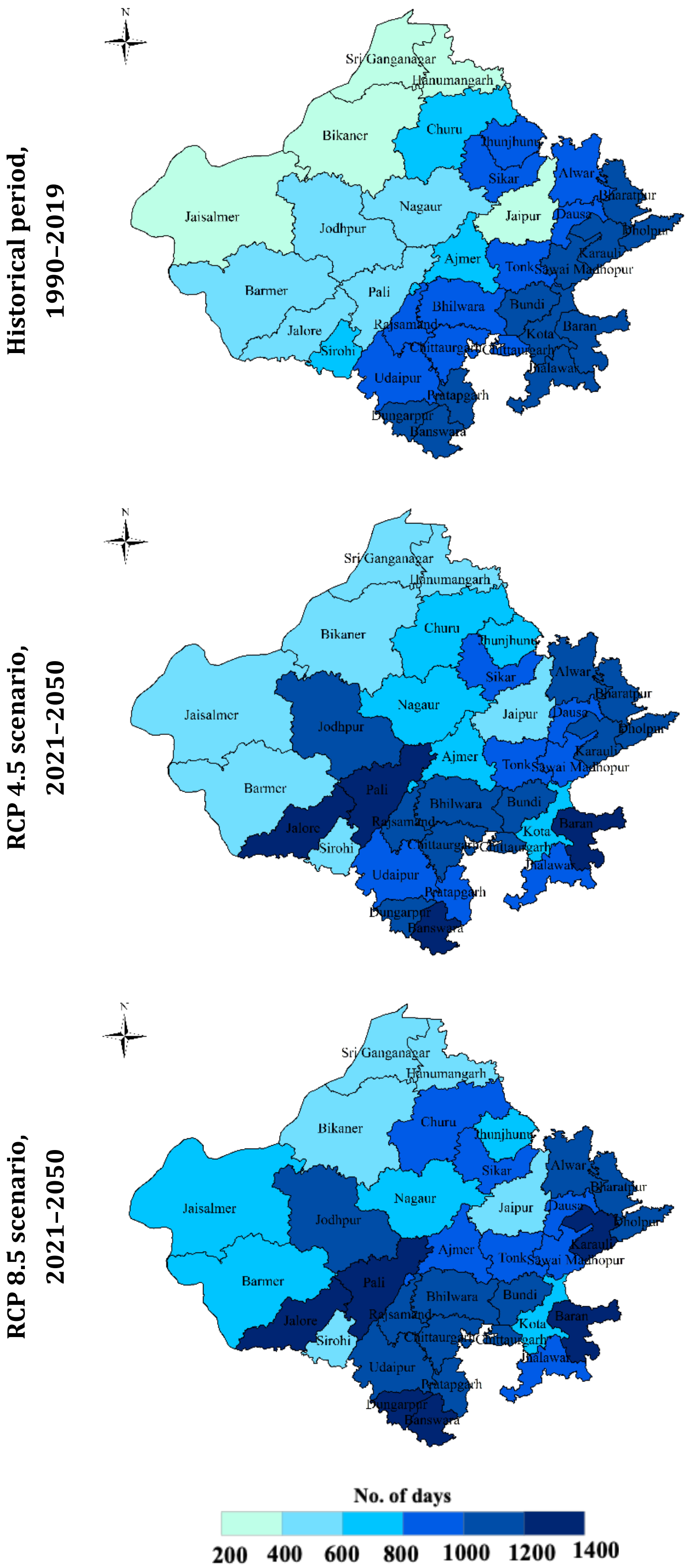


Figure 6-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

6.2.2.2. Mean rainfall and rainfall variability during the kharif season

The kharif season rainfall is projected to increase in almost 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 27 districts, from 1% in Churu, Jhalawar, and Sirohi to 25% in Jalore, and no change in six districts	Increases in five districts by 2% to 3%, declines in 27 districts by 1% to 45%, and no change in Bundi
RCP 8.5	Increases in all the districts, from 2% in Dausa to 29% in Jalore	Increases in Pratapgarh by 1%, declines in 31 districts by 1% to 47%, and no change in Bundi

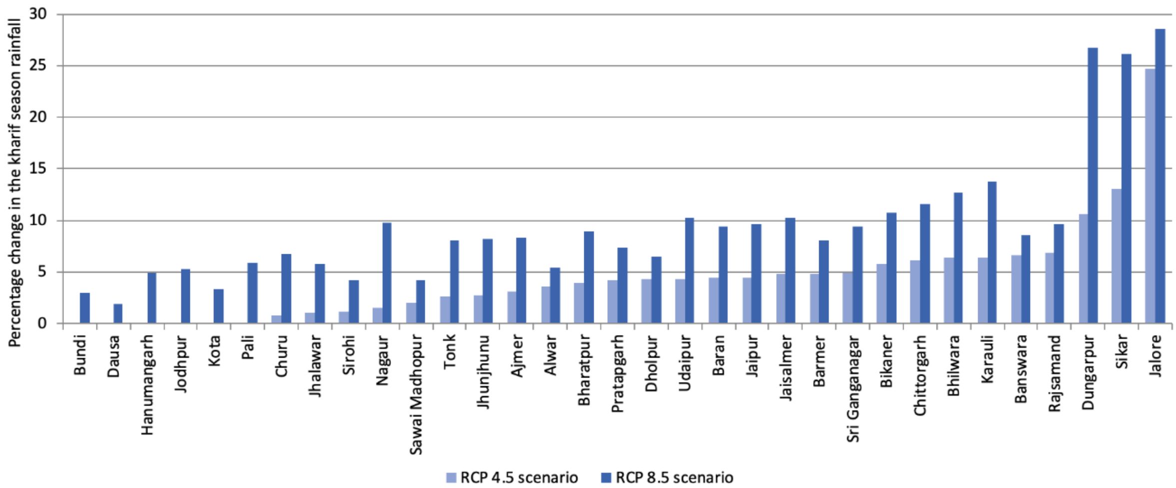


Figure 6-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

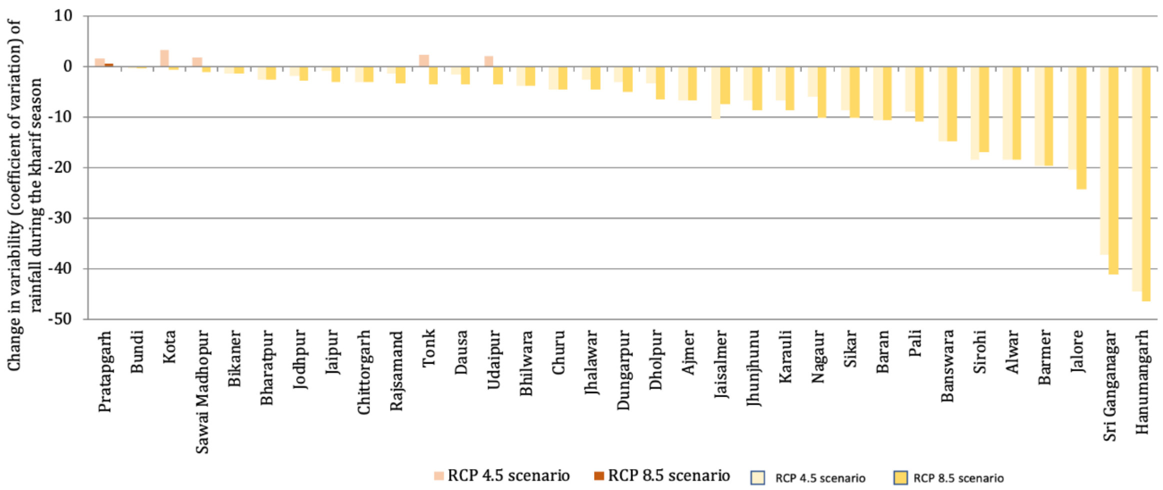


Figure 6-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

6.3. 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 Rajasthan.

High-intensity rainfall events (Figure 6-9)

The total number of high-intensity rainfall events increases from 6 to 93 days during the historical period (1990–2019) to 30 to 123 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 45 to 143 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: High-intensity rainfall events are projected to increase in all the districts of Rajasthan, in the range of one to two additional events per annum. The increase is by two events in Baran, Sri Ganganagar, Bundi, Ajmer, Jalore, Jaisalmer, and Bikaner and one event in the remaining districts.

RCP 8.5 scenario: High-intensity rainfall events are projected to increase in all the districts of Rajasthan, in the range of one to three additional events per annum. The increase is by three events in Jalore, Baran, Bikaner, Sikar; two events in 13 districts including Dungarpur, Bharatpur, Sri Ganganagar, Churu, Barmer, Tonk, Ajmer, Jaisalmer, Bundi, Nagaur, and so forth and one event in the remaining districts.

Very high-intensity rainfall events (Figure 6-10**)**

The total number of very high-intensity rainfall events increases from 1 to 46 days during the historical period (1990–2019) to 20 to 50 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 32 to 70 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: Very high-intensity rainfall events are projected to increase in all the districts of Rajasthan by one additional event per annum.
RCP 8.5 scenario: Very high-intensity rainfall events are projected to increase in all the districts of Rajasthan, in the range of one to two additional events per annum. The increase is by two events in Baran, Alwar, Bhilwara, Bikaner, Rajsamand, Jhunjhunu, Dausa, Tonk, Bundi, and Sikar and one event in the remaining districts.

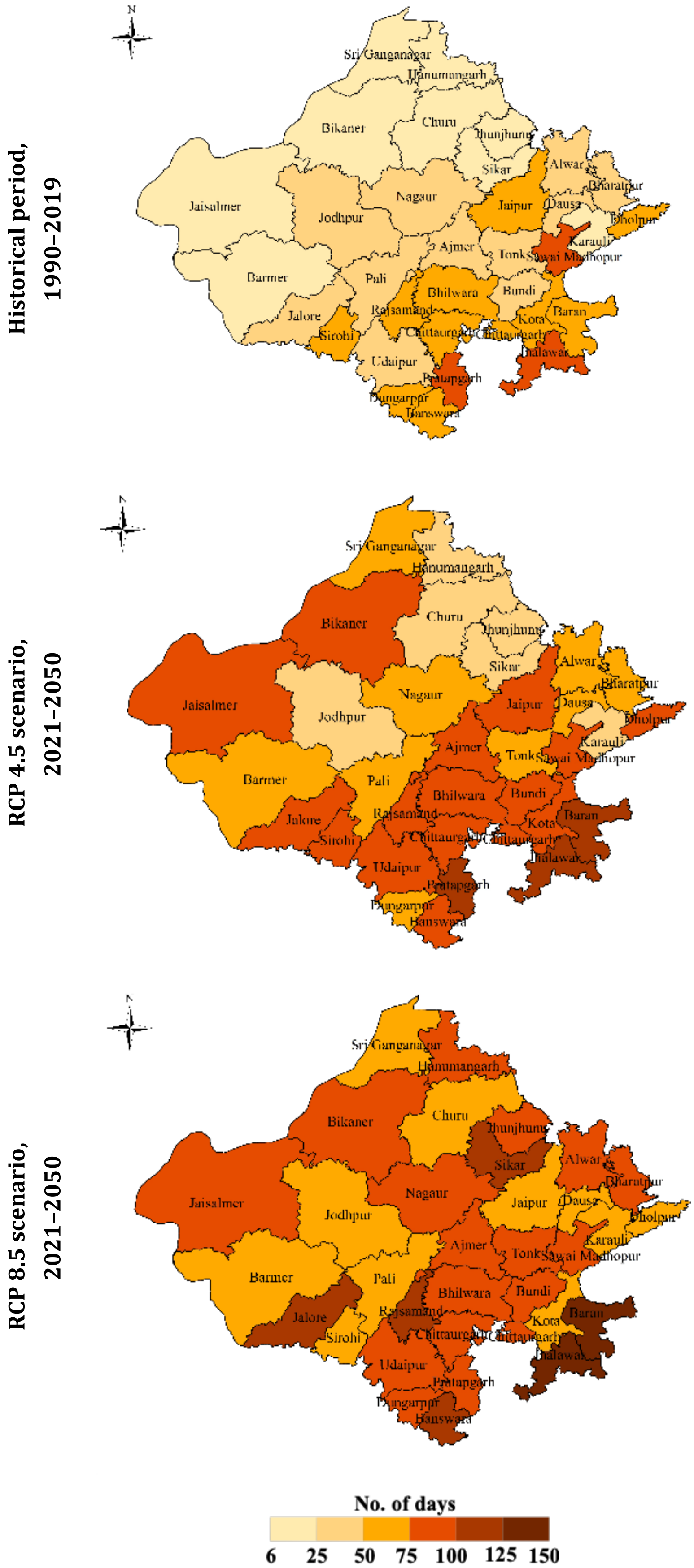


Figure 6-9: The total number of high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

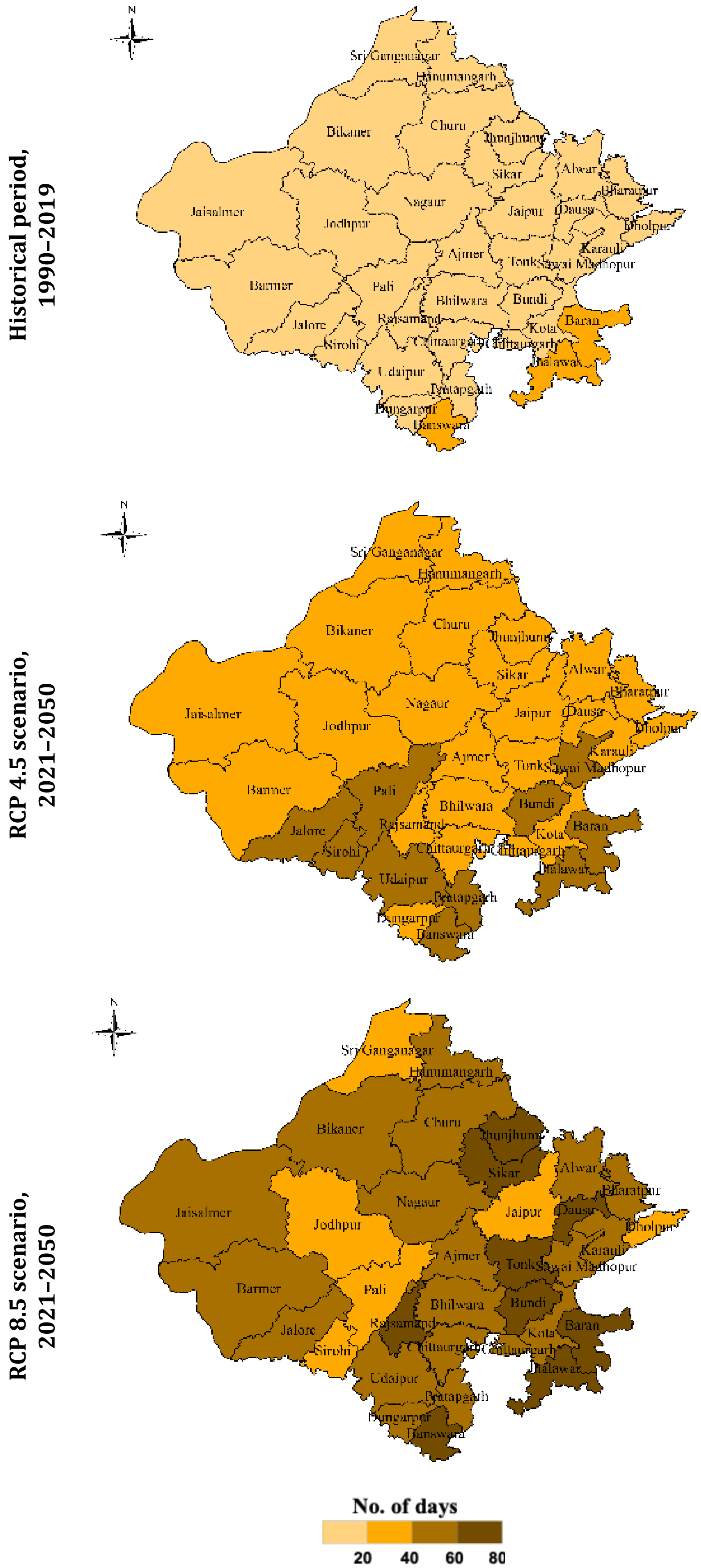


Figure 6-10: The total number of very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

Rainfall deficient years (Figure 6-11**)**

Rainfall deficient years, computed considering rainfall during the kharif season, are projected to decline in a majority of the districts of Rajasthan under both climate scenarios. The number of rainfall deficient years declines from 10 to 17 years during the historical 30-year period to 8 to 15 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 2 years in 27 of the 33 districts. No changes are projected in the remaining six districts.

RCP 8.5 scenario: The projected decline is by 1 to 4 years in 31 of the 33 districts. No changes are projected in the remaining two districts.

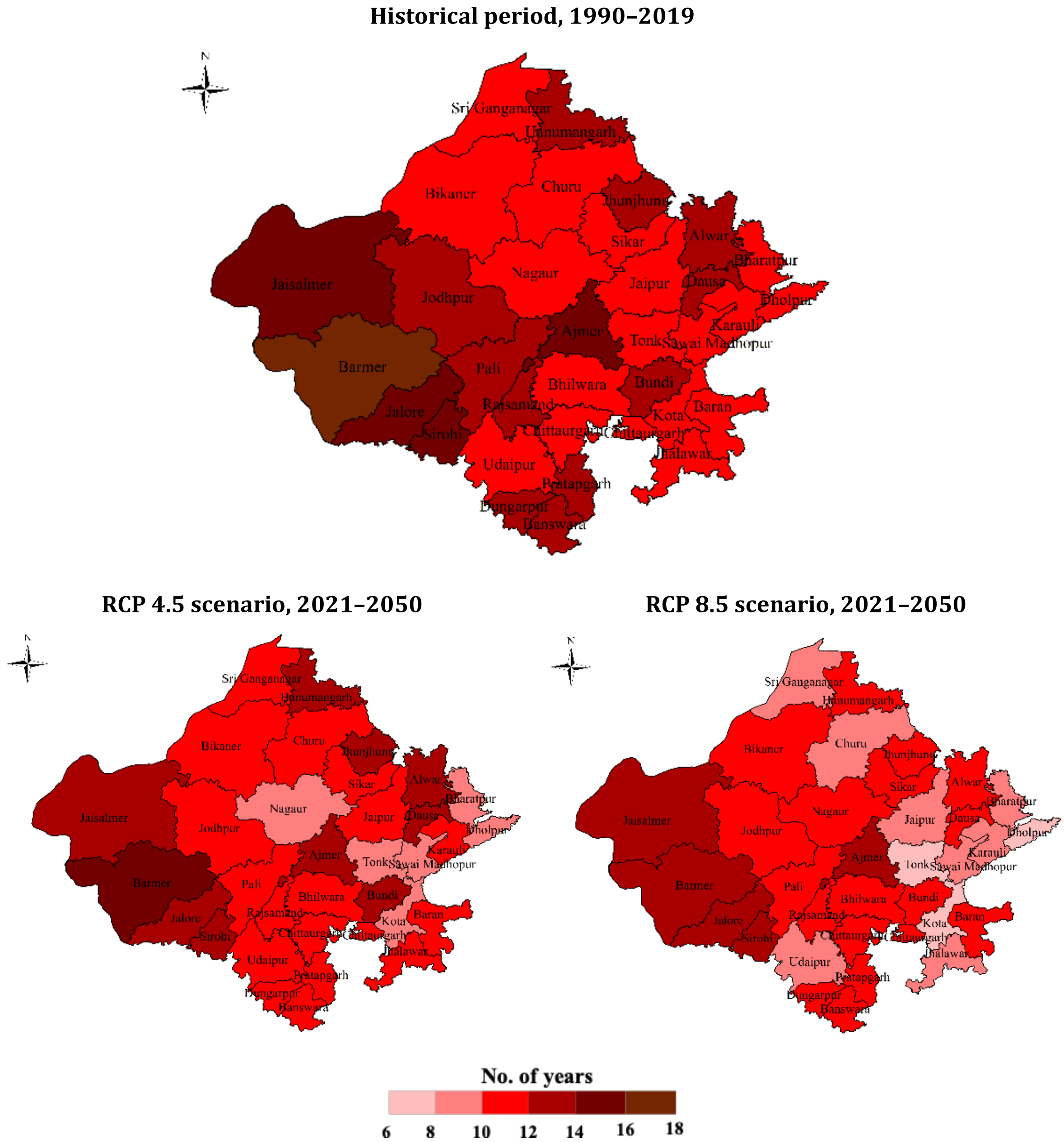


Figure 6-11: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

6.4. The summary of projected changes in the climate for Rajasthan

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).

- The summer maximum temperature is projected to warm up to 1.5^{0}C under the RCP 4.5 scenario and up to 2^{0}C under the RCP 8.5 scenario.
- The winter minimum temperature is projected to warm up to 1.5^{0}C under both RCP 4.5 and RCP 8.5 scenarios.

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

- A >10% increase in rainfall is projected in the districts of Dungarpur, Jalore, and Sikar under the RCP 4.5 scenario.
- A >10% increase in rainfall is projected in the districts of Bikaner, Chittorgarh, Bhilwara, Karauli, Dungarpur, Sikar, and Jalore under the RCP 8.5 scenario.

Rainfall variability during the kharif season is projected to decline 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).

- A ≥10% increase in rainfall variability is projected in Jaisalmer, Baran, Banswara, Sirohi, Alwar, Barmer, Jalore, Sri Ganganagar, and Hanumangarh under both climate scenarios.

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 6-3).

- The projected increase is in the range of 1 to 24 days under the RCP 4.5 scenario and 1 to 15 days under the RCP 8.5 scenario annually.

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)

- 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 event under the RCP 4.5 scenario and by one to two events under the RCP 8.5 scenario.

Rainfall deficient years are projected to decline in 27 of the 33 districts under the RCP 4.5 scenario and 31 of the 33 districts under the RCP 8.5 scenario compared to the historical period (1990–2019; Appendix 6-4).

Appendix

Appendix 6-1: 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
Ajmer	1.2	1.5	0.7	1.4
Alwar	0.9	1.3	0.7	0.9
Banswara	1.4	1.8	1.2	1.5
Baran	0.8	1.3	1.2	1.4
Barmer	1.4	1.6	0.9	1.4
Bharatpur	0.7	1.1	0.7	0.9
Bhilwara	1.4	1.7	0.8	1.3
Bikaner	1.2	1.5	0.8	1.4
Bundi	0.8	1.2	0.9	1.4
Chittorgarh	1.2	1.8	1.2	1.5
Churu	1.2	1.5	0.8	1.3
Dausa	0.8	1.4	0.7	0.9
Dholpur	0.7	1.1	0.6	0.9
Dungarpur	1.4	1.6	1.1	1.5
Hanumangarh	1.1	1.5	0.7	1.4
Jaipur	1.4	1.8	0.8	1.4
Jaisalmer	1.3	1.9	0.7	1.5
Jalore	1.3	1.8	1.2	1.3
Jhalawar	1.2	1.6	1.3	1.5
Jhunjhunu	1.2	1.5	0.8	1.3
Jodhpur	1.1	1.4	0.9	1.4
Karauli	0.8	1.3	0.7	0.9
Kota	0.9	1.4	1.2	1.5
Nagaur	1.4	1.5	0.8	1.4
Pali	1.4	1.8	1.2	1.5
Pratapgarh	1.3	1.9	1.2	1.4
Rajsamand	1.4	1.7	1.1	1.4
Sawai Madhopur	0.7	1.3	0.7	1.1
Sikar	1.4	1.7	0.8	1.3
Sirohi	1.4	1.8	1.3	1.5
Sri Ganganagar	1.2	1.4	0.8	1.3
Tonk	0.8	1.4	0.8	1.3
Udaipur	1.3	1.5	1.2	1.5

Appendix 6-2: 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
Ajmer	6	9	3	8	17	57
Alwar	2	4	4	5	12	28
Banswara	8	9	7	9	14	18
Baran	5	9	4	9	15	33
Barmer	4	6	5	8	27	50
Bharatpur	4	6	4	9	34	50
Bhilwara	7	12	6	13	23	48
Bikaner	6	9	6	11	26	62
Bundi	0	8	0	3	34	34
Chittorgarh	6	12	6	12	10	27
Churu	4	9	1	7	15	31
Dausa	0	4	0	2	45	45
Dholpur	10	11	4	6	5	9
Dungarpur	-18	-15	11	27	61	98
Hanumangarh	-1	5	0	5	38	87
Jaipur	4	10	4	10	20	28
Jaisalmer	3	5	5	10	-8	5
Jalore	46	52	25	29	10	22
Jhalawar	2	6	1	6	9	14
Jhunjhunu	3	8	3	8	4	10
Jodhpur	5	7	0	5	23	38
Karauli	4	10	6	14	5	16
Kota	-2	5	0	3	12	22
Nagaur	1	9	2	10	22	41
Pali	3	6	0	6	8	19
Pratapgarh	-7	-3	4	7	32	43
Rajsamand	6	13	7	10	8	25
Sawai Madhopur	0	7	2	4	10	15
Sikar	-2	3	13	26	13	16
Sirohi	2	5	1	4	10	14
Sri Ganganagar	6	10	5	9	71	119
Tonk	2	9	3	8	23	34
Udaipur	5	7	4	10	10	35

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)

Districts	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Ajmer	713	789	812
Alwar	951	1012	1090
Banswara	1195	1290	1339
Baran	1188	1222	1290
Barmer	424	590	635
Bharatpur	1019	1099	1123
Bhilwara	993	1078	1122
Bikaner	377	450	555
Bundi	1077	1116	1161
Chittorgarh	959	1023	1090
Churu	691	750	838
Dausa	845	1024	850
Dholpur	1024	1123	1079
Dungarpur	1070	1097	1233
Hanumangarh	358	480	600
Jaipur	374	390	530
Jaisalmer	307	934	420
Jalore	565	1290	1001
Jhalawar	1227	1412	1312
Jhunjhunu	851	920	945
Jodhpur	524	663	940
Karauli	1076	1123	1142
Kota	1090	1121	1220
Nagaur	587	678	732
Pali	539	678	702
Pratapgarh	1173	1233	1256
Rajsamand	869	980	1243
Sawai Madhopur	1004	1065	1091
Sikar	901	912	966
Sirohi	785	823	940
Sri Ganganagar	350	445	525
Tonk	889	987	990
Udaipur	981	990	1011

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 scenario	RCP 8.5 scenario	Historical	RCP 4.5 scenario	RCP 8.5 scenario	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Ajmer	26	77	90	4	30	44	16	14	13
Alwar	37	68	79	6	38	54	14	13	12
Banswara	71	92	105	46	50	65	14	12	11
Baran	64	112	143	21	45	66	12	12	11
Barmer	18	60	75	7	37	42	17	15	13
Bharatpur	38	70	86	3	39	45	11	10	9
Bhilwara	60	89	97	7	40	56	12	12	11
Bikaner	16	80	98	1	40	51	12	12	12
Bundi	26	76	92	5	49	70	14	13	12
Chittorgarh	65	85	90	16	40	54	11	11	11
Churu	16	40	70	1	34	45	11	11	10
Dausa	40	67	62	6	34	65	14	13	12
Dholpur	51	78	74	5	30	40	10	8	7
Dungarpur	52	55	98	15	36	48	13	12	12
Hanumangarh	6	36	79	3	20	45	14	13	12
Jaipur	53	78	69	6	40	35	12	11	10
Jaisalmer	17	78	82	4	34	46	15	14	13
Jalore	36	92	112	20	47	56	16	14	13
Jhalawar	93	123	134	24	45	68	12	11	10
Jhunjhunu	17	30	82	3	27	61	14	13	12
Jodhpur	27	45	45	6	24	32	13	12	11
Karauli	25	46	67	4	34	45	12	11	10
Kota	52	80	66	6	35	41	10	9	8
Nagaur	26	56	97	6	35	49	12	10	11
Pali	27	68	69	13	42	40	13	12	11
Pratapgarh	77	101	99	16	43	60	13	12	11
Rajsamand	51	78	124	8	34	64	13	12	11
Sawai Madhopu	89	85	94	18	48	46	11	10	9
Sikar	16	50	104	2	30	68	12	11	11
Sirohi	51	80	68	17	45	35	15	14	13
Sri Ganganagar	14	63	63	2	30	40	12	11	10
Tonk	36	70	98	3	30	66	10	9	8
Udaipur	41	78	82	7	44	46	11	11	10

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 western states.

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

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

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

Agriculture: Agriculture crops require specific conditions to thrive and have specific temperature and water requirements. Higher temperatures projected in the various districts of the western 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 western states have health implications. These implications could be both direct (thermal stress due to high summer temperatures and death, injury, or mental stress caused by forced migration due to climate- or weather-related disasters such as floods, droughts, and storms) as well as indirect (through changes in the ranges of disease vectors such as mosquitoes and rodents, changes in the availability and quality of water, air quality, and food availability and quality).

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

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

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