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

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

Vidya S

Indu K Murthy

CSTEP

September 2022

Center for Study of Science, Technology and Policy (CSTEP) is a private, not-for-profit (Section 25) Research Organisation registered in 2005.

Designed and Edited by CSTEP

Contributors: Vidya S and Indu K Murthy

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

This report should be cited as: CSTEP. (2022). *District-level changes in climate: Historical climate and climate change projections for the northern states of India.* (CSTEP-RR-2022-11).

September 2022

Center for Study of Science, Technology and Policy

Bengaluru

18, 10th Cross, Mayura Street

Papanna Layout, Nagashettyhalli

RMV II Stage, Bengaluru 560094

Karnataka (India)

Noida

1st Floor, Tower-A

Smartworks Corporate Park

Sector 125, Noida 201303

Uttar Pradesh (India)

Tel.: +91 (80) 6690 2500

Email: cpe@cstep.in

Website: www.cstep.in

Acknowledgements

The authors would like to express their gratitude to Prof Govindasamy Bala from the Centre for Atmospheric and Oceanic Sciences, Indian Institute of Science; Prof M K Ramesh, National Law School of India University; and Dr Vinaya Kumar, Research Director, Environmental Management and Policy Research Institute for their critical review and inputs during the study and report preparation. The support and constant encouragement of Mr Priyavrat Bhati (former Sector Head, Climate, Environment, and Sustainability, CSTEP) and Dr Jai Asundi (Executive Director, CSTEP) are duly acknowledged. The financial support of Rohini Nilekani Philanthropies for this study is gratefully acknowledged.

Additionally, the authors acknowledge the following CSTEP individuals for their timely contributions and reviews:

Internal review: Ms Tashina Madappa Cheranda

Editorial support: Mr Reghu Ram and Ms Sreerekha Pillai

Report design: Mr Alok Kumar Saha

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 five northern states of India: Haryana, Himachal Pradesh, Punjab, Uttarakhand, and Uttar Pradesh.

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

Findings: Historically, temperature and rainfall have increased, and rainfall variability is high across all the northern 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 northern states. Rainfall variability shows mixed trends, and rainfall deficient years are projected to largely decline.

Temperature

The projected increase in the winter minimum temperature is comparatively higher than the increase in the summer maximum temperature in almost all northern states. The summer maximum temperature is projected to increase by 1°C to 1.5°C, and the winter minimum temperature is projected to increase by 1°C to 2°C in a majority of the districts of northern India.

Rainy days

The number of rainy days is projected to increase in the 2030s in all the districts of northern India compared to the historical period. The increase is by 1 to 15 days under the RCP 4.5 scenario, with the maximum increase projected in Uttarakhand and Uttar Pradesh and a minimum increase projected in Himachal Pradesh.

Monsoon rainfall

Rainfall during kharif (June to September) and rabi (October to December) seasons are projected to increase in the 2030s in all the districts of northern India compared to the historical period. The projected increase in the kharif season rainfall is by 2% to 39% under the RCP 4.5 scenario and 5% to 46% under the RCP 8.5 scenario. The maximum increase in the kharif season rainfall is projected in the districts of Punjab and Uttar Pradesh. The rabi season rainfall is projected to increase by 3% to 97% under the RCP 4.5 scenario and 1% to 92% 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 northern India compared to the historical period. While an increase in rainfall variability is projected in some districts, a decline in variability is projected in several districts in all the states.

Heavy rainfall events

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

Rainfall deficient years

A decline in rainfall deficient years is projected in the 2030s across almost all districts of northern India compared to the historical period. The decline in rainfall deficient years is largely by 1 to 4 years out of the 30 years under RCP 4.5 and RCP 8.5 scenarios.

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

Recommendations: The district-level climate change assessment for the northern 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 2021 report of the Intergovernmental Panel on Climate Change (IPCC) 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 differs 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 needed 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 span 30 years, from 1990 to 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 the 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 (October to December). During these two seasons, the variability of rainfall has also been analysed by computing the coefficient of variation (CV). Additionally, the number of rainy days, heavy rainfall events, and rainfall deficient years have been analysed.

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

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

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

Rainfall deficient years: Considering the total quantum of rainfall received during the kharif season, rainfall deficient years have been analysed. Following the criterion defined by IMD[2], years that receive <20% of rainfall, compared to the long period average of rainfall during the kharif season, are categorised as rainfall deficient years.

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

2.2. Climate change projections

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

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

In this study, CORDEX model outputs were used for projecting temperature and rainfall at the district level. An ensemble mean from 15 bias-corrected CORDEX South Asia simulations was 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 the 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: 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 because of 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 northern states of India: Haryana, Himachal Pradesh, Punjab, Uttarakhand, and Uttar Pradesh. The state chapters are organised as follows:

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

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

3. Haryana

The state of Haryana is landlocked and spans 44,210 sq. km. It has a population of 25.35 million according to the 2011 Census. Haryana is bordered by Himachal Pradesh and Punjab in the north; Uttarakhand, Uttar Pradesh, and Delhi in the east; and Rajasthan in the west and the south. It has 22 districts, with the climate varying from moist subtropical in the northern part bordering Himachal Pradesh to arid in the southern part bordering Rajasthan. Haryana exhibits an average annual rainfall ranging between 200 mm and 1,400 mm. The rainfall is received primarily (80%) during the monsoon season. The backbone of the local economy is agriculture and related industries. The land-use pattern of the state makes this clear. Almost 85% of the land is under agriculture, with a high cropping intensity of 180%, employing 65% of the total workforce. With only one seasonal river, the state has invested in developing a large network of irrigation canals to meet water demand. The main canals span 2264 km, and the distributaries and minors span 9955 km in length.

The observed changes in climate over Haryana include increased mean annual temperatures, erratic and reduced rainfall, and extreme events such as floods, droughts, and cyclones. Recurring drought-like conditions due to below-normal monsoon rains have been observed across almost half the state. According to the Vulnerability Atlas of India 2019, 80% of the state is prone to earthquakes, with the probability to cause moderate to severe damage. Almost the entire state is at risk of damage due to high-intensity cyclones, with wind speeds ranging between 47 m/s and 55 m/s. About 27% of the state is prone to floods.

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

3.1. Historical climate

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

3.1.1. Trends in temperature

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

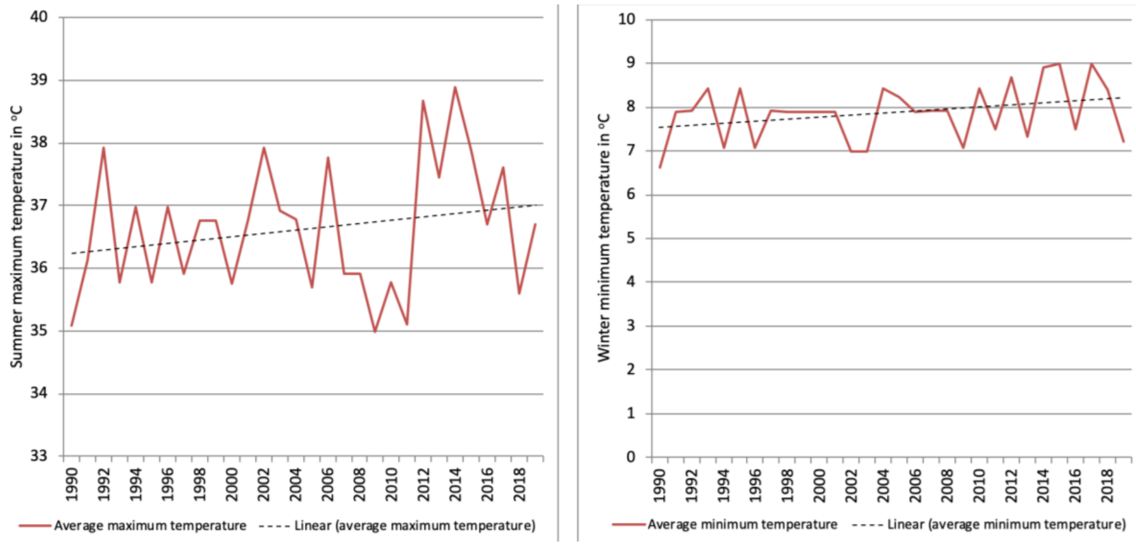


Figure 3-1: Mean summer maximum and winter minimum temperatures in Haryana during the historical period (1990–2019)

3.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and the kharif season rainfall, of up to 15%, was recorded during the historical period. In a majority of the districts, a 5%–10% increase in the kharif season rainfall was recorded during the historical period. Figure 3-2 presents the mean annual rainfall in Haryana during the historical period.

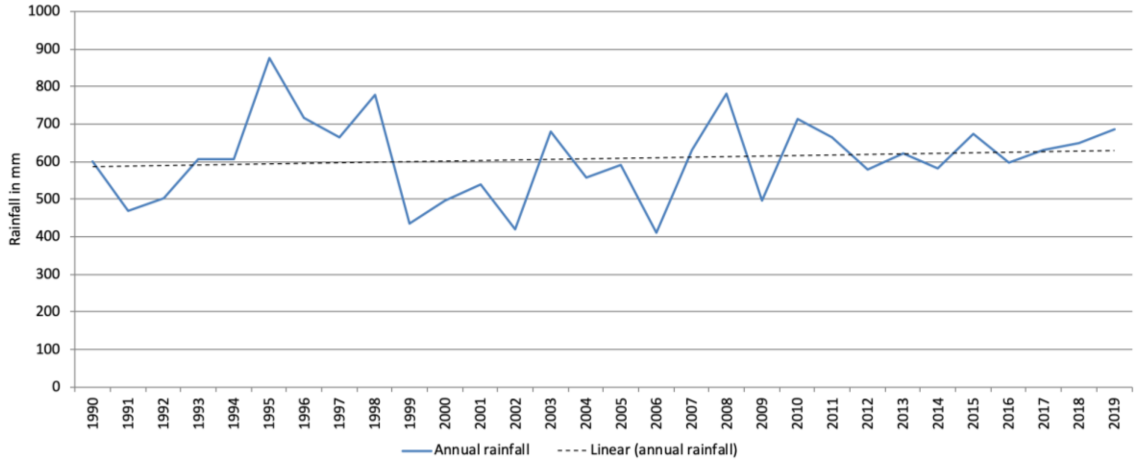


Figure 3-2: Mean annual rainfall in Haryana during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 31% in the Ambala district to 60% in the Charkhi Dadri district (Figure 3-3). The rabi season rainfall variability is >100% in all the districts during the historical period (Figure 3-3), indicating a complete failure of rainfall during the season. However, it is important to note that rainfall during this season is insignificant in Haryana.

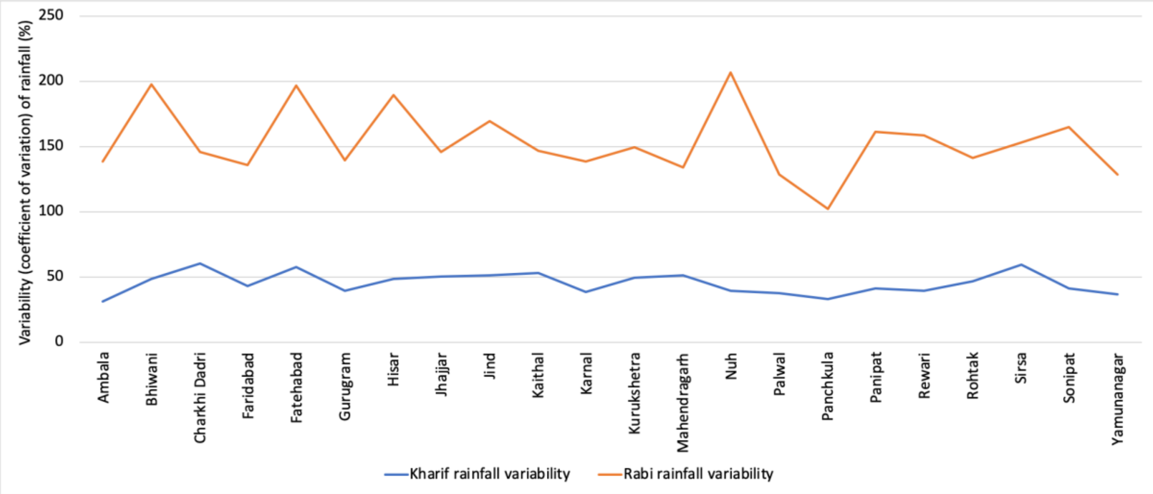


Figure 3-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

3.2. Climate change projections

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

3.2.1. Temperature projections

The projected changes in the summer maximum and winter minimum temperatures for all the districts of Haryana are presented in Figure 3-4.

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

Climate scenarios	Summer maximum	Winter minimum
RCP 4.5	Increases by 1°C to 2°C	Increases by 1°C to 1.5°C
RCP 8.5	Increases by 1°C to 2°C, with a greater number of districts experiencing warming	Increases by 1°C to 2°C

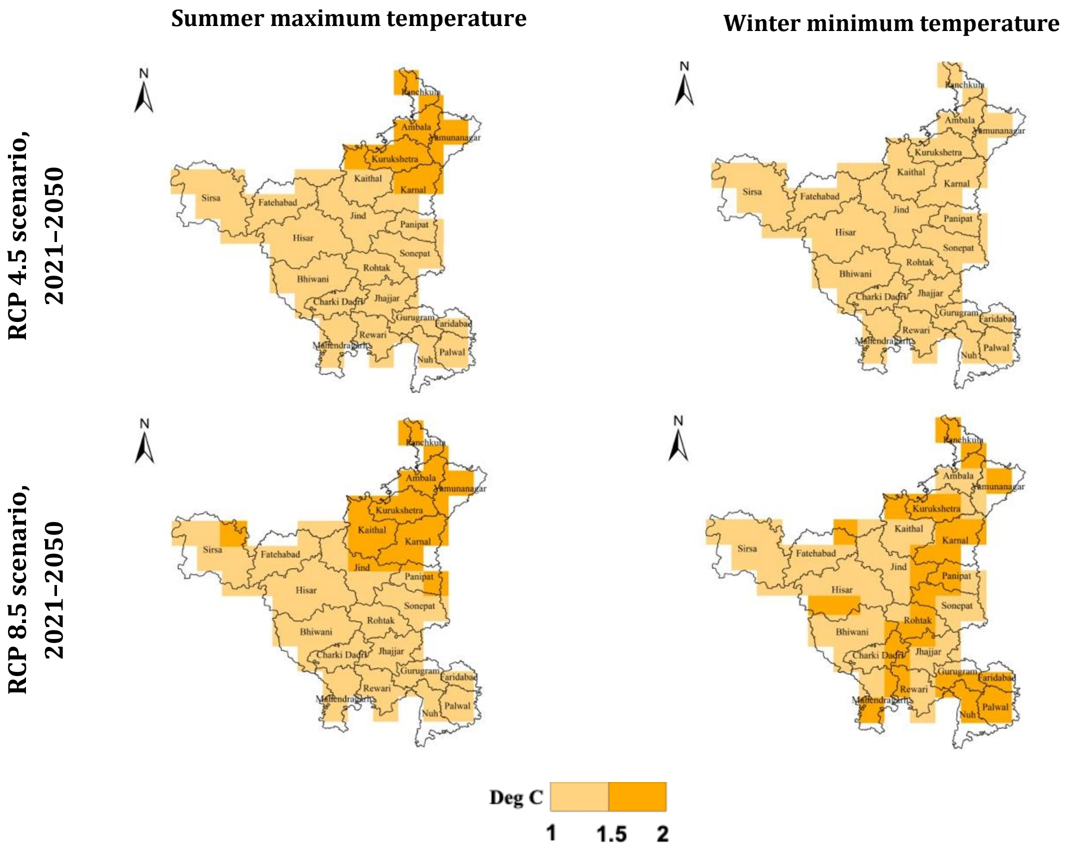


Figure 3-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

3.2.1.1. Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 1, a heatwave analysis of the Hisar 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 the number of days recording 'High' temperatures, but the number of days likely to record 'Very High' temperatures, as categorised by the India Meteorological Department (IMD), will increase under both RCP 4.5 and RCP 8.5 scenarios (Figure 3-5) compared to the historical period (1990–2019).

- 'Heatwaves' are projected to decline by approximately 1% to 3% under RCP 4.5 and RCP 8.5 scenarios.
- 'Severe Heatwaves' are projected to increase by about 20% under RCP 4.5 and RCP 8.5 scenarios, respectively.

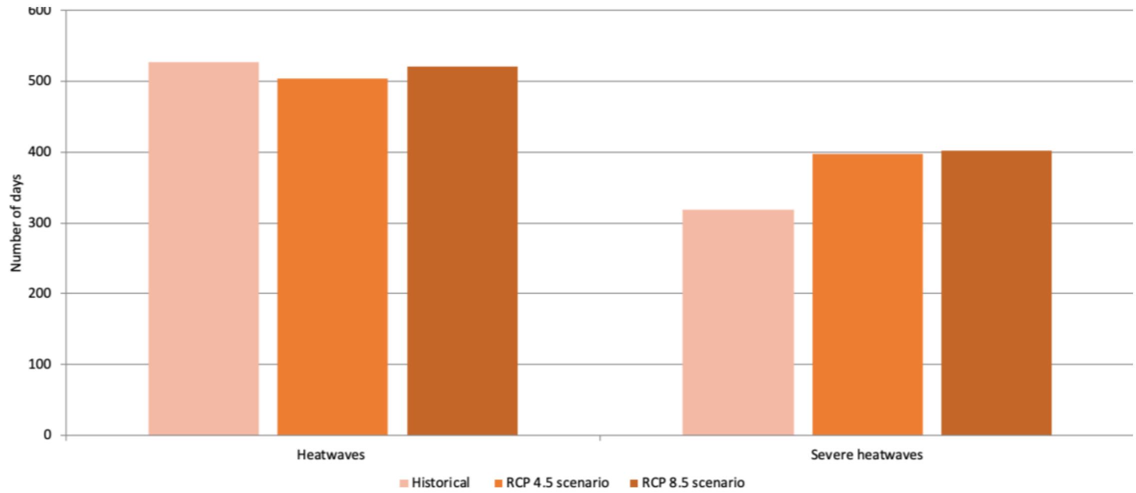


Figure 3-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

3.2.2. Rainfall projections

3.2.2.1. Number of rainy days

According to the IMD, a *rainy day* is defined as a day with rainfall of 2.5 mm or more. The analysis of rainy days under historical and projected periods shows that there will be an increase in the number of rainy days during the projected period in all the districts (Figure 3-6). The number of rainy days during the historical period and the projected 2030s under RCP 4.5 and 8.5 scenarios is presented in Appendix 3-2. The total number of rainy days that ranged from 471 to 1493 days over the 30-year historical period increases to 563 to 1789 days under the RCP 4.5 scenario and 669 to 1830 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 10 days annually in all the districts. The projected increase is by 10 days in Panchkula; 6 days in Rewari and Sonipat; 5 days in Palwal, Gurugram, Ambala, Nuh, and Rohtak; 4 days in Kurukshetra, Bhiwani, and Fatehabad; and 2 to 3 days in Kaithal, Charkhi Dadri, Karnal, Sirsa, Jind, Hisar, Panipat, Mahendragarh, Yamunanagar, Jhajjar, and Faridabad.

RCP 8.5 scenario: Projected to increase by 4 to 11 days annually in all the districts. The projected increase is by 11 days in Panchkula, 9 days in Rewari; 8 days in Sonipat, Panipat, and Rohtak; 7 days in Palwal, Bhiwani, Kaithal, Nuh, Jind, Kurukshetra, Sirsa, and Fatehabad; 6 days in Gurugram, Ambala, Karnal, and Charkhi Dadri; 5 days in Mahendragarh, Faridabad, and Yamunanagar; and 4 days in Jhajjar and Hisar.

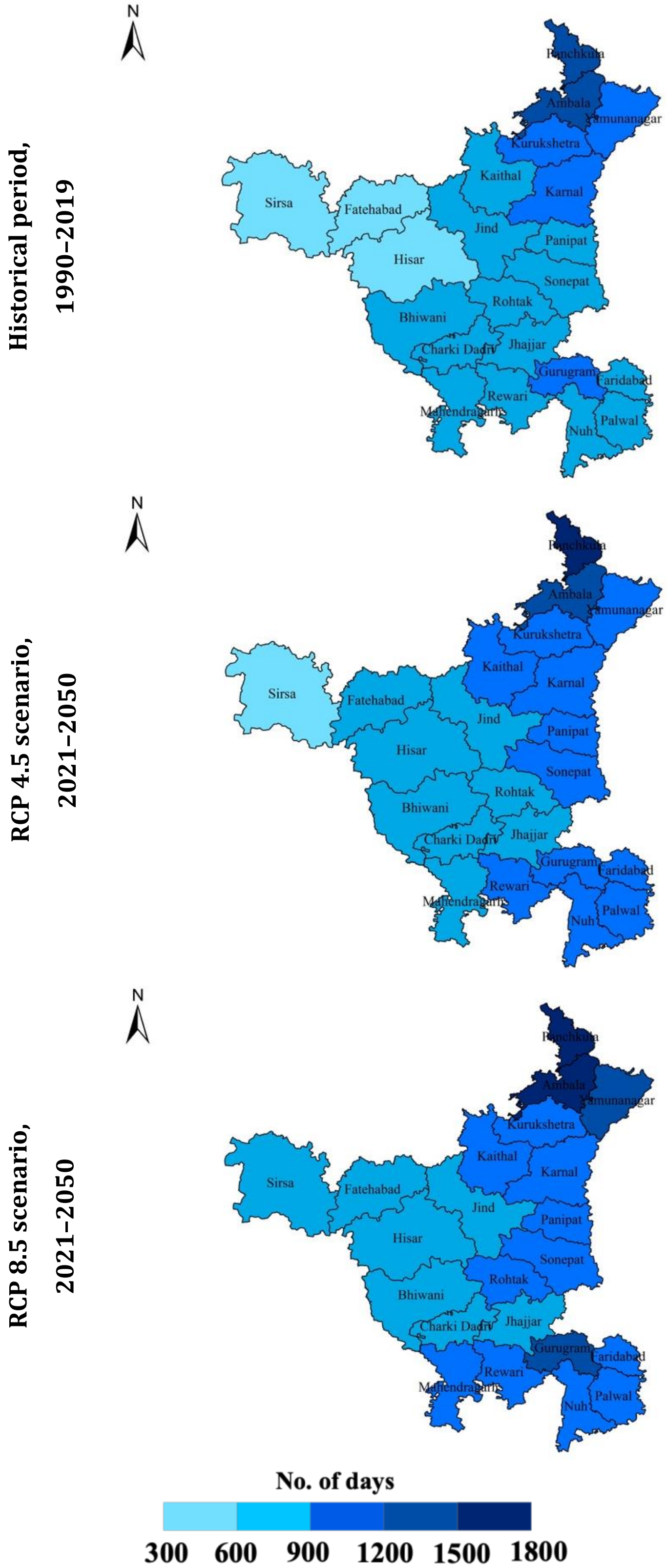


Figure 3-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

3.2.2.2. Mean rainfall and rainfall variability during the kharif season

The kharif season rainfall is projected to increase in all the districts under both climate scenarios. Figure 3-7 presents district-wise changes in the kharif season rainfall, and Figure 3-8 presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 2% in Panchkula to 23% in Faridabad	Declines in all the districts by 3% to 31%
RCP 8.5	Increases in all the districts, from 8% in Bhiwani to 29% in Fatehabad	Declines in all the districts by 7% to 32%

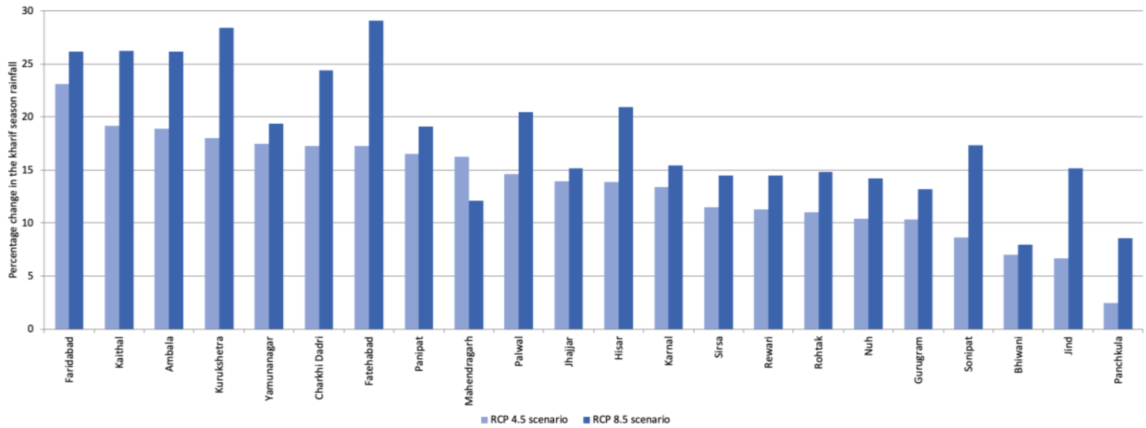


Figure 3-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

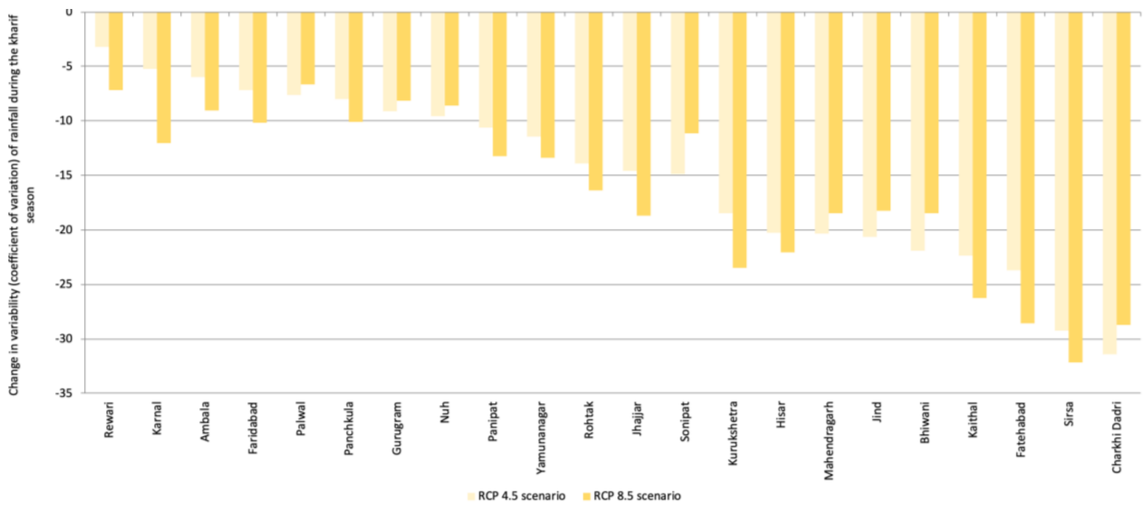


Figure 3-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

3.2.2.3. Mean rainfall and rainfall variability during the rabi season

The rabi season rainfall is projected to increase in all the districts under both climate scenarios. Figure 3-9 presents district-wise changes in the rabi season rainfall, and Figure 3-10 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 Kaithal to 44% in Fatehabad	Declines in all the districts by 38% to 91%
RCP 8.5	Increases in all the districts, from 1% in Palwal to 92% in Hisar	Declines in all the districts by 35% to 97%

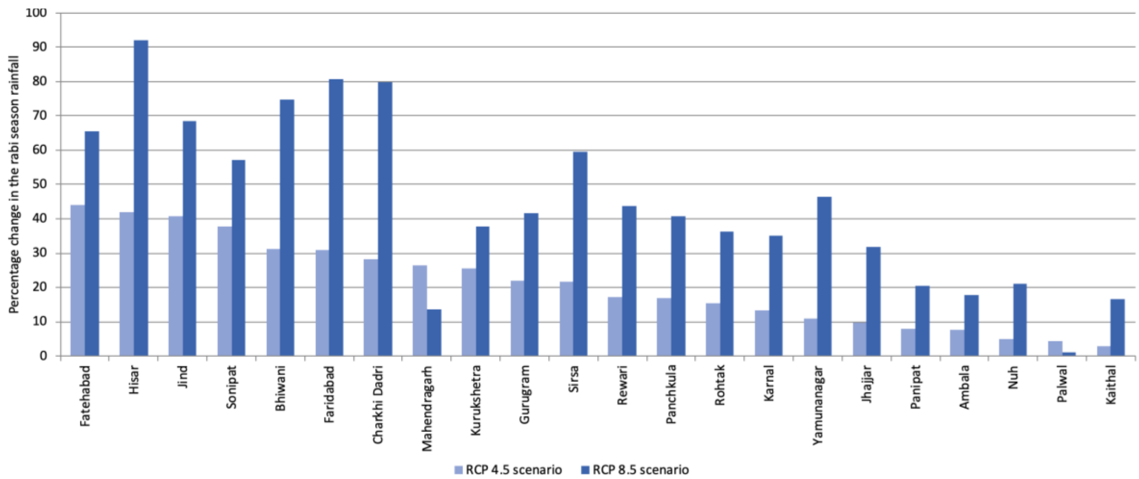


Figure 3-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

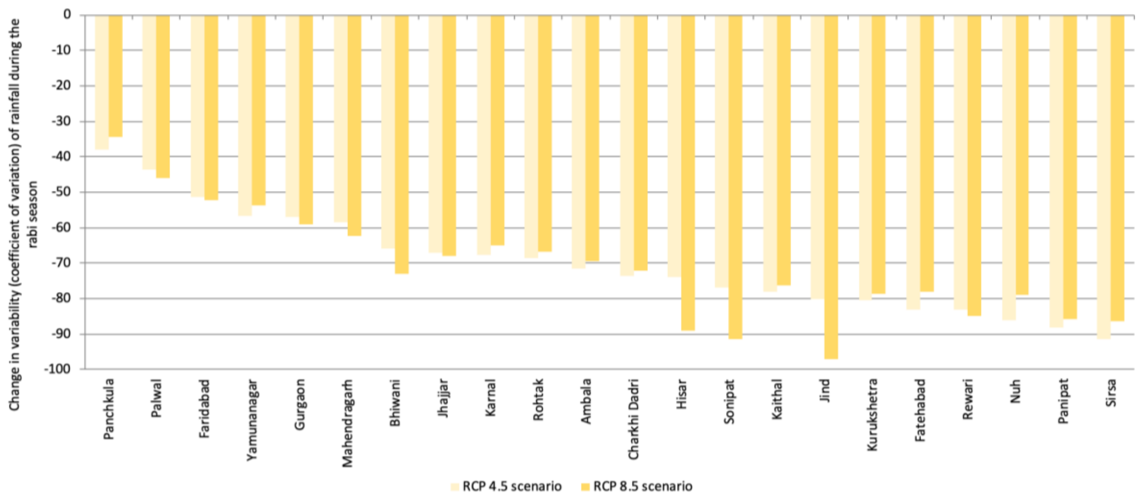


Figure 3-10 Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

3.3. Heavy rainfall events and rainfall deficient years

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

High-intensity rainfall events (Figure 3-11)

The total number of high-intensity rainfall events increases from 16 to 91 days during the historical period (1990–2019) to 46 to 112 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 72 to 134 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 except Panchkula. The increase per annum is by two events in Fatehabad, Kaithal, Sirsa, Kurukshetra, Mahendragarh, and Jind. In the remaining 15 districts, the increase is by one event.

RCP 8.5 scenario: The projected increase per annum is by one to two events. The increase per annum is by two events in Rewari, Faridabad, Panipat, Hisar, Rohtak, Gurugram, Sonipat, Fatehabad, Mahendragarh, Kurukshetra, and others.

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

The total number of very high-intensity rainfall events increases from 1 to 27 days during the historical period (1990–2019) to 19 to 56 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 30 to 75 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 except Yamunanagar. The increase per annum is by two events in Kurukshetra. In all the other districts such as Fatehabad, Kaithal, Sirsa, Panchkula, Mahendragarh, Jind, Karnal, Sonipat, and Panipat, the increase per annum is by one event.

RCP 8.5 scenario: The projected increase per annum is by one to two events in all the districts. The increase per annum is by two events in Nuh, Palwal, Sonipat, Panchkula, Rohtak, Rewari, Kurukshetra, Jind, Sirsa, Kaithal, and Karnal. In Hisar, Yamunanagar, Charkhi Dadri, Faridabad, Bhiwani, Ambala, Gurugram, Panipat, Fatehabad, Mahendragarh, and Jhajjar, the increase per annum is by one event.

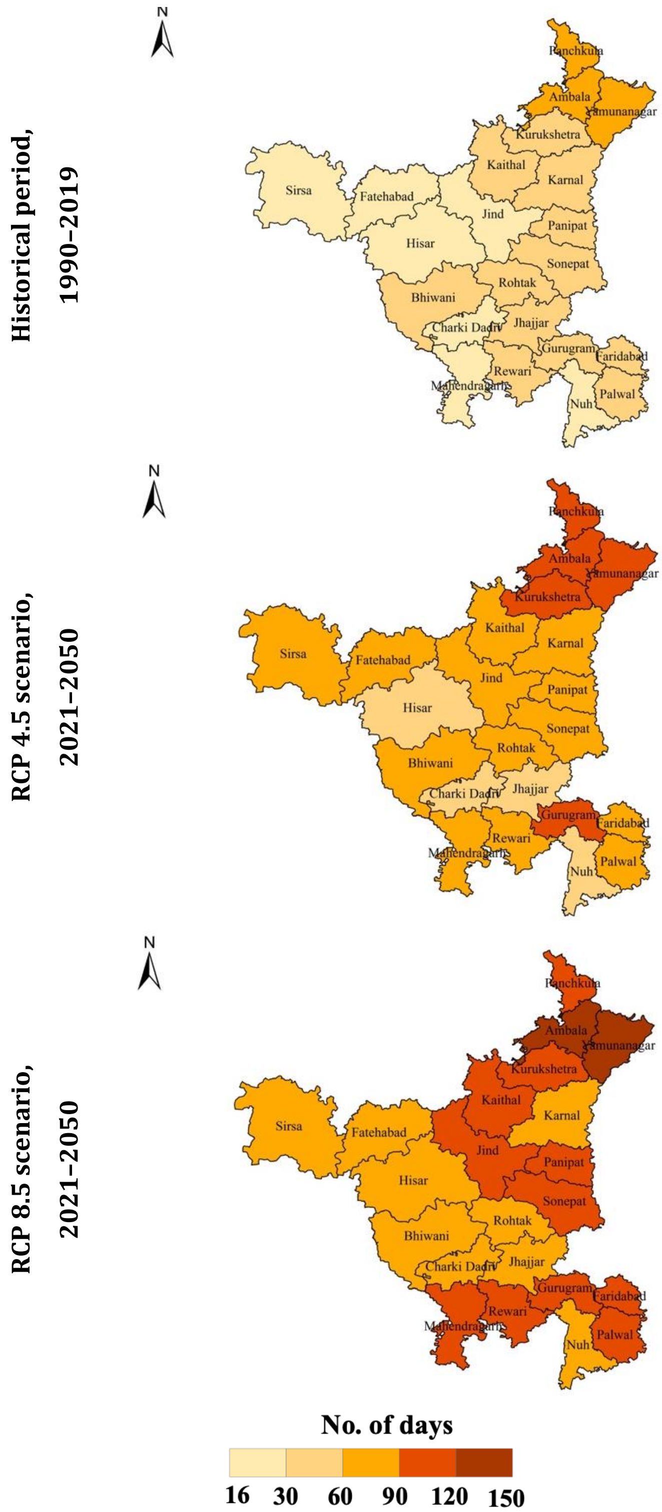


Figure 3-11: The number of high-intensity rainfall events during historical (1990–2019) and projected periods (the 2030s) under RCP 4.5 and RCP 8.5 scenarios

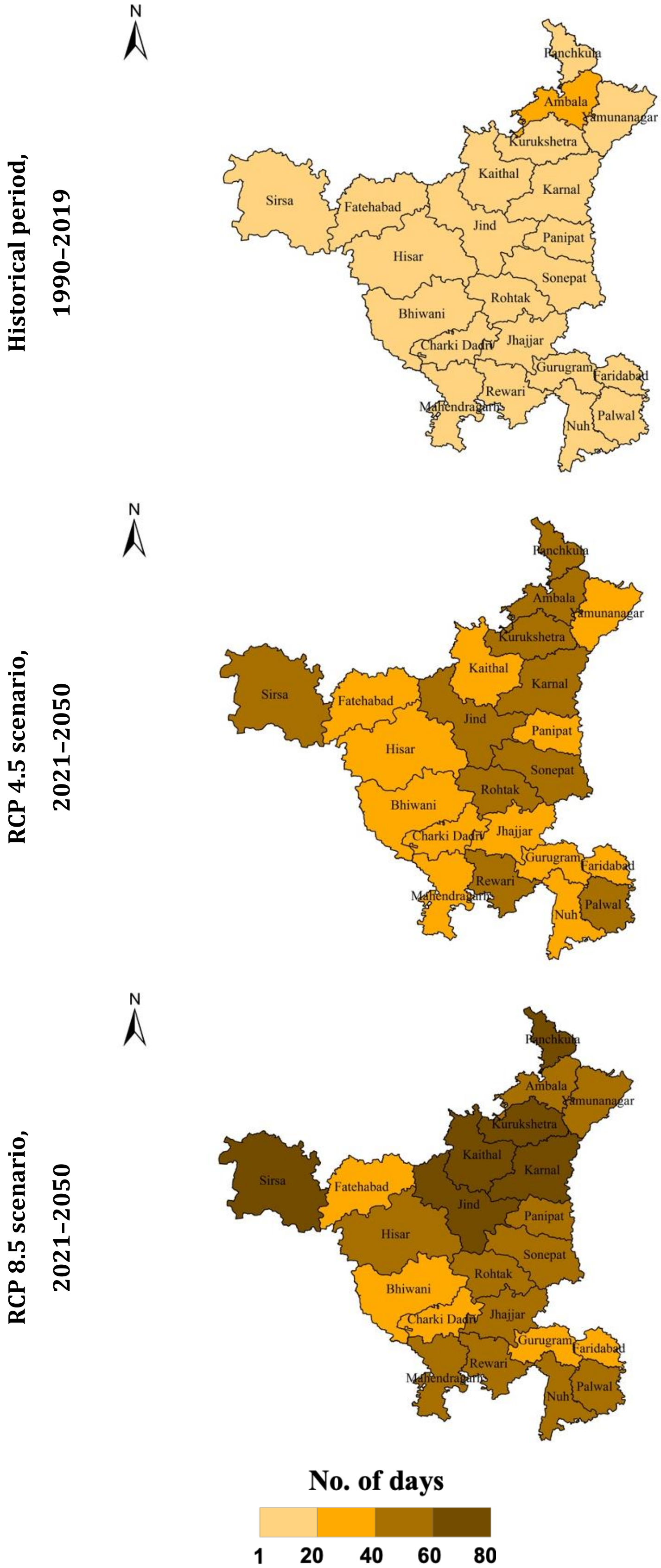


Figure 3-12: The number of very high-intensity rainfall events during historical (1990–2019) and projected periods (the 2030s) under RCP 4.5 and RCP 8.5 scenarios

Rainfall deficient years (Figure 3-13)

Rainfall deficient years, computed considering rainfall during the kharif season, shows a decline in a majority of the districts. The number of rainfall deficient years declines from 9 to 16 years during the historical 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 4 years in 14 of the 22 districts, with no change in eight districts. The projected decline is by 4 years in Rewari, Fatehabad, Jhajjar, Hisar, Nuh, and Sirsa.

RCP 8.5 scenario: The projected decline is by 1 to 4 years in all the districts. The projected decline is by 4 years in Rewari, 3 years in Bhiwani, 2 years in Fatehabad, Jhajjar, Hisar, Sirsa, and Charkhi Dadri, and 1 year in the remaining districts.

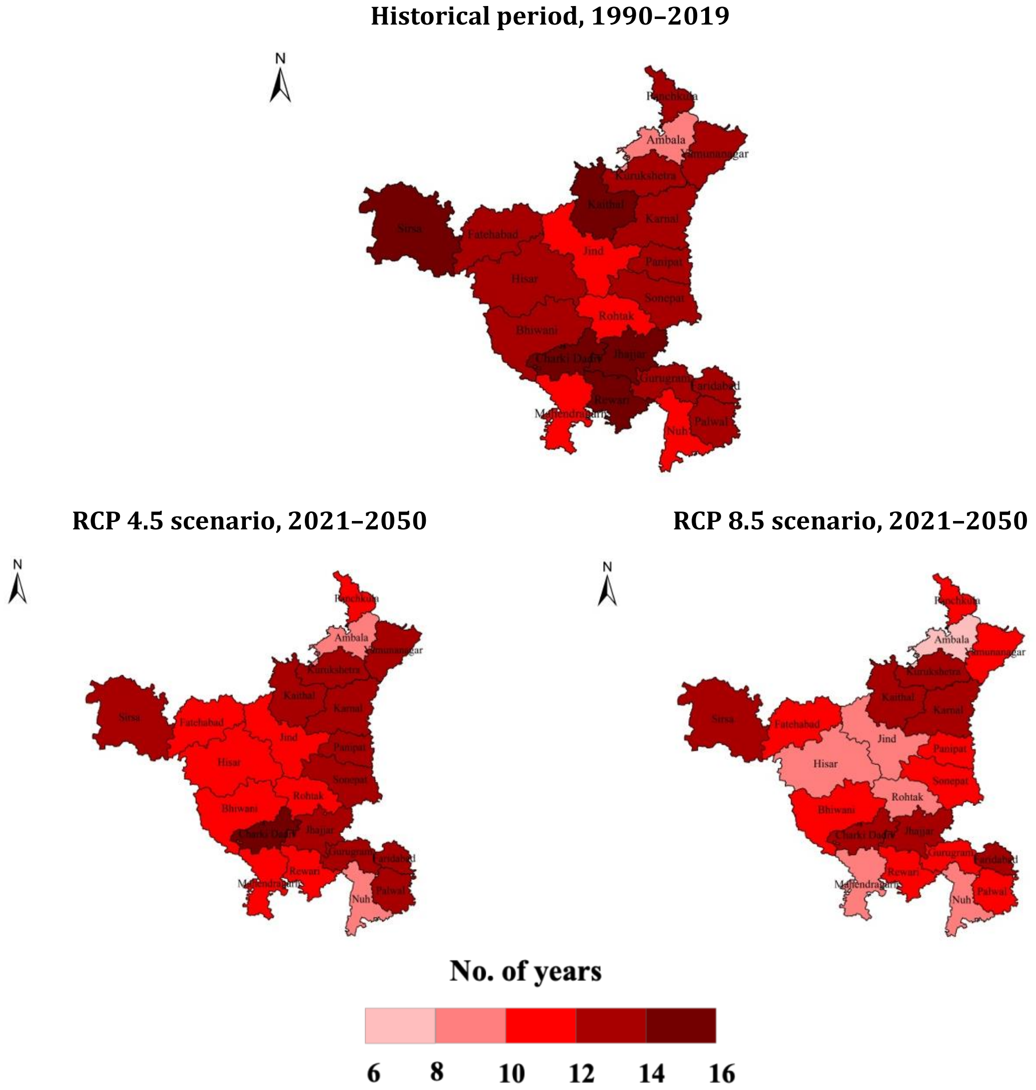


Figure 3-13: The number of rainfall deficient years during historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

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

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

- An increase by 1°C to 2°C in the summer maximum and winter minimum temperatures

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

- There is a notable increase in rainfall in all the districts during kharif and rabi seasons.

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

- Rainfall variability is projected to decline during kharif and rabi seasons. The decline is significant and in the range of 35% to 97% during the rabi season.

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 3-3).

- The increase annually is by 2 to 10 days under the RCP 4.5 scenario and 4 to 11 days under the RCP 8.5 scenario. Under both climate scenarios, the increase in rainy days is highest in the Panchkula district.

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 3-4).

- High-intensity rainfall events are projected to increase by one to two events per annum.
- Very high-intensity rainfall events are projected to increase by one to two events per annum.

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

- The projected decline is by one to four years in 14 districts under RCP 4.5 scenario, and all the districts under RCP 8.5 scenario.

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
Ambala	1.6	1.7	1.1	1.4
Bhiwani	1.2	1.3	1.2	1.3
Charkhi Dadri	1.1	1.3	1.1	1.4
Faridabad	1.2	1.4	1.4	1.7
Fatehabad	1.3	1.5	1.2	1.3
Gurugram	1.1	1.3	1.3	1.5
Hisar	1.3	1.5	1.4	1.5
Jhajjar	1.2	1.3	1.2	1.3
Jind	1.2	1.3	1.5	1.9
Kaithal	1.4	1.7	1.4	1.8
Karnal	1.6	1.6	1.4	1.6
Kurukshetra	1.5	1.7	1.5	1.7
Mahendragarh	1.1	1.4	1.2	1.3
Nuh	1.2	1.5	1.3	1.5
Palwal	1.1	1.4	1.4	1.7
Panchkula	1.7	1.8	1.2	1.3
Panipat	1.3	1.7	1.4	1.8
Rewari	1.1	1.3	1.3	1.5
Rohtak	1.2	1.5	1.4	1.6
Sirsa	1.1	1.4	1.3	1.5
Sonipat	1.2	1.5	1.5	1.8
Yamunanagar	1.6	1.7	1.2	1.6

Appendix 3-2: Changes in rainfall under climate scenarios

Districts	Changes in rainfall (%) during the 2030s (2021–2050 compared to the historical period (1990–2019)					
	Annual rainfall		Kharif season rainfall		Rabi season rainfall	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Ambala	20	24	19	26	8	18
Bhiwani	5	4	7	8	68	118
Charkhi Dadri	14	17	17	24	28	80
Faridabad	23	29	23	26	31	81
Fatehabad	16	26	17	29	44	66
Gurugram	10	12	10	13	22	42
Hisar	16	19	14	21	42	92
Jhajjar	10	15	14	15	10	32
Jind	11	16	7	15	41	69
Kaithal	19	22	19	26	3	17
Karnal	15	19	13	15	13	35
Kurukshetra	22	24	18	28	26	38
Mahendragarh	17	9	16	12	26	14
Nuh	9	14	10	14	5	21
Palwal	16	20	15	20	5	0
Panchkula	14	21	2	9	17	41
Panipat	17	25	17	19	8	21
Rewari	11	17	11	14	17	44
Rohtak	10	13	11	15	15	36
Sirsa	16	18	11	14	22	59
Sonipat	10	16	9	17	38	57
Yamunanagar	19	24	17	19	11	46

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
Ambala	1318	1455	1509
Bhiwani	637	756	850
Charkhi Dadri	664	766	851
Faridabad	895	940	1046
Fatehabad	572	682	769
Gurugram	1049	1189	1216
Hisar	591	671	723
Jhajjar	767	818	900
Jind	633	715	841
Kaithal	808	912	1018
Karnal	992	1091	1174
Kurukshetra	912	1045	1119
Mahendragarh	748	821	911
Nuh	793	928	1001
Palwal	824	980	1046
Panchkula	1493	1789	1830
Panipat	836	911	1075
Rewari	815	997	1076
Rohtak	747	882	980
Sirsa	471	563	669
Sonipat	805	970	1057
Yamunanagar	1064	1116	1213

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
Ambala	83	101	123	27	43	57	9	8	7
Bhiwani	34	63	89	7	24	36	14	11	11
Charkhi Dadri	22	48	90	3	19	30	16	15	13
Faridabad	46	67	93	5	25	32	14	14	13
Fatehabad	19	66	87	2	32	40	14	12	11
Gurugram	48	92	111	1	32	35	14	14	12
Hisar	20	48	72	2	37	44	13	11	10
Jhajjar	36	57	74	1	33	42	16	14	13
Jind	29	86	98	6	41	67	11	11	10
Kaithal	31	80	96	7	34	70	15	14	13
Karnal	38	68	81	4	46	75	14	14	13
Kurukshetra	40	92	105	11	56	68	14	14	13
Mahendragarh	23	78	96	2	35	42	12	11	10
Nuh	20	46	89	5	31	50	12	10	10
Palwal	53	80	96	7	48	52	13	13	12
Panchkula	91	98	118	16	45	65	13	12	11
Panipat	46	65	95	7	36	43	13	13	12
Rewari	46	78	92	6	45	60	15	11	11
Rohtak	36	66	89	3	45	56	12	11	10
Sirsa	16	67	80	1	44	67	16	14	13
Sonipat	49	70	105	8	46	54	14	13	12
Yamunanagar	74	112	134	17	30	42	13	13	12

4. Himachal Pradesh

Himachal Pradesh is a mountainous state situated in the western Himalayas. It has a geographical area of 55,673 sq. km and a population of 6.86 million, according to the 2011 Census, which is predominantly rural. Himachal Pradesh is bordered by Jammu and Kashmir in the north, Punjab in the west, Haryana in the south, and Uttarakhand in the south-west. It also has an international border with China in the east. Snow, glaciers, and cold deserts permanently cover about one third of the area in the state. The average annual rainfall of the state is about 1,800 mm, feeding a drainage system composed of both glaciers and perennial rivers. About 25% of the state is covered by biodiverse forests and 33% by permanent pastures and grazing lands, which support a total livestock population of 4.84 million (Livestock Census, 2012). Only about 12% is under crop production.

The state exhibits great variation in geo-climatic conditions, ranging from cold, alpine, and glacial in the northern and eastern mountain ranges to hot and sub-humid tropical in the southern tracts. This is due to an extreme variation in elevation that ranges from 350 m to 6000 m. These conditions make the state prone to various hazards, including earthquakes, landslides, flash floods, cloudbursts, snowstorms, avalanches, and droughts. Most of these hazards have severe implications such as loss and damage of built infrastructure, particularly residential houses that are predominantly *kutcha* (built with clay mud, unburnt bricks, or random rubble masonry).

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

4.1. Historical climate

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

4.1.1. Trends in temperature

Himachal Pradesh recorded a warming of 0.21°C to 0.75°C in the summer maximum temperature and 0.25°C to 0.55°C in the winter minimum temperature during the historical period. Figure 4-1 presents the mean summer maximum and winter minimum temperatures in Himachal Pradesh during the historical period.

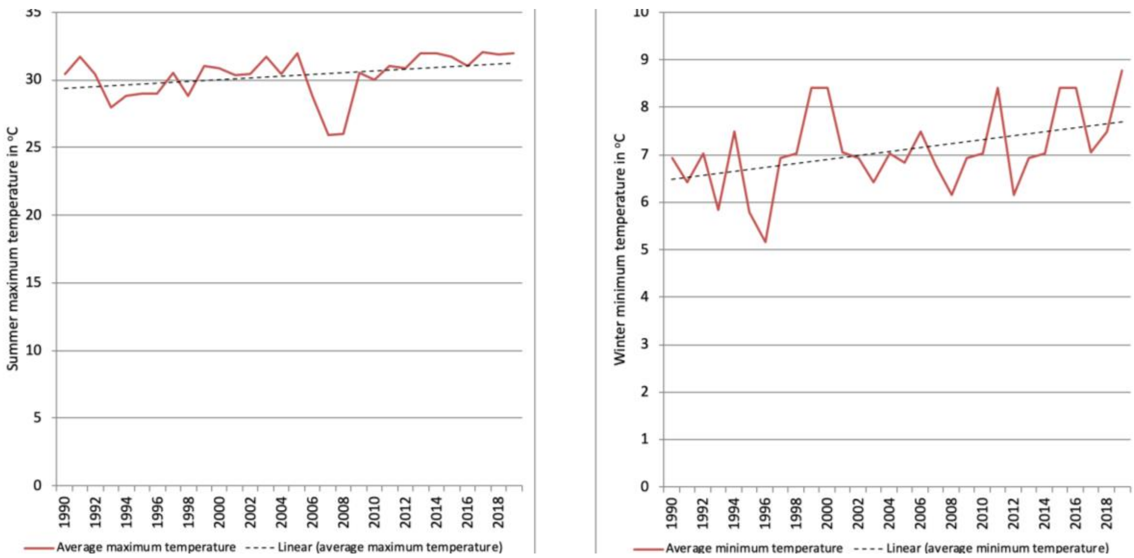


Figure 4-1: Mean summer maximum and winter minimum temperatures in Himachal Pradesh during the historical period (1990–2019)

4.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and the kharif season rainfall, of up to 15%, was recorded during the historical period. The increase in kharif season rainfall was greater than 10% in the western and southern districts of Chamba, Kangra, Sirmaur, Solan, Una, and Hamirpur. Figure 4-2 presents the mean annual rainfall in Himachal Pradesh during the historical period.

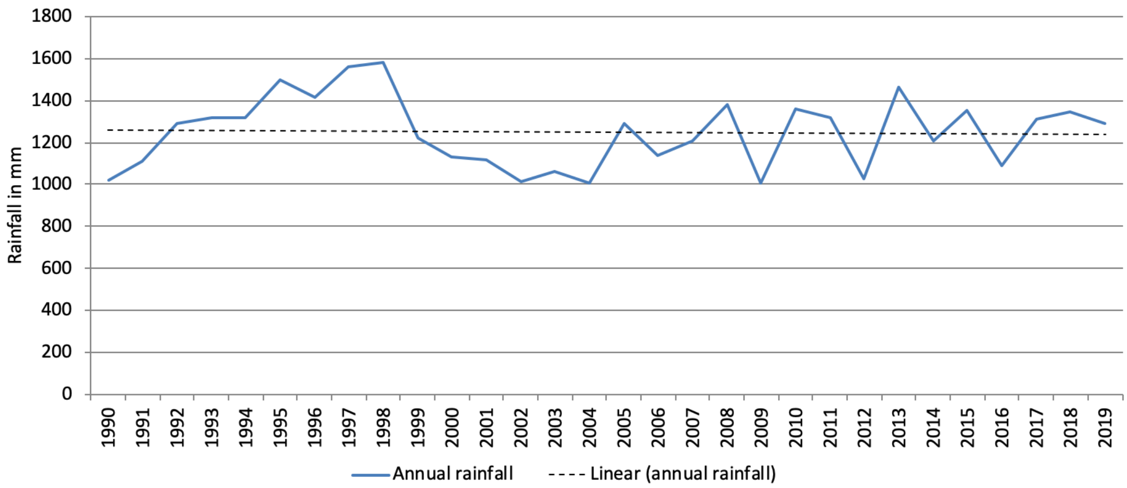


Figure 4-2: Mean annual rainfall in Himachal Pradesh during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 22% in Una to 52% in the Kinnaur district (Figure 4-3). During the rabi season, the variability of rainfall was larger and ranged from 77% in Lahaul and Spiti to >100%, indicating a total failure of rainfall in Bilaspur, Chamba, Sirmaur, Solan, and Una districts (Figure 4-3).

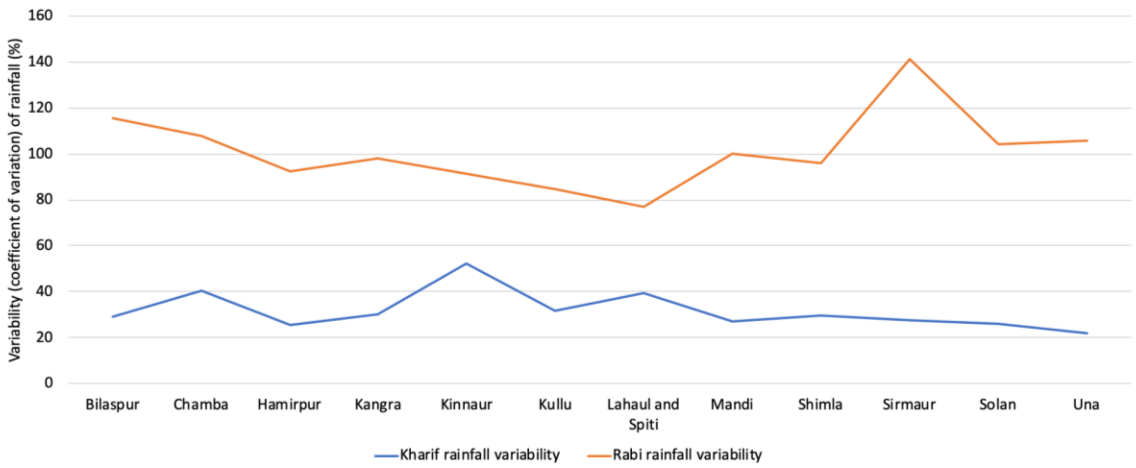


Figure 4-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

4.2. Climate change projections

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

4.2.1. Temperature projections

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

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

Climate scenarios	Summer maximum	Winter minimum
RCP 4.5	Increases by 1°C to 1.5°C	Increases by 1°C to 1.5°C
RCP 8.5	Increases by 1°C to 2°C	Increases by 1°C to 2°C

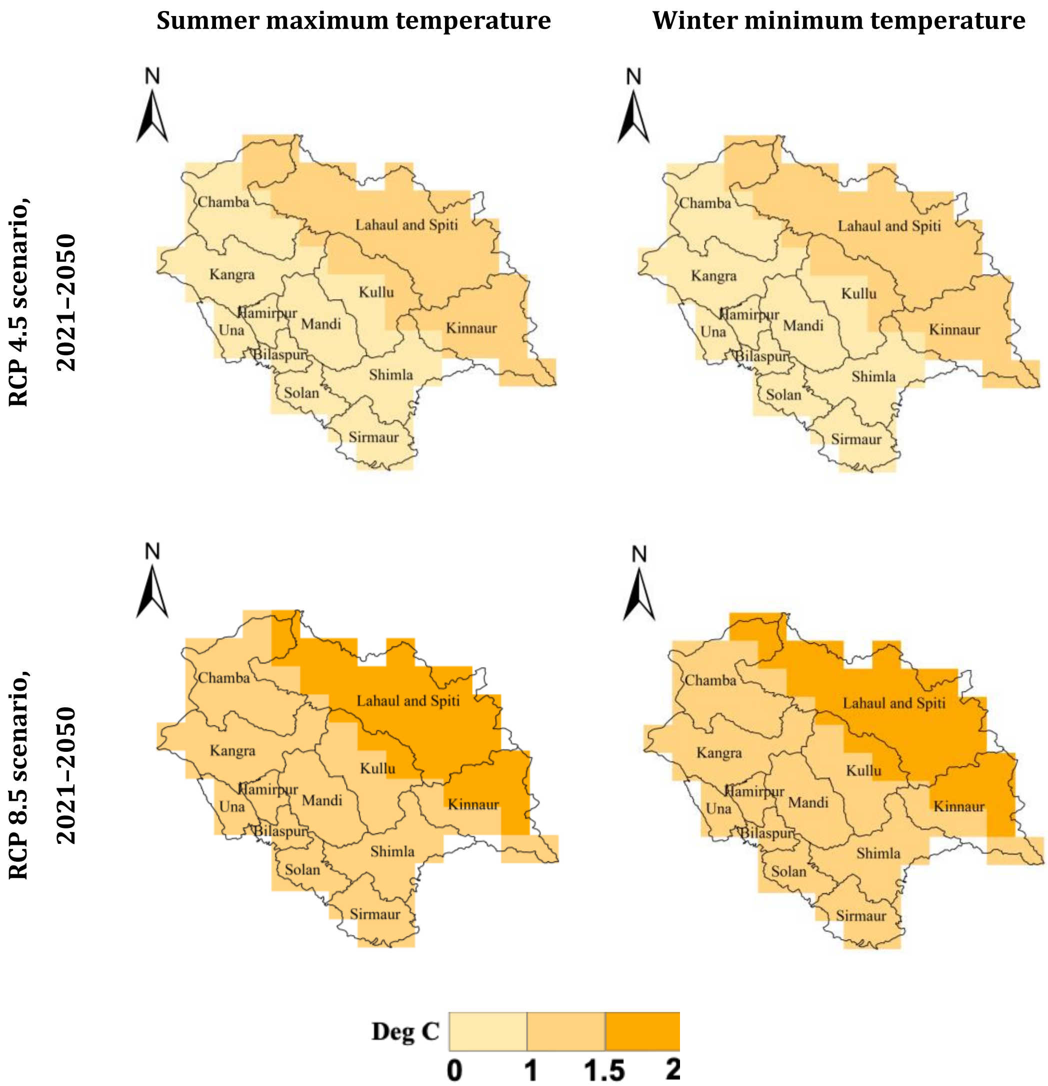


Figure 4-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

4.2.2. Rainfall projections

4.2.2.1. Number of rainy days

According to the India Meteorological Department, 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 4-5). The number of rainy days during the historical period and the projected 2030s under both RCP 4.5 and 8.5 scenarios is presented in Appendix 4-3. The total number of rainy days that ranged from 907 to 2006 days over the historical period increases to 934 to 2045 days under the RCP 4.5 scenario and 986 to 2098 days under the RCP 8.5 scenario during the projected 2030s. The increase per annum is as follows:

RCP 4.5 scenario: The projected increase is by 1 to 2 days annually in nine of the 12 districts. There is no change in Mandi, Sirmaur, and Hamirpur. The increase per annum is by 2 days in Una and Chamba and 1 day in the remaining seven districts.

RCP 8.5 scenario: The projected increase is by 1 to 3 days annually in eight of the 12 districts. There is no change in Sirmaur, Mandi, Lahaul and Spiti, and Shimla. The increase per annum is by 3 days in Chamba, 2 days in Una and Solan, and 1 day in Kinnaur, Hamirpur, Kangra, Bilaspur, and Kullu.

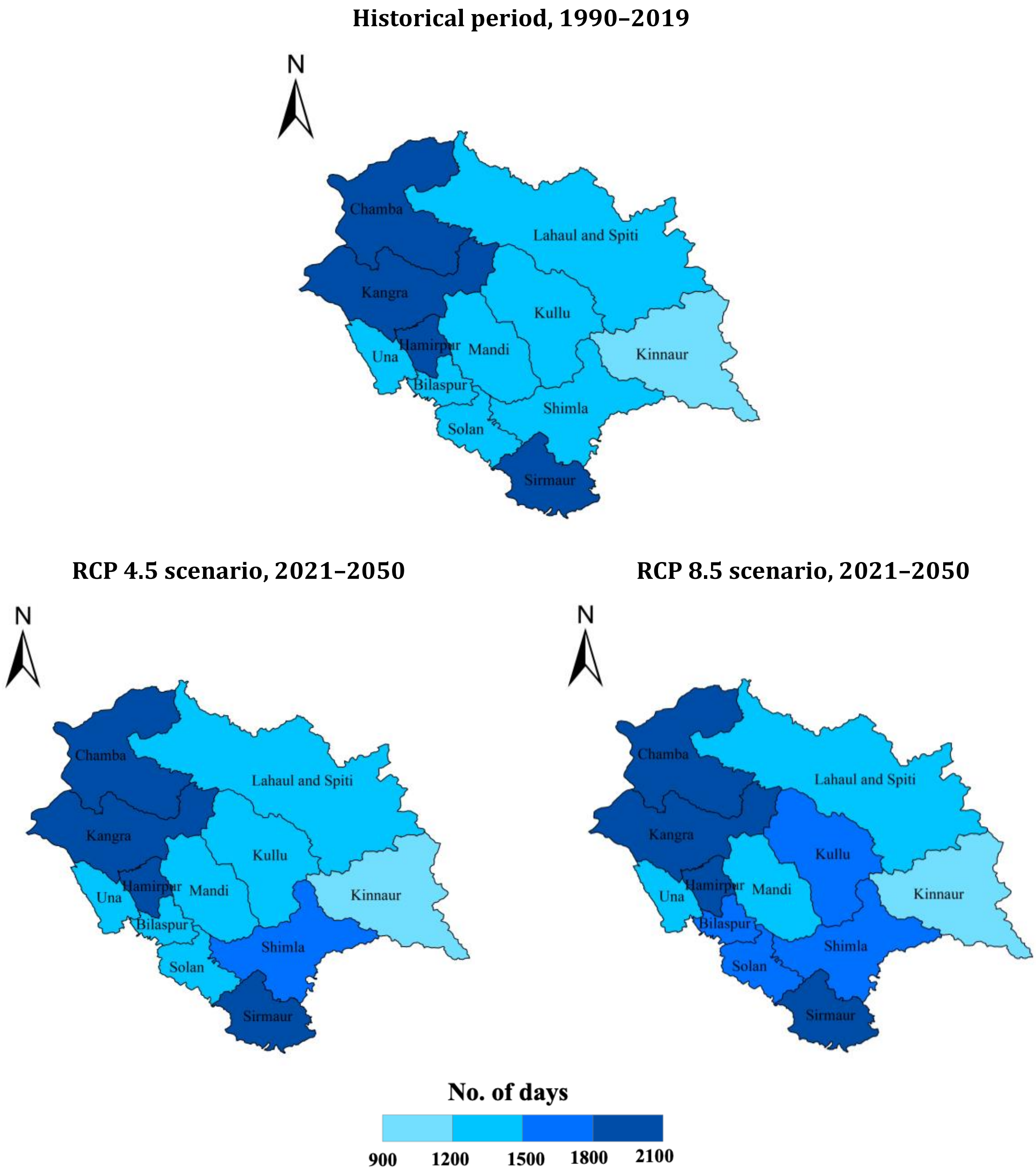


Figure 4-5: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

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 4-6 presents district-wise changes in the kharif season rainfall, and Figure 4-7 presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 7% in Bilaspur to 17% in Shimla	Declines in Chamba and Kinnaur districts by 3% to 4% and increases in 10 districts by 2% to 11%
RCP 8.5	Increases in all the districts, from 12% in Bilaspur to 22% in Shimla and Una	Declines in Chamba and Kinnaur districts by 13% and increases in 10 districts by 1% to 11%

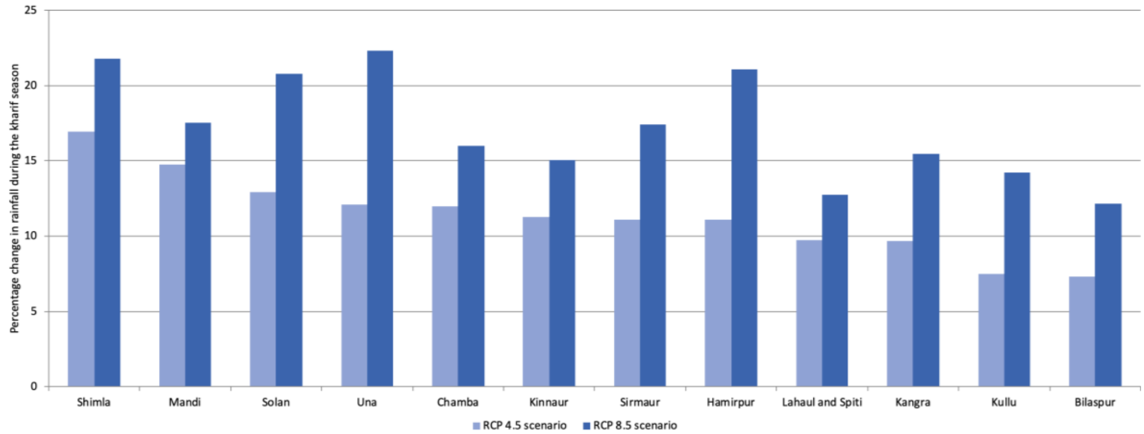


Figure 4-6: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

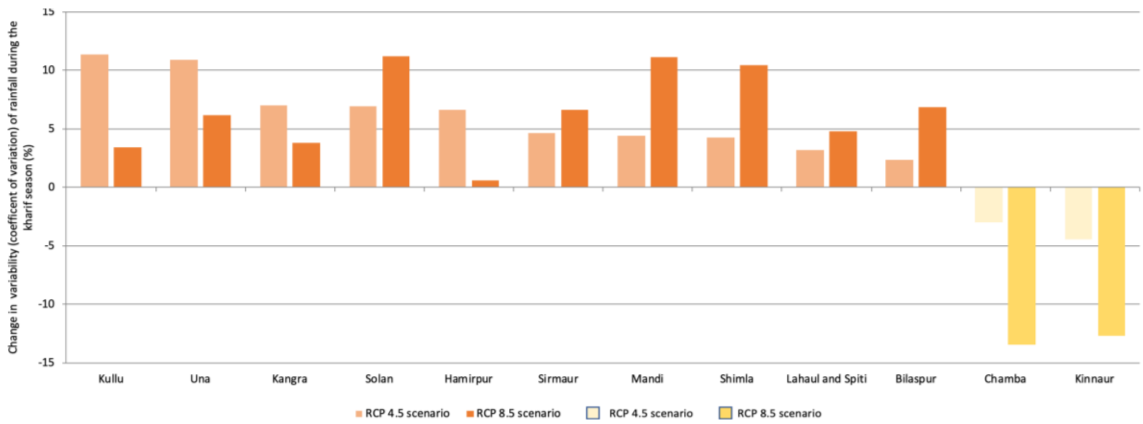


Figure 4-7: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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 4-8 presents district-wise changes in the rabi season rainfall, and Figure 4-9 presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 57% in Lahaul and Spiti to 97% in Kullu	Declines in all the districts by 14% to 95%
RCP 8.5	Increases in all the districts, from 21% in Kullu to 62% in Una	Declines in all the districts by 19% to 85%

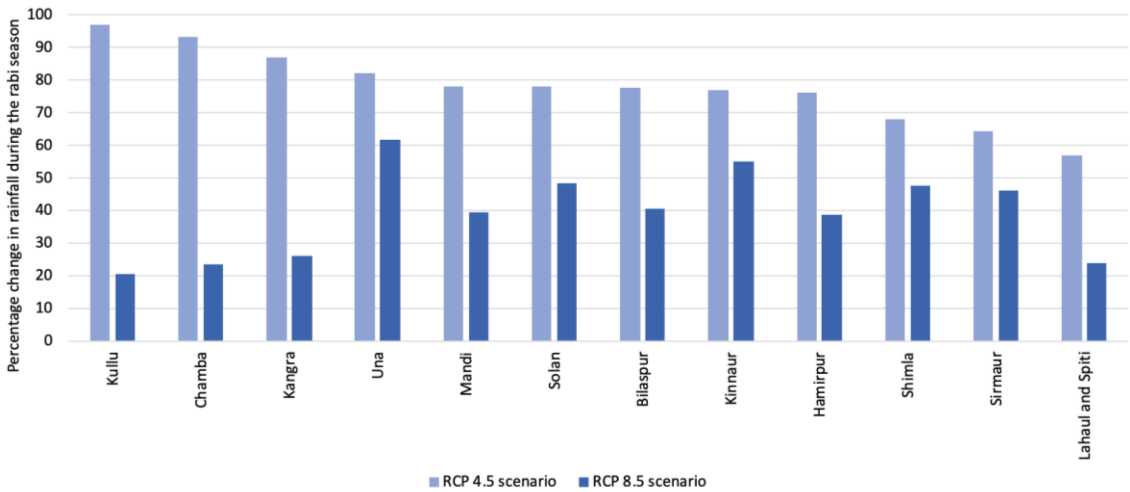


Figure 4-8: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

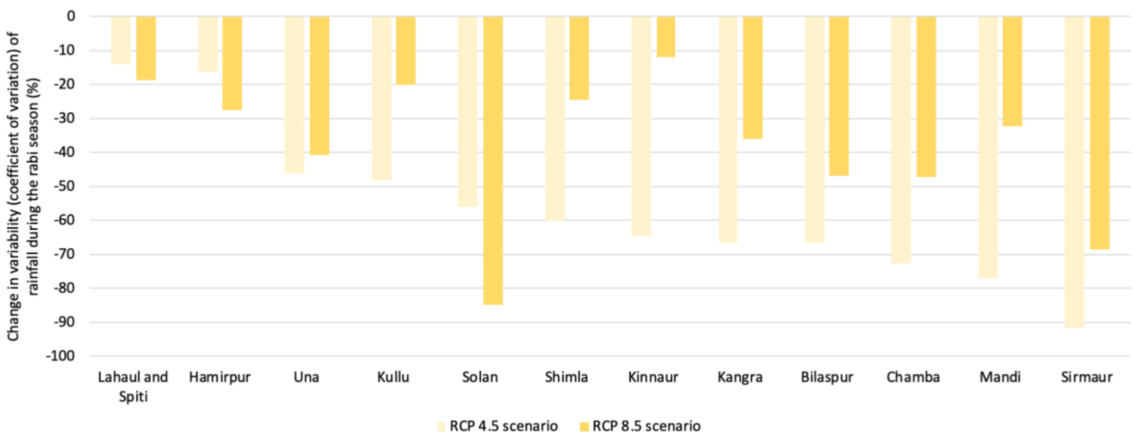


Figure 4-9: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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 Himachal Pradesh.

High-intensity rainfall events (Figure 4-10)

The total number of high-intensity rainfall events increases from 9 to 169 days during the historical period (1990–2019) to 32 to 185 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 25 to 204 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: An increase in high-intensity rainfall events is projected in five of the 12 districts. The increase per annum is by two events in Kangra and one event in Una, Bilaspur, Chamba, and Solan. No change is projected in the remaining districts.

RCP 8.5 scenario: An increase in high-intensity rainfall events is projected in all the districts except Mandi, where no change is projected. The increase per annum is by two events in Kangra and one event in Lahaul and Spiti, Hamirpur, Una, Kullu, Kinnaur, Sirmaur, Shimla, Solan, Chamba, and Bilaspur.

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

The total number of very high-intensity rainfall events increases from 1 to 42 days during the historical period (1990–2019) to 10 to 67 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 19 to 72 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: An increase in very high-intensity rainfall events is projected in all the districts, in the range of one to two events per annum. The increase per annum is by two events in Mandi, Bilaspur, Una, Solan, Sirmaur, Hamirpur, and Shimla and one event in Kullu, Kinnaur, Chamba, Lahaul and Spiti, and Kangra.

RCP 8.5 scenario: An increase in very high-intensity rainfall events is projected in all the districts, in the range of two to three events per annum. The increase per annum is by three events in Hamirpur, Kinnaur, Mandi, Solan, Kullu, Sirmaur, Kangra, Una, and Shimla and two events in Bilaspur, Lahaul and Spiti, and Chamba.

Rainfall deficient years (Figure 4-11)

Rainfall deficient years, computed considering rainfall during the kharif season, show largely a decline in a majority of the districts. The number of rainfall deficient years declines from 10 to 16 years during the historical period to 9 to 16 years under the RCP 4.5 scenario and 8 to 14 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: A decline is projected in seven of the 12 districts by 1 to 3 years. No change is projected in the remaining five districts. The increase is by 3 years in Kullu and Chamba and 1 year in Kangra, Kinnaur, Shimla, Sirmaur, and Solan. RCP 8.5 scenario: A decline is projected in all the districts, except Hamirpur (no change), by 1 to 4 years. The increase is by 4 years in Kullu and Chamba; 3 years in Shimla; 2 years in Kangra, Kinnaur, Solan, and Lahaul and Spiti; and 1 year in Sirmaur, Bilaspur, Mandi, and Una.

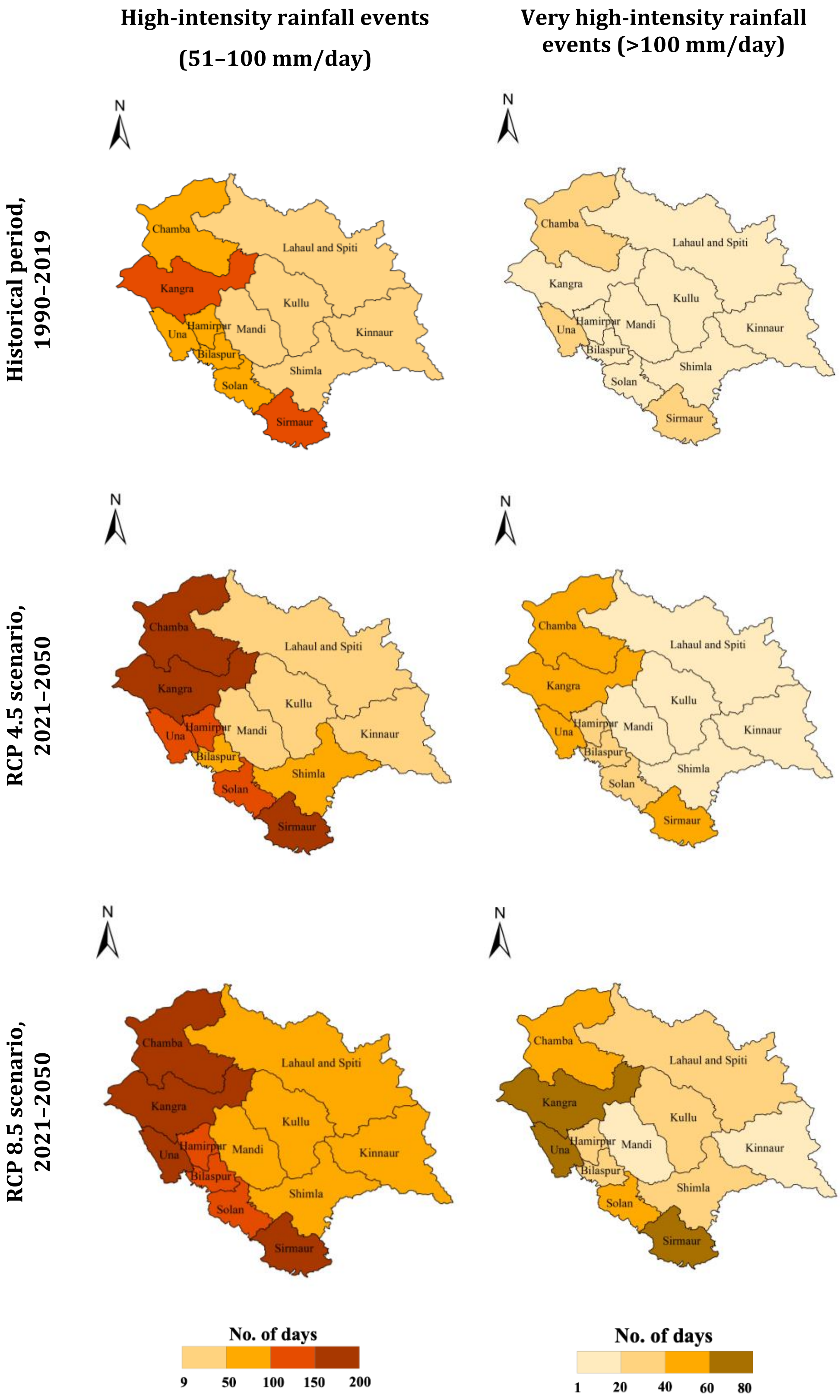


Figure 4-10: The total number of high-intensity and very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

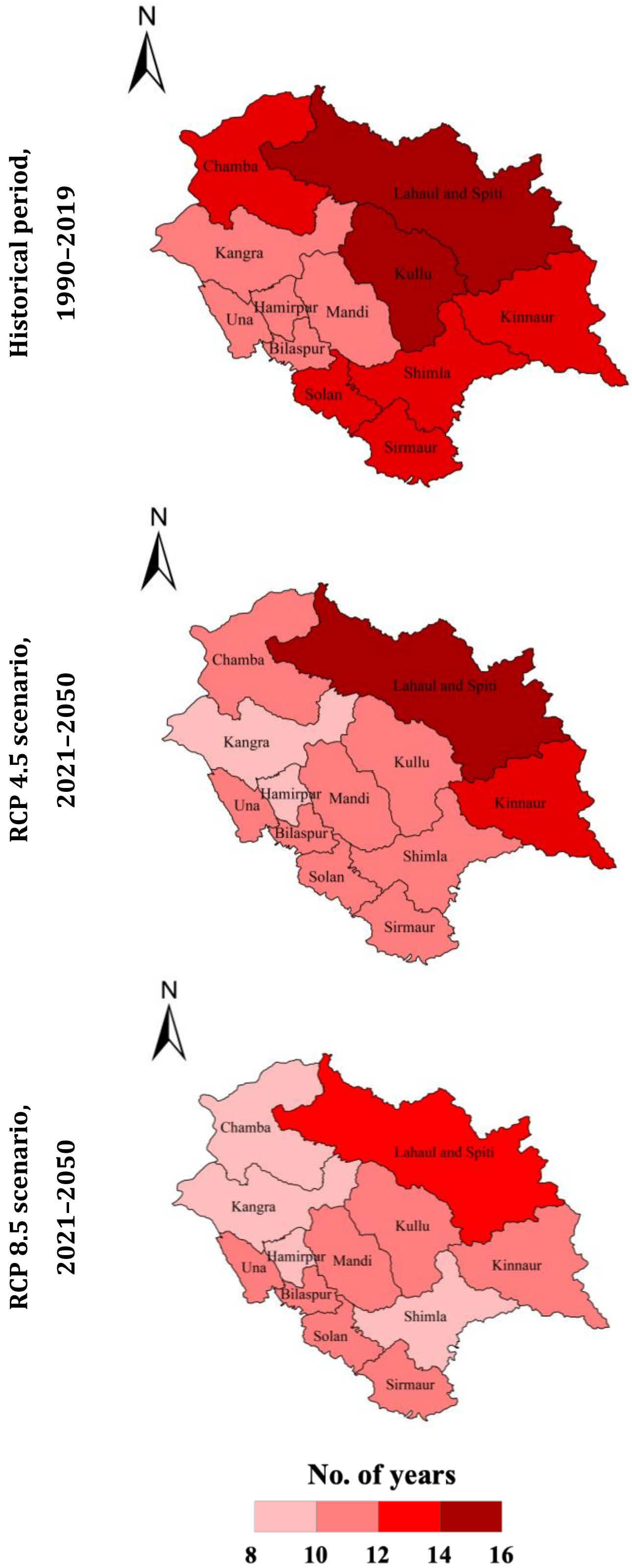


Figure 4-11: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

4.4. The summary of projected changes in the climate for Himachal Pradesh

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

- Both summer maximum and winter minimum temperatures are projected to increase by 1°C to 1.5°C under the RCP 4.5 scenario and 1°C to 2°C under the RCP 8.5 scenario.

Rainfall is projected to increase in the short term (2021–2050) in all the districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 4-2).

- The projected increase is in the range of 7% to 17% under the RCP 4.5 scenario and 12% to 22% under the RCP 8.5 scenario.

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

- An increase in rainfall variability during the kharif season is projected for all the districts except Chamba and Kinnaur.
- A decline in rainfall variability during the rabi season is projected for all the districts.

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

- The projected increase is in the range of 1 to 2 days under the RCP 4.5 scenario and 1 to 3 days under the RCP 8.5 scenario. No change is projected in Mandi and Sirmaur, and a maximum increase is projected in Chamba under both climate scenarios.

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

- Very high-intensity rainfall events are projected to increase by two to three events per annum under the RCP 8.5 scenario and one to two events per annum in all the districts under the RCP 4.5 scenario.

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

- The projected decline is by one to three years in seven districts under RCP 4.5 scenario and one to four years in all the districts under RCP 8.5 scenario.

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
Bilaspur	0.8	0.9	0.7	0.9
Chamba	5.0	1.5	1.2	1.3
Hamirpur	0.8	1.0	0.8	1.0
Kangra	0.6	0.9	0.7	0.9
Kinnaur	1.2	1.5	1.3	1.7
Kullu	0.9	1.5	1.2	1.3
Lahaul and Spiti	1.2	1.9	1.3	1.6
Mandi	0.9	1.2	0.7	0.8
Shimla	0.8	1.4	0.7	0.9
Sirmaur	0.8	0.9	0.8	1.0
Solan	0.6	0.8	0.8	0.9
Una	0.8	0.9	0.8	1.0

Appendix 4-2: Changes in rainfall under climate scenarios

Districts	Changes in rainfall (%) during the 2030s (2021–2050) compared to the historical period (1990–2019)					
	Annual rainfall		Kharif season rainfall		Rabi season rainfall	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bilaspur	12	17	7	12	78	41
Chamba	32	39	12	16	93	23
Hamirpur	5	6	11	21	76	39
Kangra	31	32	10	15	87	26
Kinnaur	12	14	11	15	77	55
Kullu	16	20	7	14	97	21
Lahaul and Spiti	8	13	10	13	57	24
Mandi	3	7	15	18	78	40
Shimla	2	6	17	22	68	47
Sirmaur	6	9	11	17	64	46
Solan	18	21	13	21	78	48
Una	13	17	12	22	82	62

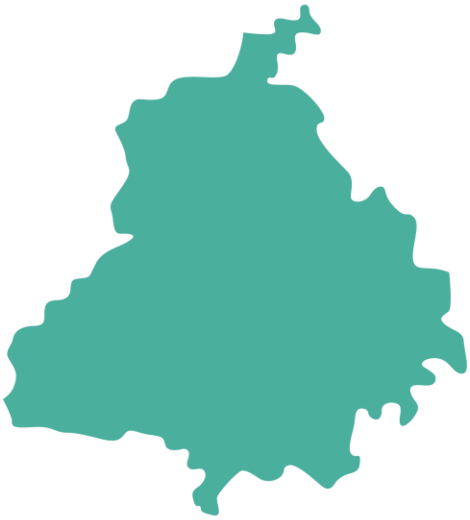
Appendix 4-3: The total number of rainy days (>2.5 cm/day) during the historical period (1990–2019) and the projected 2030s (2021–2050)

Districts	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Bilaspur	1441	1488	1512
Chamba	1938	1976	1998
Hamirpur	1802	1856	1877
Kangra	2006	2045	2098
Kinnaur	907	934	986
Kullu	1451	1476	1532
Lahaul and Spiti	1340	1378	1402
Mandi	1411	1457	1490
Shimla	1480	1543	1580
Sirmaur	1913	1964	1998
Solan	1441	1490	1521
Una	1384	1432	1480

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
Bilaspur	70	95	105	6	33	38	12	12	11
Chamba	96	154	187	22	48	54	14	11	10
Hamirpur	98	112	123	14	24	30	10	10	10
Kangra	169	185	204	19	67	72	10	9	8
Kinnaur	9	32	25	1	12	20	14	13	12
Kullu	21	43	61	2	11	21	15	12	11
Lahaul and Spi	14	34	27	8	20	23	16	16	14
Mandi	34	44	46	6	12	19	12	12	11
Shimla	33	54	47	2	10	23	13	12	10
Sirmaur	158	171	167	42	51	62	13	12	12
Solan	75	115	122	13	35	40	13	12	11
Una	90	135	142	22	51	40	12	12	11

5. Punjab



The state of Punjab is situated in north-western India. It is bordered by Pakistan in the west, Jammu and Kashmir in the north, Himachal Pradesh in the east, and Haryana and Rajasthan in the south. According to the 2011 Census, it has a geographical area of 50,362 sq. km and a population of 27.74 million, which is distributed among 22 districts. The state has tropical, semi-arid, hot, and subtropical monsoon type climates, with cold winters and hot summers. The temperature varies from 0°C to 47°C, and the annual rainfall ranges between 480 mm and 960 mm.

Punjab is endowed with fertile alluvial lands, and almost 82% of its total geographical land is under cultivation, making it one of the top food producers in the country. Forests cover only 5%. Because of intensive cropping of paddy and wheat across the state, soil and water resource degradation is prevalent. In the south-western districts of the state, groundwater resources are brackish or saline, making them unfit for any use. The non-extraction of groundwater in these districts is leading to an increase in the groundwater table, causing waterlogging. The state is also prone to loss and damage by hazards such as earthquakes, floods, droughts, hailstorms, and heat and cold waves.

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

5.1. Historical climate

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

5.1.1. Trends in temperature

Punjab recorded a warming of 0.3°C to 0.75°C in the summer maximum temperature and 0.14°C to 0.34°C in the winter minimum temperature during the historical period. Figure 5-1 presents the mean summer maximum and winter minimum temperatures in Punjab during the historical period.

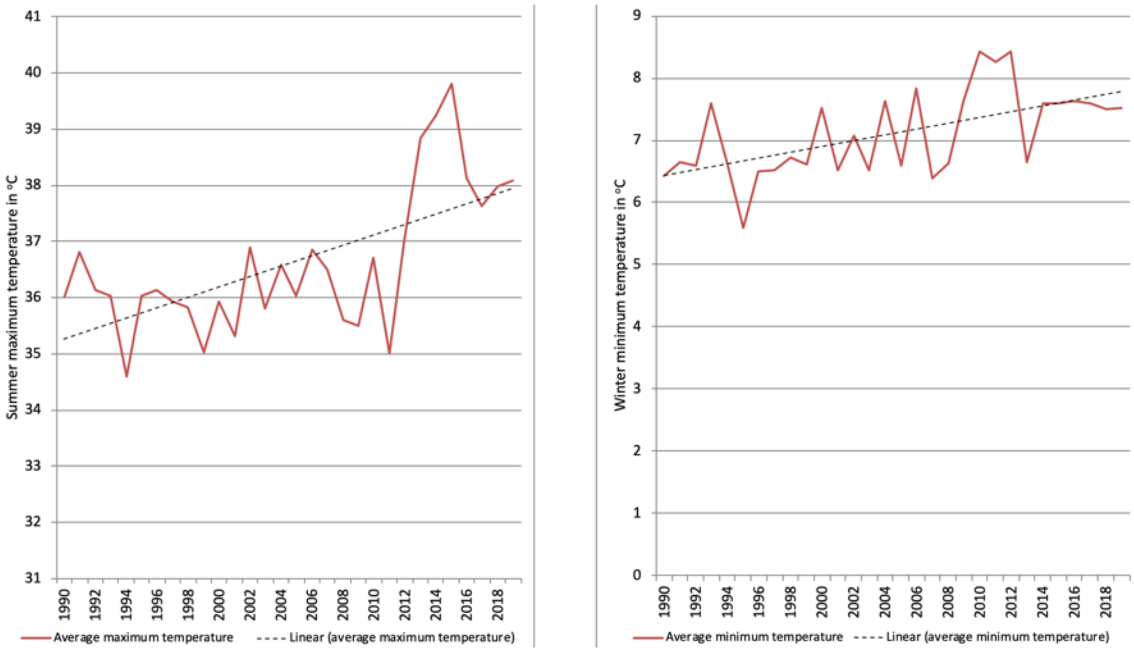


Figure 5-1: Mean summer maximum and winter minimum temperatures in Punjab during the historical period (1990–2019)

5.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and kharif season rainfall, in the range of 5% to 10%, was recorded during the historical period. Figure 5-2 presents the mean annual rainfall in Punjab during the historical period.

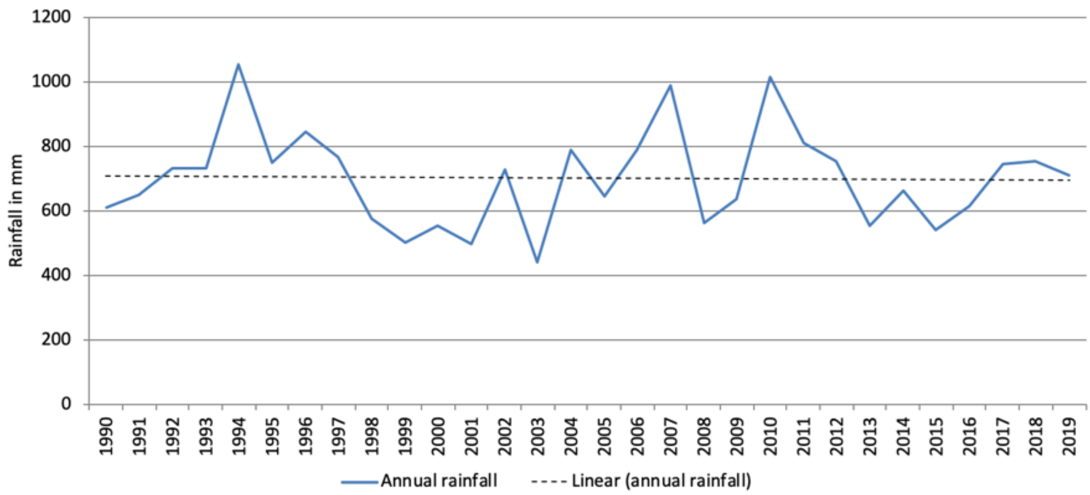


Figure 5-2: Mean annual rainfall in Punjab during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 30% in Patiala to 69% in Ferozepur (Figure 5-3). The variability of rainfall during the rabi season was high and >100% in a majority of the districts—an indication of the total failure of rainfall during the season (Figure 5-3).

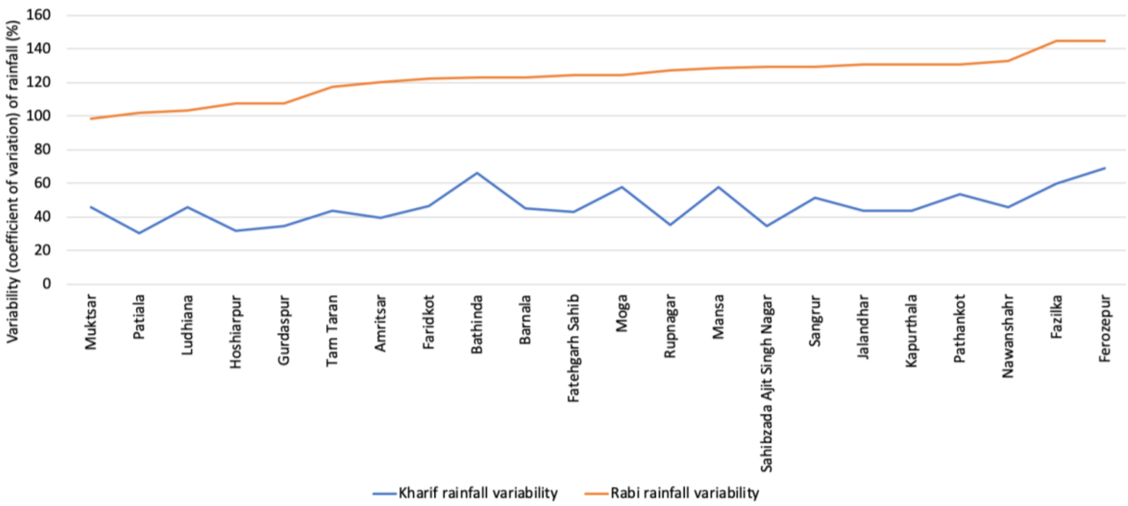


Figure 5-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

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

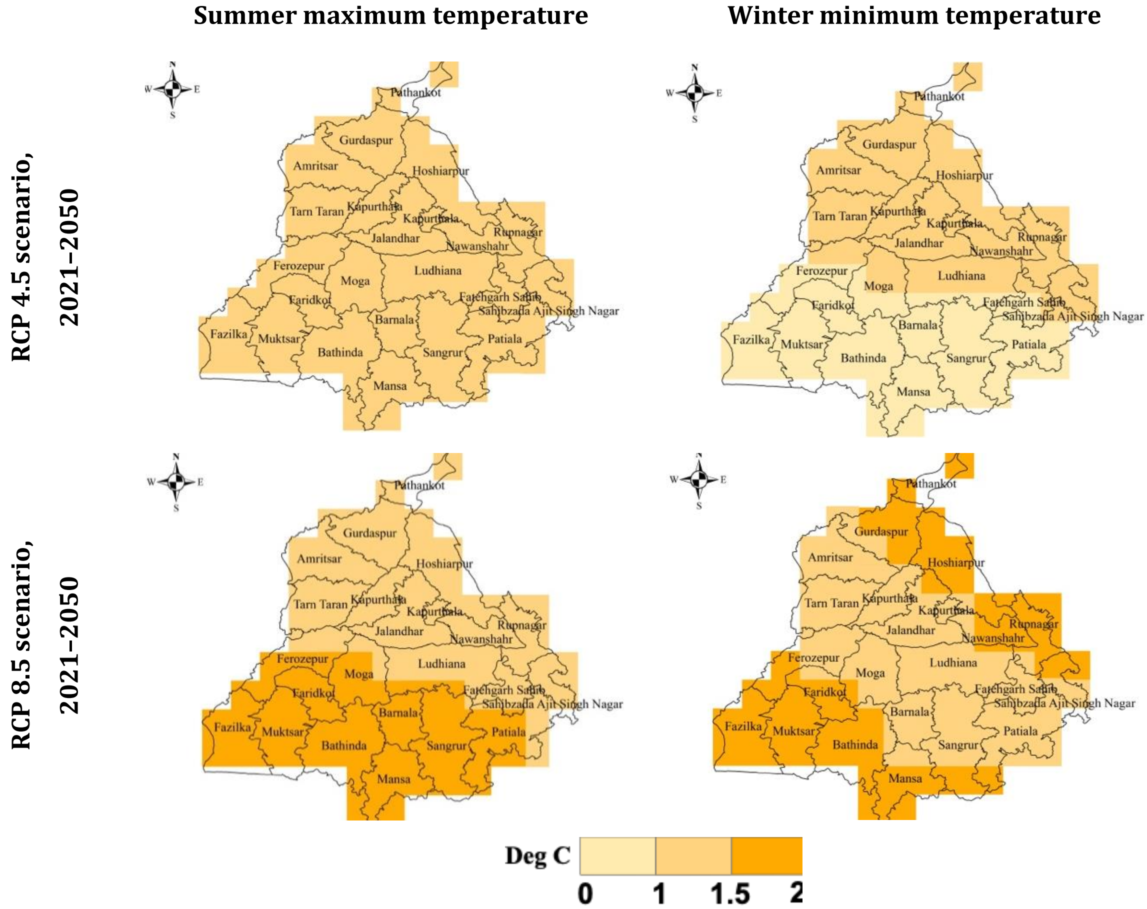


Figure 5-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

5.2.1.1. Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 1, a heatwave analysis of the Ludhiana 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 2030s shows that there would be a decline in the number of days recording 'High' temperatures. However, the number of days likely to record 'Very High' temperatures, as categorised by the India Meteorological Department (IMD), will increase under both RCP 4.5 and RCP 8.5 scenarios (Figure 5-5).

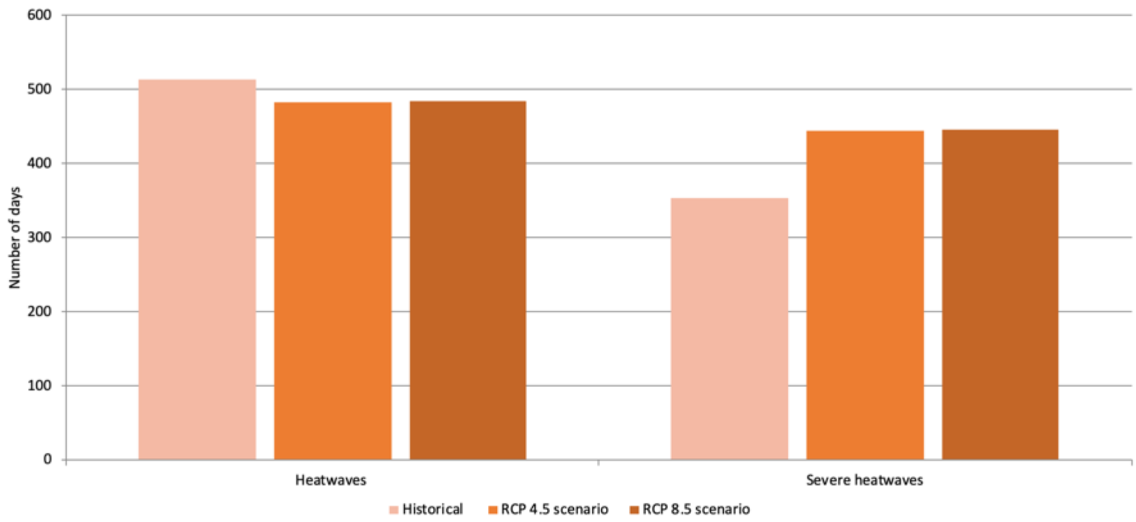


Figure 5-5: The number of heatwaves during the historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

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. The total number of rainy days that ranged from 396 to 1363 days over the 30-year historical period increases to 560 to 1521 days under the RCP 4.5 scenario and 630 to 1585 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 8 days annually in all the districts. The increase is by 8 days in Pathankot; 5 days in Fazilka; 4 days in Bathinda, Faridkot, Ferozepur, Mansa, and Sangrur; 3 days in Barnala, Gurdaspur, Jalandhar, Kapurthala, and Moga; and 1 to 2 days in the remaining districts.

RCP 8.5 scenario: Projected to increase by 1 to 10 days annually in all the districts. The increase is by 10 days in Pathankot; 8 days in Fazilka; 7 days in Sangrur; 6 days in Mansa, Faridkot, and Bathinda; 5 days in Barnala, Fatehgarh Sahib, Ferozepur, Kapurthala, Moga, and Muktsar; and 1 to 4 days in the remaining districts.

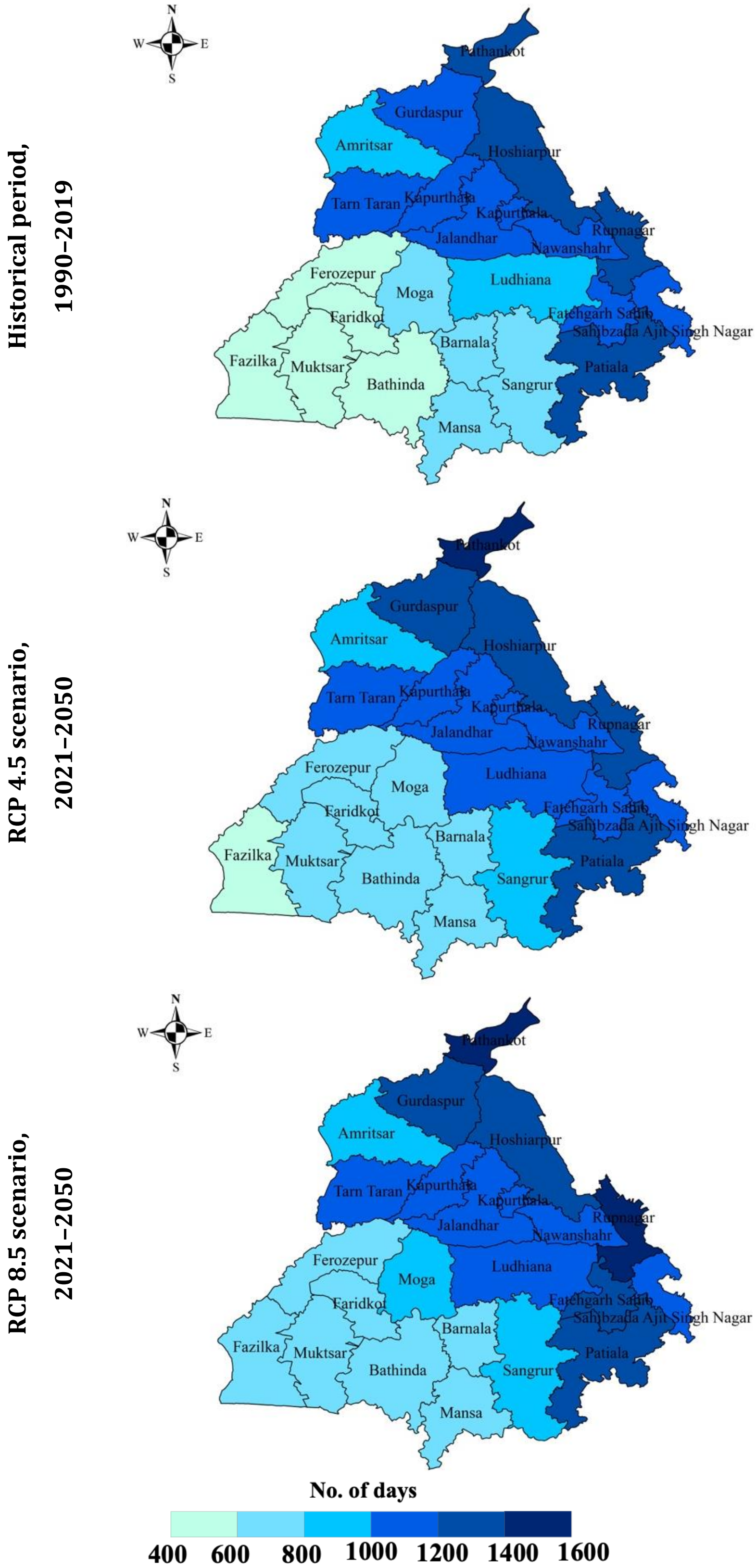


Figure 5-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

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 (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 Fatehgarh Sahib to 39% in Pathankot	Declines in all the districts by 1% to 25%
RCP 8.5	Increases in all the districts, from 9% in Fatehgarh Sahib to 46% in Sahibzada Ajit Singh Nagar and Pathankot	Declines in all the districts by 5% to 32%

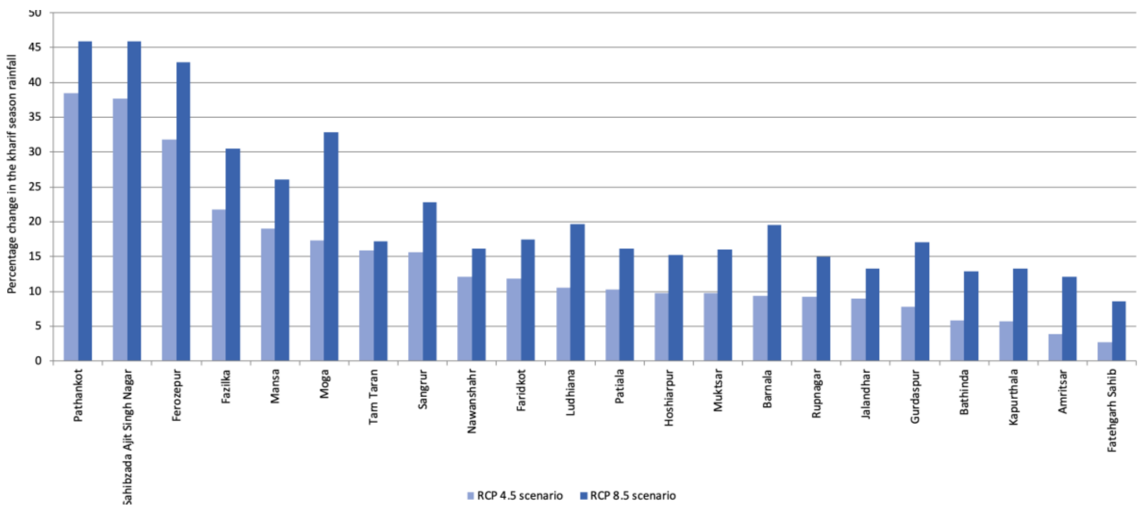


Figure 5-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

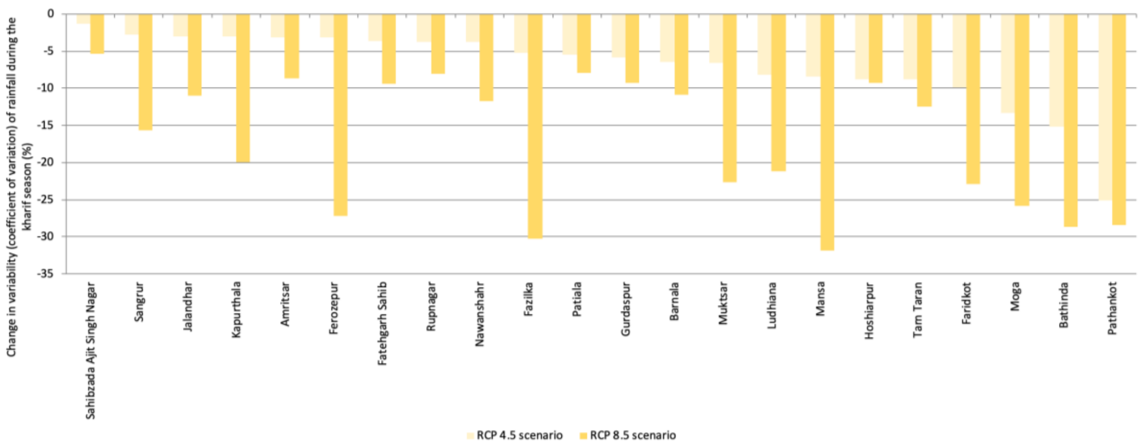


Figure 5-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

5.2.2.3. Mean rainfall and rainfall variability during the kharif season

The rabi season rainfall is projected to increase in all the districts under both climate scenarios. Figure 5-9 presents district-wise changes in the rabi season rainfall, and Figure 5-10 presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 2% in Patiala to 28% in Moga, Jalandhar, and Ferozepur	Declines in all the districts by 33% to 83%
RCP 8.5	Increases in all the districts, from 19% in Kapurthala to 75% in Sangrur	Declines in all the districts by 37% to 87%

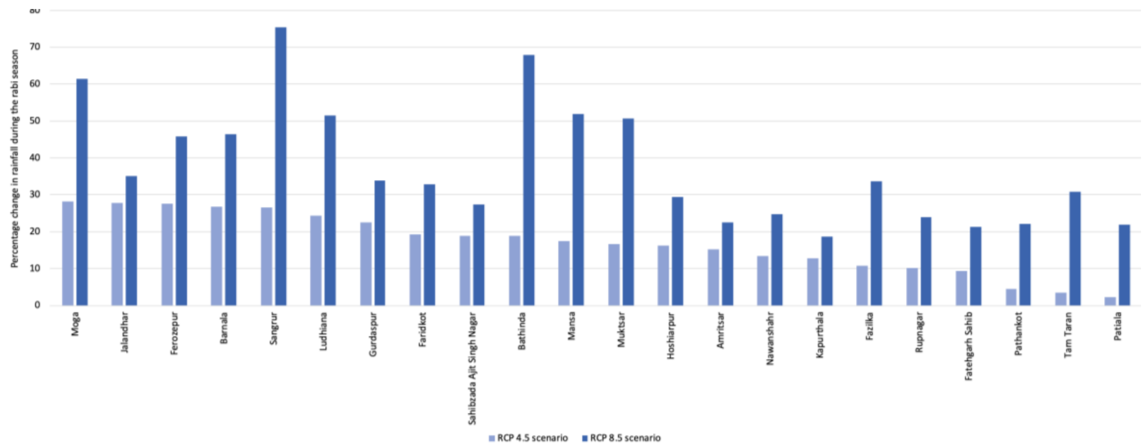


Figure 5-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

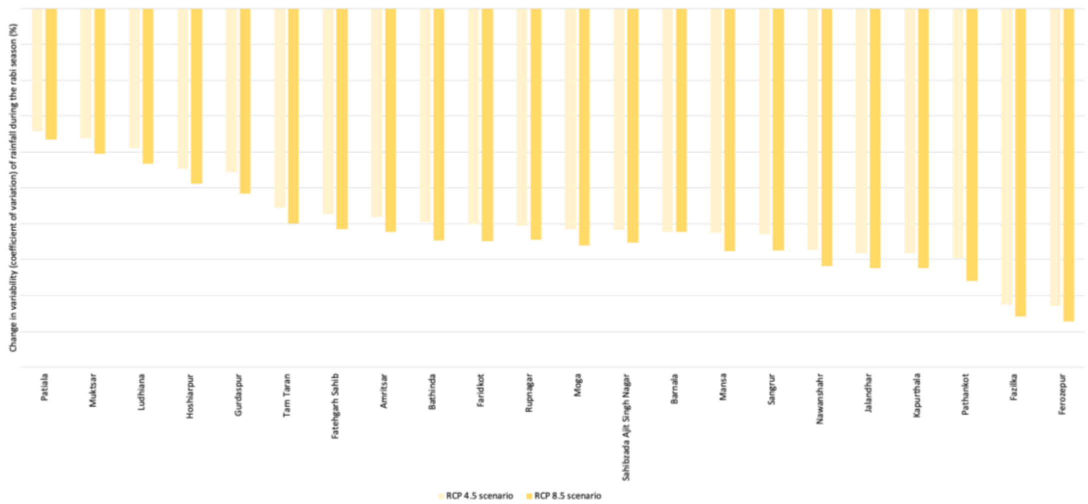


Figure 5-10: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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

High-intensity rainfall events (**Figure 5-11**)

The total number of high-intensity rainfall events increases from 12 to 95 days during the historical period (1990–2019) to 62 to 156 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 70 to 189 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 four events in all the districts, except Nawanshahr and Patiala. The increase is by four events in Muktsar and Pathankot; three events in Fazilka, Bathinda, Moga, and Mansa; two events in Barnala, Faridkot, Ferozepur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, and Sangrur; and one event in the remaining districts.

RCP 8.5 scenario: The projected increase per annum is by 1 to 4 days in all the districts. The increase is by four events in Pathankot; three events in Muktsar; two events in Barnala, Faridkot, Ferozepur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, and Sangrur; and one event in the remaining districts.

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

The total number of very high-intensity rainfall events increases from 1 to 28 days during the historical period (1990–2019) to 28 to 60 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 30 to 89 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: The projected increase per annum is by one to two events in all the districts, except Nawanshahr district. The increase is by two events in Fazilka and one event in all the remaining districts.

RCP 8.5 scenario: The projected increase per annum is by one to two events in all the districts. The increase is by two days in Amritsar, Barnala, Bathinda, Fatehgarh Sahib, Fazilka, Ferozepur, Gurdaspur, Jalandhar, Kapurthala, Moga, Muktsar, and Pathankot; and one event in the remaining 10 districts.

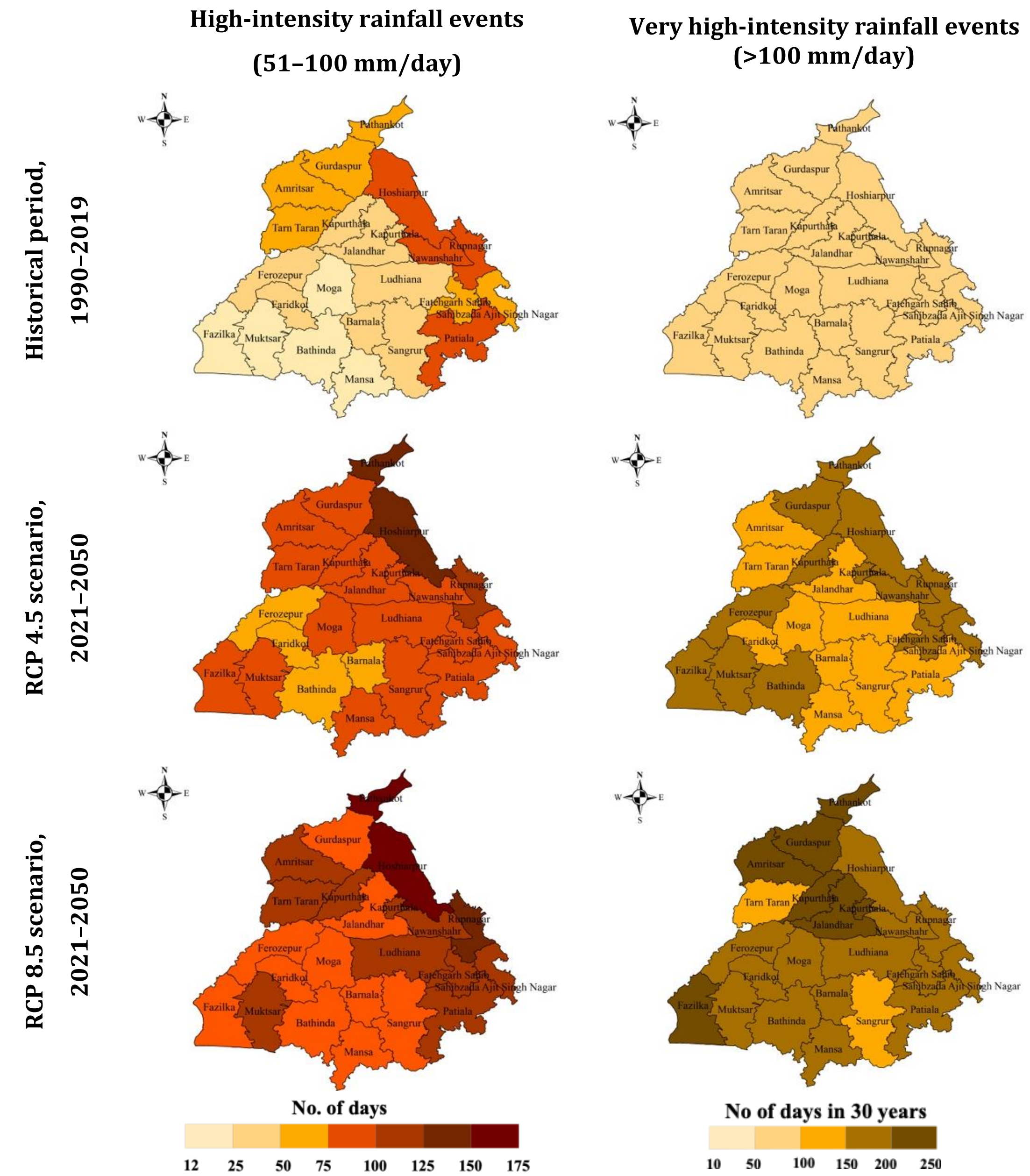


Figure 5-11: The total number of high-intensity and very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

Rainfall deficient years (Figure 5-12)

Rainfall deficient years, computed by considering the rainfall during the kharif season, are projected to decline in all the districts of Punjab under both climate scenarios. The number of rainfall deficient years declines from 9 to 14 years during the historical 30-year period to 9 to 15 years under the RCP 4.5 scenario and 6 to 12 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: Projected to decline in 11 of the 22 districts by 1 to 5 years. No change, compared to the historical period, is projected in the remaining 11 districts.

RCP 8.5 scenario: Projected to decline in 17 of the 22 districts by 1 to 5 years. No change, compared to the historical period, is projected in the remaining five districts.

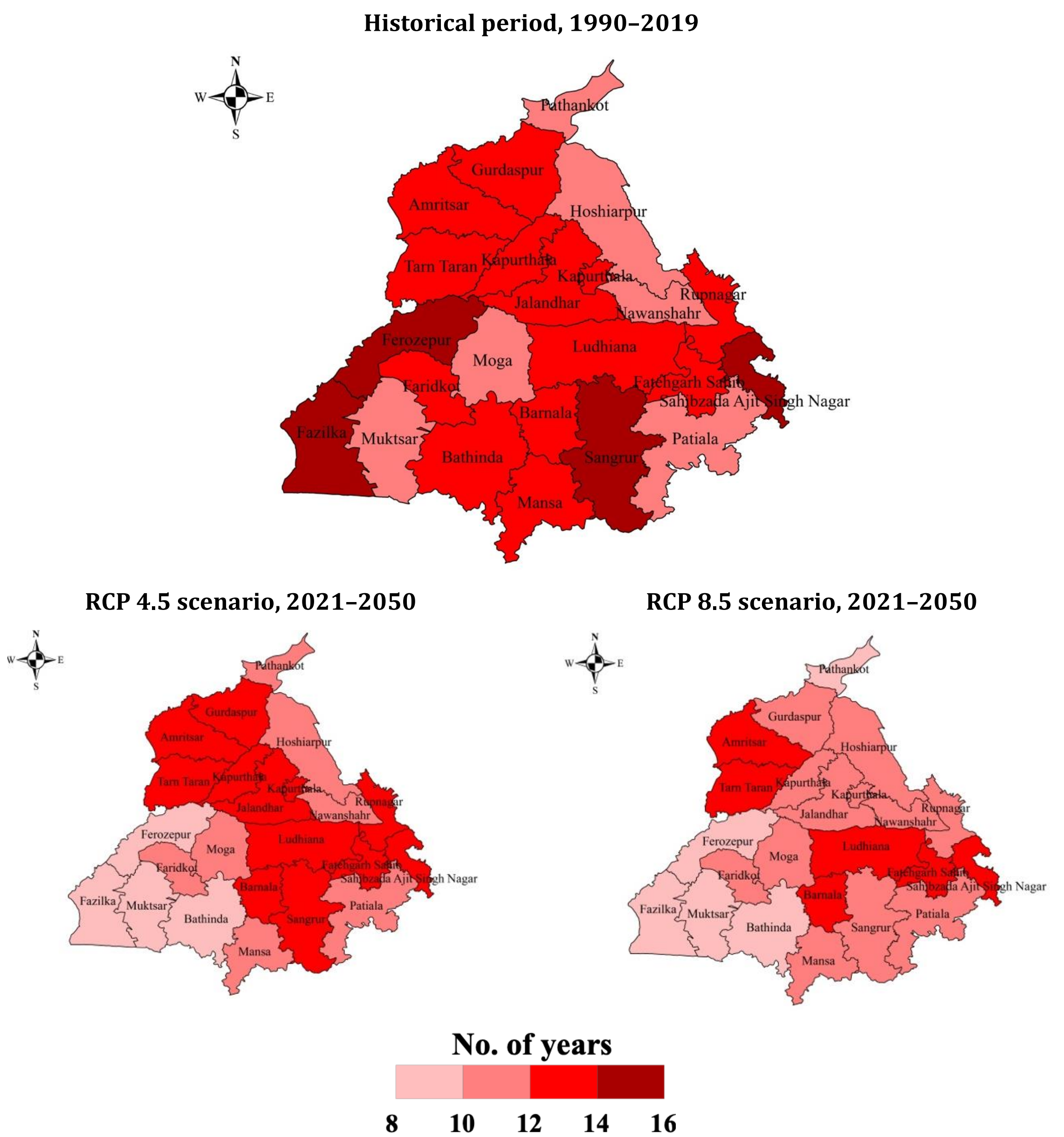


Figure 5-12: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

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

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

- An increase of up to 1.5°C in both summer maximum and winter minimum temperatures under RCP 4.5 scenario and up to 2°C under RCP 8.5 scenario is projected.

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

- A notable increase in rainfall is projected in the northern and western districts of Punjab.

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

- A decline in the variability of rainfall is projected during kharif and rabi seasons in all the districts of Punjab. The decline in the variability of the kharif season rainfall is >20% in Muktsar, Fazilka, Mansa, Bathinda, and a few other districts. During the rabi season, the decline in variability is >50% in a majority of the districts.

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

- The increase annually is in the range of 1 to 8 days under the RCP 4.5 scenario and 1 to 10 days under the RCP 8.5 scenario, with the maximum increase projected for Fatehgarh Sahib 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 marginally by one to four events per annum during the projected period.
- Very high-intensity rainfall events are projected to increase marginally by one to two events per annum during the projected period in many of the districts of Punjab.

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

- The projected decline is by one to five years in 11 and 17 districts, respectively. In the remaining districts, no change is projected.

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
Amritsar	1.1	1.4	1.2	1.5
Barnala	1.4	1.8	0.8	1.5
Bathinda	1.3	1.9	0.9	1.6
Faridkot	1.2	1.8	1.1	1.6
Fatehgarh Sahib	1.1	1.5	1.2	1.5
Fazilka	1.3	1.8	0.8	1.7
Ferozepur	1.4	1.9	0.7	1.6
Gurdaspur	1.2	1.4	1.4	1.6
Hoshiarpur	1.1	1.3	1.3	1.7
Jalandhar	1.3	1.5	1.1	1.4
Kapurthala	1.2	1.4	1.2	1.5
Ludhiana	1.1	1.3	1.3	1.4
Mansa	1.3	1.9	0.8	1.6
Moga	1.2	1.8	0.8	1.3
Muktsar	1.4	1.8	0.9	1.6
Nawanshahr	1.2	1.4	1.2	1.4
Pathankot	1.3	1.4	1.3	1.7
Patiala	1.2	1.5	1.3	1.5
Rupnagar	1.3	1.4	1.2	1.5
Sahibzada Ajit Singh Nagar	1.3	1.5	1.2	1.6
Sangrur	1.3	1.7	0.8	1.1
Tarn Taran	1.2	1.4	1.1	1.3

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
Amritsar	4	12	4	12	15	22
Barnala	9	17	9	19	27	46
Bathinda	8	13	6	13	19	68
Faridkot	12	18	12	17	19	33
Fatehgarh Sahib	4	9	3	9	9	21
Fazilka	27	35	22	30	11	34
Ferozepur	51	61	32	43	28	46
Gurdaspur	8	15	8	17	23	34
Hoshiarpur	9	13	10	15	16	29
Jalandhar	12	19	9	13	28	35
Kapurthala	6	10	6	13	13	19
Ludhiana	9	14	11	20	24	51
Mansa	18	26	19	26	17	52
Moga	21	25	17	33	28	61
Muktsar	11	19	10	16	17	51
Nawanshahr	3	8	12	16	13	25
Pathankot	42	50	39	46	4	22
Patiala	5	10	10	16	2	22
Rupnagar	8	13	9	15	10	24
Sahibzada Ajit Singh Nagar	3	6	38	46	19	27
Sangrur	14	22	16	23	27	75
Tarn Taran	10	13	16	17	4	31

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)

Districts	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Amritsar	867	920	990
Barnala	639	730	789
Bathinda	525	640	710
Faridkot	554	660	720
Fatehgarh Sahib	1127	1200	1265
Fazilka	396	560	630
Ferozepur	549	680	702
Gurdaspur	1154	1246	1280
Hoshiarpur	1225	1258	1283
Jalandhar	1023	1120	1143
Kapurthala	1023	1126	1182
Ludhiana	990	1027	1067
Mansa	610	720	789
Moga	655	745	801
Sahibzada Ajit Singh Nagar	1095	1133	1189
Muktsar	548	616	690
Nawanshahr	1127	1147	1183
Pathankot	1274	1521	1585
Patiala	1296	1347	1358
Rupnagar	1363	1394	1403
Sangrur	729	847	926
Tarn Taran	1025	1076	1109

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
Amritsar	70	84	120	14	40	65	13	13	13
Barnala	33	70	88	5	30	56	14	13	13
Bathinda	12	65	70	5	42	52	14	10	10
Faridkot	26	70	92	2	38	46	13	11	11
Fatehgarh Sahib	70	89	103	4	44	56	14	13	14
Fazilka	24	76	89	7	60	75	15	10	10
Ferozepur	28	62	89	5	48	56	15	10	10
Gurdaspur	60	82	96	10	46	62	13	13	12
Hoshiarpur	95	142	167	15	45	58	12	12	12
Jalandhar	37	77	96	10	40	67	13	13	12
Kapurthala	37	80	103	10	52	74	14	14	12
Ludhiana	50	87	104	8	39	43	14	13	13
Mansa	23	82	96	3	30	45	14	12	12
Moga	23	78	92	1	38	48	12	12	12
Sahibzada Ajit Singh Naga	75	90	102	14	50	55	15	15	14
Muktsar	24	99	112	4	47	54	12	9	9
Nawanshahr	87	89	104	28	41	48	12	12	12
Pathankot	74	156	189	24	55	89	11	11	10
Patiala	81	90	123	15	40	46	12	12	11
Rupnagar	91	120	137	16	53	60	13	13	12
Sangrur	33	82	97	1	28	30	16	13	12
Tarn Taran	75	89	120	14	36	38	14	13	13

6. Uttarakhand

The state of Uttarakhand is landlocked and mountainous. It covers an area of 53,483 sq. km and has a population of 10.09 million, which is predominantly rural, according to the 2011 Census. Uttarakhand is bordered by Himachal Pradesh in the west and north-west, Uttar Pradesh in the south, Nepal in the east, and China (Tibet) in the North. Located in the Indian Himalayas, the elevation across the state ranges from 210 m to 7,817 m, leading to great variations in climate and vegetation. Glaciers, ice, and bare rocks cover the higher elevations, and subtropical forests cover the lower elevations. Forests cover about 72% of the state's area. The state is drained by main rivers such as Ganga, Ramganga, Sharda, and Yamuna and their tributaries. The annual temperature varies from 0°C to 43°C, and the average annual rainfall is 1,500 mm.

Uttarakhand has 13 districts. Agriculture and allied activities are the major source of income for more than three fourths of the state's population, although only about 14.42% of the state's area is under crop production. Given the geotectonic set-up of the region and the geomorphology and meteorological characteristics of Uttarakhand, it is prone to a number of natural hazards, including earthquakes, landslides, cloudbursts, flash floods, floods, avalanches, droughts, cold waves, and hailstorms.

These characteristics make Uttarakhand 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 to 2019 are presented in the subsequent sections.

6.1.1. Trends in temperature

Uttarakhand recorded a warming 0.15°C to 0.32°C in the summer maximum temperature and 0.01°C to 0.12°C in the winter minimum temperature during the historical period. Figure 6-1 presents the mean summer maximum and winter minimum temperatures in Uttarakhand during the historical period.

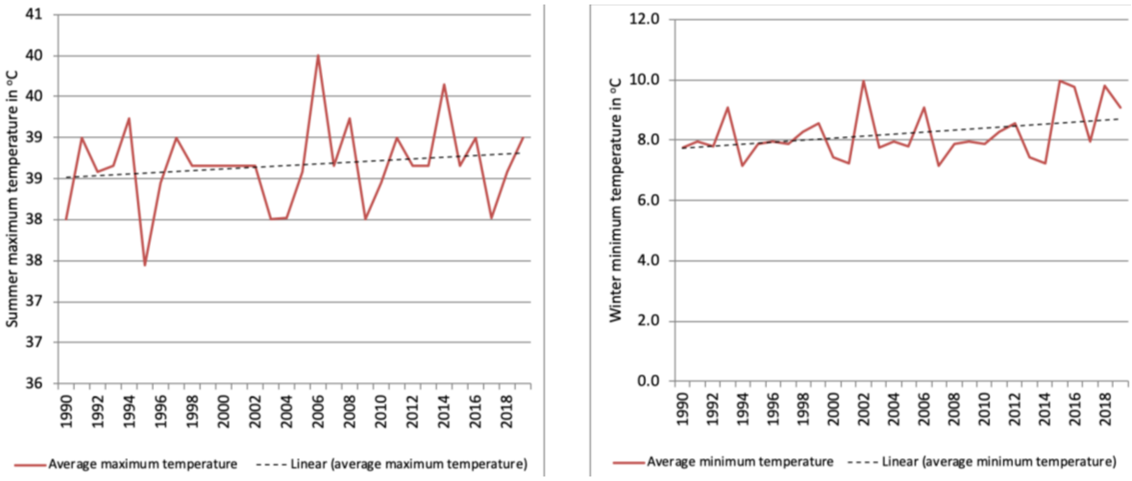


Figure 6-1: Mean summer maximum and winter minimum temperatures in Uttarakhand during the historical period (1990–2019)

6.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and the kharif season rainfall in the range of 5% to 15% was recorded during the historical period. Figure 6-2 presents the mean annual rainfall in Uttarakhand during the historical period.

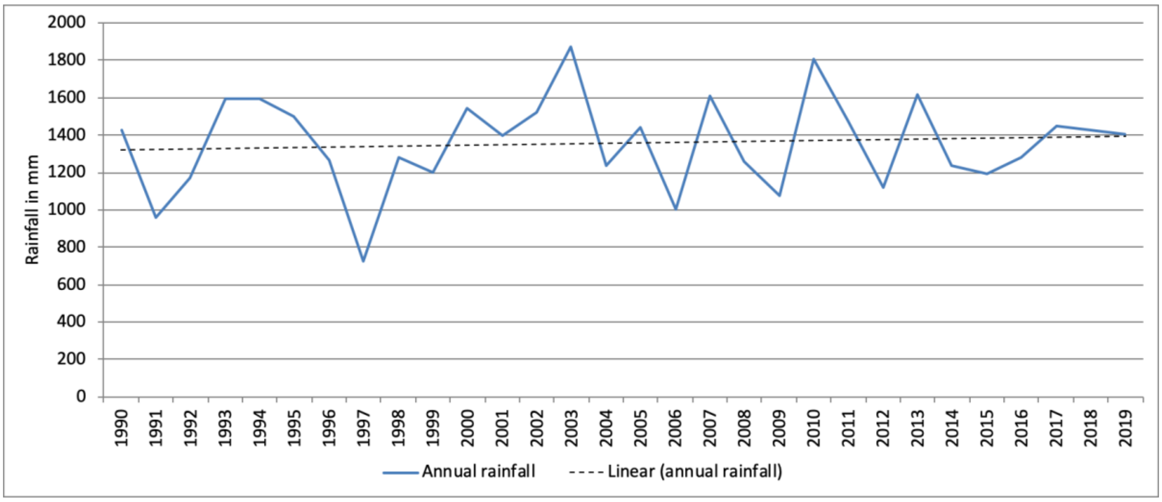


Figure 6-2: Mean annual rainfall in Uttarakhand during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 26% in Nainital to 41% in Rudraprayag (Figure 6-3). The variability of rainfall during the rabi season was high and ranged from 68% in Chamoli to >100% in eight districts, an indication of the total failure of rainfall during the season (Figure 6-3).

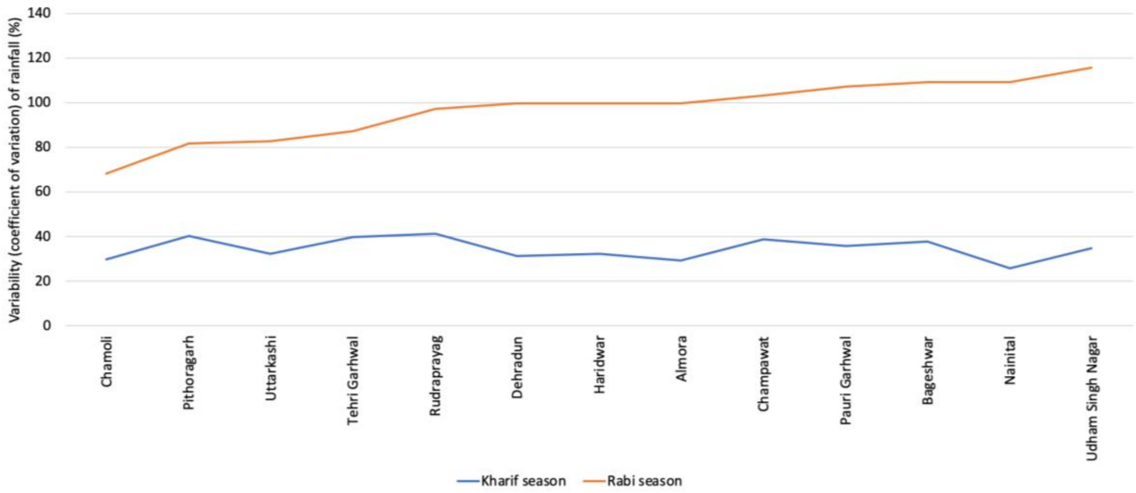


Figure 6-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

6.2. Climate change projections

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

6.2.1. Temperature projections

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

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

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

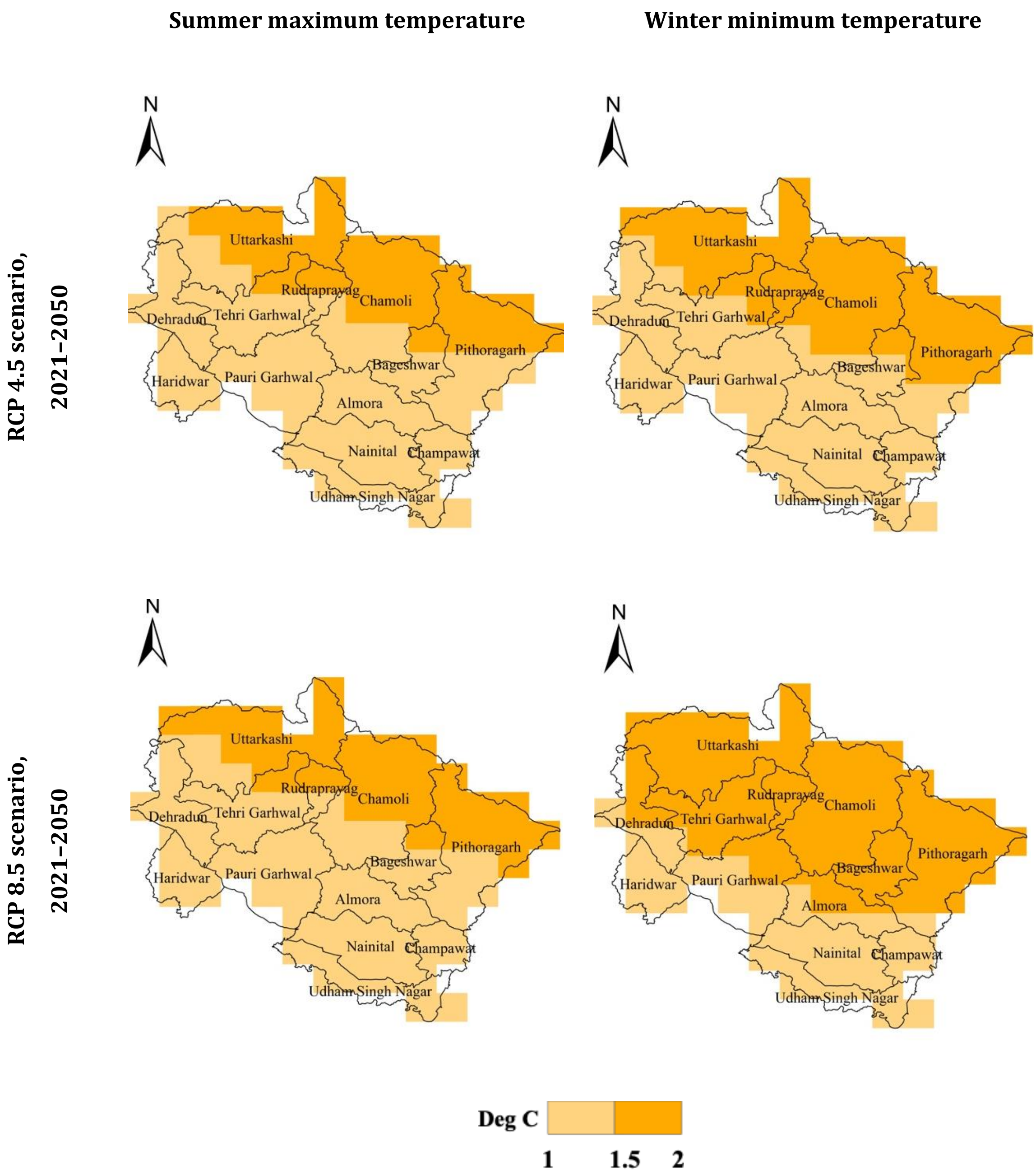


Figure 6-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

6.2.2. Rainfall projections

6.2.2.1. Number of rainy days

According to the India Meteorological Department, 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 6-5). The number of rainy days during the historical period and the projected 2030s under both RCP 4.5 and 8.5 scenarios is presented in Appendix 6-3. The total number of rainy days that ranged from 942 to 2219 days over the 30-year historical period increases from

1123 to 2345 days under the RCP 4.5 scenario and 1170 to 2324 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 4 to 11 days annually in all the districts. The increase is by 4 days in Pithoragarh and Uttarkashi; 5 days in Almora and Dehradun; 6 days in Chamoli, Champawat, Rudraprayag and Tehri Garhwal; 7 days in Haridwar, Nainital, and Udham Singh Nagar, and 11 days in Pauri Garhwal.

RCP 8.5 scenario: Projected to increase by 4 to 14 days annually in all the districts. The increase is by 4 days in Pithoragarh; 6 days in Bageshwar; 7 days in Almora and Champawat; 8 days in Chamoli, Uttarkashi and Dehradun; 10 days in Haridwar, Rudraprayag, Tehri Garhwal, and Udham Singh Nagar; 11 days in Nainital; and 14 days in Pauri Garhwal.

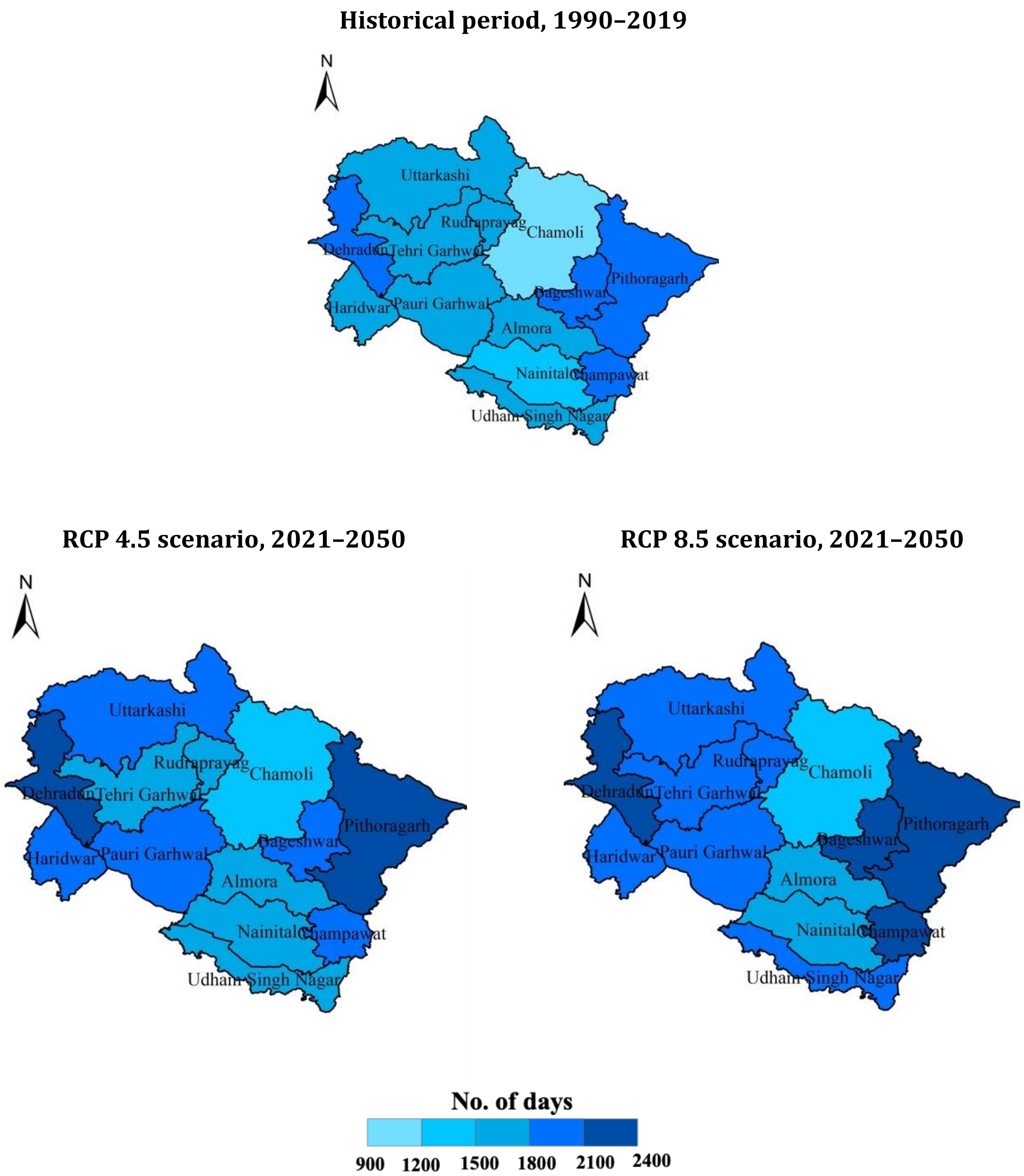


Figure 6-5: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

6.2.2.2. Mean rainfall and rainfall variability during the kharif season

The kharif season rainfall is projected to increase in all the districts, under both climate scenarios. Figure 6-6 presents district-wise changes in kharif season rainfall, and Figure 6-7 presents changes in the variability of rainfall.

Climate scenarios	Mean seasonal rainfall	Rainfall variability
RCP 4.5	Increases in all the districts, from 7% in Almora and Pauri Garhwal to 17% in Pithoragarh	Declines in all the districts by 1% to 6%
RCP 8.5	Increases in all the districts, from 12% in Almora to 22% in Pithoragarh and Udham Singh Nagar	Declines in all the districts by 2% to 13%

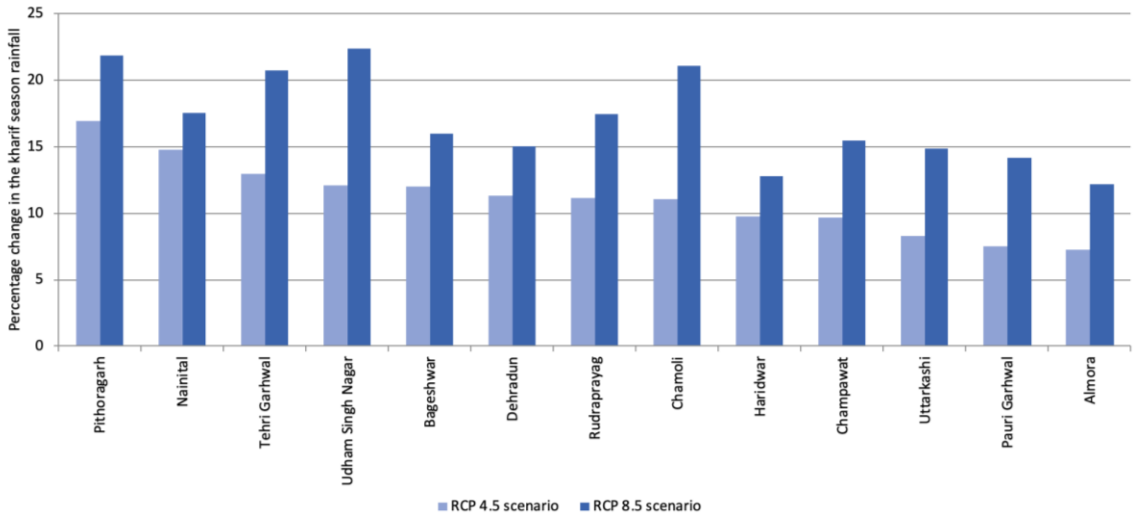


Figure 6-6: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

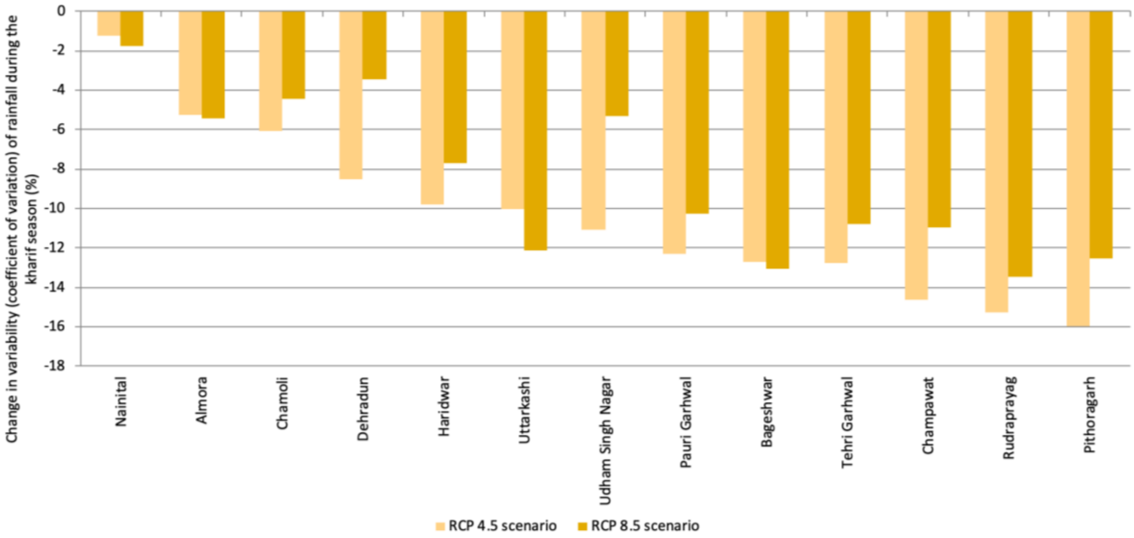


Figure 6-7: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

6.2.2.3. Mean rainfall and rainfall variability during the rabi season

The rabi season rainfall is projected to increase in all the districts under both climate scenarios. Figure 6-8 presents district-wise changes in the rabi season rainfall, and Figure 6-9 presents changes in the variability (coefficient of variation) of rainfall.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 4% in Chamoli to 20% in Pauri Garhwal	Declines in all the districts by 7% to 36%
RCP 8.5	Increases in all the districts, from 9% in Nainital to 33% in Pauri Garhwal	Decline in all the districts by 8% to 34%

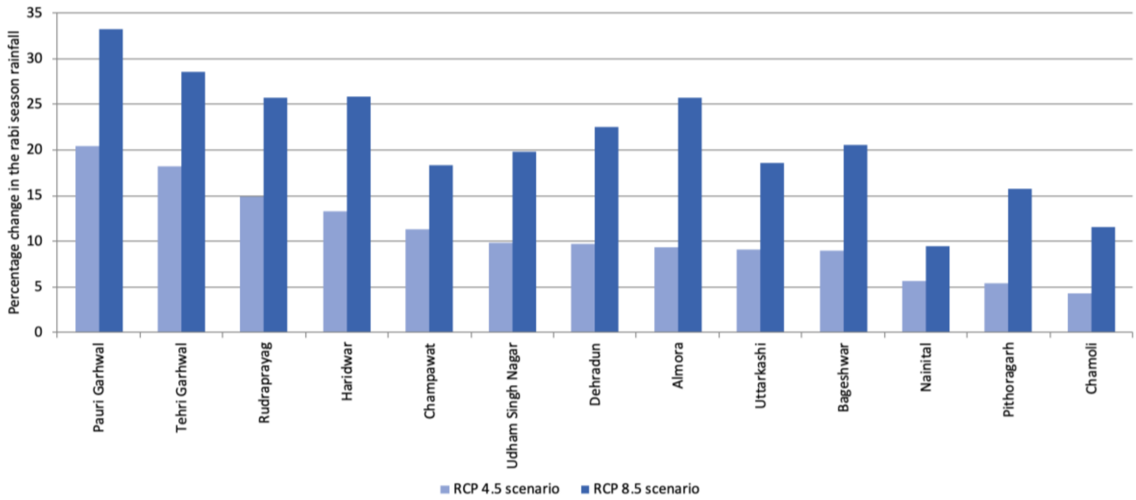


Figure 6-8: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

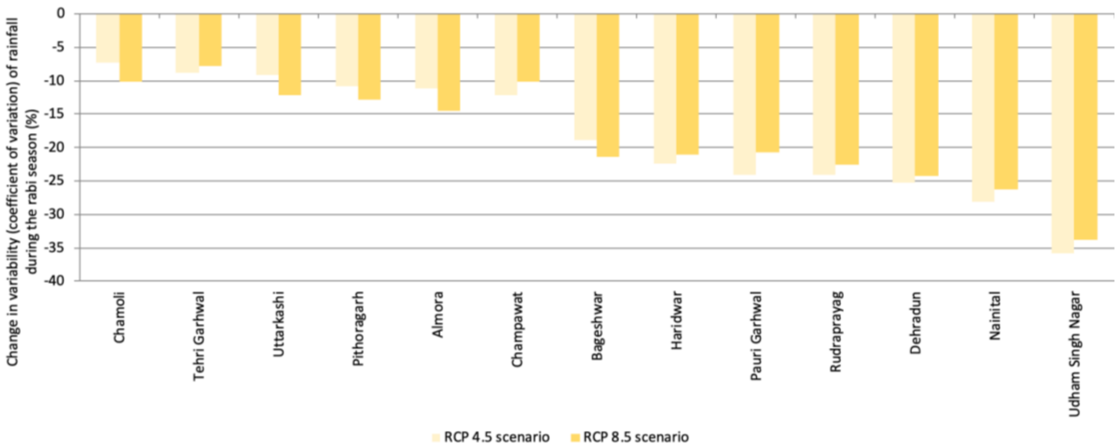


Figure 6-9: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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

High-intensity rainfall events (Figure 6-10)

The total number of high-intensity rainfall events increases from 37 to 161 days during the historical period to 58 to 208 days in the 2030s under the RCP 4.5 scenario and 80 to 223 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 Almora, Nainital, Pithoragarh, and Nainital 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 Pithoragarh; two events in Uttarkashi, Chamoli, Champawat, Pauri Garhwal, Almora, Nainital, Udham Singh Nagar, and Haridwar; 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 3 to 30 days during the historical period to 58 to 208 days in the 2030s under the RCP 4.5 scenario and 38 to 97 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 Tehri Garhwal and Pithoragarh 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 Pithoragarh; two events in Dehradun, Tehri Garhwal, Uttarkashi, Pauri Garhwal, Udham Singh Nagar, and Haridwar; and one event in the remaining districts.

Rainfall deficient years (Figure 6-11)

Rainfall deficient years, computed by considering the rainfall during the kharif season, are projected to decline in all the districts of Uttarakhand under both climate scenarios. The number of rainfall deficient years declines from 10 to 15 years during the historical 30-year period to 10 to 12 years under RCP 4.5 and RCP 8.5 scenarios during the projected period.

RCP 4.5 scenario: Projected to decline in 9 of the 13 districts by 1 to 4 years. No change, compared to the historical period, is projected in the remaining four districts.

RCP 8.5 scenario: Projected to decline in 10 of the 13 districts by 1 to 4 years. No change, compared to the historical period, is projected in the remaining three districts.

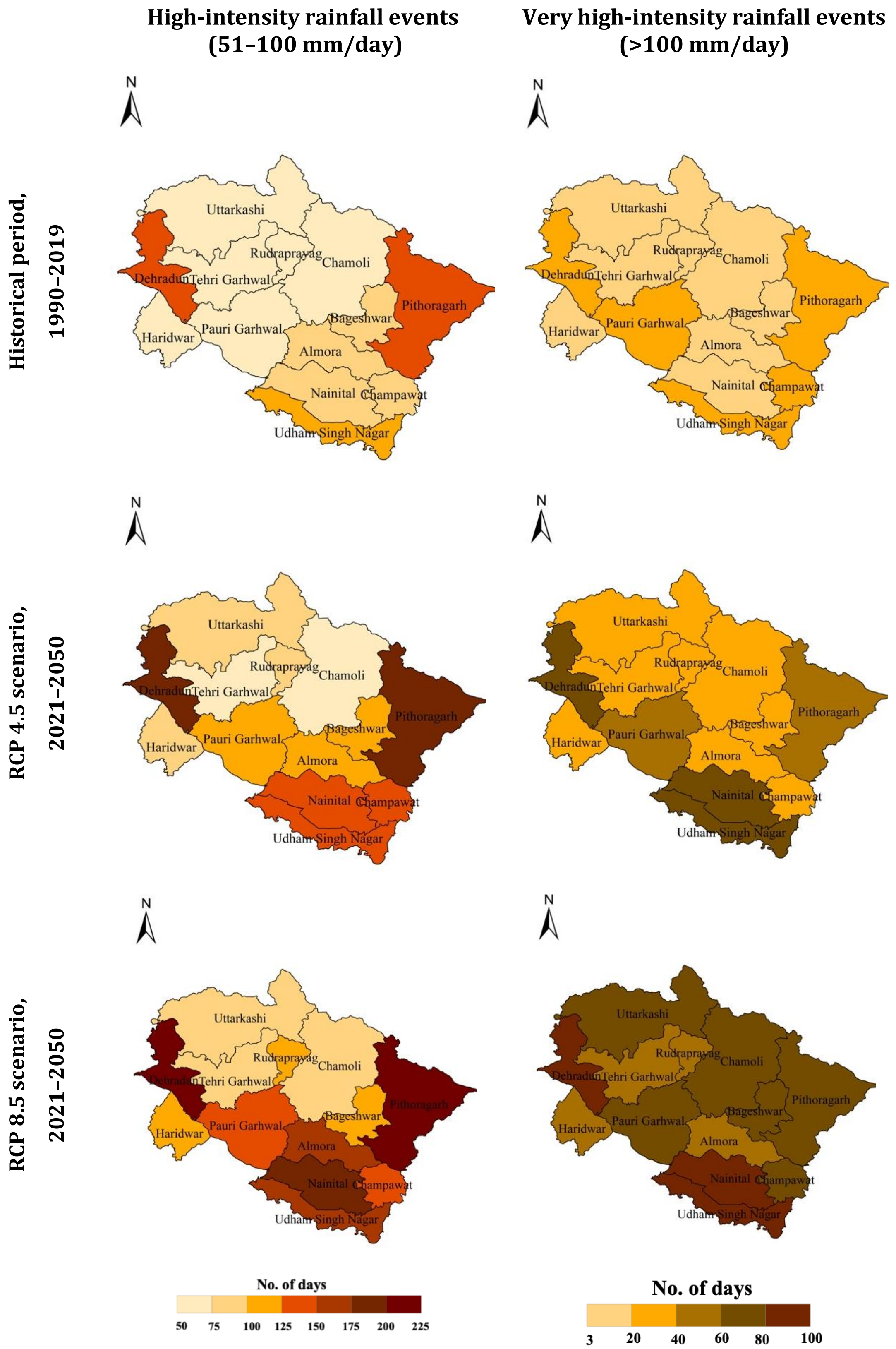


Figure 6-10: The total number of high-intensity and very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

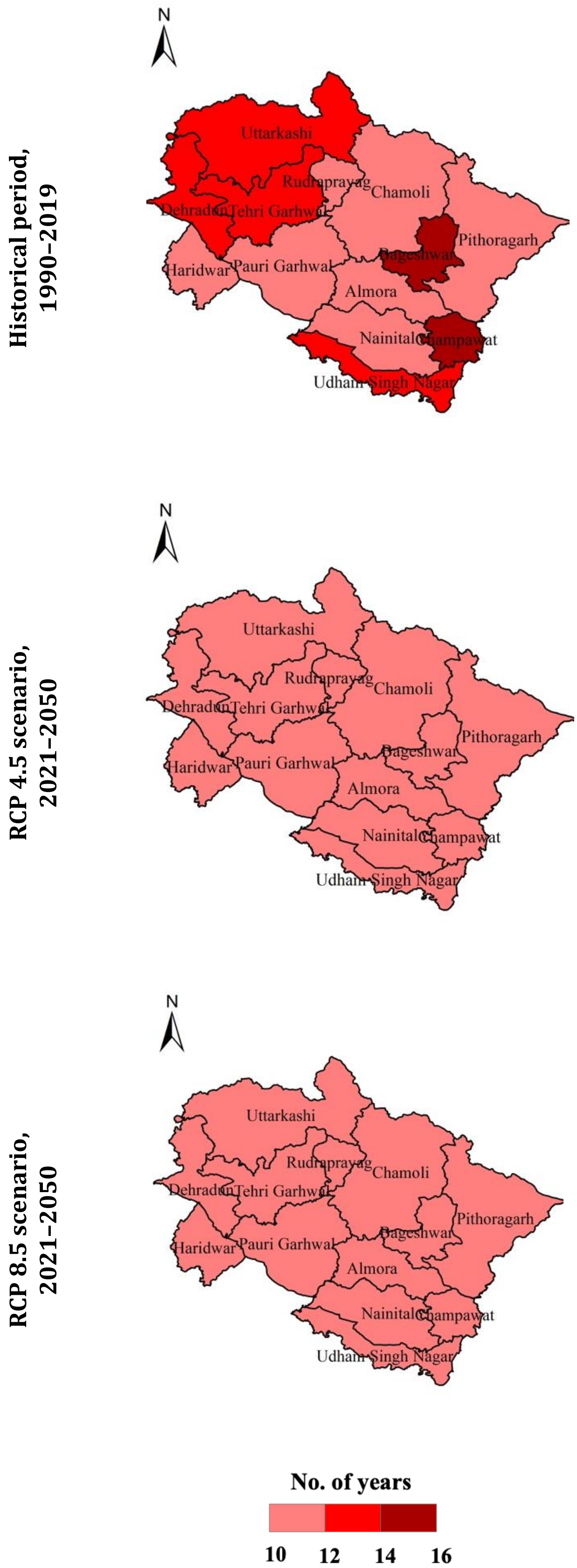


Figure 6-11: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

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

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).

- An increase of 1°C to 2°C in both summer maximum and winter minimum temperatures under RCP 4.5 and RCP 8.5 scenarios is projected.

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 6-2).

- The increase in rainfall is in the range of 7% to 17% under the RCP 4.5 scenario and 12% to 22% under the RCP 8.5 scenario.

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

- A decline in variability of rainfall by >10% is projected during the kharif season under both climate scenarios in Bageshwar, Tehri Garhwal, Champawat, Rudraprayag, and Pithoragarh districts.
- A decline in variability of rainfall by >20% is projected during the rabi season under both climate scenarios in Haridwar, Pauri Garhwal, Rudraprayag, Dehradun, Nainital, and Udham Singh Nagar districts.

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; Annexure 6-3).

- The increase annually is by 10 days or more per annum during the projected period under both climate scenarios in Tehri Garhwal, Udham Singh Nagar, Pithoragarh, and Uttarkashi districts.

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 by one to two events per annum under the RCP 4.5 scenario. The increase is by two events per annum in Dehradun, Haridwar, Pithoragarh and Rudraprayag, and by one event in the remaining districts. They are projected to increase by one to three events per annum under the RCP 8.5 scenario. The increase is by three events in Haridwar two events in Almora, Chamoli, Champawat, Dehradun, Pauri Garhwal, Nainital, Pithoragarh, and Rudraprayag, and by one event in the remaining districts.
- Very high-intensity rainfall events are projected to increase by two events per annum under the RCP 4.5 scenario in Haridwar and Udham Singh Nagar, and by one event in the remaining districts. They are projected to increase by one to three events per annum under the RCP 8.5 scenario. The increase is by three events in Haridwar; two events in Chamoli, Dehradun, Pauri Garhwal, Nainital, Udham Singh Nagar, and Uttarkashi, and by one event in the remaining districts.

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

- The projected decline is by one to four years in 9 and 10 districts under RCP 4.5 and RCP 8.5 scenario, respectively.

Appendix

Appendix 6-1: Changes in temperature under climate scenarios

Districts	Change in temperature (°C) during 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
Almora	1.3	1.4	1.1	1.3
Bageshwar	1.2	1.4	1.3	1.5
Chamoli	1.6	1.7	1.6	1.7
Champawat	1.3	1.4	1.2	1.3
Dehradun	1.2	1.4	1.1	1.4
Pauri Garhwal	1.3	1.5	1.1	1.4
Haridwar	1.1	1.5	1.2	1.5
Nainital	1.2	1.3	1.1	1.3
Pithoragarh	1.7	1.9	1.6	1.7
Rudraprayag	1.6	1.7	1.7	1.8
Tehri Garhwal	1.1	1.3	1.4	1.5
Udham Singh Nagar	1.2	1.4	1.2	1.5
Uttarkashi	1.6	1.7	1.6	1.7

Appendix 6-2: Changes in rainfall under climate scenarios

Districts	Change in rainfall (%) during 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
Almora	12	13	13	14	9	26
Bageshwar	5	7	12	16	9	21
Chamoli	5	6	6	15	4	12
Champawat	12	13	11	16	11	18
Dehradun	8	9	13	14	10	23
Pauri Garhwal	18	22	11	16	20	33
Haridwar	12	14	12	15	13	26
Nainital	7	8	10	11	6	9
Pithoragarh	10	13	3	4	5	16
Rudraprayag	21	23	10	11	15	26
Tehri Garhwal	10	18	14	15	18	29
Udham Singh Nagar	14	15	13	15	10	20
Uttarkashi	11	12	13	17	9	19

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
Almora	1506	1665	1701
Bageshwar	1924	2015	2101
Chamoli	942	1123	1170
Champawat	1913	2097	2123
Dehradun	2076	2214	2308
Pauri Garhwal	1574	1890	1980
Haridwar	1686	1897	1987
Nainital	1470	1678	1789
Pithoragarh	2219	2345	2324
Rudraprayag	1589	1765	1879
Tehri Garhwal	1588	1756	1890
Udham Singh Nagar	1586	1789	1890
Uttarkashi	1756	1890	1981

Appendix 6-4: Extreme events under historical (1990–2019) and projected short-term (2021–2050) periods. The numbers indicate the total number of days with either high- or very high-intensity rainfall over a 30-year period and the number of rainfall deficient years over a 30-year period

Districts	High intensity rainfall events			Very High intensity rainfall events			Rainfall Deficient years		
	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5	Historical	RCP 4.5	RCP 8.5
Almora	77	120	129	13	120	38	12	11	11
Bageshwar	80	107	123	14	107	42	15	12	12
Chamoli	37	58	98	3	58	68	10	10	10
Champawat	91	130	150	28	130	45	15	11	11
Dehradun	134	197	201	24	197	89	14	10	10
Pauri Garhwal	65	89	112	8	89	54	10	10	10
Haridwar	89	145	180	20	145	97	11	10	10
Nainital	70	113	136	28	113	79	11	11	11
Pithoragarh	161	208	223	23	208	67	11	11	10
Rudraprayag	42	97	105	6	97	47	11	10	10
Tehri Garhwal	49	75	80	10	75	45	14	10	10
Udham Singh Nagar	120	140	153	30	140	91	13	11	11
Uttarkashi	68	88	91	9	88	67	13	11	11

7. Uttar Pradesh

Uttar Pradesh is situated in the northern part of India, spanning an area of 240,930 sq. km. It shares an international border with Nepal and has domestic boundaries with Uttarakhand, Bihar, Madhya Pradesh, Rajasthan, Haryana, Delhi, and Himachal Pradesh. According to the 2011 Census, Uttar Pradesh is the most populous state in India with a population of 199.81 million, distributed in 75 districts. It is divided into four geographical regions: the larger Gangetic Plain, the Terrai region, the Vindhya Range, and the Rohilkhand region. Monsoon remains active normally from June to September. Most parts of the state receive scanty rains during the winter season.

The total area under agriculture in Uttar Pradesh is 17.6 Mha, of which 14.49 Mha is irrigated. The state has thermal power plants in Sonbhadra, Jhansi, Aligarh, Kanpur, and a few other districts.

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

7.1. Historical Climate

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

7.1.1. Trends in temperature

Uttar Pradesh recorded a moderate warming of 0.31°C to 0.62°C in the summer maximum temperature and 0.18°C to 0.35°C in the winter minimum temperature during the historical period (Figure 7-1).

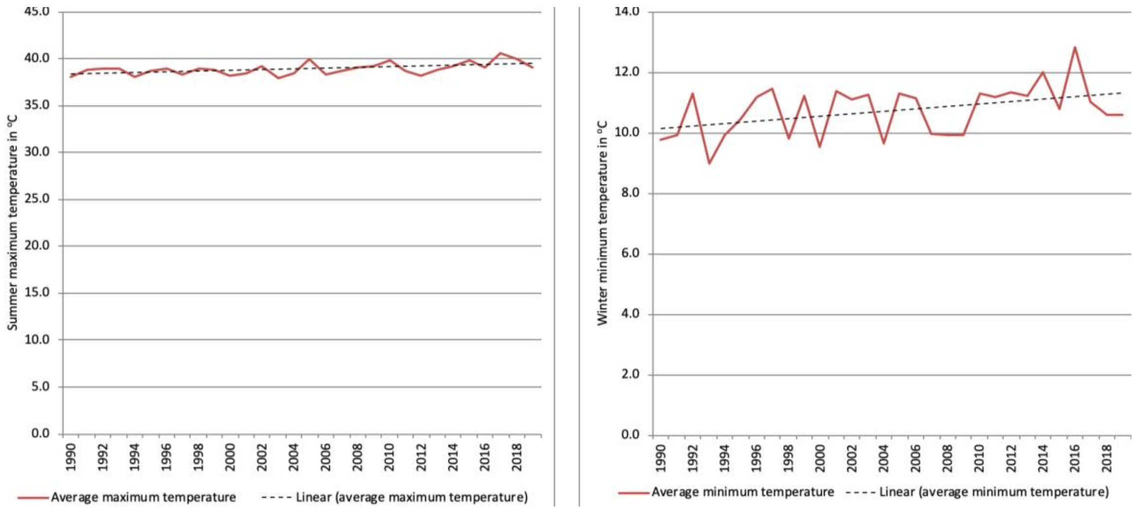


Figure 7-1: Mean summer maximum and winter minimum temperatures in Uttar Pradesh during the historical period (1990–2019)

7.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual rainfall (Figure 7-2) and kharif season rainfall, which is the main monsoon season, is recorded across the districts of Uttar Pradesh. The increase in the annual rainfall was largely in the range of 5% to 10%. The increase in the kharif season rainfall was up to 5%, which is marginal, mainly in the eastern districts and 5% to 10% in the western districts.

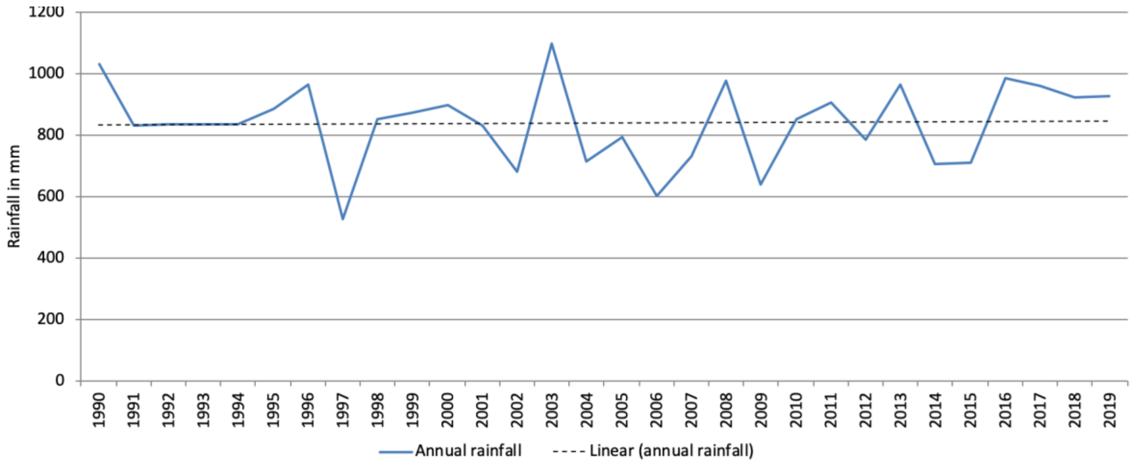


Figure 7-2: Mean annual rainfall in Uttar Pradesh during the historical period (1990–2019)

The kharif season rainfall variability ranged from 14% in Deoria and Gonda to 54% in Mainpuri (Figure 7-3). The rabi season rainfall is insignificant in Uttar Pradesh.

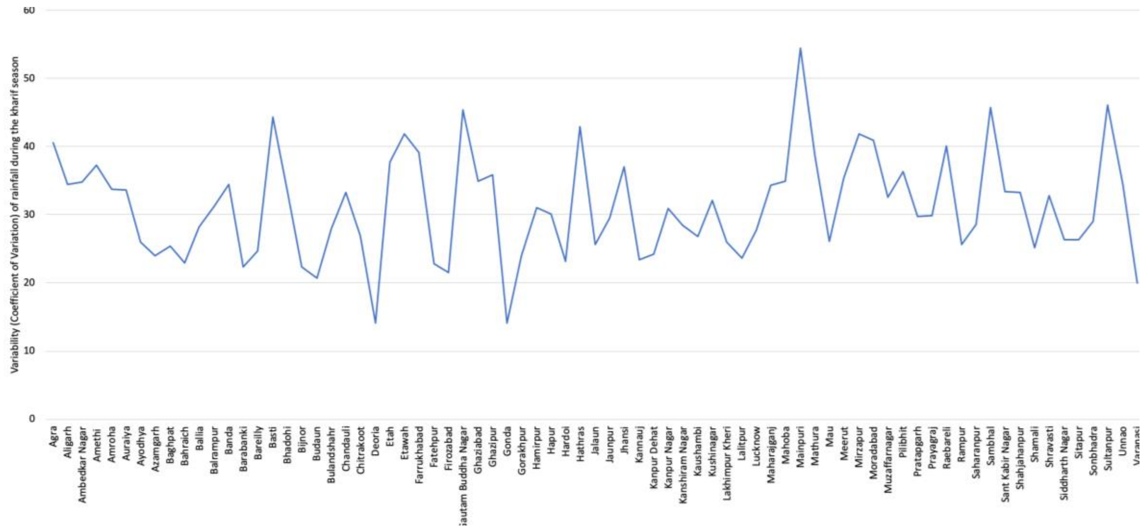


Figure 7-3: The kharif season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

7.2. 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.

7.2.1. Temperature projections

The projected changes in the summer maximum and winter minimum temperatures for all the districts of Uttar Pradesh are presented in Figure 7-4.

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

Climate scenarios	Summer maximum	Winter minimum
RCP 4.5	Increases by 1°C to 1.5°C	Increases by 1°C to 1.5°C
RCP 8.5	Increases by 1°C to 2°C	Increases by 1°C to 2°C

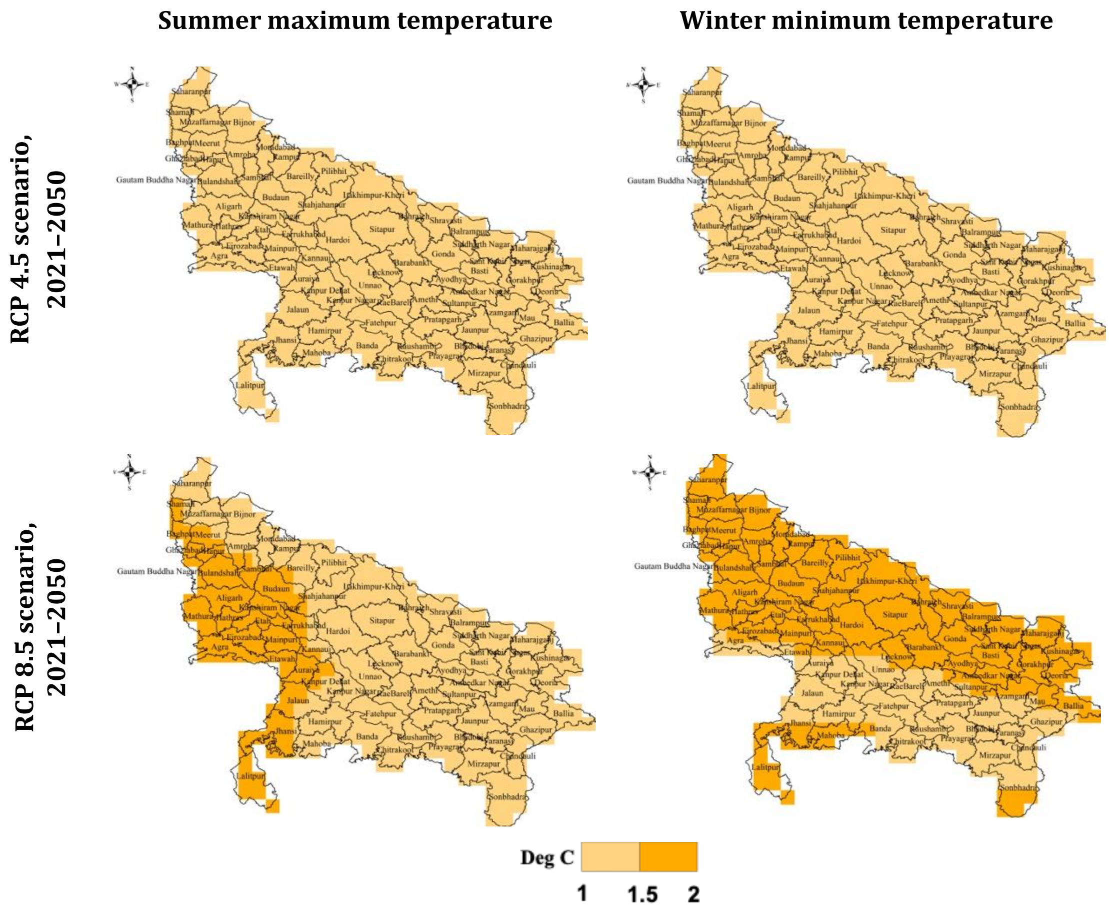


Figure 7-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

7.2.1.1. Heatwaves

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

The analysis of temperature during the projected period of the 2030s shows that there would an increase in the number of severe heatwaves (departure from the normal temperature is >6.4°C), as categorised by the India Meteorological Department (IMD), by about 28% under both RCP 4.5 and RCP 8.5 scenarios. In the case of heatwaves (departure from the normal temperature is 4.5°C to 6.4°C), as categorised by the India Meteorological Department (IMD), no significant change is projected under both climate scenarios (Figure 7-5).

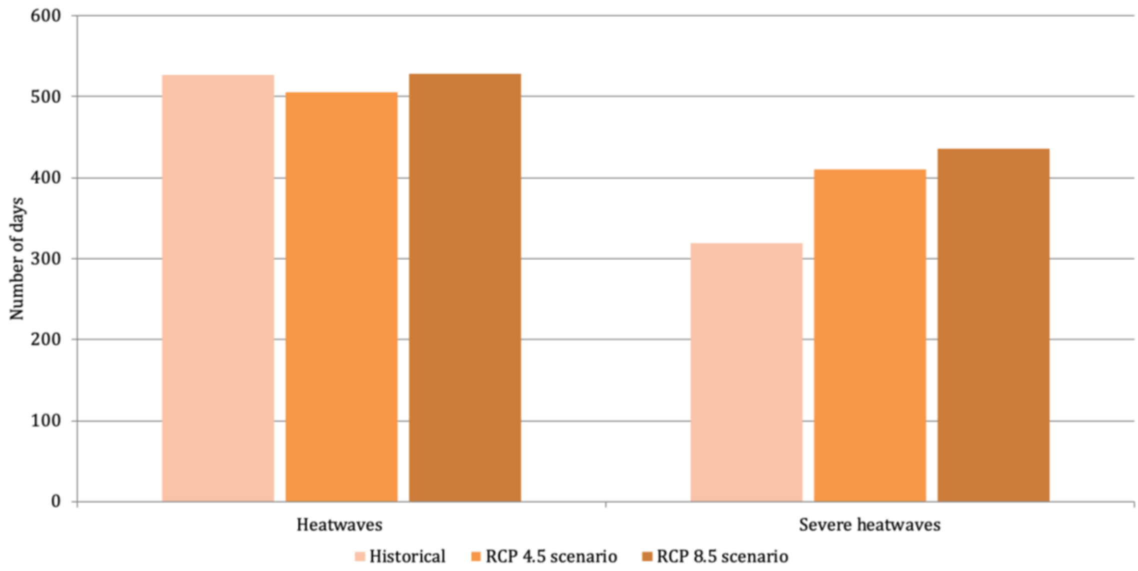


Figure 7-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

7.2.2. Rainfall projections

7.2.2.1. 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 7-6). The number of rainy days during the historical period and the projected 2030s under RCP 4.5 and 8.5 scenarios is presented in Appendix 7-3. The total number of rainy days that ranged from 840 to 1544 days over the 30-year period under the historical period increases to 912 to 1670 days under the RCP 4.5 scenario and 942 to 1699 days under the RCP 8.5 scenario during the projected 2030s. The increase per annum is as follows:

RCP 4.5 scenario: The projected increase is by one to 14 days annually in all the districts. The increase is by 14 days in Bijnor, 13 days in Chitrakoot, 12 days in Gorakhpur, 11 days in Azamgarh, 10 days in Jhansi, and <10 days in the remaining districts.

RCP 8.5 scenario: The projected increase is by 1 to 15 days annually in all the districts. The increase is by 15 days in Bijnor, 14 days in Chitrakoot and Gorakhpur, 12 days in Azamgarh, 11 days in Hamirpur, 10 days in Jhansi, and <10 days in the remaining districts.

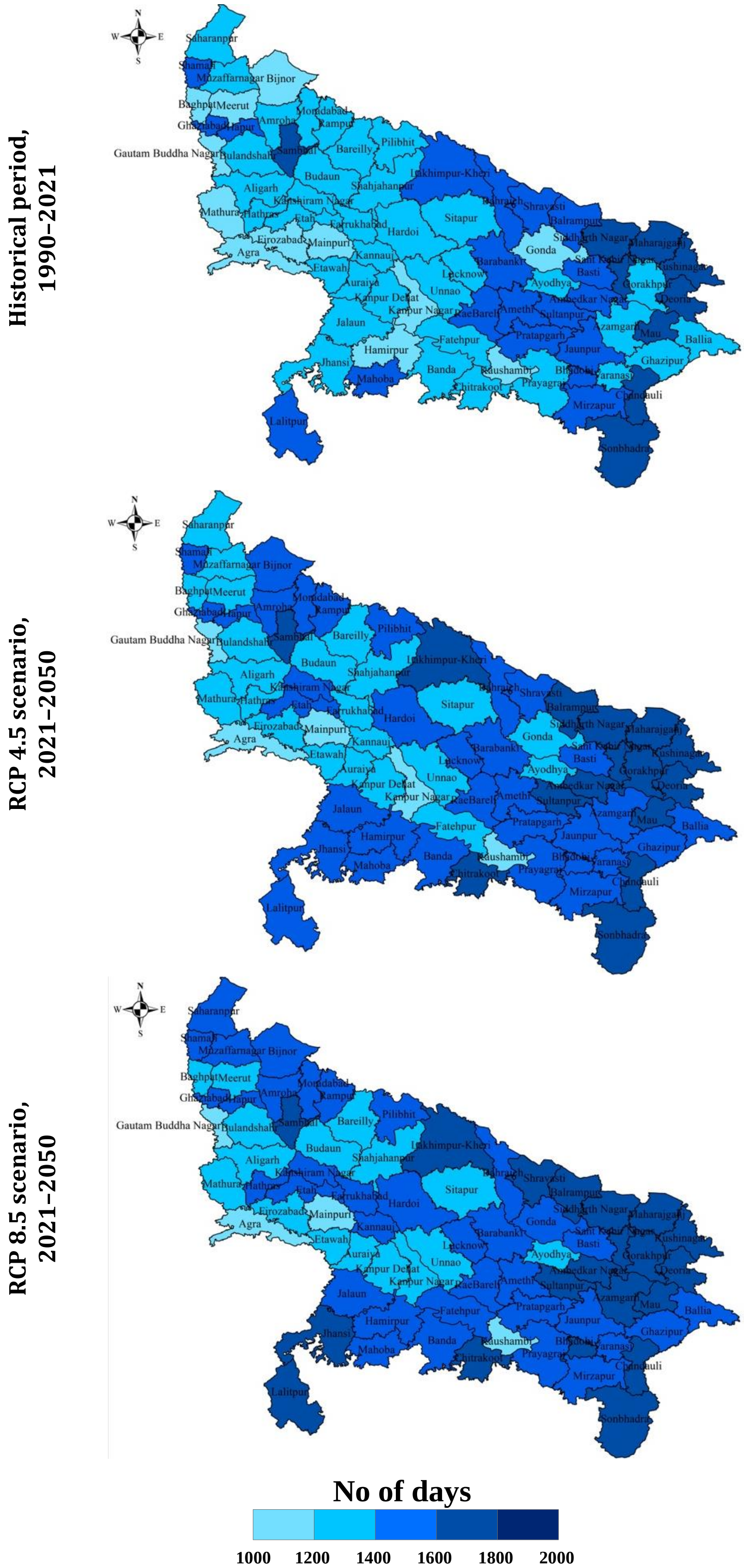


Figure 7-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

7.2.2.2. 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 7-7 presents district-wise changes in the kharif season rainfall, and Figure 7-8 presents changes in the variability (coefficient of variation) of rainfall.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 2% in Bhadohi and Lucknow to 37% in Ghazipur	Increases in 23 districts by 2% to 16% and declines in 52 districts by 0.4% to 23%
RCP 8.5	Increases in all the districts, from 5% in Kannauj and Lucknow to 41% in Ghazipur	Increases in 23 districts by 0.3% to 12% and declines in 52 districts by 1% to 27%

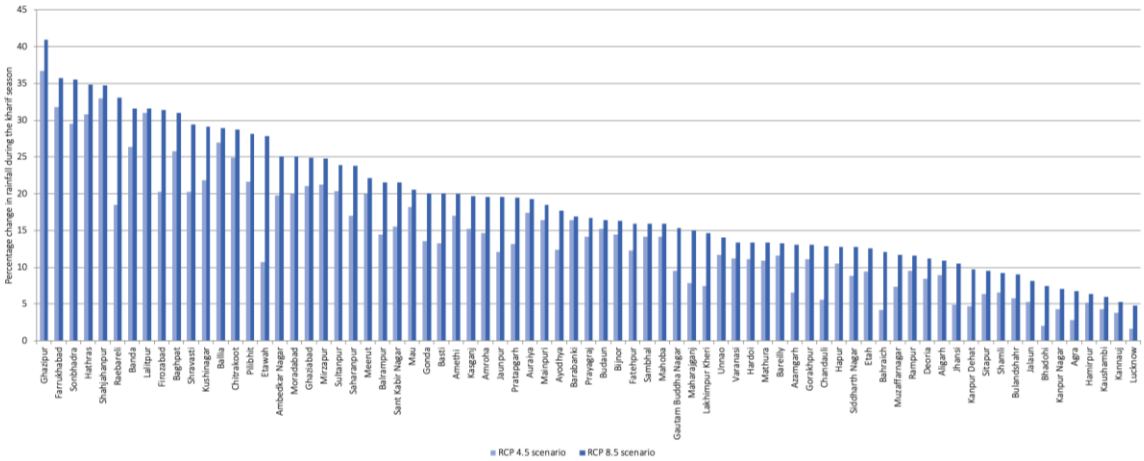


Figure 7-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

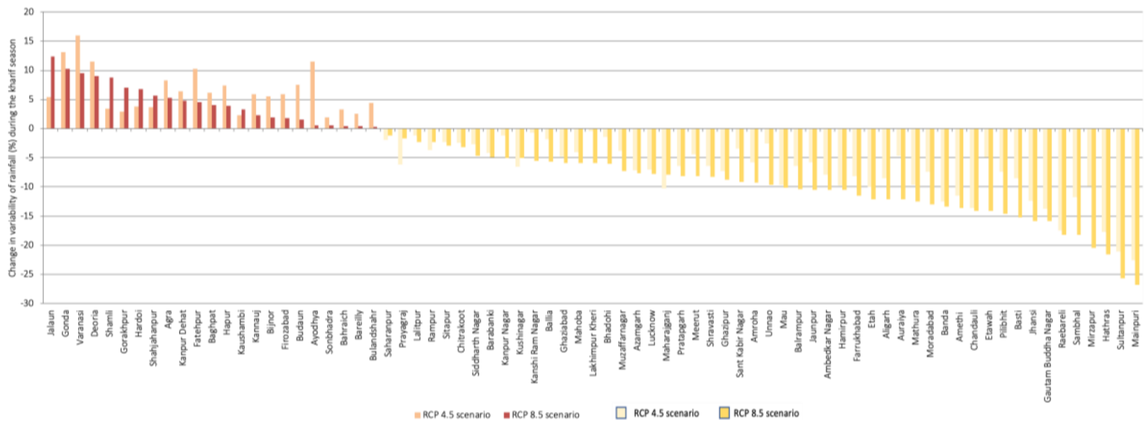


Figure 7-8: Projected changes in variability (CV) of kharif season rainfall compared to the historical period during the short-term period (2030s) under RCP 4.5 and RCP 8.5 scenarios

7.3. 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 Uttar Pradesh.

High-intensity rainfall events (Figure 7-9)

The total number of high-intensity rainfall events increases from 24 to 159 days during the historical period (1990–2019) to 56 to 199 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 78 to 204 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: An increase in high-intensity rainfall events is projected in all the districts of Uttar Pradesh. The increase per annum is by three events in Deoria, Gonda, Gorakhpur, Jaunpur and Hardoi; two events in Ambedkar Nagar, Banda, Bijnor, Chitrakoot, Farrukhabad, Fatehpur, Firozabad, Ghaziabad, Kanpur Dehat, Kanpur Nagar, Kasganj, Kushinagar, Rampur, Saharanpur, Sant Kabir Nagar, Sitapur, and Sultanpur; and one event in the remaining districts.

RCP 8.5 scenario: An increase in high-intensity rainfall events is projected in all the districts of Uttar Pradesh. The increase per annum is by one to five events. The increase per annum is by five events in Jaunpur; four events in Deoria, Gonda, Gorakhpur, Sitapur, and Hardoi districts; three events in 23 districts; and one to two events in the remaining districts.

Very high-intensity rainfall events (Figure 7-10)

The total number of very high-intensity rainfall events increases from 2 to 45 days during the historical period (1990–2019) to 23 to 87 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 34 to 102 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: An increase in very high-intensity rainfall events is projected in all the districts of Uttar Pradesh. The increase per annum is by two events in Ayodhya, Bijnor, Deoria, Fatehpur, Ghaziabad, Gonda, Gorakhpur, Hapur, Hardoi, Jaunpur, Meerut, Moradabad, Sant Kabir Nagar, and Siddharth Nagar; and one event in the remaining districts.

RCP 8.5 scenario: An increase in very high-intensity rainfall events is projected in all the districts of Uttar Pradesh. The increase per annum is by three events in 23 districts, including Fatehpur, Lalitpur, Mathura, Deoria, Kaushambi, Hapur, Lucknow, Chitrakoot, Firozabad, Jaunpur; two events in 49 districts; and one event in the remaining districts.

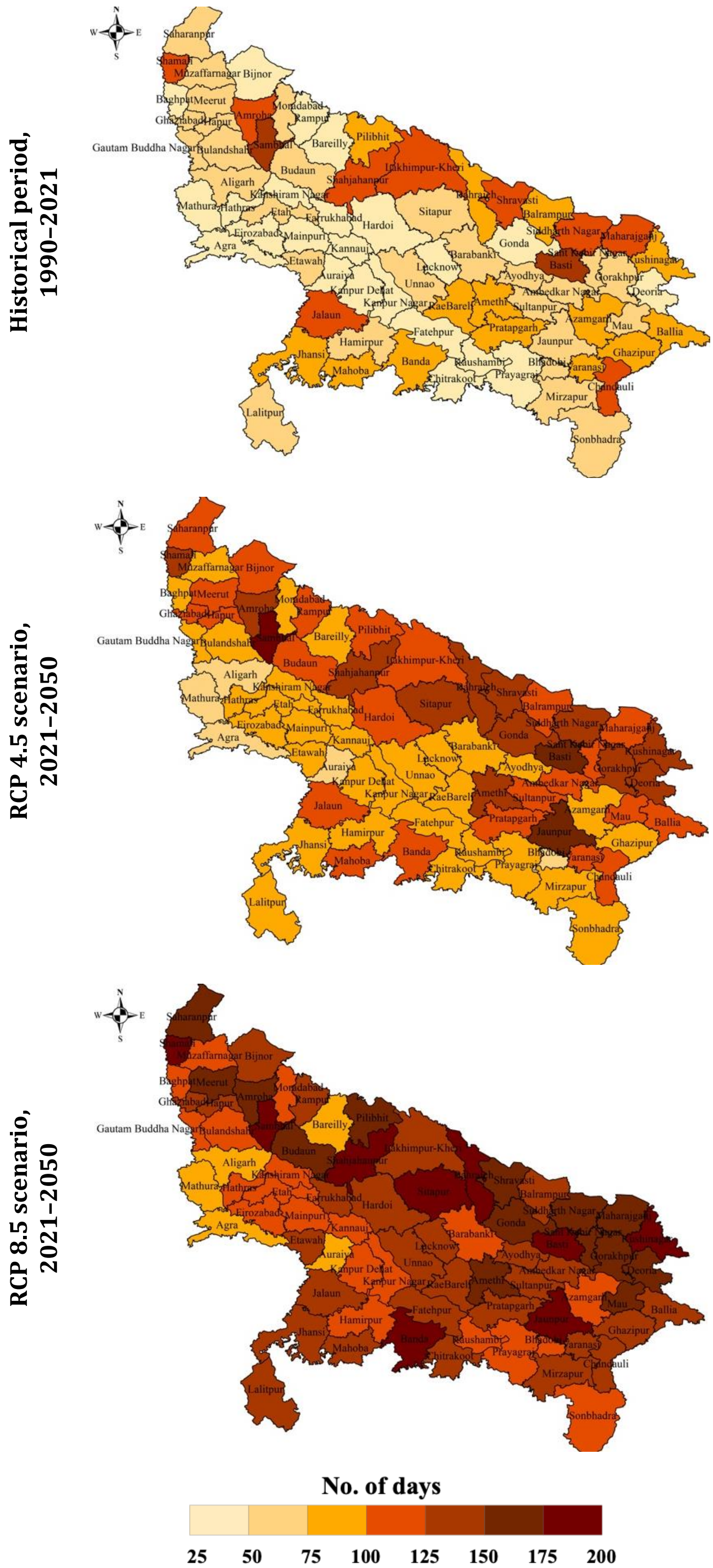


Figure 7-9: The total number of high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

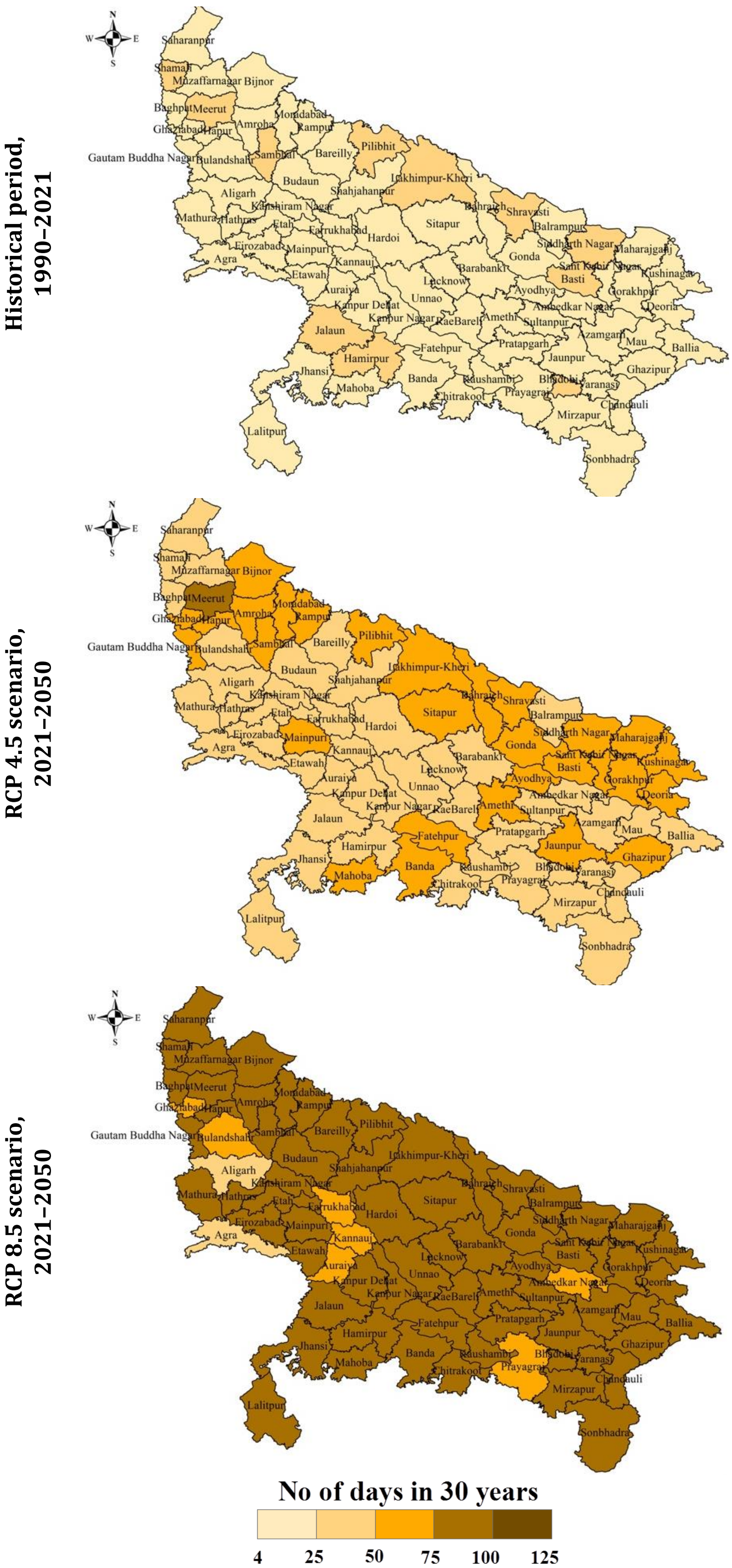


Figure 7-10: The total number of very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

Rainfall deficient years (Figure 7-11)

Rainfall deficient years, computed considering the rainfall during the kharif season, are projected to decline in all the districts of Uttar Pradesh under both climate scenarios. The number of rainfall deficient years declines from 8 to 16 years during the historical period to 7 to 14 years under the RCP 4.5 and RCP 8.5 scenarios during the projected period.

RCP 4.5 scenario: A decline in rainfall deficient years is projected in 48 of the 75 districts of Uttar Pradesh. The decline is by 5 to 7 years in Farrukhabad, Mahoba, Unnao, Bhadohi, Gonda, Jaunpur, and Shamli; 3 to 4 years in Ballia, Chandauli, Gautam Buddha Nagar, Rampur, Shahjahanpur, Sitapur, Chitrakoot, Kaushambi, Lakhimpur Kheri, Lucknow, and Pratapgarh; and one to two years in 30 districts. No change is projected in 21 districts, and an increase by 2 years is projected in Varanasi and one year is projected in Siddharth Nagar, Sitapur, Sonbhadra, Sultanpur, and Unnao.

RCP 8.5 scenario: A decline in rainfall deficient years is projected in 67 of the 75 districts of Uttar Pradesh. The decline is by 5 to 8 years in Farrukhabad, Mahoba, Unnao, Gonda, Jaunpur, Shahjahanpur, Bhadohi, Shamli, Gautam Buddha Nagar, Rampur, Sitapur, and Amethi; 3 to 4 years in 19 districts; and one to two years in 36 districts. No change is projected in Ghazipur, Basti, Etawah, Baghpat, Bulandshahr, Fatehpur, and Firozabad and an increase by one year is projected in Sant Kabir Nagar.

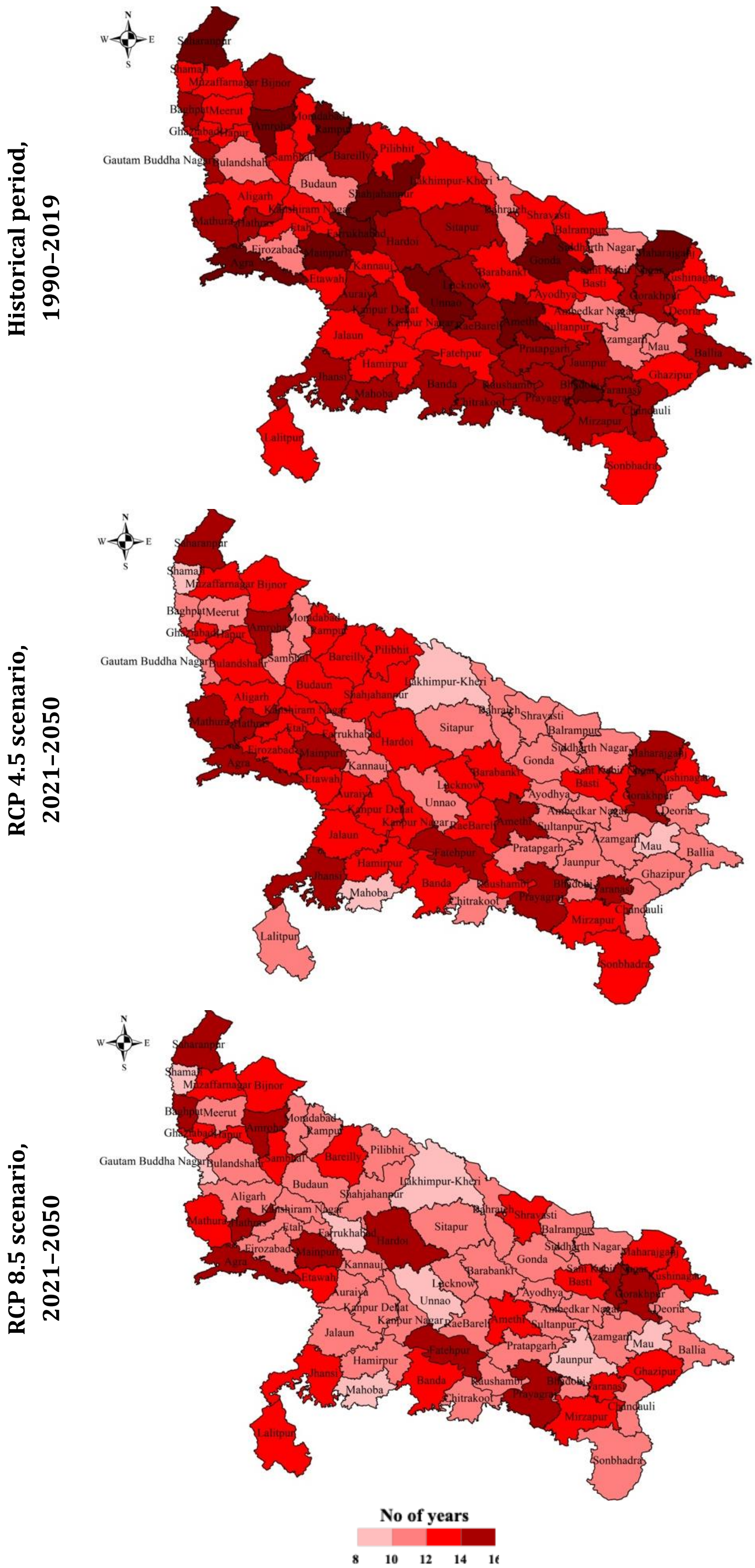


Figure 7-11: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

7.4. The summary of projected changes in the climate for Uttar Pradesh

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 7-1).

- Summer maximum and winter minimum temperatures are projected to increase by 1°C to 1.5°C under the RCP 4.5 scenario.
- Summer maximum temperature and winter minimum temperatures are projected to increase by 2°C under the RCP 8.5 scenario.

Rainfall is projected to increase in the short term (2021–2050) in all the districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 7-2).

- The projected increase is in the range of 2% to 37% under the RCP 4.5 scenario and 5% to 41% 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 both climate scenarios.

- An increase in rainfall variability during the kharif season by 2% to 16% is projected in 23 districts under the RCP 4.5 scenario and by 0.3% to 12% in 23 districts under the RCP 8.5 scenario.
- A decline in rainfall variability during the kharif season by 0.4% to 23% in 52 districts under the RCP 4.5 scenario is projected and 1% to 27% in 52 districts under the RCP 8.5 scenario is projected.

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 7-3).

- The projected increase, compared to the historical period, is by 6% to 11% under the RCP 4.5 scenario and 8% to 14% under the RCP 8.5 scenario.

An increase in the occurrence of heavy rainfall events is projected in a majority of the districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 7-4).

- High-intensity rainfall events are projected to double or treble in many districts under both the climate scenarios, and very high-intensity rainfall events are projected to largely double under both the climate scenarios.

Rainfall deficient years are projected to decline in a majority of the districts under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 7-4).

Appendix

Appendix 7-1: Changes in temperature under climate scenarios

Districts	Change in temperature (°C) during 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
Agra	1.3	1.7	1.2	1.5
Aligarh	1.6	1.8	1.1	1.4
Ambedkar Nagar	1.2	1.4	1.4	1.7
Amethi	0.5	1.5	1.0	2.0
Amroha	1.6	1.9	1.4	1.7
Auraiya	1.2	1.4	1.2	1.3
Ayodhya	1.2	1.5	1.3	1.7
Azamgarh	1.3	1.5	1.4	1.7
Baghpat	1.2	1.7	1.4	1.8
Bahraich	1.6	1.9	1.4	1.7
Ballia	1.3	1.5	1.2	1.8
Balrampur	1.4	1.6	1.5	1.8
Banda	1.4	1.5	1.4	1.7
Barabanki	1.2	1.4	1.3	1.8
Bareilly	1.6	1.8	1.3	1.9
Basti	1.2	1.4	1.4	1.7
Bhadohi	1.3	1.5	1.3	1.8
Bijnor	1.6	1.9	1.2	1.6
Budaun	1.6	1.8	1.4	1.8
Bulandshahr	1.4	1.7	1.5	1.8
Chandauli	1.2	1.5	1.3	1.6
Chitrakoot	1.1	1.3	1.4	1.7
Deoria	1.2	1.5	1.3	1.8
Etah	1.6	1.8	1.4	1.7
Etawah	1.4	1.7	1.2	1.5
Farrukhabad	1.5	1.5	1.4	1.7
Fatehpur	1.3	1.5	1.1	1.3
Firozabad	1.4	1.8	1.2	1.5
Gautam Buddha Nagar	1.2	1.7	1.2	1.4
Ghaziabad	1.3	1.6	1.2	1.6
Ghazipur	1.1	1.4	1.3	1.6
Gonda	1.2	1.5	1.1	1.6
Gorakhpur	1.3	1.4	1.4	1.8
Hamirpur	1.3	1.5	1.3	1.8

Hapur	1.2	1.6	1.3	1.8
Hardoi	1.3	1.4	1.4	1.7
Hathras	1.5	1.7	1.2	1.3
Jalaun	1.3	1.6	1.2	1.6
Jaunpur	1.1	1.4	1.1	1.7
Jhansi	1.4	1.8	1.3	1.8
Kannauj	1.2	1.4	1.3	1.7
Kanpur Dehat	1.1	1.4	1.3	1.5
Kanpur Nagar	1.2	1.4	1.3	1.6
Kasganj	1.6	1.8	1.3	1.8
Kaushambi	1.2	1.4	1.2	1.3
Kushinagar	1.1	1.3	1.3	1.7
Lakhimpur Kheri	1.3	1.6	1.2	1.6
Lalitpur	1.2	1.7	1.3	1.8
Lucknow	1.2	1.4	1.2	1.6
Maharajganj	1.1	1.3	1.4	1.8
Mahoba	1.2	1.6	1.2	1.8
Mainpuri	1.3	1.7	1.3	1.7
Mathura	1.4	1.8	1.2	1.4
Mau	1.3	1.5	1.3	1.7
Meerut	1.6	1.8	1.3	1.8
Mirzapur	1.1	1.4	1.2	1.4
Moradabad	1.6	1.7	1.3	1.7
Muzaffarnagar	1.6	1.8	1.4	1.8
Pilibhit	1.3	1.7	1.2	1.6
Pratapgarh	1.2	1.4	1.3	1.7
Prayagraj	1.0	1.3	1.3	1.5
Raebareli	1.2	1.3	1.2	1.7
Rampur	1.3	1.7	1.3	1.8
Saharanpur	1.7	1.9	1.3	1.7
Sambhal	1.3	1.7	1.2	1.6
Sant Kabir Nagar	1.2	1.4	1.3	1.7
Shahjahanpur	1.2	1.6	1.3	1.8
Shamli	1.6	2.6	2.0	2.0
Shravasti	1.4	1.7	1.2	1.6
Siddharth Nagar	1.1	1.3	1.4	1.8
Sitapur	1.2	1.4	1.2	1.6
Sonbhadra	1.3	1.5	1.3	1.6
Sultanpur	1.2	1.4	1.4	1.8
Unnao	1.2	1.4	1.3	1.8
Varanasi	1.2	1.5	1.4	1.7

Appendix 7-2: Changes in rainfall under climate scenarios

Districts	Change in rainfall (%) during 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
Agra	9	12	3	7	8	21
Aligarh	8	11	9	11	18	43
Ambedkar Nagar	11	14	20	25	12	27
Amethi	6	9	17	20	11	90
Amroha	12	14	15	20	0	21
Auraiya	9	11	17	19	5	8
Ayodhya	11	13	12	18	6	32
Azamgarh	7	12	7	13	6	23
Baghpat	8	13	26	31	13	51
Bahraich	11	15	4	12	14	32
Ballia	13	20	27	29	33	73
Balrampur	14	19	14	22	7	26
Banda	13	15	26	32	16	58
Barabanki	12	16	16	17	2	22
Bareilly	11	12	12	13	2	34
Basti	11	17	13	20	9	27
Bhadohi	11	19	2	7	5	20
Bijnor	13	15	14	16	4	19
Budaun	9	17	15	16	14	30
Bulandshahr	12	13	6	9	9	27
Chandauli	11	19	6	13	12	47
Chitrakoot	12	13	25	29	9	35
Deoria	12	21	8	11	7	22
Etah	8	12	9	13	9	34
Etawah	7	8	11	28	7	18
Farrukhabad	13	15	32	36	-4	12
Fatehpur	12	14	12	16	5	44
Firozabad	8	14	20	31	12	33
Gautam Buddha Nagar	7	11	10	15	7	34
Ghaziabad	7	9	21	25	8	39
Ghazipur	13	18	37	41	8	26
Gonda	14	19	14	20	-8	11
Gorakhpur	11	20	11	13	5	18
Hamirpur	12	17	5	6	11	52
Hapur	9	15	11	13	4	33

Hardoi	12	18	11	13	9	15
Hathras	12	15	31	35	18	58
Jalaun	8	10	5	8	6	14
Jaunpur	15	23	12	20	12	38
Jhansi	8	11	5	10	4	14
Kannauj	6	11	4	5	4	26
Kanpur Dehat	6	11	5	10	-3	35
Kanpur Nagar	9	11	4	7	8	46
Kasganj	7	10	15	20	11	68
Kaushambi	12	17	4	6	32	51
Kushinagar	14	21	22	29	8	22
Lakhimpur Kheri	12	17	7	15	9	34
Lalitpur	9	11	31	32	13	22
Lucknow	12	14	2	5	14	34
Maharajganj	11	21	8	15	22	47
Mahoba	9	12	14	16	29	53
Mainpuri	9	11	16	18	17	50
Mathura	9	13	11	13	18	92
Mau	11	16	18	21	7	39
Meerut	7	12	20	22	10	21
Mirzapur	12	17	21	25	45	66
Moradabad	12	15	20	25	20	81
Muzaffarnagar	6	12	7	12	59	82
Pilibhit	13	16	22	28	57	88
Pratapgarh	12	15	13	20	18	48
Prayagraj	14	16	14	17	16	24
Raebareli	12	17	19	33	2	32
Rampur	11	16	10	12	17	43
Saharanpur	10	16	17	24	23	69
Sambhal	13	15	14	16	9	39
Sant Kabir Nagar	13	19	16	22	11	17
Shahjahanpur	11	16	33	35	12	25
Shamli	10	15	7	9	7	35
Shravasti	11	20	20	29	9	28
Siddharth Nagar	11	14	9	13	5	25
Sitapur	12	13	6	10	3	30
Sonbhadra	14	22	30	36	8	27
Sultanpur	12	17	20	24	15	22
Unnao	12	16	12	14	17	48
Varanasi	13	17	11	13	4	22

Appendix 7-3: 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
Agra	840	916	942
Aligarh	1010	1049	1075
Ambedkar Nagar	1237	1490	1512
Amethi	1243	1296	1342
Amroha	1190	1274	1319
Auraiya	1039	1116	1143
Ayodhya	1059	1098	1129
Azamgarh	1074	1391	1428
Baghpat	978	1039	1097
Bahraich	1318	1331	1389
Ballia	1164	1204	1238
Balrampur	1374	1454	1496
Banda	1174	1225	1294
Barabanki	1281	1326	1353
Bareilly	1082	1100	1128
Basti	1335	1344	1386
Bhadohi	1241	1392	1431
Bijnor	877	1290	1325
Budaun	1065	1121	1167
Bulandshahr	1127	1142	1177
Chandauli	1488	1490	1532
Chitrakoot	1187	1586	1603
Deoria	1427	1551	1574
Etah	1071	1233	1273
Etawah	1078	1109	1145
Farrukhabad	1017	1161	1204
Fatehpur	1069	1090	1203
Firozabad	869	1098	1109
Gautam Buddha Nagar	893	934	990
Ghaziabad	1262	1311	1345
Ghazipur	1126	1298	1321
Gonda	933	1158	1210
Gorakhpur	1177	1551	1599
Hamirpur	949	1230	1289
Hapur	1210	1322	1350
Hardoi	1122	1275	1309

Hathras	1165	1177	1221
Jalaun	1178	1214	1270
Jaunpur	1340	1360	1397
Jhansi	1089	1391	1403
Kannauj	1168	1187	1201
Kanpur Dehat	1041	1089	1101
Kanpur Nagar	955	989	1046
Kasganj	1161	1204	1229
Kaushambi	890	917	957
Kushinagar	1544	1614	1664
Lakhimpur Kheri	1380	1451	1495
Lalitpur	1311	1391	1407
Lucknow	1180	1236	1279
Maharajganj	1446	1509	1544
Mahoba	1248	1305	1353
Mainpuri	840	912	953
Mathura	955	1009	1034
Mau	1417	1478	1490
Meerut	921	1042	1070
Mirzapur	1315	1372	1390
Moradabad	1182	1252	1284
Muzaffarnagar	1140	1182	1204
Pilibhit	1200	1257	1293
Pratapgarh	1249	1292	1331
Prayagraj	1162	1315	1347
Raebareli	1276	1297	1329
Rampur	1178	1345	1394
Saharanpur	1100	1180	1235
Sambhal	1511	1670	1699
Sant Kabir Nagar	1412	1571	1612
Shahjahanpur	1095	1165	1186
Shamli	1300	1341	1378
Shravasti	1342	1375	1419
Siddharth Nagar	1414	1492	1560
Sitapur	1132	1167	1192
Sonbhadra	1477	1630	1683
Sultanpur	1314	1429	1498
Unnao	1040	1099	1106
Varanasi	1182	1254	1290

Appendix 7-4: Extreme events under historical (1990–2019) and projected (2021–2050) periods

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
Agra	24	56	78	34	7	41	15	13	12
Aligarh	65	72	93	23	7	34	12	11	10
Ambedkar Nagar	55	103	145	43	18	68	10	10	9
Amethi	90	130	168	53	24	78	16	14	11
Amroha	115	140	167	54	24	89	15	13	12
Auraiya	29	67	96	29	3	52	14	12	10
Ayodhya	75	95	131	56	6	88	12	10	10
Azamgarh	81	96	113	34	15	78	10	11	9
Baghpat	34	78	105	35	5	76	13	14	13
Bahraich	100	126	189	54	24	89	10	10	9
Ballia	81	107	142	33	14	78	14	10	10
Balrampur	80	109	145	41	11	81	12	10	9
Banda	78	124	178	55	12	91	14	12	11
Barabanki	67	84	110	48	20	89	11	11	10
Bareilly	47	79	93	45	13	78	13	12	11
Basti	138	164	181	74	43	93	11	11	11
Bhadohi	67	70	102	44	26	89	15	10	10
Bijnor	44	107	145	58	12	92	13	12	11
Budaun	69	104	156	41	15	86	10	11	9
Bulandshahr	66	79	101	25	5	67	10	11	10
Chandauli	112	120	143	45	21	89	13	9	9
Chitrakoot	32	95	136	47	6	93	13	10	9
Deoria	41	141	168	55	5	89	12	10	10
Etah	66	77	102	41	17	90	12	11	9
Etawah	59	89	132	45	19	91	11	11	11
Farrukhabad	38	97	134	45	9	56	16	9	8
Fatehpur	36	97	139	55	8	91	12	13	12
Firozabad	30	86	114	45	6	97	9	11	9
Gautam Buddha Nagar	59	88	112	52	22	84	13	9	8
Ghaziabad	52	102	133	55	4	74	12	12	11
Ghazipur	94	96	134	55	19	91	11	10	11
Gonda	34	129	167	65	8	89	15	10	9
Gorakhpur	51	142	171	65	14	80	13	13	12
Hamirpur	72	96	123	46	29	86	11	11	10
Hapur	68	110	145	75	9	94	12	12	11
Hardoi	34	113	147	48	2	93	14	12	12
Hathras	44	81	107	45	12	84	13	13	12
Jalaun	114	121	137	35	27	86	12	12	10
Jaunpur	62	153	199	75	9	102	14	9	8
Jhansi	80	96	135	45	15	89	13	13	11
Kannauj	42	78	102	34	4	68	12	10	9
Kanpur Dehat	27	78	112	41	7	87	14	12	10
Kanpur Nagar	44	89	121	35	7	85	11	11	10
Kanshiram Nagar	37	89	121	35	9	88	12	12	10
Kaushambi	44	77	106	45	5	89	14	11	10
Kushi Nagar	87	137	176	56	16	92	12	12	11
Lakhimpur Kheri	112	124	142	65	27	92	11	8	7
Lalitpur	69	94	132	45	14	97	12	10	11
Lucknow	50	82	134	45	11	97	14	11	10
Maharajganj	106	123	156	54	20	89	15	13	11
Mahoba	77	102	143	55	12	87	14	8	7
Mainpuri	49	89	123	52	21	76	15	13	12
Mathura	28	67	96	35	6	89	13	13	11
Mau	69	113	154	45	8	78	8	8	7
Meerut	67	104	156	87	28	100	11	10	9
Mirzapur	58	91	126	45	17	89	13	11	11
Moradabad	69	93	125	65	13	89	11	10	9
Muzaffarnagar	66	92	124	45	15	82	12	12	11
Pilibhit	87	123	156	65	36	91	11	11	10
Pratapgarh	78	110	143	47	15	83	13	10	9
Prayagraj	36	76	101	45	4	62	14	13	12
Raebareli	76	97	141	45	22	90	13	12	10
Rampur	42	105	132	55	12	92	15	11	10
Saharanpur	67	121	166	45	18	90	15	13	12
Sambhal	159	199	204	57	45	86	12	10	11
Sant Kabir Nagar	53	106	151	65	15	89	13	12	14
Shahjahanpur	112	142	183	45	25	79	16	12	10
Shamali	123	143	180	47	34	87	12	7	7
Shravasti	103	143	169	71	32	97	12	10	11
Siddharth Nagar	105	139	168	74	28	95	10	10	9
Sitapur	71	137	178	55	15	91	14	10	9
Sonbhadra	74	95	123	44	12	78	12	11	10
Sultanpur	52	102	143	42	9	78	11	9	9
Unnao	66	91	132	43	16	78	15	9	8
Varanasi	78	104	141	44	14	83	13	13	11

Conclusion

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

Climate projections for the northern 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 northern states of India could have the following implications:

Water: 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 for the northern states clearly indicate that flood management strategies should be integrated with drought management strategies for strengthening adaptation measures and building resilience as we are looking at compounded climate risks in the future.

Agriculture: Climate change could 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. Agriculture crops have specific temperature and water requirements and thrive well under specific climate conditions. Higher temperatures projected in the various districts of northern states can adversely impact crop growth and production. Increasing rainfall 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.

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 northern states have health implications—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) and 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, and a delay in action by 10 years could almost double the costs.

References

Census (2011). Primary Census Abstracts, Registrar General of India, Ministry of Home Affairs, Government of. India. Available at: http://www.censusindia.gov.

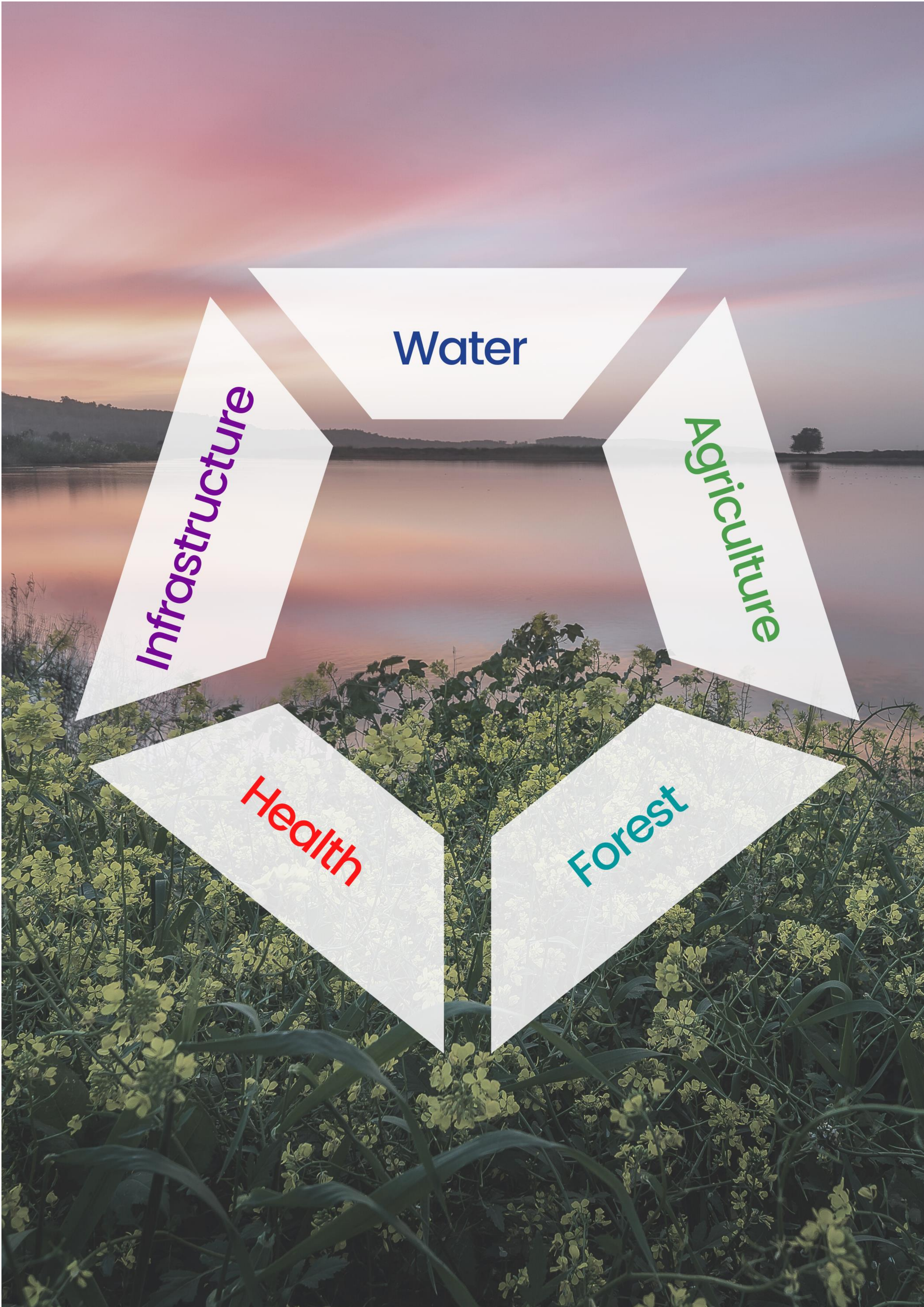
IPCC (2014). Summary for policymakers. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1-32.

IPCC (2021). Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press.

Pai, D. S. Latha, Sridhar. Rajeevan, M. Sreejith, O. P. Satbhai, N. S. & Mukhopadhyay, B. (2014). Development of a new high spatial resolution (0.25° X 0.25°) Long period (1901–2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region; *MAUSAM*, 65, 1: 1-18.

Srivastava, A. & Rajeevan, M. & Kshirsagar, S. (2009). Development of a high resolution daily gridded temperature data set (1969–2005) for the Indian region. *Atmospheric Science Letters*. 10. 249 - 254. 10.1002/asl.232.

Taylor, K. E. Stouffer, R. J. & Meehl, G. A. (2012). An overview of CMIP5 and the experiment design. *Bull Am Meteorol Soc*. 78: 485–498.


Water
Agriculture
Forest
Health
Infrastructure

CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

Bengaluru
#18 & 19, 10th Cross, Mayura Street,
Papanna Layout, Nagashettyhalli (RMV II Stage),
Bengaluru-560094, Karnataka, India

Noida
1st Floor, Tower-A, Smartworks Corporate Park, Sector-125,
Noida-201303, Uttar Pradesh, India

www.cstep.in | +91-8066902500 | cpe@cstep.in | @cstep_India