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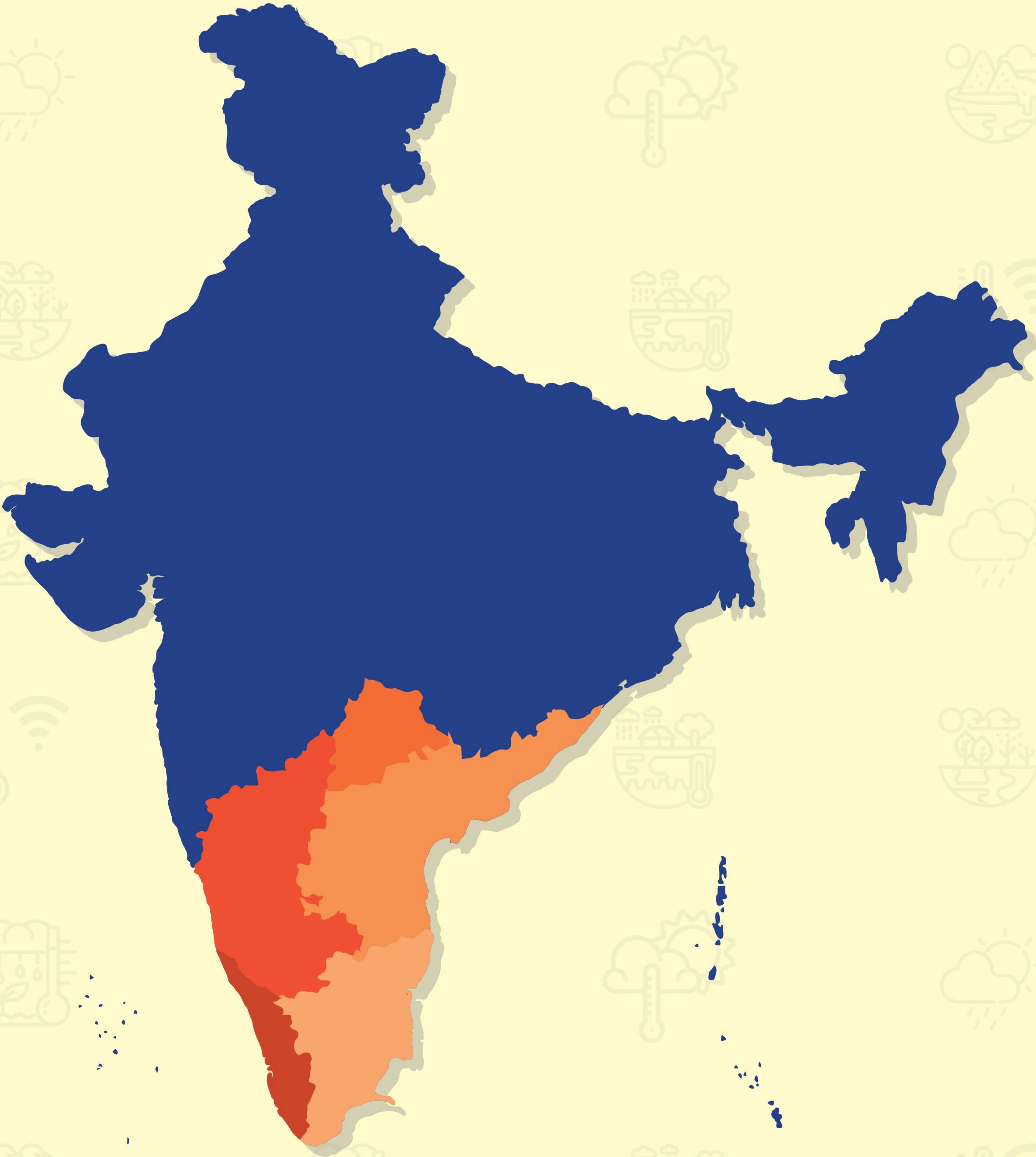
DISTRICT-LEVEL CHANGES IN CLIMATE:

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



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

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Executive Summary

Background and motivation: The impacts of climate variability, climate change, and extreme events are visible globally and in India. The Global Climate Risk Index 2021 ranks India seventh, considering the extent to which India has been affected by the impacts of weather-related loss events (storms, floods, heatwaves, etc.). The index signals that repercussions of escalating climate change are exacerbating and can no longer be ignored. The Government of India and state governments are committed to reducing the vulnerability of communities and ecosystems to climate change and building resilience to climate change risks. A good understanding of 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 southern states of India: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, and Telangana.

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

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

Temperature

The projected increase in the winter minimum temperature is comparatively higher than the increase in the summer maximum temperature in all the southern states except Kerala and Tamil Nadu. In these two states, the increase in summer and winter minimum temperatures is the same compared to the historical temperatures. The summer maximum temperature is projected to increase by 0.5^{0}C to 1.5^{0}C, and the winter minimum temperature is projected to increase by 1^{0}C to 2^{0}C in a majority of the districts of southern India.

Rainy days

The number of rainy days is projected to increase in the 2030s in almost all the districts of southern India compared to the historical period. The increase is by 1 to 31 days under the RCP 4.5 scenario, with the maximum increase projected in Kerala and a minimum increase projected in Andhra Pradesh. The increase is by 1 to 29 days under the RCP 8.5 scenario, with the maximum increase projected in Karnataka.

Monsoon rainfall

Rainfall during kharif (June to September) and rabi (October to December) seasons are projected to increase in the 2030s in almost all the districts of southern India compared to the historical period. The projected increase in the kharif season rainfall is by 2% to 29% under the RCP 4.5 scenario and 5% to 34% under the RCP 8.5 scenario. The maximum increase in the kharif season rainfall is projected in the districts of Andhra Pradesh. The rabi season rainfall is projected to increase by 1% to 59% under the RCP 4.5 scenario and 5% to 46% 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 southern India compared to the historical period. However, the increase in rainfall variability is more than the decline in all the states, particularly during the kharif season.

Heavy rainfall events

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

Rainfall deficient years

A decline in rainfall deficient years is projected in the 2030s across almost all the districts of southern India compared to the historical period. The decline in rainfall deficient years is by 1 to 5 years out of 30 years under both RCP 4.5 and RCP 8.5 scenarios.

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

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

Contents

1. Introduction

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

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

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

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

1.1. Why model climate outputs?

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

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

1.2. The need for district-level climate model outputs

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

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

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

2. Methodology

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

2.1. Historical climate analysis

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

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

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

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

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

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

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

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

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

2.2. Climate change projections

Climate science is continuously advancing as groups involved in modelling worldwide are constantly updating and incorporating better spatial resolution, new physical processes, and

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

biogeochemical cycles. The Coupled Model Intercomparison Projects (CMIP) is a forum where different modelling groups coordinate. The fifth assessment report (AR5) of the IPCC featured the fifth generation of CMIP—the CMIP5. In India, the high-resolution regional climate modelling work of CMIP5 is coordinated by the Centre for Climate Change Research (CCCR) at the Indian Institute of Tropical Meteorology, Pune.

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

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

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

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

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

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

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

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

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

2.3. Limitations of the study

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

2.4. The organisation of the report

This report is for the five southern states of India: Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, and Telangana. 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. Andhra Pradesh

Andhra Pradesh has an area of 162,968 sq. km and a population of 49.39 million. Odisha and Chhattisgarh border it in the north, Telangana and Karnataka in the west, and Tamil Nadu in the south. The state has two major regions: Coastal Andhra to the east and north-east, bordering the Bay of Bengal, and Rayalaseema—which is arid, semi-arid, and chronically drought-prone—located inland in the south-western part of the state. Andhra Pradesh has 13 districts, nine of which are located in Coastal Andhra and four in Rayalaseema. It has the second-longest coastline (974 km), and forests constitute a major natural resource, covering 22.5% of the state. Krishna and Godavari are the major rivers in the state.

The east coast of Andhra Pradesh is one of the most cyclone-prone areas in the world. It has a population of about 2.9 million people, and most of them are small landholders, making them vulnerable. Estimates from the Department of Disaster Management, Government of Andhra Pradesh, show that about 44% of the state is susceptible to tropical storms and related hazards. The coastal plains are under intense agriculture, and the state faces issues of groundwater exploitation, seawater intrusion, and land degradation. The deltas of the Krishna and Godavari rivers experience recurrent floods, and six out of the 13 districts are chronically drought-prone. Heatwaves are also a common hazard plaguing the state.

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

3.1. Historical climate

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

3.1.1. Trends in temperature

Andhra Pradesh recorded a moderate warming of 0.04°C to 0.22°C in the summer maximum temperature and a relatively higher warming of 0.3°C to 0.52°C in the winter minimum temperature during the historical period. Figure 3-1 presents the mean summer maximum and winter minimum temperatures in Andhra Pradesh during the historical period.

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

3.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual rainfall, in the range of 10% to 15%, was recorded in a majority of the districts. In the kharif season, a >15% increase in rainfall was recorded in the eastern and northern districts of the state. In the rest of the districts, the increase was in the range of 5% to 10%. Likewise, an increase in the rabi season rainfall, in the range of 5% to 10%, was recorded in a majority of the districts. Figure 3-2 presents the mean annual rainfall in Andhra Pradesh during the historical period.

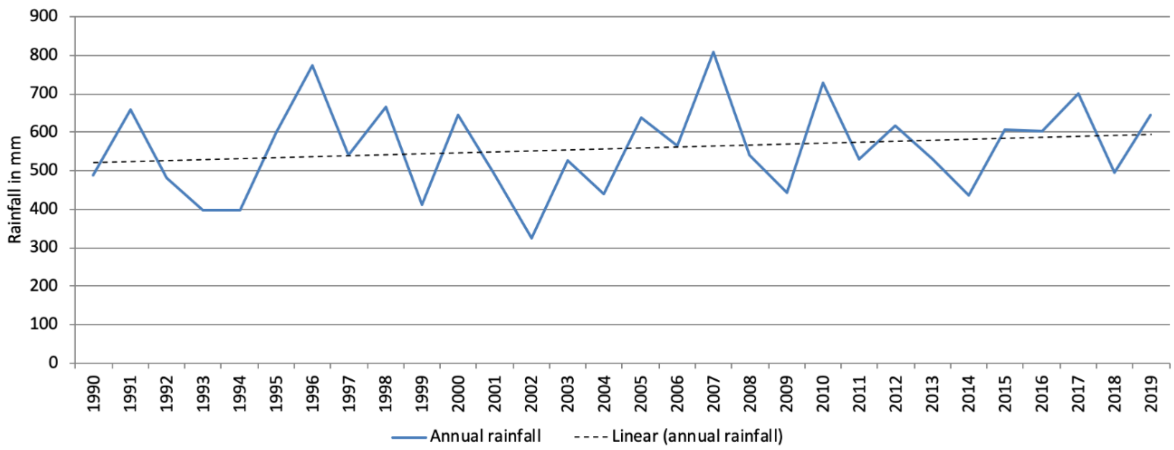


Figure 3-2: Mean annual rainfall in Andhra Pradesh during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 19% in Vizianagaram to 45% in Chittoor (Figure 3-3). The rabi season rainfall variability was in the range of 35% in Sri Potti Sriramulu Nellore to 73% in Srikakulam during the historical period (Figure 3-3).

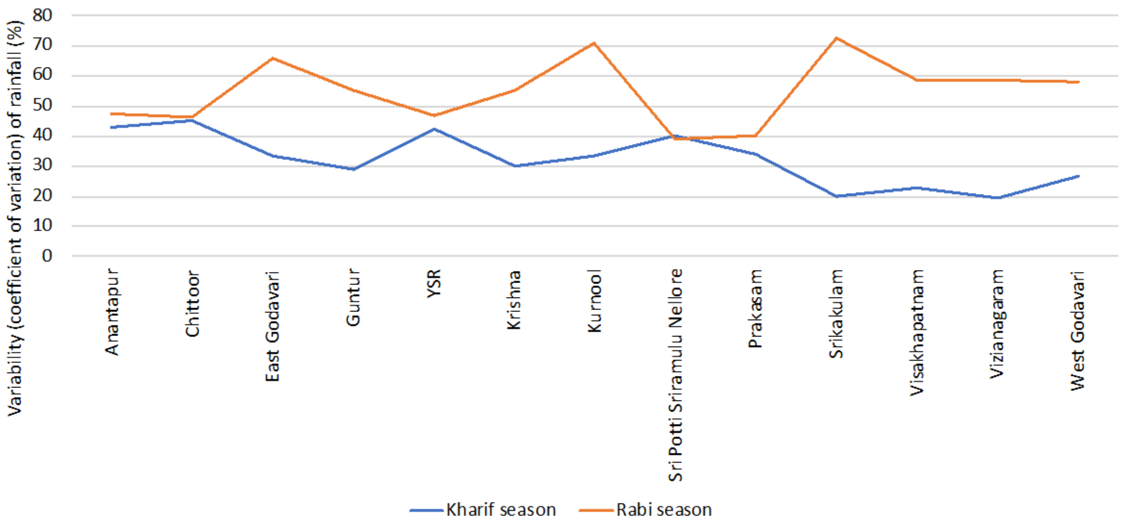


Figure 3-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

3.2. Climate change projections

Temperature and rainfall 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 summer maximum and winter minimum temperatures for all the districts of Andhra Pradesh 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 up to 1^{0}C	Increases by 1^{0}C to 1.5^{0}C
RCP 8.5	Increases by 0.5^{0}C to 1.5^{0}C	Increases by 1^{0}C to 2^{0}C

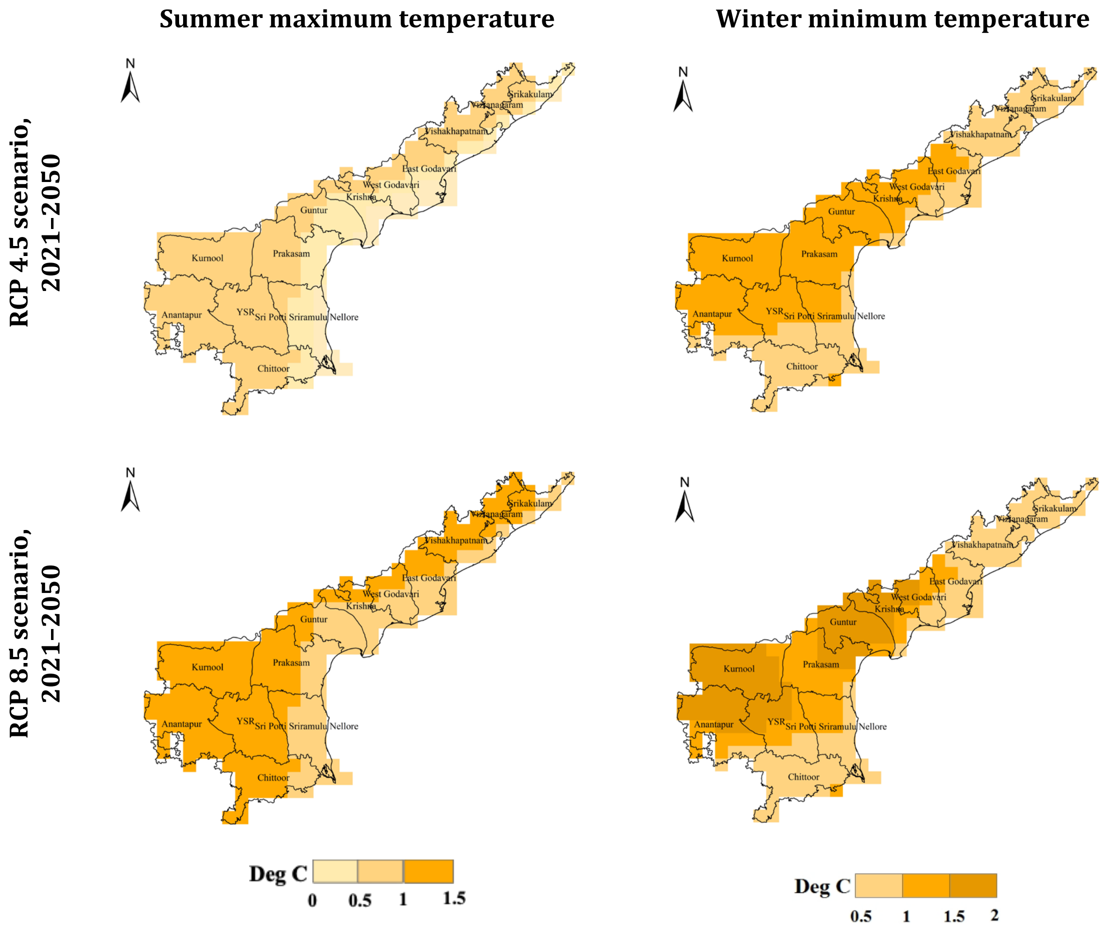


Figure 3-4: Projected changes in summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

3.2.1.1. Heatwaves

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

The analysis of temperature during the projected period of the 2030s shows that there would be a further increase in the number of heatwaves (departure from the normal temperature is 4.5°C to 6.4°C) and severe heatwaves (departure from the normal temperature is >6.4°C), as categorised by the India Meteorological Department (IMD) under both RCP 4.5 and RCP 8.5 scenarios (Figure 3-5) compared to the historical period (1990–2019).

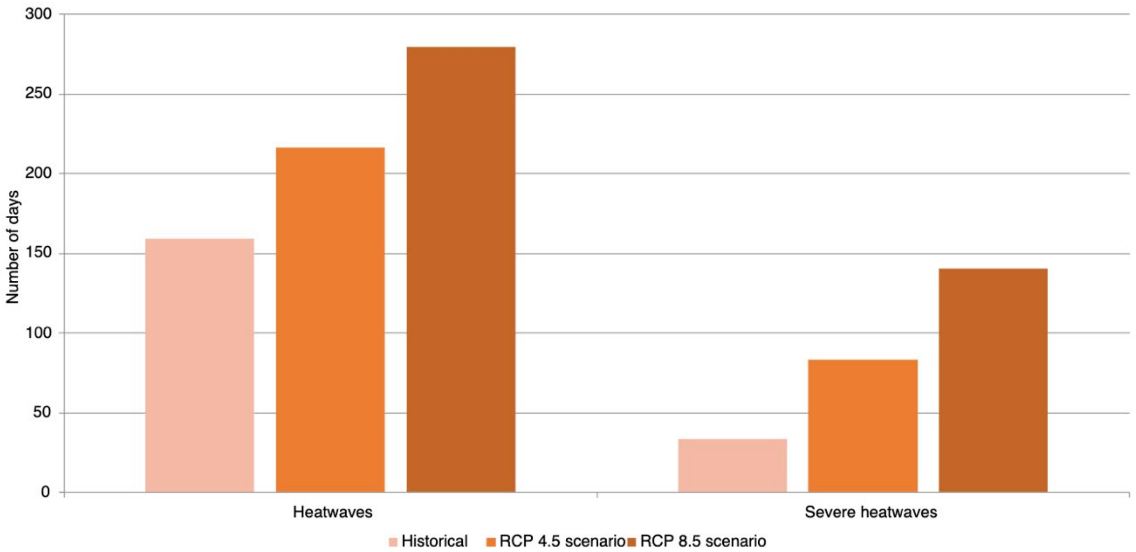


Figure 3-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

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 both RCP 4.5 and 8.5 scenarios is presented in Appendix 3-1. The total number of rainy days that ranged from 647 to 1444 days over the 30-year historical period increases to 670 to 1467 days under the RCP 4.5 scenario and 695 to 1490 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 day annually in all the districts

RCP 8.5 scenario: Projected to increase by 2 to 3 days, with an increase of 3 days per annum in YSR, Kurnool, Sri Potti Sriramulu Nellore, and Prakasam districts

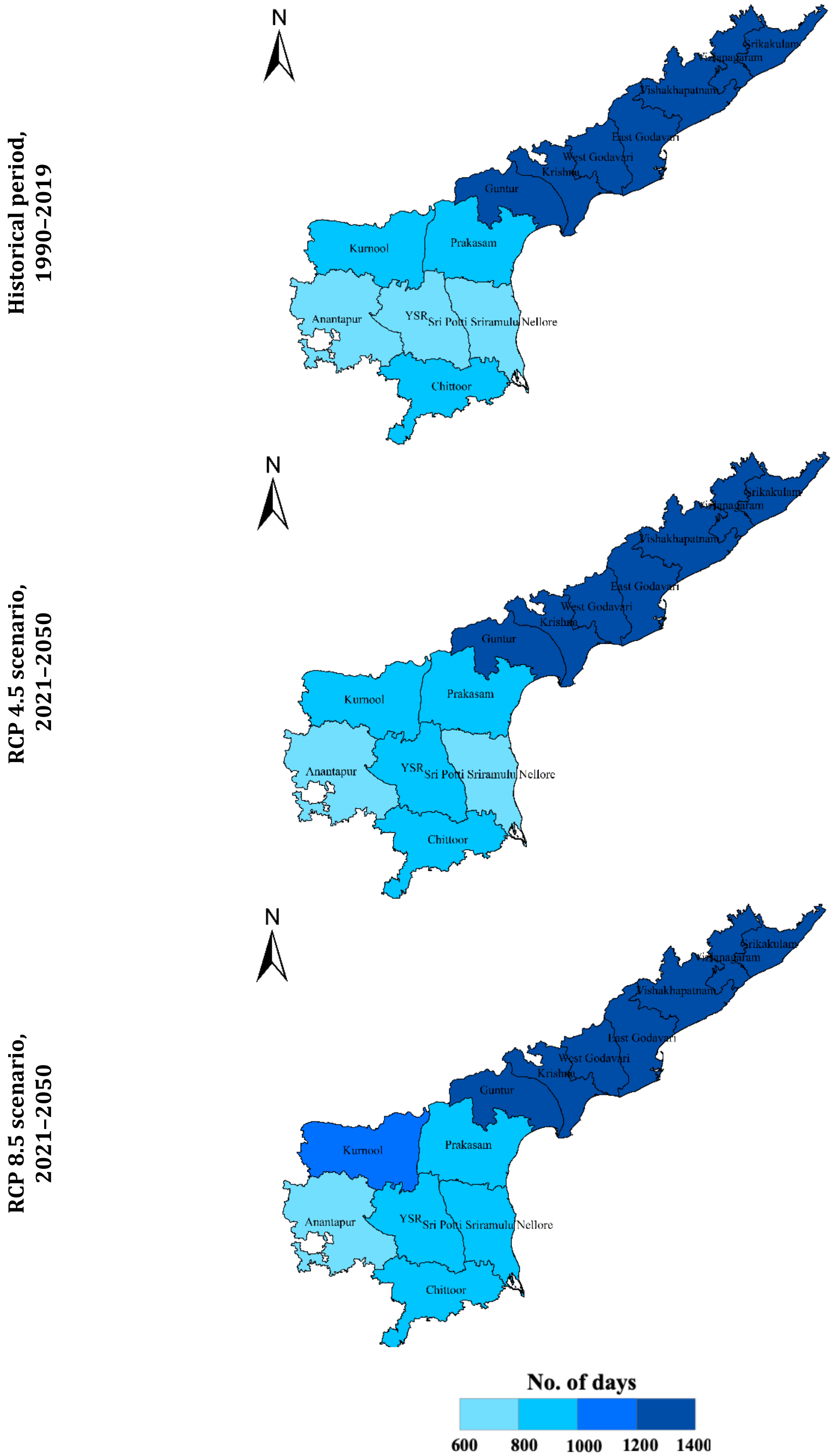


Figure 3-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

3.2.2.2. Mean rainfall and rainfall variability during the kharif season

Andhra Pradesh receives rainfall from both south-west and north-east monsoons. 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 4% in East Godavari to 29% in Sri Potti Sriramulu Nellore	Increases in six districts by 4% to 8% and declines in seven districts by 2% to 14%
RCP 8.5	Increases in all the districts, from 13% in Kurnool to 34% in Sri Potti Sriramulu Nellore and YSR	Increases in six districts by 3% to 7% and declines in seven districts by 1% to 14%

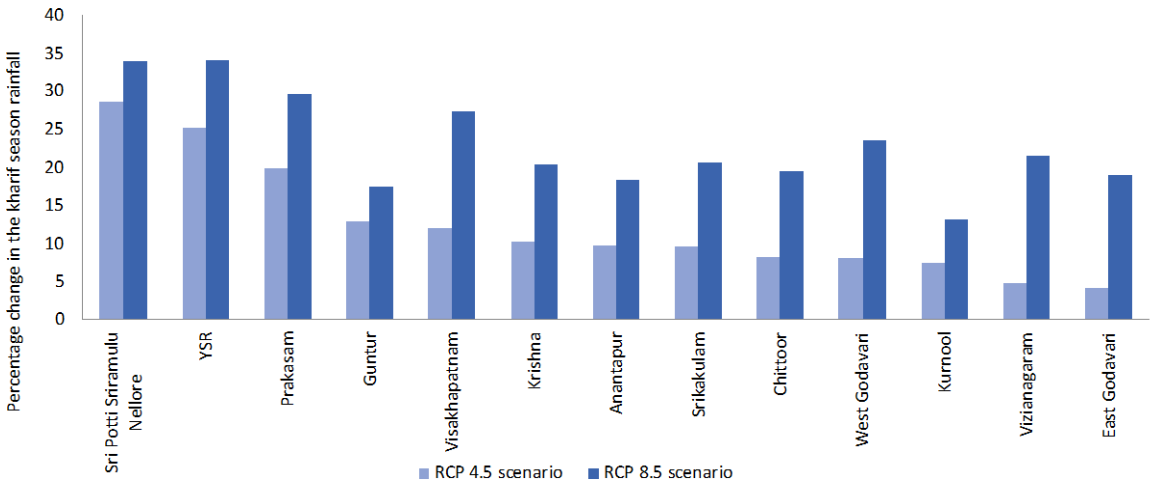


Figure 3-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

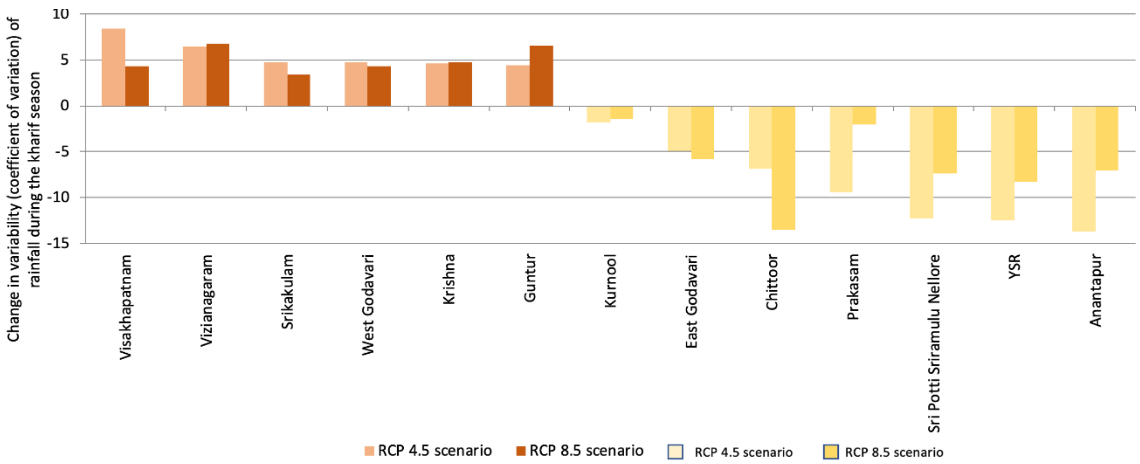


Figure 3-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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 2% in Anantapur to 40% in West Godavari	Declines in nine districts by 1% to 21% and increases in four districts by 1% to 6%
RCP 8.5	Increases in all the districts, from 6% in Chittoor and Visakhapatnam to 45% in West Godavari	Declines in nine districts by 4% to 23% and increases in four districts by 8% to 14%

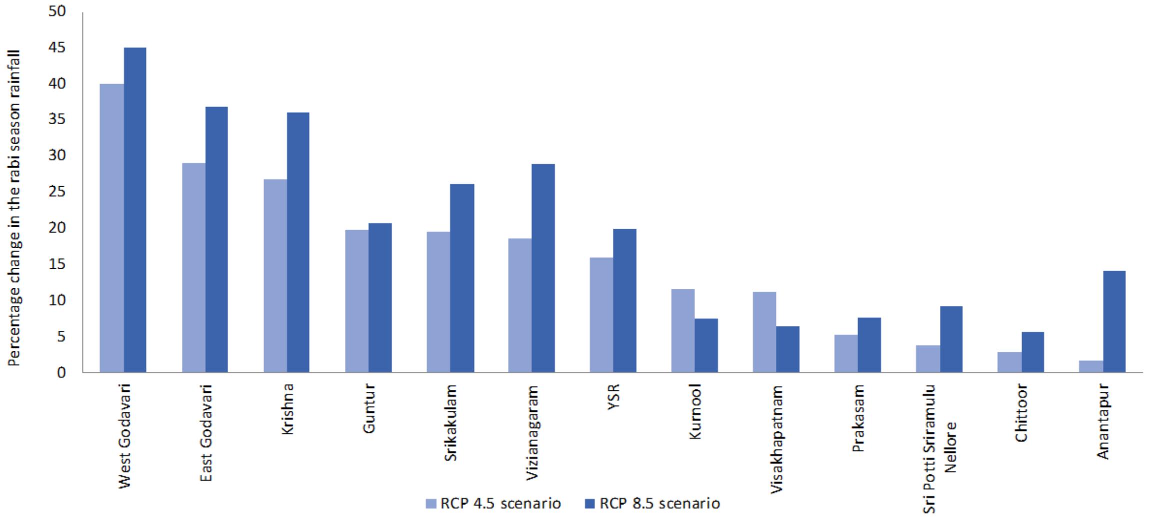


Figure 3-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

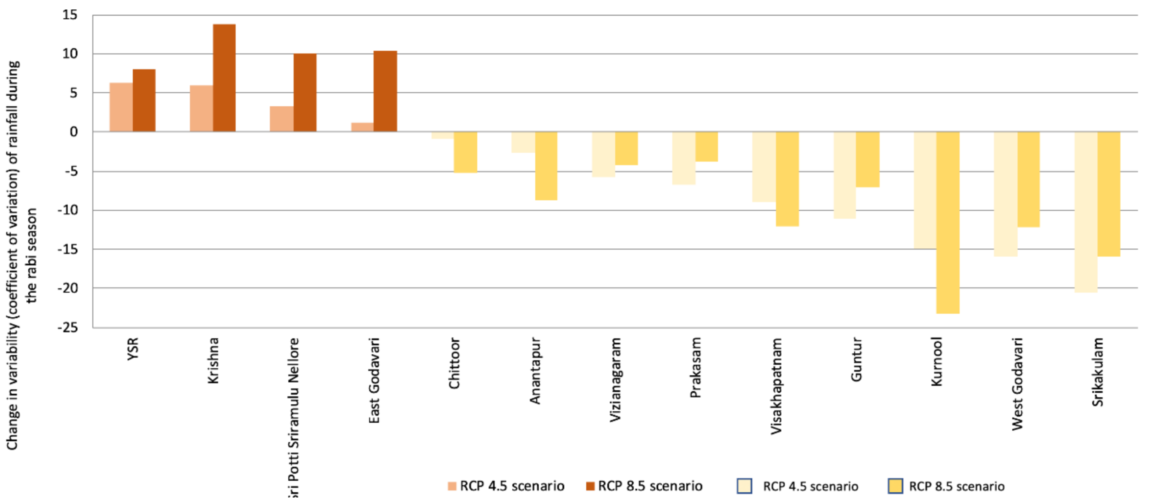


Figure 3-10: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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, termed 'Low' intensity; 51–100 mm/day, termed 'High' intensity; and >100 mm/day, termed 'Very High' intensity. The number of such events was computed for the historical period and for the 2030s under the two climate scenarios, and the change was computed for all the districts of Andhra Pradesh.

High-intensity rainfall events (Figure 3-11)

The total number of high-intensity rainfall events increases from 32 to 65 days during the historical period (1990–2019) to 39 to 65 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 40 to 67 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 event in all the districts.

RCP 8.5 scenario: The projected increase per annum is by one event in all the districts.

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

The total number of very high-intensity rainfall events increases from 5 to 17 days during the historical period (1990–2019) to 11 to 30 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 12 to 27 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 event in all the districts.

RCP 8.5 scenario: The projected increase per annum is by one event in all the districts.

Rainfall deficient years (Figure 3-12)

Rainfall deficient years, computed by considering the rainfall during the kharif season, are projected to decline in all the districts of Andhra Pradesh under both climate scenarios. The number of rainfall deficient years declines from 8 to 15 years during the historical 30-year period to 5 to 14 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: The projected decline is by 1 to 5 years (over a 30-year period) in 10 districts and 1 year in Visakhapatnam. No changes are projected for YSR and Vizianagaram districts. The projected decline is by 2 to 5 years in East Godavari, Prakasam, Chittoor, Guntur, Krishna, and West Godavari districts.

RCP 8.5 scenario: The projected decline is by 1 to 5 years in all the districts, with 3 to 5 years decline in Prakasam, East Godavari, Chittoor, Guntur, Krishna, Anantapur, and Sri Potti Sriramulu Nellore districts.

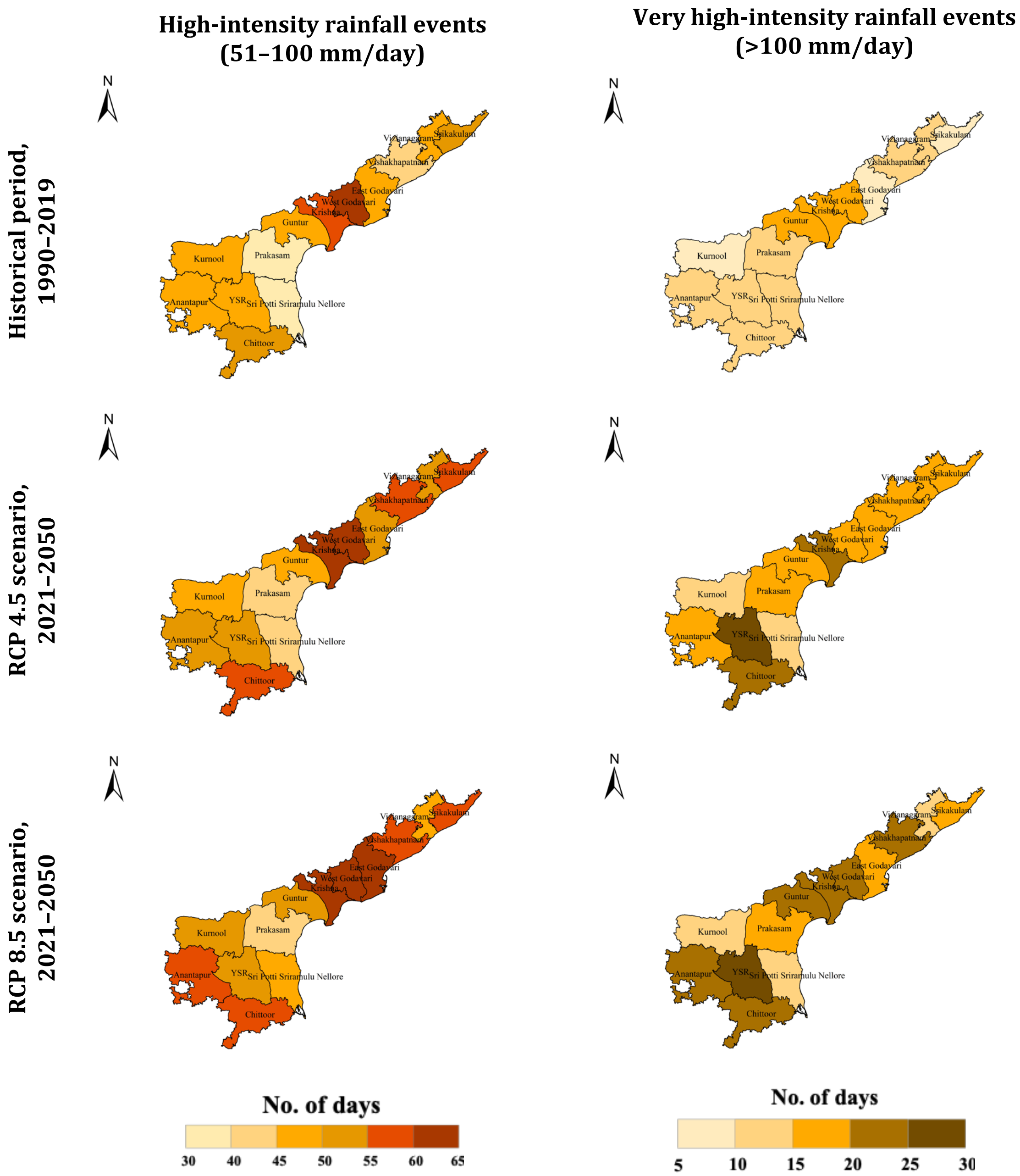


Figure 3-11: The total number of high-intensity and very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

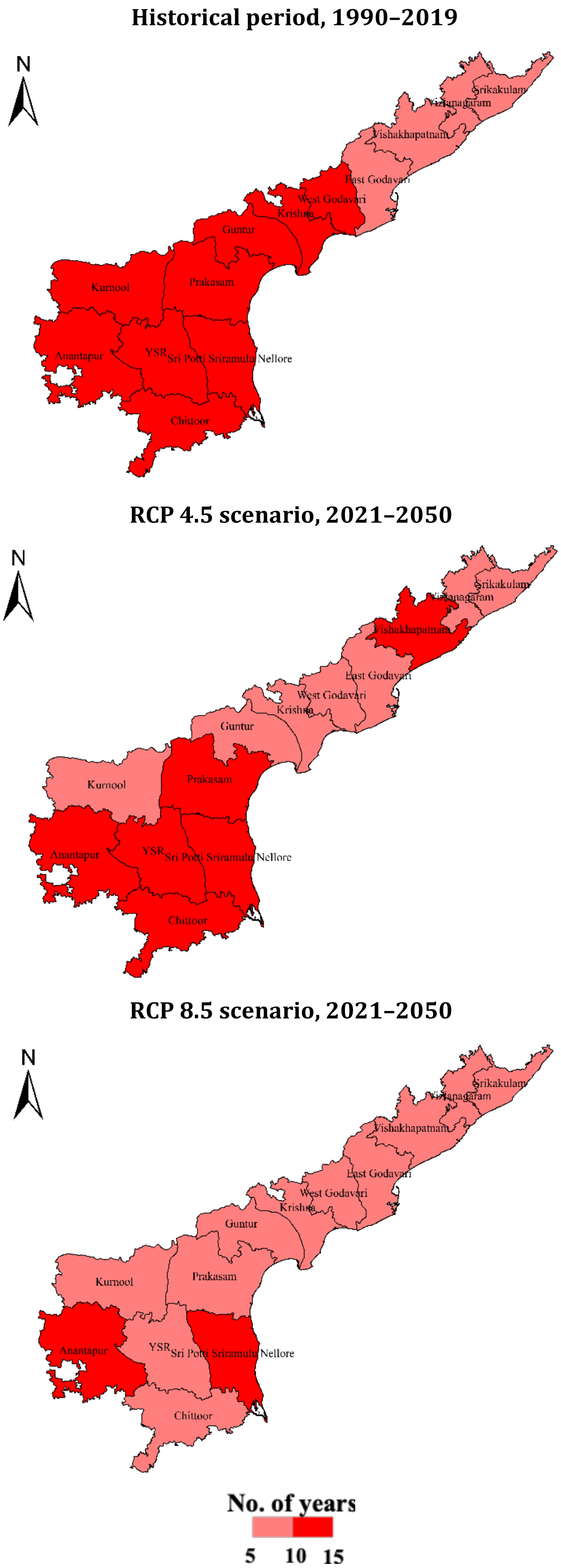


Figure 3-12: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

3.4. The summary of projected changes in the climate for Andhra Pradesh

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

- The summer maximum temperature is projected to warm by up to 1°C under the RCP 4.5 scenario and by 0.5°C to 1.5°C under the RCP 8.5 scenario.
- The winter minimum temperature is projected to warm by 1°C to 1.5°C under the RCP 4.5 scenario and 1°C to 2°C under the RCP 8.5 scenario.

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

- There will be a notable increase in rainfall in the high rainfall districts of Visakhapatnam, Srikakulam, West Godavari, and Sri Potti Sriramulu Nellore.

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

- The projected decline in rainfall variability is in the low rainfall districts: Anantapur, YSR, and Kurnool.
- The projected increase in variability is in the relatively high rainfall coastal districts: Visakhapatnam, West Godavari, and Krishna.

Rainfall variability during the rabi season is projected to decline in all the districts under the RCP 8.5 scenario but is projected to increase in a few districts under the RCP 4.5 scenario.

- The projected increase in variability is in the districts of Prakasam, Guntur, Sri Potti Sriramulu Nellore, YSR, and Krishna.

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

- The increase annually is by 1 day in all the districts under the RCP 4.5 scenario and 1 to 3 days under the RCP 8.5 scenario. An increase of 3 days per annum is projected in the YSR, Kurnool, Sri Potti Sriramulu Nellore, and Prakasam districts.

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 3-5).

- High-intensity rainfall events are projected to increase by one event per annum under both the climate scenarios.
- Very high-intensity rainfall events are projected to increase by one event per annum under both the climate scenarios.

Rainfall deficient years are projected to decline in all the districts under the RCP 8.5 scenario and in 10 of the 13 districts under the RCP 4.5 scenario compared to the historical period (1990–2019; Appendix 3-5).

Appendix

Appendix 3-2: Changes in temperature under climate scenarios

Districts	Changes in temperature (^{o}C) during the 2030s (2021–2050) compared to the historical period (1990–2019)			
	Summer maximum temperature		Winter minimum temperature	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Anantapur	0.7	1.0	1.5	1.6
Chittoor	0.2	1.2	1.2	1.4
East Godavari	0.4	1.3	1.7	2.1
Guntur	0.3	1.5	1.7	1.7
YSR	0.3	1.3	1.6	1.6
Krishna	0.4	1.2	1.5	1.7
Kurnool	0.4	1.4	1.6	1.7
Sri Potti Sriramulu Nellore	0.4	1.4	1.4	1.4
Prakasam	0.3	1.4	1.6	1.7
Srikakulam	0.5	1.4	1.7	2.0
Visakhapatnam	0.2	1.3	1.0	1.5
Vizianagaram	0.2	1.2	1.5	2.1
West Godavari	0.4	1.1	1.3	1.7

Appendix 3-3: 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
Anantapur	6	16	10	19	2	14
Chittoor	8	13	8	20	3	6
East Godavari	21	31	4	19	29	37
Guntur	14	17	13	17	20	21
YSR	13	15	25	34	16	20
Krishna	10	21	10	20	27	36
Kurnool	18	27	7	13	12	8
Sri Potti Sriramulu Nellore	14	27	29	34	4	9
Prakasam	8	26	20	30	5	8
Srikakulam	13	28	10	21	20	26
Visakhapatnam	10	21	12	27	11	6
Vizianagaram	9	21	5	21	19	29
West Godavari	11	21	8	24	40	45

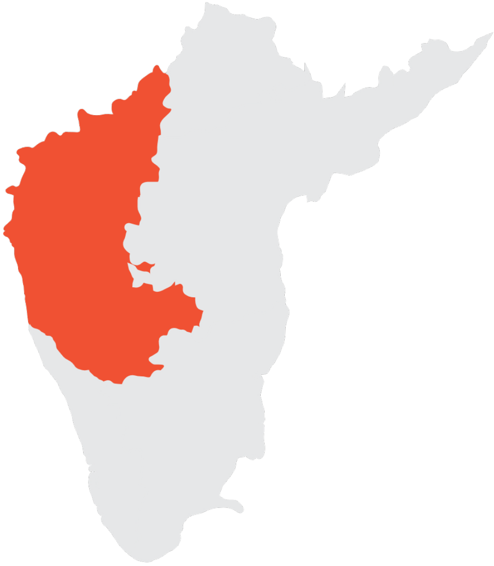
Appendix 3-4: The total number of rainy days (>2.5 cm/day) during the historical period (1990–2019) and the projected 2030s (2021–2050)

Districts	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Anantapur	647	670	695
Chittoor	916	940	990
East Godavari	1201	1230	1265
Guntur	1233	1267	1289
YSR	793	832	876
Krishna	1280	1312	1344
Kurnool	942	980	1023
Sri Potti Sriramulu Nellore	728	765	812
Prakasam	897	934	977
Srikakulam	1444	1467	1478
Visakhapatnam	1210	1233	1267
Vizianagaram	1433	1466	1490
West Godavari	1342	1373	1390

Appendix 3-5: 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
Anantapur	49	57	55	13	20	21	14	13	11
Chittoor	51	58	58	15	25	25	14	12	10
East Godavari	50	62	51	10	18	17	10	5	6
Guntur	50	55	50	16	21	19	12	10	8
YSR	50	55	52	11	30	27	11	11	10
Krishna	60	61	66	17	23	21	12	10	9
Kurnool	46	55	50	5	11	12	11	10	9
Sri Potti Sriramulu Nellore	29	50	40	12	15	14	15	14	12
Prakasam	32	39	40	12	18	17	15	12	10
Srikakulam	55	58	59	10	19	15	8	7	6
Visakhapatnam	41	57	56	13	17	24	10	11	9
Vizianagaram	48	50	52	15	20	17	10	10	8
West Godavari	65	65	67	17	20	22	12	10	10

4. Karnataka



The state of Karnataka has a geographical area of 191,791 sq. km and a population of 61.13 million, according to Census 2011. It is bordered by Maharashtra and Goa in the north, Telangana and Andhra Pradesh in the east, Kerala and Tamil Nadu in the south, and the Arabian Sea in the west. It has a coastline of 320 km. The state has 31[4] districts and can be classified into three distinct geographical regions: the coastal plains, the Western Ghats, and the Deccan Plateau. The climate ranges between arid, semi-arid, and humid tropical, with an average annual rainfall of 1151 mm. The rainfall is received mostly during the south-west monsoon season. About 20% of the state's area is covered by forests. More than half (52.7%) of the state is under agriculture, which is mostly rainfed and engages 71% of the total workforce. Karnataka is the biggest producer of coffee, sandalwood-based products, and raw silk in India. The state is also host to 75% of the Indian floriculture industry. Fishing (inland and marine) and mining (iron ore, gold, and diamonds) are other major industries.

Karnataka is prone to loss and damage by droughts, floods due to extreme rainfall, landslides, hailstones, and forest fires. Consecutive droughts impact 54% of the geographical area (18 of the 30 districts). Below normal rainfall or dry spells for more than three consecutive weeks are the main factors that cause droughts in the state. Poor storage facilities in minor irrigation tanks and depleting groundwater resources exacerbate the problem. According to the Vulnerability Atlas of India (2019)[5], about 15% of the total geographical area is under moderate earthquake damage risk zone, 10 districts are prone to flooding, and hilly areas of four districts are prone to landslides due to heavy rainfall events.

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

4.1. Historical climate

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

4.1.1. Trends in temperature

Karnataka recorded a moderate warming of 0.18°C to 0.61°C in the summer maximum temperature and 0.3°C to 0.65°C in the winter minimum temperature during the historical

[4] In this report, we consider only 30 districts as Vijayanagara is a very recently formed district.
[5] https://bmtpc.org/DataFiles/CMS/file/Publication/VAI_3rd2019.pdf

Figure 4-1 presents the mean summer maximum and winter minimum temperatures in Karnataka during the historical period.

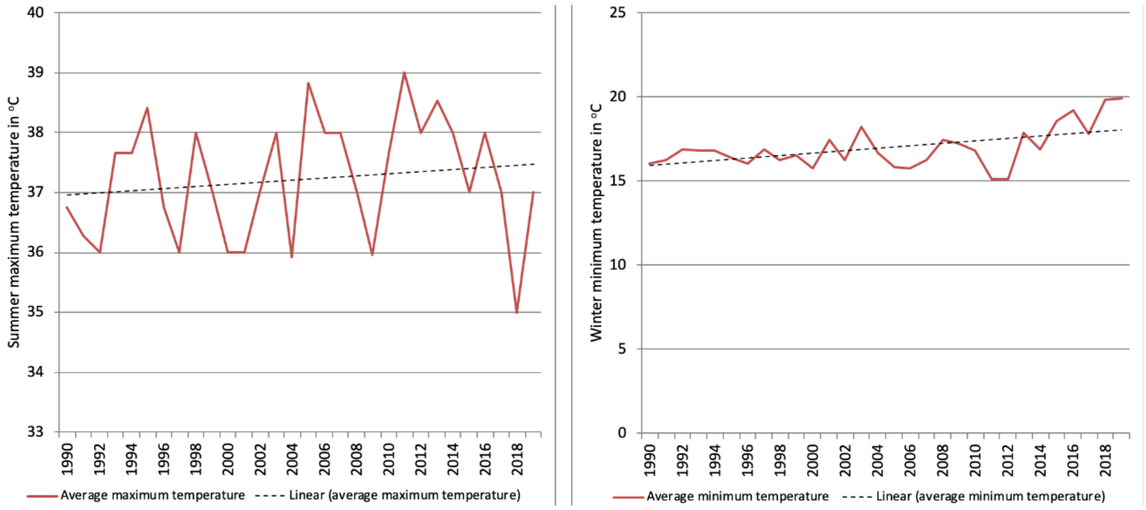
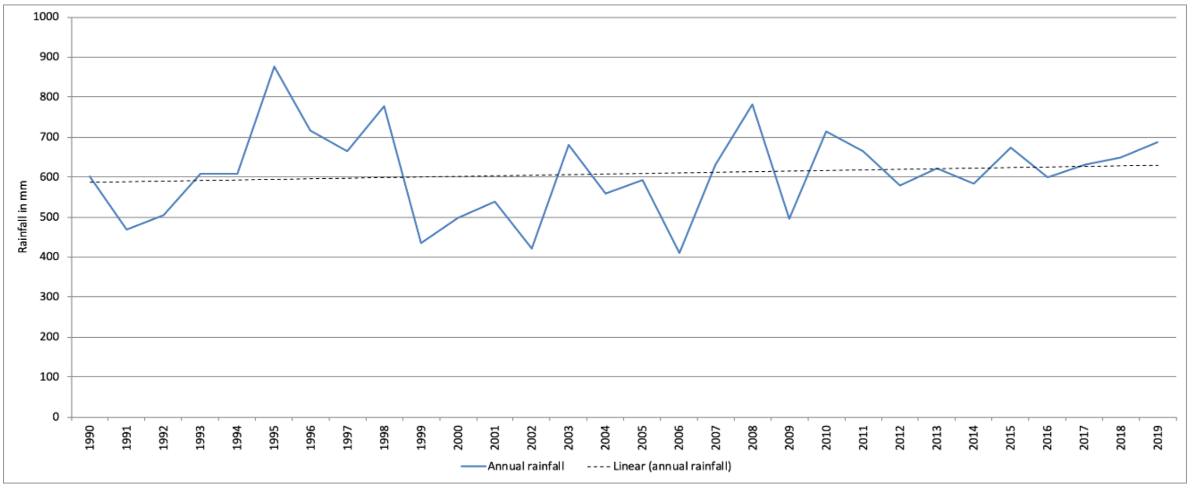


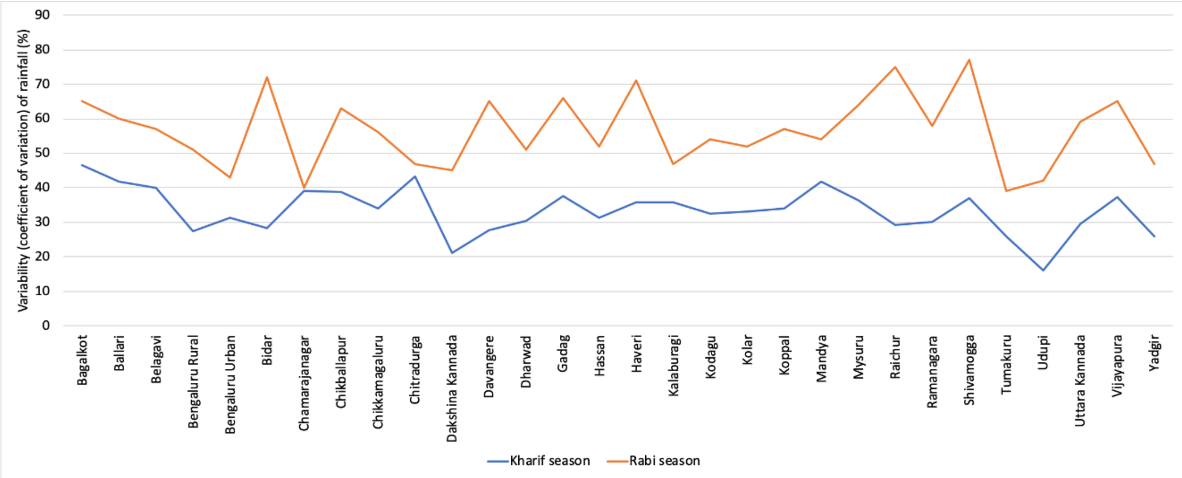
Figure 4-1: Mean summer maximum and winter minimum temperatures in Karnataka during the historical period (1990–2019)

4.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual rainfall and kharif season rainfall—which is the main monsoon season— was recorded across the districts of Karnataka. The increase in rainfall is higher, in the range of 15% to 25%, in the Western Ghats districts—which receive high rainfall. Figure 4-2 presents the mean annual rainfall in Karnataka during the historical period.



The kharif season rainfall variability (coefficient of variation) ranged from 16% in Udupi to 46% in Bagalkot (Figure 4-3). The rabi season rainfall variability ranged from 39% in Tumakuru to 77% in Shivamogga (Figure 4-3).



4.2. Climate change projections

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

4.2.1. Temperature projections

The projected changes in summer maximum and winter minimum temperatures for all the districts of Karnataka 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 0.5^{0}C to 1.5^{0}C	Increases by 0.5^{0}C to 1.5^{0}C
RCP 8.5	Increases by 0.5^{0}C to 1.5^{0}C	Increases by 0.5^{0}C to 2^{0}C

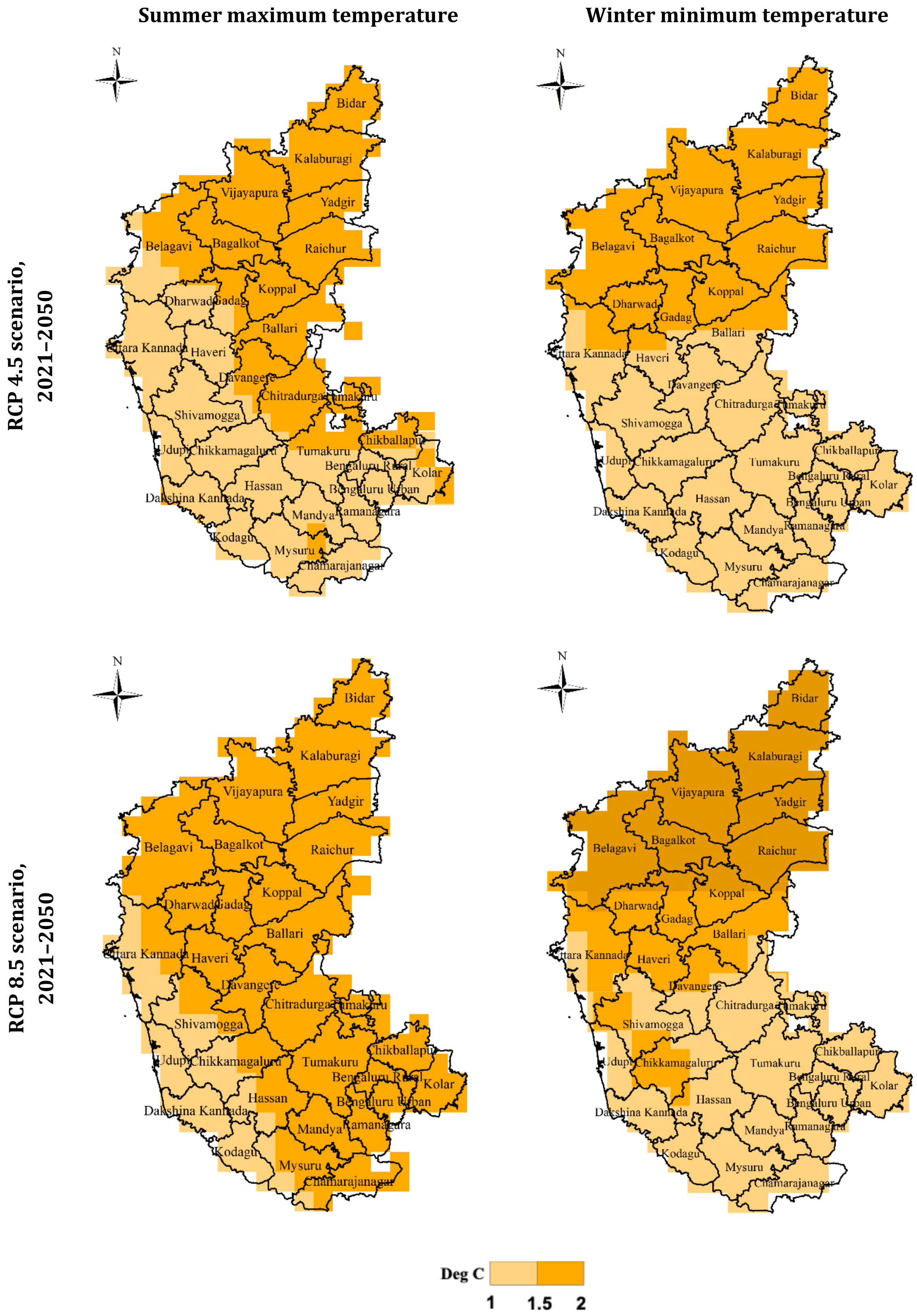


Figure 4-4: Projected changes in the summer maximum and winter minimum temperatures (°C) compared to the historical period (1990–2019) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios

4.2.1.1. Heatwaves

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

The analysis of temperature during the projected period of the 2030s shows that there would only be a marginal increase in the number of heatwaves (departure from the normal temperature is 4.5°C to 6.4°C) and severe heatwaves (departure from the normal temperature is >6.4°C), as categorised by the India Meteorological Department (IMD), will increase substantially under both RCP 4.5 and RCP 8.5 scenarios (Figure 4-5) compared to the historical period (1990–2019).

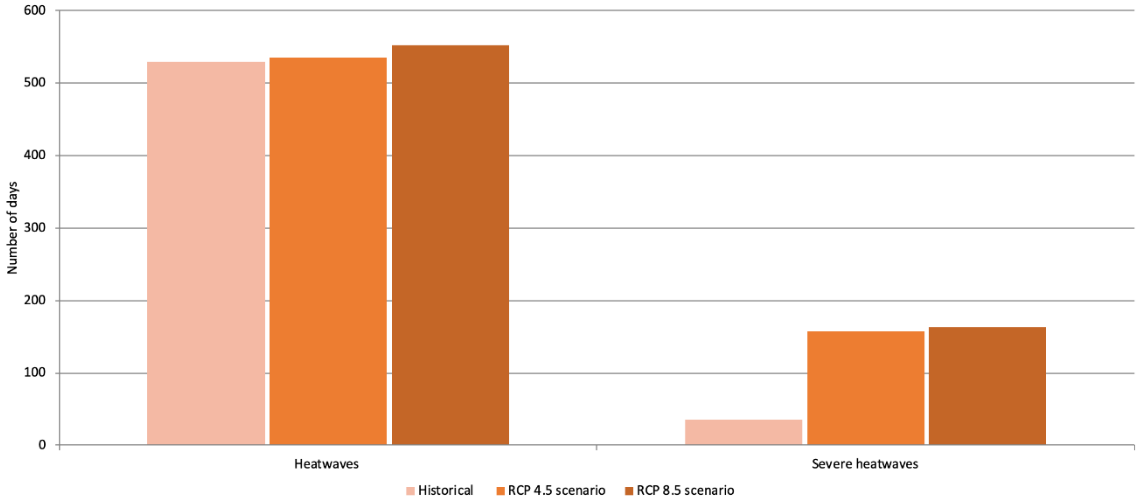


Figure 4-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

4.2.2. Rainfall projections

4.2.2.1. Number of rainy days

According to the IMD, a *rainy day* is defined as a day with rainfall of 2.5 mm or more. The analysis of rainy days under historical and projected periods shows that there will be an increase in the number of rainy days during the projected period in all the districts (Figure 4-6). The number of rainy days during the historical period and the projected 2030s under both RCP 4.5 and 8.5 scenarios is presented in Appendix 4-3. The total number of rainy days that ranged from 554 to 3038 days over the 30-year historical period increases to 687 to 3073 days under the RCP 4.5 scenario and 701 to 3092 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 12 days annually in all the districts, except Bengaluru Urban, Shivamogga, and Tumakuru districts

RCP 8.5 scenario: Projected to increase by 1 to 29 days annually in all the districts, with an increase of 5 or more days per annum in 16 districts, including Ballari, Kalaburagi, Bagalkot, Koppal, and Uttara Kannada

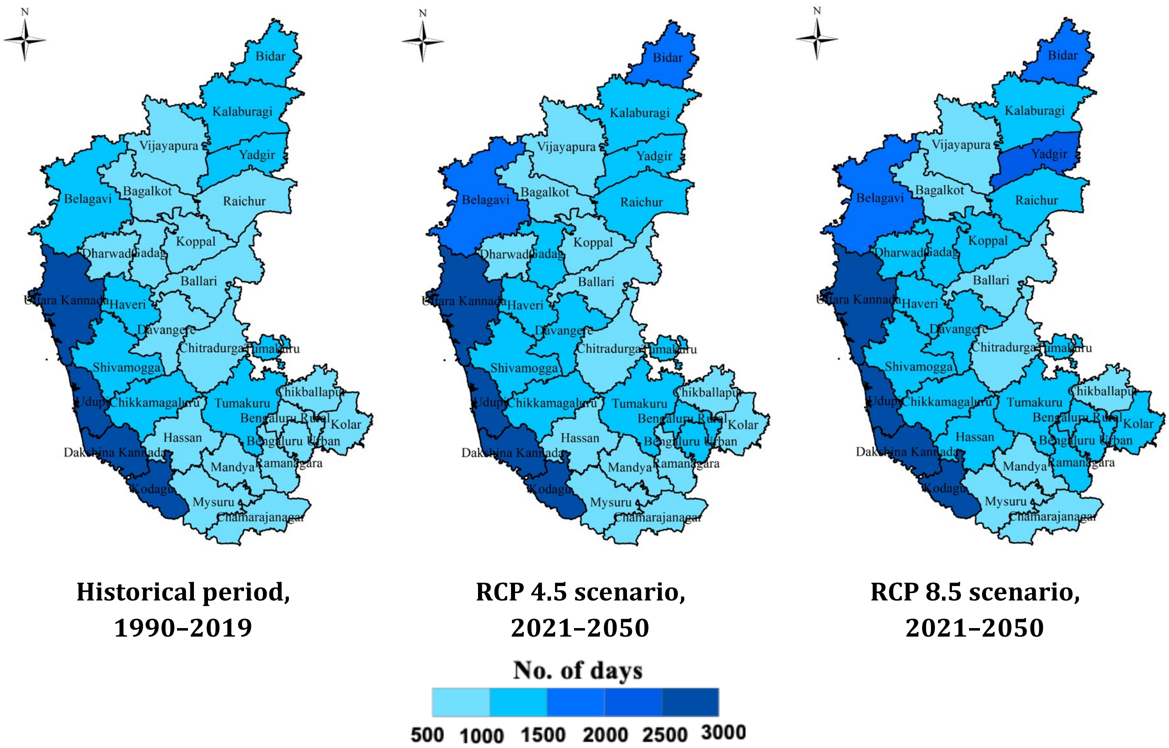


Figure 4-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

4.2.2.2. Mean rainfall and rainfall variability during the kharif season

The kharif season rainfall is projected to increase in all the districts under both climate scenarios. Figure 4-7 presents district-wise changes in the kharif season rainfall, and Figure 4-8 presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 2% in Gadag and Dharwad to 17% in Uttara Kannada and Dakshina Kannada	Increases in 22 districts by 1% to 11% and declines in eight districts by 1% to 9%
RCP 8.5	Increases in all the districts, from 5% in Gadag to 26% in Kolar	Increases in 22 districts by 2% to 14% and declines in eight districts by 2% to 10%

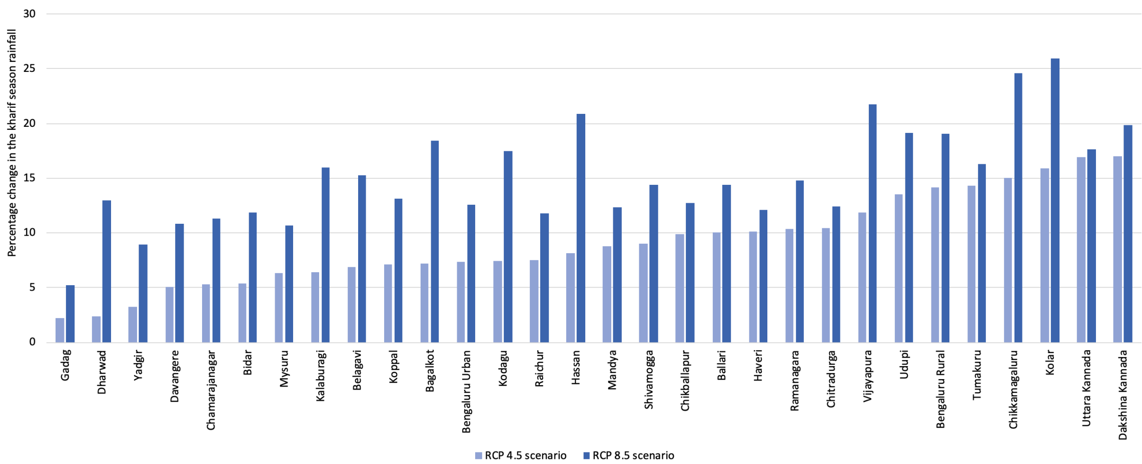


Figure 4-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

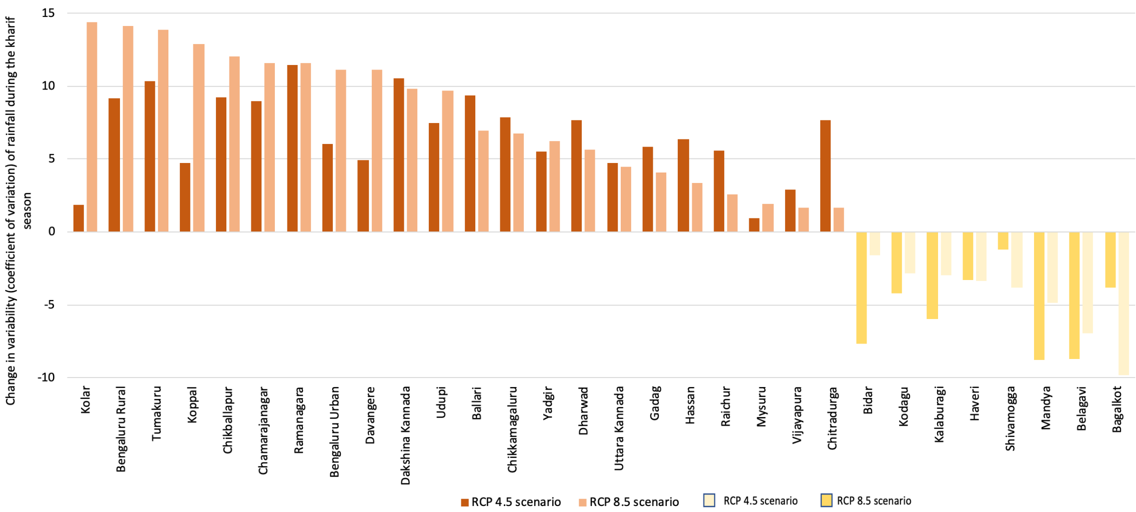


Figure 4-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

4.2.2.3. Mean rainfall and rainfall variability during the rabi season

The rabi season rainfall is projected to increase in all the districts under both climate scenarios. Figure 4-9 presents district-wise changes in the rabi season rainfall, and Figure 4-10 presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	**Mean seasonal rainfall**	**Rainfall variability (coefficient of variation)**
RCP 4.5	Increases in all the districts, from 2% in Davangere to 27% in Dakshina Kannada	Increases in six districts by 4% to 11% and declines in 24 districts by 1% to 35%
RCP 8.5	Increases in all the districts, from 7% in Shivamogga and Davangere to 34% in Bidar	Increases in six districts by 1% to 10% and declines in 24 districts by 8% to 43%

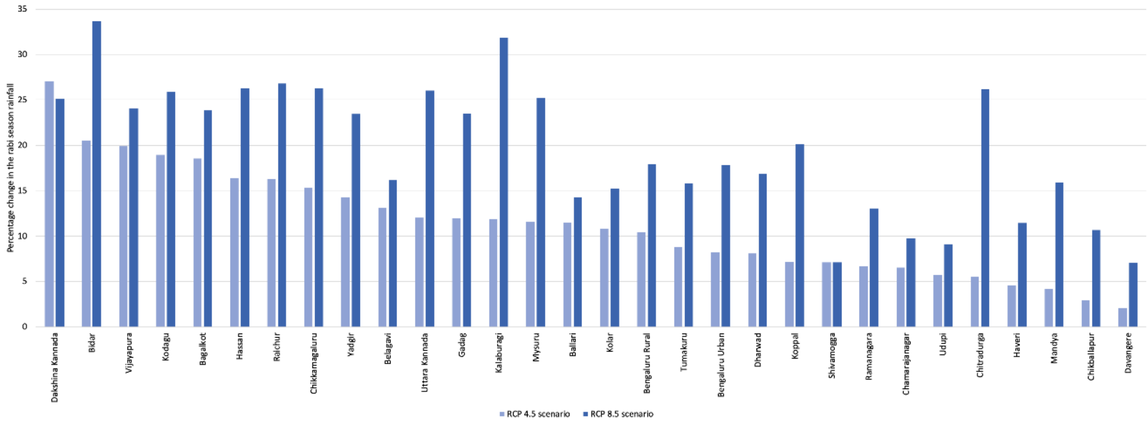


Figure 4-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

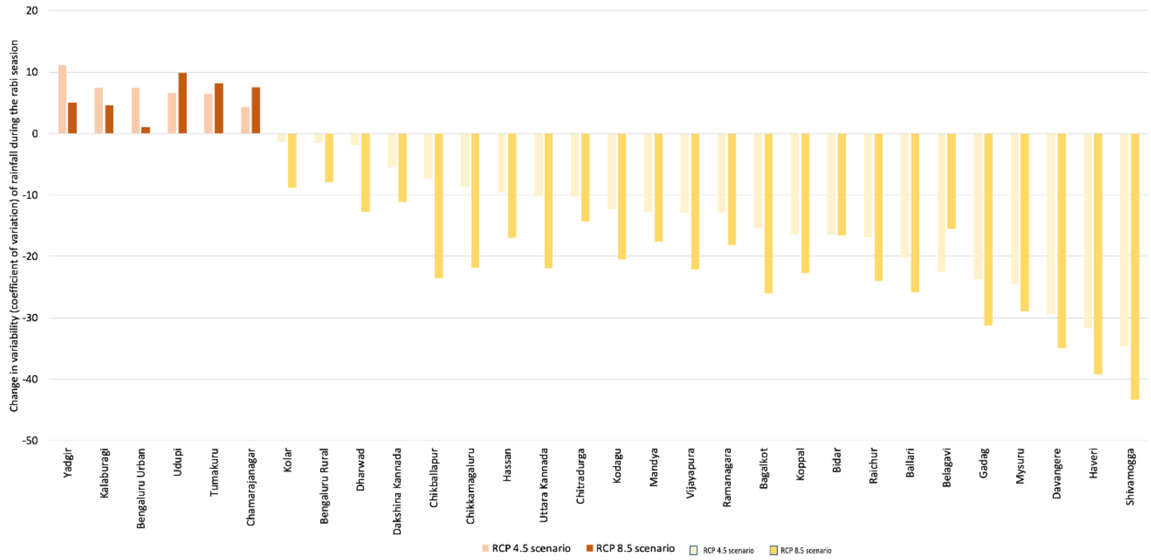


Figure 4-10: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

4.3. Heavy rainfall events and rainfall deficient years

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

High-intensity rainfall events (Figure 4-11)

The total number of high-intensity rainfall events increases from 9 to 615 days during the historical period (1990–2019) to 23 to 760 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 34 to 800 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: High-intensity rainfall events are projected to increase per annum by one to five events in all the districts. The increase is by five events in Uttara Kannada and Udupi, three events in Kodagu and Dakshina Kannada, and one to two events in the remaining districts.

RCP 8.5 scenario: High-intensity rainfall events are projected to increase per annum by one to seven events in all the districts. The increase is by seven events in Dakshina Kannada, six events in Udupi, four events in Uttara Kannada, three events in Kodagu, Kolar, and Mandya, and one to two events in the remaining districts.

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

The total number of very high-intensity rainfall events increases from 0 to 188 days during the historical period (1990–2019) to 12 to 195 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 18 to 198 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: Very high-intensity rainfall events are projected to increase per annum by one to two events. The increase is by two events in Uttara Kannada and one event in the remaining districts.

RCP 8.5 scenario: Very high-intensity rainfall events are projected to increase per annum by one to three events. The increase is by three events in Uttara Kannada, two events in Bengaluru Urban, Belagavi, Dakshina Kannada, Davangere, Kalaburagi, Hassan, Kodagu, Mysuru, and Raichur, and one event in the remaining districts.

Rainfall deficient years (Figure 4-12)

Rainfall deficient years, computed considering the rainfall during the kharif season, are projected to decline in a few districts under the RCP 4.5 scenario and in a large number of districts under the RCP 8.5 scenario. The number of rainfall deficient years declines from 6 to 16 years during the historical 30-year period to 5 to 15 years under the RCP 4.5 scenario and 4 to 13 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: Rainfall deficient years are projected to decline in 11 districts by 1 to 2 years and increase marginally by 1 year in Raichur and Bengaluru Rural districts. No change is projected in 17 districts.

RCP 8.5 scenario: Rainfall deficient years are projected to decline in 28 districts by 1 to 3 years. No change is projected in Kolar and Bengaluru Rural districts.

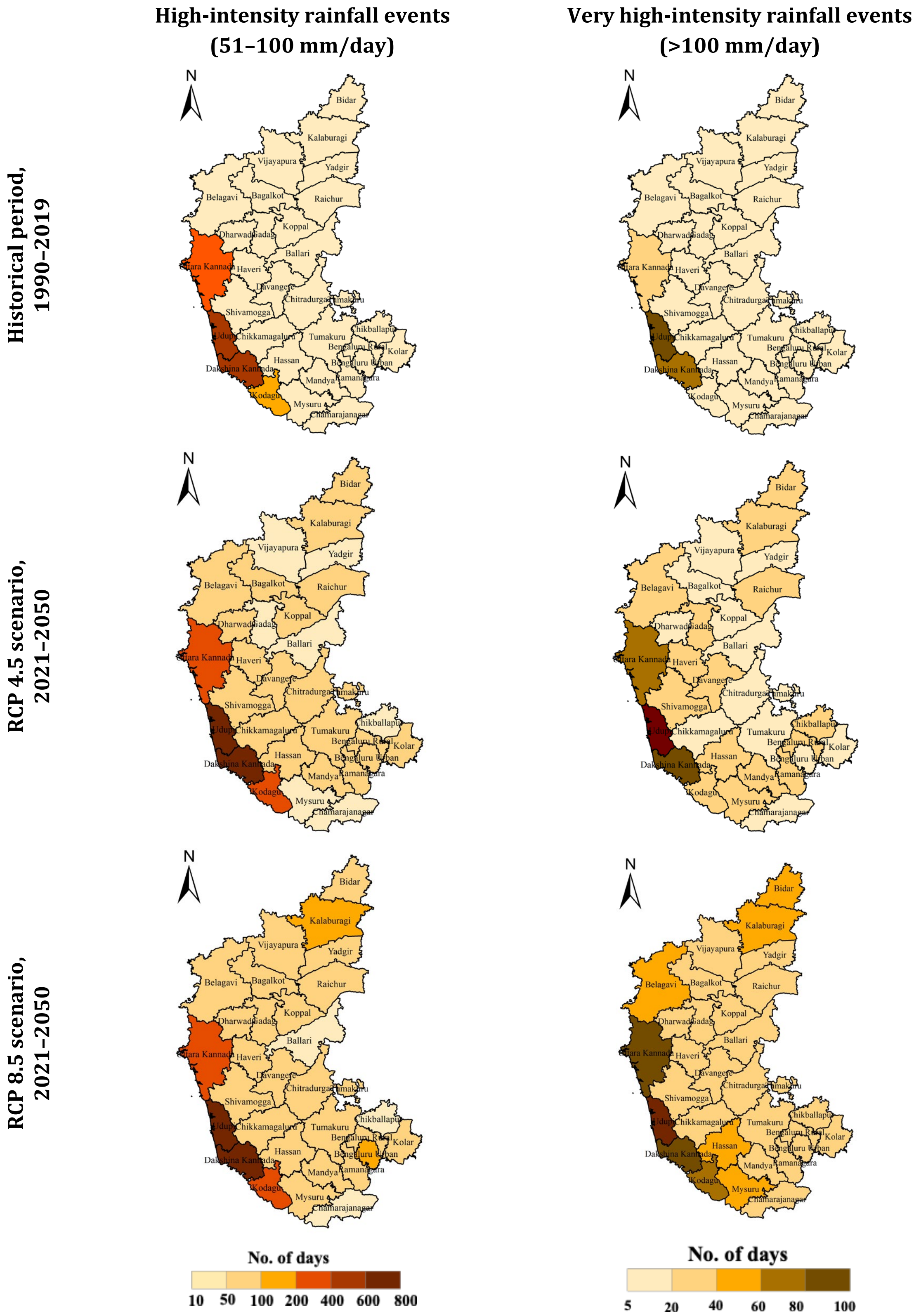


Figure 4-11: The total number of high-intensity and very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

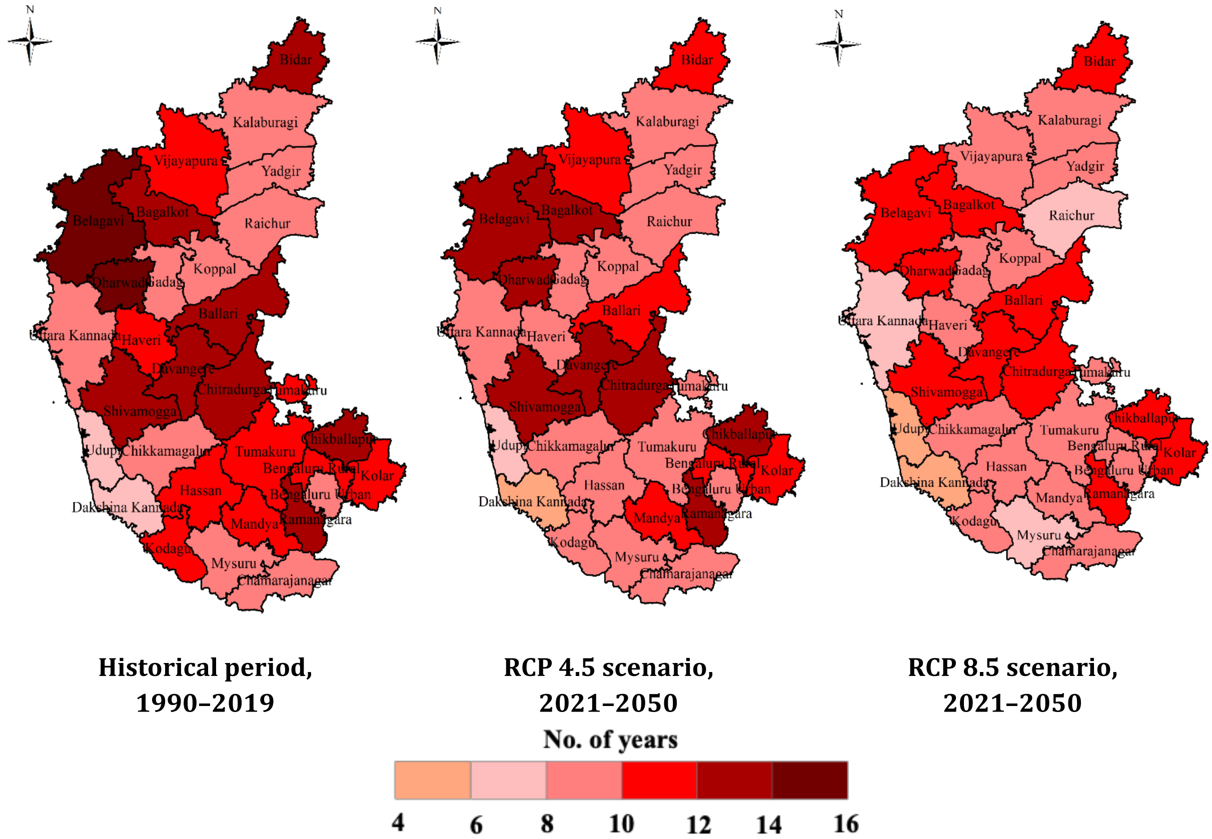


Figure 4-12: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

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

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

- An increase in winter minimum temperature is projected to be higher than the projected increase in summer maximum temperature in all the districts.
- Warming is projected to be higher in the northern districts of Karnataka.

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

- A notable increase in rainfall, particularly in the Western Ghats districts, is projected.

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

- The projected increase in rainfall variability is ≥10% in 11 districts under the RCP 4.5 scenario and three districts under the RCP 8.5 scenario.
- In Tumakuru, Dakshina Kannada, and Ramanagara districts, this increase is applicable under both climate scenarios.

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

- The increase per annum is 1 to 12 days under the RCP 4.5 scenario and 1 to 29 days under the RCP 8.5 scenario.
- The increase is >5 days per annum in Yadgir, Bidar, Bengaluru Rural, Koppal, Kolar, and Uttara Kannada districts under both scenarios.

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

- Very high-intensity rainfall events are projected to increase in the range of one to two events annually in 25 districts under the RCP 4.5 scenario and 29 districts under the RCP 8.5 scenario.

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

Appendix

Appendix 4-1: Changes in temperature under climate scenarios

Districts	Changes in temperature (°C) during the 2030s (2021–2050) compared to the historical period (1990–2019)			
	Summer maximum temperature		Winter minimum temperature	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Bagalkot	1.3	2.3	1.2	2.1
Bengaluru Rural	0.0	0.0	0.0	0.0
Bengaluru Urban	0.0	0.0	0.0	0.0
Belagavi	1.1	1.7	1.9	2.2
Ballari	1.4	1.9	1.6	1.7
Bidar	1.5	2.2	1.5	2.3
Chamarajanagar	0.9	1.3	0.9	1.5
Chikballapur	1.3	1.6	0.7	1.5
Chikkamagaluru	0.8	1.2	0.9	1.8
Chitradurga	1.4	1.8	0.8	1.5
Dakshina Kannada	0.9	1.3	0.9	1.7
Davangere	1.4	1.9	0.9	1.5
Dharwad	0.7	1.3	1.4	1.8
Gadag	1.6	1.8	1.5	1.8
Hassan	0.8	1.4	0.8	2.2
Haveri	0.8	1.5	1.0	1.9
Kalaburagi	1.3	2.2	1.4	2.2
Kodagu	0.9	1.4	0.8	1.7
Kolar	0.9	1.5	0.8	1.3
Koppal	1.4	1.8	1.3	1.8
Mandya	1.0	1.5	0.8	1.5
Mysuru	0.9	1.5	0.8	1.9
Raichur	1.5	2.4	1.4	1.8
Ramanagara	0.8	1.5	0.9	1.5
Shivamogga	0.8	1.5	0.9	1.8
Tumakuru	0.9	1.8	0.9	1.4
Udupi	0.9	1.4	0.9	1.9
Uttara Kannada	0.8	1.4	0.9	1.7
Vijayapura	1.4	2.2	1.5	2.5
Yadgir	1.1	2.2	1.5	2.2

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
Bagalkot	6	14	7	18	19	24
Bengaluru Rural	9	10	10	14	10	18
Bengaluru Urban	6	8	7	15	8	18
Belagavi	12	16	14	19	13	16
Ballari	8	17	7	13	12	14
Bidar	12	15	5	12	21	34
Chamarajanagar	10	12	5	11	7	10
Chikballapur	7	9	10	13	3	11
Chikkamagaluru	14	21	15	25	15	26
Chitradurga	10	20	10	12	6	26
Dakshina Kannada	6	14	17	20	27	25
Davangere	4	8	5	11	2	7
Dharwad	4	10	2	13	8	17
Gadag	1	7	2	5	12	23
Hassan	14	19	8	21	16	26
Haveri	4	9	10	12	5	11
Kalaburagi	11	21	6	16	12	32
Kodagu	12	18	7	17	19	26
Kolar	12	15	16	26	11	15
Koppal	7	11	7	13	7	20
Mandya	7	10	9	12	4	16
Mysuru	12	18	6	11	12	25
Raichur	7	14	8	12	16	27
Ramanagara	10	12	10	15	7	13
Shivamogga	9	12	9	14	7	7
Tumakuru	9	13	14	16	9	16
Udupi	9	12	14	19	6	9
Uttara Kannada	12	17	17	18	12	26
Vijayapura	1	5	12	22	20	24
Yadgir	5	15	3	9	14	23

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
Bagalkot	720	800	876
Ballari	777	830	912
Belagavi	1464	1513	1560
Bengaluru Rural	789	1025	1123
Bengaluru Urban	997	1006	1099
Bidar	1374	1614	1765
Chamarajanagar	618	765	776
Chikballapur	745	776	876
Chikkamagaluru	1181	1195	1254
Chitradurga	554	687	701
Dakshina Kannada	2903	2963	2991
Davangere	981	1057	1134
Dharwad	886	989	1044
Gadag	989	1024	1116
Hassan	941	970	1011
Haveri	1065	1137	1153
Kalaburagi	1105	1151	1243
Kodagu	2515	2528	2552
Kolar	854	986	1080
Koppal	835	944	1075
Mandya	781	812	950
Mysuru	869	907	951
Raichur	973	1023	1122
Ramanagara	909	952	1009
Shivamogga	1438	1443	1461
Tumakuru	1042	1050	1145
Udupi	3038	3073	3092
Uttara Kannada	2581	2745	2830
Vijayapura	747	821	965
Yadgir	1184	1197	2056

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

Districts	High-intensity rainfall events			Very high-intensity rainfall events			Rainfall deficient years		
	Historical	RCP 4.5 scenario	RCP 8.5 scenario	Historical	RCP 4.5 scenario	RCP 8.5 scenario	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Bagalkot	14	56	67	2	14	20	14	14	13
Ballari	18	45	39	1	12	41	13	12	11
Belagavi	45	88	69	8	32	60	16	14	13
Bengaluru Rural	36	93	110	3	23	45	9	10	9
Bengaluru Urban	31	87	89	0	31	47	11	11	10
Bidar	44	65	98	8	35	51	13	11	11
Chamarajanagar	12	33	34	1	17	31	10	10	9
Chikballapur	19	43	44	1	33	29	14	13	12
Chikkamagaluru	13	51	65	1	18	33	10	10	9
Chitradurga	14	78	88	0	21	40	14	13	12
Dakshina Kannada	547	623	762	93	108	140	6	5	4
Davangere	19	66	67	0	30	45	13	13	11
Dharwad	27	71	80	7	22	49	15	15	13
Gadag	27	45	56	6	33	18	10	10	9
Hassan	32	90	87	4	31	52	11	10	9
Haveri	16	76	71	2	39	34	11	10	10
Kalaburagi	29	84	101	6	38	56	10	10	9
Kodagu	152	231	250	24	50	77	11	10	9
Kolar	15	60	95	1	15	30	12	11	12
Koppal	22	59	88	2	25	45	10	10	9
Mandya	15	57	90	4	33	42	11	11	10
Mysuru	17	40	87	4	30	64	10	10	8
Raichur	21	60	85	2	30	47	9	10	8
Ramanagara	43	65	70	6	32	43	13	13	11
Shivamogga	25	88	91	0	30	44	14	14	12
Tumakuru	30	60	90	3	25	37	11	10	9
Udupi	615	760	800	188	195	198	7	7	6
Uttara Kannada	239	390	370	45	90	122	9	9	7
Vijayapura	14	23	61	2	12	22	12	12	10
Yadgir	9	43	55	0	25	32	10	10	9

5. Kerala

The state of Kerala has a geographical area of 38,852 sq. km and a total population of 33.41 million, according to Census 2011. It has the highest population density in the country and the highest literacy rate. The state is bordered by Karnataka in the north and north-east, Tamil Nadu in the east and south-east, and the Lakshadweep Sea in the west. The state has a coastline spanning 590 km. Kerala has 14 districts, and physiographically, the state can be divided into coastal, midland, and highland zones. It experiences a humid and tropical monsoon climate with seasonally excessive rainfall and hot summers. The mean temperature ranges from 19.8°C to 36.7°C, and the average annual rainfall ranges between 1,520 mm and 4,075 mm. Almost 28% of the state is under biodiversity-rich forests, owing to the prevalence of the Western Ghats all along the state. The Western Ghats plays a major role in influencing the climate of the state. More than half the state (58%) is arable, of which 91% is under cultivation. Agriculture and forest sectors together account for almost 86% of the state's land area. The service sectors—such as public administration, banking and finance, communications, transportation, and tourism—remittances from emigrants working in foreign countries, and the agricultural and fishing industries dominate the state's economy.

Kerala is a multi-hazard prone state. According to the Vulnerability Atlas of India (2019)[5], 15.7% of the state's area is flood-prone. It also experiences a high incidence of lightning pre- and post-monsoon. The hilly terrain and heavy rainfall during the monsoon lead to frequent landslides, with 14.4% of the state's area being susceptible to landslides. Drought in Kerala mostly impacts drinking water availability during the summer months, and more than 50% of the state's land area is susceptible to moderate to severe drought. The state's coastline is exposed to high waves, storm surges, and tsunamis, leading to rampant coastal erosion and consequent beach loss. 36.6% of the coastline is highly prone to erosion. Saltwater intrusion due to groundwater exploitation and tidal effects also affect the coastal community.

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

5.1. Historical climate

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

5.1.1. Trends in temperature

Kerala recorded a moderate warming of 0.31°C to 0.62°C in the summer maximum temperature and 0.1°C to 0.32°C in the winter minimum temperature during the historical period. Figure 5-1 presents the mean summer maximum and winter minimum temperatures in Kerala during the historical period.

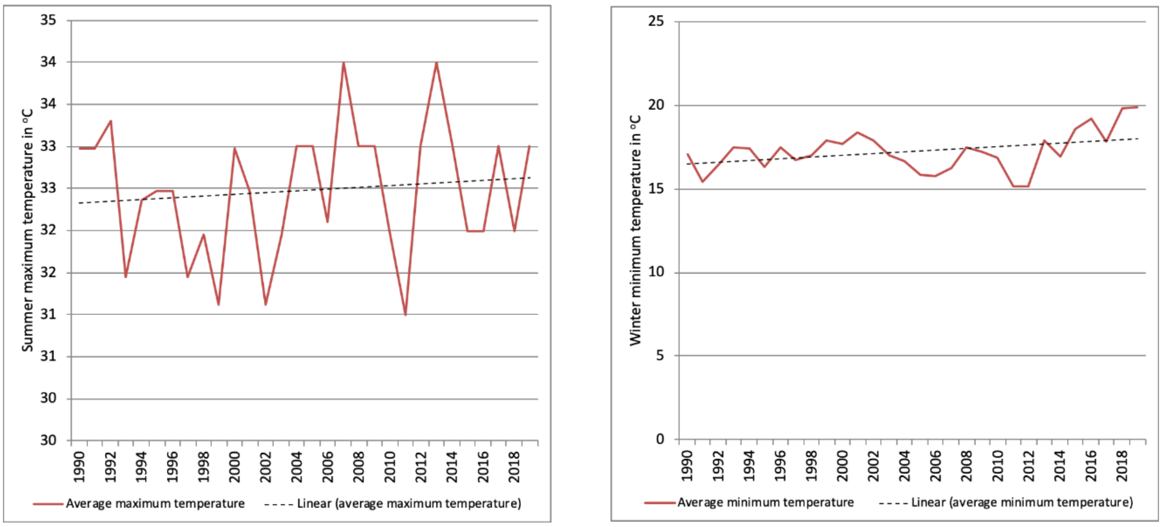


Figure 5-1: Mean summer maximum and winter minimum temperatures in Kerala during the historical period (1990–2019)

5.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and kharif season rainfall was recorded in a majority of the districts. The increase in annual rainfall was in the range of 10% to 20%. During the kharif season—which is the main monsoon season—the increase was in the range of 10% to 25%. A higher increase of 20% to 25% was recorded in the southern districts and parts of the central districts of Thrissur, Malappuram, and Palakkad during the historical period. Figure 5-2 presents the mean annual rainfall in Kerala during the historical period.

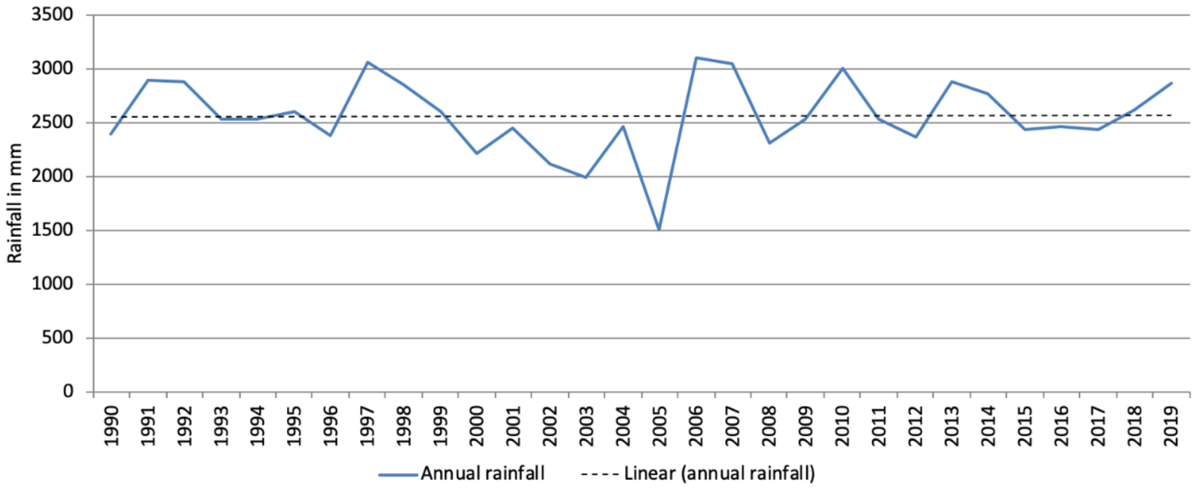


Figure 5-2: Mean annual rainfall in Kerala during the historical period (1990–2019)

The kharif season rainfall variability ranged from 22% in Kasaragod to >30% in Kollam, Idukki, Thiruvananthapuram, and Palakkad (Figure 5-3). The rabi season rainfall variability was also very high in the range of 23% in Kasaragod to 46% in Idukki (Figure 5-3).

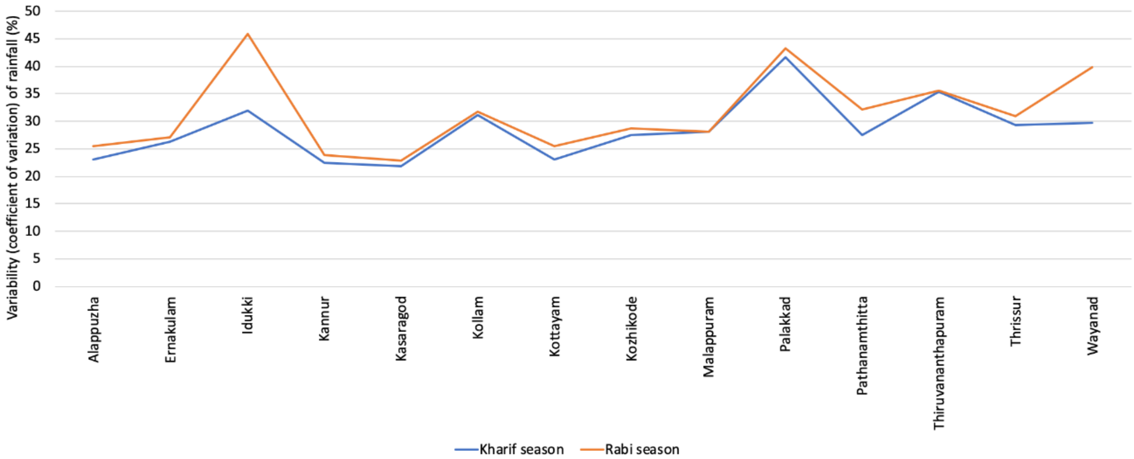


Figure 5-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

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 summer maximum and winter minimum temperatures for all the districts of Kerala are presented in Figure 5-4.

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

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

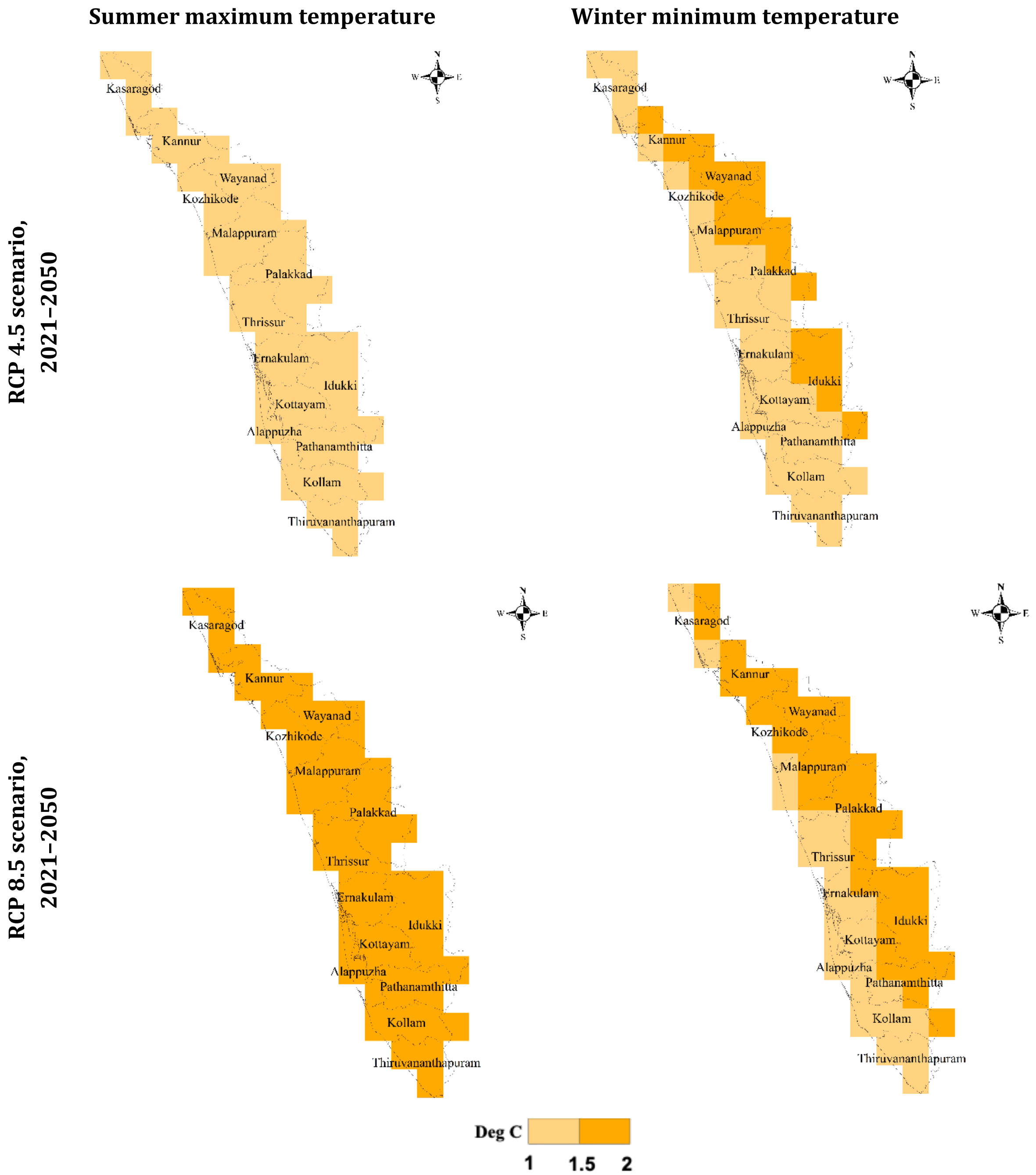


Figure 5-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

5.2.2. Rainfall projections

5.2.2.1. Number of rainy days

According to the India Meteorological Department (IMD), a *rainy day* is defined as a day with rainfall of 2.5 mm or more. The analysis of rainy days under historical and projected periods shows that there will be an increase in the number of rainy days during the projected period in all the districts (Figure 5-5). 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 5-3. The total number of rainy days that ranged from 1386 to 3061 days over the 30-year historical period increases to 1485 to 3145 days under the RCP 4.5 scenario and 1554 to 3210 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 31 days annually in all the districts. The increase is by 31 days in Idukki, 27 days in Kottayam, and 1 to 6 days in the remaining districts.

RCP 8.5 scenario: Projected to increase by 1 to 25 days in all the districts. The increase is by 25 days in Kottayam, 24 days in Idukki, and 1 to 6 days in the remaining districts.

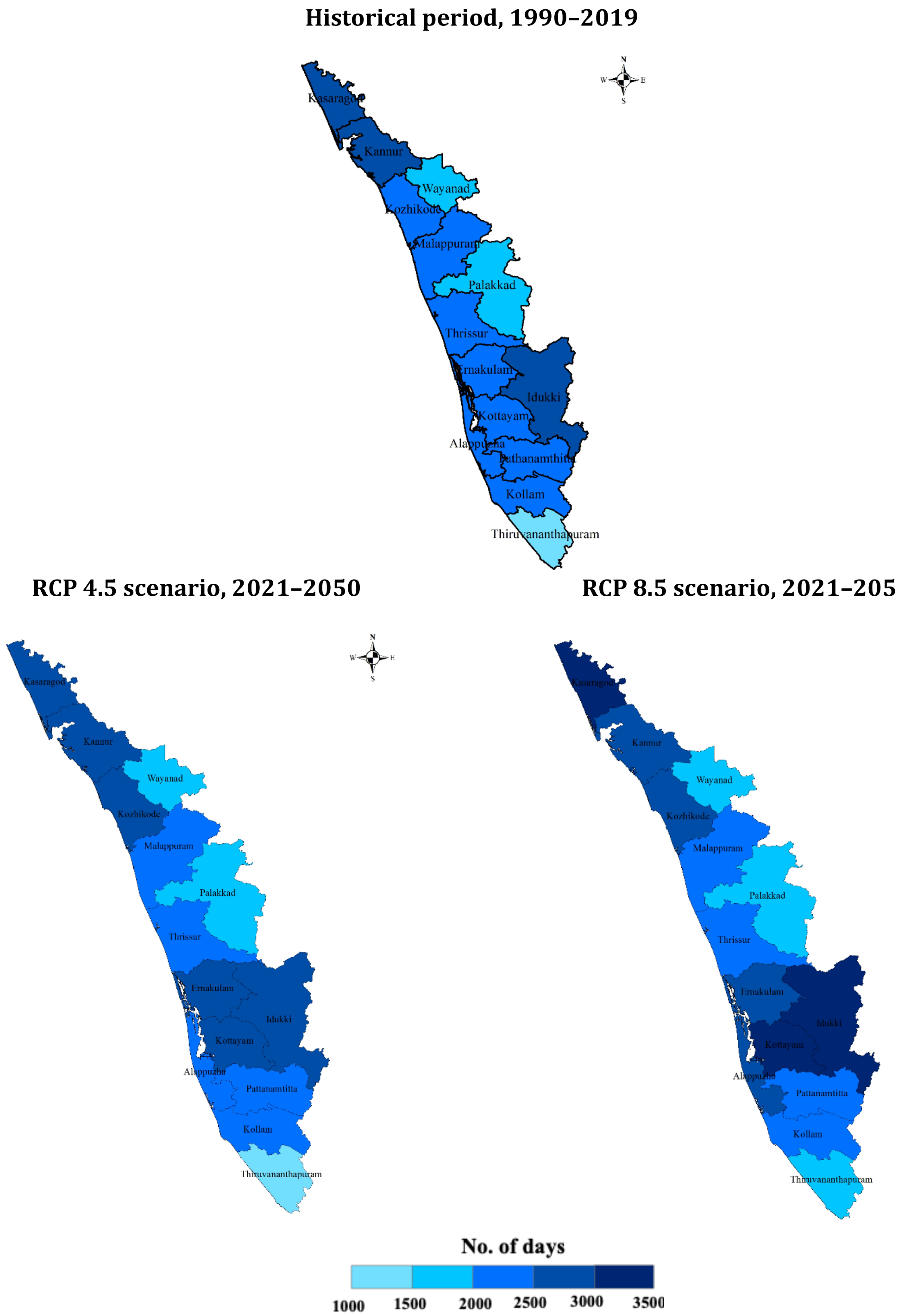


Figure 5-5: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

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 5-6 presents district-wise changes in the kharif season rainfall, and Figure 5-7 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 5% in Thiruvananthapuram to 14% in Ernakulam and Kannur	Declines in all the districts, except Kannur, by 1% to 23%
RCP 8.5	Increases in all the districts, from 7% in Thiruvananthapuram to 17% in Kollam and Pathanamthitta	Declines in all the districts, except Kannur, by 1% to 24%

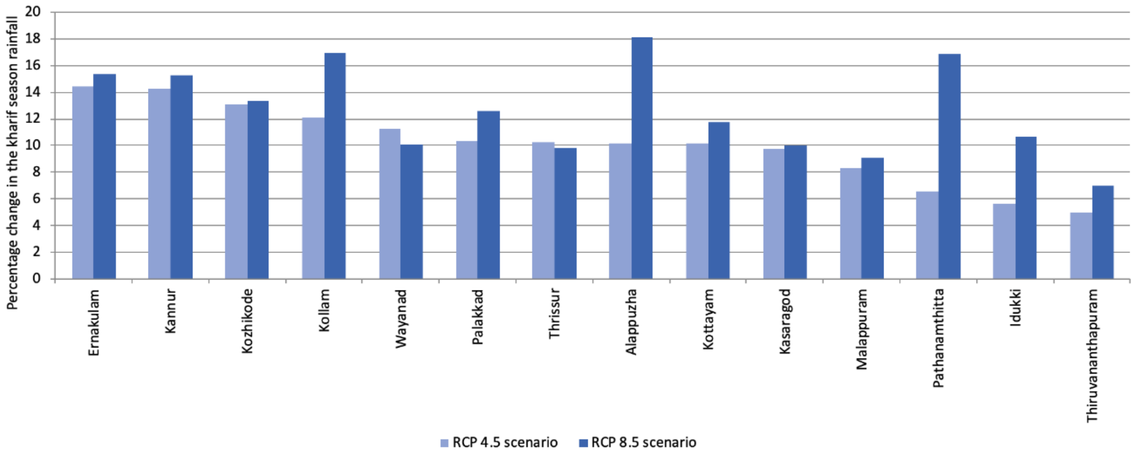


Figure 5-6: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

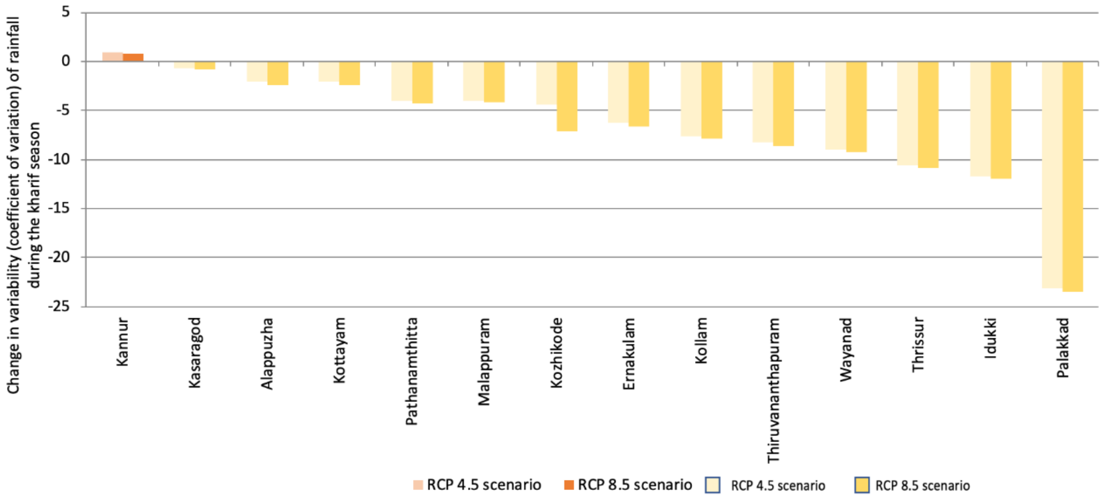


Figure 5-7: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

5.2.2.3. Mean rainfall and rainfall variability during the rabi season

The rabi season rainfall is projected to increase in all the districts under both climate scenarios. Figure 5-8 presents district-wise changes in the kharif season rainfall, and Figure 5-9 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 1% in Thiruvananthapuram to 26% in Wayanad	Declines in seven districts by 0.4% to 13.6% and increases in seven districts by 0.8% to 7%
RCP 8.5	Increases in all the districts, from 3% in Thiruvananthapuram to 20% in Palakkad	Declines in seven districts by 0.5% to 13.6% and increases in seven districts by 0.8% to 7.1%

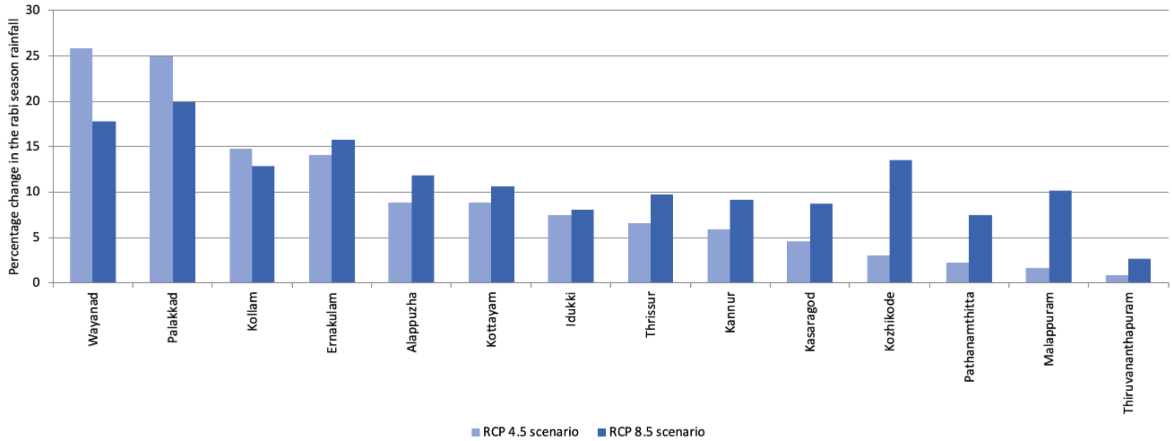


Figure 5-8: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

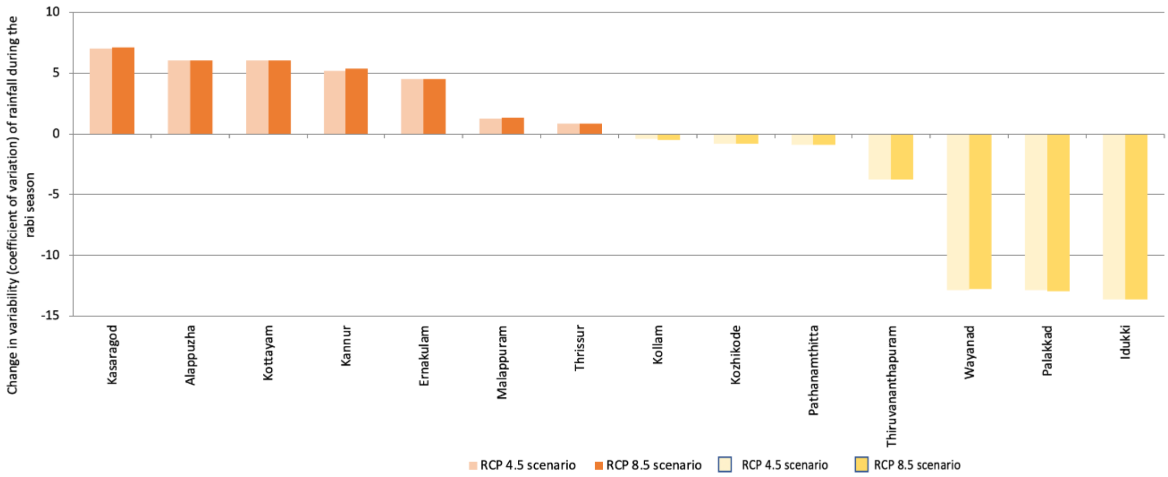


Figure 5-9: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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

High-intensity rainfall events (Figure 5-10)

The total number of high-intensity rainfall events increases from 20 to 381 days during the historical period (1990–2019) to 67 to 410 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 103 to 450 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: High-intensity rainfall events are projected to increase per annum by one to three events. The increase is by three events in Alappuzha and Kottayam; two events in Wayanad, Thiruvananthapuram, and Pathanamthitta; and one event in the remaining districts.

RCP 8.5 scenario: High-intensity rainfall events are projected to increase per annum by two to six events. The increase is by six events in Alappuzha and Palakkad; five events in Kottayam; three events in Kannur, Idukki, Wayanad, Kozhikode, and Ernakulam; and two events in the remaining six districts.

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

The total number of very high-intensity rainfall events increases from 2 to 78 days during the historical period (1990–2019) to 22 to 85 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 35 to 105 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: Very high-intensity rainfall events are projected to increase per annum by one to two events. The increase is by two events in Thrissur and one event in the remaining districts.

RCP 8.5 scenario: Very high-intensity rainfall events are projected to increase per annum by one to three events. The increase is by three events in Wayanad; two events in Thrissur, Malappuram, Palakkad, Kollam, and Pathanamthitta; and one event in the remaining districts.

Rainfall deficient years (Figure 5-12)

Rainfall deficient years, computed considering rainfall during the kharif season, show an overall decline in all the districts of Kerala under both climate scenarios. The number of rainfall deficient years declines from 10 to 16 years during the historical 30-year period to 9 to 14 years under the RCP 4.5 scenario and 9 to 13 years under the RCP 8.5 scenario during the projected period.

RCP 4.5 scenario: The projected decline is by 1 year in Thrissur and Idukki, 3 years in Palakkad, and 4 years in Wayanad. In the remaining districts, except Thiruvananthapuram, there is no change compared to the historical period.

RCP 8.5 scenario: The projected decline is by 1 year in Idukki, Malappuram, and Kozhikode; 3 years in Palakkad; and 4 years in Wayanad. In the remaining districts, except Thiruvananthapuram, there is no change compared to the historical period.

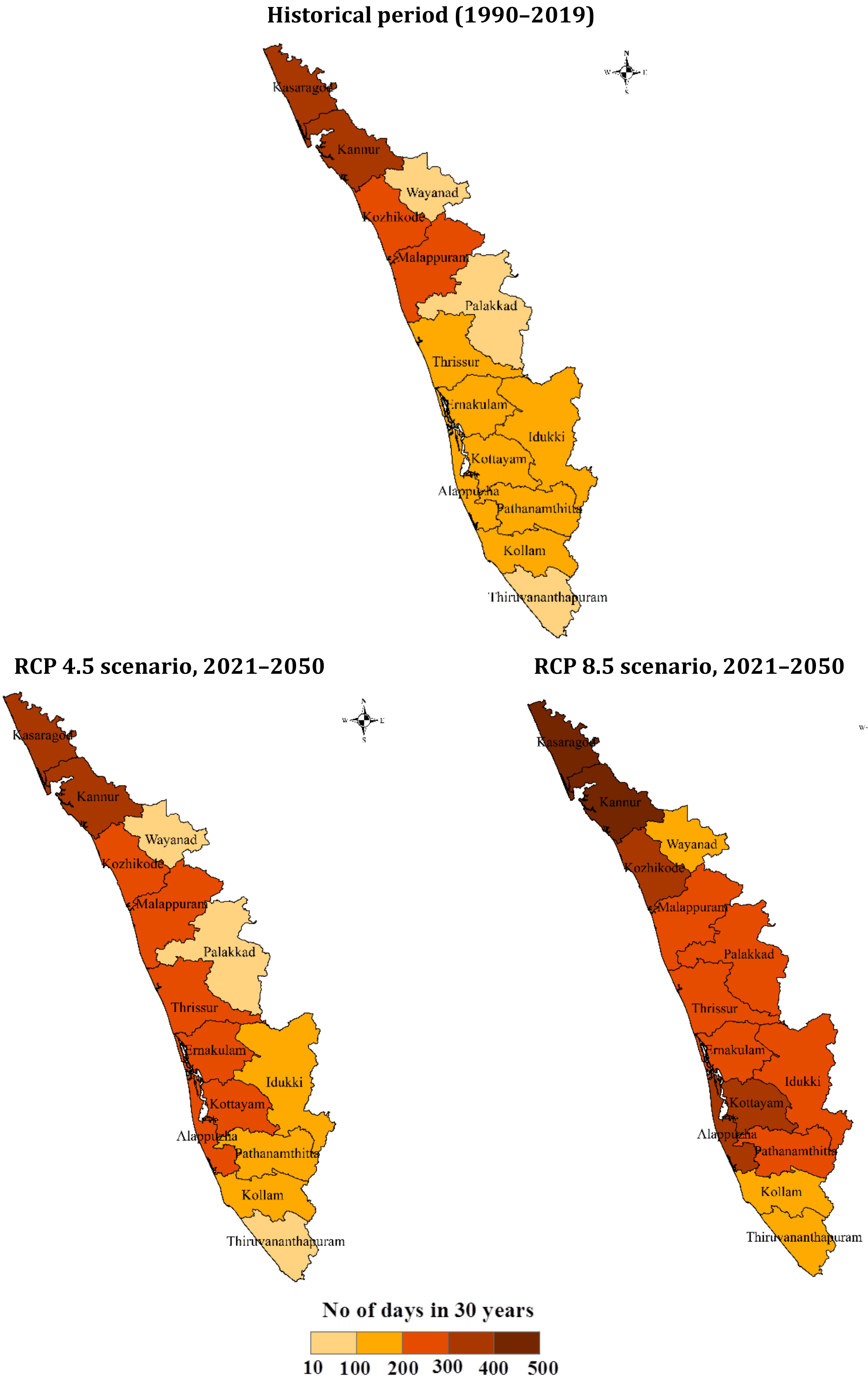


Figure 5-10: The total number of high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

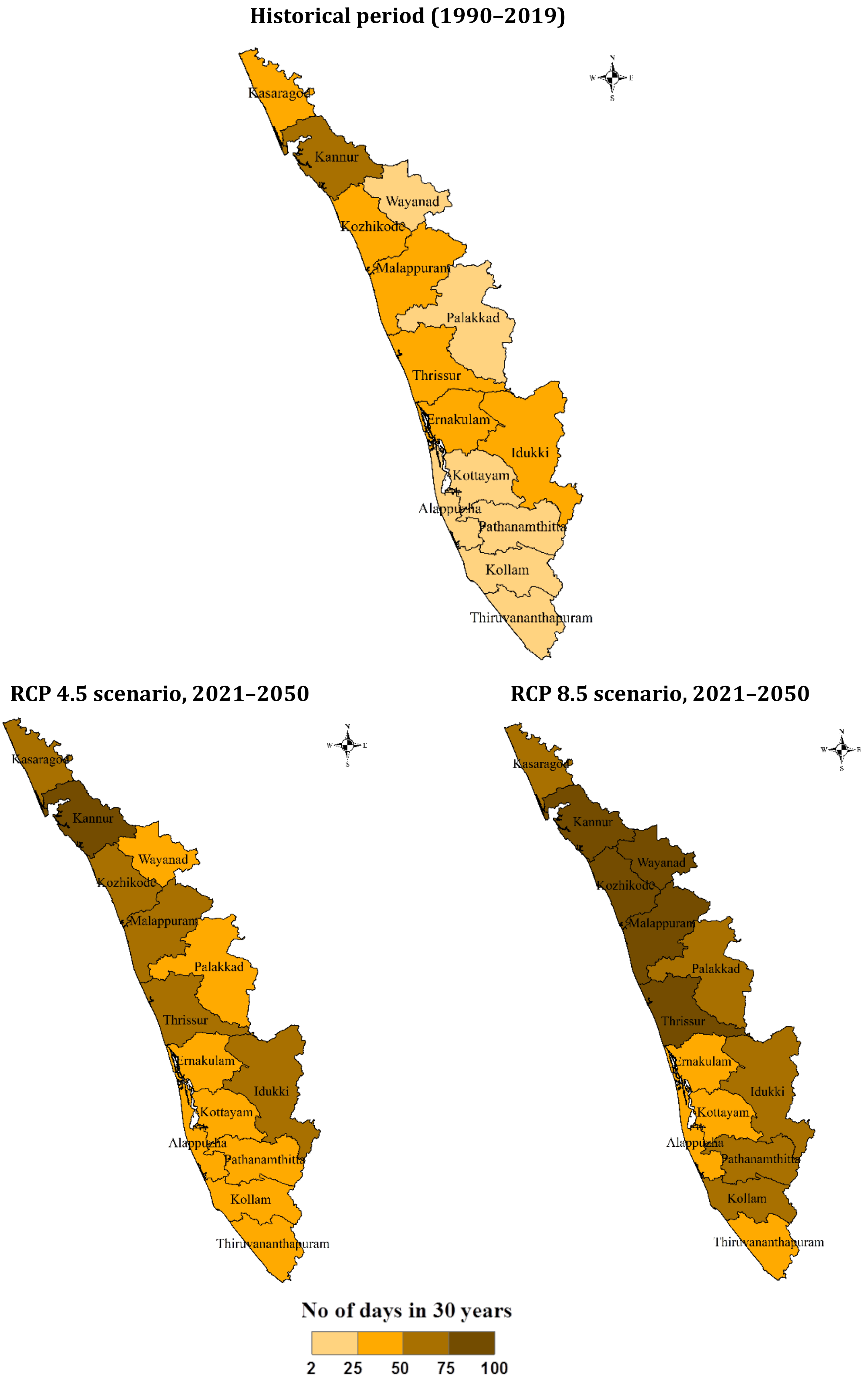


Figure 5-11: The total number of very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

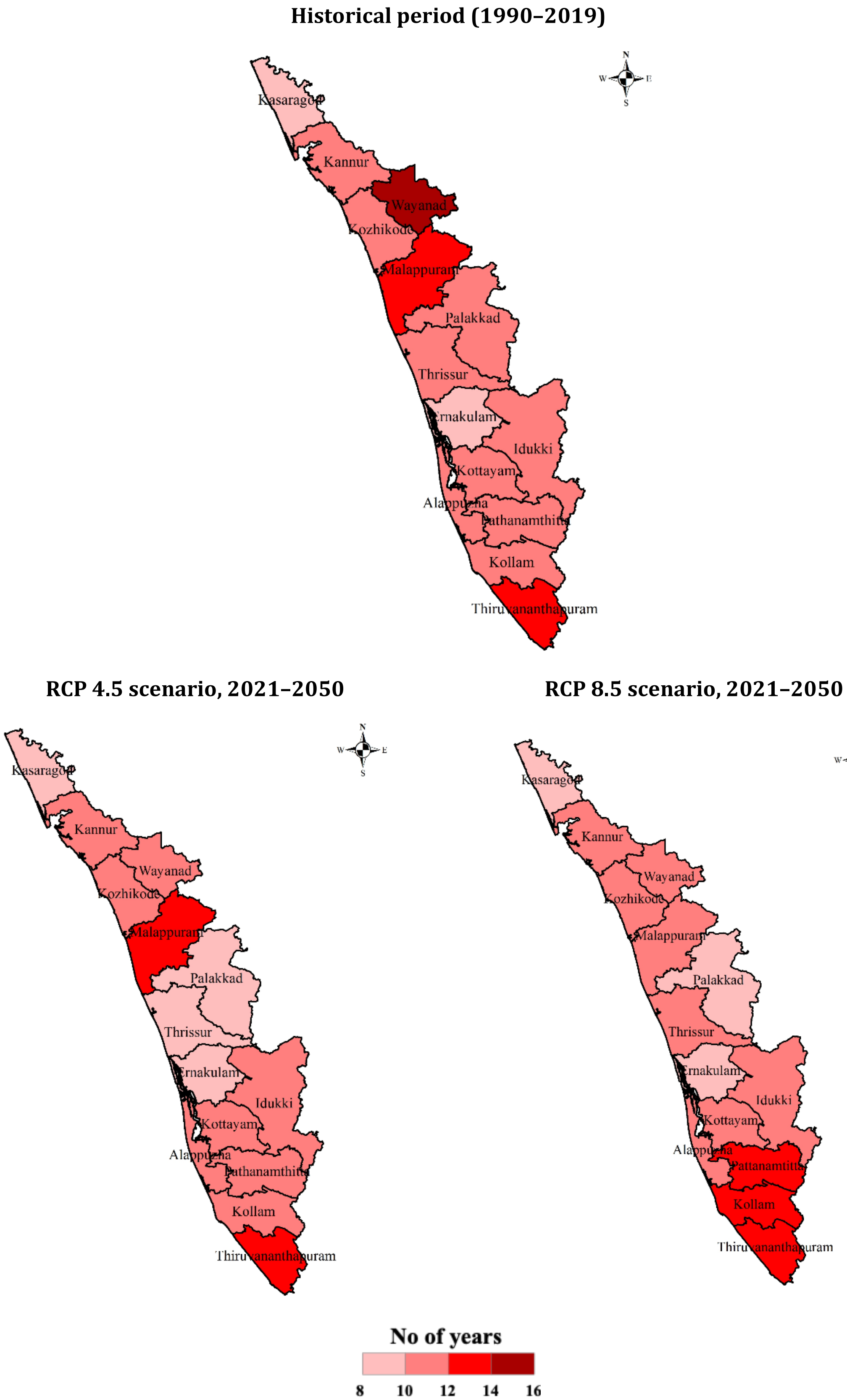


Figure 5-12: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

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

Temperature is projected to increase in all the districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 5-1).

- A higher increase in winter minimum temperature than summer maximum temperature is projected in all the districts.

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

- A >10% increase in rainfall is projected in Ernakulam, Kannur, Kozhikode, and Kollam under both climate scenarios.

Rainfall variability during the kharif season is projected to decline in all the districts, except Kannur, under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019).

- A >10% decline in rainfall variability is projected in Thrissur, Idukki, and Palakkad.

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).

- A large increase in the number of rainy days—an additional 24 to 31 days per annum—is projected in Idukki and Kottayam under both climate scenarios.

Heavy rainfall events are projected to increase in a majority of the districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 5-4)

- An additional 3 days or more of high-intensity rainfall events are projected for Alappuzha and Kottayam districts under both climate scenarios.

- Very high-intensity rainfall events are projected to increase marginally in all the districts, in the range of one to three events per annum.

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

Appendix

Appendix 5-1: Changes in temperature under climate scenarios

Districts	Change in temperature (°C) during the 2030s (2021–2050) compared to the historical period (1990–2019)			
	Summer maximum temperature		Winter minimum temperature	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Alappuzha	1.3	1.7	1.1	1.5
Ernakulam	1.4	1.8	1.3	1.8
Idukki	1.1	1.9	1.4	2.0
Kannur	1.3	1.6	1.5	1.8
Kasaragod	1.2	1.5	1.7	1.9
Kollam	1.3	1.7	1.7	1.6
Kottayam	1.4	1.5	1.5	1.8
Kozhikode	1.3	1.7	1.3	1.7
Malappuram	1.3	1.6	1.4	1.7
Palakkad	1.2	1.9	1.4	1.8
Pathanamthitta	1.4	1.7	1.3	1.7
Thiruvananthapuram	1.3	2.0	1.4	1.3
Thrissur	1.2	1.9	1.2	1.8
Wayanad	1.4	2.0	1.7	2.0

Appendix 5-2: Changes in rainfall under climate scenarios

Districts	Change in rainfall (%) during the 2030s (2021–2050) compared to the historical period (1990–2019)					
	Annual rainfall		Kharif season rainfall		Rabi season rainfall	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Alappuzha	12	14	10	18	9	12
Ernakulam	15	12	14	15	14	16
Idukki	9	12	6	11	8	8
Kannur	13	12	14	15	6	9
Kasaragod	9	10	10	10	5	9
Kollam	9	18	12	17	15	13
Kottayam	9	12	10	12	9	11
Kozhikode	17	19	13	13	3	14
Malappuram	8	10	8	9	2	10
Palakkad	16	14	10	13	25	20
Pathanamthitta	8	12	7	17	2	7
Thiruvananthapuram	13	16	70	43	1	3
Thrissur	10	12	10	10	7	10
Wayanad	16	13	11	10	26	18

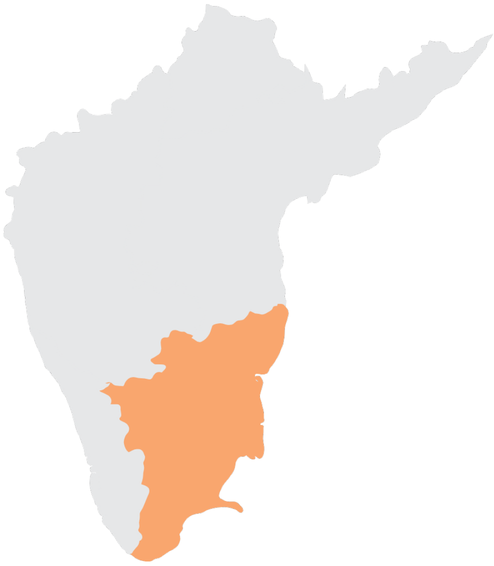
Appendix 5-3: The total number of rainy days (>2.5 cm/day) during the historical period (1990–2019) and the projected 2030s (2021–2050)

Districts	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Alappuzha	2430	2464	2535
Ernakulam	2488	2504	2520
Idukki	2504	3120	3210
Kannur	2580	2663	2623
Kasaragod	3061	3145	3200
Kollam	2037	2056	2159
Kottayam	2430	2965	3189
Kozhikode	2498	2552	2569
Malappuram	2332	2410	2476
Palakkad	1763	1836	1840
Pathanamthitta	2195	2245	2296
Thiruvananthapuram	1386	1485	1554
Thrissur	2419	2453	2480
Wayanad	1645	1762	1810

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
Alappuzha	164	253	332	19	29	35	11	11	11
Ernakulam	194	210	292	37	46	47	10	10	10
Idukki	156	180	237	34	67	72	12	11	11
Kannur	332	375	410	78	85	105	11	11	11
Kasaragod	381	410	450	49	56	66	10	10	10
Kollam	103	141	170	18	49	68	12	12	13
Kottayam	164	253	311	19	29	40	11	11	11
Kozhikode	248	290	343	50	67	92	12	12	11
Malappuram	225	265	290	28	55	83	13	14	12
Palakkad	26	68	212	2	45	55	12	9	9
Pathanamthitta	140	195	201	20	22	62	12	12	13
Thiruvananthapuram	29	74	103	4	34	45	13	14	13
Thrissur	189	204	260	28	75	89	11	10	11
Wayanad	20	67	110	2	43	78	16	12	12

6. Tamil Nadu



Tamil Nadu is the southernmost state of India, with a geographical area of 1,30,060 sq. km and a population of 72.15 million (Census 2011). The population is distributed fairly evenly in urban and rural areas and spread across 38 districts[6]. The state is bordered by Kerala in the west, Karnataka in the northwest, and Andhra Pradesh in the north. It has a coastline of 1076 km with the Bay of Bengal to its east and the Indian Ocean to the south. Tamil Nadu has a humid tropical climate.

The north-western, western, and southern parts of the state are bound by the Western Ghats and are rich in vegetation. Forests cover 16.5% of the state. The northern regions are a combination of plains and hills. The south-central and central regions are arid plains. The eastern regions are coastal plains that are fertile. Only about 37% of the state's area is under cultivation, with 27% culturable area left fallow.

Tamil Nadu is heavily dependent on both the north-east (48%) and south-west (32%) monsoon rains for recharging its water resources. As it is already severely water-stressed, failures in monsoons have led to acute water scarcity and severe droughts across the state. Due to its large coastline, the coastal communities and ecosystems of the state are exposed to coastal pollution, siltation, erosion, saltwater intrusion, storm surges, and wind damage due to recurring cyclones. They are also at risk of loss and damage due to tsunamis. Other hazards that plague the state include flooding due to cyclones and heavy rains, heatwaves, and landslides.

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

6.1. Historical climate

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

6.1.1. Trends in temperature

Tamil Nadu recorded a moderate warming of 0.12°C to 0.29°C in the summer maximum temperature and 0.15°C to 0.41°C in the winter minimum temperature during the historical period. Figure 6-1 presents the mean summer maximum and winter minimum temperatures in Tamil Nadu during the historical period.

[6]The current report presents analysis for only 32 districts of Tamil Nadu as climate information for the newly formed districts is not available.

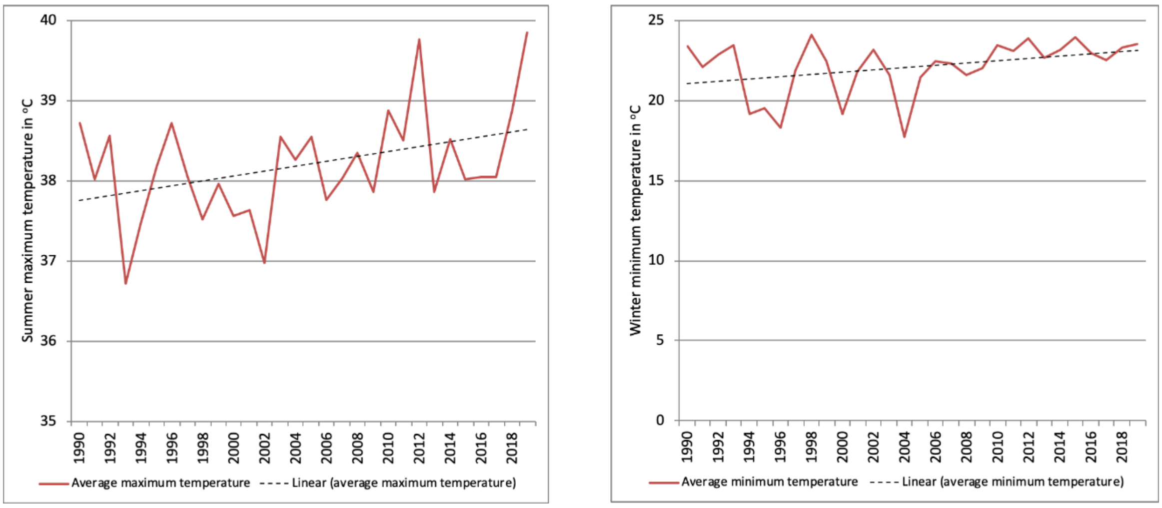


Figure 6-1: Mean summer maximum and winter minimum temperatures in Tamil Nadu during the historical period (1990–2019)

6.1.2. Trends in rainfall and rainfall variability

In Tamil Nadu, rainfall is received from both the north-east monsoon and the south-west monsoon. An increasing trend in the annual kharif and rabi season rainfall was recorded across the districts. The increase in rabi season rainfall was largely in the range of 10% to 15%. Figure 6-2 presents the mean annual rainfall in Tamil Nadu during the historical period.

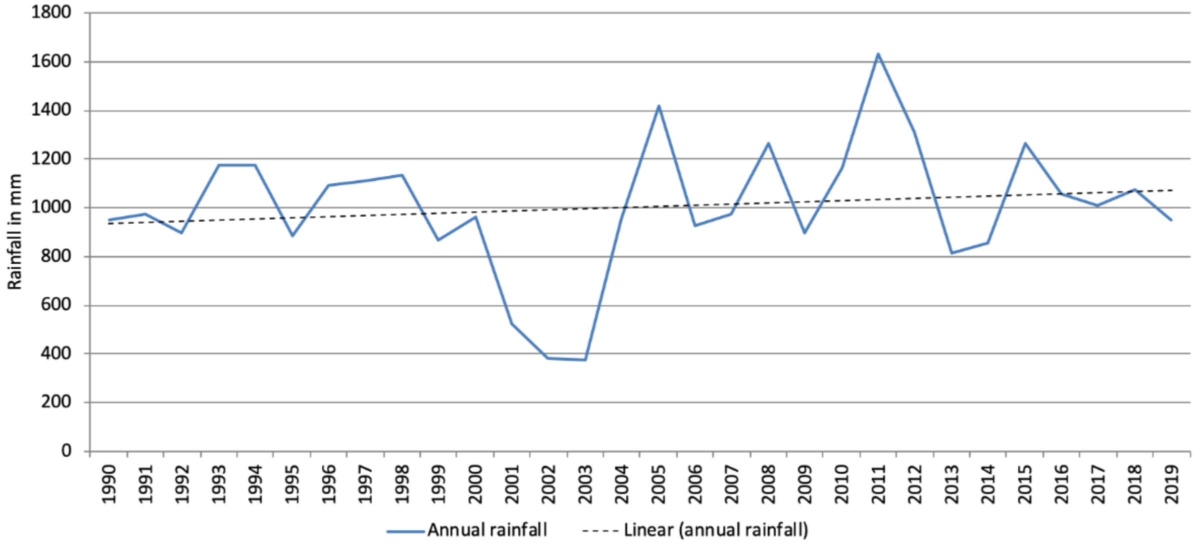


Figure 6-2: Mean annual rainfall in Tamil Nadu during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 28% in Chennai to >100% in Coimbatore, Ramanathapuram, and Theni districts, indicating a total failure of rainfall (Figure 6-3). The rabi season rainfall variability ranged from 36% in Nagapattinam to 63% in Kanchipuram (Figure 6-3).

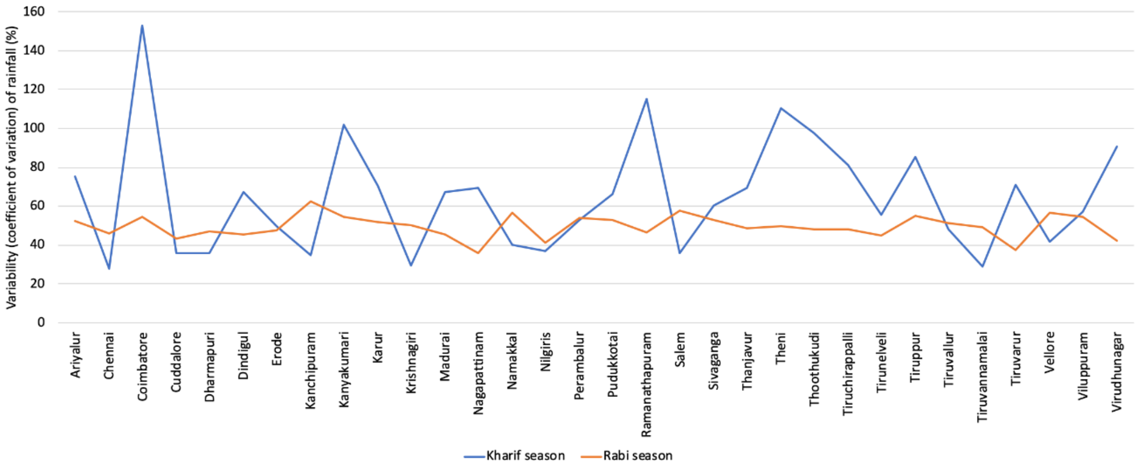


Figure 6-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

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 Tamil Nadu are presented in Figure 6-4.

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

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

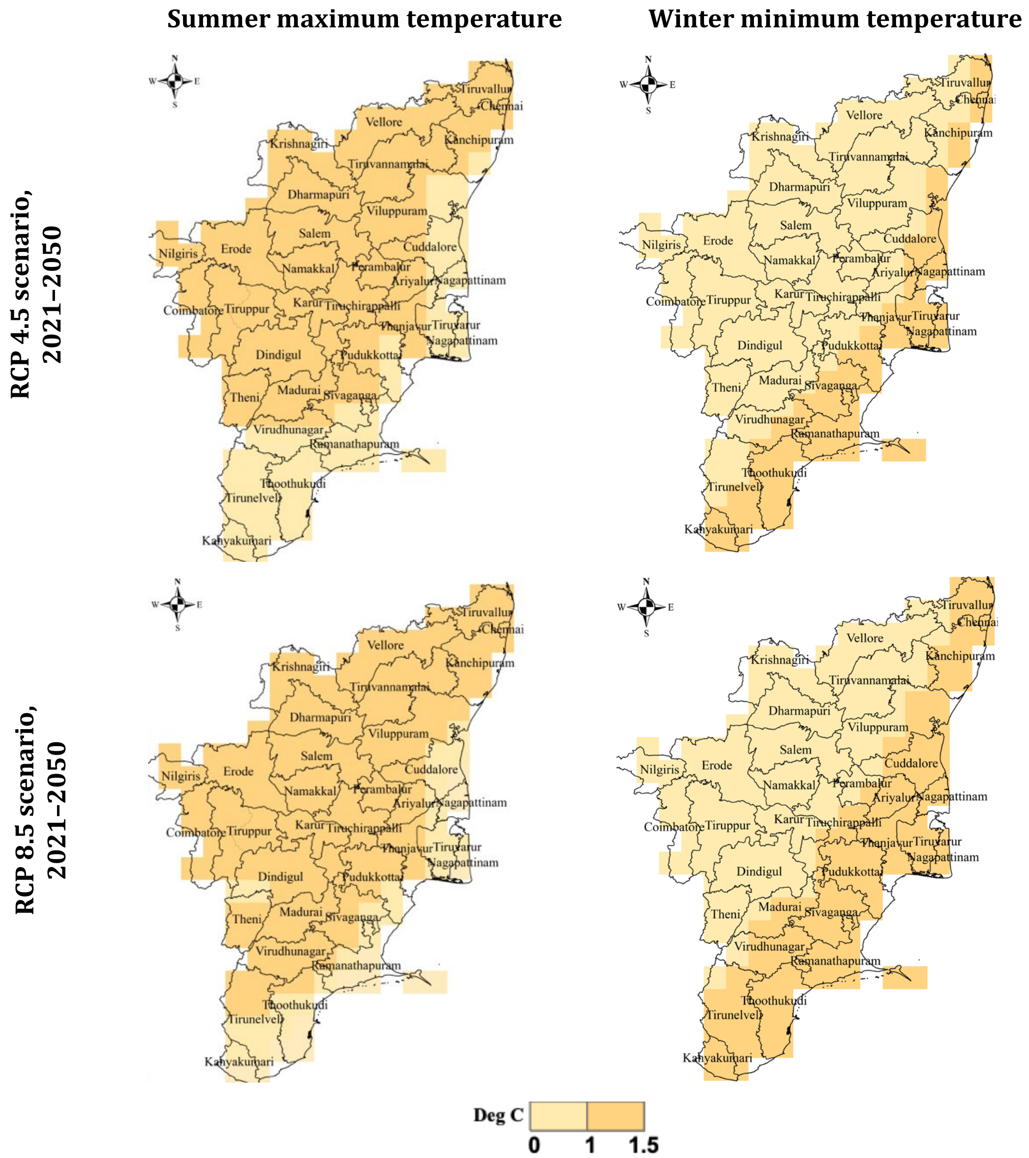


Figure 6-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

6.2.1.1. Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 1, a heatwave analysis of the Vellore 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 doubling in the number of heatwaves (departure from the normal temperature is 4.5°C to 6.4°C) and severe heatwaves (departure from the normal temperature is >6.4°C), as categorised by the India Meteorological Department (IMD), under both RCP 4.5 and RCP 8.5 scenarios (Figure 6-5) compared to the historical period (1990–2019).

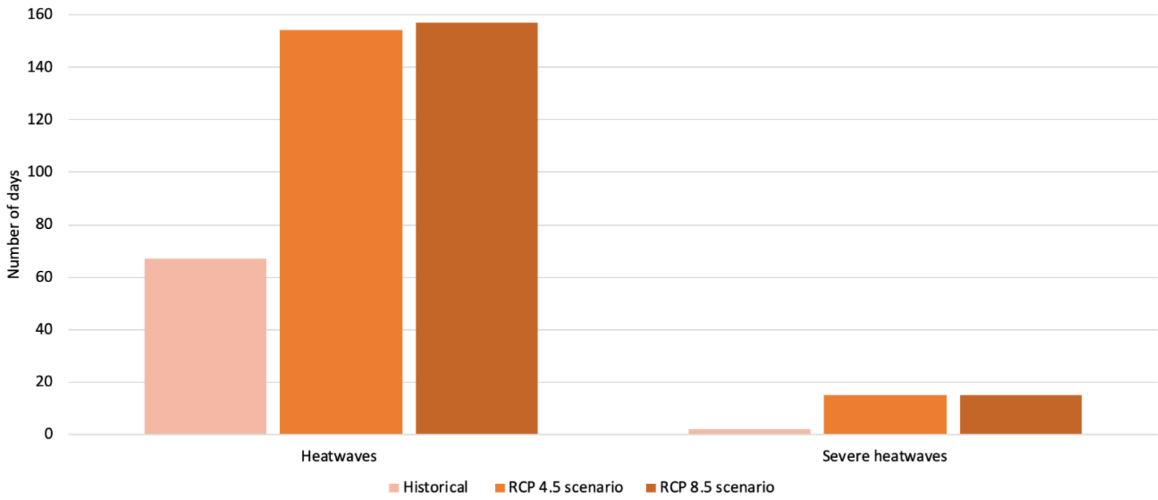


Figure 6-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

6.2.2. Rainfall projections

6.2.2.1. Number of rainy days

According to the IMD, a *rainy day* is defined as a day with rainfall of 2.5 mm or more. The analysis of rainy days under historical and projected periods shows that there will be an increase in the number of rainy days during the projected period in all the districts (Figure 6-6). The number of rainy days during the historical period and the projected 2030s under both RCP 4.5 and 8.5 scenarios is presented in Appendix 6-3. The total number of rainy days that ranged from 1726 to 2460 days over the 30-year historical period increases to 1967 to 2576 days under the RCP 4.5 scenario and 1991 to 2612 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 14 days annually in all the districts. The increase is by 14 days in Namakkal and Cuddalore; 13 days in Tiruvarur and Nagapattinam; 12 days in Dindigul and Kanchipuram; 11 days in Sivaganga and Tiruvannamalai; 10 days in Thanjavur, Tiruvallur, and Virudhunagar districts; and 2 to 9 days in the remaining 21 districts.

RCP 8.5 scenario: Projected to increase by 2 to 12 days annually in all the districts. The increase is by 12 days in Tiruvarur; 11 days in Namakkal and Cuddalore; 9 days in Tiruvallur, Kanchipuram, Tiruvannamalai, and Nagapattinam; and 2 to 8 days in the remaining 25 districts.

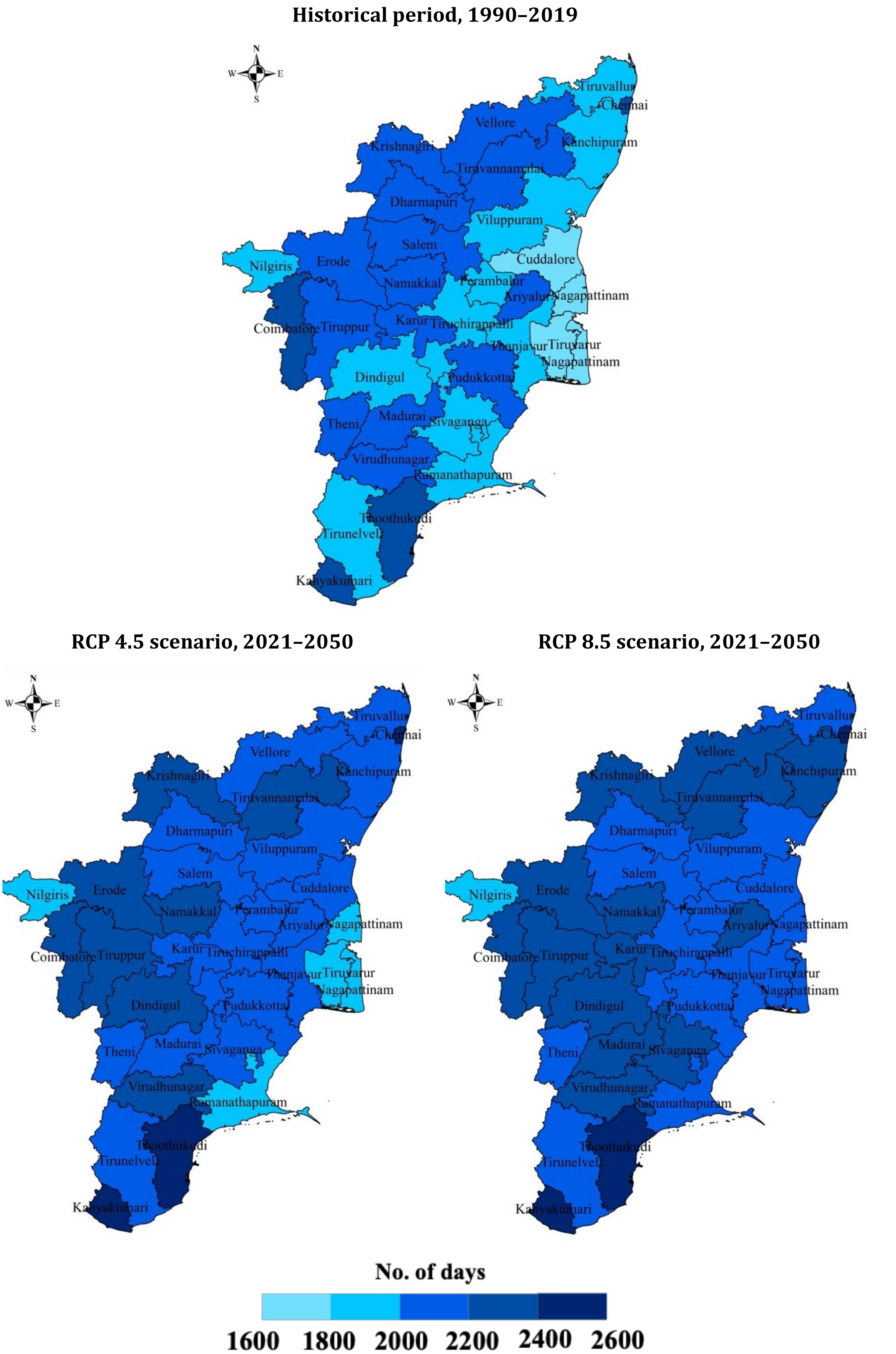


Figure 6-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

6.2.2.2. Mean rainfall and rainfall variability during the kharif season

Tamil Nadu receives rainfall from both south-west and north-east monsoons. The kharif season rainfall is projected to increase in all the districts under both climate scenarios. Figure 6-7 presents district-wise changes in the kharif season rainfall, and Figure 6-8 presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 7% in Tiruvarur to 19% in Krishnagiri	Increases in two districts by 1% to 2% and declines in 30 districts by 2% to 95%
RCP 8.5	Increases in all the districts, from 12% in Kanyakumari, Kanchipuram, and Cuddalore to 27% in Krishnagiri	Increases in two districts by 2% to 4% and declines in 30 districts by 2% to 88%

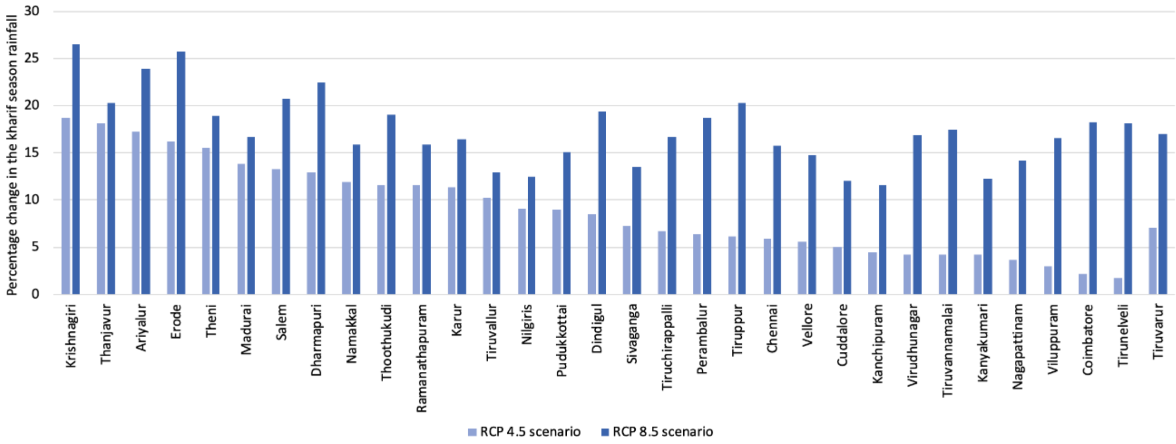


Figure 6-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

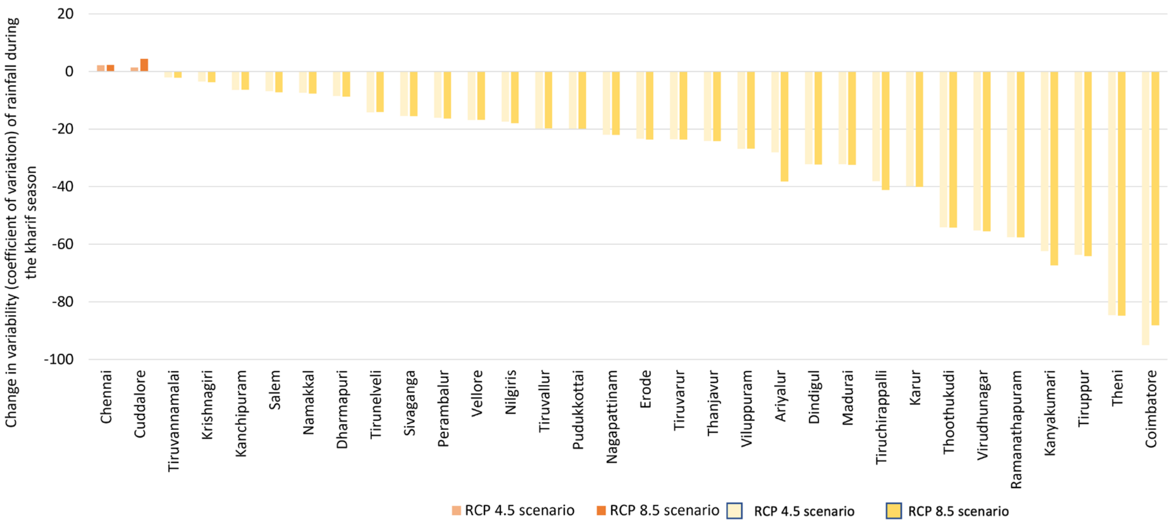


Figure 6-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

6.2.2.3. Mean rainfall and rainfall variability during the rabi season

The rabi season rainfall is projected to increase in all the districts under both climate scenarios. Figure 6-9 presents district-wise changes in the rabi season rainfall, and Figure 6-10 presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability (coefficient of variation)
RCP 4.5	Increases in all the districts, from 1% in Viluppuram to 21% in Coimbatore	Declines in all the districts, from 6% in Virudhunagar to 29% in Salem
RCP 8.5	Increases in all the districts, from 5% in Nagapattinam to 38% in Tirupur	Declines in all the districts, from 4% in Virudhunagar to 29% in Kanchipuram

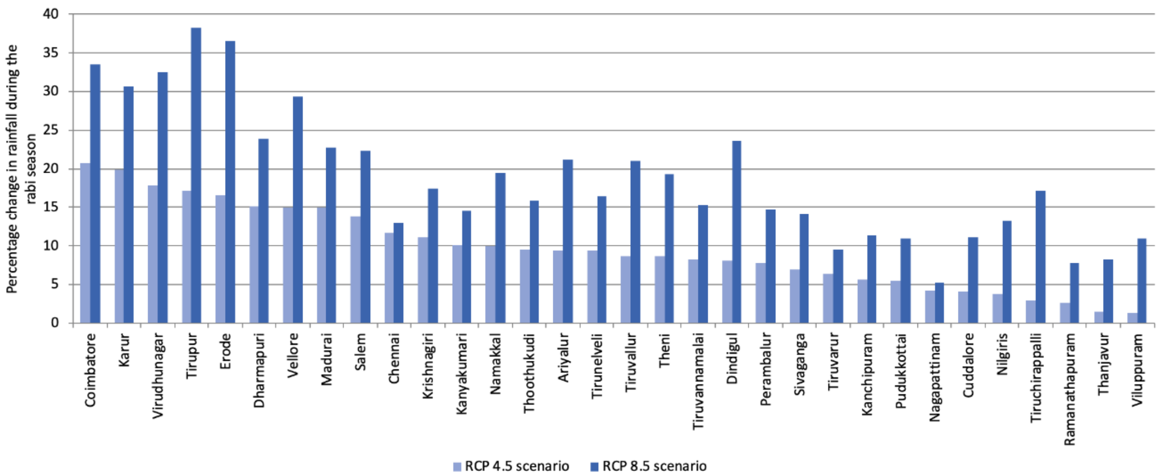


Figure 6-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

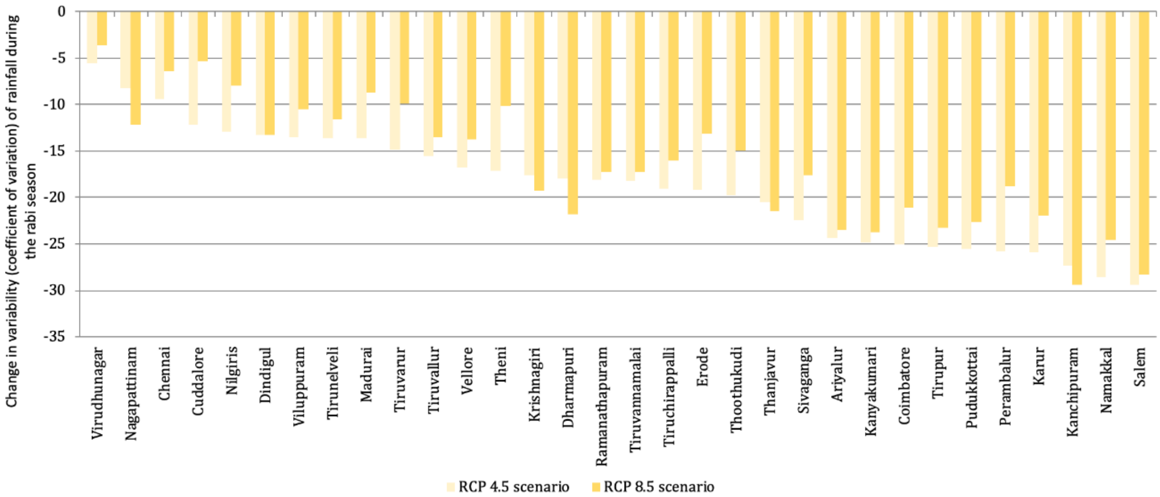


Figure 6-10: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

6.3. Heavy rainfall events and rainfall deficient years

Rainfall during the rabi season has been analysed 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 projected 2030s under the two climate scenarios, and the change was computed for all the districts of Tamil Nadu.

High-intensity rainfall events (Figure 6-11)

The total number of high-intensity rainfall events increases from 517 to 1029 days during the historical period (1990–2019) to 570 to 1077 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 612 to 1112 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 three events in six districts, including Krishnagiri, Nagapattinam, Vellore, and others; two events in 18 districts; and one event in eight districts.

RCP 8.5 scenario: The projected increase per annum is by five events in Vellore, three events in 16 districts, two events 12 districts, and one event in three districts.

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

The total number of very high-intensity rainfall events increases from 0 to 45 days during the historical period (1990–2019) to 12 to 90 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 20 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: The projected increase per annum is by one to two events in 29 of the 32 districts in Tamil Nadu. The increase is by two events in 19 districts and one event in 10 districts. In Vellore, Cuddalore, and Coimbatore, no change is projected.

RCP 8.5 scenario: The projected increase per annum is by three events in Virudhunagar and Sivaganga, two events in 19 districts, and one event in the remaining 11 districts.

Rainfall deficient years (Figure 6-13)

Rainfall deficient years is computed considering rainfall during the rabi season, as much of the rainfall is received from the northeast monsoon in Tamil Nadu. Rainfall deficient years are projected to decline in a majority of the districts under both the climate scenarios. The number of rainfall deficient years declines from 11 to 17 years during the historical 30-year 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: Projected to decline in 26 districts by 1 to 4 years. No change is projected in six districts.

RCP 8.5 scenario: Projected to decline in all the districts by 1 to 5 years. The decline is by 5 years in Theni, Dharmapuri, Dindigul, Kanchipuram, and Tiruvarur districts.

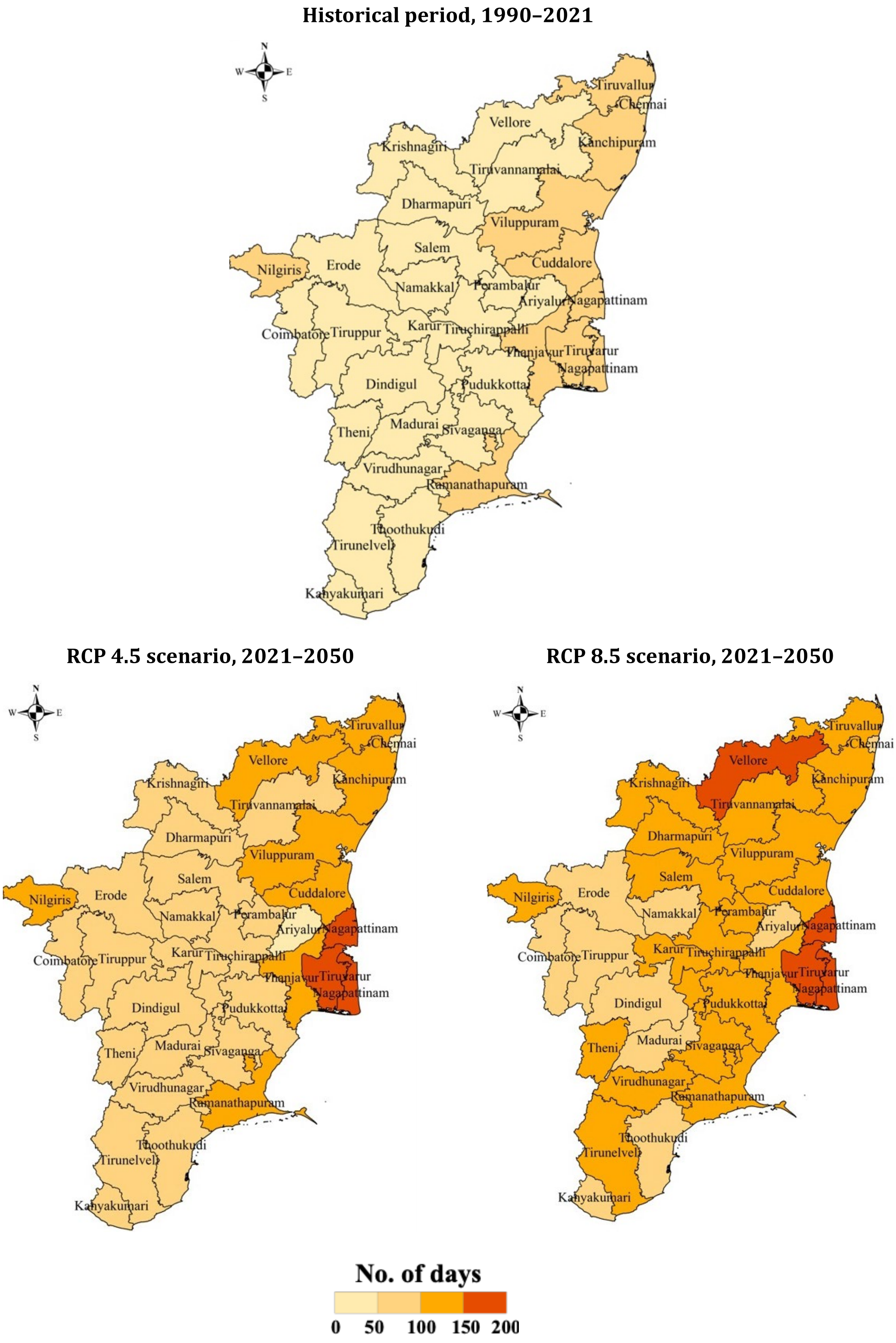


Figure 6-11: The number of high-intensity rainfall events during historical and projected periods under RCP 4.5 and RCP 8.5 scenarios

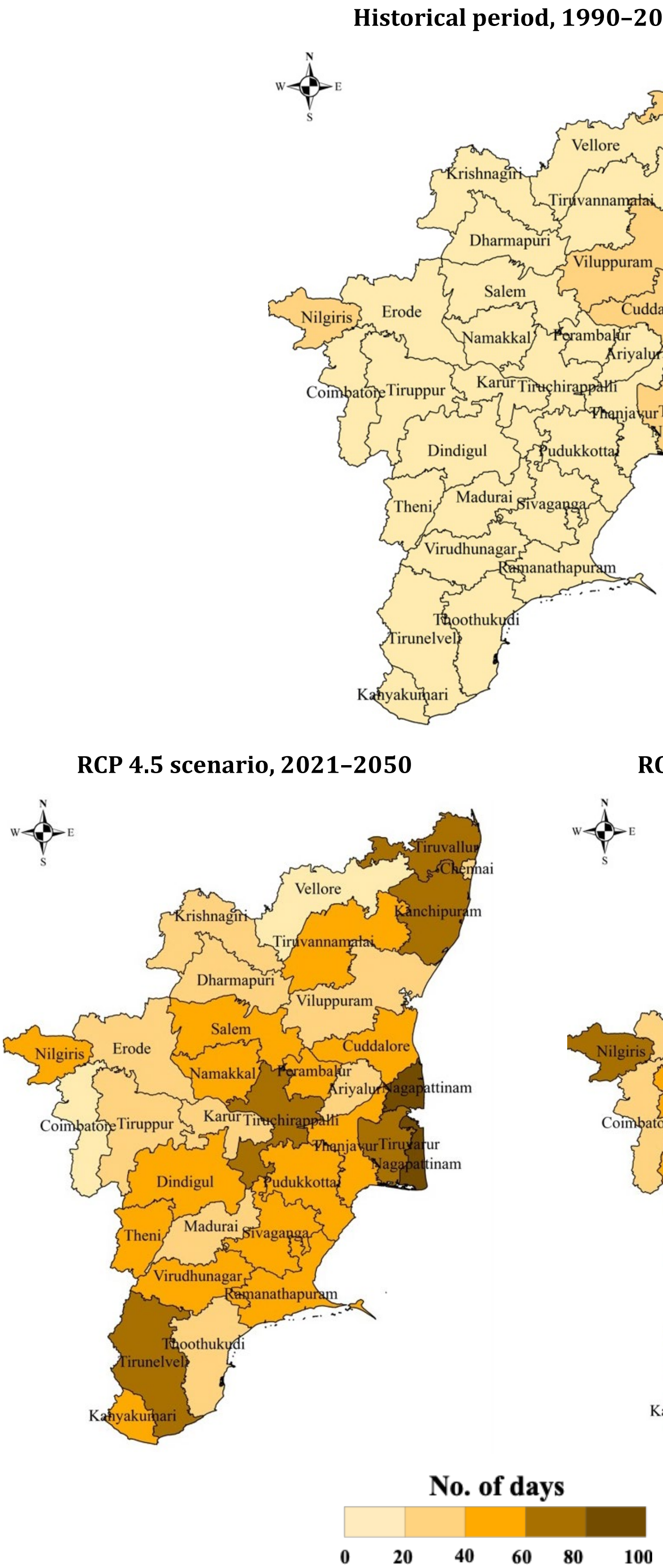


Figure 6-12: The number of very high-intensity rainfall events during historical and projected periods under RCP 4.5 and RCP 8.5 scenarios

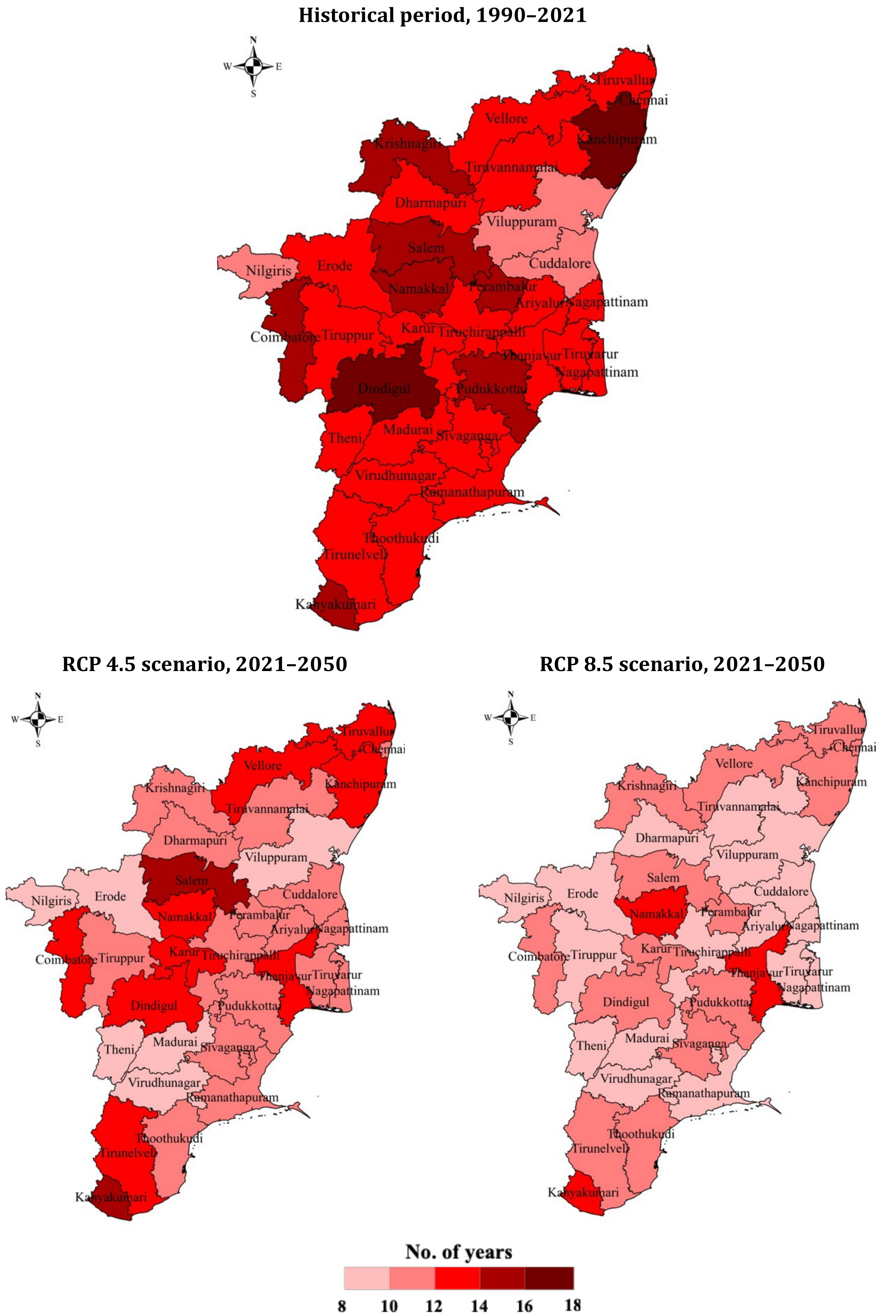


Figure 6-13: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

6.4. The summary of projected changes in the climate for Tamil Nadu

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

- A higher warming of $1^{\circ}C$ to $1.5^{\circ}C$ during summer is projected in all the districts except the eastern coastal districts under both the climate scenarios.
- A higher warming of $1^{\circ}C$ to $1.5^{\circ}C$ during winter is projected, particularly in the eastern coastal districts, under both the climate scenarios.

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

- The projected increase in rainfall during the rabi season is higher than that projected during the kharif season under both climate scenarios.

Rainfall variability is projected to decline in almost all the districts during the kharif season and in all the districts during the rabi season.

- The projected increase in rainfall variability is larger during the kharif season compared to the rabi season.

The number of rainy days is projected to increase in all the districts under both RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019; Appendix 6-3).

- The increase annually during the projected 2030s (2021–2050) is in the range of 2 to 14 days under the RCP 4.5 scenario and 2 to 12 days under the RCP 8.5 scenario.

An increase in the occurrence of heavy rainfall events is projected in the range of one to five events annually under both RCP 4.5 and RCP 8.5 scenarios (Appendix 6-4).

- A larger increase in heavy rainfall events is projected, particularly in the eastern coastal districts of Tamil Nadu.

Rainfall deficient years are projected to decline in the range of 1 to 4 years under the RCP 4.5 scenario in a majority of the districts and 1 to 5 years under the RCP 8.5 scenario in all the districts (Appendix 6-4).

Appendix

Appendix 6-1: Changes in temperature under climate scenarios

Districts	Change in temperature (°C) during the 2030s (2021–2050) compared to the historical period (1990–2019)			
	Summer maximum temperature		Winter minimum temperature	
Ariyalur	1.6	1.8	1.5	1.7
Chennai	1.3	1.5	1.6	1.8
Coimbatore	1.6	1.8	1.3	1.5
Cuddalore	1.6	1.7	1.6	1.8
Dharmapuri	1.5	1.7	1.2	1.4
Dindigul	1.6	1.8	1.3	1.5
Erode	1.3	1.5	1.1	1.4
Kanchipuram	1.6	1.7	1.5	1.7
Kanyakumari	1.1	1.2	1.7	1.8
Karur	1.6	1.7	1.2	1.2
Krishnagiri	1.6	1.7	1.2	1.3
Madurai	1.7	1.9	1.1	1.4
Nagapattinam	1.7	1.8	1.3	1.8
Namakkal	1.6	1.7	1.2	1.3
Nilgiris	1.3	1.8	1.2	1.3
Perambalur	1.6	1.7	1.1	1.2
Pudukkotai	1.4	1.5	1.2	1.3
Ramanathapuram	1.1	1.2	1.6	1.7
Salem	1.4	1.6	1.2	1.3
Sivaganga	1.5	1.6	1.3	1.7
Thanjavur	1.6	1.7	1.6	1.7
Theni	1.2	1.3	1.2	1.5
Thoothukudi	1.3	1.8	1.4	1.8
Tiruchirappalli	1.5	1.9	1.4	1.8
Tirunelveli	1.1	1.6	1.4	1.7
Tirupur	1.6	1.7	1.3	1.4
Tiruvallur	1.2	1.6	1.6	1.7
Tiruvannamalai	1.6	1.8	1.2	1.4
Tiruvarur	1.6	1.8	1.5	1.6
Vellore	1.4	1.6	1.2	1.3
Viluppuram	1.7	1.9	1.3	1.8
Virudhunagar	1.6	1.7	1.1	1.3

Appendix 6-2: Changes in rainfall under climate scenarios

Districts	Change in rainfall (%) during the 2030s (2021–2050) compared to the historical period (1990–2019)					
	Annual rainfall		Kharif season rainfall		Rabi season rainfall	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Ariyalur	6	16	17	24	9	21
Chennai	6	11	6	16	12	13
Coimbatore	5	22	2	18	21	34
Cuddalore	1	12	5	12	4	11
Dharmapuri	14	23	13	22	15	24
Dindigul	9	18	9	19	8	24
Erode	15	28	16	26	17	37
Kanchipuram	4	11	4	12	6	11
Kanyakumari	8	17	4	12	10	15
Karur	16	23	11	16	20	31
Krishnagiri	10	27	19	27	11	17
Madurai	8	16	14	17	15	23
Nagapattinam	1	6	4	14	4	5
Namakkal	13	21	12	16	10	19
Nilgiris	6	15	9	13	4	13
Perambalur	4	9	6	19	8	15
Pudukkotai	7	13	9	15	6	11
Ramanathapuram	2	15	12	16	3	8
Salem	10	20	13	21	14	22
Sivaganga	5	13	7	14	7	14
Thanjavur	3	10	18	20	2	8
Theni	13	18	16	19	9	19
Thoothukudi	10	19	12	19	9	16
Tiruchirappalli	6	15	7	17	3	17
Tirunelveli	13	16	2	18	9	16
Tirupur	14	22	6	20	17	38
Tiruvallur	6	14	10	13	9	21
Tiruvannamalai	10	17	4	17	8	15
Tiruvarur	-4	6	7	17	6	10
Vellore	6	14	6	15	15	29
Viluppuram	2	14	3	17	1	11
Virudhunagar	18	23	4	17	18	33

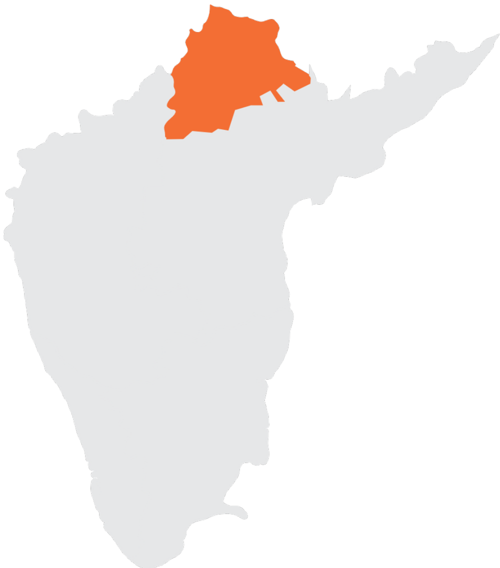
Appendix 6-3: The total number of rainy days (>2.5 cm/day) during the historical period (1990–2019) and the projected 2030s (2021–2050)

Districts	Historical	RCP 4.5 scenario	RCP 8.5 scenario
Ariyalur	2066	2166	2231
Chennai	2460	2576	2612
Coimbatore	2218	2314	2356
Cuddalore	1781	2067	2123
Dharmapuri	2078	2137	2189
Dindigul	1988	2228	2234
Erode	2147	2211	2235
Kanchipuram	1956	2190	2231
Kanyakumari	2410	2450	2478
Karur	2105	2198	2209
Krishnagiri	2107	2205	2356
Madurai	2065	2145	2221
Nagapattinam	1726	1976	2009
Namakkal	2052	2341	2390
Nilgiris	1883	1988	1991
Perambalur	1967	2078	2077
Pudukkotai	2061	2134	2189
Ramanathapuram	1825	1967	2013
Salem	2033	2145	2189
Sivaganga	1969	2189	2207
Thanjavur	1944	2145	2113
Theni	2065	2177	2189
Thoothukudi	2460	2567	2566
Tiruchirappalli	1933	2108	2178
Tirunelveli	1966	2111	2133
Tirupur	2110	2267	2278
Tiruvallur	1900	2100	2178
Tiruvannamalai	2015	2227	2290
Tiruvarur	1726	1980	2078
Vellore	2064	2155	2213
Viluppuram	1992	2167	2190
Virudhunagar	2041	2234	2278

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
Ariyalur	35	50	56	14	30	59	13	11	10
Chennai	0	31	45	0	33	32	13	12	11
Coimbatore	23	54	59	8	20	29	16	13	12
Cuddalore	94	125	149	38	42	67	11	11	9
Dharmapuri	25	78	105	4	35	42	14	11	9
Dindigul	28	81	78	8	46	61	17	14	12
Erode	12	85	91	0	36	39	13	10	9
Kanchipuram	89	109	124	25	78	81	17	14	12
Kanyakumari	0	76	89	0	55	62	16	16	14
Karur	20	90	101	5	28	56	14	13	12
Krishnagiri	13	95	113	4	34	47	15	12	11
Madurai	33	89	100	3	34	45	13	10	9
Nagapattinam	89	165	178	42	90	102	14	11	10
Namakkal	20	88	97	3	45	50	16	13	13
Nilgiris	58	108	145	21	55	80	11	10	9
Perambalur	28	96	106	8	42	68	15	12	11
Pudukkottai	42	93	114	5	41	45	15	12	11
Ramanathapuram	64	120	135	8	49	67	14	11	10
Salem	22	86	115	4	56	76	16	15	12
Sivaganga	27	98	118	1	52	85	13	12	11
Thanjavur	64	104	134	20	45	69	14	14	13
Theni	34	88	112	3	51	60	13	9	8
Thoothukudi	0	81	90	0	30	44	14	12	11
Tiruchirappalli	37	97	108	9	64	75	14	12	10
Tirunelveli	20	92	102	4	67	75	14	14	12
Tiruppur	26	80	89	5	40	44	13	11	10
Tiruvallur	84	118	132	36	76	88	13	13	12
Tiruvannamalai	35	94	109	4	56	77	13	11	10
Tiruvarur	89	165	180	42	77	90	14	11	9
Vellore	34	124	170	10	12	67	14	13	11
Viluppuram	71	112	134	22	40	56	10	10	9
Virudhunagar	31	97	110	4	55	87	13	10	9

7. Telangana



Telangana has an area of 1,14,870 sq. km. and a population of 3,50,03,674. It is surrounded by Andhra Pradesh in the south and east directions, Karnataka in the west, and Maharashtra and Chhattisgarh in the north. The main cities of the state include Hyderabad, Nizamabad, Karimnagar, and Warangal. The state is divided into 33 districts. The total area under agriculture is 6.5 Mha, of which the irrigated area is 2.66 Mha. There are several dams and thermal, solar, and wind power plants in the state.

Historically, Telangana is prone to droughts, and the districts of Rangareddy, Mahabubnagar and Nalgonda are highly susceptible. According the Vulnerability Atlas of India 2019, 2.2% of the state is prone to floods, and Khammam district has been identified as being most prone to monsoon floods. The city of Hyderabad is also prone to urban flooding, due to improper management of drainage systems. Heat waves and fatalities due to sunstroke are a common occurrence in the state, particularly in the month of May, when temperature reaches 47°C across almost 50% of the area of the state.

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

7.1. Historical climate

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

7.1.1. Trends in temperature

Telangana recorded a moderate warming of 0.06°C to 0.3°C in the summer maximum temperature and 0.05°C to 0.15°C in the winter minimum during the historical period. Figure 7-1 presents the mean summer maximum and winter minimum temperatures in Telangana during the historical period.

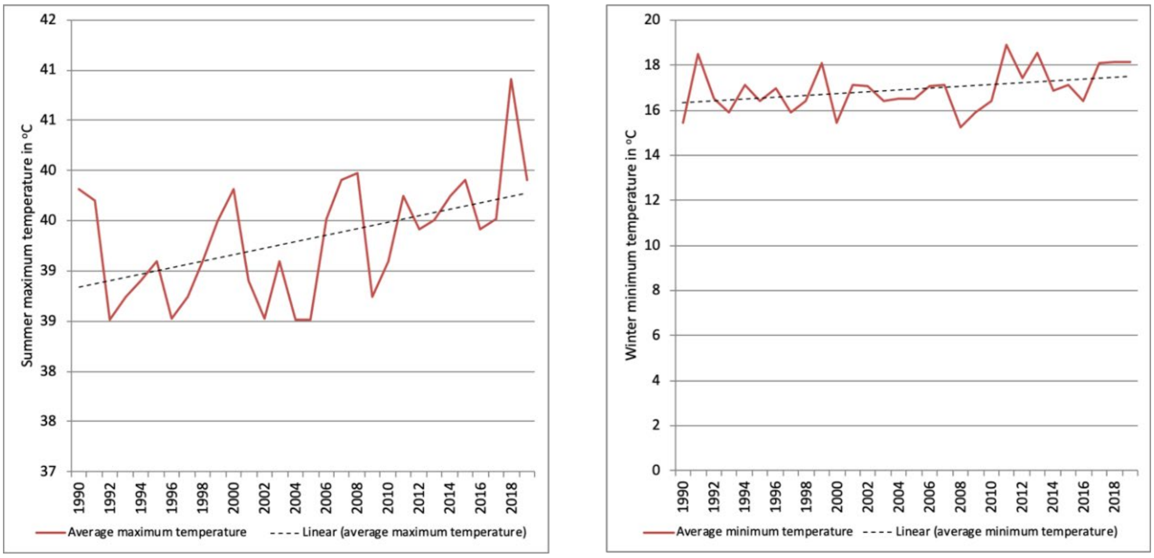


Figure 7-1: Mean summer maximum and winter minimum temperatures in Telangana during the historical period (1990–2019)

7.1.2. Trends in rainfall and rainfall variability

An increasing trend in the annual and kharif season rainfall, which is the main monsoon season, was recorded across the districts of Telangana. The increase in annual and kharif season rainfall was largely up to 15% in a majority of the districts of Telangana. A higher increase in the kharif season rainfall, in the range of 15% to 20%, was recorded in some of the northern districts (Figure 7-2).

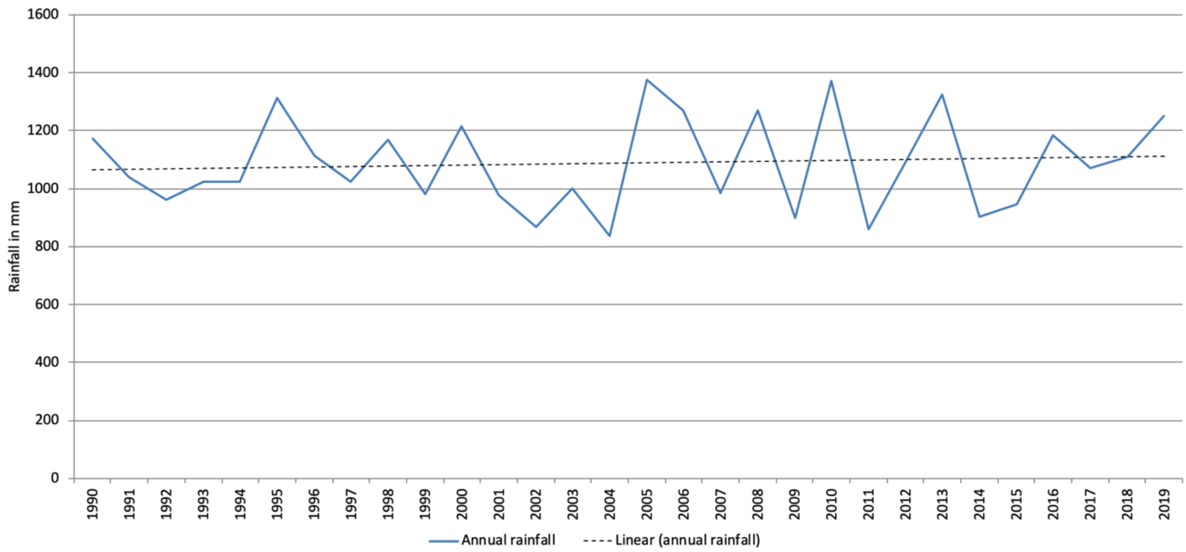


Figure 7-2: Mean annual rainfall in Telangana during the historical period (1990–2019)

The kharif season rainfall variability (coefficient of variation) ranged from 20% in Karimnagar to 37% in the Warangal Urban district (Figure 7-3). The rabi season rainfall variability was from 53% in Mulugu to 95% in Nirmal during the historical period.

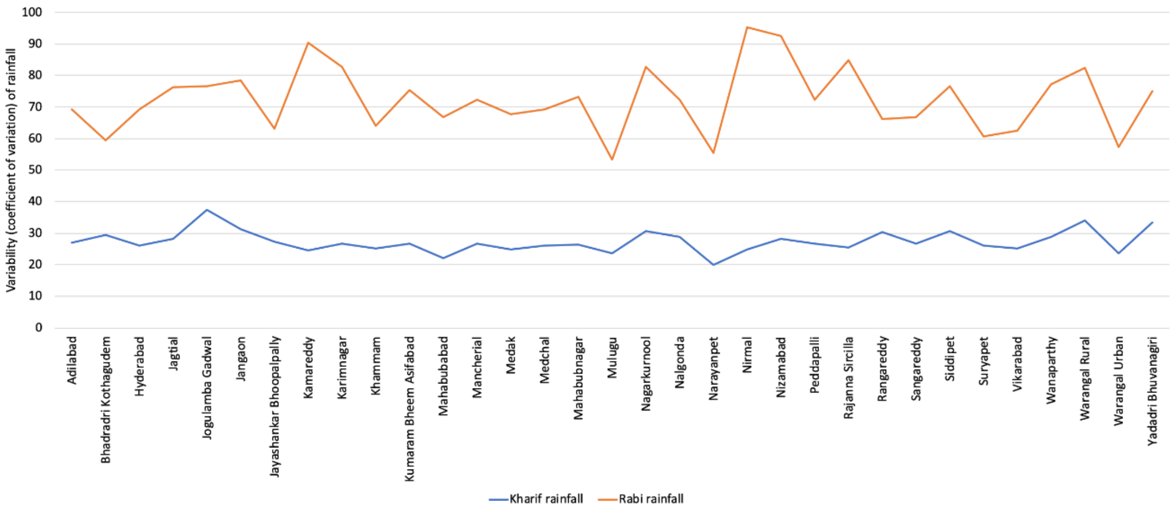


Figure 7-3: The kharif and rabi season rainfall variability (coefficient of variation) in the districts during the historical period (1990–2019)

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 Telangana 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 up to 2^0C	Increases up to 1.5^0C
RCP 8.5	Increases up to 2^0C	Increases up to 2^0C

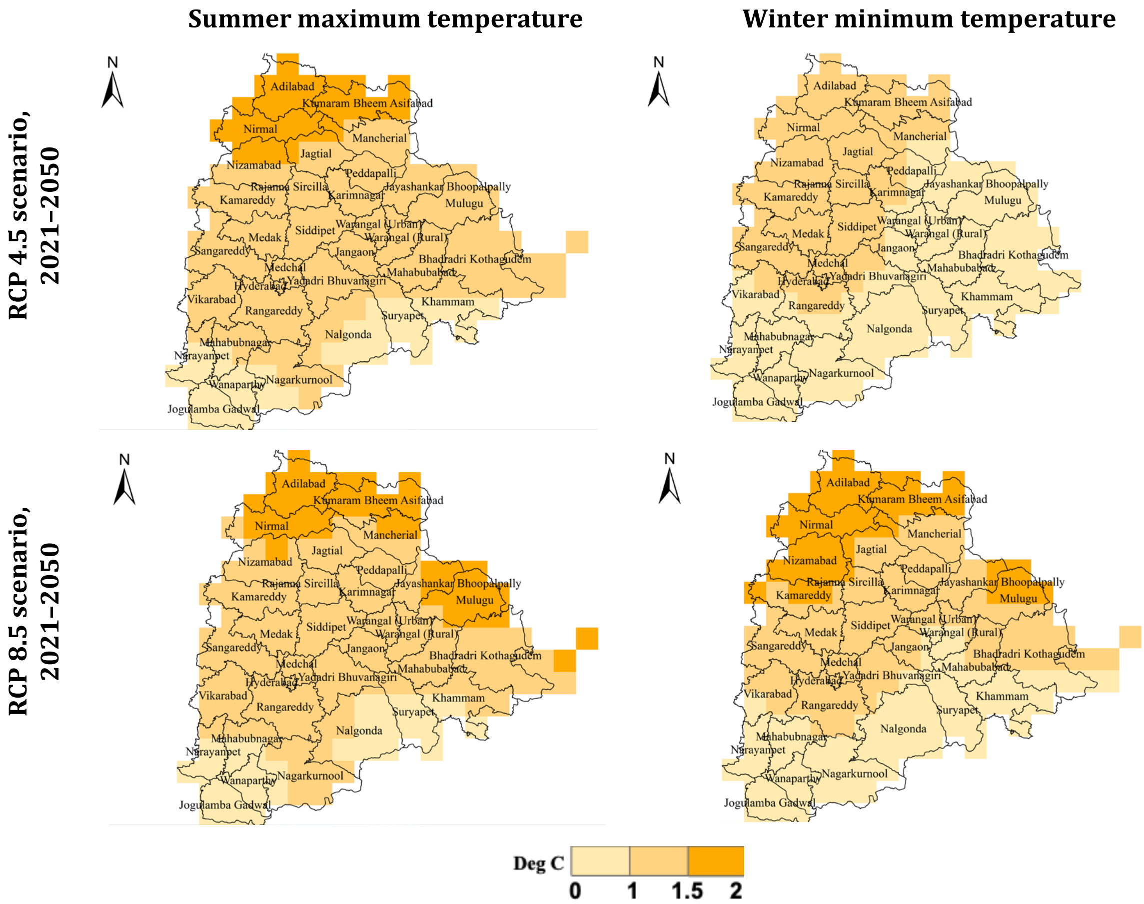


Figure 7-4: Projected changes in the summer maximum and winter minimum temperatures (°C) during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios. The changes are calculated by subtracting the mean over 1990–2019 from the mean over 2021–2050.

7.2.1.1. Heatwaves

Following the criteria of departure from normal temperature, as discussed in Chapter 2, a heatwave analysis of the Nalgonda district was conducted.

The analysis of temperature during the projected period of the 2030s shows that there would be a decline in the number of heatwaves (departure from the normal temperature is 4.5°C to 6.4°C) and severe heatwaves (departure from the normal temperature is >6.4°C), as categorised by the India Meteorological Department (IMD), will nearly double under both RCP 4.5 and RCP 8.5 scenarios (Figure 7-5).

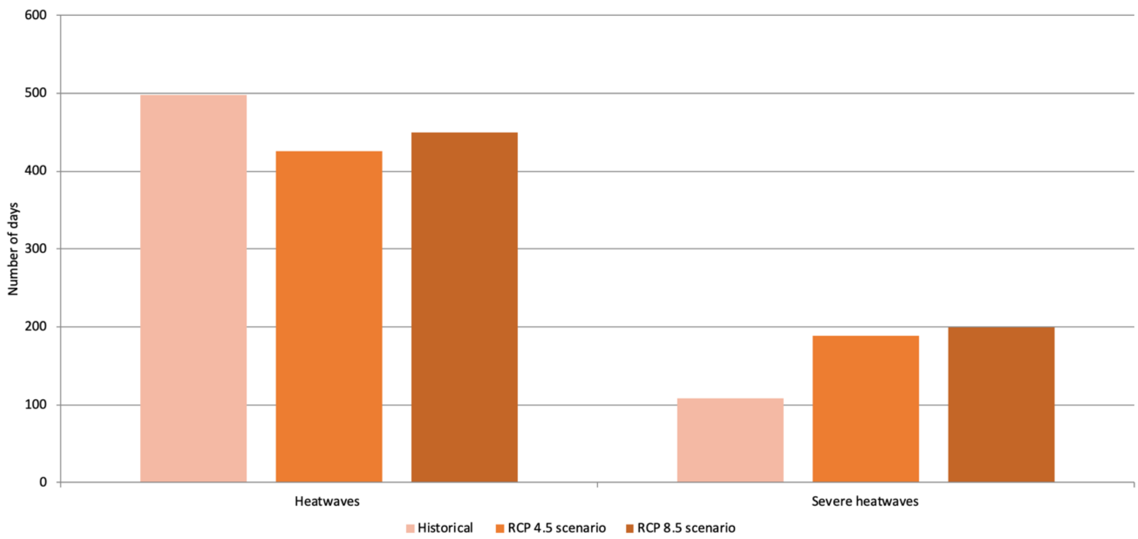


Figure 7-5: The number of heatwaves during the historical period (1990–2019) and the projected 2030s (2021–2050) under RCP 4.5 and RCP 8.5 scenarios

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 both RCP 4.5 and 8.5 scenarios is presented in Appendix 7-3. The total number of rainy days that ranged from 1002 to 2581 days over the 30-year historical period increases to 1130 to 2627 days under the RCP 4.5 scenario and 1145 to 2645 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 increase is by 10 days in Jogulamba Gadwal; 9 days in Hyderabad, Mahabubnagar, and Jangaon; 5 to 8 days in 14 districts; and 2 to 4 days in 15 districts.

RCP 8.5 scenario: Projected to increase by 1 to 9 days annually in all the districts. The increase is by 9 days in Jogulamba Gadwal, Hyderabad, Medchal , Vikarabad, and Nizamabad; 8 days in Karimnagar and Mahabubnagar; 7 days in Suryapet and Kumaram Bheem Asifabad; 6 days in five districts; 5 days in six districts; and 1 to 4 days in 13 districts.

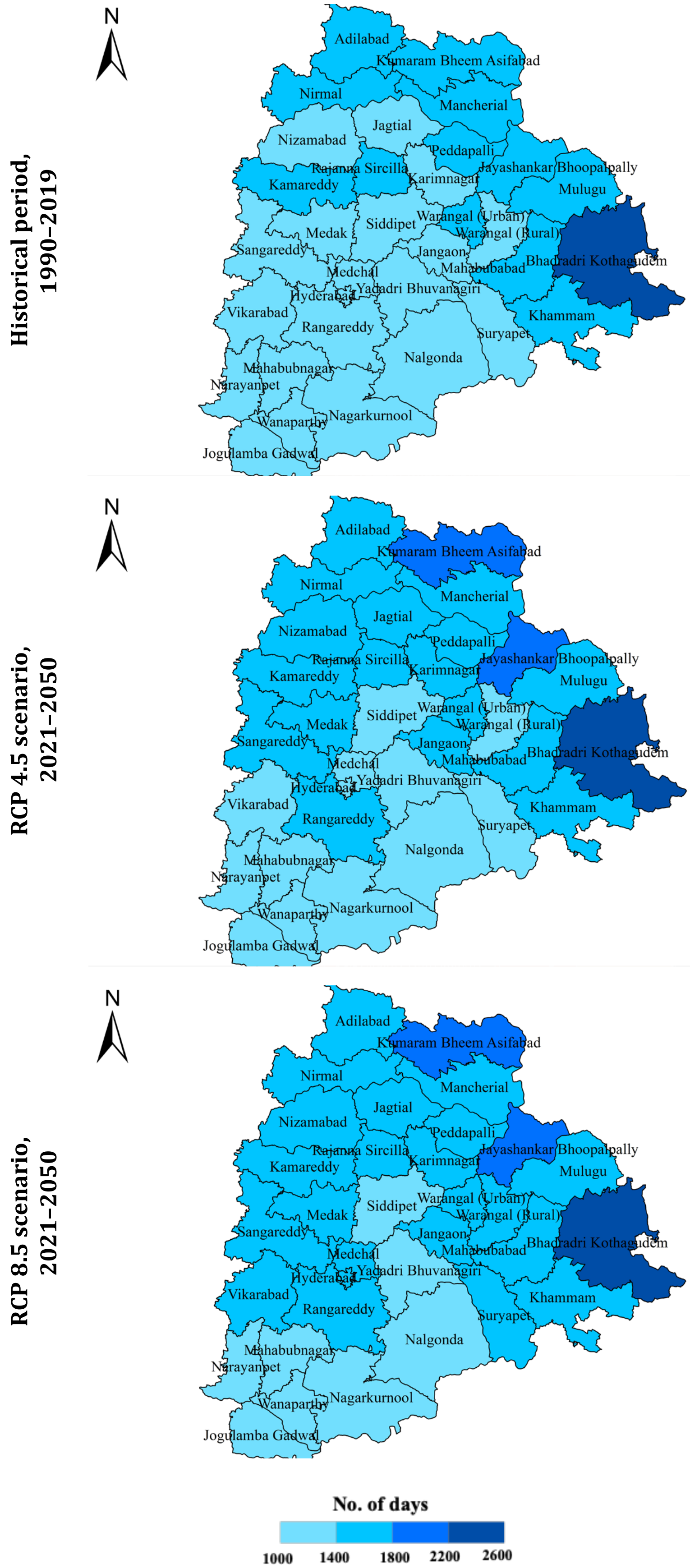


Figure 7-6: The total number of rainy days during the 30-year historical (1990–2019) and projected (the 2030s) periods under RCP 4.5 and RCP 8.5 scenarios

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 under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability
RCP 4.5	Increases in all the districts, from 3% in Siddipet to 16% in Narayanpet	Increases in three districts by 1% to 3% and declines in 30 districts by 1% to 15%
RCP 8.5	Increases in all the districts, from 5% in Nalgonda to 24% in Narayanpet	Increases in three districts by 5% to 7% and declines in 30 districts by 1% to 7%

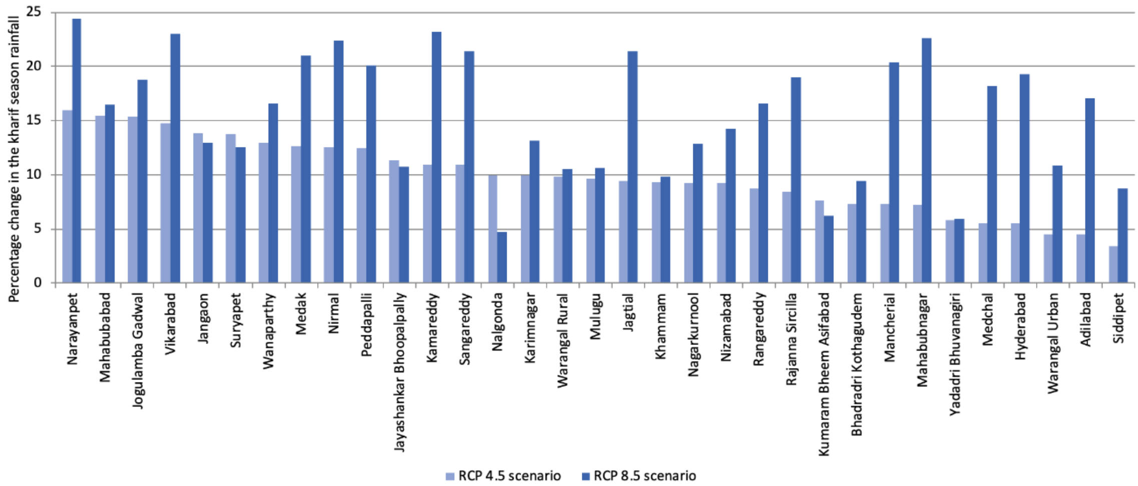


Figure 7-7: Projected percentage change in the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

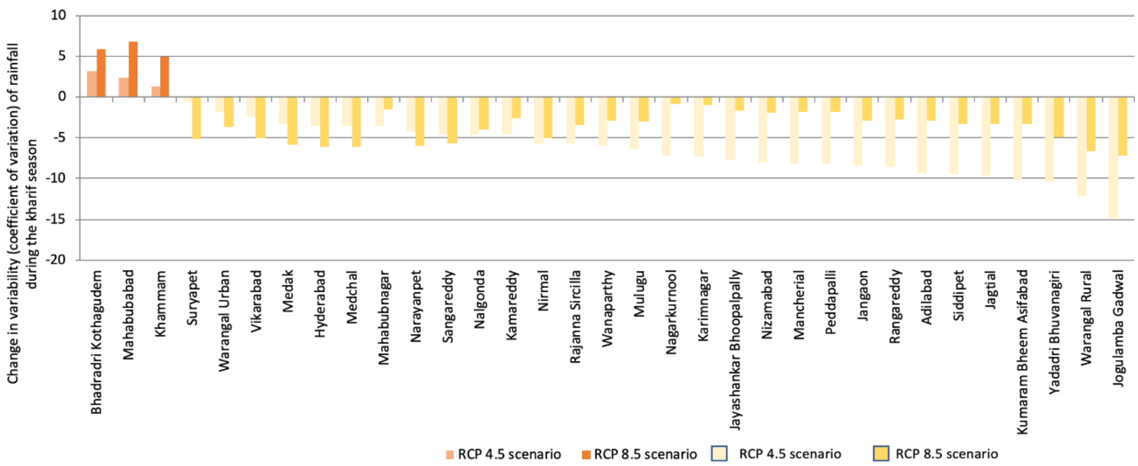


Figure 7-8: Projected changes in the variability (coefficient of variation) of the kharif season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

7.2.2.3. 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 7-9 presents district-wise changes in the rabi season rainfall, and Figure 7-10 presents changes in the variability (coefficient of variation) of rainfall under both climate scenarios.

Climate scenarios	Mean seasonal rainfall	Rainfall variability
RCP 4.5	Increases in all the districts, from 7% in Rangareddy and Nagarkurnool to 59% in Siddipet	Declines in all the districts, from 6% in Vikarabad to 39% in Nirmal
RCP 8.5	Increases in all the districts, from 9% in Jangaon and Warangal Urban to 46% in Jogulamba Gadwal	Declines in all the districts, from 4% in Narayanpet and Vikarabad to 37% in Nirmal

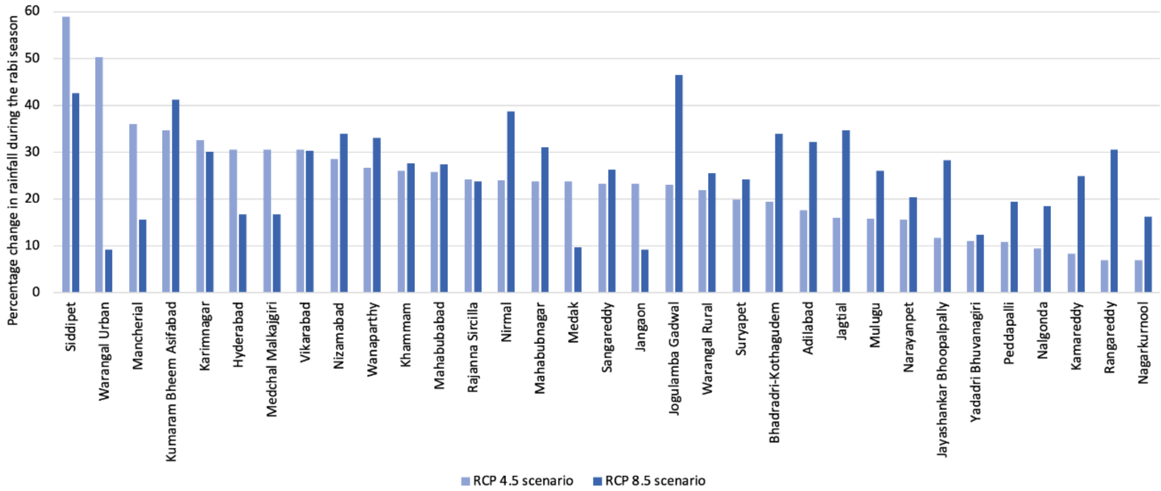


Figure 7-9: Projected percentage change in the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

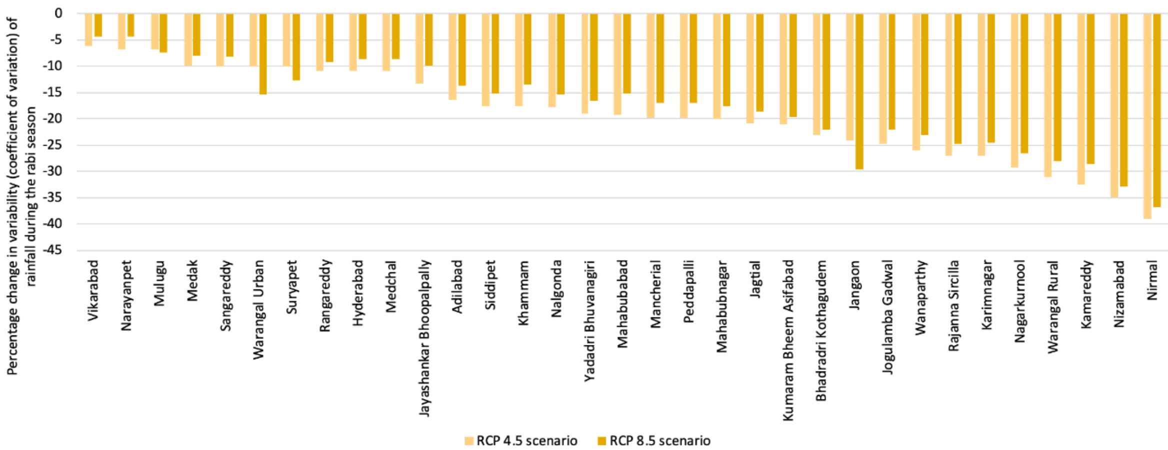


Figure 7-10: Projected changes in the variability of the rabi season rainfall during the short-term period (the 2030s) under RCP 4.5 and RCP 8.5 scenarios compared to the historical period (1990–2019)

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, termed 'Low' intensity; 51–100 mm/day, termed 'High' intensity; and >100 mm/day, termed 'Very High' intensity. The number of such events was computed for the historical and for the 2030s under the two climate scenarios, and the change was computed for all the districts of Telangana.

High-intensity rainfall events (Figure 7-11)

The total number of high-intensity rainfall events increases from 8 to 209 days during the historical period (1990–2019) to 60 to 232 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 85 to 265 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 Telangana, except Adilabad. The projected increase is by five events in Warangal Rural; three events in Nagarkurnool, Nalgonda, Nirmal, Nizamabad, Rajanna Sircilla, Sangareddy, and Wanaparthy; two events in 18 districts; and one event in six districts.

RCP 8.5 scenario: An increase in high-intensity rainfall events per annum is projected in all the districts of Telangana. The projected increase is by five events in Warangal Rural; four events in Nizamabad, Nagarkurnool, and Nirmal; three events in 17 districts; and two events in the remaining 12 districts.

Very high-intensity rainfall events (Figure 7-11)

The total number of very high-intensity rainfall events increases from 0 to 35 days during the historical period (1990–2019) to 12 to 89 days in the 2030s (2021–2050) under the RCP 4.5 scenario and 40 to 99 days under the RCP 8.5 scenario. On a per annum basis, the increase under the two climate scenarios is as follows:

RCP 4.5 scenario: The projected increase per annum is by one to three events in all the districts of Telangana, except Jangaon and Hyderabad. The increase is by three events in Rajanna Sircilla; two events in Nalgonda, Nirmal, Nizamabad, Suryapet, Warangal Rural, Warangal Urban, and Yadadri Bhuvanagiri; and one event in 23 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 Suryapet, Sangareddy, Wanaparthy, Rangareddy, Sangareddy, Warangal Rural, Rajanna Sircilla, and Yadadri Bhuvanagiri; two events in 16 districts; and one event in the remaining nine districts.

Rainfall deficient years (Figure 7-12)

Rainfall deficient years, computed by considering the rainfall during the kharif season, are projected to decline in all the districts of Telangana under both climate scenarios. The number of rainfall deficient years declines from 10 to 16 years during the historical 30-year period to 9 to 15 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: The projected decline is by 1 to 4 years in 24 districts. No change is projected in the nine districts, including Jogulamba Gadwal, Jangaon, Kamareddy, Mahabubabad, Medak, Nagarkurnool, Nalgonda, Wanaparthy, and Yadadri Bhuvanagiri.

RCP 8.5 scenario: The projected decline is by 1 to 3 years in nine districts including Vikarabad, Karimnagar, Nizamabad, Jagtial, Medak, Siddipet, Warangal Rural, Mulugu, and Bhadradri Kothagudem. No change is projected in the remaining 24 districts.

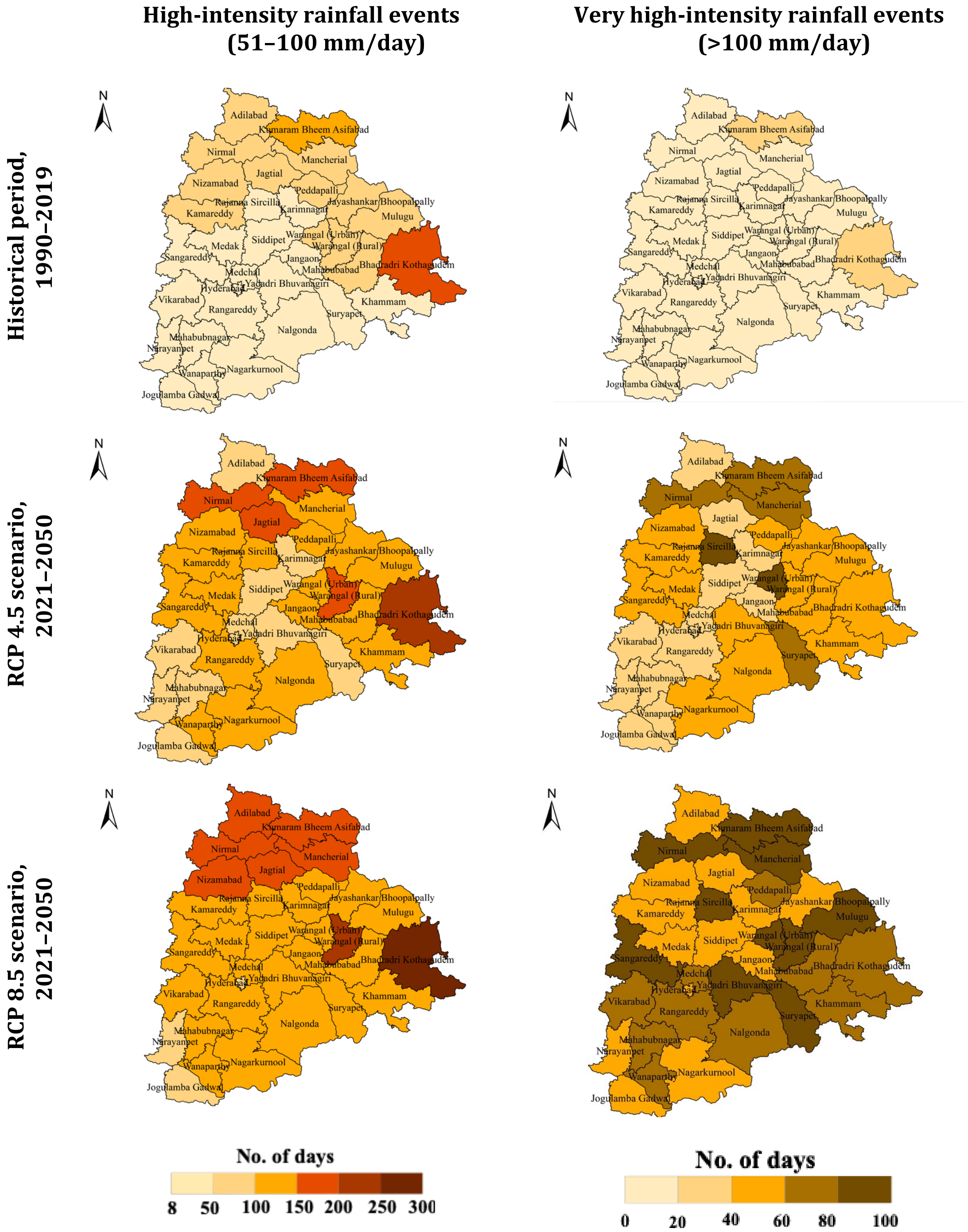


Figure 7-11: The total number of high-intensity and very high-intensity rainfall events over a 30-year period during historical (1990–2019) and the projected short-term (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

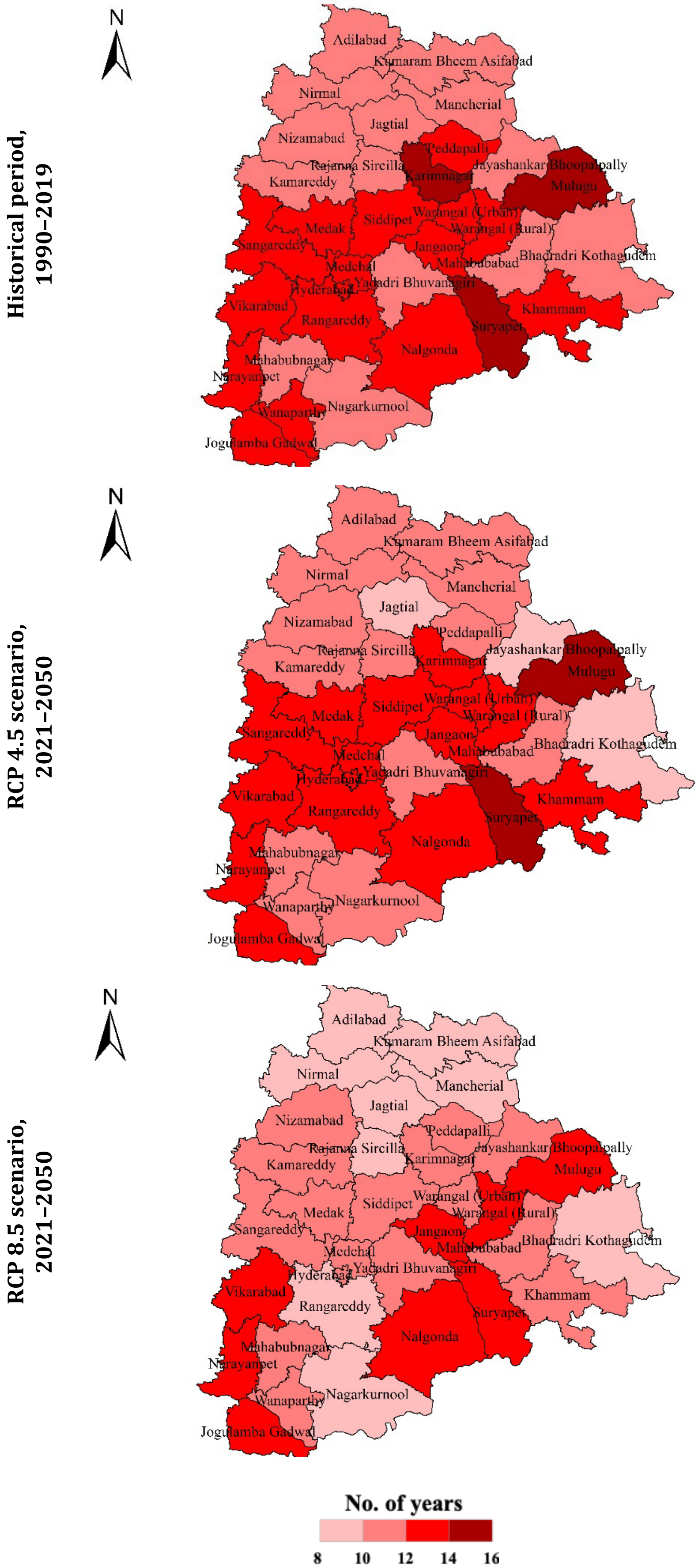


Figure 7-12: The number of rainfall deficient years over a 30-year period during the historical period (1990–2019) and the projected short-term (2021–2050) period under RCP 4.5 and RCP 8.5 scenarios

7.4. The summary of projected changes in the climate for Telangana

Temperature is projected to increase in all the districts under both the climate scenarios (Appendix 7-1).

- A higher warming of 1.5^{0}C to 2^{0}C is projected in the northern districts under the RCP 8.5 scenario.

Rainfall is projected to increase in all the districts during both kharif and rabi seasons under both the climate scenarios (Appendix 7-2).

- There is a notable increase in rainfall, particularly in the northern districts, under both RCP 4.5 and RCP 8.5 scenarios.

Rainfall variability is projected to decline in most districts during the kharif season and in all the districts during the rabi season.

- The projected increase in rainfall variability is larger during the rabi season compared to the kharif season.

The number of rainy days is projected to increase in all the districts under both the climate scenarios (Appendix 7-3).

- The increase annually during the projected 2030s (2021–2050) is in the range of 2 to 10 days under the RCP 4.5 scenario and 1 to 9 days under the RCP 8.5 scenario.

An increase in the occurrence of heavy rainfall events is projected, in the range of one to five events annually, under both RCP 4.5 and RCP 8.5 scenarios (Appendix 7-4).

- A larger increase in very high-intensity rainfall events is projected, particularly in the eastern districts of Telangana.

Rainfall deficient years are projected to decline, in the range of 1 to 4 years, under the RCP 4.5 scenario in a majority of the districts and remain the same in a majority of the districts under the RCP 8.5 scenario (Appendix 7-4).

Appendix

Appendix 7-1: 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
Adilabad	1.6	1.8	1.3	1.7
Bhadradri Kothagudem	1.3	1.5	0.9	1.3
Hyderabad	1.4	1.1	0.7	0.8
Jagtial	1.6	1.7	1.3	1.8
Jogulamba Gadwal	0.7	1.2	0.6	0.7
Jangaon	1.4	1.3	1.4	1.3
Jayashankar Bhoopalpally	1.2	1.4	0.6	0.7
Kamareddy	1.4	1.6	1.3	1.7
Karimnagar	1.2	1.3	1.2	1.4
Khammam	0.7	1.3	0.6	0.9
Kumaram Bheem Asifabad	1.6	1.8	1.2	1.3
Mahabubabad	0.6	1.1	0.5	1.1
Mancherial	1.6	1.7	1.2	1.6
Medak	1.3	1.4	1.3	1.4
Medchal	1.2	1.1	0.9	1.1
Mahabubnagar	0.7	1.2	0.4	0.6
Mulugu	1.2	1.4	1.4	1.7
Nagarkurnool	0.4	0.7	0.5	0.9
Nalgonda	0.6	0.9	0.4	0.8
Narayanpet	0.8	1.3	0.7	0.9
Nirmal	1.6	1.7	1.2	1.7
Nizamabad	1.7	1.8	1.1	1.6
Peddapalli	1.1	1.3	1.2	1.7
Rajanna Sircilla	1.3	1.4	1.1	1.3
Rangareddy	1.1	1.2	1.2	1.4
Sangareddy	1.2	1.4	1.1	1.3
Siddipet	1.3	1.4	1.2	1.3
Suryapet	0.7	1.2	0.7	0.9
Vikarabad	1.3	1.4	0.7	1.2
Wanaparthy	0.8	0.9	0.7	0.9
Warangal Rural	1.3	1.4	1.1	1.2
Warangal Urban	1.2	1.3	1.3	1.4
Yadadri Bhuvanagiri	1.3	0.9	0.7	0.9

Appendix 7-2: Changes in rainfall under climate scenarios

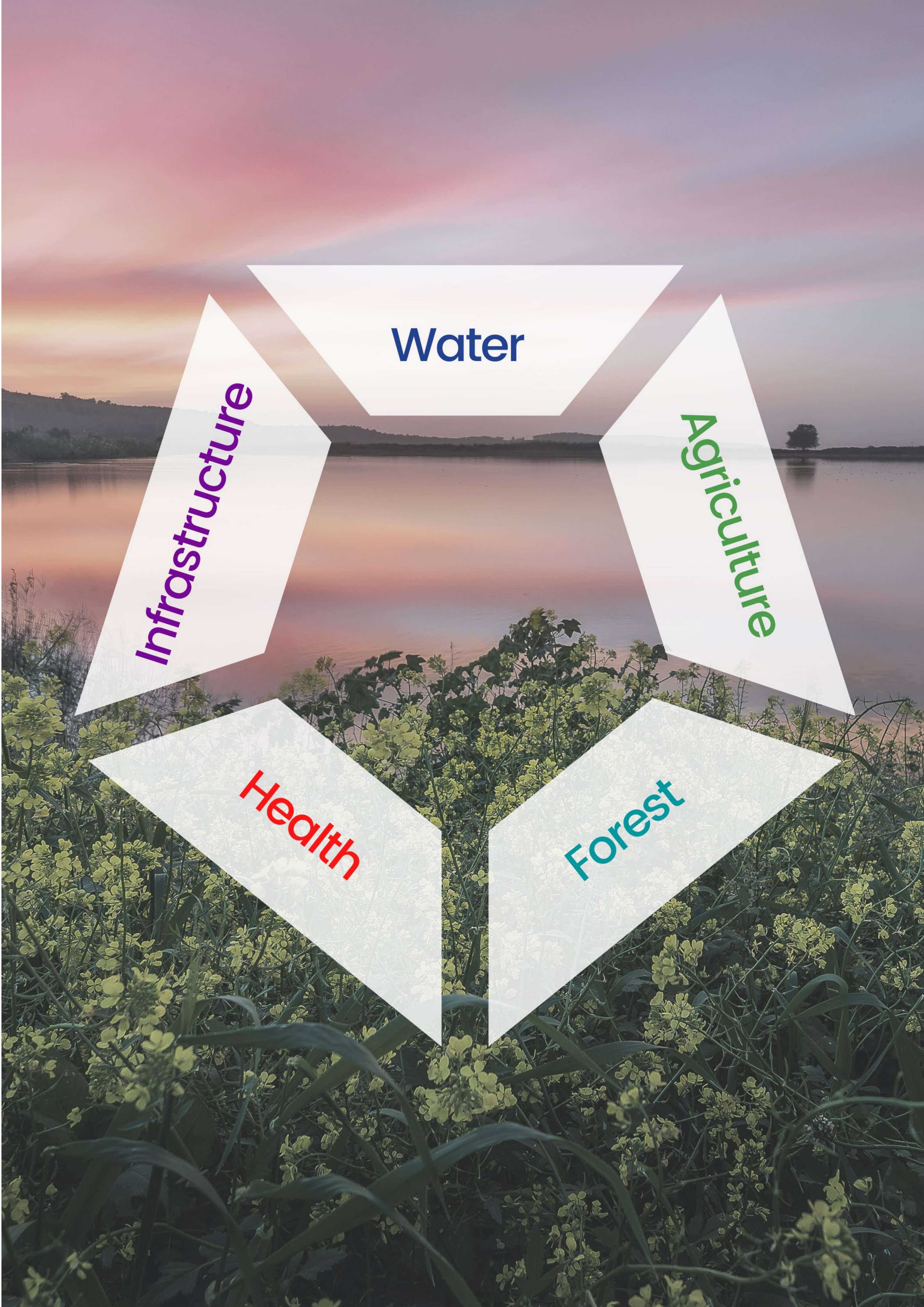
Districts	Changes in rainfall (%) during the 2030s (2021–2050) compared to the historical period (1990–2019)					
	Annual rainfall		Kharif season rainfall		Rabi season rainfall	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
Adilabad	4	3	4	17	17	32
Bhadradri Kothagudem	11	13	7	9	19	34
Hyderabad	9	17	6	19	31	17
Jagtial	5	15	9	21	16	35
Jogulamba Gadwal	14	20	15	19	23	46
Jangaon	13	12	14	13	23	9
Jayashankar Bhoopalpally	10	11	11	11	12	28
Kamareddy	5	18	11	23	8	25
Karimnagar	6	17	10	13	33	30
Khammam	4	8	9	10	26	28
Kumaram Bheem Asifabad	10	12	8	6	35	41
Mahabubabad	12	16	15	16	26	27
Mancherial	8	18	7	20	36	16
Medak	11	18	13	21	24	10
Medchal	7	16	6	18	31	17
Mahabubnagar	15	26	7	23	24	31
Mulugu	10	12	10	11	16	26
Nagarkurnool	17	17	9	13	7	16
Nalgonda	10	3	10	5	9	18
Narayanpet	13	23	16	24	15	20
Nirmal	8	20	13	22	24	39
Nizamabad	12	24	9	29	29	34
Peddapalli	10	19	12	20	11	19
Rajanna Sircilla	6	22	8	19	24	24
Rangareddy	8	19	9	17	7	30
Sangareddy	10	22	11	21	23	26
Siddipet	4	9	3	9	59	42
Suryapet	11	13	14	13	20	24
Vikarabad	16	23	15	29	30	30
Wanaparthy	12	13	13	17	27	33
Warangal Rural	8	9	10	11	22	25
Warangal Urban	9	9	4	11	50	9
Yadadri Bhuvanagiri	5	8	6	6	11	12

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
Adilabad	1650	1767	1790
Bhadradri Kothagudem	2581	2627	2645
Hyderabad	1199	1377	1470
Jagtial	1370	1451	1546
Jogulamba Gadwal	1069	1265	1340
Jangaon	1284	1456	1444
Jayashankar Bhoopalpally	1682	1801	1843
Kamareddy	1483	1527	1525
Karimnagar	1308	1443	1551
Khammam	1536	1634	1623
Kumaram Bheem Asifabad	1675	1841	1872
Mahabubabad	1444	1543	1503
Mancherial	1469	1521	1560
Medak	1382	1467	1574
Medchal	1199	1367	1468
Mahabubnagar	1088	1265	1330
Mulugu	1678	1758	1796
Nagarkurnool	1002	1130	1145
Nalgonda	1216	1354	1369
Narayanpet	1078	1156	1201
Nirmal	1425	1485	1473
Nizamabad	1382	1445	1645
Peddapalli	1469	1521	1549
Rajanna Sircilla	1425	1531	1561
Rangareddy	1376	1504	1559
Sangareddy	1298	1456	1474
Siddipet	1193	1251	1307
Suryapet	1258	1389	1467
Vikarabad	1227	1344	1490
Wanaparthy	1104	1178	1190
Warangal Rural	1301	1371	1472
Warangal Urban	1678	1732	1771
Yadadri Bhuvanagiri	1174	1216	1265

Appendix 7-4: 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.

Disricts	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
Adilabad	79	90	152	16	40	45	11	9	11
Bhadradri Kothagudem	209	232	265	35	56	76	10	9	9
Hyderabad	40	70	97	5	12	40	13	12	13
Jagtial	83	155	169	13	35	52	11	10	9
Jogulamba Gadwal	8	60	99	2	30	45	14	14	14
Jangaon	46	107	122	1	15	45	13	13	13
Jayashankar Bhoopalpally	82	120	150	14	45	55	12	10	12
Kamareddy	58	119	135	4	43	59	11	11	11
Karimnagar	33	66	101	10	34	49	15	11	13
Khammam	45	107	129	4	46	68	13	12	13
Kumaram Bheem Asifabad	127	176	190	32	76	94	11	8	11
Mahabubabad	52	102	138	6	56	69	11	11	11
Mancherial	82	141	181	19	75	90	12	9	12
Medak	43	106	145	2	42	54	13	13	11
Medchal	40	90	112	5	36	78	13	12	13
Mahabubnagar	20	83	111	1	30	61	16	15	16
Mulugu	69	102	123	18	57	87	12	10	11
Nagarkurnool	18	117	147	5	47	59	14	14	14
Nalgonda	37	116	137	6	59	75	13	13	13
Narayanpet	8	67	85	1	32	44	11	10	11
Nirmal	75	151	189	16	62	85	12	11	12
Nizamabad	57	141	188	8	44	55	13	11	11
Peddapalli	82	123	150	19	57	76	12	9	12
Rajanna Sircilla	29	119	130	7	89	99	13	9	13
Rangareddy	36	101	127	4	32	79	13	12	13
Sangareddy	42	121	137	4	44	89	13	12	13
Siddipet	32	84	106	0	31	42	15	11	14
Suryapet	42	98	138	6	67	99	13	12	13
Vikarabad	34	86	108	0	30	69	14	12	11
Wanaparthy	21	101	120	2	39	77	14	14	14
Warangal Rural	53	189	206	7	59	87	14	11	13
Warangal Urban	69	131	141	18	89	92	12	11	12
Yadadri Bhuvanagiri	35	92	124	2	48	85	13	13	13


Water
Agriculture
Forest
Health
Infrastructure

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 southern states.

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

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

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

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

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

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

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

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

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