CSTEP
CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

DISTRICT-LEVEL ANALYSIS OF HISTORICAL AND PROJECTED CLIMATE CHANGE SCENARIOS

CLIMATE ATLAS OF INDIA

Climate Atlas of India

District-level analysis of historical and projected climate change scenarios

Center for Study of Science, Technology and Policy
December 2022

Designed and Edited by CSTEP

Contributors: Vidya S, Anushiya J, and Indu K Murthy

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

This report should be cited as: CSTEP. (2022). *Climate atlas of India: District-level analysis of historical and projected climate change scenarios.* (CSTEP-RR-2022-14).

December, 2022

Center for Study of Science, Technology and Policy

Bengaluru

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

Tel.: +91 (80) 6690 2500
Email: cpe@cstep.in

Noida

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

Acknowledgements

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

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

Editorial support: Mr Reghu Ram and Ms Sreerekha Pillai

Report design: Mr Alok Kumar Saha

Executive Summary

Climate change is the biggest challenge today and will be so in the coming decades. The increase in extreme events and their impact on natural and artificial ecosystems and lives and livelihoods are conspicuous. Formulation of climate policies and planning and implementation of programmes and projects for adaptation require climate information at various spatial scales. To cater to this need and to build awareness, we conducted historical climate analysis and future climate projections at a district level for the 28 states of India—published as regional reports of the southern (Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, and Telangana), central (Chhattisgarh and Madhya Pradesh), western (Goa, Gujarat, Maharashtra, and Rajasthan), eastern (Bihar, Jharkhand, Odisha, and West Bengal), north-eastern (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura), and northern (Haryana, Himachal Pradesh, Punjab, Uttarakhand, and Uttar Pradesh) states.

This report summarises the findings of the assessment for all 28 states of India. The timescale for the analysis is the near or short-term period of the 2030s (2021–2050), and it has been compared with the climate of the near past historical period (1990–2019) at a district level. Climate change projections are done for two Representative Concentration Pathways (RCP) or climate scenarios, namely RCP 4.5 (moderate emissions scenario) and RCP 8.5 (high emissions scenario). Historical climate data and gridded data for climate change projections are from the India Meteorological Department (IMD).

Temperature and rainfall have increased in most of India during the historical period. The analysis of historical climate data (1990–2019) shows that around 70% of the districts in India experienced an increase in the summer maximum temperature by up to 0.9°C. Likewise, winter minimum temperature has increased by up to 0.5°C in 54% of the districts. Rainfall during the kharif or the monsoon season has increased, and the increase is particularly high in the north-east and Western Ghats districts—about 10% to 15%.

A warmer and wetter future is projected for almost the whole of India during the short-term period of the 2030s under both climate scenarios.

- **Temperature**
    - An increase in the summer maximum temperature by 1.5°C to 2°C is projected for 15% of the districts under the RCP 4.5 scenario and 63% of the districts under the RCP 8.5 scenario.
    - Under the RCP 8.5 scenario, higher levels of warming (>2°C) are projected for 7% of the districts as compared to the historical period.
    - An increase in the winter minimum temperature by 1.5°C to 2°C is projected for 18% of the districts under the RCP 4.5 scenario and 63% of the districts under the RCP 8.5 scenario.
- **Rainfall**
    - An increase in the kharif season rainfall of 15%–25% is projected for 17% of the districts under the RCP 4.5 scenario and 50% of the districts under the RCP 8.5 scenario.
    - A higher increase of 25%–35% is projected for 2% of the districts under the RCP 4.5 scenario and 7% of the districts under the RCP 8.5 scenario.

- **Extreme events**
    - Heatwaves are projected to further increase under both climate scenarios. An increase in the number of days with temperature departure from the normal by 4.5°C to 6.4°C and >6.4°C is projected under both climate scenarios compared to the historical period in all the 15 districts analysed for heatwaves.
    - The number of high-intensity (51–100 mm/day) rainfall events is projected to increase from 4 to 615 days during the historical period to 15 to 760 days under the RCP 4.5 scenario and 23 to 805 days under the RCP 8.5 scenario.
        - The increase per annum is by one to four events under the RCP 4.5 scenario and one to five events under the RCP 8.5 scenario.
    - The number of very high-intensity rainfall events is projected to increase from 0 to 550 days during the historical period to 0 to 600 days under the RCP 4.5 scenario and 2 to 612 days under the RCP 8.5 scenario. It is important to note that of the 723 districts, only 629 (87%) districts had recorded very high-intensity rainfall events during the historical period.
        - Annually, very high-intensity rainfall events are projected to increase by one to two events under the RCP 4.5 scenario and one to three events under the RCP 8.5 scenario.

This district climate profile provides an understanding of the changes in climate during the current day or near past and the near or short-term future. It is evident from this analysis that the future climate will not be the same and this will impact natural resources, dependent livelihoods, and infrastructure. The need of the hour is, therefore, to create awareness on the likely changes and build the capacity to integrate climate information into policies and plans to minimise loss and damage.

Contents

List of Figures

1. Introduction

India has diverse geography and landscapes spanning plains, hills, plateaus, deserts, coastal regions, and islands. To frame climate policies, data on the impacts of climate change across different spatial and temporal scales and sectors are needed, for which climate information is crucial. Further, the National and State Action Plans on Climate Change (SAPCC) require climate information at different scales. In this context, district-level changes in temperature and rainfall find utility and can be the basis for assessing climate risks and impacts on sectors, regions, and communities.

The Center for Study of Science, Technology and Policy (CSTEP) has assessed the changes in observed and future climate and its variability at the district level for 28 states (723 districts) of India (excluding union territories). The findings of this assessment have been published as six regional reports for the southern (Andhra Pradesh, Karnataka, Kerala, Tamil Nadu, and Telangana), central (Chhattisgarh and Madhya Pradesh), western (Goa, Gujarat, Maharashtra, and Rajasthan), eastern (Bihar, Jharkhand, Odisha, and West Bengal), north-eastern (Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura), and northern (Haryana, Himachal Pradesh, Punjab, Uttarakhand, and Uttar Pradesh) states.

This report is a summary of the assessment across the 28 states of India and presents the following:

- Historical trends in summer (March to May) and winter (December to February) minimum temperatures and the kharif (June to September) season rainfall during the 1990–2019 period
- Future trends in temperature, rainfall, and extreme events for the 2030s (2021–2050) as change compared to the historical period for two climate scenarios—Representative Concentration Pathway (RCP) 4.5 and RCP 8.5

While heavy rainfall events have been analysed and presented for all the states of India, heatwave occurrence is analysed and presented for only selected districts with a history of occurrence of such events. These include Ahmedabad (Gujarat), Bikaner (Rajasthan), Birbhum (West Bengal), Chandrapur (Maharashtra), East Godavari (Andhra Pradesh), Gorakhpur (Uttar Pradesh), Hisar (Haryana), Jamshedpur (Jharkhand), Kalaburagi (Karnataka), Khargone (Madhya Pradesh), Ludhiana (Punjab), Nalgonda (Telangana), Raipur (Chhattisgarh), Sambalpur (Odisha), and Vellore (Tamil Nadu). The details of the methodology adopted, data sources, and models used for historical climate analysis and climate change projections are presented in the Appendix.

2. Trends in Climate During the Historical Period

The historical trends in summer maximum and winter minimum temperatures and rainfall during the 1990–2019 period were analysed. In this section, we present the trends in summer maximum and winter minimum temperatures and the kharif season (June to September) rainfall. The rabi season (October to December) rainfall was analysed only for some states that receive significant rainfall during this season, such as Tamil Nadu, and is not presented in this report.

2.1. Temperature

Temperature in all the districts of India showed an increase in both summer maximum and winter minimum temperatures (Figure 2-1 and Figure 2-2).

Summer Maximum Temperature	Winter Minimum Temperature
An increase of up to 0.9°C was recorded in all the districts of India	**An increase of 0.5°C was recorded in all the districts of India**
• A warming of up to 0.5°C was recorded in 70% of the districts of India. • A higher warming of 0.5°C–0.9°C was recorded in the districts of the northern states of Punjab, Haryana, Uttarakhand, Uttar Pradesh, Bihar, Rajasthan, Gujarat, and the north-eastern states.	• The warming in the northern states was higher compared to the southern states. • The highest warming of 0.5°C–0.9°C was recorded in 54% of the districts of India, including those in the northern states of Punjab, Haryana, Uttarakhand, Uttar Pradesh, and Bihar; the western states of Rajasthan and Gujarat; and the north-eastern states.

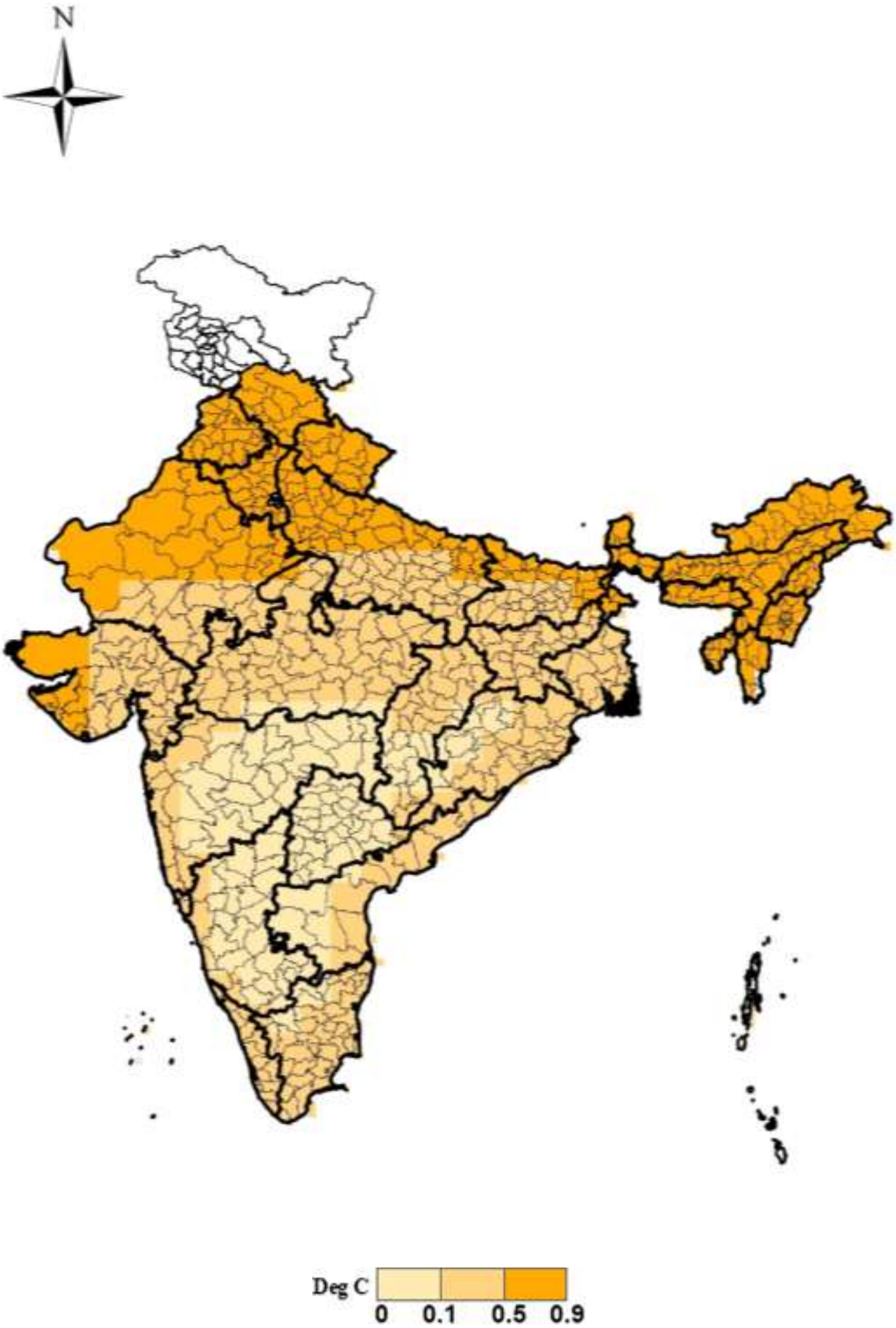


Figure 2-1: Trends in the summer maximum temperature during 1991–2019

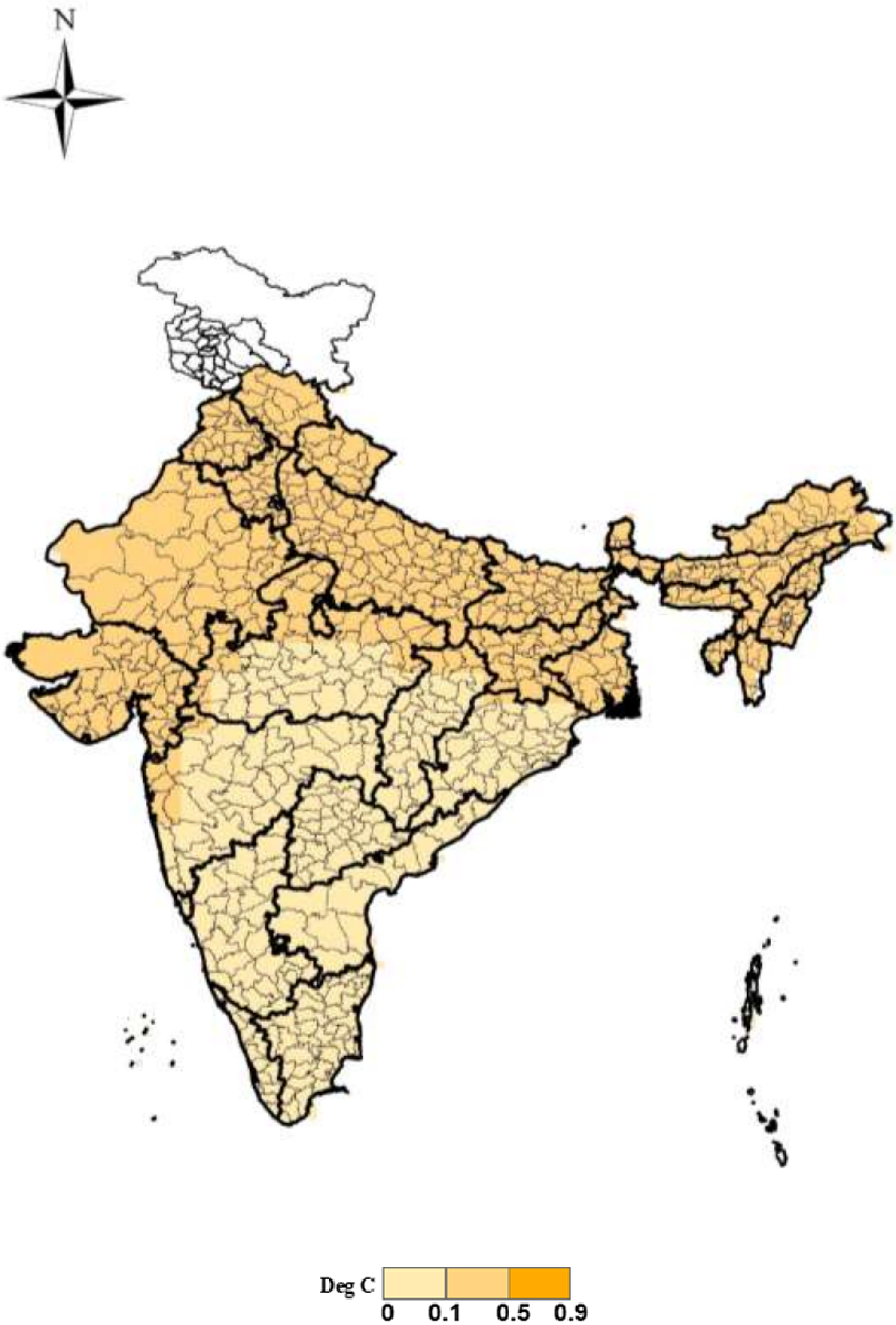


Figure 2-2: Trends in the winter minimum temperature during 1991–2019

2.2. Rainfall

An increasing trend in rainfall during the kharif season (June to September) was recorded during the historical period across all the districts of India. Overall, an increase in rainfall of up to 15% was recorded during the kharif season (

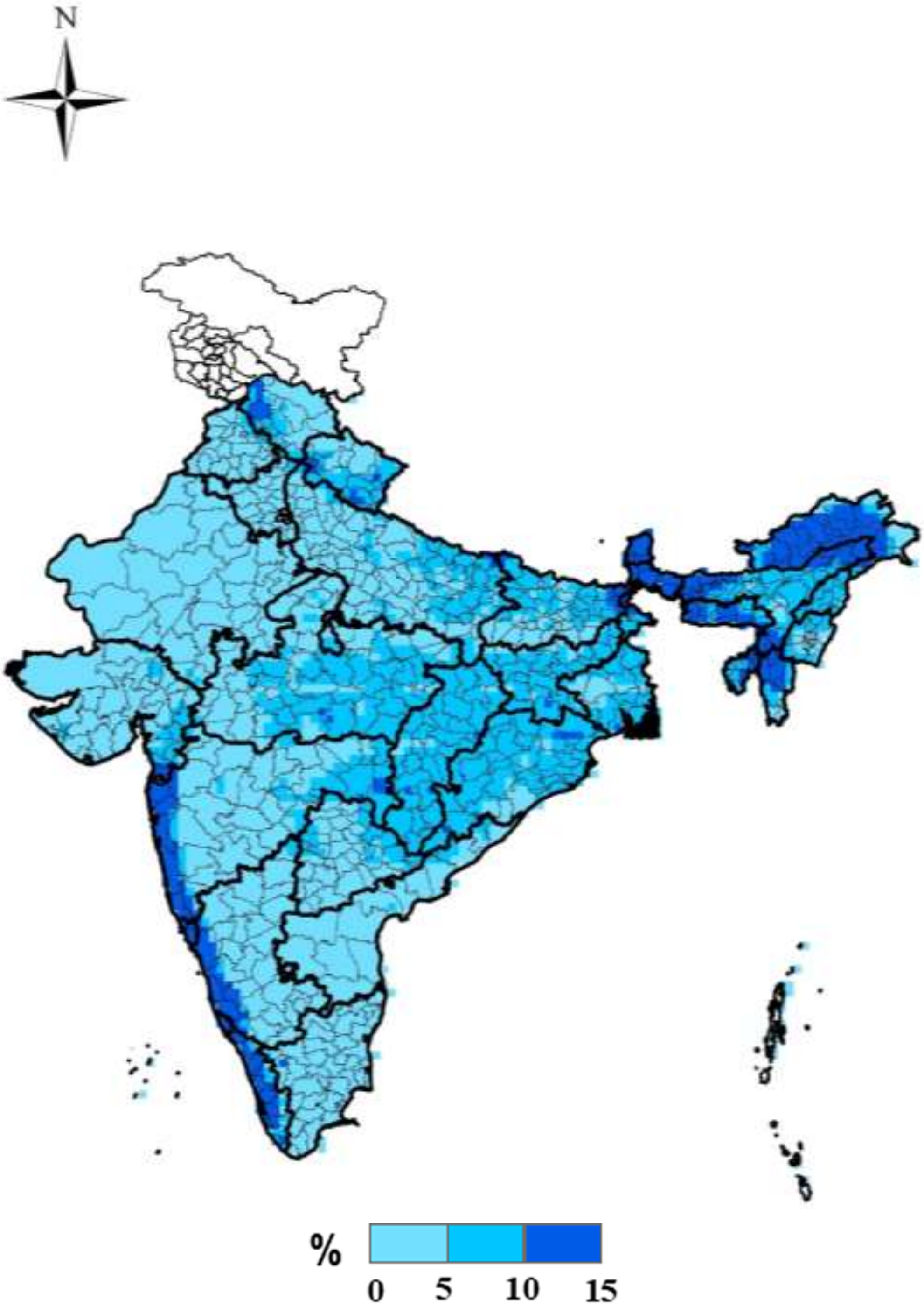


Figure 2-3).

- A maximum increase in rainfall by 10%–15% was recorded in the districts of north-east India: Arunachal Pradesh, Sikkim, and Meghalaya; the northern districts of Nagaland; and the Western Ghats districts in southern India.

- An increase in rainfall by 5%–10% was recorded in about 20% of the districts of India, including those in the states of Bihar, Chhattisgarh, Odisha, and Jharkhand and a majority of the districts of Madhya Pradesh.
- An increase in rainfall of 1%–5% was recorded in 45% of the districts of India, including those falling in the states of Karnataka, Tamil Nadu, Telangana, Andhra Pradesh, the northern states of Haryana and Punjab, and the western states of Rajasthan and Gujarat.

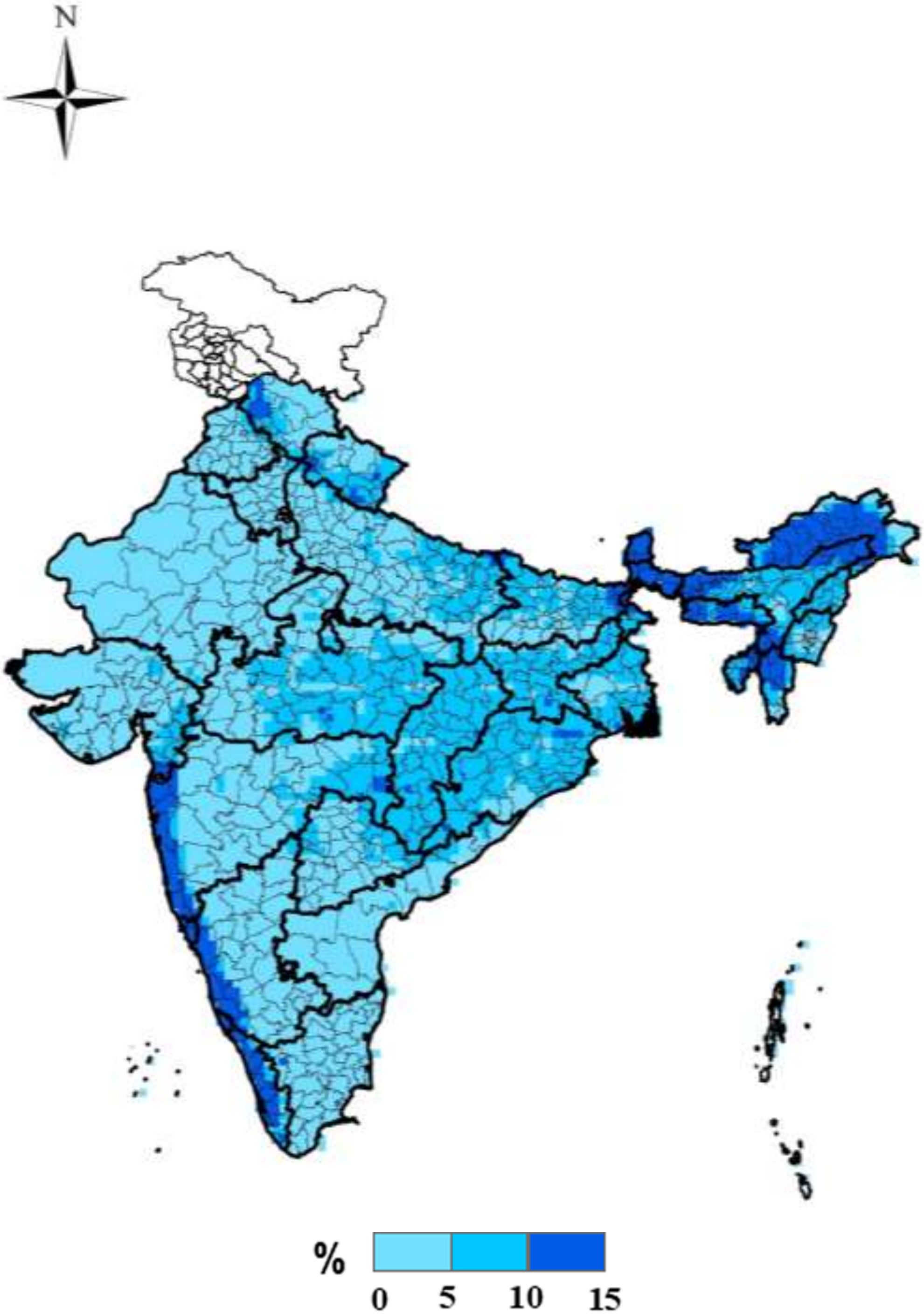


Figure 2-3: Trends in the kharif season rainfall (in percentage) during 1991 to 2019

3. Projected Changes in Climate Relative to the Historical Period During the 2030s

Temperature, kharif season rainfall, and extreme events projected for the 2021–2050 period (the 2030s) have been compared to the recorded historical (1991–2019) period and the changes have been computed. These changes compared to the historical period in the summer maximum (March to May) and winter minimum (December to February) temperatures, the kharif season (June to September) rainfall, and extreme events—such as heatwaves and heavy rainfall events—are presented in this section.

3.3. Temperature

An increase in both the summer maximum and winter minimum temperatures during the 2030s is projected across almost all the districts of India.

Summer Maximum Temperature	Winter Minimum Temperature
• A warming of 1°C to 2.5°C is projected for a majority of the districts compared to the historical period, considering both RCP 4.5 and RCP 8.5 scenarios.	• A warming of >1°C is projected for a majority of the districts compared to the historical period, considering both RCP 4.5 and RCP 8.5 scenarios.

3.3.1. Summer maximum temperature

The summer maximum temperature is projected to increase in the 2030s relative to the historical period in all the districts of India under both RCP 4.5 and RCP 8.5 scenarios.

RCP 4.5 scenario (Figure 3-1): A warming of 1°C to 1.5°C is projected for 72% of the districts, 1.5 °C to 2°C for 15% of the districts, 2°C to 2.5°C for 2% of the districts, and 1°C for 11% of the districts.

- A warming of 1°C is projected for the districts of Karnataka, such as Belagavi, Gadag, Bagalkot, Dakshina Kannada, and Chikkamagaluru.
- A warming of 1 °C to 1.5°C is projected for most of the districts in Rajasthan and Gujarat and the north-east states of Arunachal Pradesh, Assam, and Nagaland.
- A warming of 1.5°C to 2°C is projected for some of the districts in Uttarakhand, Uttar Pradesh, Arunachal Pradesh, Assam, Gujarat, Madhya Pradesh, Tamil Nadu, Karnataka, and Telangana.
- A maximum warming of 2°C to 2.5°C is projected for a few districts of Manipur such as Bishnupur, Churachandpur, Chandel, and Noney.

RCP 8.5 scenario (Figure 3-2): Higher levels of warming of >2°C are projected for 15% of the districts. A warming of 1.5°C to 2°C is projected for 63% of the districts, 2°C to 2.5°C for 2% of the districts, 1°C to 1.5°C for 17% of the districts, and 1⁰C for 3% of the districts.

- A maximum warming of 2°C to 3.5°C is projected for some of the districts of Maharashtra and Manipur, such as Amravati, Jalna, Chandel, and Pherzawl.
- A warming of 2°C to 2.5°C is projected for districts in Maharashtra and the northern part of Karnataka and Bihar.
- A warming of 1.5°C to 2°C is projected for many districts of Himachal Pradesh, Punjab, northern Uttar Pradesh, Gujarat, Rajasthan, Madhya Pradesh, Arunachal Pradesh, Assam, Sikkim, Bihar, West Bengal, Jharkhand, and Odisha and several districts of the southern states.
- A warming of 1°C to 1.5°C is projected for a majority of the districts of Madhya Pradesh, Rajasthan, Uttar Pradesh, West Bengal, Odisha, and western Karnataka.

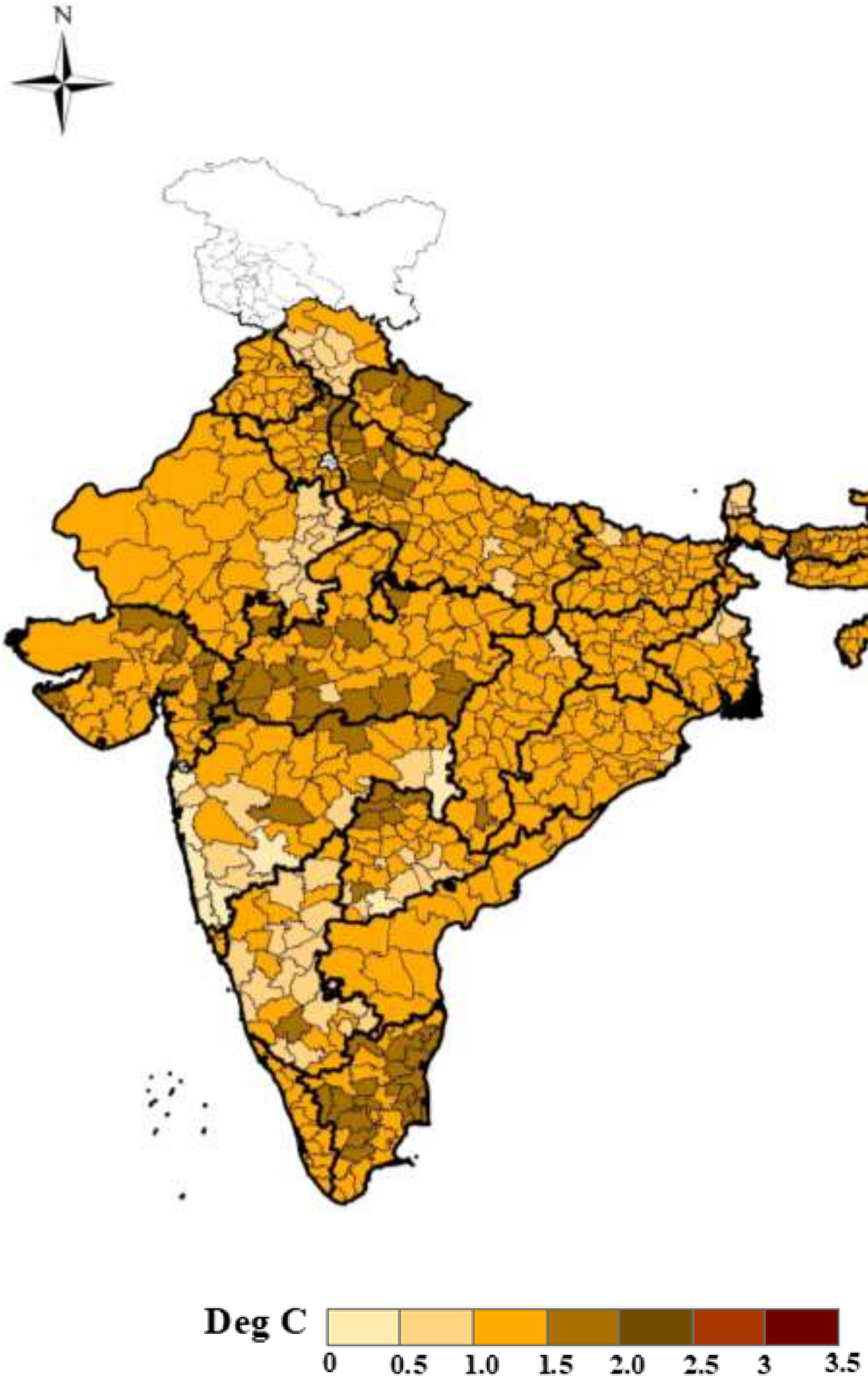


Figure 3-1: Changes in the summer maximum temperature (°C) under the RCP 4.5 scenario relative to 1991 to 2019

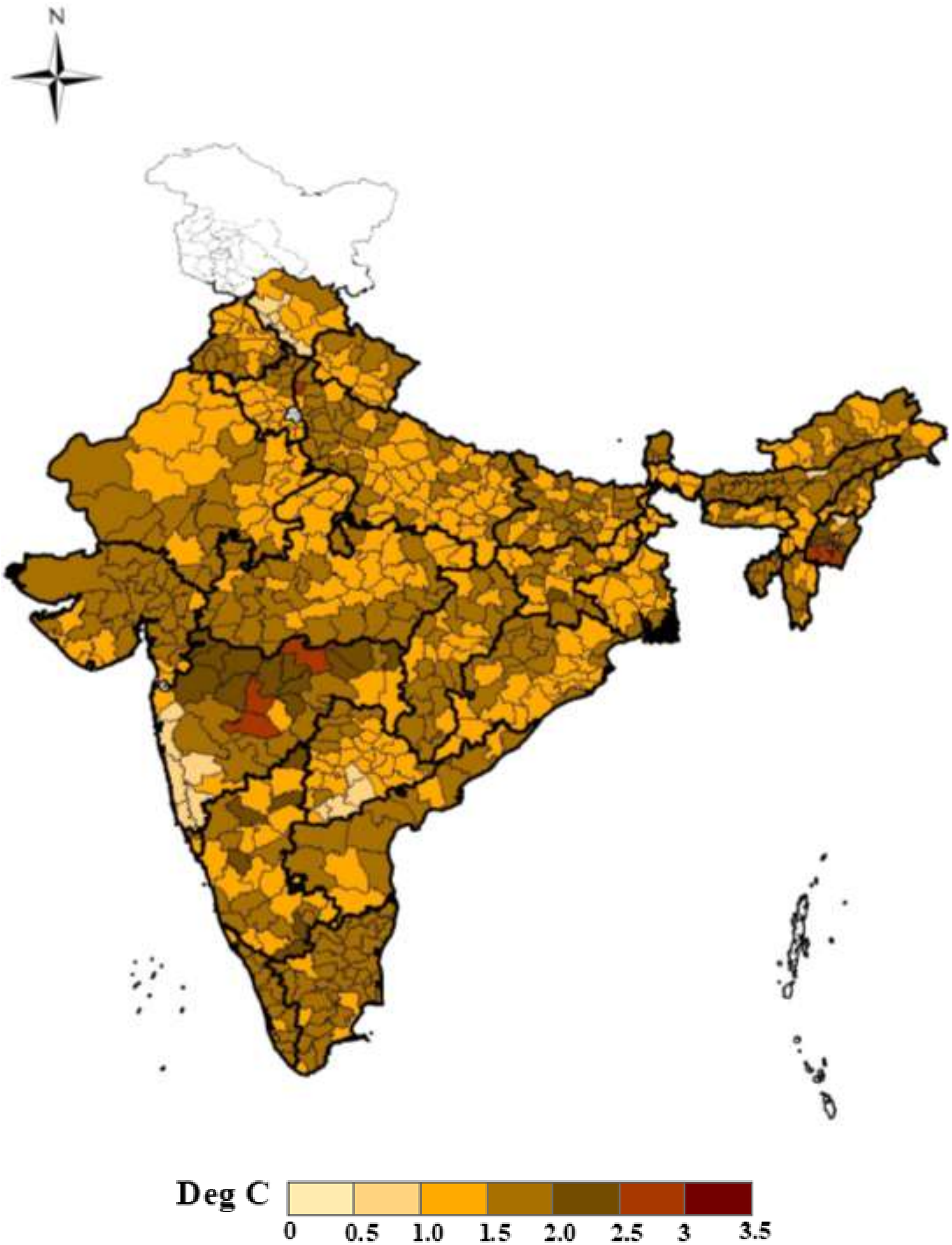


Figure 3-2: Changes in the summer maximum temperature (°C) under the RCP 8.5 scenario relative to 1991 to 2019

3.3.2. Winter minimum temperature

The winter minimum temperature is projected to increase in the 2030s relative to the historical period in all the districts of India under both RCP 4.5 and RCP 8.5 scenarios. The warming is slightly higher, in the range of 1.5°C to 2°C, in several districts under the RCP 8.5 scenario. However, there is no clear state-level trend.

RCP 4.5 scenario (Figure 3-3): The highest warming of 2.5°C to 3°C is projected for a few districts (1%). A warming of 1°C to 1.5°C is projected for 67% of the districts, and in 19% of the districts, the warming is projected to be 1.5°C to 2°C in the 2030s. In the remaining 13% of the districts, less than 1°C warming is projected during this period.

- A maximum warming of 2.5°C to 3°C is projected for the Nashik and Jalgaon districts in Maharashtra.
- A warming in the range of 1.5°C to 2°C is projected for the districts of Chhattisgarh, Meghalaya, Arunachal Pradesh, Manipur, Maharashtra, Madhya Pradesh, Gujarat, Uttarakhand, and Telangana.
- A warming of 1°C to 1.5°C is projected for a majority of the districts of India, except a few districts in Karnataka and Rajasthan where the warming is less than 1°C—only up to 0.5°C.

RCP 8.5 scenario (Figure 3-4 Figure 3-4**):** A warming of 1.5°C to 2°C is projected for about 53% of the districts, and in 30% of the districts, the warming is projected to be in the range of 1°C to 1.5°C. Higher levels of warming of >2 are projected for about 11% of the districts. A warming of less than 1°C is projected only in a few districts (about 6%).

- A maximum warming of 2.5°C to 3°C is projected for a few districts in Maharashtra and Manipur.
- Warming in the range of 2°C to 2.5°C is projected for some districts of Maharashtra, Manipur, and Telangana and the northern districts of Karnataka.
- Warming in the range of 1.5°C to 2°C is projected for many districts spanning all the states of India, particularly Karnataka, Madhya Pradesh, Gujarat, Odisha, Chhattisgarh, Himachal Pradesh, Punjab, Kerala, Haryana, and Uttar Pradesh.
- Warming in the range of 1°C to 1.5°C is projected for districts in Tamil Nadu, Andhra Pradesh, Rajasthan, Gujarat, Punjab, West Bengal, and Uttar Pradesh.

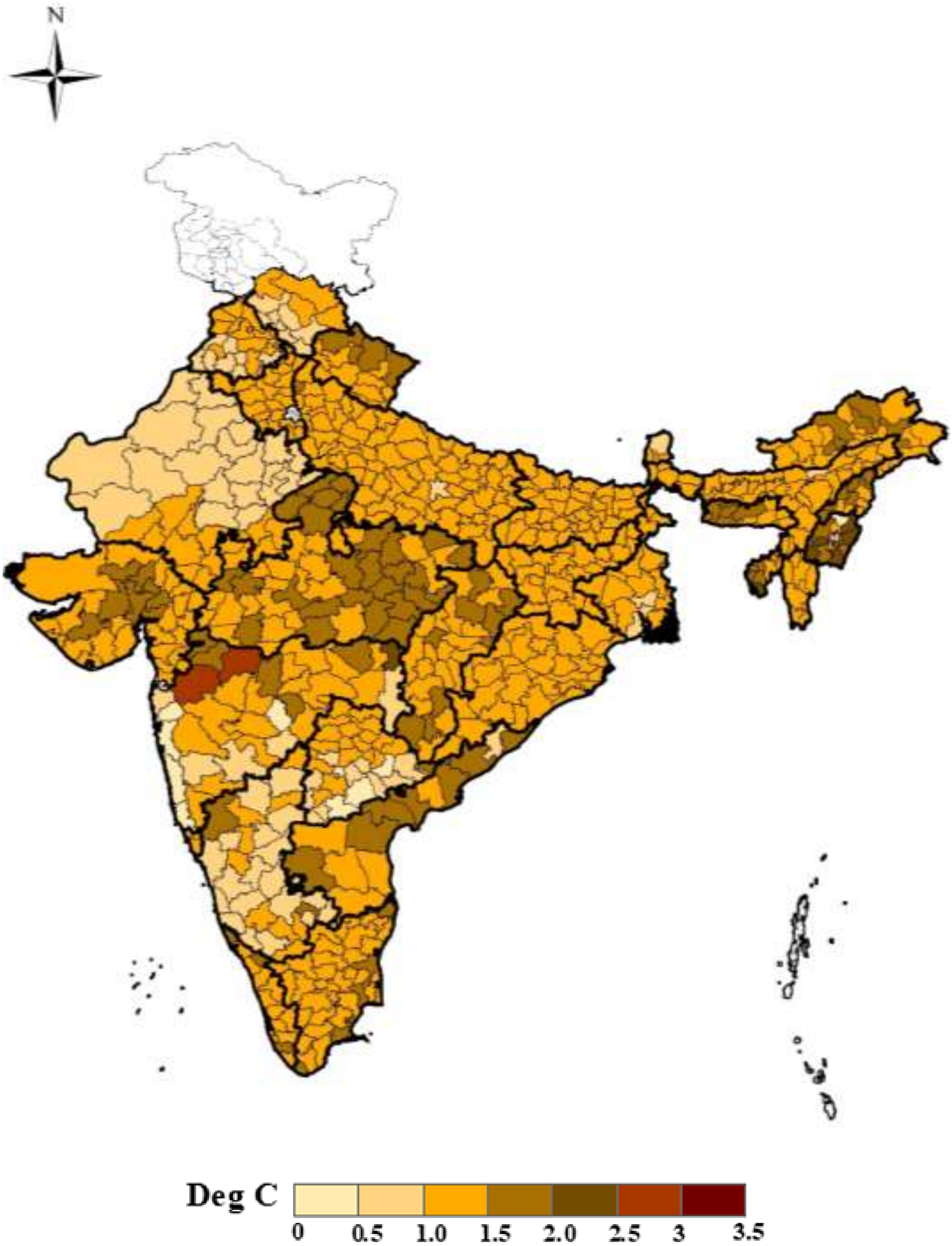


Figure 3-3: Changes in the winter minimum temperature (°C) under the RCP 4.5 scenario relative to 1991 to 2019

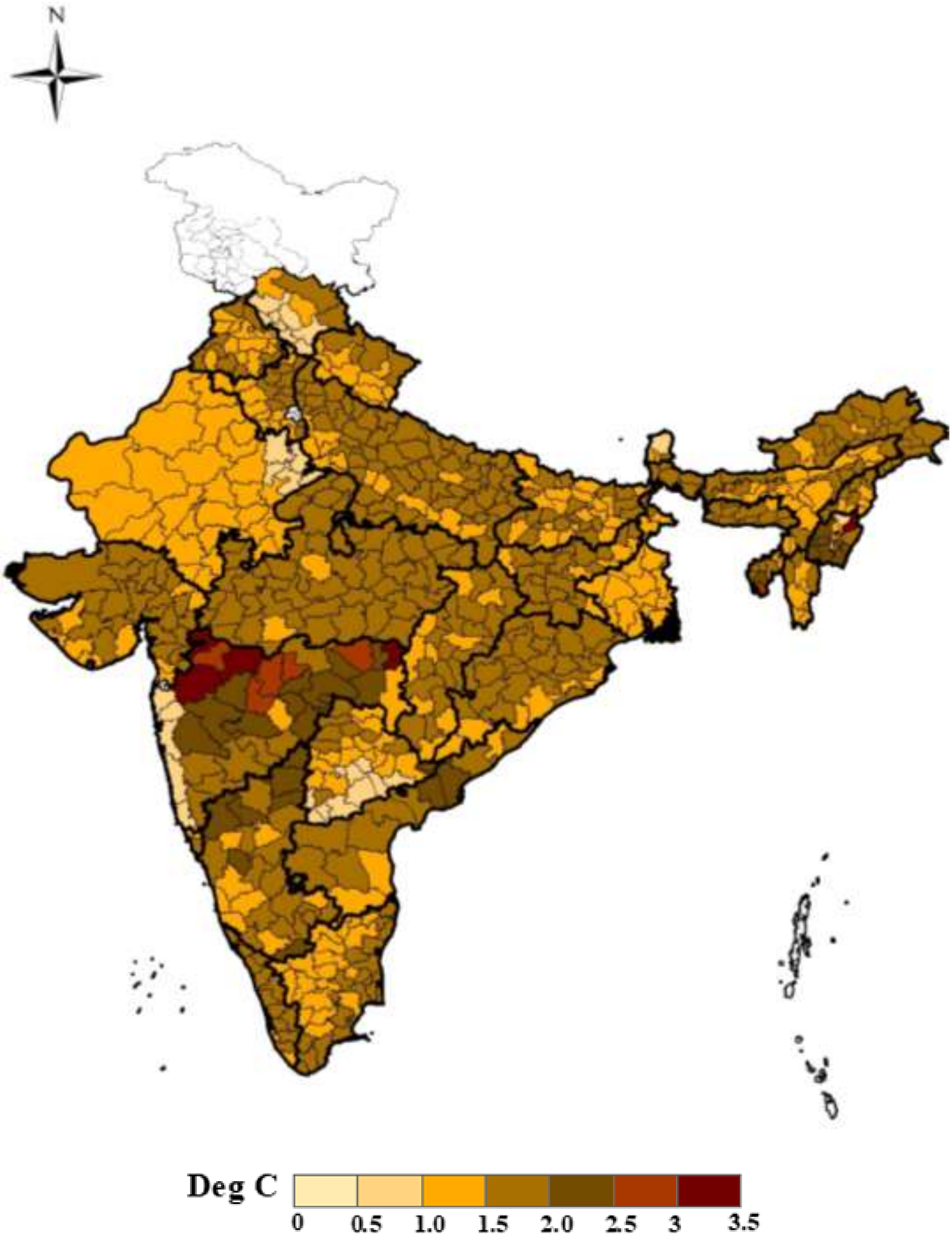


Figure 3-4: Changes in the winter minimum temperature (°C) under the RCP 8.5 scenario relative to 1991 to 2019

3.4. Rainfall

In this section, district-level projections of the kharif season rainfall for the short-term period (2021–2050) are presented as change compared to the historical period.

RCP 4.5 scenario (Figure 3-5): The kharif season rainfall is projected to increase relative to the historical period by 25%–35% in 2% of the districts, 15%–25% in 18% of the districts, and 10%–15% in 35% of the districts. In the remaining 45% of the districts, less than 10% change in rainfall relative to the historical period is projected.

- An increase of 25%–35% is projected for only a few districts in the states of Maharashtra, Madhya Pradesh, Uttar Pradesh, Gujarat, and Bihar.
- An increase of 15%–25% is projected for only a few districts in the states of Arunachal Pradesh, Chhattisgarh, Gujarat, Tamil Nadu, Manipur, Maharashtra, Madhya Pradesh, Tripura, Uttar Pradesh, and Bihar.
- An increase of 10%–15% is projected for many districts in the states of Karnataka, Tamil Nadu, Kerala, Maharashtra, Madhya Pradesh, Odisha, West Bengal, Rajasthan, Chhattisgarh, Assam, Tripura, Manipur, Mizoram, Meghalaya, Uttar Pradesh, Punjab, Haryana, and Uttarakhand.

RCP 8.5 scenario (Figure 3-6): The kharif season rainfall is projected to increase relative to the historical period by 25%–35% in 9% of the districts, 15%–25% in 50% of the districts, and 10%–15% in 25% of the districts. In the remaining 16% of the districts, up to 10% change in rainfall relative to the historical period is projected.

- An increase in rainfall of 25%–35% is projected for all the districts of Tamil Nadu, Karnataka, Telangana, Arunachal Pradesh, Bihar, Gujarat, Meghalaya, Sikkim, and Himachal Pradesh.
- An increase of 15%–25% is projected for many districts spanning all the states of India.
- An increase in rainfall of 10%–15% is projected for some districts of Maharashtra, Madhya Pradesh, Gujarat, Uttar Pradesh, and Rajasthan.

Overall, the kharif season rainfall is projected to increase by >15% in 12% and 61% of the districts under RCP 4.5 and RCP 8.5 scenarios, respectively. Except for Rajasthan (where the increase is lower across all the districts), no state-level trend is observed in the short-term period.

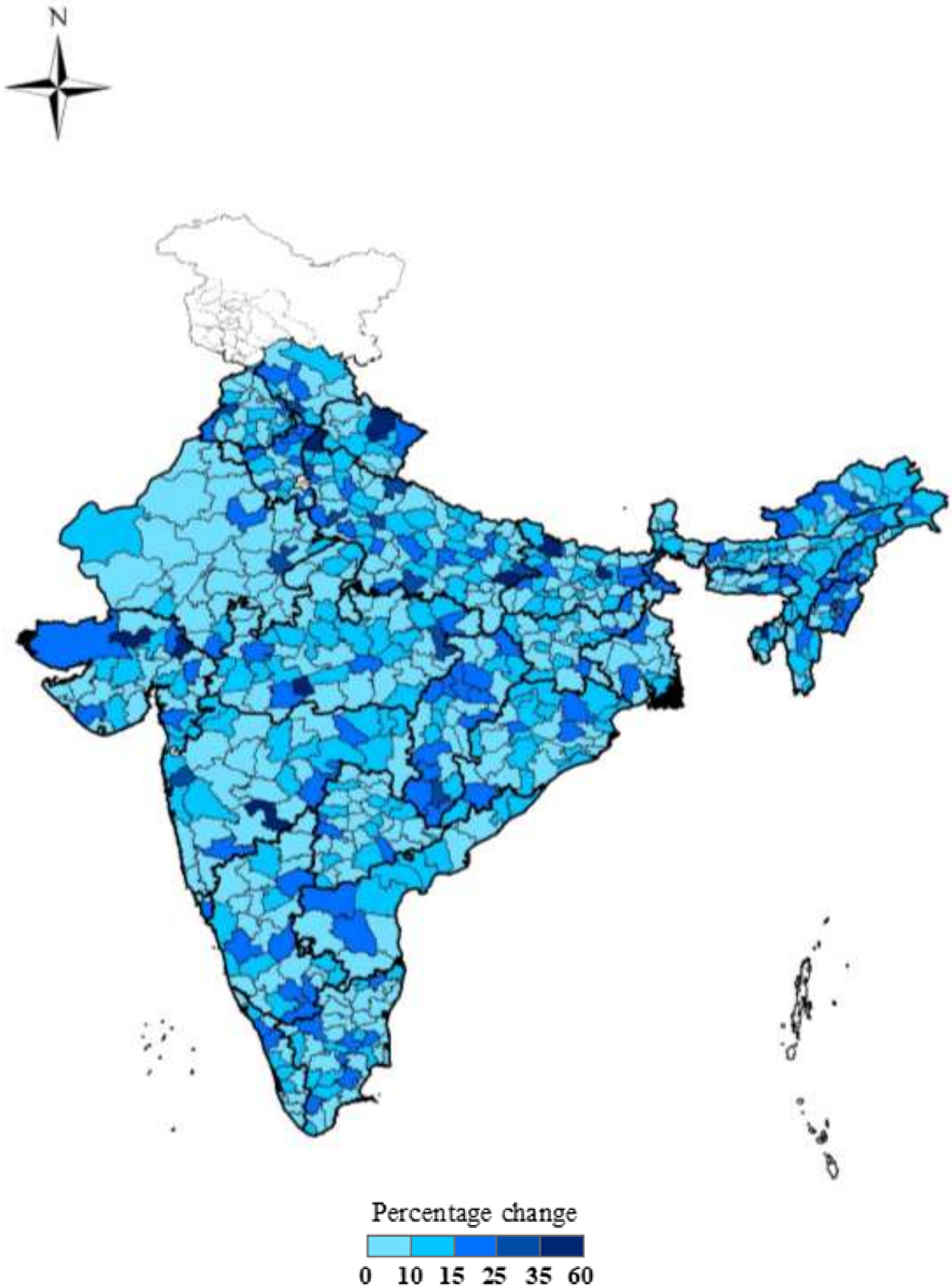


Figure 3-5: Percentage changes in the kharif season rainfall relative to the historical period for the short term (2030s) under the RCP 4.5 scenario

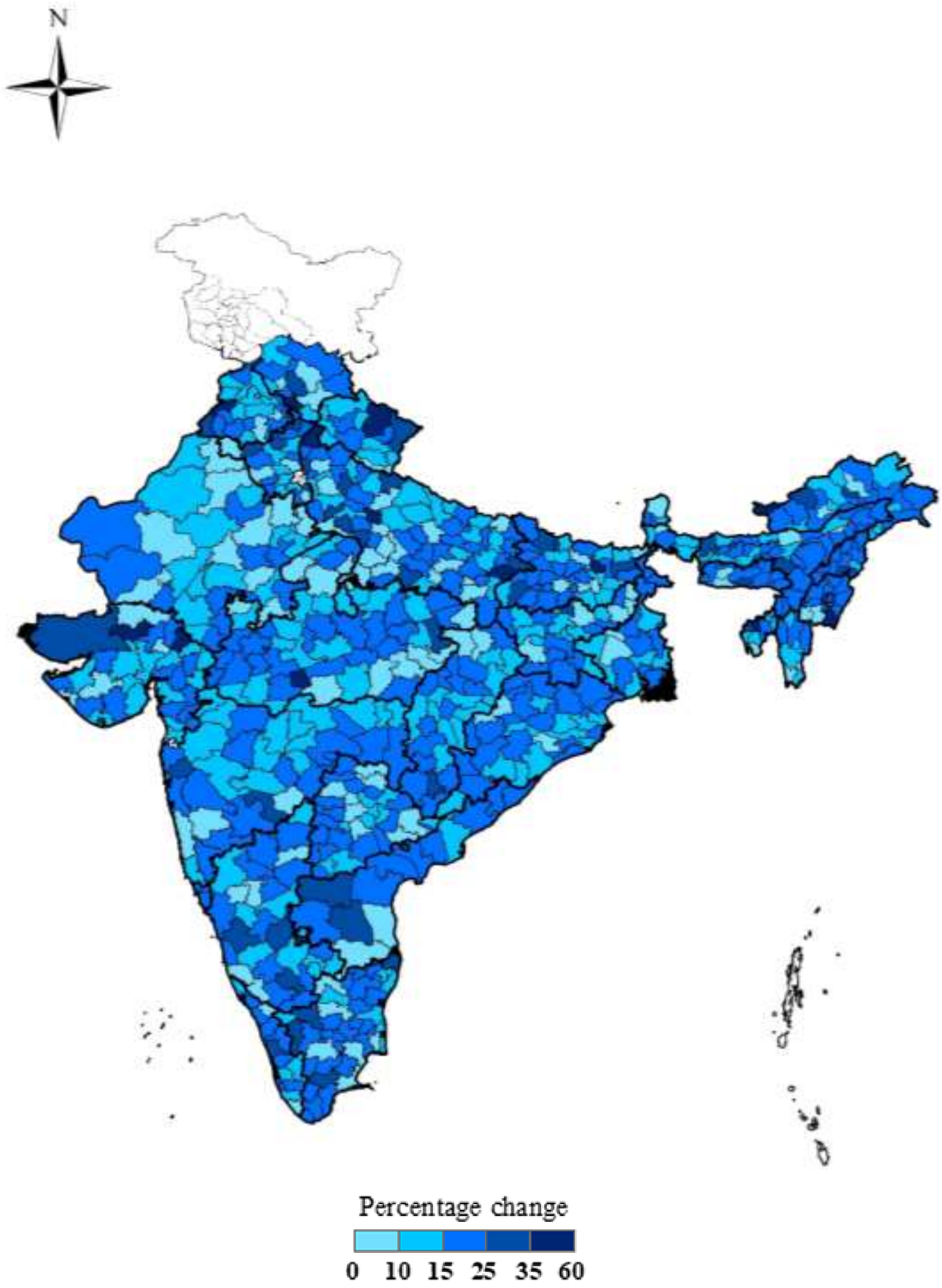


Figure 3-6: Percentage changes in the kharif season rainfall relative to the historical period for the short term (2030s) under the RCP 8.5 scenario

3.5. Extreme Events

3.5.3. Heatwaves

The analysis of temperature during the projected period of the 2030s shows that there would be a further increase in the number of heatwaves or days with temperature departure from the normal by 4.5°C to 6.4°C under both RCP 4.5 and RCP 8.5 scenarios. Likewise, severe heatwaves or days with temperature departure from the normal by >6.4°C are projected under both climate scenarios compared to the historical period (Figure 3-7 and Figure 3-8).

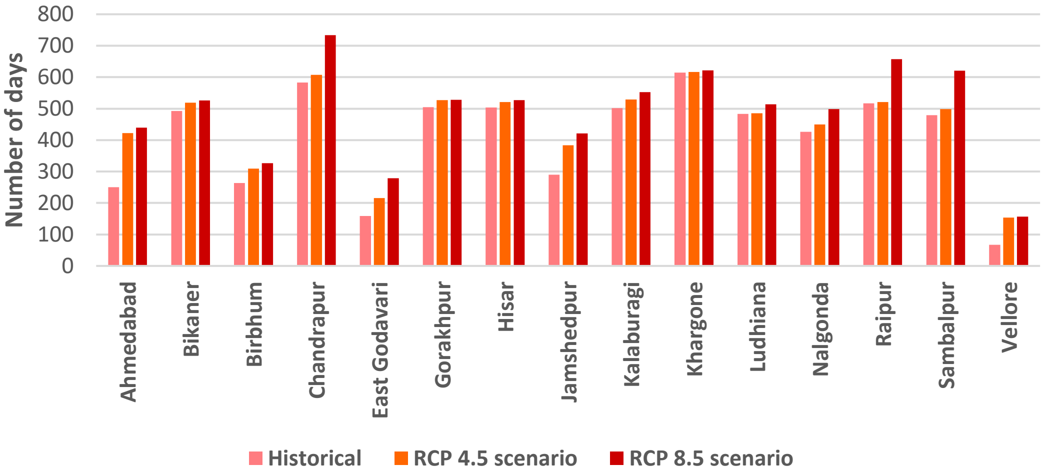


Figure 3-7: The number of heatwaves during the historical (1990–2019) and projected (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

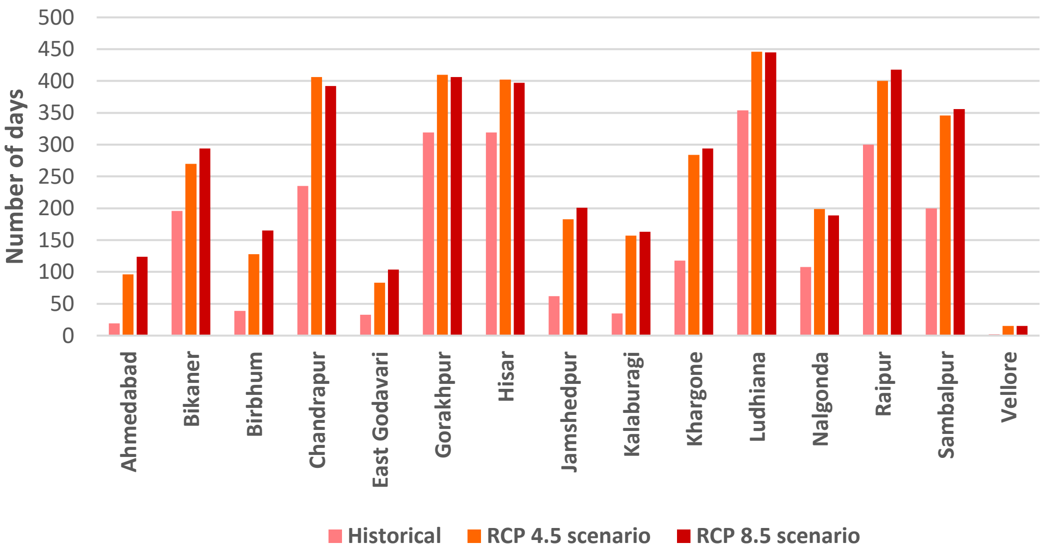


Figure 3-8: The number of severe heatwaves during the historical (1990–2019) and projected (2021–2050) periods under RCP 4.5 and RCP 8.5 scenarios

3.5.4. Heavy rainfall events

Rainfall during the kharif season was analysed by considering the intensity of rainfall under two categories: 51–100 mm/day (termed high intensity) and >100 mm/day (termed very high intensity). The number of such events was analysed during the historical period and the projected 2030s under the two climate scenarios and the change was computed for the districts of India.

3.5.4.1. High-intensity rainfall events

The number of high-intensity rainfall events increases from 4 to 615 days during the historical period (1991–1920) to 15 to 760 days under the RCP 4.5 scenario and 23 to 805 days under the RCP 8.5 scenario during the projected period (2021–2050).

RCP 4.5 scenario: An increase in high-intensity rainfall events is projected for most of the districts of Maharashtra, Chhattisgarh, Madhya Pradesh, Odisha, Gujarat, Uttar Pradesh, Uttarakhand, and Himachal Pradesh.

RCP 8.5 scenario: An increase in high-intensity rainfall events is projected for the districts of Telangana, Maharashtra, Chhattisgarh, Madhya Pradesh, Odisha, Uttar Pradesh, Uttarakhand, and Himachal Pradesh.

Overall, the percentage of districts projected to receive high-intensity rainfall will increase, indicating an increase in the frequency of such events.

- High-intensity rainfall events between 0 and 50 days were recorded for 37% of the districts during the historical period. This decreases to 13% and 10% under the RCP 4.5 and RCP 8.5 scenarios, respectively, for the projected 2030s.
- High-intensity rainfall events between 50 and 100 days were recorded for 42% of the districts during the historical period. This decreases to 39% and 18% under the RCP 4.5 and RCP 8.5 scenarios, respectively, for the projected 2030s.
- High-intensity rainfall events between 100 and 150 days were recorded for 12% of the districts during the historical period. This increases to 31% and 37% under the RCP 4.5 and RCP 8.5 scenarios, respectively, for the projected 2030s.
- High-intensity rainfall events between 150 and 200 days were recorded for 4% of the districts during the historical period. This increases to 7% and 21% under the RCP 4.5 and RCP 8.5 scenarios, respectively, for the projected 2030s.
- High-intensity rainfall events of more than 200 days were recorded for 5% of the districts during the historical period. This increases to 9% and 12% under the RCP 4.5 and RCP 8.5 scenarios, respectively, for the projected 2030s.

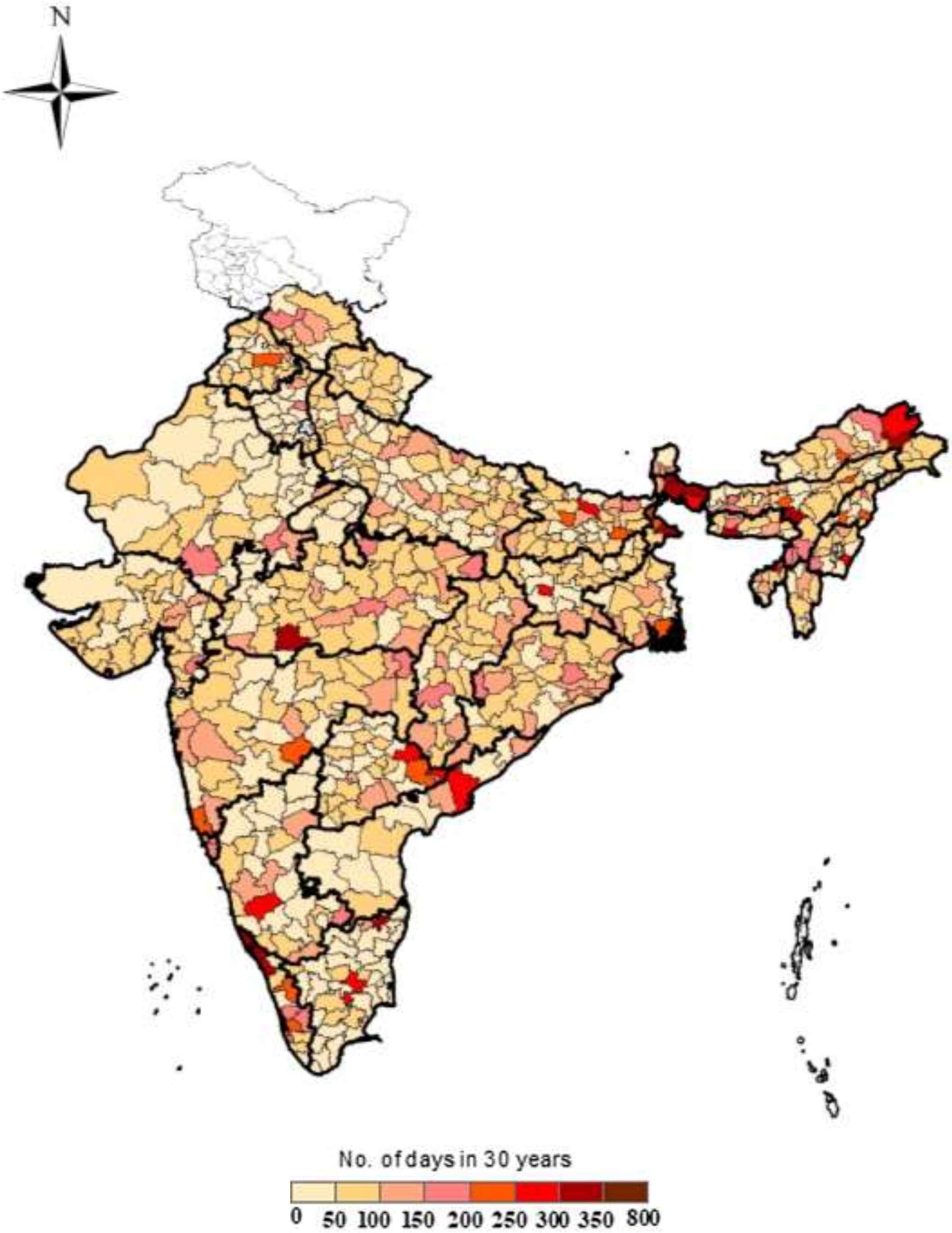


Figure 3-9: The number of high-intensity rainfall events during the historical (1990–2019) period

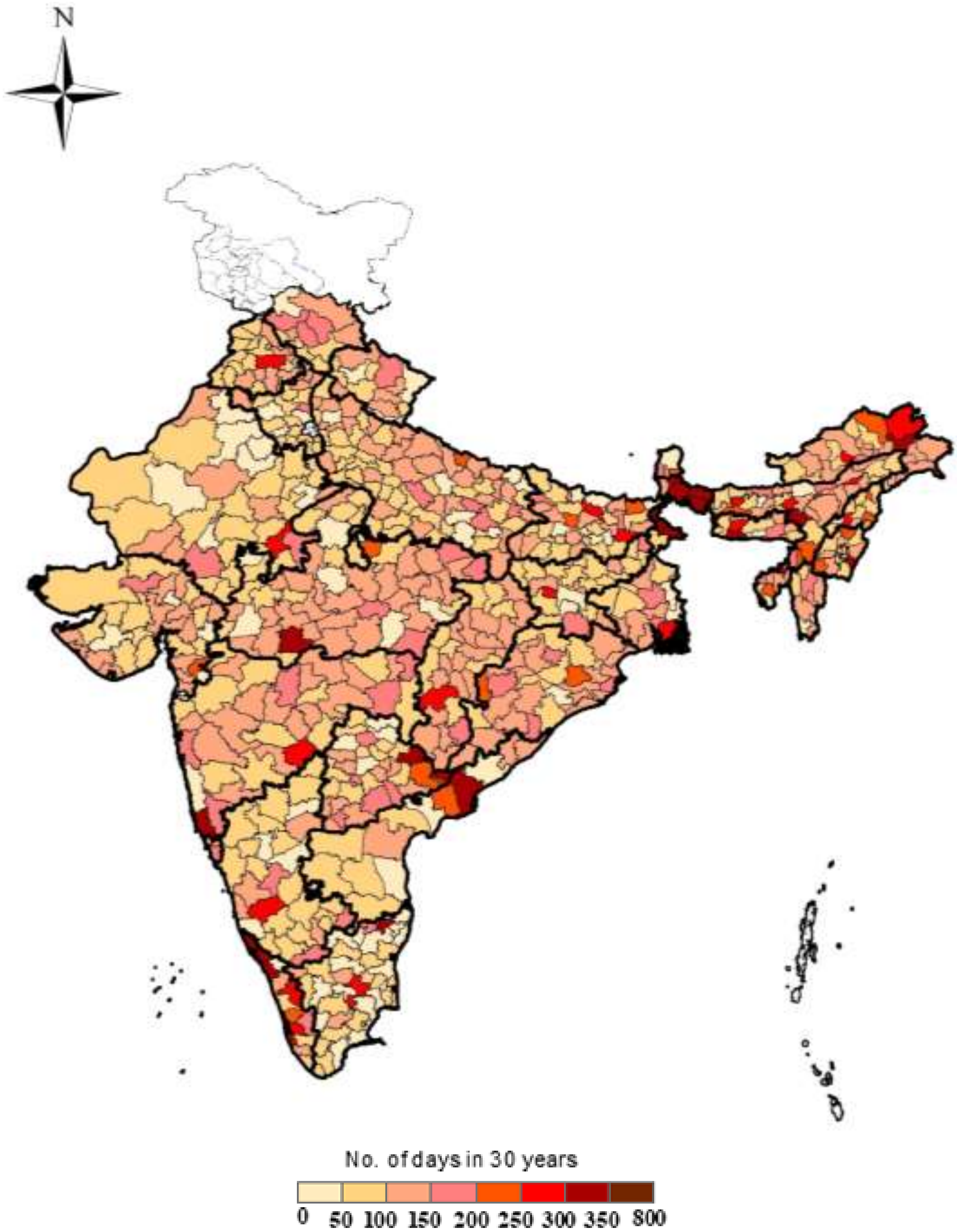


Figure 3-10: The number of high-intensity rainfall events during the projected period (the 2030s) under the RCP 4.5 scenario

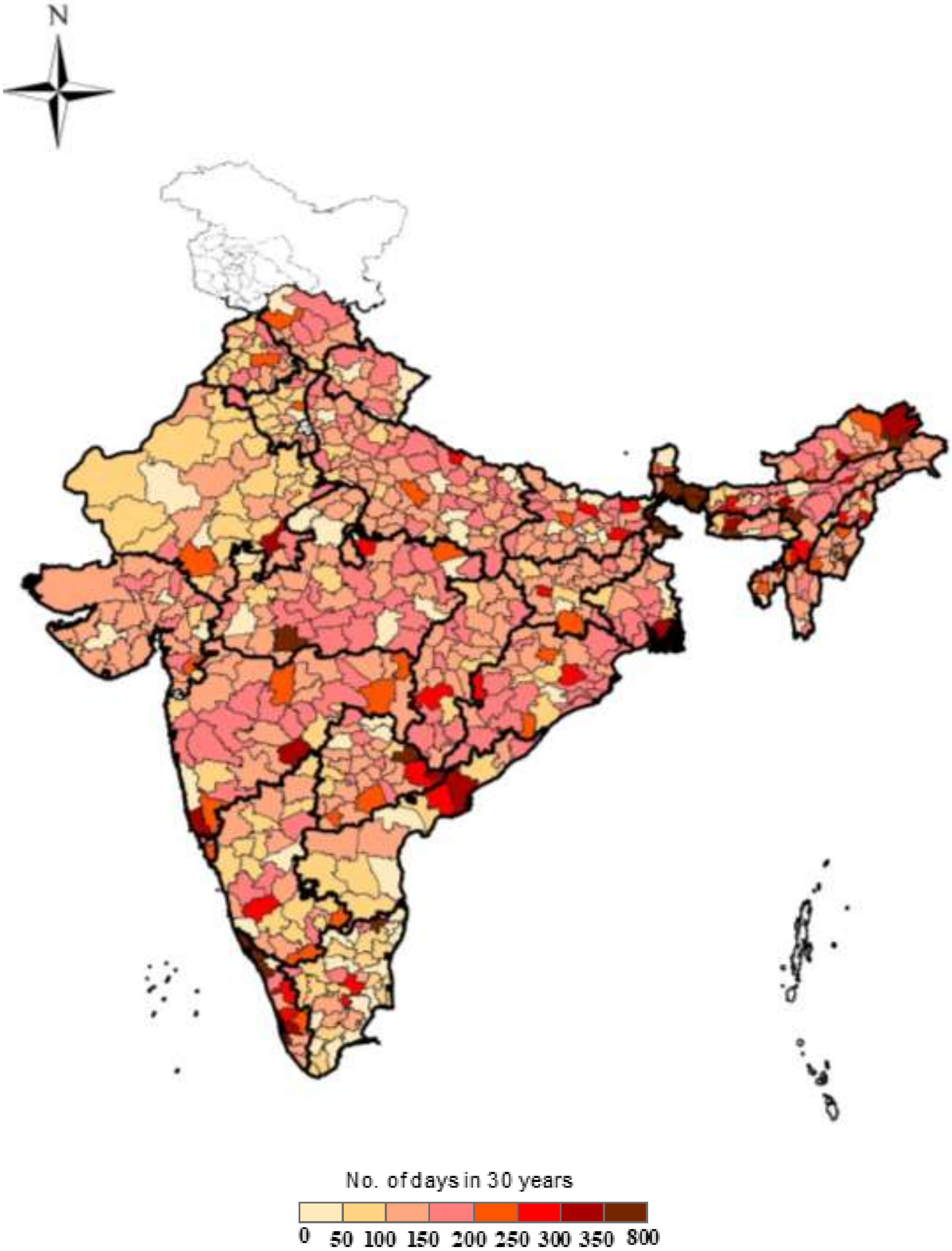


Figure 3-11: The number of high-intensity rainfall events during the projected period (the 2030s) under the RCP 8.5 scenario

3.5.4.2. Very high-intensity rainfall events

Of the 723 districts, 87% of the districts (629 districts) recorded very high-intensity rainfall events during the historical period. This increases during the projected period under both climate scenarios.

RCP 4.5 scenario: The projected increase is for a few districts of Maharashtra, Madhya Pradesh, Chhattisgarh, Odisha, Telangana, Bihar, Uttar Pradesh, and Himachal Pradesh.

RCP 8.5 scenario: The projected increase is for most districts of the states of Maharashtra, Madhya Pradesh, Chhattisgarh, Odisha, Telangana, Bihar, Uttar Pradesh, and Himachal Pradesh.

Overall, the percentage of districts projected to receive very high-intensity rainfall increases under both climate scenarios, indicating an increase in the frequency of such events.

- Of the 723 districts, 94% of the districts recorded very high-intensity rainfall events between 0 and 50 days during the historical period. The number of districts projected to receive very high-intensity rainfall at this frequency decreases to 61% and 29% under RCP 4.5 and RCP 8.5 scenarios, respectively, for the 2030s.
- Very high-intensity rainfall between 50 and 100 days was recorded in 3% of the districts during the historical period. In the 2030s, 35% and 64% of the districts are projected to receive very high-intensity rainfall at this frequency under RCP 4.5 and RCP 8.5 scenarios, respectively.
- Very high-intensity rainfall between 100 and 150 days was recorded in only 1% of the districts during the historical period. In the 2030s, 2% and 4% of the districts are projected to receive very high-intensity rainfall at this frequency under RCP 4.5 and RCP 8.5 scenarios, respectively.
- Very high-intensity rainfall of >150 days was received by 1% of the districts during the historical period, and this increases to 2% of the districts receiving very high-intensity rainfall at this frequency in the 2030s under both climate scenarios.

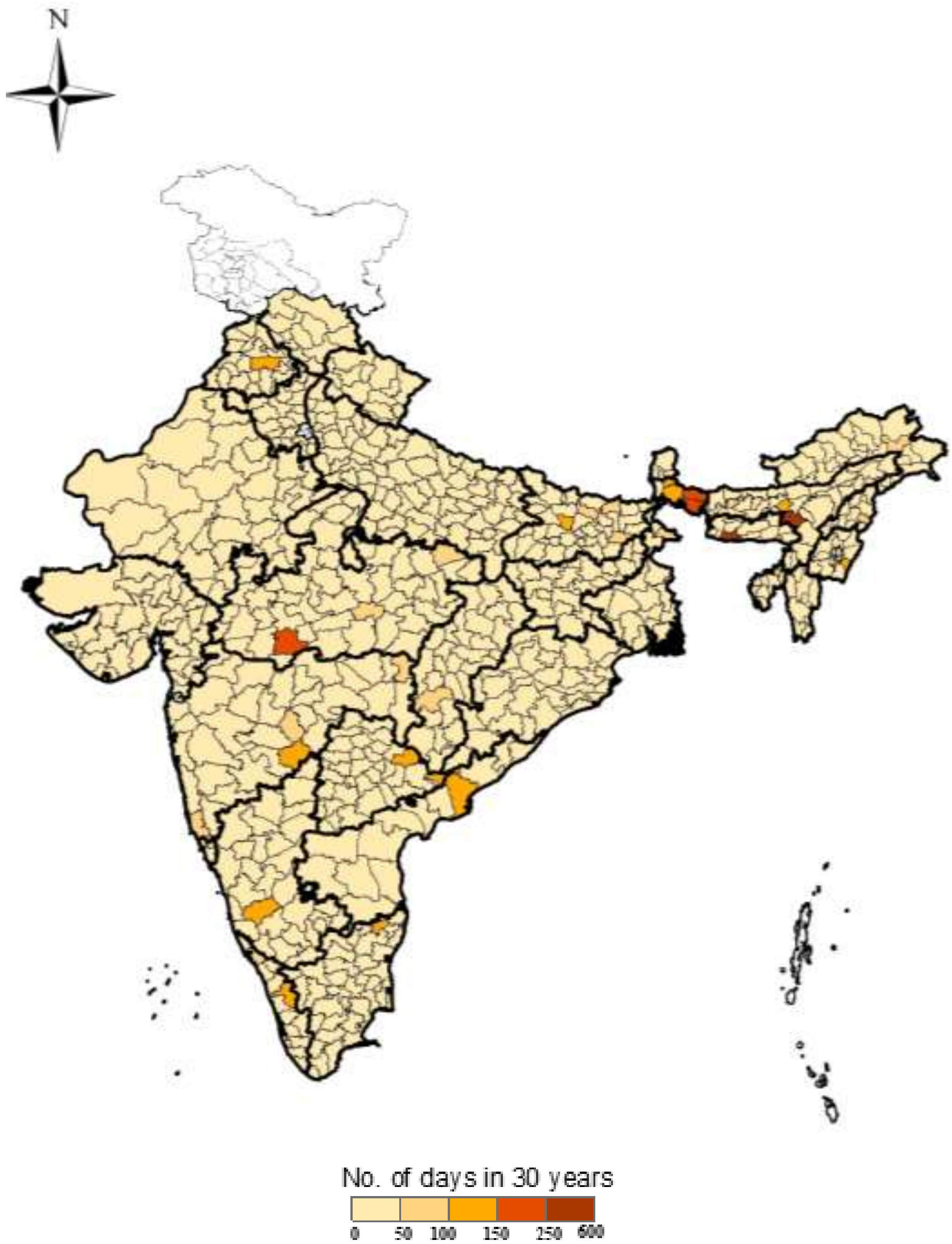


Figure 3-12: The number of very high-intensity rainfall events during the historical (1990–2019) period

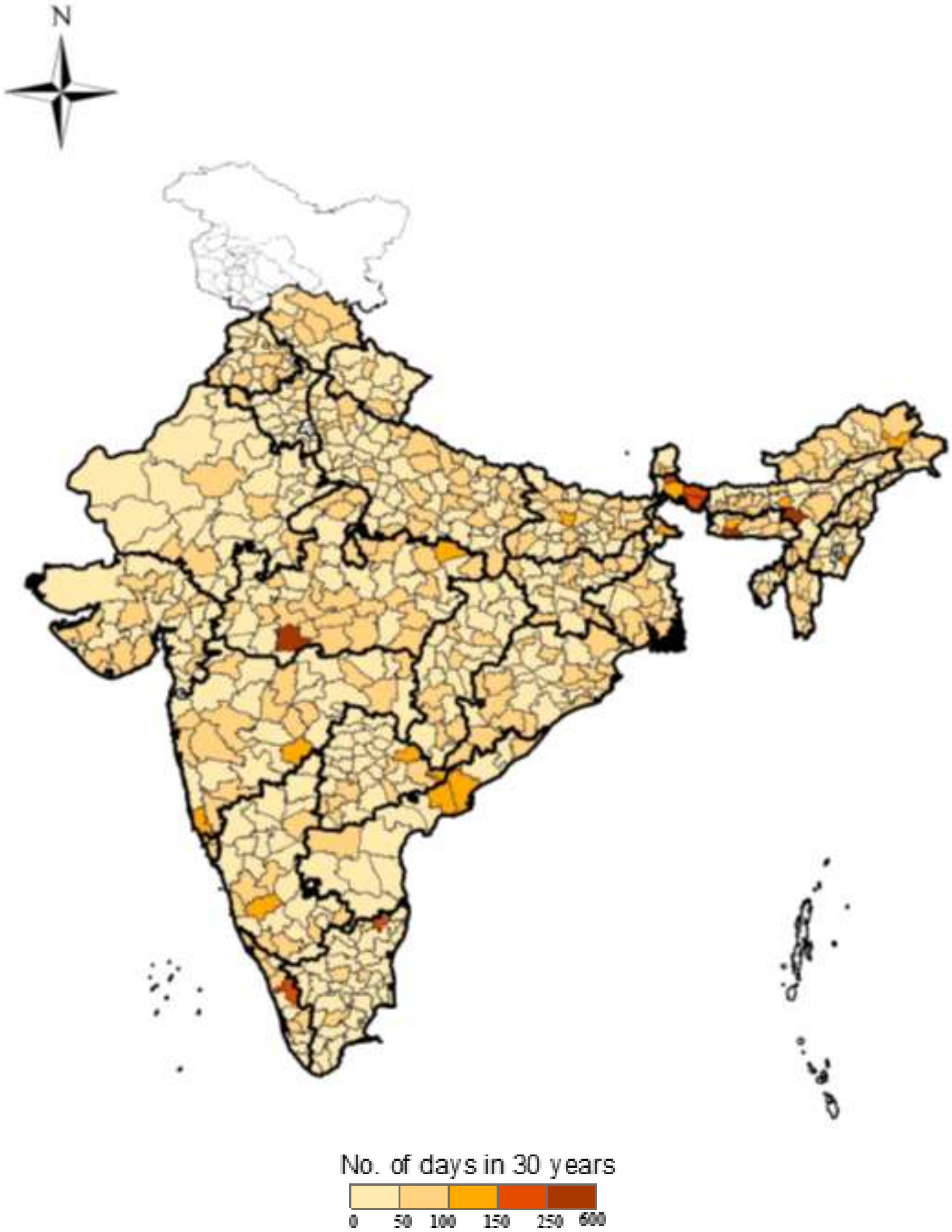


Figure 3-13: The number of very high-intensity rainfall events during the projected period (the 2030s) under the RCP 4.5 scenario

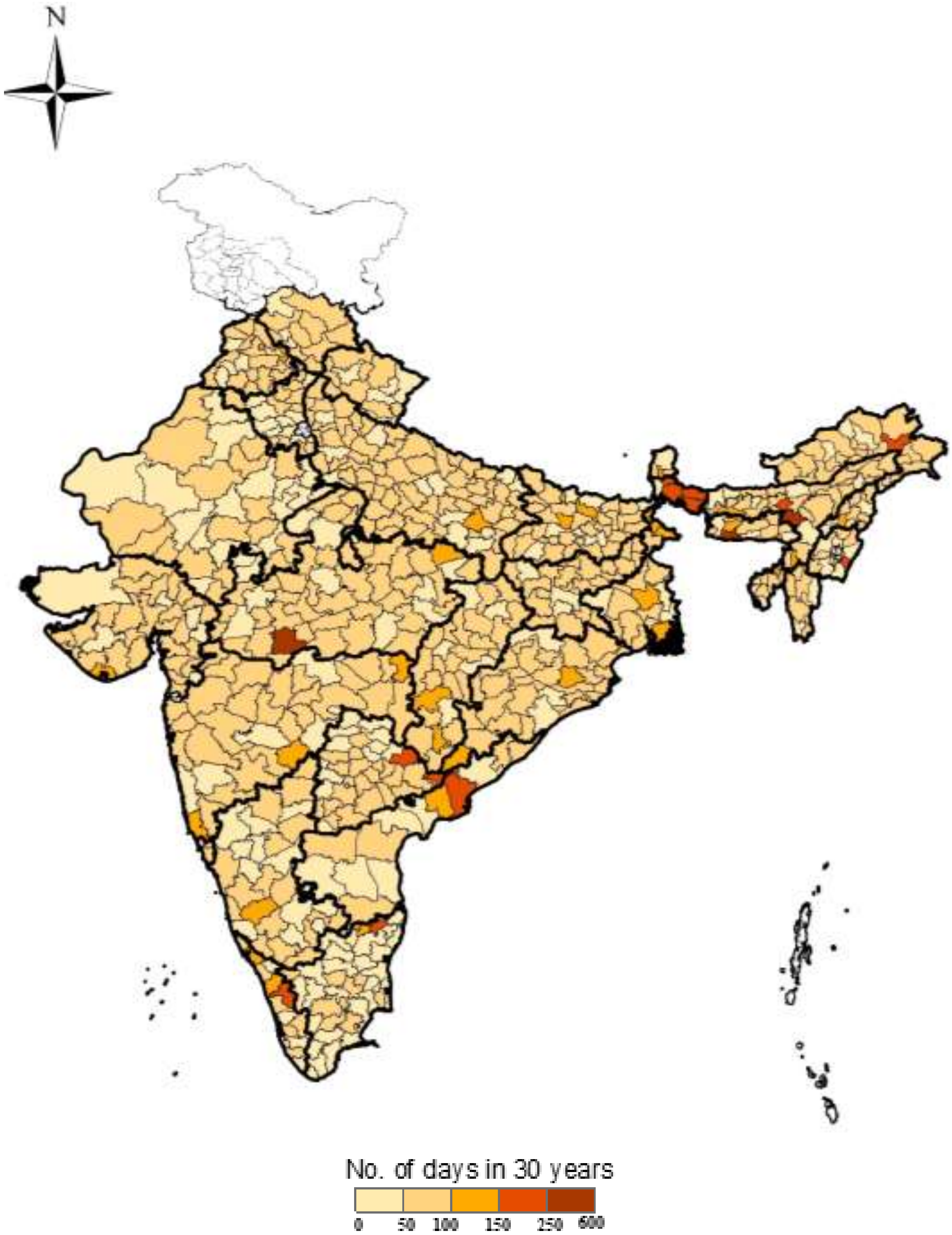


Figure 3-14: The number of very high-intensity rainfall events during the projected period (the 2030s) under the RCP 8.5 scenario

4. Conclusion

Significant increases in summer maximum and winter minimum temperatures and increase in rainfall were recorded during the historical period spanning 1990 to 2019. Climate projections for India at the district level for the period 2021–2050 (the 2030s) indicate a warmer and wetter future with an increase in extreme events, particularly heavy rainfall events. These findings are aligned with other global, regional, and national-level studies, particularly the national-level projections of climate by the Ministry of Earth Sciences.

- Changes in rainfall and increase in high-intensity rainfall events will affect surface and groundwater availability with implications for water quality, availability, and management for drinking and irrigation. An increase in heavy rainfall events could
  - destroy agricultural crops, with implications for farm incomes and livelihoods and
  - increase flooding events and weaken and/or destroy infrastructure such as communication and power networks, bridges, roads, and railways.
- An increase in temperature has implications for agricultural crop growth and productivity, as well as human and livestock health.
  - Agriculture crops have specific temperature and water requirements during various growth phases; an increase in temperature impacts yields.
  - Livestock health and productivity are adversely impacted.
  - Extreme hot weather and heatwaves lead to exhaustion and heat strokes and worsen chronic health conditions in humans. The indirect impact on health is an increase in disease-causing vector-borne insects and rodents.
- Changes in temperature and rainfall adversely impact the forest ecosystem, resulting in higher incidences of pests and diseases and an increase in forest fires.

Thus, the projected changes in climate for the various districts in India could adversely impact water, agriculture, forest and biodiversity, and health and infrastructure. There is, therefore, a need to climate-proof all systems through planning and implementation of resilience building and adaptation strategies across all the states to ensure development is not derailed. This research is an effort in that direction, and this information is being integrated into some of the State Action Plans on Climate Change and is being used for creating climate risk maps in a few states of India.

5. References

IPCC. (2014). Summary for policymakers. In: Climate change 2014: Impacts, adaptation, and vulnerability. Part A: Global and sectoral aspects. Contribution of working group ii to the fifth assessment report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, pp. 1–32.

IPCC. (2021). Summary for policymakers. In: *Climate Change 2021: The physical science basis. Contribution of working group i to the sixth assessment report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In Press. https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf

Pai, D. S., Rajeevan, M., Sreejith, O. P., Mukhopadhyay, B., & Satbha, N. S. (2021). Development of a new high spatial resolution (0.25° × 0.25°) long period (1901–2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region. *MAUSAM, 65*(1), https://doi.org/10.54302/mausam.v65i1.851

Srivastava, A. K., Rajeevan, M., & Kshirsagar, S. R. (2009). Development of a high resolution daily gridded temperature data set (1969–2005) for the Indian region. Atmospheric Science Letters, 10(4), 249–254. https://doi.org/10.1002/asl.232

Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012). An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, *93*(4), 485–498. https://journals.ametsoc.org/view/journals/bams/93/4/bams-d-11-00094.1.xml

6. Appendix

Appendix 6-1: Methodology (Reproduced from the Regional Reports)

The study analyses the changes in historical climate and projects future climate using climate models. The data sources, models, climate scenarios, timescale, and methods are presented here.

Historical climate data analysis

Gridded daily data sets for grids of 0.25° x 0.25° (~25 km X 25 km) for rainfall (Pai et al., 2021) and 1.0°x 1.0° (~100 km X 100 km) daily temperature (Srivastava et al., 2009) data sets from the Indian Meteorological Department (IMD) have been used. The present-day or historical data span the 30-year period from 1990 to 2019. Temperature has been analysed for maximum temperature during the summer season (March to May) and minimum temperature during the winter season (December to February). Rainfall has been analysed for the kharif season (June to September)—the main cropping season. In addition, rainfall variability has been analysed by computing the coefficient of variation (CV). Extreme events such as heatwaves and heavy rainfall events have also been analysed.

- Heatwaves have been computed based on the deviation from the normal temperature, following the criterion defined by IMD. IMD declares a heatwave when the departure from the normal temperature is in the range of 4.5°C to 6.4°C. A severe heatwave is declared when the departure from the normal temperature is >6.4°C.
  - The occurrence of heatwaves during summer has been analysed for a select few districts (15 in total) that are frequently subject to heatwaves.
- Heavy rainfall events have been computed based on the amount of rainfall received per day (in mm) during the kharif season and split into two categories:
  - High-intensity rainfall: 51 to 100 mm/day
  - Very high-intensity rainfall: >100 mm/day

Climate change projections

Climate science is continuously advancing as groups involved in modelling worldwide are constantly updating and incorporating better spatial resolution, new physical processes, and biogeochemical cycles. The Coupled Model Intercomparison Project (CMIP) is a forum where different modelling groups coordinate. The Fifth Assessment Report 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[1]. 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

[1] http://cccr.tropmet.res.in/home/cordexsa_datasets.jsp

pathway (RCP) scenarios. In this study, CORDEX model outputs were used for analysing future changes in temperature and rainfall at the district level. The IPCC recommends the use of ensemble means for achieving more reliable and quantitative information on future climate compared to a single model run. For this analysis, an ensemble means of 15 bias-corrected (delta method used for bias correction) CORDEX South Asia simulations were used.

- 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 historical 30-year period (1990–2019). This time frame is in consensus with the World Meteorological Organization's approach—the use of 30-year averages for representing the climatology of the present day and short term for the future. This is unlike the United Nations Framework Convention on Climate Change (UNFCCC) and IPCC reports, where the comparison of the projected climate is with pre-industrial periods.

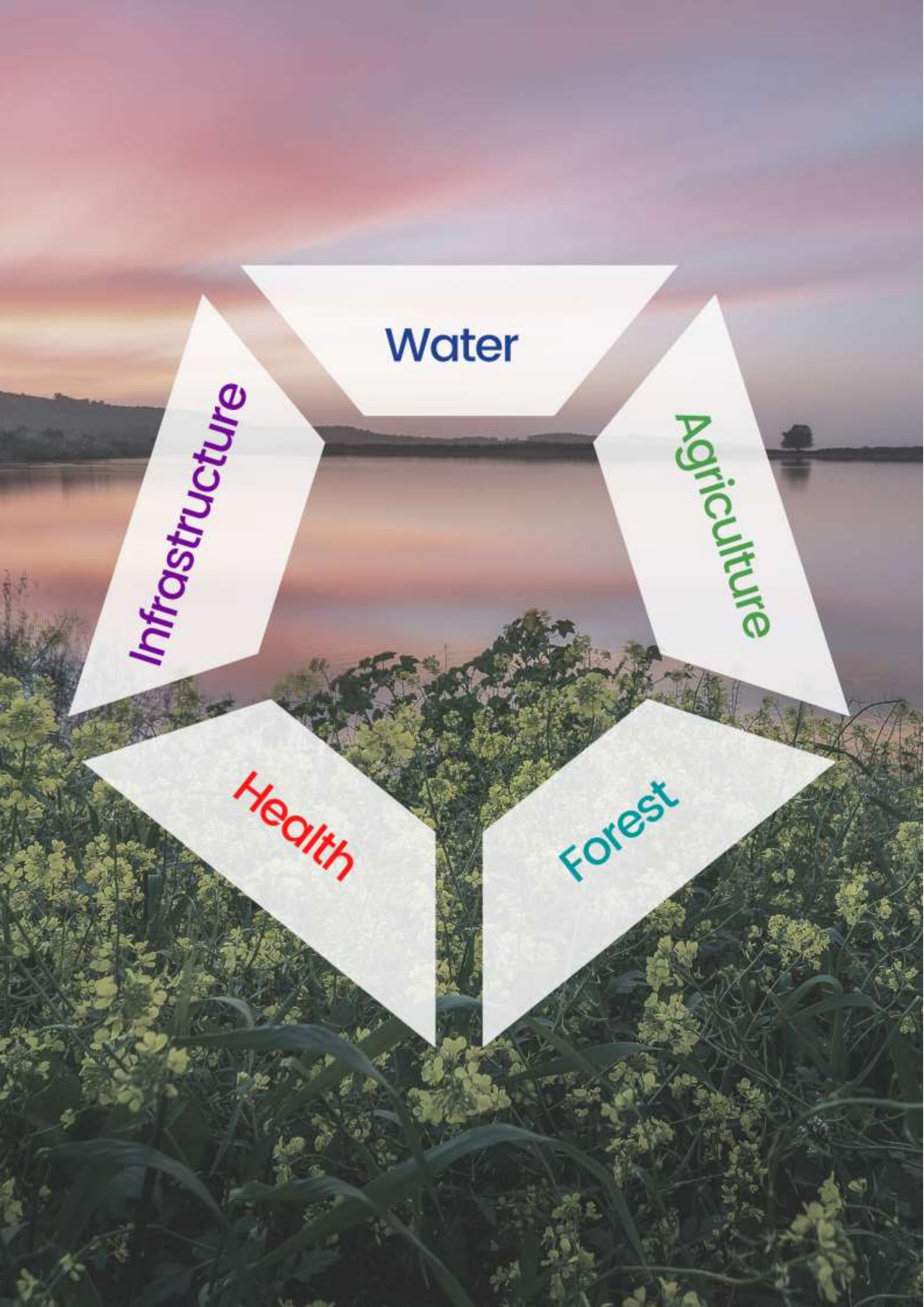
District-level averages of climatic variables were prepared using outputs from the re-gridded data. The mean value for a district was obtained by considering the mean of multiple grid points that might cover a district. Only grid points that fall fully within a district or those with at least 60% of the area falling within a district were considered for computing the mean. All analyses were performed using district means—gridded (latitude–longitude) information of the districts. The projected climate (2021–2030) was compared with the historical climate (1990–2019) to estimate the magnitude of climate change.

- **Temperature projections:** Both summer maximum (March to May) temperature and winter minimum (December to February) temperature
- **Rainfall projections:** Kharif season (June to September) and rabi season (October to December) rainfall
- **Projections of extreme events:** Heatwaves and heavy rainfall events

The changes in temperature and rainfall during the projected period (2021–2050) under the two climate scenarios have been computed relative to the historical period (1990–2019).

List of CORDEX models used for the analysis

CORDEX simulation	RCM	GCM boundary condition
CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	SMHI-RCA4	CNRM
NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	SMHI-RCA4	GFDL
IPSL-CM5A-MR_SMHI-RCA4	SMHI-RCA4	IPSL-CM5A
MIROC-MIROC5_SMHI-RCA4	SMHI-RCA4	MIRCO
MPI-M-MPI-ESM-LR_SMHI-RCA4	SMHI-RCA4	MPI-M
CNRM-CERFACS-CNRM-CM5_ IITM–RegCM4-4	IITM–RegCM4-4	CNRM
NOAA-GFDL-GFDL-ESM2M_ IITM–RegCM4-4	IITM–RegCM4-4	GFDL
IPSL-CM5A-MR_IITM–RegCM4-4	IITM–RegCM4-4	IPSL-CM5A
MIROC-MIROC5_ IITM–RegCM4-4	IITM–RegCM4-4	MIRCO
MPI-M-MPI-ESM-LR_ IITM–RegCM4-4	IITM–RegCM4-4	MPI-M
CCMA-CANESM2_ IITM–RegCM4-4	IITM–RegCM4-4	CCMA
CSIRO-QCCCE-CSIRO-Mk3-6-0_ IITM–RegCM4-4	IITM–RegCM4-4	CSIRO
NOAA-GFDL/GFDL-ESM2M	IITM–RegCM4-4	GFDL-ESM2M
MPI-M-MPI-ESM-LR	IITM–RegCM4-4	MPI-M
MOHC-HadGEM2-ES	IITM–RegCM4-4	HadGEM2


Water
Agriculture
Forest
Health
Infrastructure

CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

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

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

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