National River Conservation Directorate
Ministry of Jal Shakti,
Department of Water Resources,
River Development & Ganga Rejuvenation
Government of India

Climate Change Assessment Report in Krishna River Basin

February 2026

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Climate Change Assessment in Krishna River Basin

National River Conservation Directorate (NRCD)

The National River Conservation Directorate, functioning under the Department of Water Resources, River Development & Ganga Rejuvenation, and Ministry of Jal Shakti providing financial assistance to the State Government for conservation of rivers under the Centrally Sponsored Schemes of 'National River Conservation Plan (NRCP)'. National River Conservation Plan to the State Governments/ local bodies to set up infrastructure for pollution abatement of rivers in identified polluted river stretches based on proposals received from the State Governments/ local bodies.

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Centres for Krishna River Basin Management Studies (cKrishna)

The Centres for Krishna River Basin Management Studies (cKrishna) is a Brain Trust dedicated to River Science and River Basin Management. Established in 2024 by NIT Warangal and NIT Surathkal, under the supervision of cGanga at IIT Kanpur, the center serves as a knowledge wing of the National River Conservation Directorate (NRCD). cKrishna is committed to restoring and conserving the Krishna River and its resources through the collation of information and knowledge, research and development, planning, monitoring, education, advocacy, and stakeholder engagement.

www.ckrishna.org

Centre for Ganga River Basin Management and Studies (cGanga)

cGanga is a think tank formed under the aegis of NMCG, and one of its stated objectives is to make India a world leader in river and water science. The Centre is headquartered at IIT Kanpur and has representation from most leading science and technological institutes of the country. cGanga's mandate is to serve as think-tank in implementation and dynamic evolution of Ganga River Basin Management Plan (GRBMP) prepared by the Consortium of 7 IITs. In addition to this, it is also responsible for introducing new technologies, innovations, and solutions into India.

www.cganga.org

Acknowledgment

This report is a comprehensive outcome of the project jointly executed by NIT Warangal (Lead Institute) and NIT Surathkal (Fellow Institute) under the supervision of cGanga at IIT Kanpur. It was submitted to the National River Conservation Directorate (NRCD) in 2024. We gratefully acknowledge the individuals who provided information and photographs for this report.

Disclaimer

This report is a preliminary version prepared as part of the ongoing Condition Assessment and Management Plan (CAMP) project. The analyses, interpretations and data presented in the report are subject to further validation and revision. Certain datasets or assessments may contain provisional or incomplete information, which will be updated and refined in the final version of the report after comprehensive review and verification.

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Preface

In an era of unprecedented environmental change, understanding our rivers and their ecosystems has never been more critical. This report aims to provide a comprehensive overview of our rivers, highlighting their importance, current health, and the challenges they face. As we explore the various facets of river systems, we aim to equip readers with the knowledge necessary to appreciate and protect these vital waterways.

Throughout the following pages, you will find an in-depth analysis of the principles and practices that support healthy river ecosystems. Our team of experts has meticulously compiled data, case studies, and testimonials to illustrate the significant impact of rivers on both natural environments and human communities. By sharing these insights, we hope to inspire and empower our readers to engage in river conservation efforts.

This report is not merely a collection of statistics and theories; it is a call to action. We urge all stakeholders to recognize the value of our rivers and to take proactive steps to ensure their preservation. Whether you are an environmental professional, a policy maker, or simply someone who cares about our planet, this guide is designed to support you in your efforts to protect our rivers.

We extend our heartfelt gratitude to the numerous contributors who have generously shared their stories and expertise. Their invaluable input has enriched this report, making it a beacon of knowledge and a practical resource for all who read it. It is our hope that this report will serve as a catalyst for positive environmental action, fostering a culture of stewardship that benefits both current and future generations.

As you delve into this overview of our rivers, we invite you to embrace the opportunities and challenges that lie ahead. Together, we can ensure that our rivers continue to thrive and sustain life for generations to come.

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Abbreviations

Abbreviation	**Full Form**
CMIP6	Coupled Model Intercomparison Project - Phase 6
CV	Coefficient of Variation
EC-Earth	European Centre Earth System Model
GCM	Global Climate Model
GIS	Geographic Information System
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
MK Test	Mann–Kendall Test
MPI	Max Planck Institute Earth System Model
MME	Multi-Model Ensemble
SSP	Shared Socioeconomic Pathway
SSP245	Shared Socioeconomic Pathway 2-4.5
SSP585	Shared Socioeconomic Pathway 5-8.5
Tmin	Minimum Temperature
Tmax	Maximum Temperature
WFE	Water-Food-Energy Nexus

1. Introduction

Rainfall and temperature are the most important climate variables that vary across space and time. Variations in precipitation affect the region's water resources by altering streamflow, soil moisture, and groundwater recharge (Adarsh and Reddy, 2015). Almost all hydrological variables are influenced by temperature in some way. Future changes in precipitation and temperature will have an impact on the economy, society and ecosystems. The consequences of such changes across many regions are highlighted in several studies (IPCC 2014). There is some uncertainty in estimating the impacts at finer scales using the available climate models and scenarios (Ghosh and Mujumdar, 2009). The complex nature of the climate system and local-scale hydrological processes, including soil moisture and evapotranspiration, is poorly understood and inadequately modelled due to large uncertainties at regional scales. Each climate model output has its own set of limitations and varies depending on the climatic scenario. Furthermore, the ambiguity of the various climate model outputs is exacerbated by the fact that different models employ different parameterisation schemes, model structures, and responses to atmospheric forcings. As a result, multiple models representing different scenarios should be used to achieve a diverse set of climate change impacts on meteorological variables. Different methods, such as dynamical and statistical downscaling, have been developed to provide reliable projections of climate change at finer scales.

The Krishna River Basin covers about 258,900 km^2 across Maharashtra, Karnataka, Telangana, and Andhra Pradesh and has a tropical monsoon climate strongly influenced by seasonality and topography. Most rainfall occurs during the southwest monsoon (June - September), with very high precipitation in the Western Ghats (>2000 mm/year) and much lower rainfall in interior rain-shadow regions. Recent studies indicate spatially variable trends, including declining rainfall and changing extremes in some sub-basins. Temperatures show winter minima (December - January) and pre-monsoon maxima (April - May), with minimum temperatures below ~10°C in highlands and maxima often exceeding 40°C in interior regions. Observations and models consistently indicate a basin-wide warming trend in both maximum and minimum temperatures. Figure 1.1 represents the spatial distribution of major sub-basins in the Krishna River Basin.

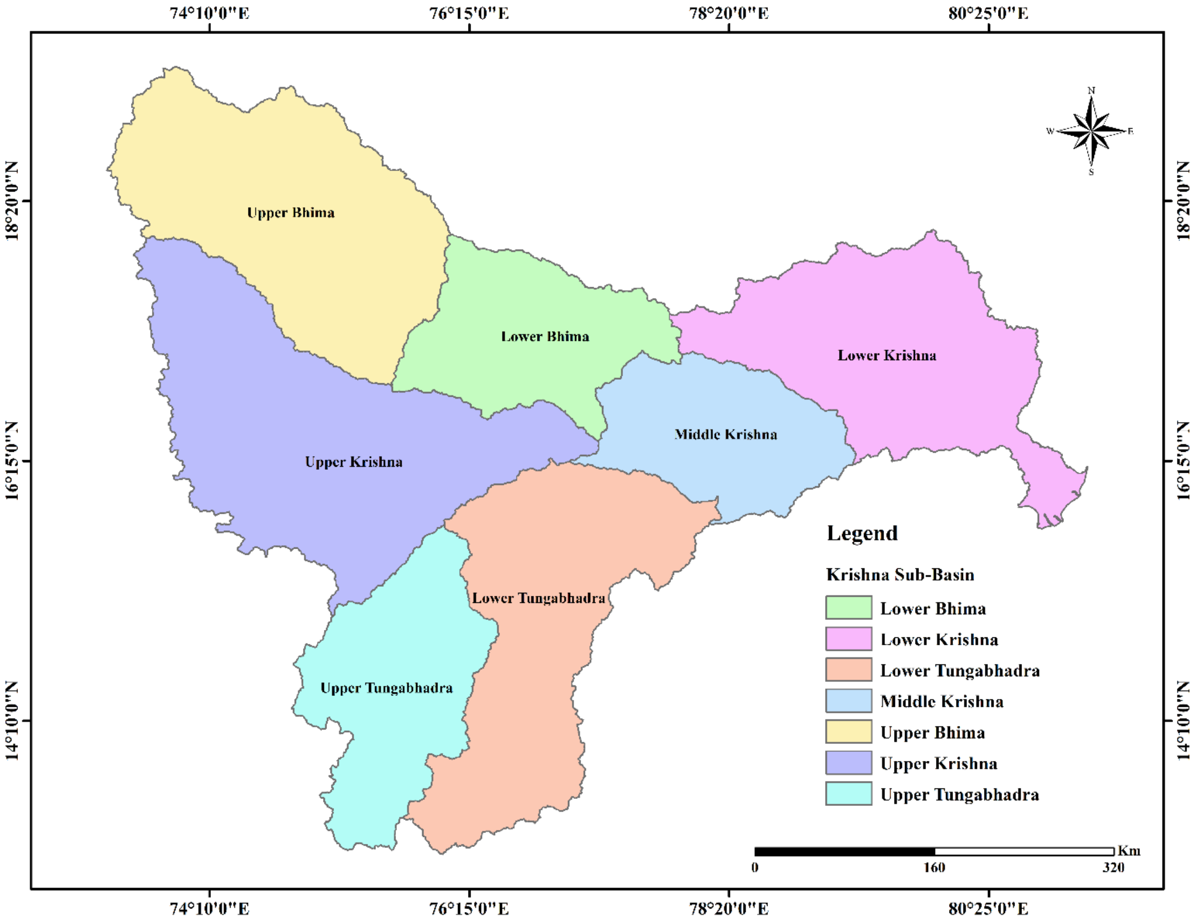

Figure 1. 1 Spatial distribution of major sub-basins in the Krishna River Basin

2. Data Used

The India Meteorological Department (IMD) provides reliable climate data on temperature and precipitation that are widely used in research, agriculture, water resources management, and climate modeling. IMD offers daily gridded rainfall data at 0.25° × 0.25° resolution from 1901 onwards and daily maximum and minimum temperature data at 1.0° × 1.0° resolution from 1951 onwards, generally in NetCDF format. These datasets are suitable for detailed spatial and temporal analysis and form a critical foundation for hydrological modeling, trend analysis, agricultural forecasting, and climate change impact assessment across India. Considering climate change impacts in South Asia, Mishra et al. (2020) developed a bias-corrected dataset of daily precipitation and maximum and minimum temperatures using outputs from 13 CMIP6 global climate models under four scenarios (SSP126, SSP245, SSP370, and SSP585). These models were selected based on data availability for both historical and future periods. The bias-corrected projections enable reliable assessment of future changes in mean and extreme climate and support hydrological simulations for 18 major sub-continental river basins. In the present study, IMD observational data for the period 1951–2014 and bias-corrected CMIP6 climate projections for 2015–2100 are used to analyze historical variability and future climate change impacts over the study region.

3. Methodology

The methodology for the climate assessment report over the Krishna River Basin is designed to systematically evaluate historical climate variability and future climate change impacts using observed and projected datasets. The climate data used was quality-checked for missing values and inconsistencies and then spatially extracted for the Krishna Basin using geographic information system (GIS) techniques. Basin and sub-basin boundaries were used to compute average precipitation and temperature for each sub-basin unit. Spatial analysis was conducted to examine sub-basin level variations in climate change impacts. Climate projections under SSP245 and SSP585 were compared in terms of mean changes. Differences between scenarios were quantified to evaluate the sensitivity of basin climate to emission pathways.

4. Results and Discussions

The climate assessment of the Krishna River Basin indicates that the basin has a monsoon-dominated rainfall regime, with annual precipitation averaging about 700–800 mm and strong spatial variability influenced by topography and distance from the Western Ghats. Lower and Tungabhadra sub-basins generally receive higher rainfall, while Bhima and interior Krishna regions are relatively drier. Inter-annual variability is moderate, with coefficients of variation of 18–20%, and drought frequency ranges from 9% to 19%, indicating occasional but recurrent water stress. Trend analysis of historical rainfall shows mostly weak and statistically insignificant changes, except for limited wetting tendencies in the upper catchments, suggesting that natural variability has dominated past hydroclimatic behaviour.

Future rainfall projections under SSP245 and SSP585 scenarios indicate substantial uncertainty and enhanced variability. Under SSP245, mean annual rainfall is projected to range from approximately 295 mm to 550 mm across models, with an ensemble mean of about 350 mm. Inter-annual variability increases markedly, with coefficients of variation rising to 30-45% and drought frequency increasing to 27-41%. Several models project modest but statistically significant wetting trends (1-3 mm/year), although these trends remain small relative to year-to-year fluctuations. Under SSP585, rainfall extremes intensify further, with projected means ranging from about 247 mm to 585 mm, coefficients of variation exceeding 50% in some models, and drought frequency increasing to 35-45%. Strong positive trends are simulated by several models, particularly CanESM5 and EC-Earth3, but these are accompanied by more frequent extreme dry and wet years, indicating greater climatic instability.

Analysis of historical temperature records shows clear seasonal and spatial patterns across the basin. Maximum temperatures peak during the pre-monsoon months (April-May), frequently exceeding 40°C in interior plateau regions, while minimum temperatures are lowest in winter (December-January), falling below 10°C in highland areas. Long-term observations reveal a statistically significant warming trend in both average annual maximum temperature (Tmax) and average annual minimum temperature (Tmin), consistent with regional and global climate change signals. The increase in Tmin is generally more pronounced than that in Tmax, reflecting a narrowing diurnal temperature range and enhanced nighttime warming.

Projected temperature changes under SSP245 indicate a continued rise in both Tmax and Tmin throughout the 21st century, with average warming rates of about 0.02-0.04°C per year. By the end of the century, basin-averaged Tmax and Tmin are expected to increase by approximately 1.5-2.5°C relative to the historical baseline. Under SSP585, warming is substantially stronger, with rates exceeding 0.05°C per year in several models and end-century temperature increases of 3.5-5.0°C. Extreme heat events become more frequent and intense, particularly during the pre-monsoon season, increasing the risk of heat stress, evaporation losses, and irrigation demand.

Overall, the integrated analysis of rainfall, Tmax, and Tmin indicates that while historical climate variability in the Krishna Basin has been dominated by natural fluctuations, future climate under SSP245 and SSP585 is projected to be characterized by enhanced warming, increased rainfall variability, higher drought frequency, and intensified extremes. These changes are likely to exert significant pressure on water resources, agriculture, and ecosystem services, emphasizing the need for climate-resilient planning, adaptive reservoir operation, and improved drought and heatwave preparedness across the basin. Figure 4.1 represents the observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature and precipitation over the Krishna River Basin under SSP245 and SSP585 scenarios. The sub-basin-wise analysis is explained as follows.

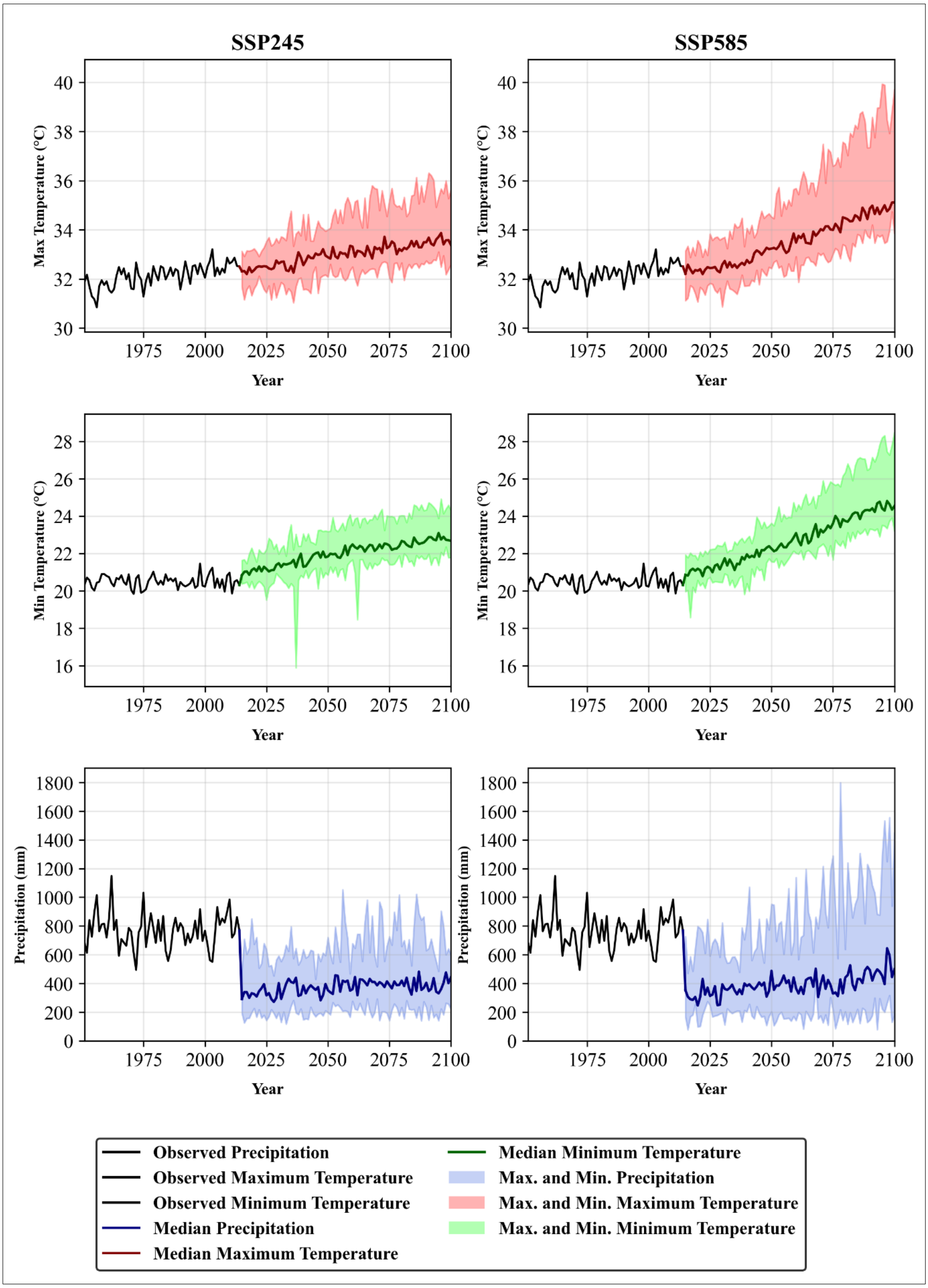

Figure 4. 1 Observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature and precipitation over the Krishna River Basin under SSP245 and SSP585 scenarios

4.1 Upper Bhima

Observed (1951–2014) and projected (2015–2100) anomalies in annual average maximum temperature, minimum temperature, and precipitation over the Upper Bhima sub-basin show clear quantitative evidence of climate change under SSP245 and SSP585 scenarios. During the historical period, Tmax and Tmin anomalies were generally confined to ±0.5 °C of the long-term mean, indicating relatively stable thermal conditions, while annual precipitation anomalies typically varied by ±15 to 20%, reflecting moderate inter-annual monsoon variability, with occasional drought and excess-rainfall years. Under SSP245, projected temperature anomalies exhibit a persistent positive shift throughout the 21st century. Basin-averaged Tmax anomalies increase gradually, reaching about +1.5 °C to +2.0 °C by 2100 relative to the historical baseline, while Tmin anomalies rise slightly faster, attaining approximately +1.8 °C to +2.3 °C. This stronger increase in Tmin suggests enhanced nighttime warming and a reduction in diurnal temperature range. Precipitation anomalies under SSP245 fluctuate mostly between −20% and +25%, with an increase in the frequency of negative anomalies, indicating more frequent moderate drought conditions. Under SSP585, warming anomalies intensify substantially. Tmax anomalies increase at rates exceeding 0.04–0.05 °C per year in several models and reach approximately +3.5 °C to +4.5 °C by the end of the century, while Tmin anomalies rise even more strongly to about +4.0 °C to +5.0 °C. These large positive anomalies reflect strong radiative forcing and accelerated warming. Precipitation anomalies under SSP585 show higher amplitude variability, ranging from about −30% to +40%, with dry years occurring in nearly 35-45% of the projected period and extreme wet years becoming more frequent. The combined effect of rising temperature anomalies and highly variable precipitation implies enhanced evapotranspiration losses and reduced effective rainfall, particularly during dry years. Overall, the quantified anomaly analysis indicates that the Upper Bhima sub-basin is likely to experience moderate warming of about 2 °C under SSP245 and strong warming exceeding 4 °C under SSP585 by the end of the century, accompanied by a 1.5 to 2-fold increase in precipitation variability. These changes are expected to significantly intensify water stress, agricultural risk, and hydrological uncertainty, highlighting the need for targeted climate adaptation and resilient water management strategies in the region. Fig 4.2 represents the observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature and precipitation over the Upper Bhima sub-basin under SSP245 and SSP585 scenarios.

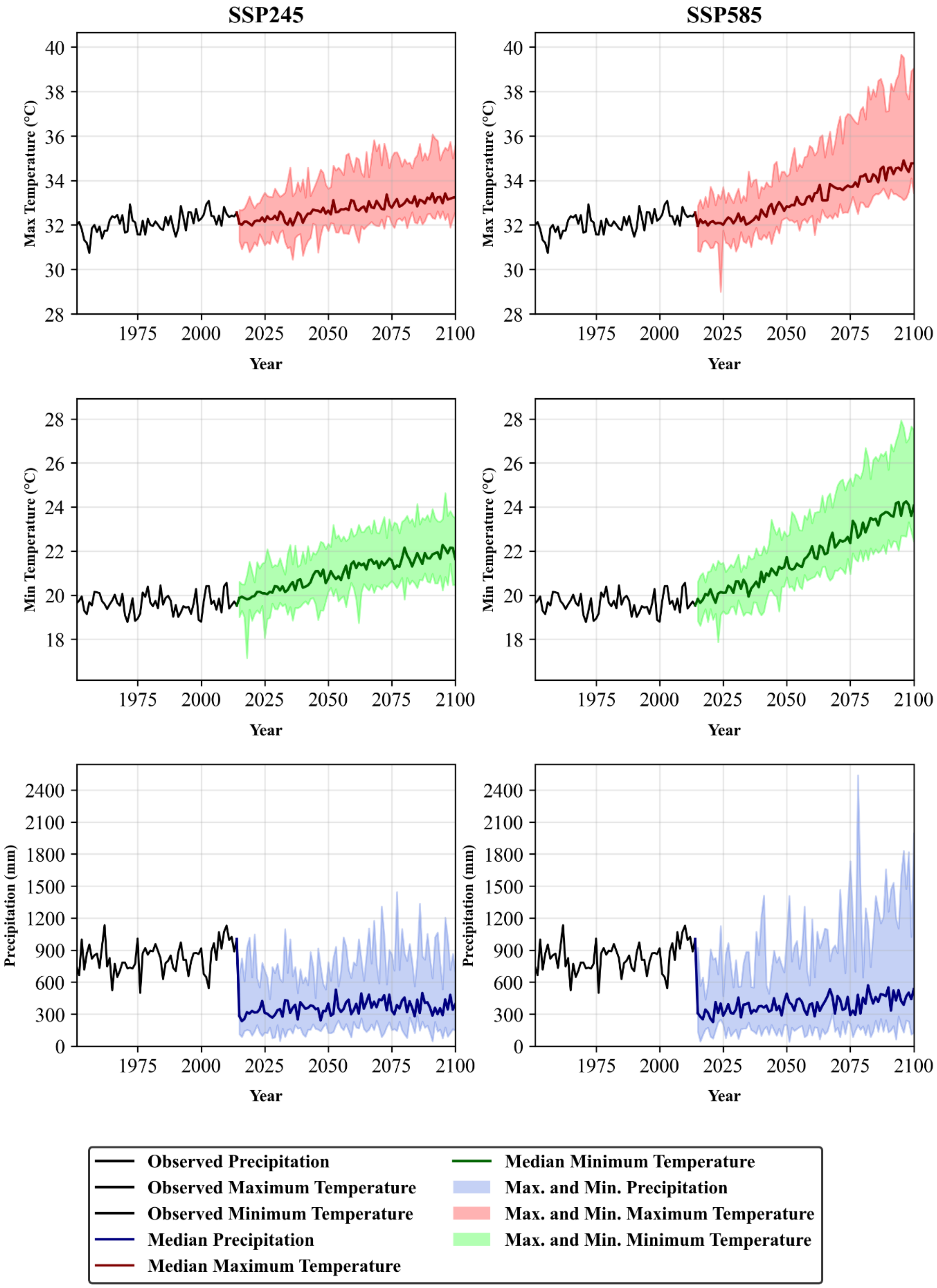

Figure 4. 2 Observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature and precipitation over the Upper Bhima Sub-basin under SSP245 and SSP585 scenarios

4.2 Lower Bhima

Observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature, and precipitation over the Lower Bhima sub-basin indicate pronounced climate-change signals under the SSP245 and SSP585 scenarios. During the historical period, Tmax and Tmin anomalies were mostly confined within ±0.4 °C, while precipitation anomalies generally varied within ±18–20%, reflecting moderate climatic variability with recurrent drought years. Under SSP245, Tmax anomalies increase gradually and reach approximately +1.4 °C to +1.9 °C by 2100, while Tmin anomalies rise to about +1.6 °C to +2.1 °C, indicating enhanced nighttime warming. Precipitation anomalies under SSP245 range mainly between −25% and +22%, with dry years occurring in nearly 30% of the projected period. Under SSP585, warming intensifies considerably, with Tmax anomalies reaching about +3.3 °C to +4.2 °C and Tmin anomalies increasing to +3.8 °C to +4.8 °C by the end of the century. Rainfall anomalies expand to −35% to +40%, and drought frequency rises to nearly 40-45%. The combined effects of strong warming and increased rainfall variability are likely to intensify evapotranspiration losses and water stress.

4.3 Upper Krishna sub-basin

Observed and projected anomalies over the Upper Krishna sub-basin reveal clear evidence of climatic shifts under future emission scenarios. During 1951-2014, Tmax and Tmin anomalies were generally within ±0.5 °C, and precipitation anomalies ranged between −18% and +20%. Under SSP245, Tmax anomalies increase steadily to about +1.6 °C to +2.0 °C, while Tmin anomalies rise to approximately +1.8 °C to +2.4 °C by 2100. Precipitation anomalies fluctuate between −22% and +25%, with drought years increasing to about 25–30%. Under SSP585, Tmax and Tmin anomalies intensify further, reaching about +3.5 °C to +4.6 °C and +4.0 °C to +5.1 °C, respectively. Rainfall anomalies widen to −30% to +42%, reflecting heightened hydroclimatic instability. These changes are expected to amplify agricultural and hydrological risks. Figure. 4.3 and Figure 4.4 represent the observed and projected anomalies in annual average maximum temperature, minimum temperature, and precipitation over the Lower Bhima sub-basin and Upper Krishna sub-basin under SSP245 and SSP585 scenarios, respectively.

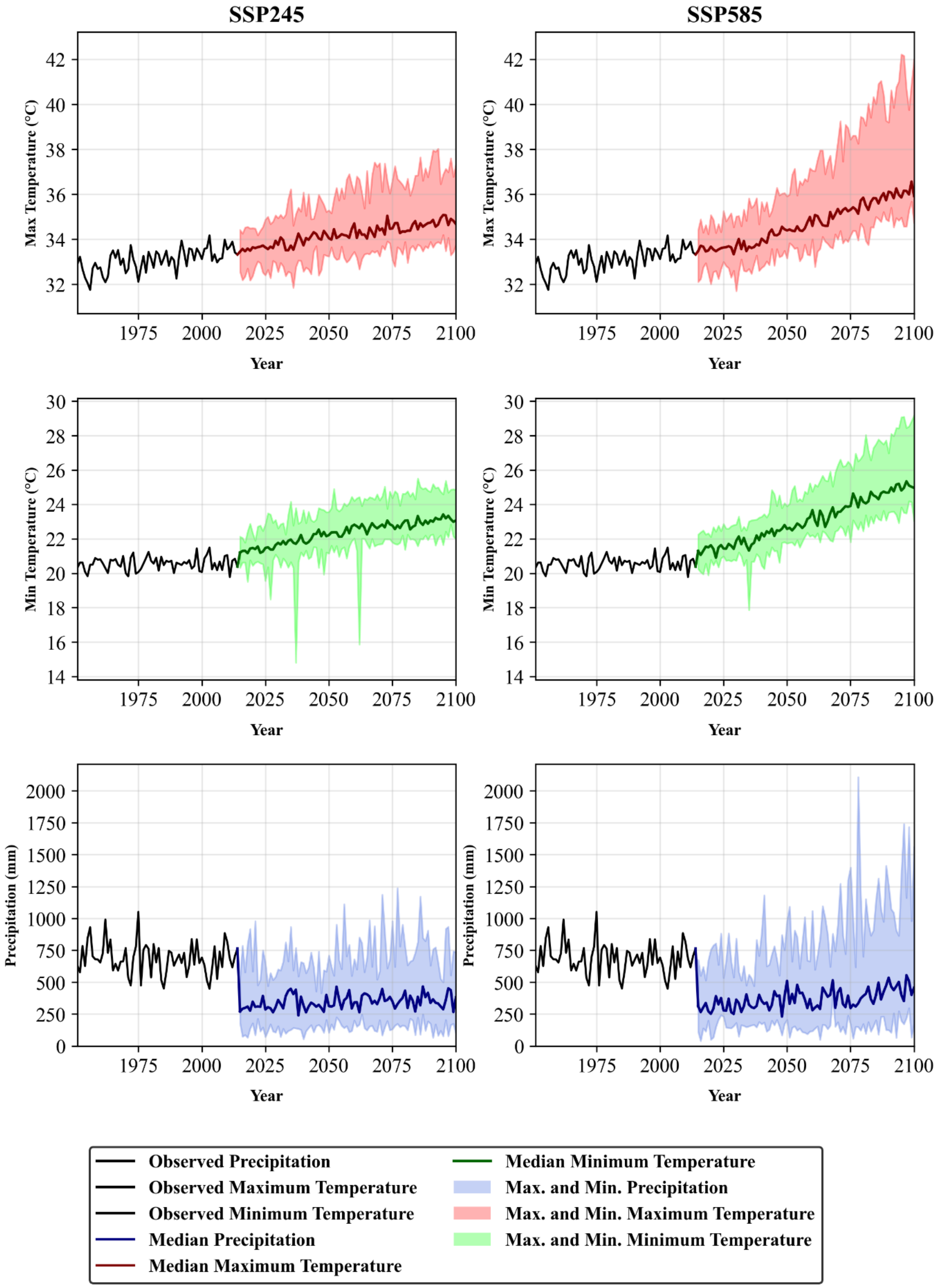

Figure 4. 3 Observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature and precipitation over the Lower Bhima Sub-basin under SSP245 and SSP585 scenarios

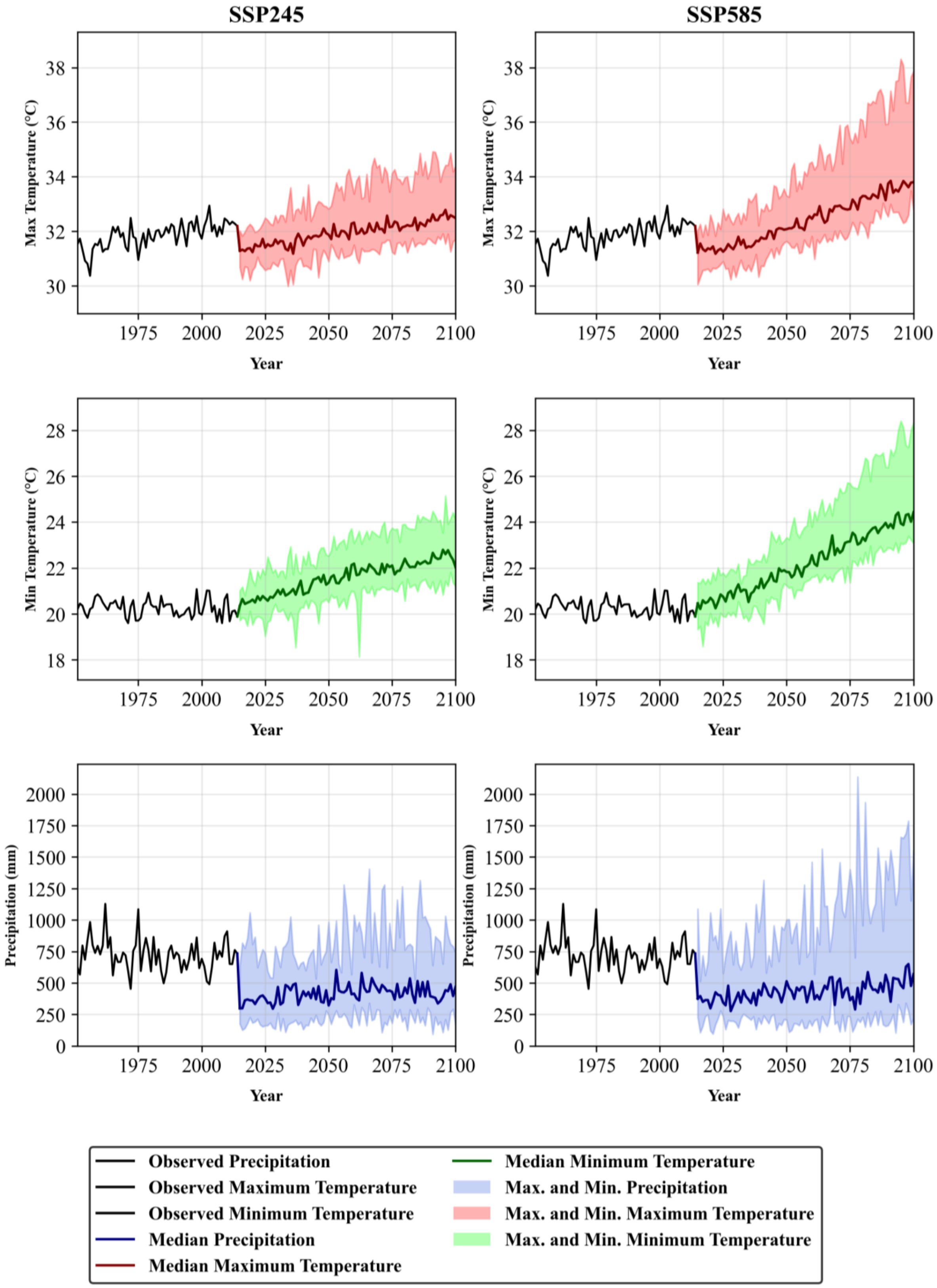

Figure 4. 4 Observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature and precipitation over the Upper Krishna Sub-basin under SSP245 and SSP585 scenarios

4.4 Middle Krishna Sub-basin

The Middle Krishna sub-basin exhibits substantial changes in temperature and precipitation anomalies under future climate scenarios. Historically, temperature anomalies were confined within ±0.4 °C, while rainfall anomalies ranged from −22% to +25%. Under SSP245, Tmax anomalies increase to approximately +1.5 °C to +2.1 °C and Tmin anomalies to +1.7 °C to +2.3% by 2100. Precipitation anomalies range from −28% to +30%, with drought frequency rising to nearly 30–35%. Under SSP585, Tmax anomalies reach about +3.6 °C to +4.7 °C and Tmin anomalies increase to +4.1 °C to +5.2 °C. Rainfall anomalies extend from −35% to +45%, indicating high vulnerability to both droughts and floods.

4.5 Lower Krishna Sub-basin

Observed and projected anomalies in the Lower Krishna sub-basin indicate comparatively stable historical conditions followed by pronounced future changes. During 1951-2014, temperature anomalies remained within ±0.3 °C, while rainfall anomalies were mostly between −15% and +18%. Under SSP245, Tmax and Tmin anomalies rise to about +1.3 °C to +1.8 °C and +1.5 °C to +2.0 °C, respectively. Precipitation anomalies fluctuate between −20% and +25%, with drought frequency increasing to about 22–25%. Under SSP585, Tmax anomalies reach +3.2 °C to +4.0 °C and Tmin anomalies increase to +3.6 °C to +4.5 °C. Rainfall anomalies widen to −28% to +38%, indicating increasing exposure to hydrological extremes. Figure. 4.5 and Figure 4.6 represent the observed and projected anomalies in annual average maximum temperature, minimum temperature, and precipitation over the Middle Krishna sub-basin and Lower Krishna sub-basin under SSP245 and SSP585 scenarios, respectively.

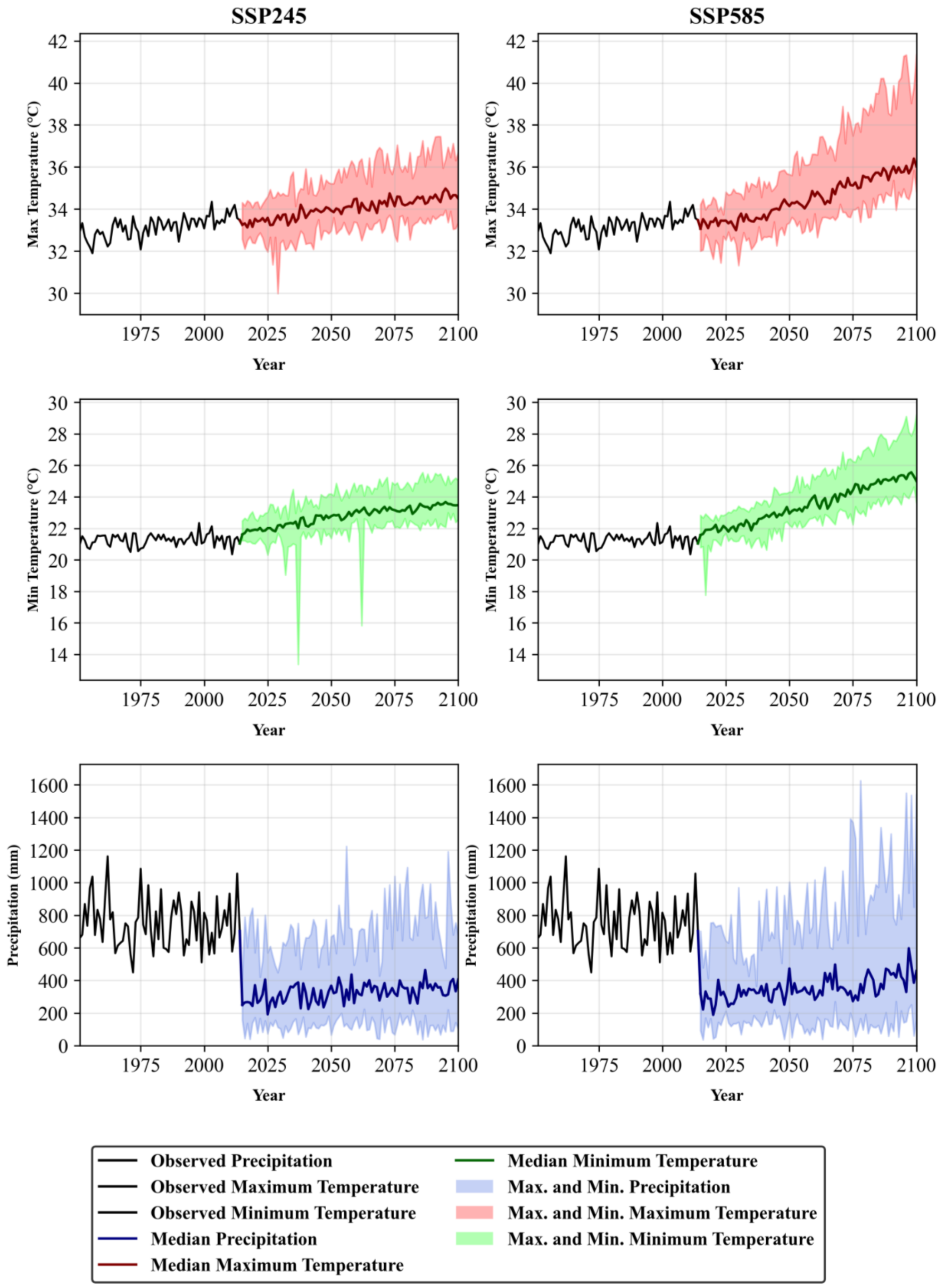

Figure 4. 5 Observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature and precipitation over the Middle Krishna Sub-basin under SSP245 and SSP585 scenarios

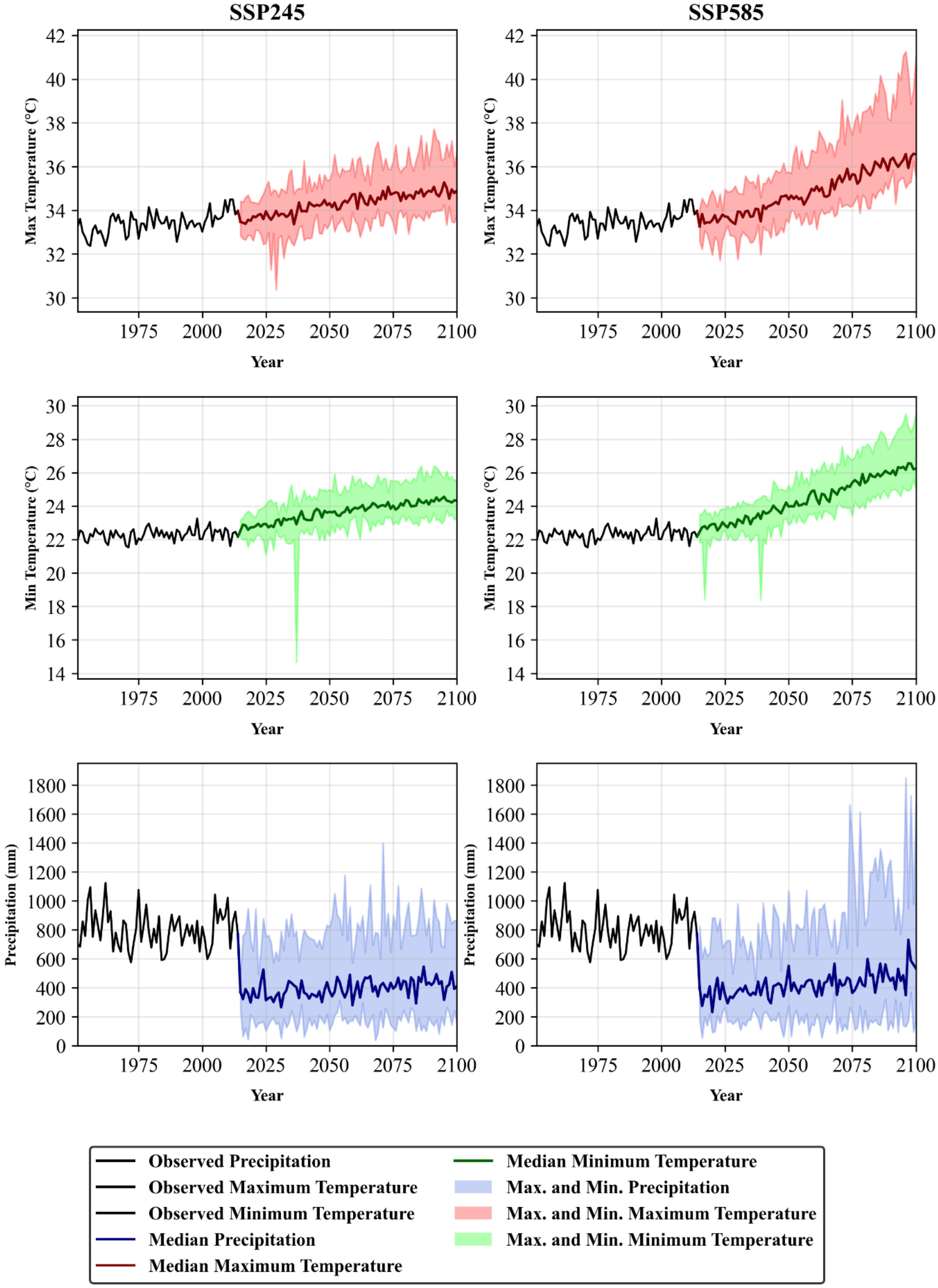

Figure 4. 6 Observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature and precipitation over the Lower Krishna Sub-basin under SSP245 and SSP585 scenarios

4.6 Upper Tungabhadra Sub-basin

The Upper Tungabhadra sub-basin is highly sensitive to climate change, particularly in precipitation variability. Historically, Tmax and Tmin anomalies remained within ±0.5 °C, while rainfall anomalies ranged from −20% to +28%. Under SSP245, Tmax anomalies increase to about +1.7 °C to +2.2 °C and Tmin anomalies to +1.9 °C to +2.5 °C by 2100. Rainfall anomalies range from −25% to +32%, with drought frequency at 28–32%. Under SSP585, Tmax anomalies rise sharply to +3.8 °C to +4.9 °C and Tmin anomalies to +4.2 °C to +5.4 °C. Precipitation anomalies increase further to −35% to +48%, reflecting heightened climate sensitivity.

4.7 Lower Tungabhadra Sub-basin

Observed and projected anomalies over the Lower Tungabhadra sub-basin indicate increasing thermal and hydrological stress under future scenarios. During the historical period, Tmax and Tmin anomalies were mostly within ±0.4 °C, while precipitation anomalies ranged from −18% to +22%. Under SSP245, Tmax anomalies reach about +1.5 °C to +2.0 °C and Tmin anomalies +1.7 °C to +2.2 °C by 2100. Rainfall anomalies vary from −23% to +28%, with drought frequency around 25–30%. Under SSP585, Tmax anomalies increase to +3.4 °C to +4.4 °C and Tmin anomalies to +3.9 °C to +4.9 °C. Precipitation anomalies widen to −32% to +42%, reflecting increased hydrological uncertainty. Figure. 4.7 and Figure 4.8 represent the observed and projected anomalies in annual average maximum temperature, minimum temperature, and precipitation over the Upper Tungabhadra sub-basin and Lower Tungabhadra sub-basin under SSP245 and SSP585 scenarios, respectively.

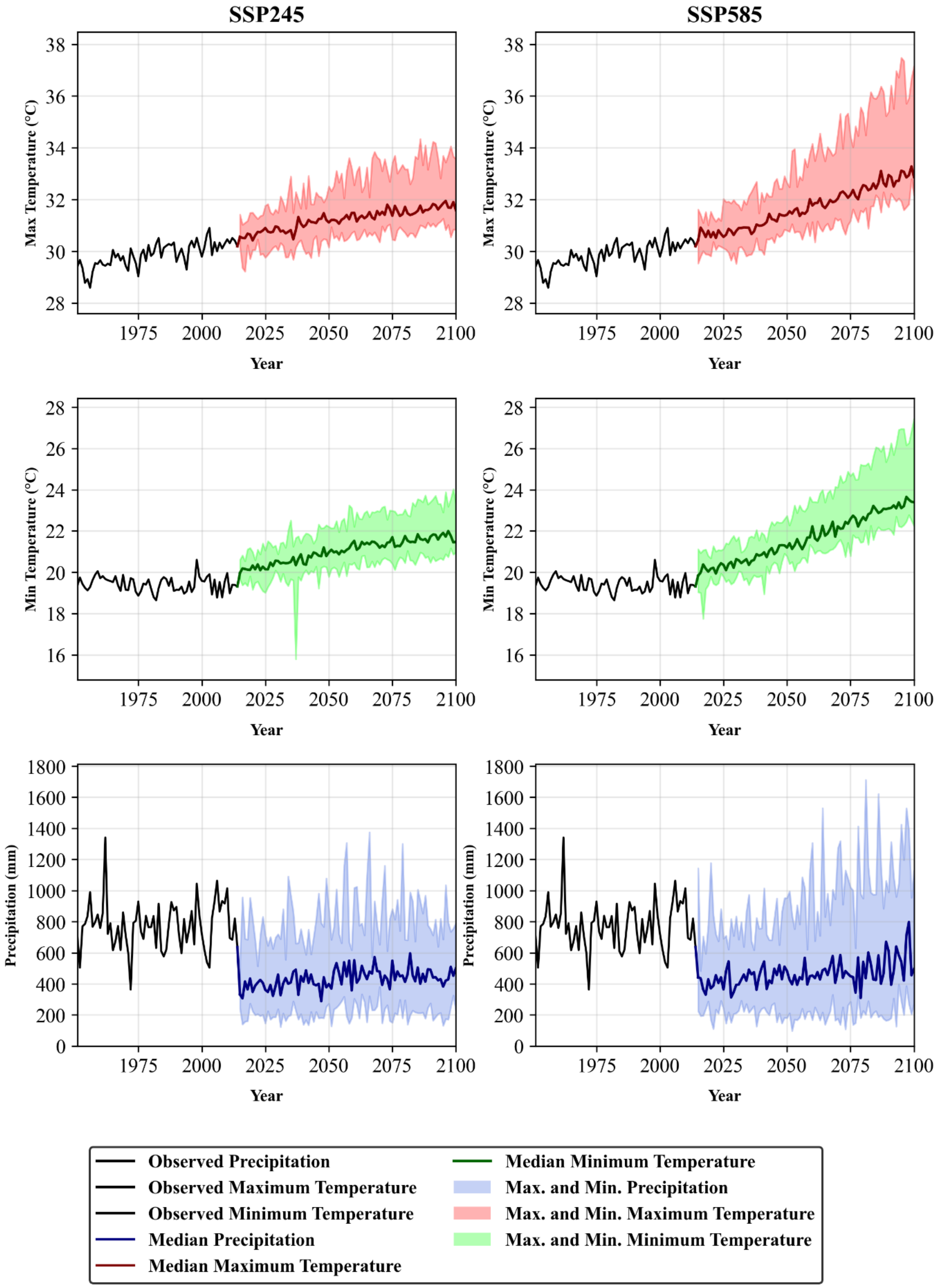

Figure 4. 7 Observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature and precipitation over the Upper Tungabhadra Sub-basin under SSP245 and SSP585 scenarios

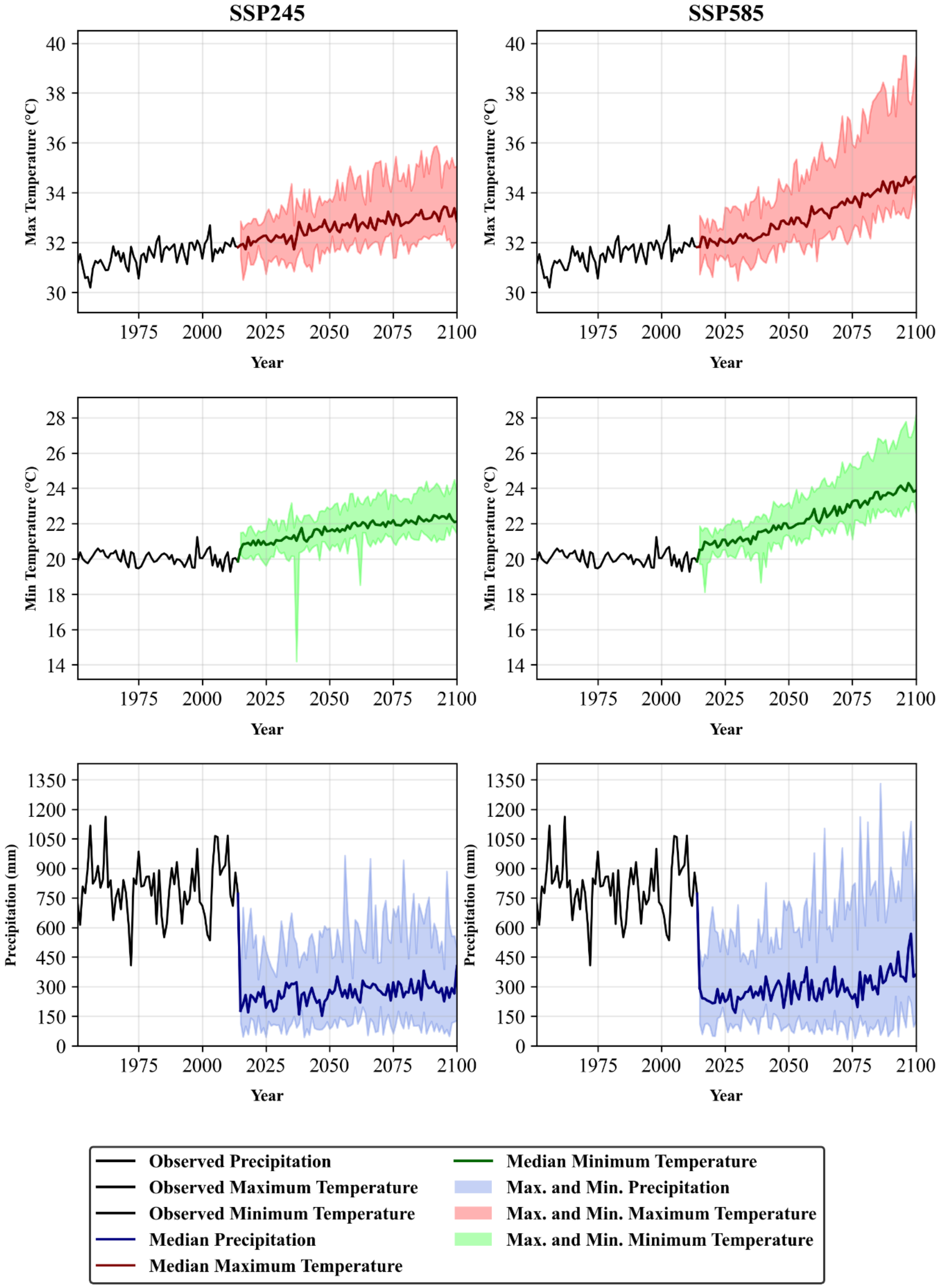

Figure 4. 8 Observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature and precipitation over the Upper Tungabhadra Sub-basin under SSP245 and SSP585 scenarios

5. Conclusions

The comprehensive analysis of observed (1951-2014) and projected (2015-2100) anomalies in annual average maximum temperature, minimum temperature, and precipitation across the Krishna River Basin reveals clear, consistent signals of climate change under both the SSP245 and SSP585 scenarios. Historical records indicate that the basin experienced moderate natural variability, with temperature anomalies generally confined within ±0.5 °C and precipitation anomalies mostly within ±20%, reflecting a relatively stable hydroclimatic regime dominated by monsoon dynamics. Future projections indicate a persistent, statistically significant warming trend across all sub-basins. Under SSP245, basin-wide Tmax and Tmin anomalies are projected to increase by approximately 1.5-2.3 °C by the end of the century, with Tmin rising slightly faster than Tmax, indicating enhanced nighttime warming and a gradual reduction in diurnal temperature range. Under SSP585, warming intensifies substantially, with projected temperature anomalies exceeding 4 °C in most sub-basins and reaching up to 5 °C in some regions. This strong warming signal reflects the impact of higher greenhouse gas concentrations and accelerated radiative forcing.

Precipitation projections indicate a marked increase in inter-annual variability under both scenarios. While long-term mean rainfall trends remain uncertain and model-dependent, the magnitude and frequency of rainfall anomalies increase significantly in the future. Under SSP245, precipitation anomalies commonly range between −25% and +30%, with drought frequency increasing to about 25-35%. Under SSP585, rainfall variability intensifies further, with anomalies extending from −35% to +45% and drought occurrence rising to nearly 40-45% of years. These changes indicate a shift toward more frequent and severe dry spells, interspersed with occasional extreme wet events. The combined effects of rising temperature and increasing rainfall variability are expected to substantially alter the basin's hydrological balance. Enhanced warming leads to higher evapotranspiration losses, reduced soil moisture, and increased irrigation demand, particularly during dry years. Simultaneously, intensified rainfall extremes raise the risk of floods, reservoir inflow surges, and soil erosion. As a result, the availability of effective rainfall for agriculture and water supply is likely to decline despite occasional high-precipitation years.

Spatially, interior and semi-arid sub-basins such as Bhima and Upper Krishna are projected to face greater drought vulnerability, while downstream and Tungabhadra sub-basins are expected to experience higher variability and flood risk. However, all sub-basins exhibit increasing climate stress, indicating basin-wide exposure to future hydroclimatic uncertainty.

From a hydrological modeling perspective, the dataset indicates strong non-stationarity in rainfall behavior. While long-term averages remain relatively stable, the variance and frequency of extremes have changed over time. This challenges the traditional assumption of stationarity in water resources planning and highlights the need for climate-informed modeling approaches. Incorporating this variability into hydrological and optimization models is essential for reliable future projections. For basin-scale governance, the heterogeneous distribution of rainfall underscores the importance of cooperative water-sharing mechanisms. Upstream sub-basins with relatively higher rainfall and storage potential play a crucial role in regulating downstream flows. During drought periods, conflicts over water allocation tend to intensify, especially between the Bhima and Lower Krishna regions. Understanding historical rainfall variability provides an objective basis for designing equitable and flexible allocation frameworks.

Overall, the anomaly-based assessment indicates that the Krishna River Basin is transitioning from a relatively stable historical climate regime to a future characterized by stronger warming, higher rainfall variability, and more frequent extremes. Under SSP245, moderate but significant climate stress is anticipated, whereas SSP585 represents a high-risk pathway with severe implications for water security, agriculture, and ecosystem sustainability. These findings emphasize the urgent need for climate-resilient water management, adaptive reservoir operation, improved drought and heatwave preparedness, and integrated basin-scale planning to enhance long-term resilience under changing climatic conditions.

REFERENCES

- Adarsh, S., & Janga Reddy, M. (2015). Trend analysis of rainfall in four meteorological subdivisions of southern India using nonparametric methods and discrete wavelet transforms. *International Journal of Climatology, 35*, 1107–1124. https://doi.org/10.1002/joc.4042
- Ghosh, S., & Mujumdar, P. P. (2009). Climate change impact assessment: Uncertainty modeling with imprecise probability. *Journal of Geophysical Research: Atmospheres, 114*, D18.
- India Meteorological Department (IMD), Ministry of Earth Sciences, Government of India. Gridded Climate Data Products (Rainfall, Maximum and Minimum Temperature). Available at: https://mausam.imd.gov.in
- IPCC. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Available online: https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_AR5_FINAL_full_wcover.pdf
- Mishra, V., Bhatia, U. and Tiwari, A.D., 2020. Bias-corrected climate projections for South Asia from coupled model intercomparison project-6. *Scientific data*, *7*(1), p.338.