



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

# Godavari River Basin Climate Change Assessment Report



April 2026



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

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## Acknowledgment

This report is a comprehensive outcome of the project jointly executed by CSIR-NEERI (Lead Institute) and IIT Hyderabad (Fellow Institute) under the supervision of cGanga at IIT Kanpur. It is 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.

Centres for Godavari River Basin Management Studies

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## 1 Introduction

Hydrological systems are heavily altered due to climate change, influencing water availability, extreme events, and socio-economic stability across river major river basins worldwide. Godavari River Basin is not an exception which is facing extreme hydrological shifts like never before. IPCC underscores that due to rise in greenhouse gas concentrations there is a significant warming and intensification of climate extremes, including heatwaves and heavy precipitation (IPCC, 2021; 2022). Detailed assessment of historic and future climate change can be made accessible under the Coupled Model Intercomparison Project Phase 6 framework where future climate scenarios are represented through Shared Socioeconomic Pathways. Scenarios such as SSP245 and SSP585 representing moderate and high emission trajectories, respectively (Eyring et al., 2016; O'Neill et al., 2016). In recent years, emphasis has shifted toward analyzing extreme climate indices, as they provide more direct insights into impacts on water resources and ecosystems (Zhang et al., 2011; Alexander et al., 2006). Furthermore, robust statistical techniques such as the Mann–Kendall test and Sen's slope estimator are widely used to detect and quantify trends in climate variables due to their suitability for non-parametric data (Mann, 1945; Sen, 1968). In this context, the present study evaluates changes in temperature and precipitation extremes over the Godavari River basin using multi-model climate projections, with the objective of understanding their implications for hydrological behavior and supporting climate-resilient water resource management. Further, it is to be noted that the present report has been prepared to complement the earlier report on Climatology where the average trends of climatic variables have been discussed along with the IMD datasets.

## 2 Collection of different GCMs and RCMs data

The climate change assessment of a region can be quantified based on the data simulated by the Global Climate Models (GCMs) and Regional Climate Models (RCMs), which captures both large-scale climatic driers and regional hydro-meteorological fluctuations. The GCMs parts of Coupled Modelled Intercomparison Project (CMIPv6) framework capture long-term simulations of climatic variables under various Shared Socio-economic Pathways (SSPs). This enables understanding of both historic and future trends in the climatic data. Due to the coarse spatial resolution of the model simulations, evaluation of of basin-scale studies related to monsoon dynamics, orographic impacts in the Godavari basin can be impacted. This limitation can be addressed using dynamically down-scaled datasets like CORDEX, which

offers finer spatial resolution with improved representation of seasonal variability and extreme rainfall events. Several studies have applied multi-modal ensemble approaches by combining the results of various GCMs viz. ACCESS-CM2, MPI-ESM1-2-HR, and MIROC6 to reduce the model-specific biases and uncertainties and to enhance the robustness. To match the GCMs with observed datasets, model outputs are bias corrected using various statistical techniques such as quantile mapping. In the present report, the climatic data of various GCMs are synthesized over the basin and their spatio-temporal trends have been quantified to understand the climate variability and future projections, specifically related to hydrological processes in the basin. Table 1 shows characteristics of the GCM models used in the analysis.

*Table 1 Characteristics of GCM models considered in the present study*

S. No.	GCM Model	Institution	Country	Resolution	Key Strengths	Limitations
1	ACCESS-CM2	CSIRO & BoM	Australia	~1.25°×1.875°	Good monsoon simulation	Wet bias in tropics
2	BCC-CSM2-MR	BCC	China	~1.125°×1.125°	Land-atmosphere coupling	Weak extremes
3	CanESM5	ECCC	Canada	~2.8°×2.8°	High variability	Coarse resolution
4	CNRM-CM6-1	CNRM-CERFACS	France	~1.4°×1.4°	Stable simulations	Moderate bias
5	GFDL-ESM4	NOAA	USA	~1.0°×1.25°	Land-biosphere interaction	Dry monsoon bias
6	INM-CM5-0	INM	Russia	~2.0°×1.5°	Low sensitivity	Low variability
7	IPSL-CM6A-LR	IPSL	France	~2.5°×1.25°	Aerosol interaction	Warm bias
8	MIROC6	UTokyo/JAMSTEC	Japan	~1.4°×1.4°	Monsoon dynamics	Precipitation bias

9	MPI-ESM1-2-HR	MPI	Germany	$\sim 0.9^\circ \times 0.9^\circ$	High resolution	High compute
10	MRI-ESM2-0	MRI	Japan	$\sim 1.1^\circ \times 1.1^\circ$	Extreme events	Temperature bias

### 3 Climate change assessment

Comprehensive climate change assessment in the present report has been carried out by detecting trends using Sen's slope and Mann-Kendall Tau, and extreme event characterization. The emphasize has been given to understand the ramifications of climate changes in terms of precipitation and temperature.

#### 3.1 Trend analysis

Trend analysis was focused on temperature (maximum and minimum) and precipitation based on the outputs from GCMs simulated during the historic time period during 1985 to 2014. Non-parametric trend analysis methods were adopted in the analysis to mitigate the influences of non-normality and outliers in the climate datasets. The methods include, Mann-Kendall (MK) test statistic represented by Tau ( $\tau$ ) and Sen's slope ( $s$ ). The MK test statistic ranges between -1 and +1, where  $\tau > 0$  indicates an increasing trend in the data,  $\tau < 0$  indicates a decreasing trend, whereas  $\tau = 0$  indicates no discernible trend. The statistical significance of the  $\tau$  was evaluated at a threshold of 0.05 in the analysis. The quantification of the detected trends was estimated using the Sen's slope ( $s$ ), which computes the median of slopes between all possible observation pairs in the time series. The Sen's slope provides a robust estimate of the rate of change, which is expressed in physical units of the variable considered.

Mann-Kendall tau determines the direction and consistency of the trends, and Sen's slope quantifies the rate of change of the trends. The data sets were processed in Google Earth Engine (GEE) using NASA NEX-GDDP-CMIP6 archives in the GEE platform. The variables viz. daily maximum temperature (tasmax), daily minimum temperature (tasmin), and daily precipitation from the ten GCMs considered in the study (Table 1) to obtain yearly aggregates. All the datasets have various native spatial resolutions (Table 1) at daily scales, which were processed at their native spatial resolutions and later resampled at a spatial resolution of .25 degrees ( $\sim 25$  km) and clipped to the extent of the basin. The native units of the temperature (in K) and precipitation ( $\text{kg}/\text{m}^2/\text{s}$ ) in the GCMs models were converted into

degree Celsius and mm/day, respectively. The trend analysis was carried out at the pixel level using the gridded GCMs data. Annual aggregates were computed viz. Tmax: annual maximum of daily temperature (tasmax), Tmin: annual minimum of daily temperature (tasmin), and pr: annual total of daily precipitation. This resulted in a annual time-series of each variable at every pixel in the basin.

The entire trend analysis was implemented in GEE using the built-in reduces that compute the Sen's slope and Mann-Kendall tau. The results were exported as a multi-band raster layers, where each band represents a specific GCM output. These raster stacks were further analyzed in R for visualization.

### 3.1.1 Tmax

The results on spatial patterns for Tmax across different GCMs reflect a dominant warming trend over the basin (Figure 1), although the magnitude and spatial patterns vary among the models. Majority of GCMs show consistent increase in the extreme maximum temperature in the basin. The data from the models including GFDL-ESM4, CNRM-CM6-1, BCC-CSM2-MR, and IPSL-CM6A-LR show uniformly positive slope throughout the basin, with strong magnitudes over northern and north-eastern parts of the basin with values ranging between 0.02 and 0.10 °C/year. The regions with the warmest signals indicate the potential for extreme heat events. In contrast, the simulations of models MPI-ESM1-2-HR and MRI-ESM2-0 display mixed trends with pockets of negative trends in eastern and western regions of the basin. These regions indicate the variability and uncertainty among the model projections. ACCESS-CM2 and CanESM5 model projections maintain a moderate positive rate of warming trends with a relatively spatial homogeneity.

### 3.1.2 Tmin

The spatial distribution of Sen's slope for Tmin (Figure 2) reveals an overall warming trend across the Godavari River basin with significant inter model variability. Most of the models indicate a positive Sen's slope values with IPSL-CM6A-LR model showing a predominant warming trend. The magnitude of the warming rates vary between 0.02 and 0.10 °C/year, predominantly in the central and western regions. In contrast several other models including MPI-ESM1010HR, MRI-ESM2-0, and INM-CM5-0 display mixed or negative Sen's slope, especially in the northern and eastern parts of the basin. The overall patterns suggest that

night time temperatures trends are varying more predominantly across the basin with strong model-specific processes.

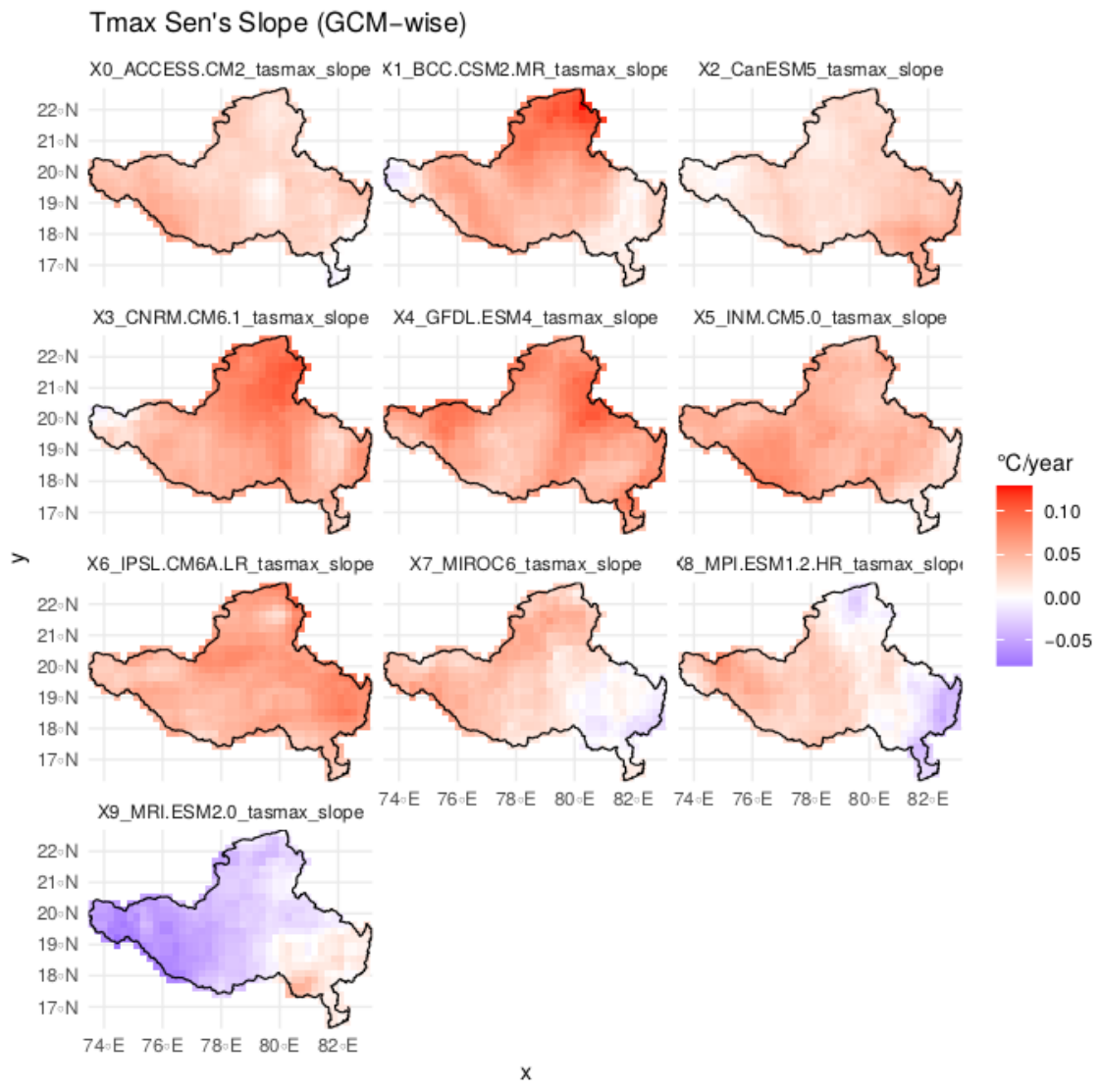


Figure 1 Sen's slope (temporal trends) of Tmax: annual maximum daily temperature (tasmax) over the Godavari River Basin simulated by different GCMs during 1985-2014

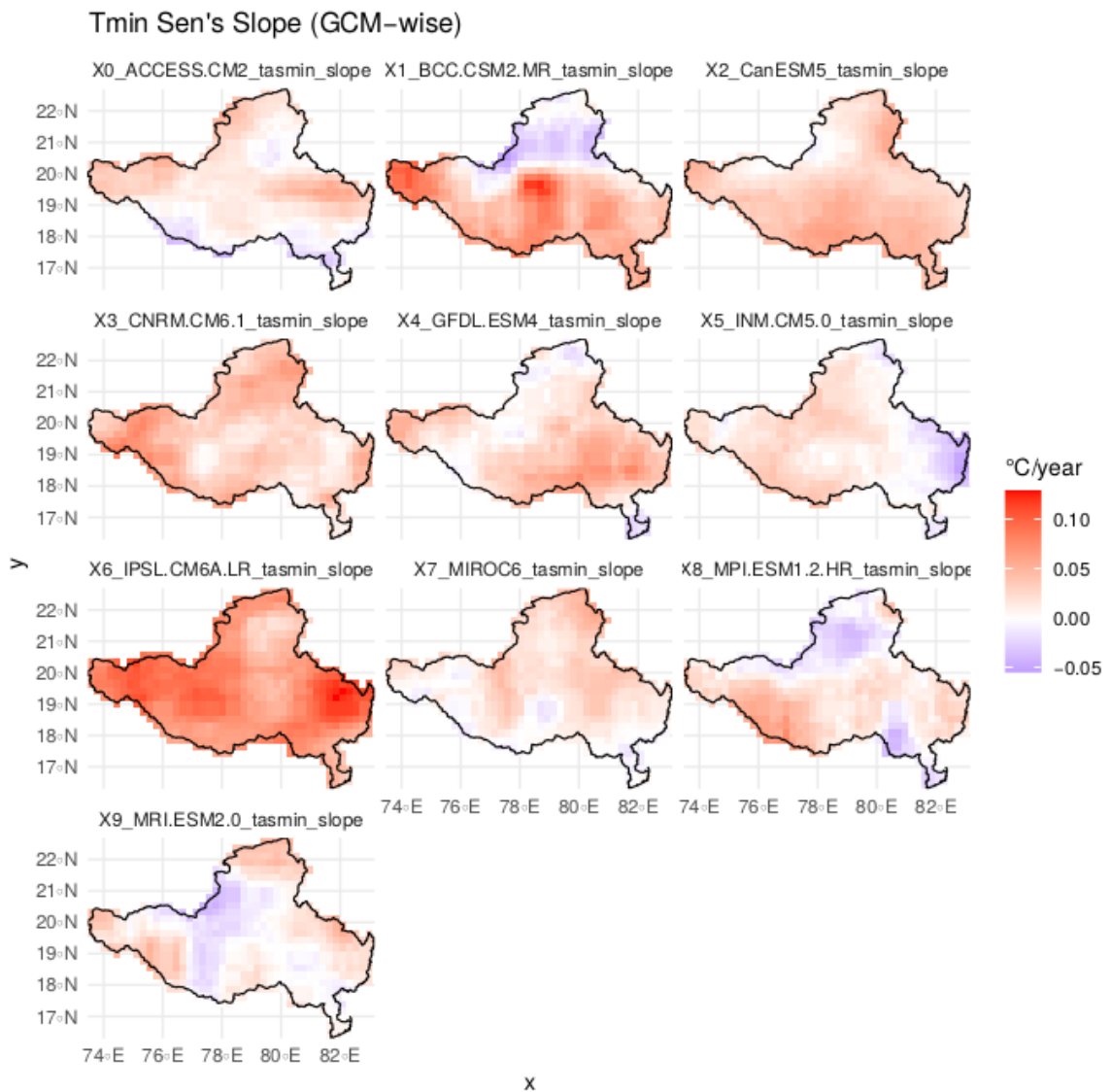


Figure 2 Sen's slope (temporal trends) of Tmin: annual minimum daily temperature (tasmin) over the Godavari River Basin simulated by different GCMs during 1985-2014

### 3.1.3 Precipitation

The results indicate (Figure 3) a high degree of spatial heterogeneity in temporal trends of annual total precipitation in the Godavari River Basin. Both increasing and decreasing trends are observed among different GCMs. Compared to Tmax or Tmin, the Pr spatial patterns indicated a mixed trend, with significant inter-model variability in both magnitude and spatial distribution. GCMs like CanESM5, IPSL-CM6A-LR, and MIROC6, have quantified a decreasing trend in the precipitation pattern with predominantly negative Sen's slope values over the basin. Particularly the declining

annual trends are predominant over the central, northern and eastern regions with values varying in the range of -10 to -20 mm/year, indicating potential drying conditions. In contrast, model outcomes such as CNRM-CM6-1, INM-CM5-0, and MRI-ESM2-0 have quantified positive precipitation trends ranging between 10-15 mm/year, predominantly in central, northern and western regions of the basin. These patterns suggest a potential intensification of rainfall in localized areas. Models like ACCESS-CM2 and GFDL-ESM4 portray moderate spatial variability with a combination of both positive and negative trends. The mixed patterns highlight the spatial inconsistency in the model responses. However, the overall analysis of the Sen's slope indicates that rainfall changes do not follow a uniform spatial pattern, but varying significantly across the basin and among the models.

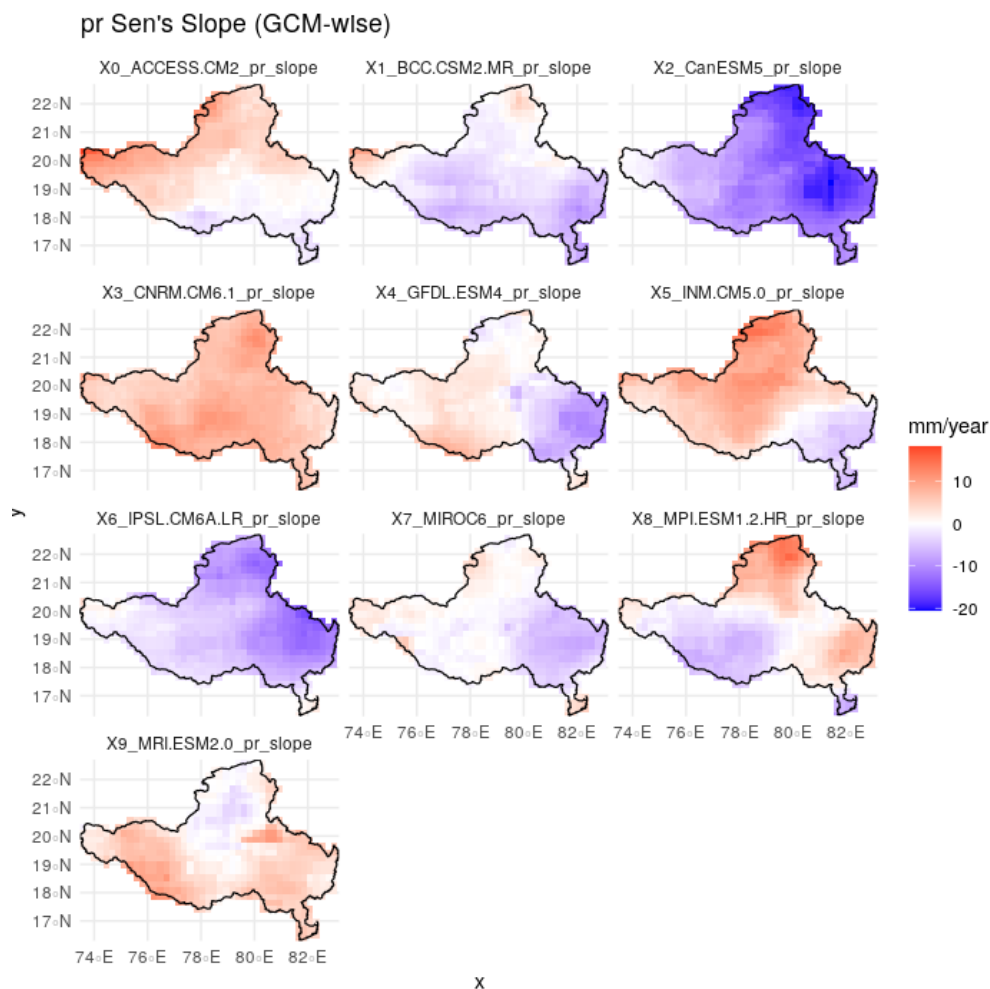


Figure 3 Sen's slope (temporal trends) of pr: annual total of daily precipitation over the Godavari River Basin simulated by different GCMs during 1985-2014

### 3.1.4 Mann-Kendall Tau values

The results indicate that the distribution of Mann–Kendall tau ( $\tau$ ) values derived from different GCMs have variability among the climatic variables considered (Figure 4). For Tmax, the  $\tau$  values are positive for almost all GCMs, except for MRI-ESM2 model. The predominance of the consistent positive  $\tau$  values across the GCMs corresponds with the Sen’s slope patterns shown in Figure 1. The detected  $\tau$  values are in the range of 0.10 to 0.25, indicating a moderately strong and consistent warming trend in extreme daytime temperature values. Similarly, the  $\tau$  values for Tmin also exhibit a persistent warming trend in the night time temperatures corresponding the Sen’s slope pattern (Figure 2). The variability in  $\tau$  values (Figure 4) for Tmin reveals greater inter-model variability with some models showing weaker to near neutral strengths. Particularly, IPSL-CM6A-LR exhibits both stronger slope and  $\tau$ , which reinforces the robust warming trends in the basin.

In contrast, precipitation (pr) exhibits a markedly different behaviour, with  $\tau$  values varying from negative to positive ranges, approximately between  $-0.15$  and  $+0.15$ , indicating poor consistency and significantly high variability in the precipitation trends across the GCMs. Some models suggest an increasing precipitation trends, while others indicate decreasing trends, and several show near-zero  $\tau$  values, implying weak or non-monotonic behaviour, which corresponds to the temporal trends in the precipitation (Figure 3). Such discrepancies highlight the high uncertainty and stochastic nature of precipitation processes, where even moderate changes in magnitude may not correspond to a consistent monotonic trend.

Overall, the  $\tau$  analysis confirms that temperature trends are more consistent and robust across GCMs, whereas precipitation trends are highly uncertain and model-dependent, reflecting the inherent complexity and variability of rainfall processes under changing climatic conditions.

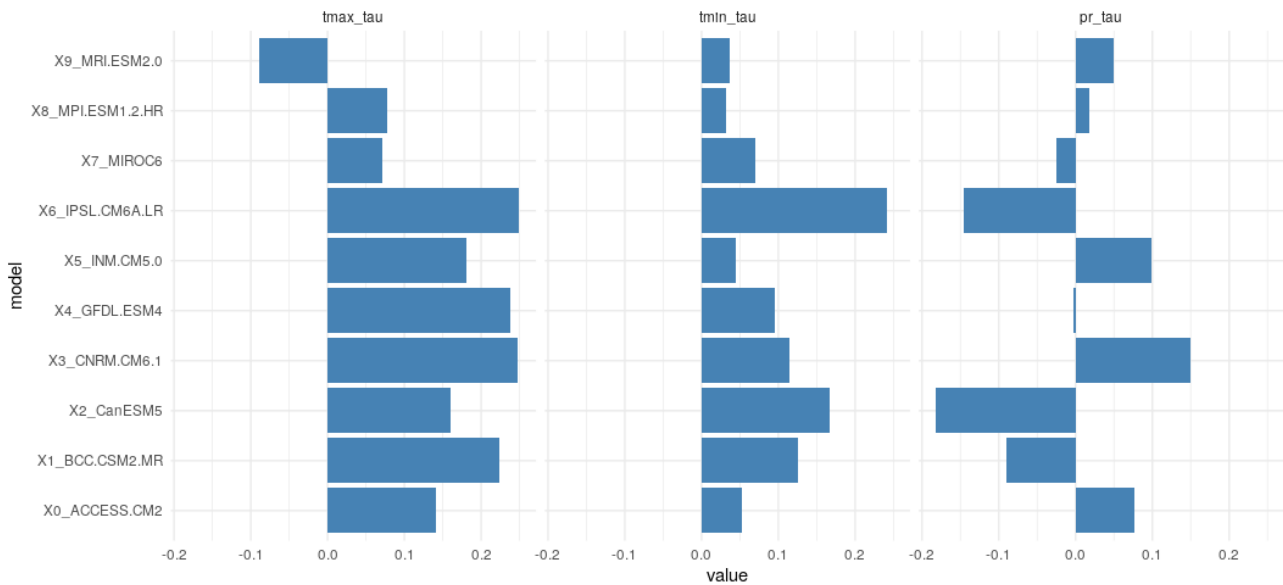


Figure 4 The maximum values of Mann-Kendall's Tau values plotted for Tmax, Tmin, and Pr for different GCMs

### 3.2 Variability and extremes analysis

Extreme climate indices related to Temperature and precipitation were employed in the present analysis to quantify the changes in the extreme values over the Godavari Basin under both historic and future climate change scenarios. The indices were consistent with the Expert Team on Climate Change Detection and Indices (ETCCDI) recommendations – viz. TXx (Annual Maximum of Daily Maximum Temperature), TNn (Annual Minimum of Daily Minimum Temperature), and Rx1day (Maximum 1-Day Precipitation). In the context of Godavari Basin, these indices are relevant for assessing the heatwave and drought risks and for evaluating the flood-risk due to sudden high-intensity extreme rains. Integration of results from multiple GCMs enables robust assessment and its impacts by capture reliable projections and uncertainties.

The analysis was carried out for different time periods for both historical and future time periods. Historical period ranged from 1985-2014, near-future period ranges from 2021-2040, mid future ranges from 2041-2070, and far future ranges from 2071-2100. For future projections, two climate change scenarios data were considered viz. SSP-245 and SSP-585, representing intermediate and high emission scenarios, respectively. In this study, the future climate projections are relied on Shared Socio-economic Pathways (SSPs) representing different trajectories of Greenhouse gas (GHGs) emissions, climate policies, and socioeconomic development which are defined under the CMIP6 modeling framework.

SSP245 scenario assumes a moderate emission pathway considering that socioeconomic development replicates historical trends, with implementation of some climate mitigation policies, where the GHGs peak around mid-century and fades afterwards. While, SSP585 scenario assumes high-emission scenario, with rapid economic growth driven by fossil fuel consumption with limited climate action, and GHGs are assumed to increase continuously throughout the century.

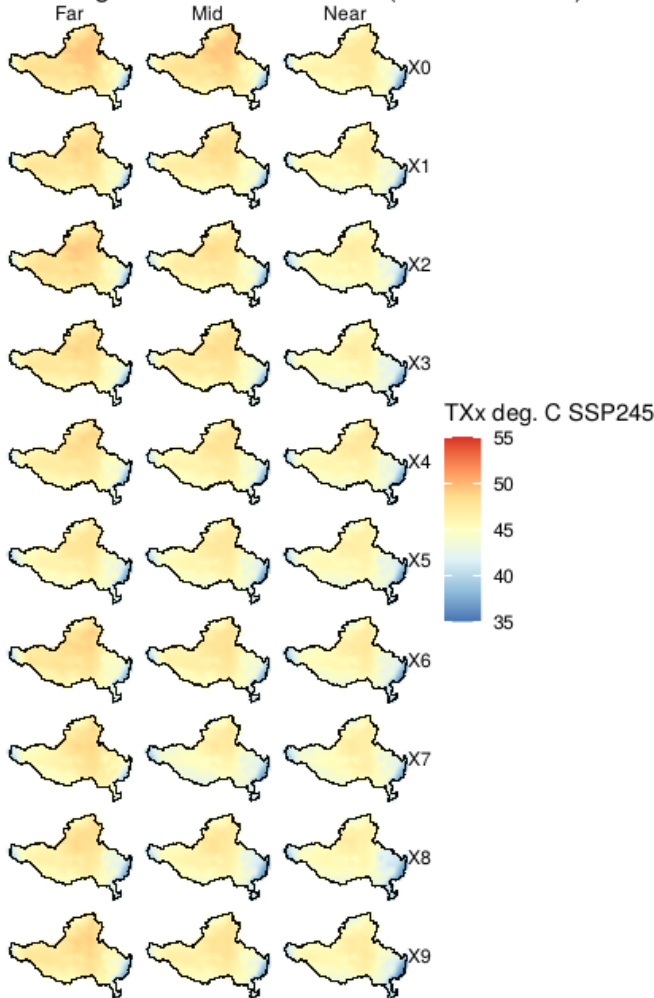
Firstly, the annual extreme indices were derived from the daily climate data for each pixel / grid cell obtained from different GCMs. Subsequently, the annual values were aggregated over the defined time periods viz. historical and future periods (near, mid, and far) for two scenarios. For each variable, TXx, TNn, and Rx1day, the period aggregation was computed by taking the arithmetic mean of the annual values. This approach was followed to ensure that the resulting value should represent the average behavior of the extremes over the specified time horizon, thereby highlights the long-term climate changes.

### 3.2.1 TXx

The results indicate a progressive intensification of the extreme temperatures across the Godavari River Basin from near to far future time periods (Figure 5). Under SSP245 scenario, the increase is gradual across most of the GCMs, within the range of 45-52°C. The increase in temperature is observed mainly in the central and northern parts of the basin, predominantly in the far future. In contrast, under SSP585, the warming is substantial and more wide spread across all GCMs. Several models projected the rise in extreme temperature in the range of 52–55°C, particularly in central, western, and northern parts of the basin. The far future under SSP585 is projected to experience extreme heat across the basin, which could impact the water balance and lead to droughts.

Overall, the spatial pattern of warming suggests that the interior, northern, and western parts of the basin remain under relatively higher extremes, compared to the relatively lower temperatures in the eastern parts of the basin. However, the rate of increase in extremes is evident under SSP585, due to higher GHGs emissions and little climate action. Although inter-model variability is recognizable, but most of the GCMs suggest an upward shift in the warming in future. The results show an increased heatwave risk and water demand.

TXx deg. C SSP245 Extremes (Near–Mid–Far)



TXx deg. C SSP585 Extremes (Near–Mid–Far)

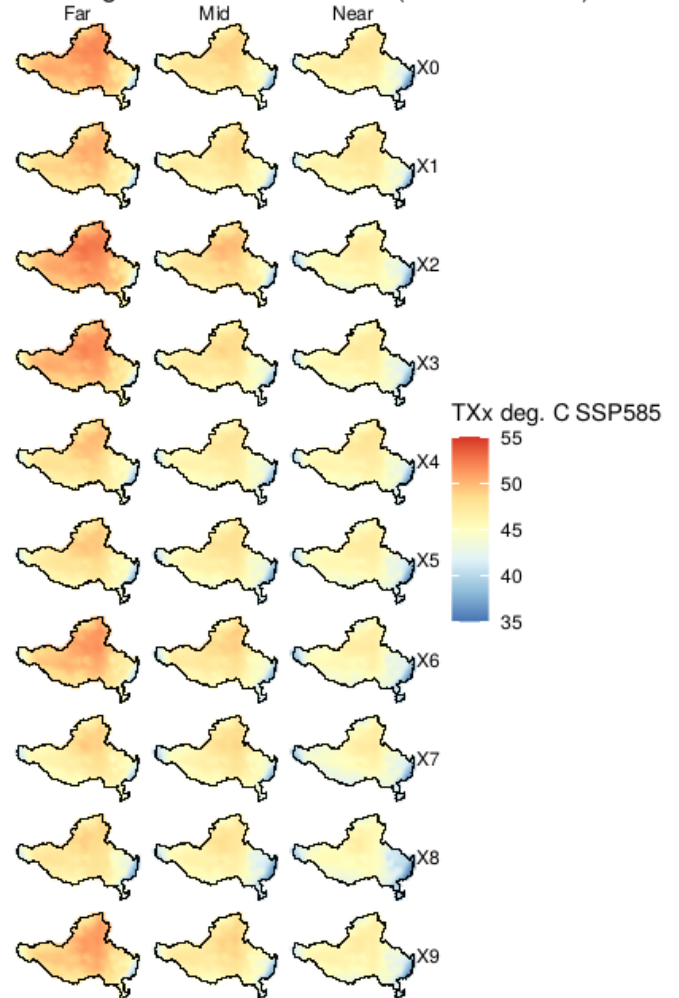


Figure 5 GCM model projections of TXx under SSP245 and SSP585 climate change scenarios for near, mid and far future

### 3.2.2 TNn

The spatial distribution of annual minimum of daily nighttime minimum temperature averaged over different time periods indicate a progress increase in the values from near to far future periods in the basin. Under SSP245, the warming of night temperatures are evident with the gradual shift in lower values (5-10°C) to moderately higher values in mid to far periods (10-18°C), shown in Figure 6. This indicates a gradual reduction in cold extremes with warming nighttime conditions. Similar to TXx, the increase in TNn is more evident and spatially extensive in SSP585 scenario compared to SSP245. Results show that the nighttime lower temperature values exceeds 20-25°C in the far future, mostly in central and south-eastern parts of the basin.

The results signify the conditions with warm nights leading to a reduced diurnal temperature range. This could lead to increased heat stress and pose significant challenges for agriculture, ecosystems and human health in the basin.

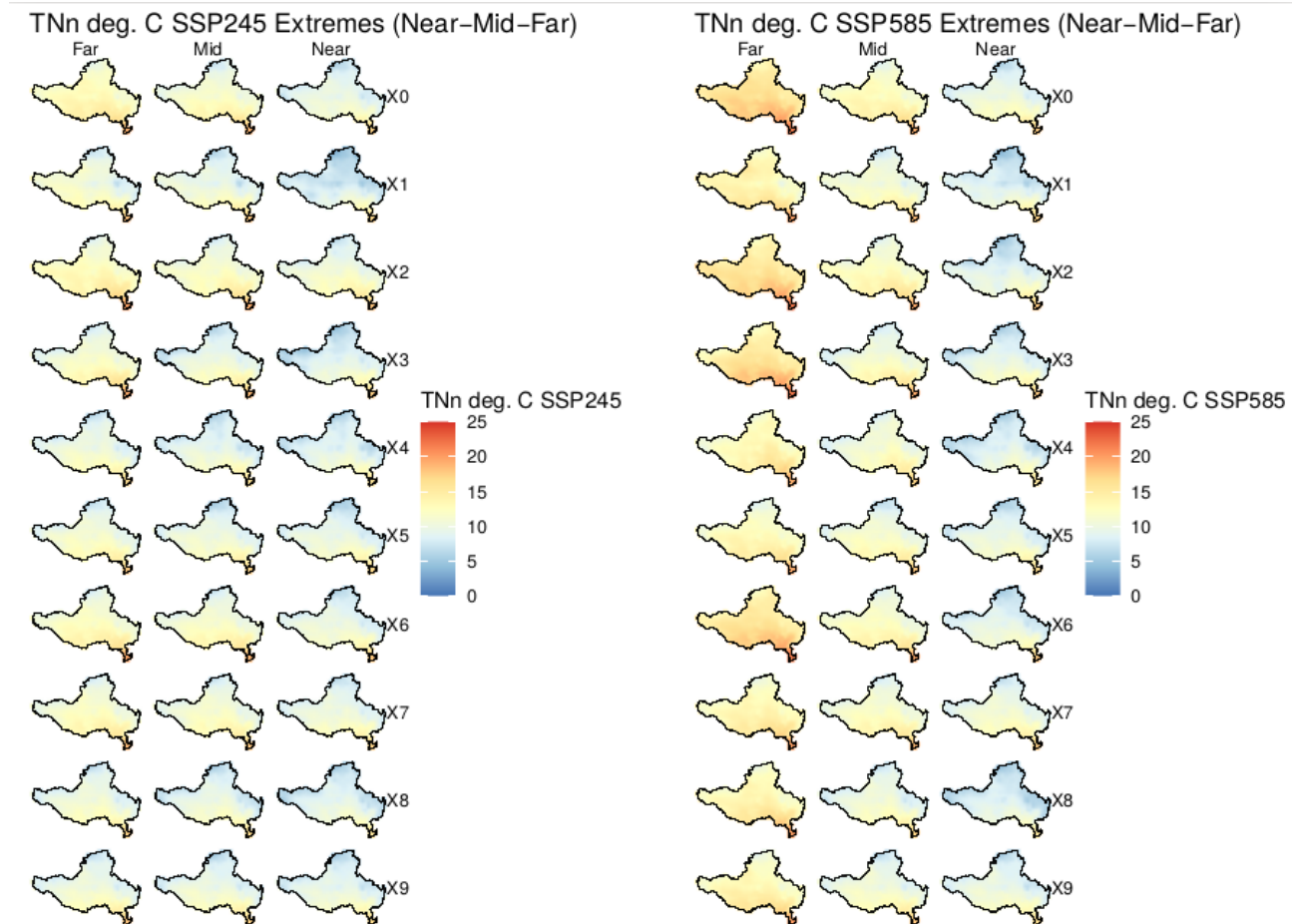


Figure 6 GCM model projections of TNn under SSP245 and SSP585 climate change scenarios for near, mid and far future

### 3.2.3 Rx1day

The results on spatial distribution of annual maximum 1-day precipitation averaged over near, mid, and far future periods indicate high degree of variability and inter-model differences in the Godavari River Basin (Figure 7). Under SSP245, Rx1day increased moderately from near to far future periods with precipitation varying in the range of 100-300 mm/day. However, hotspots of extremely high intensity precipitation exceeding >300 mm/day are recorded predominantly in central parts of the basin, particularly modeled by CanESM5 GCM. These high intensity rainfall events in central and eastern parts of the basin could lead to episodic heavy rainfalls with devastating effects on crop productivity and sediment export into the river.

Further, under SSP585, extreme precipitation events become more intense with several GCMs projected values exceed 1000 mm/day. This indicates a significant intensification of extreme rainfall in very short duration under high emission scenarios. These high-intensity extreme rainfall hotspots are localized in specific regions in central, north-western, south-eastern parts, while most of the basin showed relatively modest variations in Rx1day.

Overall, under both scenarios, the spatial patterns of Rx1day recorded heterogeneous patterns with higher inter-model variability compared to TXx and TNn values. Some GCMs indicated strong increase in Rx1day, while others displayed relatively stable changes. The results suggest that under moderate emission scenario SSP245, Rx1day follows a gradual increase compared to significant enhancement in Rx1day intensity under SSP585 scenario with higher GHGs emission. The increase in extreme precipitation events lead to increased risk of flash floods, soil erosion and hydrological disturbances in the basin.

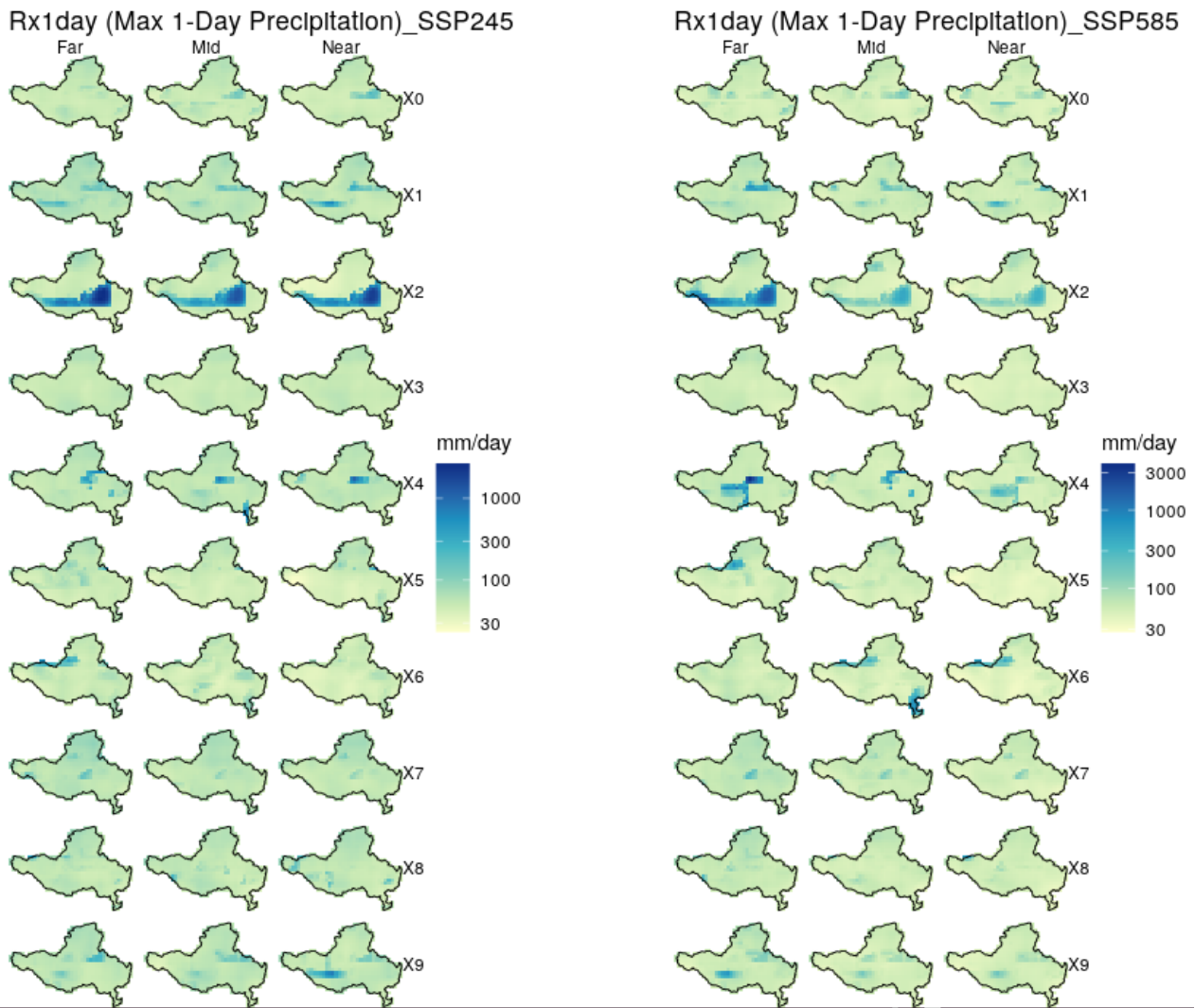


Figure 7 GCM model projections of Rx1day under SSP245 and SSP585 climate change scenarios for near, mid and far future

## 4 Summary

The analysis of long-term historical trends and extreme indices of climate data in different time periods reveal a consistent intensification of climate variables. The magnitude and variability of the climate extremes have increased from near to far future. The boxplots in Figure 8 indicate that TXx (annual maximum of daily maximum temperature) increased steadily across periods from near to far future. Similarly, the TNn (nighttime minimum temperature) exhibited a more predominant increase across the periods, indicating a strong warming of nighttime temperatures. The distribution of Rx1day (extreme 1-day precipitation) displays a gradual upward shift across the periods with high inter-model variability. The model-wise plots indicate that TXx and TNn exhibit upward trends across all GCMs, whereas Rx1day display a divergent behavior.

The ensemble mean values plotted in Figure 8 indicate a systematic increase in the indices considered in the study, with the most predominant increase observed in TNn, followed by Rx1day and TXx, which is substantiated with the percentage change calculation. Results show that the TNn has increased by 50-60% in far future compared to near future, followed by Rx1day which followed a moderate increase by 10-30%, and TXx exhibited a comparatively smaller changes in the range of 5-10%.

It can be concluded from the analysis carried out in this study that the nighttime warming is significant impact due to climate change, followed by an increase in extreme rainfall events and a consistent increase in daytime temperature extremes. The uncertainty associated with precipitation extremes is greater compared to temperature-related changes.

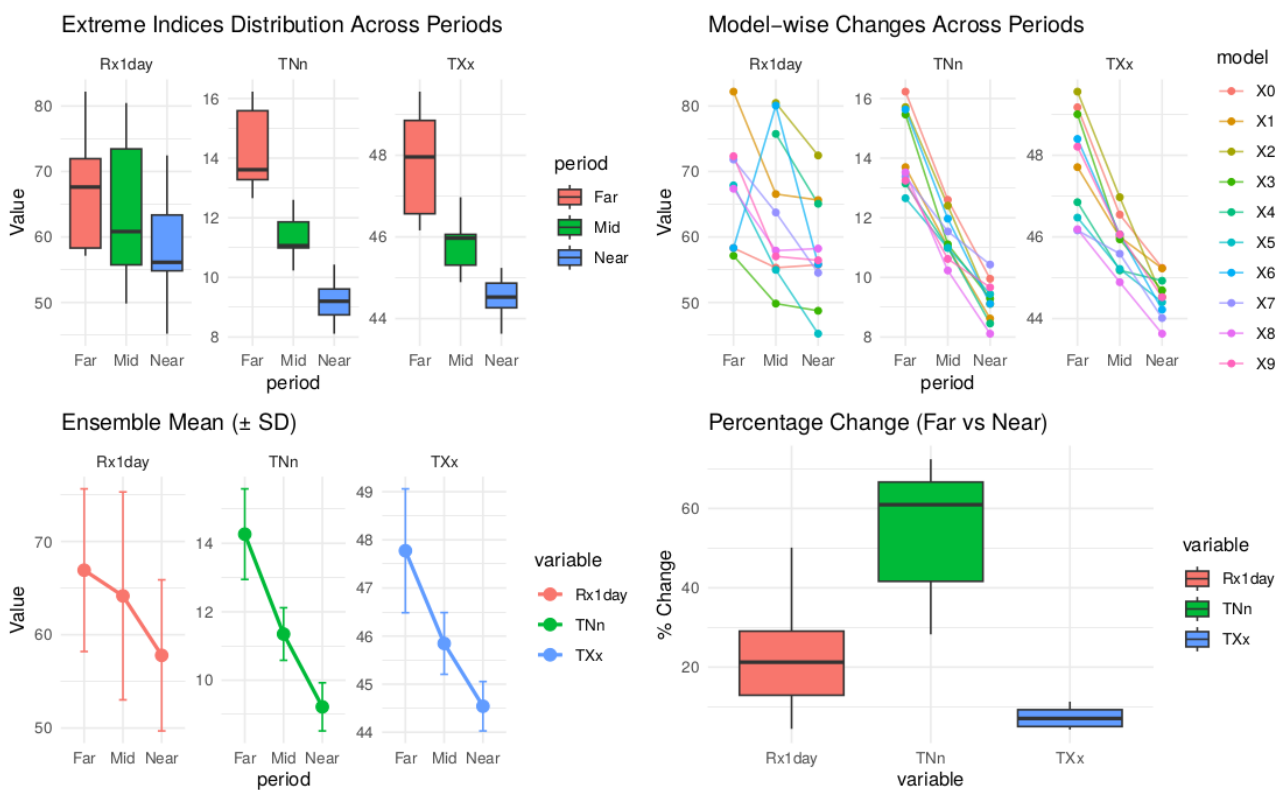


Figure 8 Change detection of extreme indices across near, mid and future time periods

## 5 Implications on basin hydrology

The analysis including temperature and precipitation in the present study indicates a major shift in the hydrological behavior of the basin. The consistent increase in TXx and TNn (extremes) indicate an enhanced evapotranspiration and higher atmospheric demand. This can lead to declining soil moisture and baseflow in the river, effectively in summer/dry

seasons. However, with increasing Rx1day extremes, the region is expected to experience high-intensity short duration rainfall triggering rapid surface run-off, increasing peak flows leading to increased flood risk. This pattern could lead to a flashier hydrological regime, with higher variability in river discharge with high likelihood of floods in wet season and scarce river flows in summer seasons. Further, this extreme river flow conditions could be impacted by adverse water quality, as intense runoff leads to more sediments and pollutant loads.

The disturbances in hydrological cycles could impact socioeconomic sectors in the basin which depend on water resources. Rising day time temperatures with warming nights leads to increased crop water demand, and reduces crop yield due to heat stress. Extremities in rainfall leads to dried soils and water logging. Industrial sector could face acute water shortages during dry season with reduced baseflow and elevated temperature conditions. In contrast, infrastructure related to water management like dams, barrages, canals and other drainage networks could face threats from intensified flood risk. Ecological balance could be impacted through altered flow regimes, and due to increased thermal stress, and due to degraded water quality. The findings indicate that the basin is likely to experience more variable and extreme hydrological regime with critical implications on water availability, warranting adaptation and mitigation measures to ensure regional resilience.

The findings guide the policymakers in identifying the high-risk zones for heat-stress, flooding, and water scarcity, where targeted adaptation strategies such as climate-smart agriculture, enhanced irrigation efficiency, and ground water recharge interventions can be planned. The projected increased risk of floods and extreme rainfall events underscores the need for early warning systems, reservoir operation policies, to handle higher inflows. District-level water resource planning can be benefited by capturing the sector-specific vulnerabilities due to the changing hydrological regimes in the basin. Overall, by integrating these climate projections into district planning processes, policymakers can improve the risk preparedness, optimize resource allocation, and build long-term resilience strategies against the combined impacts of climate change on water, agriculture, and livelihoods.

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