



Characterization of future climate extremes over Tamil Nadu, India, using high-resolution regional climate model simulation

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Received: 21 March 2018 / Accepted: 10 May 2019 / Published online: 25 May 2019
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Abstract

Tamil Nadu, an agriculturally important state in India, is recurrently exposed to floods, cyclones, and droughts that have devastating effects on human, agriculture, and economy. This persuades the study to focus on future climate extremities of the state. The future climate extremes are examined using daily temperature and rainfall simulations developed by Hadley Center's Regional Climate Model termed PRECIS (Providing REgional Climates for Impacts Studies) at a horizontal resolution of 25 km. The study uses the simulations that are driven by the lateral boundary condition of HadCM3Q0 (Hadley Centre Coupled Model-Q0) generated by a Perturbed Physical Ensemble of 17 ensembles under A1B scenario for the period of 2005 to 2095. Extreme indices have been acquired from the simulations using RCLimDex. The trends of extreme indices are computed and verified for statistical significance using Mann–Kendall and Sen's slope test. The changes in extreme indices with respect to baseline (1970–2000) reveal that almost all temperature indices denote a highly significant trend. The minimum temperature indices have shown prominent increase compared with maximum temperature indices, which is also upheld by the significant decrease in the diurnal temperature range trend. The summer days above 40 °C have indicated a substantial increase with a stronger slope of 0.77. However, the rainfall indices depict the insignificant trend. The changes in extreme wet days (R99p) and very wet days (R95p) exhibit a positive shift, and the increase of maximum 1-day rainfall is projected to be higher than maximum 5-day rainfall. Furthermore, the probability of rainfall indices exemplifies the increase of intense rainfall by the end of the century. The overall results of indices intimate that Tamil Nadu will be shifted to the extreme warmer and wetter condition by 2080s (2065–2095). Such information will act as a baseline to study the future impact assessment on different sectors thereby supporting policymakers and stakeholders to formulate suitable adaptation and mitigation strategies.

1 Introduction

Climate change has emerged as one of the major challenges in the twenty-first century. Changes in the global climate are altering the average characteristics of climate systems, intensity, frequency, spatial extent, duration, and timing of climate extremes (IPCC 2013; Herring et al. 2014). Any changes in

the frequency or severity of climate extreme events could have profound impacts on nature and society. Globally, in some regions, both temperature and precipitation extremes have already shown amplified responses to changes in means (Wigley 1985; Meehl et al. 2007; Ongoma et al. 2018). This might result in more dramatic shifts than those that have been seen up to now (Lisa 2007; Folland et al. 2001). Thus, the assessment of extreme events and their predictability have received increased attention. It was projected that some extremes will become widespread, more frequent, and intense during the twenty-first century (IPCC 2007). These extremes may lead to more droughts or flooding events and may affect water resources, agriculture, infrastructure, and biodiversity.

Global climate models (GCMs) provide a reasonable basis for assessing future climate extremities. GCMs have so far been too coarse to resolve the high-resolution features of regional climate dynamics. Therefore, one has to resort to either dynamical or statistical methods to downscale the

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large-scale information to the regional scale (Cubasch et al. 1996). Increasingly reliable climate change projections at high resolution are now available for many regions of the world due to advances in understanding the physical processes of the climate system and modeling (IPCC 2007). Statistical downscaling methods apply climate variables from GCMs to statistical transfer functions to evaluate point-scale meteorological series (Wilby et al. 1998; Diaz-Nieto and Wilby 2005). Dynamical downscaling uses a limited-area, high-resolution model (a regional climate model, or RCM) driven by boundary conditions from a GCM or atmosphere-ocean general circulation models (AOGCMs) to derive smaller-scale information. These high-resolution dynamic RCMs nested in GCM are becoming an increasingly important tool in climate research (Giorgi et al. 2001).

PRECIS (Providing REgional Climates for Impacts Studies) is a state-of-the-art regional climate model, which downscales the GCMs over a region of interest to the resolution of 25 or 50 km. This allows for a realistic representation of the climate over the region of interest, accounting for complex surface features such as coastlines, mountains, and islands, which are not resolved in the global climate models (Jones et al. 2004). Many studies used PRECIS to simulate the high-resolution climate change scenarios over different regions of the globe. Studies by Bhaskaran et al. (1996, 1998,

Bhaskaran et al., 2012) have analyzed the seasonal simulations of Indian summer monsoon using nested RCMs; Rupa Kumar et al. (2006), Krishna Kumar et al. (2011), Revadekar et al. (2011), Kulkarni et al. (2013), and Bal et al. (2016) have simulated the climate variability over the Indian region; and Nazrul Islam (Islam et al. 2009) and Rajib and Rahman (2012) have evaluated the seasonal forecasting for Bangladesh. These studies indicate that the PRECIS simulations for temperature and rainfall over all the analyzed regions have shown better performance when compared to GCMs. Several studies have emphasized the analysis of future climate extremes using PRECIS simulation data. Nowreen et al. (2015) evaluated the various aspects of future projections of rainfall and temperature extremes for the haor basin areas of Bangladesh. Islam et al. (2009) estimated the future change in frequency of warm and cold spells over Pakistan simulated by PRECIS. Masud et al. (2016) analyzed climate extreme indices over North Thailand using RCM, and Revadekar et al. (2011) investigated various aspects of future projections of precipitation extremes over India using A2 and B2 scenarios.

Tamil Nadu, an important state in India for cultivation, receives the major part of its annual rainfall during the north-east monsoon (IMD 1973). The failure of this monsoon will have a greater impact that the state is frequently subjected to extreme weather conditions such as flooding in coastal

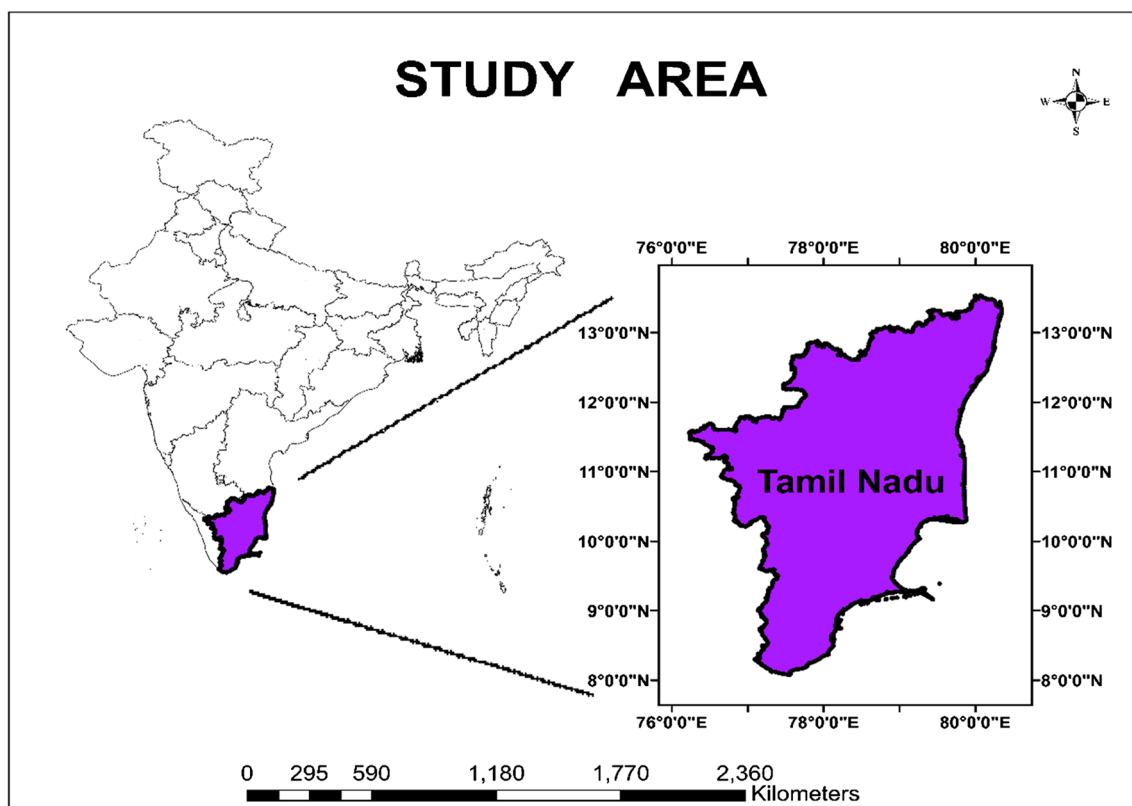


Fig. 1 Location map of the study area in India

Table 1 List of temperature and rainfall indices used in the study

ID	Indicator name	Definitions	Units
Temperature indices			
SU40	Summer days	Annual count when TX (daily maximum) ≥ 40 °C	Days
TXx	Max Tmax	Monthly maximum value of daily maximum temp	°C
TNx	Max Tmin	Monthly maximum value of daily maximum temp	°C
TXn	Min Tmax	Monthly maximum value of daily maximum temp	°C
TNn	Min Tmin	Monthly maximum value of daily maximum temp	°C
TN10p	Cool nights	Percentage of days when TN < 10th percentile	Days
TX10p	Cool days	Percentage of days when TX < 10th percentile	Days
TN90p	Warm nights	Percentage of days when TN > 90th percentile	Days
TX90p	Warm days	Percentage of days when TX > 90th percentile	Days
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	°C
Rainfall indices			
RX1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation	mm
RX5day	Max 5-day precipitation amount	Monthly maximum consecutive 5-day precipitation	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days in the year	mm/day
CDD	Consecutive dry days	Maximum number of consecutive days with RR < 1 mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with RR ≥ 1 mm	Days
R95p	Very wet days	Annual total PRCP when RR > 95th percentile	mm
R99p	Extremely wet days	Annual total PRCP when RR > 99th percentile	mm
PRCPT OT	Annual total wet-day precipitation	Annual total PRCP in wet days (RR ≥ 1 mm)	mm

districts and severe droughts chronically in some areas (Bal et al. 2015), which consequently affect the production and productivity of the food grains. Any disturbance in this production has a multiplier impact on the economy of a country (Suresh Kumar et al. 2011). Thane in 2011, Nilam in 2012, Nada and Vardah in 2016, and Ockhi in 2017 are the noticeable cyclones that affected the state. Recently, the state was affected by severe flood in the years 2015 and 2017 and by extreme drought in the year 2016. Though the state is often affected by extremities, very few research was initiated to study the impacts of climate extremes. Hence, this study emerges to provide eminent attention to the future climate extremities of Tamil Nadu state using PRECIS, the state-of-the-art regional climate modeling system.

1.1 Study area

1.1.1 Geography

Tamil Nadu is situated in the southern part of India between north latitude 8°5' and 13°35' and east longitude between 76°15' and 80°20' (Fig. 1). It has 32 districts,

and the total area of the state is 1,30,058 km², making it the eleventh largest state in the country with 4.11% of the Union areas. It is one of the important coastal states with a coastline of 1076 km. To its southernmost tip is the town of Kanyakumari, which is the meeting point of the Arabian Sea, the Bay of Bengal, and the Indian Ocean.

1.1.2 Climatology of the state

The climate of Tamil Nadu is tropical semiarid. In the inland, the temperature may reach extreme in some places, while it tends to be moderate in the coastal areas. By and large, the average temperature for most parts of

Table 2 Average future change in the temperature and precipitation

	TMax (°C)	TMin (°C)	Precip (°C)
2020s	1.21	1.15	-6.94
2050s	2.20	2.32	-3.91
2080s	3.30	3.55	-3.24

the state ranges between 28 °C and 40 °C in the summer season and between 18 °C and 26 °C in the short-lived winter seasons. In the more hilly terrain, the maximum temperature may be as low as 26 °C. Tamil Nadu is the only state in India that receives rain from both the

northeast (NE) and southwest (SW) monsoons. Of the annual rainfall, 32% is received during the SW monsoon (June–September) and 48% during the NE monsoon (October–December). The normal annual rainfall is 950 mm (TNSAPCC Report 2013; IMD 1973).

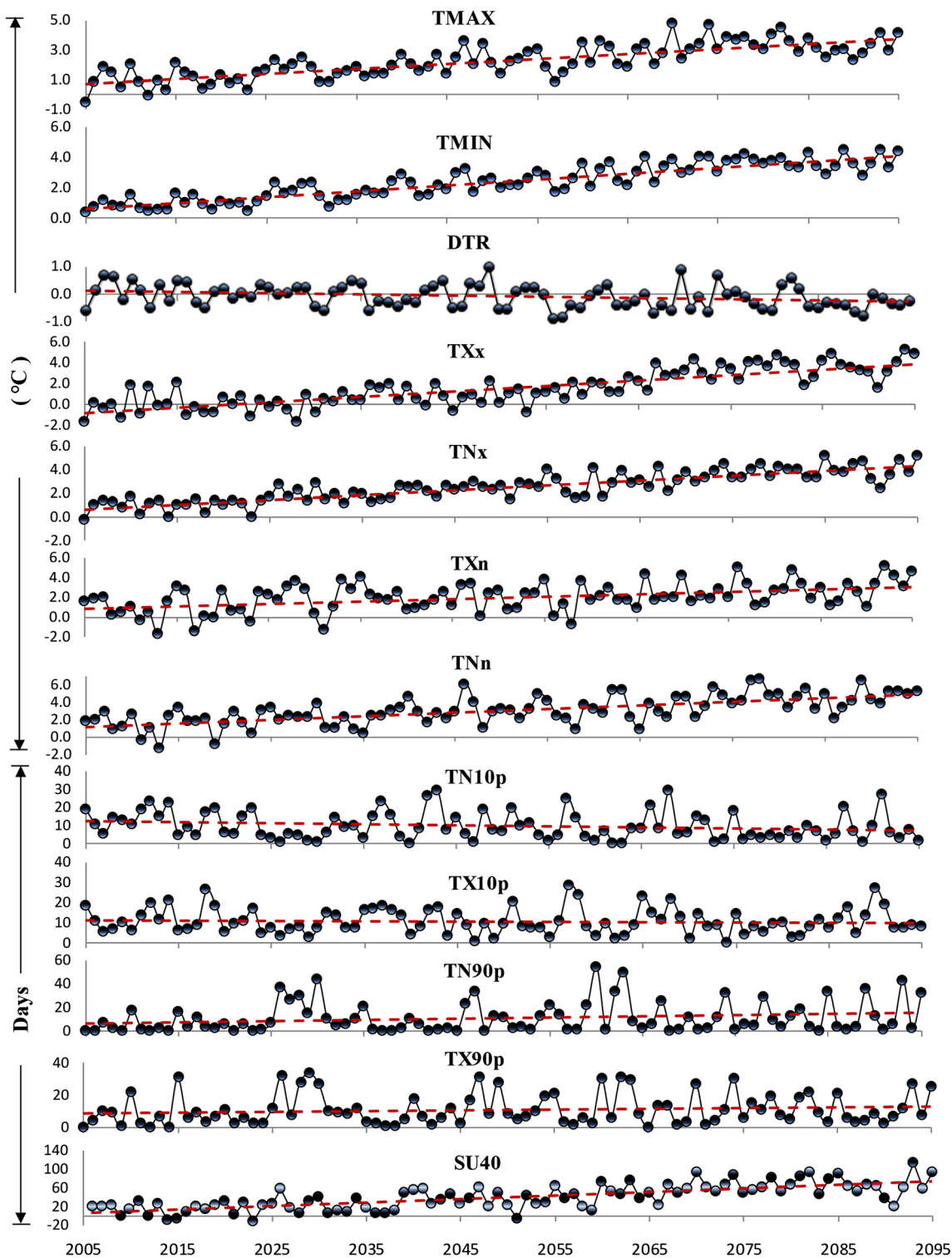


Fig. 2 The anomaly of temperature and its indices relative to the mean values of baseline (1970–2000)

2 Methodology

2.1 Data used

PRECIS has been run at 25 km × 25 km horizontal grid resolution and 19 vertical levels, which covers the Indian domain extending from about 8°4' and 37°6' N latitude to 68°7' and 97°25' E longitude to generate a daily time series (1970–2100) using IPCC-SRES A1B scenario of increasing anthropogenic forces such as greenhouse gas concentrations and sulfate aerosols. These simulations are based on the 17-member (HadCM3Q0-Q16) global perturbed physics ensemble (PPE) produced under the Quantifying Uncertainty in Model Predictions (QUMP) project of the Hadley Centre, Met Office, UK (Murphy et al. 2004). These global models were used to drive the corresponding HadCM3 regional climate models (Bhaskaran 2012). This study used HadCM3Q0 simulation for Tamil Nadu in which the bias is relatively smaller compared with the other ensemble members (Bal et al. 2015). This dynamically downscaled simulation data were utilized for investigating the change in future climate extremes of Tamil Nadu.

Though the model has biases, a common hypothesis is made based on stationarity, which indicates that the empirical relationships in the correction algorithm and its parameterization for the present climate conditions do not vary over time and are also valid for future climate conditions (Ehret et al. 2012; Teutschbein and Seibert 2013). Bal et al. (2015) mathematically represented it as

$$(\text{Model}_{\text{future}} + \text{bias}) - (\text{Model}_{\text{baseline}} + \text{bias}) = \text{Change}$$

Therefore, the analysis of future climate change extremes in this study is performed by ignoring the model biases. However, this linear bias correction assumption may not hold in the future due to nonlinear response of the climate system to the global warming.

2.2 Indices calculation

The indices of climate extremes are calculated from daily rainfall and temperature using the software called RClimDex (Zhang and Yang 2004), which provides a user-friendly interface to compute 27 cores of indices recommended by the joint World Meteorological Organization Commission for Climatology (CCI)/World Climate Research Programme (WCRP) project on climate variability and predictability (CLIVAR) and Expert Team on Climate Change Detection, Monitoring and Indices (ETCCDMI) (Islam et al. 2009; Revadekar et al. 2011). The indices used in this study are presented in Table 1. Alexander et al. (2006) have classified the indices into 5 categories. Based on the categories, the indices utilized are as follows:

1. Absolute indices denote the maximum or minimum values within a year. They include TXx, TXn, TNn, TNx, RX1, and RX5.
2. Percentile-based indices represent TN90p, TN10p, TX90p, TX10p, and R95p.
3. Threshold indices define the number of days on which a temperature or precipitation value falls above or below a fixed threshold, which includes the annual occurrence of summer days (SU).
4. Duration indices represent the periods of excessive warmth, cold, wetness, or dryness including CDD and CWD.
5. Other indices include PRCPTOT, DTR, and SDII.

The quality control procedures are applied on the daily data, which includes checking for inaccurate data such as negative precipitation, a maximum temperature higher than minimum temperature, and examination of outliers and homogeneity (Sohrabi et al. 2009). The details of quality control procedures are outlined by Stephenson et al. (2008, 2014). The results are averaged over Tamil Nadu for the period of 2005–2095.

2.3 Trend analysis

The trends of all climate extreme indices are tested for statistical significance at the 95% significant level using the Mann–Kendall (MK) test (Mann 1945; Hipel and McLeod 1994). This test has been recommended by the World Meteorological Organization in assessing trends in environmental time series data (Yue et al. 2002). Sen’s nonparametric estimator is utilized to assess the true slope and robust estimation of an existing trend (Masud et al. 2016).

Table 3 Mann–Kendall significance test for the temperature extreme indices for the period of 2005–2095

	Kendall’s Tau	MK Z	S	p value	Sen’s slope
TMax	0.58	8.14***	2374	< 0.0001	0.03
TMin	0.69	9.80***	2861	< 0.0001	0.04
SU40	0.53	7.38***	2119	< 0.0001	0.77
TXx	0.63	8.82***	2574	< 0.0001	0.06
TNx	0.68	9.55***	2787	< 0.0001	0.04
TXn	0.29	4.05***	1182	< 0.0001	0.02
TNn	0.48	6.74***	1967	< 0.0001	0.04
TN10p	−0.15	−2.09*	−612	0.04	−0.05
TX10p	−0.03	−0.44	−131	0.66	−0.01
TN90p	0.17	2.31**	675	0.02	0.04
TX90p	0.11	1.57**	458	0.02	0.04
DTR	−0.20	−2.83**	−826	0.01	−0.01

*Significant; **Highly significant; ***Very highly significant

3 Results and discussion

Validating the PRECIS RCM with the observed data from the India Meteorological Department (IMD), Bal et al. (2015) have conferred that the model has shown a reasonable skill in

simulating temperature and rainfall patterns for Tamil Nadu, and the magnitudes and frequency characteristics of the variability of the surface temperature and precipitation on annual time scales are in good agreement. They also added that although there are some underestimations and regional errors found in

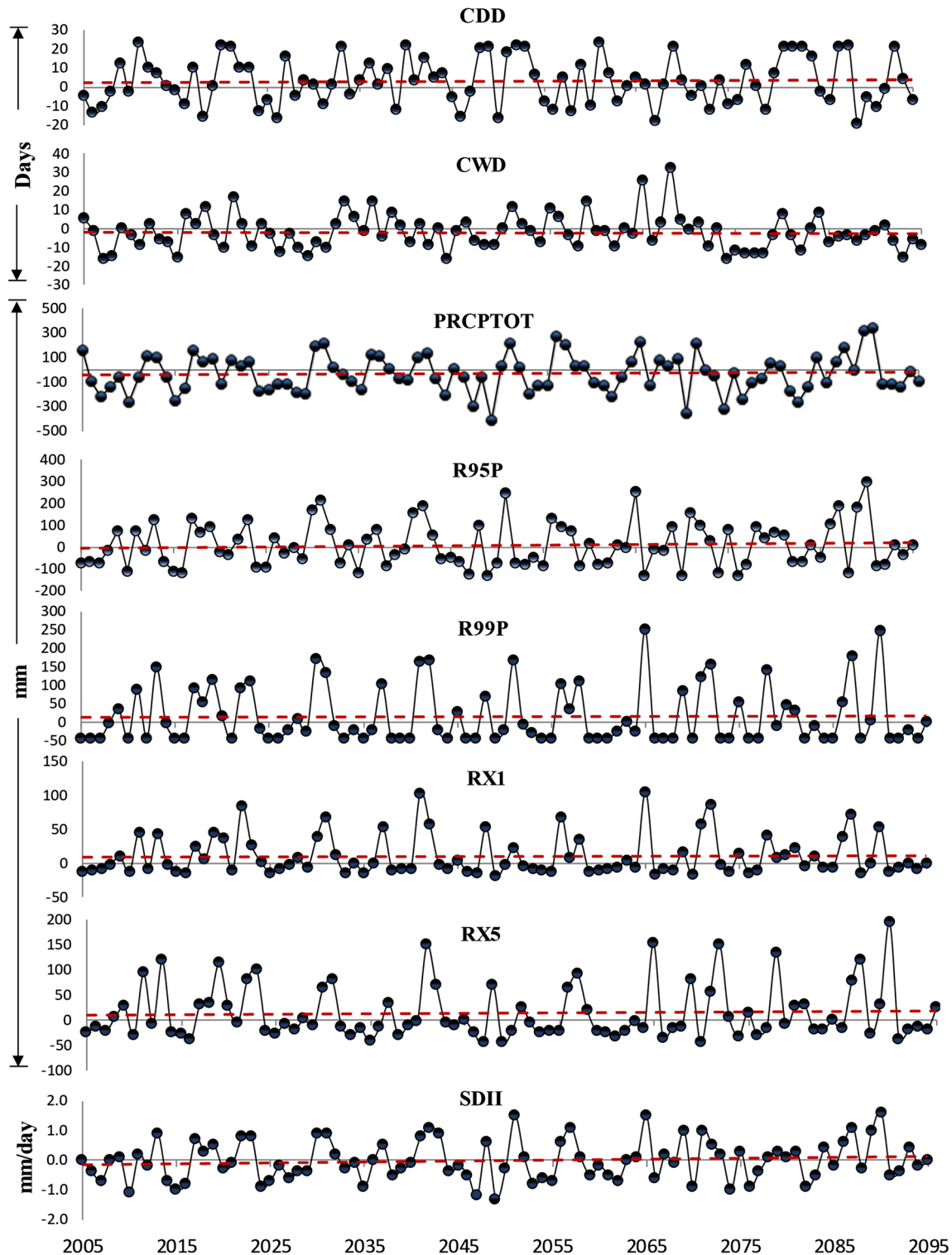


Fig. 3 The anomaly of precipitation and its indices relative to the mean values of baseline (1970–2000)

cases of annual rainfall variability, they determined that the overall model performance is quite reasonable, realistic, and statistically significant while assessing with IMD observed data set. Hence, this study attempts to evaluate various aspects of future extremes over Tamil Nadu using the PRECIS projected data.

3.1 Climate projections

The future change in climate over the whole Tamil Nadu with respect to the baseline of 1970–2000 is listed in Table 2. The maximum (TMax) and minimum temperature (TMin) projections illustrate an increase of 3.30 °C and 3.55 °C, respectively, by the end of the century. The TMin has indicated a consistently more pronounced increase when compared with TMax, and this result is in agreement with earlier global studies by Jones et al. (1999) and regional studies by Rupa Kumar et al. (2006), Klein Tank and Konnen (2003), and Manton et al. (2001). The percentage change of precipitation (Precip) indicates an increasing shift though it decreases with respect to the baseline (1970–2000). The Precip projections are expected to decrease by 6.94%, 3.91%, and 3.24% for the periods of 2020s (2005–2035), 2050s (2035–2065), and 2080s (2065–2095), respectively, with respect to the baseline.

3.2 Trend analysis of temperature and its indices

The change in trends of temperature indices relative to the baseline period is determined for the future epochs of 2005–2095 (Fig. 2). The absolute indices, including TXx, TNx, TXn, and TNn, show a positive shift towards the analysis period. The percentile-based indices such as the occurrence of warm days and warm nights show an increasing trend, whereas the occurrence of cold days and cold nights shows a consistent decrease. The summer days (SU40) of threshold indices represent an increase in exceedance rate. The increasing tendency of SU40 has favored the increment of temperature in the study area. Other indices include DTR, which exhibit a negative change and the key reason for this marked reduction is due to the rapid increase of minimum temperature.

The significance of temperature indices trend is assessed by Mann–Kendall (MK) test. The result shows that almost all the temperature extreme indices (SU40, TXx, TNx, TXn, and TNn) are increasing with a highly significant trend of $p > 0.001$ (Table 3). However, TX90p and TN90p are increasing with less significance ($p = 0.02$) compared with the above indices. Furthermore, TN10p and TX10p reveal the reverse trend with less and no significance, respectively ($p = 0.04$ and $p = 0.66$). Kendall test statistic Z and Sen’s slope represent that the cold extremes (TX10p and TN10p) have weaker trends than warm extremes (TX90p and TN90p) and minimum temperature extremes (TNx and TNn) have stronger trends than maximum temperature extremes (TXx and TXn). Thus, minimum temperature will increase more than the maximum

Table 4 Mann–Kendall significance test for the rainfall extreme indices for the period of 2005–2025

	Kendall’s Tau	MK Z	S	p value	Sen’s slope
CDD	0.02	0.27	79	0.7	0.00
CWD	−0.04	−0.58	−169	0.6	−0.0
PRCPTOT	0.04	0.54	157	0.6	0.36
R95P	0.03	0.48	140	0.6	0.17
R99P	0.02	0.23	−64	0.8	0.00
RX1	0.01	0.15	45	0.8	0.01
RX5	0.03	0.45	133	0.6	0.05
SDII	0.09	1.26	367	0.2	0.00

temperature, which is consistent with the highly significant decrease in the trend of the diurnal temperature range (DTR). SU40 has shown the strongest slope of all indices of 0.77 indicating a shift towards warmer conditions by the end of the century. However, the decadal variability of indices may amplify or dampen the trend depending on decadal timescales.

3.3 Trend analysis of precipitation and its indices

The change in trends of precipitation with respect to baseline is evaluated for the period of 2005–2095. The result shows that almost all precipitation-related indices such as PRCPTOT, CDD, maximum event intensity indices (RX1 and RX5), and percentile-based extreme precipitation indices (R95p and R99p) exhibit positive shift, whereas CWD indicates a reverse shift throughout the analysis period (Fig. 3). Similar studies of Nowreen et al. (2015) for Bangladesh and Revadekar et al. (2011) for India support our findings of increasing rainfall indices, signifying the wetter climate in the future.

Though the changes in the precipitation indices reveal wetter climate, the MK tests of all precipitation-related indices lack a consistent pattern and significant trend (Table 4). Kendall test statistic Z and Sen’s slope indicate a weaker trend and milder slope. Hence, in contrast to the temperature indices, precipitation indices are found to be less coherent.

Table 5 Future change in temperature extreme indices over Tamil Nadu

	TX10p (Percentage of days)	TX90p	TN10p	TN90p	TXn (Temperature °C)	TXx	TNx	TNn
2020s	0.24	−0.09	−0.06	0.10	1.36	1.04	1.28	1.74
2050s	0.17	0.04	−0.10	0.11	1.89	2.10	2.48	3.02
2080s	0.04	0.37	−0.36	0.82	2.73	3.44	3.75	4.34

3.4 Average future change in the temperature extreme indices

The future change in temperature extreme indices indicates that the minimum value of minimum temperature (TNn) has shown a substantial increase of about 1.74 °C in 2020s, 3.02 °C in 2050s, and 4.34 °C by the end of the century

(Table 5). Additionally, the maximum value of minimum temperature (TNx) has also specified an extensive increase than that of maximum temperature indices, at about 1.28 °C in 2020s, 2.48 °C in 2050s, and 3.75 °C in 2080s. The monthly variation of TNx indicates that more changes are epitomized during February and March for 2020s, 2050s, and 2080s (Fig. 6). Furthermore, the maximum temperature indices such

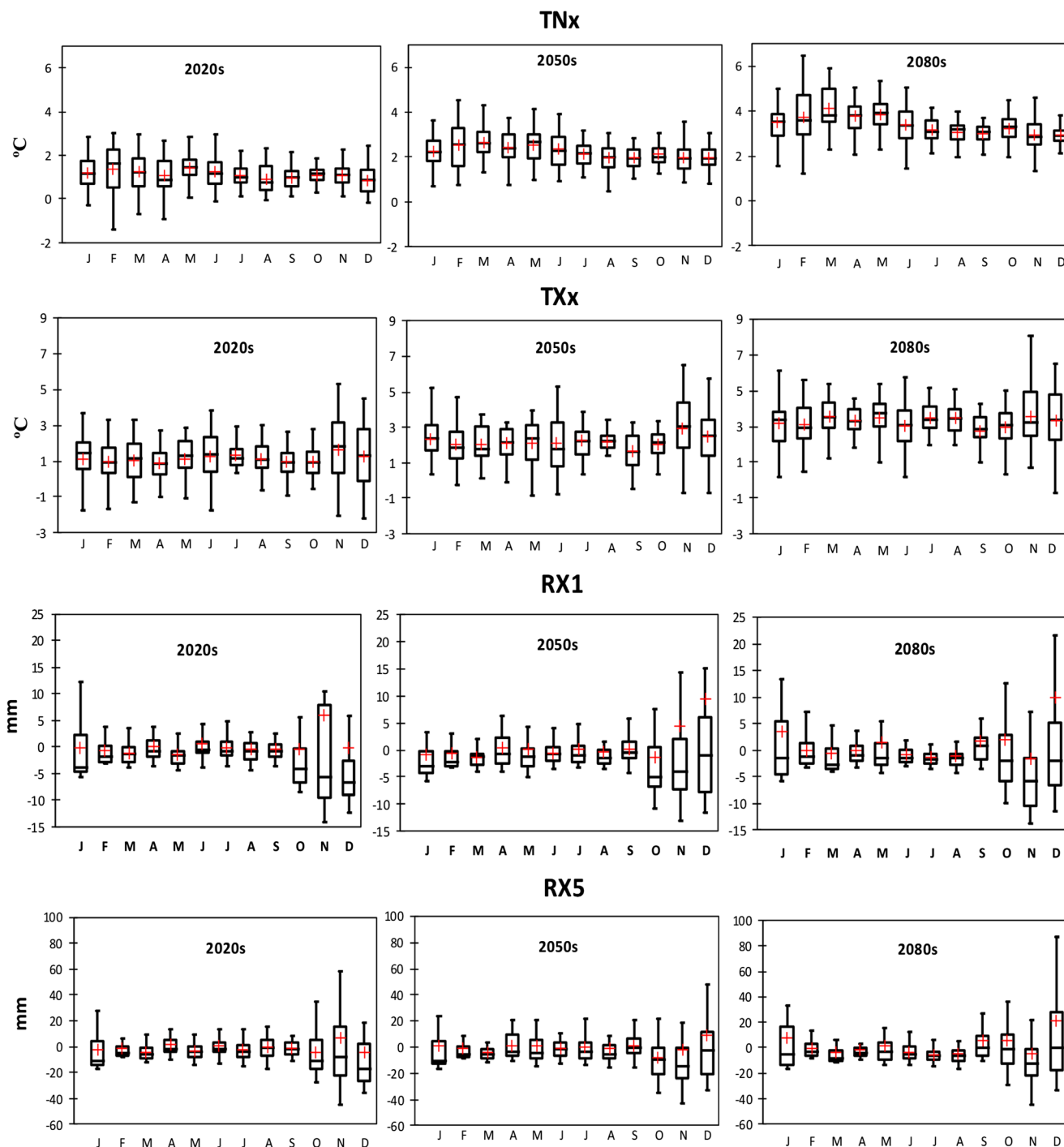


Fig. 4 Monthly variation of temperature indices (TNx and TXx) and rainfall indices (RX1 and RX5) during 2020s, 2050s, and 2080s

Table 6 Future change in rainfall extreme indices over Tamil Nadu

	R99p (%)	R95p (%)	RX1	RX5	SDII (mm/day)
2020s	28.04	2.79	40.16	6.99	-0.10
2050s	30.94	5.63	52.30	10.55	-0.02
2080s	56.32	16.23	55.25	33.29	0.16

to increase at the highest of 0.10%, 0.11%, and 0.82% in the near future, mid-future, and end of the century, respectively. Similarly, warm days (TX90p) also signify a change of -0.09%, 0.04%, and 0.37% for the same periods, respectively. However, the cold days and cold nights (TX10p and TN10p) are identified to decrease in future periods. Furthermore, change in cold nights is predicted to decrease more than cold days.

as TXx and TXn reveal the positive variation of 3.44 °C and 2.73 °C, respectively, by 2080s. The monthly assessment of TXx exemplifies that November and December have shown much deviation in the future periods (Fig. 4). On considering percentile-based indices, warm nights (TN90p) are expected

3.5 Average future change in the rainfall extreme indices

The future change in precipitation extreme indices is shown in Table 6. The two extreme rainfall indicators,

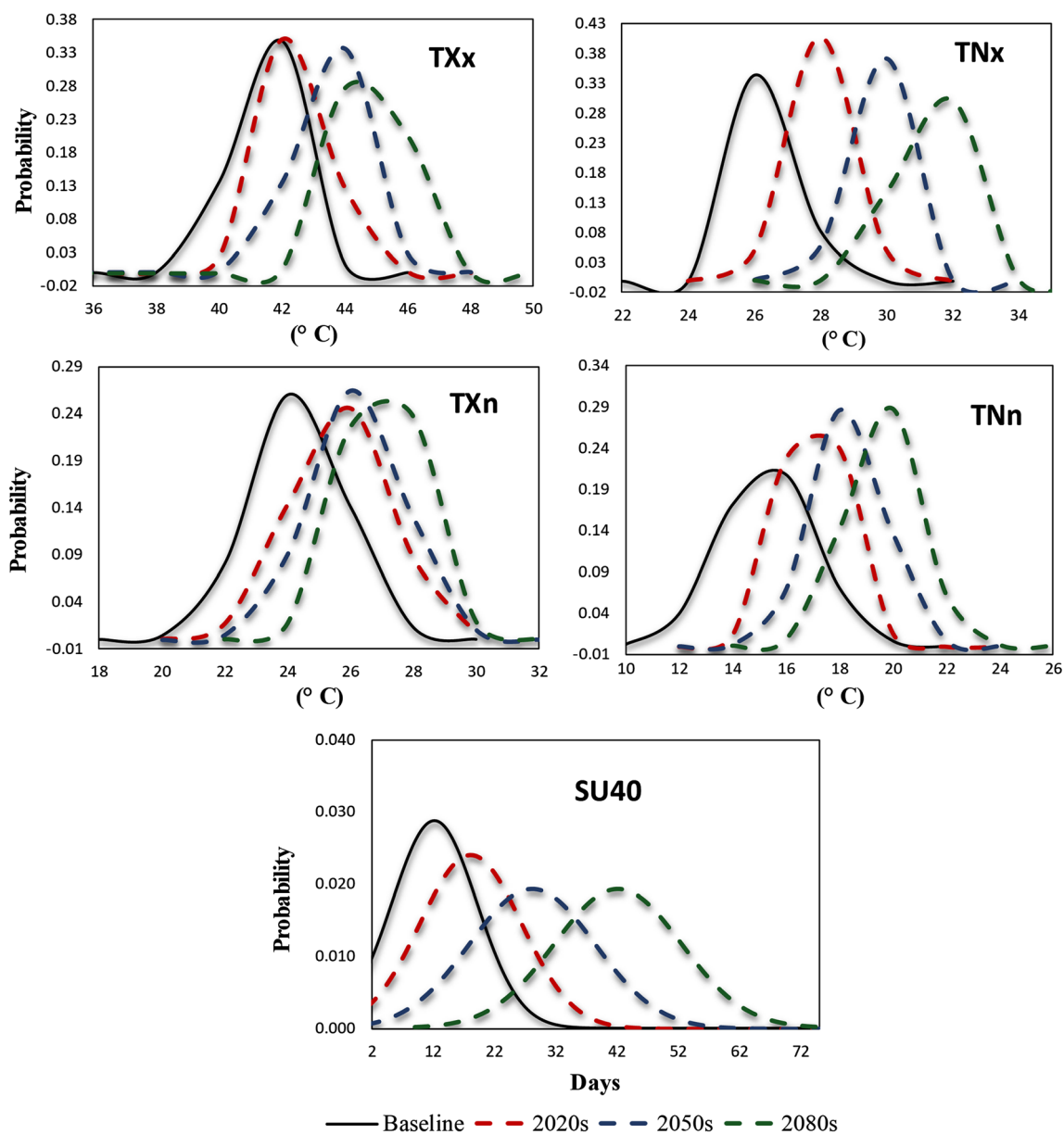


Fig. 5 Probability distribution of temperature extreme indices during MAM for baseline, 2020, 2050s, and 2080

which are liable for the large contribution of extremes, are R99p and R95p. R99p is assessed to increase by 28.04%, 30.94%, and 56.32%, whereas R95p is likely to increase by 2.79%, 5.63%, and 16.23% for 2020s, 2050s, and 2080s, respectively, with reference to the baseline. The maximum event intensity indices (RX5 and RX1) also depict the positive change. However, the increase in the magnitude of RX5, which is the major contributor for rise in rainfall intensity and occurrences of flash floods, is lesser than the increase in the magnitude of 1-day rainfall (RX1). Bhaskaran and Mitchell (1998) have elaborated

that the reason for the low precipitation events may be due to the higher increase of greenhouse gases and aerosol forcing, and increases in the frequency of the more intense events may be due to the consequence of a warmer and moister atmosphere. The dramatic rise of RX1 implies the severe rainy condition in the future and thereby provides a less-alarming condition for the high volumes of flash floods. The monthly evaluation of RX1 and RX5 denotes that enormous change is found in October, November, and December (Fig. 4). The daily rainfall intensity (SDII) also infers the increase of about 0.16 mm/

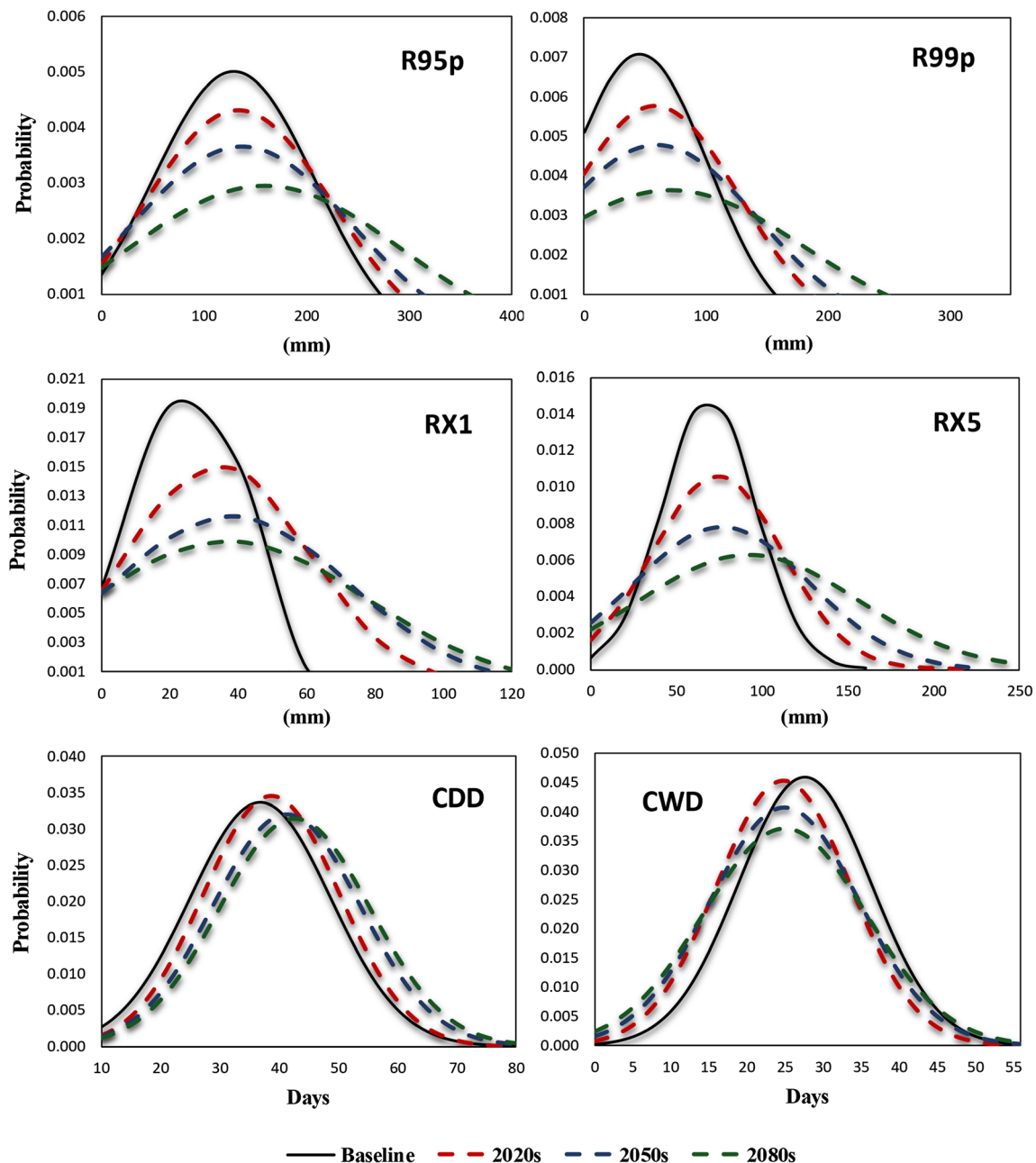


Fig. 6 Probability distribution of rainfall extreme indices during OND for baseline, 2020s, 2050s, and 2080s

day by the end of the century. Thus, this notable positive change of R99p, R95p, RX1, RX5, and SDII may favor the last quartile of the century to be in wetter conditions.

3.6 Probability distribution function

The probability distribution function (PDF) of temperature indices in the course of MAM (March–April–May) and precipitation indices in the course of OND (October–November–December) are calculated for the time slices of 2020s, 2050s, and 2080s for identifying the probability of occurrence of extremities. The PDF plots of temperature indices are presented in Fig. 5, which emphasize the more pronounced rightward shift towards each time slice from the baseline. In addition, from the aforementioned temperature indices, SU40 and TN_x have implied the more prominent positive shift, which will lead to a hotter climate during the summer months of 2020s, 2050s, and 2080s. From the PDF of precipitation indices (R95p, R99p, RX1, and RX5), it is very interesting to note that during the northeast monsoon, the occurrence of low intense rainfall is declining whereas high intense rainfall is increasing from the baseline to 2020s, 2050s, and 2080s (Fig. 6). This outcome initiates the alarming situation for flashy floods. However, on relating the indices, RX1 illustrates the noticeable rightward shift from the baseline indicating a shift towards the rainy condition. The CDD portrays the less prominent positive shift, and on the contrary, CWD indicates the leftward shift with trivial change.

4 Conclusion

Tamil Nadu is one of the extremes-prone states in India that faces more extremities of cyclones and drought recurrently. This study attempts to evaluate the future changes in extremes of temperature and precipitation using high-resolution PRECIS RCM data under simulation of A1B scenario, thereby provides a baseline for presenting a gateway towards building substantial information required for climate change impact assessment across Tamil Nadu. The major conclusions identified from the analysis of the future impact of the study area are as follows:

- The change in future climate projections with reference to baseline indicates an increase of 3.30 °C during daytime and 3.55 °C during night-time and denotes a decrease in rainfall of 3.24% by the end of the century.
- Mann–Kendall test and Sen's slope depict that the minimum temperature indices (TN_n, TN_x, and TN90) seem to increase significantly higher than maximum temperature indices (TX_n, TX_x, and TX90), which is indicated by the extreme positive change of TN_n by 4.34 °C and TN_x by 3.75 °C by the end of the century. The result is also

reinforced by a highly significant decrease in DTR during the analysis period.

- The maximum temperature above 40 °C (summer days) is projected to increase drastically with a strong slope. In addition, the probability distribution of both maximum and minimum temperature indices during MAM represents a more pronounced rightward shift. These results intimate that Tamil Nadu will be adversely affected by warmer condition by the last quartile of the century, which will make the environment hostile for ecosystem and crop productions, and furthermore, the change may increase the occurrences of heat wave and health hazards in the future.
- All rainfall extreme indices exhibit an insignificant trend. However, the overall results of rainfall extremes elucidate an increasing pattern. The changes in both extreme wet days and very wet days exemplify a positive shift. Thus, the possibility of storm and flash floods may be augmented in the 2080s. Additionally, the probability of 1-day rainfall is higher than 5-day rainfall. Hence, the duration of extremes will be reduced but the intensity will be increased. These consequences will have a profound impact on agriculture, health, water resources, and coastal and economic sectors.

Thus, this study emphasizes the paramount importance in evaluating the socioeconomic consequences due to the change in temperature and rainfall pattern. Therefore, in order to evade these circumstances, there is a great need to facilitate sectoral impact studies and thereby provide that information to policymakers, stakeholders, and government agencies, who then have to put concrete efforts to formulate adaptation and mitigation strategies for the different developing sectors.

Acknowledgments The authors are grateful to the Hadley Centre for Climate Prediction and Research, Met office, UK, for providing Lateral Boundary Condition data and assisting in using PRECIS. The authors also thank the ETCCDMI for making the software freely accessible for extreme analysis. The authors gratefully acknowledge the Department of Environment, Government of Tamil Nadu, for financially supporting Centre for Climate Change & Adaptation Research (CCC&AR). The authors are also thankful to Dr. Jayanthi Narendran for supporting and technically guiding the CCC&AR team.

Compliance with ethical standards

Conflict of interests The authors declare that they have no conflict of interest.

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