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Climate variability trend and extreme indices for the Thanjavur Delta region of Tamil Nadu in South India

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सार – तमिलनाडु का तंजावुर डेल्टा क्षेत्र काफी हद तक कृषि पर निर्भर है। जलवायु की स्थिति में परिवर्तन के कारण कृषि उत्पादन की वर्तमान प्रवृत्ति काफी प्रभावित हुई है। जलवायु प्रवृत्ति और चरम विश्लेषण के लिए प्रेक्षित प्राचलों को 1971-2014 की अवधि के लिए IMD (भारत मौसम विज्ञान विभाग) से और 2015-2050 की अवधि के लिए CCAFS (जलवायु परिवर्तन, कृषि और खाद्य सुरक्षा) से प्राप्त किया गया है। इस अध्ययन से यह पता चलता है कि 1971-2014 की अवधि के दौरान एआरपी, एनपीटी और आईएमडी ग्रिड में प्रेक्षित अधिकतम तापमान (T_{Max}) में क्रमशः 0.8 डिग्री सेल्सियस, 1.5 डिग्री सेल्सियस और 0.9 डिग्री सेल्सियस की वृद्धि हुई है। इसके अलावा, न्यूनतम तापमान (T_{min}) ने एआरपी और एनपीटी में एक नगण्य प्रवृत्ति और आईएमडी ग्रिड (0.5 डिग्री सेल्सियस) में एक महत्वपूर्ण प्रवृत्ति दिखाई है। इसके अलावा, प्रेक्षित वर्षा ने एआरपी (-3.8%), एनपीटी (-11.1%) और आईएमडी ग्रिड (+22.5%) में एक नगण्य प्रवृत्ति दिखाई है। अनुमानित T_{Max} और T_{min} ने क्रमशः लगभग 1.05 डिग्री सेल्सियस और 1.1 डिग्री सेल्सियस की महत्वपूर्ण वृद्धि की प्रवृत्ति दिखाई और 2015 से 2050 की अवधि में वर्षा में 21% की मामूली कमी का अनुमान है। डेल्टा क्षेत्र के चरम विश्लेषण में, तापमान सूचकांकों ने प्रेक्षित तापमान और भावी तापमान दोनों में महत्वपूर्ण वृद्धि की प्रवृत्ति देखी गई। वर्षा सूचकांकों ने प्रेक्षित और भविष्य में एक बड़े बदलाव के संक्रेत दिए हैं। इस अध्ययन के परिणाम तंजावुर डेल्टा क्षेत्र में कृषि और जल क्षेत्रों के लिए जलवायु परिवर्तन अनुकूलन के कार्यक्रमों को तैयार करने में उपयोगी होंगे।

ABSTRACT. The Thanjavur delta region of Tamil Nadu vastly depends on agriculture.The current trend of agricultural production has been significantly affected due to changes in climatic conditions.The observedparameters have been acquired from IMD (Indian Meteorological Department) for the period 1971-2014 and CCAFS (Climate Change, Agricultural and Food Security) over the period 2015-2050 for climate trend and extremities analysis. This study indicated that observed maximum temperature (T_{Max}) has significantly increased about 0.8 ºC, 1.5 ºC and 0.9 ºC in ARP, NPT and IMD grid, respectively, over the period 1971-2014. Besides that, minimum temperature (T_{Min}) has shown an insignificant trend in ARP and NPT and a significant trend in the IMD grid (0.5 ºC), respectively. Moreover, the observed rainfall showed an insignificant trend in ARP (-3.8%), NPT (-11.1%) and IMD grid (+22.5%). The projected T_{Max} & T_{Min} showed a significant increasing trend of about 1.05 °C and 1.1 °C, respectively, and the rainfall is projected to decrease insignificantly at 21% over the period 2015 to 2050. In the extreme analysis of the delta region, temperature indices showed a significant increasing trend inboth the observed and future. The rainfall indices showed a larger variation in the observed and future period. The study's outcome would be useful in framing the climate change adaptation strategies for agriculture and water sectors for the Thanjavur delta region.

Key words – Climate change, Thanjavur delta region, Extreme indicesand trend.

1. Introduction

Variation in climatic events and the increase in extreme weather have a significant serious threat to socio-economic and livelihood (Zhang *et al*., 2011). Soltani *et al*., 2016 reported that alteration in the frequency of temperature and rainfall leads to increases in an extreme events like heat waves (extreme temperature), flood and cyclones (extreme rainfall), drought (an increase of dry spell, evapotranspiration and failure of monsoon). Several

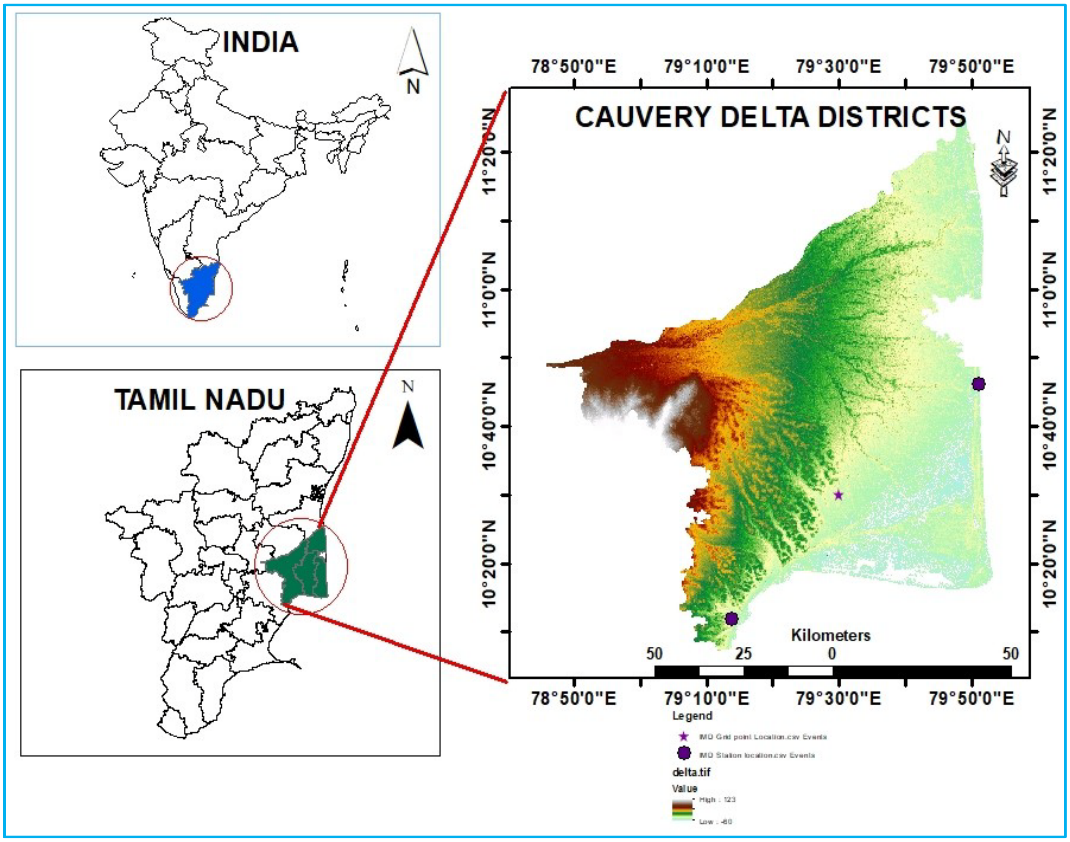


Fig. 1. Location of the study area map

global studies (Zhang *et al*., 2005; Alexander *et al*., 2006; Guan *et al*., 2015;) explored the trends and variations of temperature and rainfall. The global surface temperature has increased by about 0.12 °C per decade from 1951 to 2012 (IPCC, 2013). Frich *et al.* (2002) reported that the extreme amount of wet spells and the number of extreme rainfall events has increased. During the mid-century, the global land surface area has experienced a significant increase in extreme events. Based on the Expert Team on Climate Change Detection and Indices (ETCCDI), climate extreme indices have been studied (Alexander *et al*., 2007; Soltani *et al*., 2016).

Shahid (2011) reported decreasing consecutive dry days and increasing extreme rainfall in the Bangladesh region for the period 1985-2007. In Iran, the extreme temperature and rainfall indices showed a significant increasing trend at extreme warm events and decreased the magnitude and frequency of cold events for 1960-2014 (Rahimi *et al*., 2018). The extreme rainfall and temperature indices of 1960 to 2099 in northern Thailand have been studied by Masud *et al*., 2016 and, it was found that summer days and tropical nights has a significant increasing trend, the insignificant decreasing trend in the number of rainy days with more than 20 mm and 10 mm rainfall.

The numerous regional studies in India investigated the temperature and rainfall trends and their variability. The maximum temperature and minimum temperature series of the 30 years (1981-2010) showed faster warming (Srivastava *et al*., 2017). The temperature trend of India has shown a significant increasing trend at 0.05°C/ decade from 1901 to 2003, which causes the warming effect during the daytime and nighttime temperature (Kothawale and Kumar, 2005). Rao *et al*. (2014) reported that the projected Consecutive Dry Days (CDD) increased about 10-20% in west-central and peninsular Indian, very heavy rainfall (R95p) and the number of rainy days >10 mm (R10) also showed a significant increasing trend in the west coast, east-central India and north-eastern parts. A recent study by Rai *et al.* (2020) evaluated the future extreme rainfall events (CDD, CWD, R10, R20, SDII and RX1 day) over Indian by using RegCM4. They reported that CDD projected to be increased over the west-central part of India and CWD are projected to reduce in most parts of India during the end century. The wet indices of CWD, R10, R20, SDII and RX1 day showed a significant

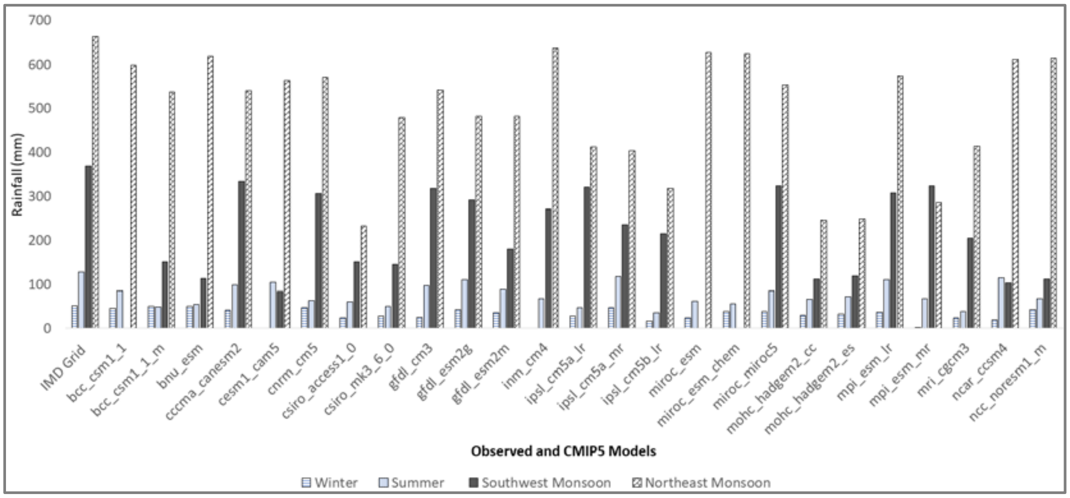


Fig. 2. Seasonal rainfall pattern of 25 CMIP5 model

decreasing trend in western coastal, interior land and high topographical regions.

Tamil Nadu observed temperature trend and its variation has been studied by Jeganathan *et al*. (2018). The maximum trend showed a significant increasing trend with a rate of change from 0.01 to 0.54 °C per decade from 1969-2015. The minimum temperature showed an increasing trend at the major 13 stations and a decreasing trend in a few Tamil Nadu stations, and it varied from -0.05 to 0.31°C. Rajalakshmi *et al*. (2015) examined the projected maximum and minimum temperature over Tamil Nadu, and it showed an increasing trend with 1.7 to 3.7°C and 1.9 to 4.3°C, respectively. The future climate extreme indices of temperature and rainfall by PRECIS over Tamil Nadu has been studied by Geetha *et al*. (2019). The future temperature indices of Tamil Nadu showed a significant increasing trend. However, the future extreme rainfall indicators showed an increase in extreme events (flash flood and storms). In this present study, the climate trend and extreme indices (Absolute, Percentile and Duration) are used for observed and future under the RCP 4.5 scenario.

2. Study area

In Tamil Nadu, the Thanjavur delta regions comprise three major districts : Thanjavur, Thiruvarur and Nagapattinam. It is popularly known as the state's rice bowl due to the presence of Alluvial soil and the most fertile tract of the Cauvery basin. The region is considered to be the prime agro-climatic zone of Tamil Nadu. The total geographical area is 8281.72 sq km, and the average elevation is about 88MSL. It has two India Meteorology Department (IMD) stations, namely Adirampattinam (ARP) and Nagapattinam (NPT). ARP lies between 10° 20′ N and 79° 23′ E and NPT lies between 10° 77′ N and 79° 85′ E (Fig. 1). The region has an average maximum temperature is about 35 °C, and the minimum temperature is about 25 °C. The average annual rainfall is about 1038 mm, primarily contributed by the northeast monsoon.

3. Methodology

3.1. *Data used*

The observed climate data of ARP and NPT stations (maximum, minimum temperature and rainfall) were obtained from regional IMD, Chennai for the period 1971 to 2014 (45 years) and the nearest grid point data extracted from IMD gridded datafor temperature (Srivastava *et al*., 2009) and rainfall (Pai *et al*., 2014) for 1971-2014. The future projection data was obtained from CCAFS climate (http://ccafs-climate.org/data/)

3.2. *Model selection*

The twenty-five models have been bias-corrected with the observed IMD gridded data through the CCAFS-Climate portal (http://www.ccafs-climate.org/data_bias_correction/). The best model was chosen based on the seasonal rainfall pattern (Fig. 2), mean & slope deviation, root mean square error and Z value (Table 1). The RMSE value (Bal *et al*., 2016) was calculated by using the following equation:

$$\text{RMSE} = \sqrt{\sum}\ (x^1, - x^2)\ \ 2nt = 1n\ (2) \qquad (1)$$

where, x^1, is the simulated rainfall while x^2, t is the observed rainfall.

Fig. 3. Temporal analysis of observed maximum temperature

TABLE 1

Quantitative performance of selected CMIP5 model

S. No.	Model	Mean	Slope	Mean deviation	Slope deviation	RMSE	Z value	Overall Rank
	IMD (Observed Value)	**1211**	**3.01**					
1.	cnrm_cm5	987.3	-4.94	0.17	2.64	13.12	0.9572	3
2.	gfdl_csm3	983.2	-0.88	0.19	1.29	12.22	0.7012	2
3.	mpi_esm_lr	1028.3	3.72	0.15	-0.23	11.87	0.3581	1
4.	gfdl_esm2g	925.1	-32.07	0.24	11.63	12.87	1.2671	5
5.	micro micro5	1000.7	-5.96	0.2	2.98	13.36	1.1381	4

*Based on mean, slope, mean deviation and slope deviation, RMSE, Z value best model to be selected for future projection

The selected models are CNRM_CM5, GFDL_CM3, GFDL_ESM2G, MIROC_MIROC5 and MPI_ESM_LR. The MPI_ESM_LR is the highest among the selected five CMPI5 modelswas used for the analysis of future trendvariation and extremities.

3.3. *Extreme indices*

The climate extreme indices are calculated from daily temperature and rainfall by using RClimDex software (Zhang *et al*., 2011) in R programming, which provide 27 core indices by ETCCDMI (Expert Team on Climate Change Detection and Monitoring). Among the 27 indices, 6 indices forrainfall and 11 indices for temperature have been used for extremities analysis.It is classified based on absolute, percentile and, duration indices (Alexander *et al*., 2007) for temperature and rainfall. The extreme indices used for this study are listed in Table 2.

3.4. *Statistical analysis*

In this study statistical analysis have been carried out by R programming. [R Core Team (2013)]. A large number of global, national and local studies were used the non-parametric Mann Kendall test (Mann, 1945;

TABLE 2

Daily Temperature and precipitation indices

Indices	Definition	Units
	Temperature Indices	
Absolute indices		
TNx	Monthly maximum value of daily minimum temp	°C
TXx	Monthly maximum value of daily maximum temp	°C
TNn (Min *T*min)	Monthly minimum value of daily minimum temp	°C
TXn (Max *T*min)	Monthly minimum value of daily maximum temp	°C
DTR (Diurnal temperature range)	Monthly mean difference between the maximum and minimum temperature	°C
Percentile indices		
TX10P (Cool days)	Annual Percentage of days, maximum temp is less than 10^{th} percentile	%
TX90P (Warm days)	Annual Percentage of days, maximum temp is greater than 90^{th} percentile	%
TN10P (Cool nights)	Annual Percentage of days, minimum temp is less than 10^{th} percentile	%
TN90P (Warm nights)	Annual Percentage of days, minimum temp is greater than 90^{th} percentile	%
Duration indices		
CSDI	Number of days with 6 consecutive days, where the minimum temperature is less than 10^{th} percentile	Days
WSDI	Number of days with 6 consecutive days, where the maximum is greater than 90^{th} percentile	Days
Threshold indices		
SU (Summer days)	Annual count when 90^{th} percentile of TX (daily maximum)	Days
	Precipitation indices	
Absolute indices		
R×1 day (Max 1-day precipitation amount)	Annual maximum 1 - day precipitation	mm
R ×3 day(Max 3-day precipitation amount)	Annual maximum 3 - day precipitation	mm
Percentile indices		
R95P (Very wet day precipitation)	Annual total precipitation is greater than 95^{th} percentile of observed (1971-2014) and future (2015-2050) precipitation	mm
R99P (Extreme wet day precipitation)	Annual total precipitation is greater than 95^{th} percentile of observed (1971-2014) and future (2015-2050) precipitation	mm
Duration indices		
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	Days
Threshold indices		
R10 mm (Number of heavy precipitation)	Annual count of days when PRCP ≥ 10 mm	Days
R20 mm (Number of heavy precipitation)	Annual count of days when PRCP ≥ 20 mm	Days
	Other indices	
PRCPTOT (Annual total wet day precipitation)	Annual total PRCP in wet days (RR ≥ 1 mm)	mm
SDII	Simple daily intensity index	mm/day

*According to the ETCCDMI (Expert Team on Climate Change Detection and Monitoring), 10 indices for precipitation and 11 indices for temperature are used for extremities analysis. The indices have been categorized based on Absolute, Percentile, Duration, Threshold and other indices (*Source*: (Geetha*et al*., 2019; Alexander *et al*., 2006)

TABLE 3

Trend analysis of observed Maximum temperature change

Parameter/Period	T_{Max}			Z			Rate of temperature change (°C)		
	ARP	NPT	IMD Grid	ARP	NPT	IMD Grid	ARP	NPT	IMD Grid
Annual	32.6	32.7	33.4	3.64*	6.0*	4.7*	0.8	1.3	0.9
Winter	30.9	29.3	30.8	3.37*	5.7*	4.3*	0.9	2.2	1.3
Summer	33.8	33.8	35.4	1.89	4.4*	3.1*	0.6	1.5	0.9
Southwest Monsoon	34	35.6	35.2	1.4	2.5*	2.8*	0.4	0.9	0.9
Northeast Monsoon	30.6	30.1	30.7	3.59*	5.2*	3.8*	0.9	1.2	0.9
1st decade	32.3	32.2	32.9	1.98*	1.26	1.56	1.2	0.6	0.51
2nd decade	32.7	32.5	33.4	0.18	0.36	0.72	0.11	0.06	0.23
3rd decade	32.5	32.7	33.4	-0.54	-1	-0.18	-0.25	-0.24	-0.24
4th decade	32.8	33.2	33.7	1.64	1.34	0.59	0.34	0.51	0.16

*Significant at 95% confidence level.

Kendall, 1975) and sen's slope for trend detection (Sen, 1968). The MK test and sen's slope were used to detect the trend of temperature and rainfall variation and extremities. The magnitude change percentage (Eqn.2) of rainfall was calculated based on sen's slope, length of the study period and mean of rainfall variability (Ghiami-Shamami *et al*., 2019).

$$\text{Magnitude change \%} = \frac{\text{Sens'slope} \times \text{length of study period}}{\text{Mean}} \times 100 \qquad (2)$$

4. Results and discussion

4.1. *Trend analysis of observed temperature*

The observed maximum temperature trend is presented in Fig. 3. The changes in observed T_{Max} showed a high significant (significant level at 0.05) positive trendthroughout 1971- 2015 (45 years). The trend lines indicated that the T_{Max} over the Thanjavur delta region has increased by about 1.3 °C, 0.7 ºC and 0.9 °C in IMD Grid, NPT and ARP respectively. Most of the studies in India (Dash *et al*., 2009) (Kothawale *et al*., 2010), showed a significant trend in annual and seasonal maximum temperature.

Table 3 showed a seasonal, annual and decadal statistical analysis and rate of change of T_{Max} and T_{Min}. During winter, T_{Max} has increased by about 2.2 °C, 0.9 °C and 1.3 °C in NPT, ARP and IMD Grid respectively whereas summer has increased at 1.5 °C, 0.6 °C and 0.9 °C in NPT, ARP and IMD Grid for 1971 to 2014 (43 years). During the south-west monsoon, the rate change of T_{Max} showed a significant increasing trend in ARP (0.4 °C), NPT (0.9 °C) and IMD Grid (0.9 °C) respectively. However, the trend of Northeast monsoon exposed a significant positive change in both station (0.9 °C in ARP and 1.2 °C in NPT) and IMD grid (0.9 °C) respectively. For the seasonal analysis, the trend of maximum temperature was higher in the winter season than the other seasons (summer, northeast monsoonand south-west monsoon). T_{Max} was increased in 1st decade (1970-1979) 2nd decade (1980-1989) and 4th (recent) decade (2000-2014) of NPT, ARP and IMD Grid, but the 3rd decade (1990-1999) was decreased.

The time series of T_{Min} in NPT showed a significantly decreasing, whereas ARP was slightly increased by about 0.01 °C and IMD Grid showed a significant increasing trend (Fig. 4). There is no significantincreasing trend during winter and Northeast monsoon, decreasing insignificant trend at summer and Southwest monsoon (Table 4). The decadal analysis of T_{Min} showed an increasing trend in the 1st decade, 2nd decade and 4th decade of all ARP, NPT and IMD Grid. The 3rd decade showed a negative trend in NPT, which influence the annual trend of the NPT station. Jeganathan *et al*., (2018) studied the observed temperature trends of 17 climatological stations in Tamil Nadu. They reported that the minimum temperature trend of Tamil Nadu showed anincreasing trend in 13 stations and decreasing trend at 4 stations and it showed a large variation with a rate of change at0.05 to 0. 31 °C per every decadefor 1969-2016. A significant increasing trend has been observed for India, it showed a 0.05 °C/10 yr from 1901 to 2003 (Kothawale and Rupa Kumar, 2005).

4.2. *Trend analysis of observed rainfall*

The observed annual average rainfall for the period 1971-2014 of NPT, ARP and IMD Grid is about 1352.36,

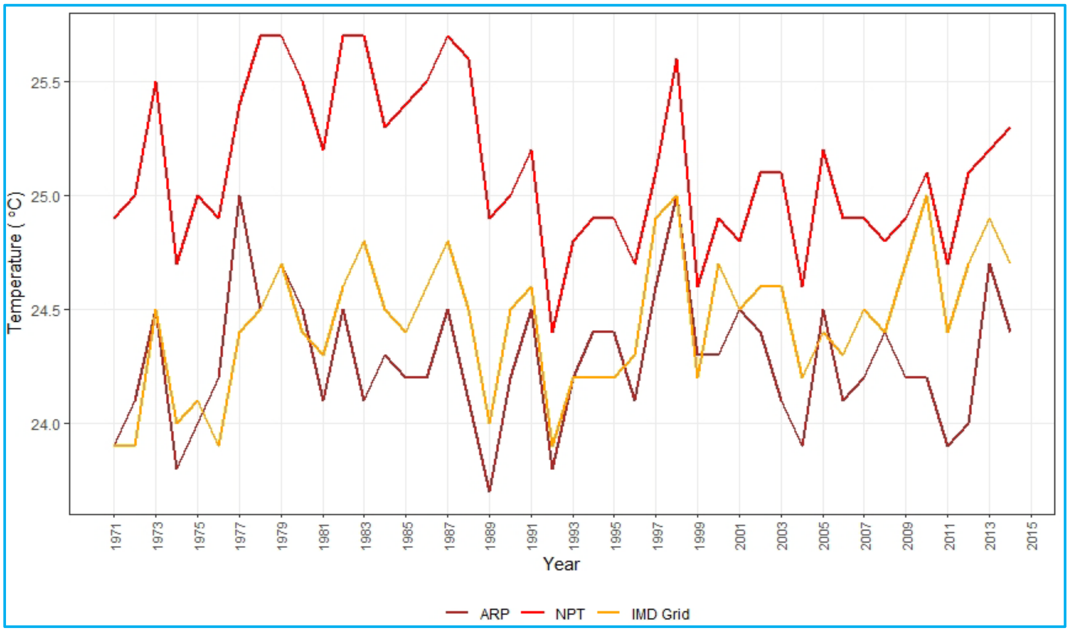


Fig. 4. Temporal analysis of observed minimum temperature

TABLE 4

Trend analysis of observed Minimum temperature change

Parameter/Period	T_{Min}			Z			Rate of temperature change (°C)		
	ARP	NPT	IMD Grid	ARP	NPT	IMD Grid	ARP	NPT	IMD Grid
Annual	24.3	25.1	24.5	0	-1.7	2.86*	0	-0.4	0.5*
Winter	21.1	22.8	21.6	1.2	-1.5	1.93	0.4	-0.6	0.6
Summer	25.6	26.2	25.7	-0.21	-2.9	0.84	-0.1	-1	0.2
Southwest Monsoon	25.7	26.2	25.8	-0.31	-1.2	2.96	-0.1	-0.2	0.5
Northeast Monsoon	23.2	24	23.3	0.73	-0.4	2.54	0.2	-0.1	0.1
1st decade	24.3	25.2	24.2	1.77	1.98*	2.19*	1.1	0.86*	0.85*
2nd decade	24.3	25.5	24.5	-1.43	0	0	-0.44	-0.02	0.07
3rd decade	24.3	24.9	24.4	1.07	0	0.72	0.56	-0.04	0.38
4th decade	24.3	25	24.5	-0.49	1.15	2.31*	-0.06	0.11	0.29*

*Significant at 95% confidence level.

1187.23 and 1258.25 mm respectively and the temporal plot is depicted in Fig. 5, Further, for seasonal rainfall, the trend of the winter and summer rainfall recorded an insignificantly positive and for Southwest and Northeast monsoon showed an insignificant negative trend. Pal and Al-Tabbaa (2011) and Guhathakurta and Rajeevan (2008) reported that Kerala, coastal Andhra Pradesh, Rayalaseema and Tamil Nadu had a significantly decreasing trend during the monsoon season.

The magnitude of change for the rainfall during annual, seasonal and decade are presented in Table 5, The IMD stations of ARP and NPT had an insignificant negative change of 3.8% and 11.1%, respectively whereas, the Grid Point of IMD around the Thanjavur delta region showed an insignificant positive change of 22.5%. The distinct variation between the two stations and grid point could be due to the estimated calculation for IMD grid from various rain gauge station around 25 km, particularlyduring the south-west monsoon the isolated rainfall could attribute a positive trend and impacted overall differences in trend. The rainfall variation of ARP and NPT during the south-west monsoon season showed an insignificantnegative change of 24.1% and 11.8%, respectively but the IMD grid point has no significant

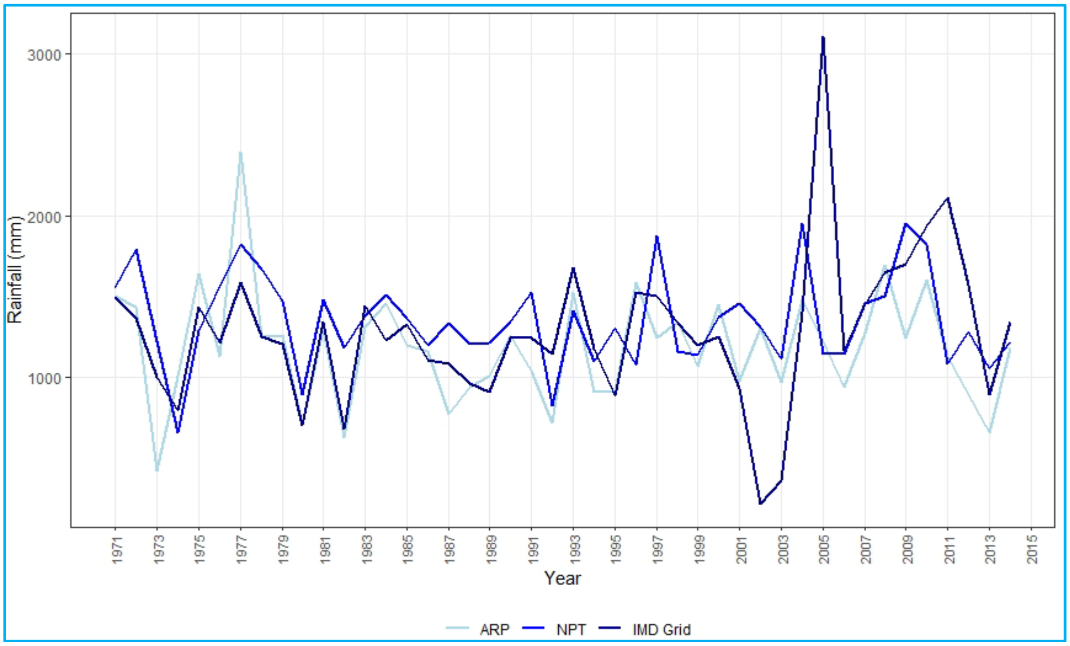


Fig. 5. Temporal analysis of observed rainfall

TABLE 5

Trend analysis of observed rainfall changes

Parameter/Period	T_{Max}			Z			Rate of temperature change (°C)		
	ARP	NPT	IMD Grid	ARP	NPT	IMD Grid	ARP	NPT	IMD Grid
Annual	1187.2	1352.4	1258.3	-0.27	-1	1.37	-3.8	-11.1	22.5
Winter	102.9	68.6	50.9	0.68	0.6	1.16	14.7	13.2	26
Summer	162.9	100.1	142.3	0.88	1.3	1.27	28.9	53.1	45.1
Southwest Monsoon	237.6	259.3	387.1	-1.35	-0.4	0.68	-24.1	-11.8	14.3
Northeast Monsoon	490.8	931.7	697.9	0.33	-0.9	-0.5	9.4	-13.4	-11.5
1st decade	1338.6	1451	1262.5	0.31	0.52	-0.31	25.68	15.44	-11.9
2nd decade	1050.8	1279.4	1080.5	-0.18	0	-0.89	-25.52	-4.46	-43.19
3rd decade	1163	1276.9	1295.1	0.36	-0.36	0	18.14	-16.6	-1.78
4th decade	1203.5	1392.1	1408.3	-1.09	-0.79	1.48	-17.24	-10.7	9.48

The average of rainfall in different seasons with no significant changes

positive change of 14.3%. Thus, this season has impacted the annual variation between the stations and the grid point. During the northeast monsoon, an insignificantly negative change in both stations and IMD grid point. The northeast monsoon has the highest contribution (Fig. 6) among the seasonal rainfall for ARP (49.3%), NPT (68.6%) and IMD grid point (54.6%). India received the highest rainfall during the Southwest monsoon but in the case of Tamil Nadu coastal region received more than 50% of rainfall during the North-East monsoon than the south-west monsoon and summer season (TNSAPCC, 2015). Ramaraj *et al.* (2017) found that trend of Thanjavur Northeast monsoon rainfall has increased due to cyclonic activity and monsoonal circulation.

4.3. *Projected climate variability*

The projected climate variability under the RCP4.5 scenario (maximum & minimum temperature and rainfall) has been examined during the period 2015-2050 and three decadal time slices as the 2020s (2020-2029), 2030s (2030-2039) and 2040s (2040-2049).

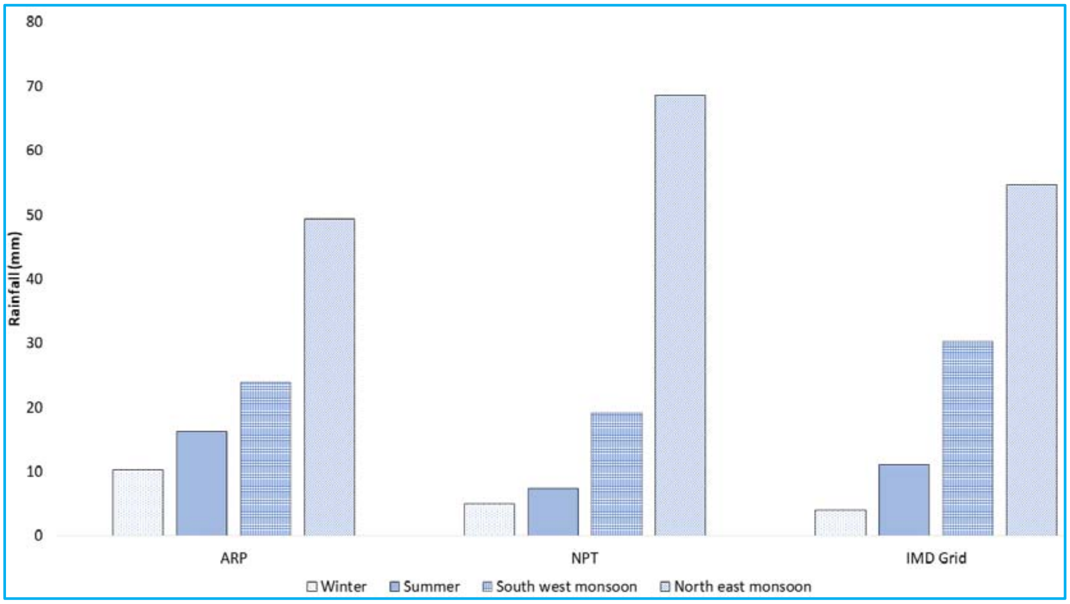


Fig. 6. Seasonal rainfall contribution

TABLE 6

Trend analysis of projected *T*max and *T*min

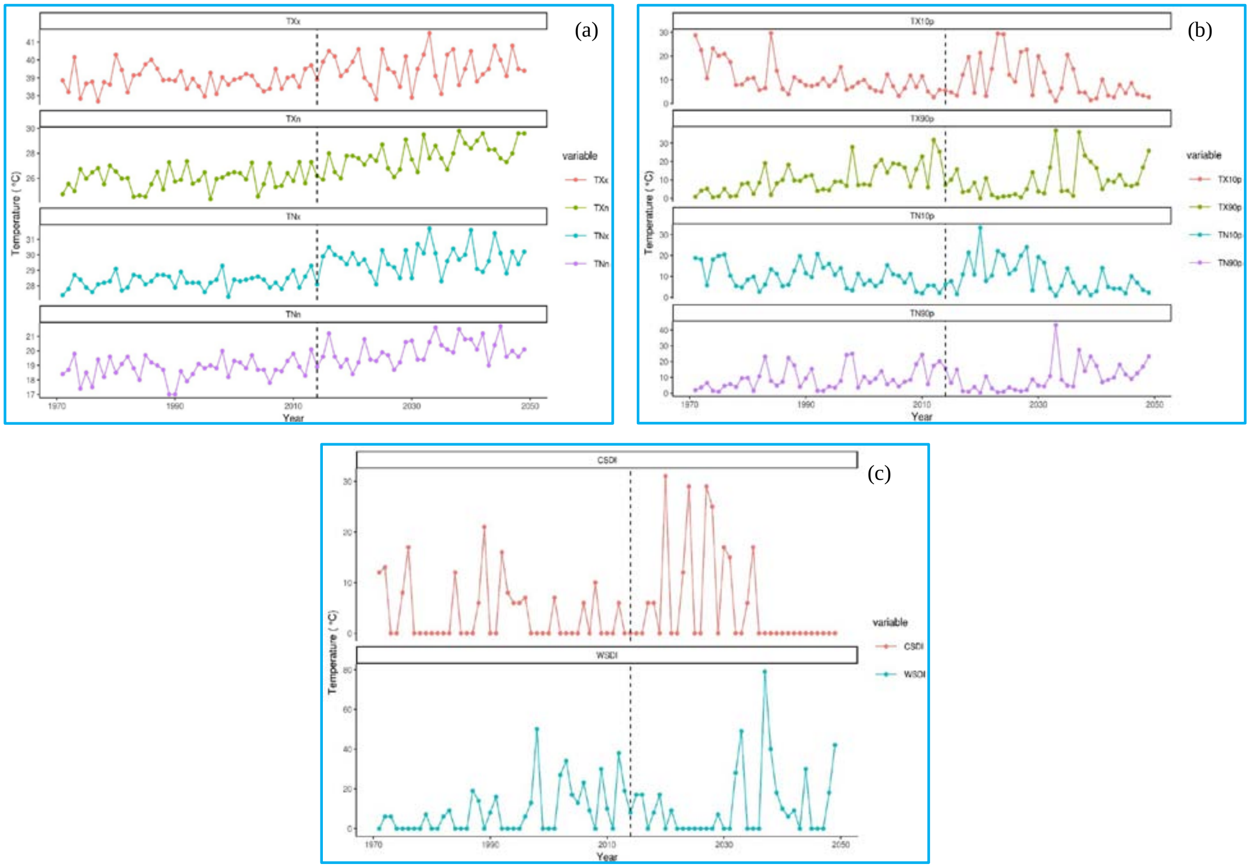
Period	T_{max}			T_{min}		
	Mean	Z	Rate of change/Time Period	Mean	Z	Rate of change/Time Period
Annual	34.2	2.27	1.05*	25.4	3.29	1.10*
Winter	31.7	1.48	0.7	22.8	2.07	1.05*
Summer	36.2	1.85	1.05	26.9	1.93	0.7
South west Monsoon	35. 9	1.9	0.7	26.6	3.1	0.7*
North east Monsoon	31.4	0.02	1.4*	24.1	3.29	1.05*
2020s	33.7	0.72	0.3	25	0.53	0.39
2030s	34.3	0.89	0.9	25.7	1.6	0.91
2040s	34.5	0.36	0.1	25.7	0.72	0.21

*****Significant at 95% level. Mean, Z value and rate of change also calculated for projected maximum and minimum temperature

4.3.1. *Temperature trend analysis*

The projected change rate of T_{Max} and T_{Min} for the study period under seasonal and decadal is given in Table 6. The trend of T_{Max} is projected to significantly increase at the rate of 1.05 °C between 2015 and 2050. The seasonal change of T_{Max} showed an insignificant increasing trend in winter (0.7 °C), summer (1.05 °C) and the south-west monsoon (0.7 °C), whereas northeast monsoon showed a significant increasing trend at the rate of 1.4 °C. The decadal change of T_{Max} is projected to be insignificantly increased at 0.3 °C, 0.9 °C and 0.1 °C during the 2020s, 2030s and 2040s respectively.

Similarly, the trend of T_{Min} projected to be increasing significantly at the rate of change at 1.10 °C for the 2015-2050 period. The results from the MK test of T_{Min} for different seasons showsa significant increase at 95% confidence level during winter, south-west and northeast monsoon with a rate of change at 1.1 °C, 0.7 °C and 1.1 °C respectively, whereas summer, the trend indicates an insignificant increasing trend at 0.7 °C over the period. The trend of projected T_{Min} revealed a no significant increasing trend at 0.4 °C, 0.9 °C and 0.2 °C duringthe 2020s, 2030s and 2040s respectively. Similar studies have been reported for Tamil Nadu (Bal *et al.*, 2016) and (Dhanya *et al.*, 2013), the maximum and minimum



Figs. 7(a-c). Temporal analysis of temperature indices from 1971 to 2050 (a) Absolute indices, (b) Percentile indices and (c) Duration indices

temperature trends in the future scenario has shown a significant increasing trend.

4.3.2. *Projected rainfall trend analysis*

The future annual rainfall showed an insignificant decreasing trend of 1033.9 mm with a standard deviation of 270.36 for 2015 - 2050. The change percentage of the projected annual rainfall showed an insignificant variation during the 2020s (-24%,), 2030s (4%) and 2040s (40%) respectively. Studies by Krishna Kumar *et al*., 2011; -17% respectively as summarized in Table 7. The total amount of convectiverainfall and its trend during SWM season over the coastal districts of Tamil Nadu is almost similar to the observed trend to the other season. Bal *et al*. (2014) have illustrated a decreasing trend in south-west monsoon (JJAS) over Tamil Nadu.

4.4. *Variability in climate extreme indices*

4.4.1. *Trend analysis of temperature indices*

The temporal plot and statistical trend analysis of temperature (maximum and minimum) indices for

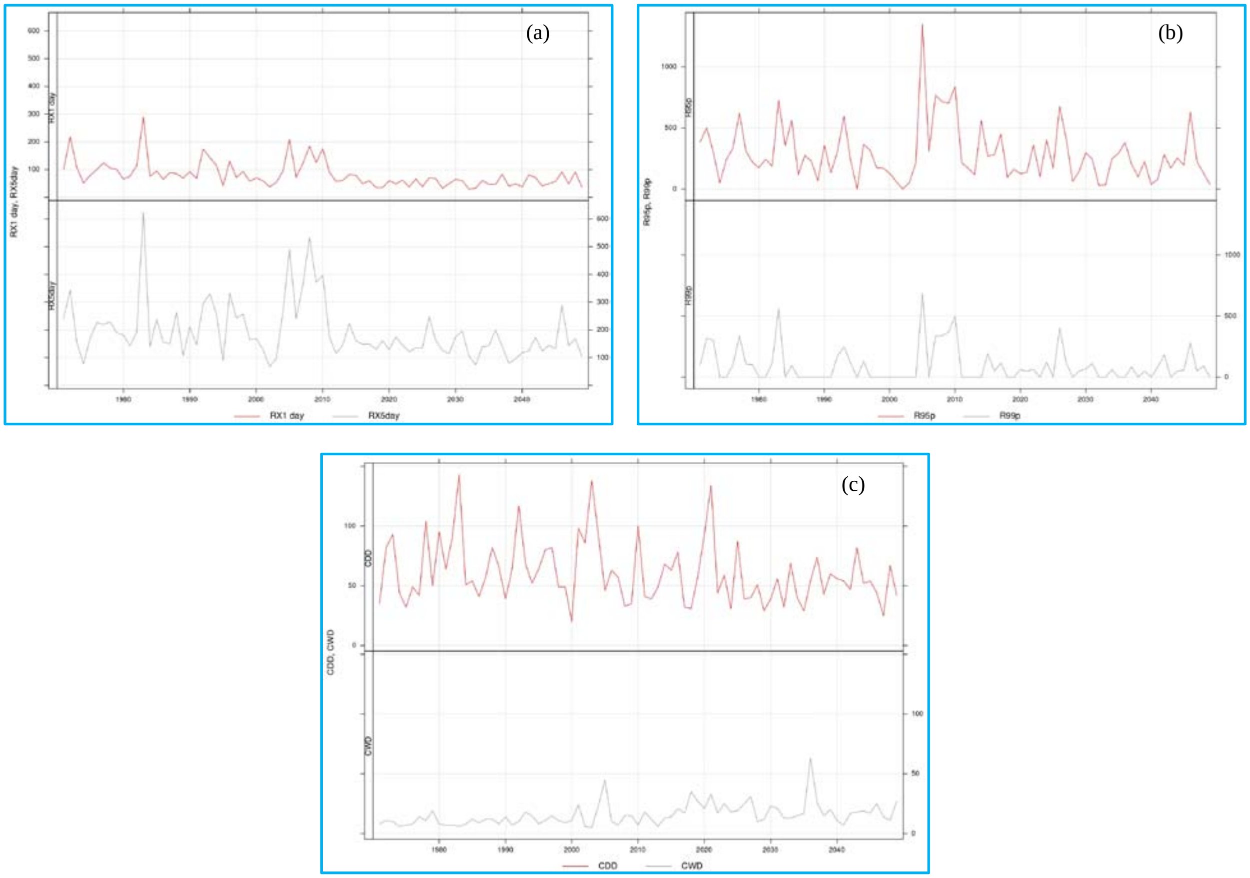
TABLE 7

Trend analysis of projected rainfall (2015-2049)

Parameter/Period	Rainfall	Sen's slope	SD	Change percentage
Annual	1033.9	-6.25	270.36	-21%
Winter	40.6	-0.15	44.34	-13%
Summer	91.4	-1.41	60.54	-54%
South west monsoon	359.2	-0.66	142.48	-6%
North east monsoon	542.6	-2.62	206.38	-17%
2020s	1139.7	-27.89	297.21	-24%
2030s	1038.4	4.48	249.39	4%
2040s	924.4	36.79	241.53	40%

*Significant at 95% level. Mean, Z value and change percentage also calculated for projected rainfall

observed (IMD Grid Point) and projected (GCM Model-MPI-ESM-LR) period from 1970-2014 and 2015-2050 Rajalakshmi *et al*., 2015 and Kumar, 2013, reported that future rainfall trend could decrease over Tamil Nadu. The projected season-wise rainfall would be decreased in



Figs. 8(a-c). Temporal analysis of precipitation indices from 1971 to 2050 (a) Absolute indices, (b) Percentile.rf indices and (c) Duration indices

winter, summer, south-west monsoon and northeast monsoon with a change percentage of -13, -54, -6 andrespectively are shown in Figs. 7(a-c) and presented in Table 8. All the temperature indices expect CSDI, showed asignificant change in trendrate at 95% confidence level during the observed period. Also, the rate of change forwarm days (0.9 °C) and nights (1.4 °C) is increased and cold days (-1 °C) and nights (-1.1 °C) is decreased significantly. In absolute indices, except a maximum of minimum temperature (TNx), other indices such as TNn, TXn and TXx are projected to have a strong positive trend. Similar results were obtained from the study of extreme indices for Tamil Nadu (Geetha *et al.*, 2019).

The cold days and nights are projected to have an insignificant increasing trend but warm days and nights could have a stronger increasing trend at a 95% confidence level. The threshold temperature range for cool days (TX10p) and nights (TN10p) considered for the base period from 1971-2025 is 29.6 °C and 21.2 °C respectively based on the density distribution of the observed temperature. The projected cold spell duration index (CSDI) could show a decreasing trend (-1.8) with no significant confident level at 95%. The trend of warm spell duration index (WSDI) during the future projection could increase (0.39) insignificantly.

Masud *et al*. (2016) investigated the extreme indices for climate parameters of North Thailand, found that the TXx, TNx, TX90p, TN90p and WSDI showed a significant positive trend in the observed and projected period however the cool days (TX10p) and cool nights (TN10p) showed a weaker trend.

4.4.2. *Trend analysis of rainfall indices*

The extreme rainfall indices for both observed and projected period have statistically examined (Table 9) and illustrated temporally in Figs. 8(a-c). During observed, the percentage change magnitude of prolonged wet days is positive and dry days is slightly negative. In contrast, during the projected period, the magnitude trend of dry days to be increased and wet days could decrease at the end of the year 2050. The percentile rainfall indices of R99p have no trend during observed and future projection. The R95p indices showed a weaker decreasing trend for both study period.

TABLE 8

Statistical analysis of extreme temperature indices

Category	Indices	Average		SD		Change rate	
		Observed	Projected	Observed	Projected	Observed	Projected
Threshold	SU35	36	42	14.23	29.93	0.65*	0.51*
Absolute	TNn	18.8	20	0.73	0.83	0.44*	0.5*
	TNx	28.3	29.8	0.45	0.84	0.34*	0.1
	TXn	25.9	27.9	0.83	1.08	0.55*	0.7*
	TXx	38.9	39.6	0.58	0.87	0.06*	0.9*
Percentile	TX10p	10.5	10.1	6.43	7.32	-0.9*	-1
	TX90p	10.4	9.8	7.71	9.5	1.5*	0.9*
	TN10p	9.9	9.9	5.48	7.95	-0.8*	-1.1
	TN90p	9.5	9.7	7.1	9.17	0.9*	1.4*
Duration	CSDI	4	6	5.62	9.8	0	-1.8
	WSDI	9	12	12.05	17.95	1.0*	0.39

*95% significant level, observed and projected change rate of temperature indices calculated

TABLE 9

Statistical analysis of extreme rainfall indices

Category	Indices	Average		SD		Magnitude change (%)	
		Observed	Projected	Observed	Projected	Observed	Projected
Duration	CDD (days)	66	54	28.2	22.2	-3.3	10.8
	CWD (days)	12	21	6.8	9.9	34.9	-26.7
Percentile	R95P	336.2	227.5	269.5	156.4	-30.54	-76.4
	R99p	114.2	67.8	174.6	86.9	0	0
Threshold	R10mm	37.5	34	12.5	10.8	18.4	-22
	R20mm	20	14	8.02	5.5	28.8	-17.9
Absolute	R×1 day	102	55	51.9	17.1	-16.8	9.3
	R× 3 day	187	145	104.6	30.8	5	1.1
Other	PRCPTOT (mm)	1268.4	1004.9	460.1	271.9	22.2	-21.3
	SDII	14.4	8.9	54.9	19.1	6.7	-1.8

*95% significant level, observed and projected magnitude change of rainfall indices calculated

The trend of absolute rainfall indices for the highest one-day rainfall showed an insignificant negative change during the observed and an insignificant positive change during the future period. The highest 3-day maximum cumulative rainfall trend is shown a very narrow increasing trend during both past and future period. The Tamil Nadu future projection of extreme indices using the A1B scenario also infers the slight increase in the Rx1 day index. (Geetha *et al.*, 2019) Furthermore, the overall results indicatethat none of the extreme rainfall indices shows a significant confident level at 95% the variation between the observed and projected model is not complementary to each other in the Thanjavurdelta region. Rai *et al*. (2020) studied the extreme rainfall indicesduring long-term observed and projected using the CORDEX model and the trend results of CDD over coastal Tamil Nadu with IMD datasets are decreasing.

5. Conclusions

This study focused on the trend of climate parameters and its extreme indices for observed and projected periods over the Thanjavur Delta region of Tamil Nadu. T_{Max} showed a significant warming trend in both datasets (stations and the IMD grid point), but T_{Min} showed relatively no change of trend in ARP and an insignificant decreasing trend in NPT and IMD grid for 1970 to 2014. The projected T_{Max} and T_{Min} showed a significant increasing trend.The observed rainfallshowed an insignificant decreasing trend in ARP and NPT and an increasing trend in the IMD grid. The projected rainfall showed an insignificantly decreasing trend over the period 2015-2050.

The temperature extremesindices showed a significant positive trend. The extreme rainfall events during the observed period showed a lesser trend and during the future period frequency of the extreme events could be increased. The extreme rainfall indices have not shown distinct temporal change and it is due to the uncertainty of the northeast monsoon which is a major contribution in this region.

The above findings indicate the warming of the delta region could reduce the crop yield in future scenarios. The climate extreme analysis reveals an alarming indication of climate change and likely to affect crop production, declining of water resources and reduce the socio-economic status of Thanjavur delta districts. Thus,the study will be helpful for policymakers and scientific researcher to framing the local adaptation strategies for the water and agriculture sectors.

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Reference

Alexander, L. V., Hope, P., Collins, D., Trewin, B., Lynch, A. and Nicholls, N., 2007, "Trends in Australia's climate means and extremes: A global context", *Aust. Meteorol. Mag.*, **56**, 1-18.

Alexander, L. V., Zhang, X., Peterson, T. C., Caser, J., Gleason, B., Klein Tank, A. M. G., Haylock, M., Collins, D., Trewin, B., Rahimzadeh, F. Tagipour, A. Rupa Kumar, K. Revadekar, J. Griffiths, G., Vincet, L., Stepheson, D. B., Burn, J., Aguilar, E., Brunet, M., Taylor, M., New, M., Zhai, P., Rusticucci, M. and Vazquez Aguirre, J. L., 2006, "Global observed changes in daily climate extremes of temperature and precipitation", *Journal of Geophysical Research*, **111**, 1-22. doi : 10.1029/ 2005JD006290.

Bal, P. K., Ramachandran, A., Geetha, R., Bhaskaran, B., Thirumurugan, P., Indumathi, J. and Jayanthi, N., 2016, "Climate change projections for Tamil Nadu, India: deriving high-resolution climate data by a downscaling approach using PRECIS", *Theoretical and Applied Climatology*, **123**, 523-535. doi : 10.1007/s00704-014-1367-9.

Dash, S. K., Kulkarni, M. A., Mohanty, U. C. and Prasad, K., 2009, "Changes in the characteristics of rain events in India", *J. Geophys. Res. Atmos*., **114**, 1-12. doi : 10.1029/2008JD010572.

Dhanya, P., Ramachandran, A., Bal, P. K. and Thirumurugan, P., 2013, "Recent and future weather and climate trends of Kancheepuram (TN)", *Journal of Agrometerology*, **15**, 1-7.

Frich, P., Alexander, L. V., Della Marta, P., Gleason, B., Haylock, M., Klein Tank, A. M. G. and Peterson, T., 2002, "Observed coherent changes in climatic extremes during the second half of the twentieth century", *Climate Research*, **19**, 193-212.

Geetha, R., Ramachandran, A., Indumathi, J., Palanivelu, K., Uma, G. V., Bal, P. K. and Thirumurugan, P., 2019, "Characterization of future climate extremes over Tamil Nadu, India, using high-resolution regional climate model simulation", *Theoretical and Applied Climatology*, **138**, 1297-1309. doi : 10.1007/s00704-019-02901-0.

Ghiami Shamami, F., Sabziparvar, A. A. and Shinoda, S., 2019, "Long-term comparison of the climate extremes variability in different climate types located in coastal and inland regions of Iran", *Theoretical and Applied Climatology*, **136**, 875-897. doi : 10.1007/s00704-018-2523-4.

Guan, Y., Zhang, X., Zheng, F. and Wang, B., 2015, "Trends and variability of daily temperature extremes during 1960-2012 in the Yangtze River Basin, China", *Glob. Planet Change*, **124**, 79-94. doi : 10.1016/j.gloplacha.2014.11.008.

Guhathakurta, P. and Rajeevan M., 2008, "Trends in the rainfall pattern over India", *International Journal of Climatology*, **1469**, 1453-1469. doi : 10.1002/joc.

IPCC, 2013, "Climate change 2013 : the physical science basis", In : Stocker T. F., Qin, D., Plattner, G. K., Tignor, M., Allen, S. K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P. M. (eds) Contribution of working group I to the fifth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY. p1535. https://doi.org/10.1017/CBO9781107415324.

Jeganathan, A., Andimuthu, R. and Kandasamy, P., 2018, "Trends of the observed temperature and its variations in the Tamil Nadu State of India", *Theoretical and Applied Climatology*, **137**, 103-116. doi : 10.1007/s00704-018-2582-6.

Kendall, M. G., 1975, "Rank correlation methods", Charles Griffin, London, p202.

Kothawale, D. R. and Rupa Kumar, K., 2005, "On the recent changes in surface temperature trends over India", *Geophysical Research Letters*, **32**, 1-4. doi : 10.1029/2005GL023528.

Kothawale, D. R., Revadekar, J. V. and Kumar, K. R., 2010, "Recent trends in pre-monsoon daily temperature extremes over India", *J. Earth Syst. Sci.*, **119**, 51-65. doi : 10.1007/s12040-010-0008-7.

Krishna Kumar, K., Patwardhan, K., Kulkarni, S. K., Kamala, A., Rao, K., K. K. and Jones, R., 2011, "Simulated projections for summer monsoon climate over India by a high-resolution regional climate model (PRECIS) Impact of global warming on the Indian monsoon climate is examined using Hadley Centre's high-resolution regional climate model, PRECIS", *Current. Science*, **101**, 3, 312-326.

Kumar, P., Wiltshire, A., Mathison, C., Asharaf, S., Ahrens, B., Lucas Picher, P., Christensen, J. H., Gobiet, A., Saeed, F., Hagemann and S., Jacob, D., 2013, "Downscaled climate change projections with uncertainty assessment over India using a high-resolution multi-model approach", *Sci. Total Environ*., 468-469, S18-S30. doi : 10.1016/j.scitotenv.2013.01.051.

Mann, H. B., 1945, "Nonparametric tests against trend", *Econometrica*, **13**, 3, 245-259.

Masud, M. B., Soni, P., Shrestha, S. and Tripathi, N. K., 2016, "Changes in Climate Extremes over North Thailand, 1960–2099", *Journal of Climatology*, 2016, 1-18. doi : 10.1155/2016/4289454.

Pai, D. S., Sridhar, L., Rajeevan, M., Sreejith, O. P., Satbhai and Mukhopadyay, N. S., 2014, "Development of a new high spatial resolution (0.25 × 0.25) long period (1901-2010) daily gridded rainfall data set over India and its comparison with existing data sets over the region", *MAUSAM*, **65**, 1, 1-18.

Pal, I. and Al-Tabbaa, A., 2011, "Assessing seasonal precipitation trends in India using parametric and non-parametric statistical techniques", *Theoretical and Applied Climatology*, **103**, 1-11. doi : 10.1007/s00704-010-0277-8.

R. Core Team, 2013, "A language and environment for statistical computing", R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/.

Rahimi, M., Mohammadian, N., Vanashi, A. R. and Whan, K., 2018, "Trends in Indices of Extreme Temperature and Precipitation in Iran over the Period 1960-2014", *J. Ecol*., **8**, 396-415. doi : 10.4236/oje.2018.87024.

Rai, P. K. Singh, G. P. and Dash, S. K., 2020, "Projected changes in extreme precipitation events over various subdivisions of India using RegCM4", *Climate Dynamics*, **54**, 247-272. https://doi.org/10.1007/s00382-019-04997-6.

Rajalakshmi, D., Jagannathan, R. and Geethalakshmi, V., 2015, "Future climate uncertainty and spatial variability over Tamil Nadu State, India", *Global Nest*, **17**, 1, 175-185.

Ramaraj, A. P., Geethalakshmi, V. and Bhuvaneswari, K., 2017, "Understanding the uncertainty cascaded in climate change projections for agricultural decision making", *MAUSAM*, **68**, 2, 223-234.

Rao, K. K., Patwardhan, S. K., Kulkarni, A., Kamala, K., Sabade, S. S. and Kumar, K. K., 2014, "Projected changes in mean and extreme precipitation indices over India using PRECIS", *Glob. Planet Change*, **113**, 77-90. doi : 10.1016/j.gloplacha. 2013.12.006.

Sen, P. K., 1968, "Estimates of the regression coefficient based on Kendall's tau", *J. Am. Stat. Assoc*., **63**, 1379-1389.

Shahid, S., 2011, "Trends in extreme rainfall events of Bangladesh", *Theoretical and Applied Climatology*, **104**, 489-499. doi : 10.1007/s00704-010-0363-y.

Soltani, M., Laux, P., Kunstmann, H., Stan, K., Sohrabi, M. M., Molanejad, M., Sabziparvar, A. A., Ranjbar Saadat Abadi, A., Ranjbar, F., Rousta, I. Zawar-Reza, P. Khoshakhlagh, F. Soltanzadeh, I. Babu, C. A., Azizi, G. H. and Martin, M. V., 2016, "Assessment of climate variations in temperature and precipitation extreme events over Iran", *Theoretical and Applied Climatology*, **126**, 775-795. doi : 10.1007/s00704-015-1609-5.

Srivastava, A. K., Kothawale, D. R. and Rajeevan, M. N., 2017, "Variability and long-term changes in surface air temperatures over the Indian subcontinent", In : Rajeevan, M. N., Nayak, S. (eds) Observed climate variability and change over the Indian region. *Springer Geology*, 17-35. https://doi.org/10.1007/978-981-10-2531-0_2.

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

TNSAPCC (Tamil Nadu State Action Plan on CLimate Change), 2015, Chapter 4 Observed climate and projections in final draft report Tamil Nadu State action plan on Climate change. http://www.moef.gov.in/sites/default/files/Tamilnadu%20Final % 20report.pdf.

Zhang, X., Alexander, L., Hegerl, G. C., Jones, P., Tank, A. K., Peterson, T. C., Trewin, B. and Zwiers, F. W., 2011, "Indices for monitoring changes in extremes based on daily temperature and precipitation data", *Clim. Chang*., **2**, 851-870. doi : 10.1002/ wcc.147.

Zhang, X., Hegerl, G., Zwiers, F. W. and Kenyon, J., 2005, "Avoiding in homogeneity in percentile-based indices of temperature extremes", *Journal of Climatology*, **18**, 1641-1651. doi : 10.1175/JCLI3366.1.