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

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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 observed parameters 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 extremity analysis. This study indicated that observed maximum temperature (T_max) has significantly increased about 0.8°C, 1.5°C and 0.9°C 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°C), respectively. Moreover, the observed rainfall showed an insignificant trend in ARP (-3.8%), NPT (+1.1%) 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 in both 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 indices and 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 event 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

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
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, Thiruvur 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 data for 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:

\[ \text{RMSE} = \sqrt{\frac{1}{n} \sum (x^1 - x^2)^2} \]

where, \( x^1 \) is the simulated rainfall while \( x^2 \), \( t \) is the observed rainfall.
Fig. 3. Temporal analysis of observed maximum temperature

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Model</th>
<th>Mean</th>
<th>Slope</th>
<th>Mean deviation</th>
<th>Slope deviation</th>
<th>RMSE</th>
<th>Z value</th>
<th>Overall Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>cnrm_cm5</td>
<td>987.3</td>
<td>-4.94</td>
<td>0.17</td>
<td>2.64</td>
<td>13.12</td>
<td>0.9572</td>
<td>3</td>
</tr>
<tr>
<td>2.</td>
<td>gfdl_csm3</td>
<td>983.2</td>
<td>-0.88</td>
<td>0.19</td>
<td>1.29</td>
<td>12.22</td>
<td>0.7012</td>
<td>2</td>
</tr>
<tr>
<td>3.</td>
<td>mpi_esm_lR</td>
<td>1028.3</td>
<td>3.72</td>
<td>0.15</td>
<td>-0.23</td>
<td>11.87</td>
<td>0.3581</td>
<td>1</td>
</tr>
<tr>
<td>4.</td>
<td>gfdl_esm2g</td>
<td>925.1</td>
<td>-32.07</td>
<td>0.24</td>
<td>11.63</td>
<td>12.87</td>
<td>1.2671</td>
<td>5</td>
</tr>
<tr>
<td>5.</td>
<td>micro</td>
<td>1000.7</td>
<td>-5.96</td>
<td>0.2</td>
<td>2.98</td>
<td>13.36</td>
<td>1.1381</td>
<td>4</td>
</tr>
</tbody>
</table>

*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 CMIP5 model was used for the analysis of future trend variation 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 for rainfall 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>
<thead>
<tr>
<th>Indices</th>
<th>Definition</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature Indices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Absolute indices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TNx</td>
<td>Monthly maximum value of daily minimum temp</td>
<td>°C</td>
</tr>
<tr>
<td>TXx</td>
<td>Monthly maximum value of daily maximum temp</td>
<td>°C</td>
</tr>
<tr>
<td>TNn (Min Tmin)</td>
<td>Monthly minimum value of daily minimum temp</td>
<td>°C</td>
</tr>
<tr>
<td>TXn (Max Tmin)</td>
<td>Monthly minimum value of daily maximum temp</td>
<td>°C</td>
</tr>
<tr>
<td>DTR (Diurnal temperature range)</td>
<td>Monthly mean difference between the maximum and minimum temperature</td>
<td>°C</td>
</tr>
<tr>
<td><strong>Percentile indices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TX10P (Cool days)</td>
<td>Annual Percentage of days, maximum temp is less than 10th percentile</td>
<td>%</td>
</tr>
<tr>
<td>TX90P (Warm days)</td>
<td>Annual Percentage of days, maximum temp is greater than 90th percentile</td>
<td>%</td>
</tr>
<tr>
<td>TN10P (Cool nights)</td>
<td>Annual Percentage of days, minimum temp is less than 10th percentile</td>
<td>%</td>
</tr>
<tr>
<td>TN90P (Warm nights)</td>
<td>Annual Percentage of days, minimum temp is greater than 90th percentile</td>
<td>%</td>
</tr>
<tr>
<td><strong>Duration indices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSDI</td>
<td>Number of days with 6 consecutive days, where the minimum temperature is less than 10th percentile</td>
<td>Days</td>
</tr>
<tr>
<td>WSDI</td>
<td>Number of days with 6 consecutive days, where the maximum is greater than 90th percentile</td>
<td>Days</td>
</tr>
<tr>
<td><strong>Threshold indices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SU (Summer days)</td>
<td>Annual count when 90th percentile of TX (daily maximum)</td>
<td>Days</td>
</tr>
<tr>
<td><strong>Precipitation indices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Absolute indices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R×1 day (Max 1-day precipitation amount)</td>
<td>Annual maximum 1 - day precipitation</td>
<td>mm</td>
</tr>
<tr>
<td>R ×3 day(Max 3-day precipitation amount)</td>
<td>Annual maximum 3 - day precipitation</td>
<td>mm</td>
</tr>
<tr>
<td><strong>Percentile indices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R95P (Very wet day precipitation)</td>
<td>Annual total precipitation is greater than 95th percentile of observed (1971-2014) and future (2015-2050)</td>
<td>mm</td>
</tr>
<tr>
<td>R99P (Extreme wet day precipitation)</td>
<td>Annual total precipitation is greater than 95th percentile of observed (1971-2014) and future (2015-2050)</td>
<td>mm</td>
</tr>
<tr>
<td><strong>Duration indices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CDD (Consecutive dry days)</td>
<td>Maximum number of consecutive days with RR &lt; 1 mm</td>
<td>Days</td>
</tr>
<tr>
<td>CWD (Consecutive wet days)</td>
<td>Maximum number of consecutive days with RR</td>
<td>Days</td>
</tr>
<tr>
<td><strong>Threshold indices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>R10 mm (Number of heavy precipitation)</td>
<td>Annual count of days when PRCP ≥ 10 mm</td>
<td>Days</td>
</tr>
<tr>
<td>R20 mm (Number of heavy precipitation)</td>
<td>Annual count of days when PRCP ≥ 20 mm</td>
<td>Days</td>
</tr>
<tr>
<td><strong>Other indices</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRCPTOT (Annual total wet day precipitation)</td>
<td>Annual total PRCP in wet days (RR ≥ 1 mm)</td>
<td>mm</td>
</tr>
<tr>
<td>SDII</td>
<td>Simple daily intensity index</td>
<td>mm/day</td>
</tr>
</tbody>
</table>

*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)
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).

\[
\text{Magnitude change} \% = \left( \frac{\text{Sen's slope} \times \text{length of study period}}{\text{Mean}} \right) \times 100
\]  

(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 $T_{\text{Max}}$ showed a high significant (significant level at 0.05) positive trend throughout 1971-2015 (45 years). The trend lines indicated that the $T_{\text{Max}}$ over the Thanjavur delta region has increased by about 1.3 °C, 0.7 °C 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 $T_{\text{Max}}$ and $T_{\text{Min}}$. During winter, $T_{\text{Max}}$ 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 $T_{\text{Max}}$ 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 monsoon and south-west monsoon). $T_{\text{Max}}$ 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 $T_{\text{Min}}$ 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 significant increasing trend during winter and Northeast monsoon, decreasing insignificant trend at summer and Southwest monsoon (Table 4). The decadal analysis of $T_{\text{Min}}$ 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 an increasing trend in 13 stations and decreasing trend at 4 stations and it showed a large variation with a rate of change at 0.05 to 0. 31 °C per every decade for 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,
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, particularly during 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 insignificant negative change of 24.1% and 11.8%, respectively but the IMD grid point has no significant

---

**Fig. 4.** Temporal analysis of observed minimum temperature

**TABLE 4**

Trend analysis of observed Minimum temperature change

<table>
<thead>
<tr>
<th>Parameter/Period</th>
<th>$T_{Min}$</th>
<th>$Z$</th>
<th>Rate of temperature change (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ARP</td>
<td>NPT</td>
<td>IMD Grid</td>
</tr>
<tr>
<td>Annual</td>
<td>24.3</td>
<td>25.1</td>
<td>24.5</td>
</tr>
<tr>
<td>Winter</td>
<td>21.1</td>
<td>22.8</td>
<td>21.6</td>
</tr>
<tr>
<td>Summer</td>
<td>25.6</td>
<td>26.2</td>
<td>25.7</td>
</tr>
<tr>
<td>Southwest Monsoon</td>
<td>25.7</td>
<td>26.2</td>
<td>25.8</td>
</tr>
<tr>
<td>Northeast Monsoon</td>
<td>23.2</td>
<td>24</td>
<td>23.3</td>
</tr>
<tr>
<td>1st decade</td>
<td>24.3</td>
<td>25.2</td>
<td>24.2</td>
</tr>
<tr>
<td>2nd decade</td>
<td>24.3</td>
<td>25.5</td>
<td>24.5</td>
</tr>
<tr>
<td>3rd decade</td>
<td>24.3</td>
<td>24.9</td>
<td>24.4</td>
</tr>
<tr>
<td>4th decade</td>
<td>24.3</td>
<td>25</td>
<td>24.5</td>
</tr>
</tbody>
</table>

*Significant at 95% confidence level.
TABLE 5

Trend analysis of observed rainfall changes

<table>
<thead>
<tr>
<th>Parameter/Period</th>
<th>$T_{\text{Max}}$</th>
<th>$Z$</th>
<th>Rate of temperature change (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ARP</td>
<td>NPT</td>
<td>IMD Grid</td>
</tr>
<tr>
<td>Annual</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Winter</td>
<td>102.9</td>
<td>68.6</td>
<td>50.9</td>
</tr>
<tr>
<td>Summer</td>
<td>162.9</td>
<td>100.1</td>
<td>142.3</td>
</tr>
<tr>
<td>Southwest Monsoon</td>
<td>237.6</td>
<td>259.3</td>
<td>387.1</td>
</tr>
<tr>
<td>Northeast Monsoon</td>
<td>490.8</td>
<td>931.7</td>
<td>697.9</td>
</tr>
<tr>
<td>1$^{\text{st}}$ decade</td>
<td>1338.6</td>
<td>1451</td>
<td>1262.5</td>
</tr>
<tr>
<td>2$^{\text{nd}}$ decade</td>
<td>1050.8</td>
<td>1279.4</td>
<td>1080.5</td>
</tr>
<tr>
<td>3$^{\text{rd}}$ decade</td>
<td>1163</td>
<td>1276.9</td>
<td>1295.1</td>
</tr>
<tr>
<td>4$^{\text{th}}$ decade</td>
<td>1203.5</td>
<td>1392.1</td>
<td>1408.3</td>
</tr>
</tbody>
</table>

The average of rainfall in different seasons with no significant changes

The average of rainfall in different seasons with no significant changes
4.3.1. Temperature trend analysis

The projected change rate of $T_{\text{Max}}$ and $T_{\text{Min}}$ for the study period under seasonal and decadal is given in Table 6. The trend of $T_{\text{Max}}$ is projected to significantly increase at the rate of 1.05 °C between 2015 and 2050. The seasonal change of $T_{\text{Max}}$ 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 $T_{\text{Max}}$ 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 $T_{\text{Min}}$ 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 $T_{\text{Min}}$ for different seasons shows a 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 $T_{\text{Min}}$ revealed a no significant increasing trend at 0.4 °C, 0.9 °C and 0.2 °C during the 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
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 convective rainfall 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 temperature trends in the future scenario has shown a significant increasing trend.

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

*Significant at 95% level. Mean, Z value and change percentage also calculated for projected rainfall.
winter, summer, south-west monsoon and northeast monsoon with a change percentage of -13, -54, -6 and respectively are shown in Figs. 7(a-c) and presented in Table 8. All the temperature indices except CSDI, showed a significant change in trend rate at 95% confidence level during the observed period. Also, the rate of change for warm 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

<table>
<thead>
<tr>
<th>Category</th>
<th>Indices</th>
<th>Average</th>
<th>SD</th>
<th>Change rate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Observed</td>
<td>Projected</td>
<td>Observed</td>
</tr>
<tr>
<td>Threshold</td>
<td>SU35</td>
<td>36</td>
<td>42</td>
<td>14.23</td>
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<tr>
<td></td>
<td>TNn</td>
<td>18.8</td>
<td>20</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>TNx</td>
<td>28.3</td>
<td>29.8</td>
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<tr>
<td></td>
<td>TXn</td>
<td>25.9</td>
<td>27.9</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>TXx</td>
<td>38.9</td>
<td>39.6</td>
<td>0.58</td>
</tr>
<tr>
<td>Absolute</td>
<td>TX10p</td>
<td>10.5</td>
<td>10.1</td>
<td>6.43</td>
</tr>
<tr>
<td></td>
<td>TX90p</td>
<td>10.4</td>
<td>9.8</td>
<td>7.71</td>
</tr>
<tr>
<td></td>
<td>TN10p</td>
<td>9.9</td>
<td>9.9</td>
<td>5.48</td>
</tr>
<tr>
<td></td>
<td>TN90p</td>
<td>9.5</td>
<td>9.7</td>
<td>7.1</td>
</tr>
<tr>
<td>Percentile</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>TX10p</td>
<td>10.5</td>
<td>10.1</td>
<td>6.43</td>
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<tr>
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<td>10.4</td>
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<td>7.71</td>
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<td></td>
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<td>5.48</td>
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<tr>
<td></td>
<td>TN90p</td>
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<td>7.1</td>
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<tr>
<td>Duration</td>
<td>CSDI</td>
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<td>6</td>
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<tr>
<td></td>
<td>WSDI</td>
<td>9</td>
<td>12</td>
<td>12.05</td>
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</tbody>
</table>

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

### TABLE 9
Statistical analysis of extreme rainfall indices

<table>
<thead>
<tr>
<th>Category</th>
<th>Indices</th>
<th>Average</th>
<th>SD</th>
<th>Magnitude Change %</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Observed</td>
<td>Projected</td>
<td>Observed</td>
</tr>
<tr>
<td>Duration</td>
<td>CDD (days)</td>
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<td>54</td>
<td>28.2</td>
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<tr>
<td></td>
<td>CWD (days)</td>
<td>12</td>
<td>21</td>
<td>6.8</td>
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<td>Percentile</td>
<td>R95p</td>
<td>336.2</td>
<td>227.5</td>
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<td>R99p</td>
<td>114.2</td>
<td>67.8</td>
<td>174.6</td>
</tr>
<tr>
<td>Threshold</td>
<td>R10mm</td>
<td>37.5</td>
<td>34</td>
<td>12.5</td>
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<tr>
<td></td>
<td>R20mm</td>
<td>20</td>
<td>14</td>
<td>8.02</td>
</tr>
<tr>
<td>Absolute</td>
<td>R×1 day</td>
<td>102</td>
<td>55</td>
<td>51.9</td>
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<tr>
<td></td>
<td>R× 3 day</td>
<td>187</td>
<td>145</td>
<td>104.6</td>
</tr>
<tr>
<td>Other</td>
<td>PRCPTOT (mm)</td>
<td>1268.4</td>
<td>1004.9</td>
<td>460.1</td>
</tr>
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<td></td>
<td>SDII</td>
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<td>8.9</td>
<td>54.9</td>
</tr>
</tbody>
</table>

*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 indicate that 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 Thanjavur delta region. Rai et al. (2020) studied the extreme rainfall indices during 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. $T_{\text{Max}}$ showed a significant warming trend in both datasets (stations and the IMD grid point), but $T_{\text{Min}}$ showed relatively no change of trend in ARP and an insignificant decreasing trend in NPT and IMD grid for 1970 to 2014. The projected $T_{\text{Max}}$ and $T_{\text{Min}}$ showed a significant increasing trend. The observed rainfall showed 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 extremes indices 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


