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Original Research

Change Point Detection and Trend Analysis of Rainfall and Temperature Series over the Vellar River Basin

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Abstract

Rainfall and temperature have been extensively considered as an initial point toward the apprehension of climate change progressions, establishing one of the important constituents of the hydrological cycle. The purpose of the present study is to examine the variability of rainfall and temperature for better understanding of the hydrological environment of the river basin located in northern Tamil Nadu. Mann-Kendall and Sen's slope tests were employed for monthly, seasonal, and annual temperatures, and also for annual maximum daily rainfall, seasonal, and annual rainfall statistics. A change point detection test was applied for annual maximum and minimum, mean temperature, and annual precipitation series. The results revealed that all the monthly, seasonal, and annual maximum, minimum, and mean temperatures have a significant greater rising trend. The magnitude of increasing trends in NEM (northeast monsoon) and SWM (southwest monsoon) are greater than that of summer and winter seasons for almost all the rain gauge stations. The maximum temperature and minimum temperature change points are identified in the years 1985 and 2001 and 1987 and 2013, respectively. From the mean annual temperature, it is seen that the change point is present in 1983-88 and 2000-04 at 100% confidence interval.

Keywords: trend, change point, climate change, hydrological environment, river basin

Introduction

The Fifth Assessment Report (AR5) released by the Intergovernmental Panel on Climate Change documented that the rise in global temperature since the last century is definite both over land and ocean and that the last three decades have been warmer compared to any other previous decades in instrumental records. Changes in precipitation in particular extreme events can intensely increase the vulnerable population and affect the adaptation capability under the predicted future climate change scenarios by the middle and at the end of the 21st century [1]. The work [2] reviewed numerous studies on trend analysis of rainfall, temperature, and rainy days all over India and perceived that the trend and its magnitude is assessed recurrently by Mann-Kendall and Sen's slope estimation tests. Furthermore, they documented that the river basin in the northern part of Tamil Nadu is experiencing an increase in rainfall and decrease in rainy days, which implies that more intense floods will occur. A significant

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change in discharge in the middle reach of the Yellow river analyzed by the non- parametric Mann-Kendall and Pettitt tests revealed that the methods act as a powerful tool for evaluating the previously implemented soil and water conservation measures [3]. A Mann-Kendall trend test is utilized to analyze evapotranspiration sensitivity to changes in meteorological variables, revealing that the method can be used as a water management tool with proper measures to evade climate change impacts [4]. A highly increasing annual temperature trend is identified with the long-term data 1901-2012 using Mann-Kendall test at 95% confidence level for Tbilisi, Georgia, and also reported that monthly temperature data provided insignificant trends [5].

A study [6] investigated trend and change point detection of annual and seasonal precipitation and maximum, minimum, and mean temperature for southwest Iran. The results revealed insignificant trends in precipitation and significant increasing trends in temperature using Mann-Kendall and Pettit's test. The change points are observed in temperature time series that began in the 1990s. The author [7] analyzed the time series of trend and change point detection for temperature, relative humidity, wind speed, sunshine hour, and pan evaporation using non-parametric tests. Their results showed that a significant change point was present during 1900-2000, and a significant rising trend observed in temperature and falling trend is reported for other climate variables. The agricultural and livestock sectors are affected not only by rainfall and temperature, but also by other climatic variables such as wind velocity and relative humidity [8].

A work [9] compared four different change point detection methods such as Bayesian analysis of change points (BCP), wild binary segmentation (WBS), E-agglomerative algorithm (E-Agglo.), and iterative robust detection (IR). Their results implied that BCP gives incorrect change points, and that E-Agglo and WBS provide correct location and the number of change points, but E-Agglo is computationally costlier and WBS takes less time for estimation. If a dataset has both trend and change point, analyzing with only one method can give erroneous results. A new approach is developed using locally weighted polynomial regression and segmented regression for trend and change point detection for water quality parameters. The method helps in environmental and pollution control decision making especially suited for irregular datasets [10]. Several studies have been carried out by researchers all over the world in trend analysis and change point detection [11-14].

The present work attempts to understand the variability of rainfall and temperature in order to improve the hydrological environment of the river basin. The study area is located in northern Tamil Nadu and covers an area of 7,520 km^2. The boundaries of the basin are delineated by the Bay of Bengal in the eastern side, the Kalvarayan Hills in the western side, by Ponnaiyar Basin in the northern side, by Paravanar Basin on the northeastern side, and by Cauvery Basin on the southern side (Fig. 1).

Material and Methods

Mann-Kendall Test for Trend Detection

The Mann-Kendall test is a widely used non-parametric test utilized for trend detection in environmental sciences

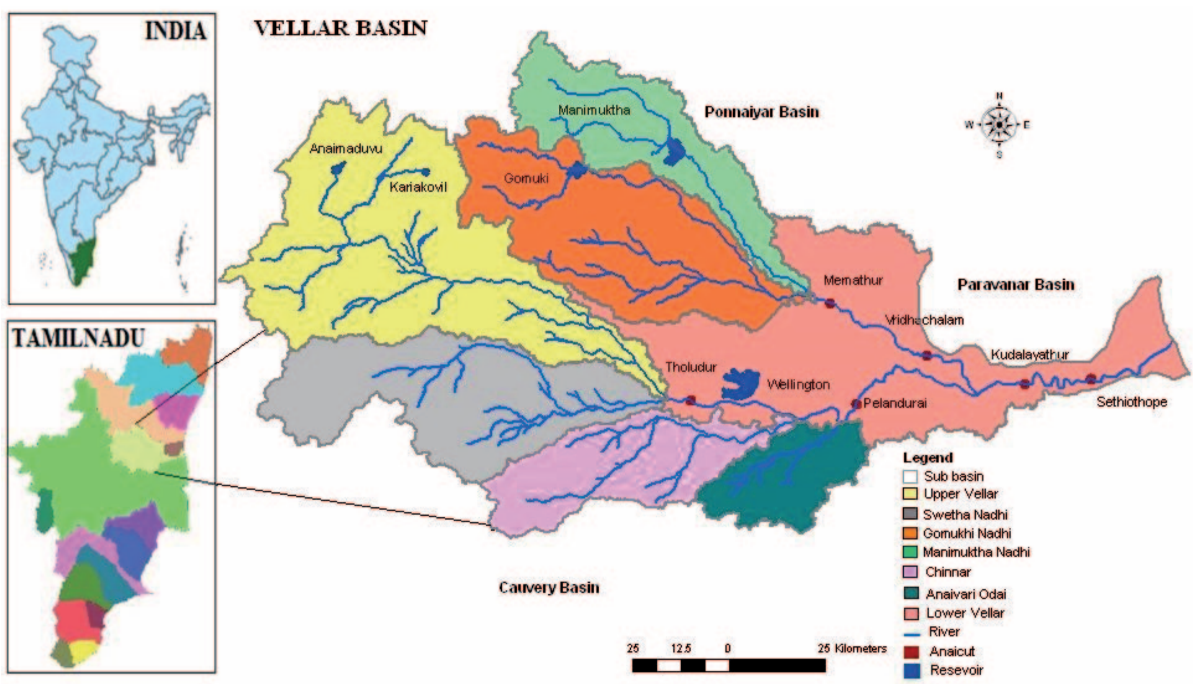

Fig. 1. Vellar River Basin of Tamil Nadu, India.

[15-16]. The standardized test statistics Z and Mann-Kendall statistic S is given by,

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\ (x_j - x_i) \qquad 3.1$$

$$sgn\ (x_j - x_i) = \begin{cases} +1, if\ X_j - X_i > 0 \\ 0, if\ X_j - X_i = 0 \\ -1, if\ X_j - X_i < 0 \end{cases} \qquad 3.2$$

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \qquad 3.3$$

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, if\ S > 0 \\ 0 \ldots\ldots\ldots, if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, if\ S < 0 \end{cases} \qquad 3.4$$

The statistical parameters are: X_i and X_j consecutive data values in the year i and j, n is the number of recorded data, tp is the number of ties for the pth values, and q is the number of tied values.

The rising trend values are identified with the positive Z values, whereas the negative Z values indicate a decreasing trend of the corresponding time series. The null hypothesis is represented as H_0 and alternate hypothesis is denoted as H_1 in the two-tailed test. If there is no trend in the series, H_0 is rejected. If there is a trend in the series, Z value is acquired from the standard normal distribution with the pre-stated significance level.

Sen's Slope Estimator

The magnitude of the trend is quantified by a median-based non-parametric slope estimator known as Theil-Sen method [17-18]. The computation of slope is given by Equation 3.5:

$$\beta = median \frac{x_j - x_k}{j-k} \ldots\ldots \forall \ldots k < j \qquad 3.5$$

…where x_j and x_k are the consecutive data values of series in the years j and k, and β is the magnitude of the trend slope of data values.

Change Point Detection Method

The change point detection method is an effective tool to recognize the Climate erraticism in the historical climate data series. The recognition of change point location in the climate series is vital since it modifies processes in the hydrological cycle. A combination of cumulative sum charts (CUSUM) and boot strapping is a method used to detect changes by several iterations [19]. The cumulative sum S_i is estimated by equation 3.6 as follows:

$$S_i = S_{i-1} + X_i - \bar{X} \qquad 3.6$$

…where $S_0 = 0$; initial cumulative sum S_0; i = 1, 2, 3,…………., 25; and $\bar{X}$ is the average of the sample series.

The difference between current value and the average to the previous sum are added to compute the CUSUM values. The upward and downward slope indicates that the period of time where the values are above or below the overall average. At the change point, the series having two means are split into segments and through the iterative process mean square of estimates is computed till the minimum mean square of error (MSE) is reached. This shows the change of time and ultimately endorses the change in the climate system. The boot strapping-based confidence level is utilized to determine the significance of the change point as given in Equation 3.7:

$$Confidence\ level = 100 \times \frac{X}{N}\% \qquad 3.7$$

…where $S_{\sim}$ is the difference between the maximum and minimum CUSUM values, X is the number of bootstrapped $S_{\sim}$ values greater than the original $S_{\sim}$ values, and N is the number of bootstraps.

The change point analyzer is a Microsoft Excel-based add-on software utilized for change point detection in the dataset. This analyzer is an efficient tool that detects the exact year when the change or shift that has been taken place by using MSE and CUSUM charts. The level of change and confidence levels indicates the major change point in the entire dataset. The likelihood of climate shift from the observation year is shown by the steady rise or decline lines in the CUSUM plots, which are computed by equation 3.7. If there is no change present in the data series, then the values normally oscillate between the horizontal axis.

Results and Discussion

Based on the Mann-Kendall test and Change point analyzer, the trends and change points were identified for the rainfall and temperature data. Twenty-two rain gauge stations and one temperature station is involved in the present study as depicted in Fig. 2.

Analyzing Monthly, Seasonal, and Annual Temperatures

We utilized the past 38 years of data for trend analysis and change point detection studies. The monthly, seasonal, and annual means of maximum, minimum, and mean temperatures indicated that there is an increasing trend. For all cases, the trends are considered statistically significant when α value is equal to 0.05. The maximum temperatures in March and September showed a significantly higher rising trend, with highest Z values of 2.96 and 2.73, respectively. The minimum temperatures in May and June specified that significant higher rising trend with highest Z values as 4.46 and 3.69, respectively.

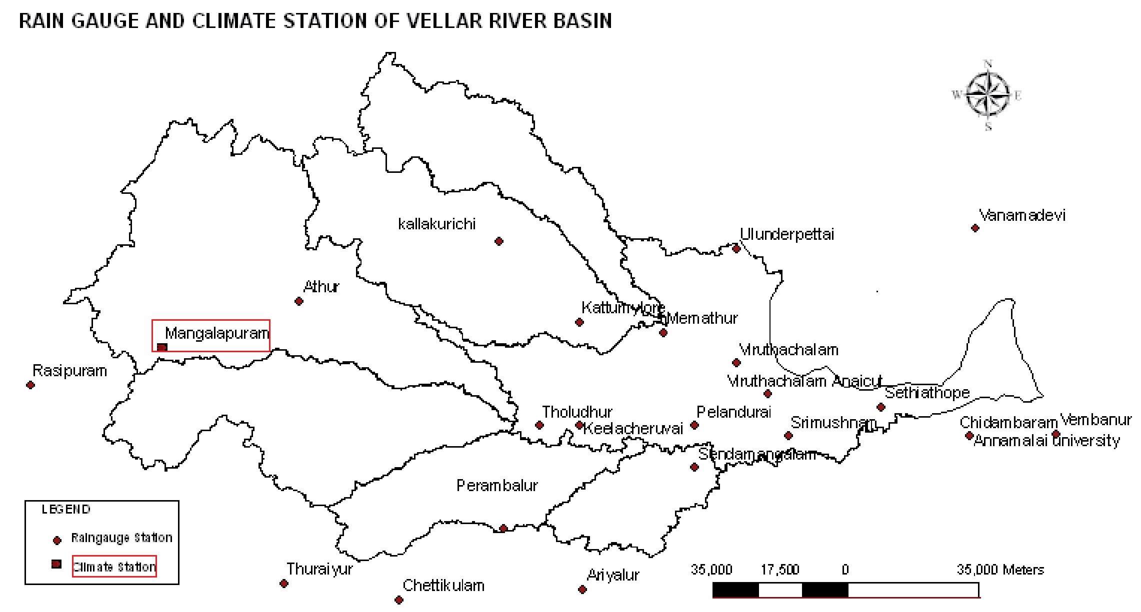

Fig. 2. Rain gauge and climate station of Vellar River Basin.

However, the minimum increasing trend is observed in the months of October and December for maximum temperature, and January and September for minimum temperature (Table 1). The mean temperature indicated that June and November see a significant rising trend with greater Z values as shown in Table 1. All the monthly, seasonal, and annual maximum, minimum, and mean temperature results obtained from the Mann-Kendall test

Table 1. Mann-Kendall statistics for monthly, seasonal, and annual temperatures.

Time Scale	Maximum Temperature			Minimum Temperature			Mean Temperature		
Monthly Statistics	Z	Sen's slope	P	Z	Sen's slope	P	Z	Sen's slope	P
January	2.13	0.087	0.033	1.96	0.068	0.050	2.28	0.081	0.022
February	2.69	0.093	0.007	3.00	0.081	0.028	2.59	0.076	0.010
March	2.96	0.099	0.003	2.64	0.032	0.008	2.11	0.048	0.035
April	2.59	0.059	0.010	3.52	0.025	0.005	2.00	0.025	0.046
May	2.68	0.051	0.048	4.46	0.056	<0.0001	2.43	0.028	0.014
June	2.02	0.05	0.044	3.69	0.045	<0.0001	3.35	0.06	<0.0001
July	2.07	0.061	0.037	2.96	0.03	0.003	2.27	0.044	0.023
August	2.45	0.068	0.014	2.86	0.036	0.004	3.28	0.051	<0.0001
September	2.73	0.078	0.006	2.00	0.033	0.046	3.09	0.054	0.002
October	1.48	0.053	0.011	2.18	0.037	0.029	2.95	0.057	0.003
November	2.53	0.039	0.028	2.03	0.036	0.041	3.48	0.077	<0.0001
December	1.52	0.065	0.034	2.37	0.085	0.018	2.28	0.083	0.022
Seasonal statistics									
Winter	2.27	0.085	0.022	2.57	0.067	0.009	2.69	0.092	0.007
Summer	1.68	0.048	0.047	4.96	0.068	<0.0001	2.36	0.023	0.018
Swm	2.86	0.087	0.004	3.07	0.04	0.002	2.96	0.043	0.003
Nem	2.35	0.052	0.016	2.03	0.046	0.041	1.75	0.029	0.081
Annual Statistics	2.23	0.037	0.025	3.10	0.043	0.002	2.11	0.04	0.035

Table 2. Mann-Kendall statistics for annual maximum daily, seasonal, and annual rainfall.

Stations	Amdr Statistics		Seasonal Statistics								Annual Statistics	
			SWM		NEM		Winter		Summer			
	S	Z	S	Z	S	Z	S	Z	S	Z	S	Z
Ariyalur	1.00	1.12	-5.491	-2.06	6.175	2.03	0.00	-0.13	-0.755	-0.26	-0.217	1.12
Athur	0.794	1.61	1.672	1.25	6.133	2.42	0.00	-1.03	1.311	1.28	9.066	1.61
Chettikulam	0.25	0.50	-2.221	-0.32	1.682	0.79	0.00	-0.72	0.067	0.23	-0.877	0.50
Chidambaram	0.726	0.62	-2.625	-1.62	8.245	1.88	0.00	0.44	0.11	0.39	6.39	0.62
Kallakurichi	-3.132	-0.92	-10.82	-4.29	-10.46	-3.58	0.00	-2.60	-1.729	-2.88	-23.17	-0.92
Kattumylore	1.192	1.45	-6.182	-2.45	9.639	3.39	0.00	-1.00	-0.99	-0.29	3.98	1.45
Keelacheruvai	2.393	2.40	2.961	1.31	13.57	3.10	-0.109	-1.24	1.674	1.74	18.836	2.40
Memathur	2.129	3.05	-12.46	-3.16	4.943	1.99	-0.024	-1.24	-0.987	-0.45	-8.84	3.05
Parangipettai	0.684	0.96	-1.618	-0.28	10.15	2.25	0.041	0.57	2.078	1.83	11.85	0.96
Pelandurai	0.854	1.07	-0.346	0.31	13.36	3.65	0.00	0.74	2.613	1.87	14.284	1.07
Perambalur	0.836	1.78	2.01	1.31	8.133	2.16	0.00	-0.24	2.748	2.42	16.299	1.78
Rasipuram	-0.365	-0.36	6.04	-2.42	1.443	0.79	0.00	-1.88	-0.351	0.11	-6.418	-0.36
Sendamangalam	-1.129	-1.93	-4.50	-1.69	1.661	0.60	0.00	-0.26	-0.972	-0.24	-1.944	-1.93
Sethiothope	2.218	2.34	-0.764	0.05	14.68	3.00	0.074	0.56	1.438	1.65	13.814	2.34
Sethiothope Anicut	2.342	2.66	-3.616	-1.59	9.832	2.19	0.00	0.43	1.683	1.46	4.967	2.66
Srimushnam	2.776	2.87	-2.502	-0.54	8.976	2.16	0.00	0.10	-0.081	0.28	3.519	2.87
Tholudur	2.867	2.39	4.121	1.77	16.42	4.52	0.00	-0.25	3.063	2.21	29.00	2.39
Thuraiyur	-0.271	-0.45	-1.587	-0.31	1.092	0.79	0.00	0.03	2.829	1.64	3.046	-0.45
Ulundurpet	1.913	2.64	-4.323	-1.25	10.13	3.32	0.00	0.00	1.227	1.41	7.145	2.64
Vembanur	0.643	0.49	0.00	0.45	0.00	0.63	0.00	-0.26	2.206	1.95	1.189	0.49
Virudhachalam	1.512	1.35	-1.764	-0.32	12.60	3.36	0.00	0.05	2.088	1.01	13.092	1.35
Virudhachalam Anicut	0.429	0.58	-10.46	-3.09	-8.445	-1.34	0.00	-1.75	-2.057	-2.21	-24.07	0.58

revealed that a significant greater rising trend is present in the series. The magnitude of Sen's slope of all the monthly, seasonal, and annual maximum, minimum, and mean temperatures specifies that there is a significant rising trend in the study area. The maximum temperature represented the greatest values of 41.6ºC, 40.4ºC, and 38.9ºC in 2002 during April, March, and summer, respectively. The greatest values of 26.9ºC, 25.7ºC, and 25.1ºC in 2003 during May, April, and June is identified for minimum temperature. The magnitude of annual mean maximum temperature shows an increasing trend of 0.2ºC and 0.6ºC per decade.

A warming trend is observed from both maximum and minimum temperature characteristics. A significant rising trend of mean annual temperature shows that there is an alarming global warming signal expressed over the entire river basin. An increase of 0.5ºC in the annual mean temperature is noted in the recent decade within the study period of 38 years. Thus the results indicate that there is a consistent warming trend during the previous three decades. The greatest monthly temperatures of 41.6ºC and 40.4ºC are noticed in April and March, and the lowest monthly temperatures of 17ºC and 18ºC are observed in January and December.

Analying Annual Maximum, Seasonal, and Annual Precipitation

The Mann-Kendall trend test is carried out for the rainfall series of the 22 rain gauge stations located in the river basin. The estimated Mann-Kendall Z and p values of each station for annual maximum, seasonal, and annual time scales are shown in Tables 2-3. The seasonal rainfall time series are more substantial than annual time series because they are subjected to greater inter-annual variability. The trend results were abbreviated as IT (increasing trend), DT (decreasing trend), and NT (no trend) in Table 3. A statistically significant increasing trend is seen in the AMDR statistics of six stations: Keelacheruvai, Memathur, Sethiothope, Sethiothope

Table 3. Trend analysis of annual maximum daily, seasonal, and annual rainfall.

Stations	Amdr Statistics		Seasonal Statistics								Annual Statistics	
			SWM		NEM		Winter		Summer			
	P	Trend	P	Trend	P	Trend	P	Trend	P	Trend	P	Trend
Ariyalur	0.263	NT	0.024	DT	0.111	NT	0.644	NT	0.535	NT	0.988	NT
Athur	0.108	NT	0.433	NT	0.019	IT	0.196	NT	0.433	NT	0.045	IT
Chettikulam	0.614	NT	0.438	NT	0.701	NT	0.342	NT	0.951	NT	0.842	NT
Chidambaram	0.538	NT	0.063	NT	0.173	NT	0.815	NT	0.926	NT	0.317	NT
Kallakurichi	<0.0001	DT	0.0001	DT	0.001	DT	0.006	NT	0.002	DT	<0.0001	DT
Kattumylore	0.148	NT	0.0009	DT	0.002	IT	0.209	NT	0.457	NT	0.415	NT
Keelacheruvai	0.016	IT	0.274	NT	0.003	IT	0.132	NT	0.239	NT	0.009	IT
Memathur	0.002	IT	0.001	DT	0.092	NT	0.133	NT	0.403	NT	0.223	NT
Parangipettai	0.338	NT	0.570	NT	0.065	NT	0.651	NT	0.092	NT	0.190	NT
Pelandurai	0.284	NT	0.939	NT	0.001	IT	0.729	NT	0.085	NT	0.002	IT
Perambalur	0.074	NT	0.348	NT	0.065	NT	0.749	NT	0.024	IT	0.005	IT
Rasipuram	0.721	NT	0.007	DT	0.634	NT	0.038	NT	0.724	NT	0.223	NT
Sendamangalam	0.050	DT	0.059	NT	0.509	NT	0.634	NT	0.466	NT	0.770	NT
Sethiothope	0.019	IT	0.747	NT	0.011	IT	0.639	NT	0.204	NT	0.065	NT
Sethiothope Anicut	0.008	IT	0.051	NT	0.075	NT	0.923	NT	0.239	NT	0.415	NT
Srimushnam	0.004	IT	0.348	NT	0.086	NT	0.923	NT	0.877	NT	0.701	NT
Tholudur	0.017	IT	0.179	NT	<0.0001	IT	0.575	NT	0.107	NT	0.0001	IT
Thuraiyur	0.650	NT	0.451	NT	0.678	NT	0.924	NT	0.086	NT	0.364	NT
Ulundurpet	0.008	IT	0.104	NT	0.003	IT	0.759	NT	0.386	NT	0.179	NT
Vembanur	0.626	NT	0.582	NT	0.507	NT	0.634	NT	0.029	IT	0.521	NT
Virudhachalam	0.180	NT	0.476	NT	0.003	IT	0.799	NT	0.227	NT	0.08	NT
Virudhachalam Anicut	0.559	NT	0.002	DT	0.17	NT	0.059	NT	0.014	DT	0.013	DT

anaicut, Srimushnam, and Tholudur and Ulundurpet. Seasonal trend statistics indicated an increasing trend observed for Perambalur and Vembanur stations and a decreasing trend in Kallakurichi and Virudhachalam anaicut stations in summer. A statistically insignificant trend is perceived in all the stations for winter, and a decreasing trend was observed in six stations, and the other stations are having a statistically insignificant trend for the SWM season shown in Table 3. For the NEM season, a statistically significant increasing trend is specified in eight stations except Kallakurichi, which shows a decreasing trend and other stations are having an insignificant trend as depicted in Table 3. A statistically significant increasing trend resulted in five stations except Kallakurichi and Vridhachalam Anaicut stations, which shows a decreasing trend, and other stations are having an insignificant trend as depicted in Table 3.

The Sen's slope is utilized to compute trend magnitude. In AMDR statistics, the greatest increase in trend magnitude is seen in Memathur station by 3.05 mm/10 years. Sendamangalam station has a decreasing rainfall trend magnitude of 1.9 mm/10 years. The magnitude of increasing trends in NEM and SWM are greater than that of summer and winter seasons for almost all the stations. The 2005 year is the surplus year in the period of study, with rainfall of 1,470 mm, which is above the average rainfall.

Analysis of Change Points

The recognition of change points is a statistical technique that plays a vital role in spotting climate jumps in the whole climatological data period. The change points were identified for maximum, minimum, and mean temperatures. It is clearly evident that the maximum, minimum, and mean temperature values appear to be outside the control limits, which reveals that change took place during the examined data period (Fig. 3).

The level represented in Fig. 4 implies change and is strongly linked with climate change. The maximum

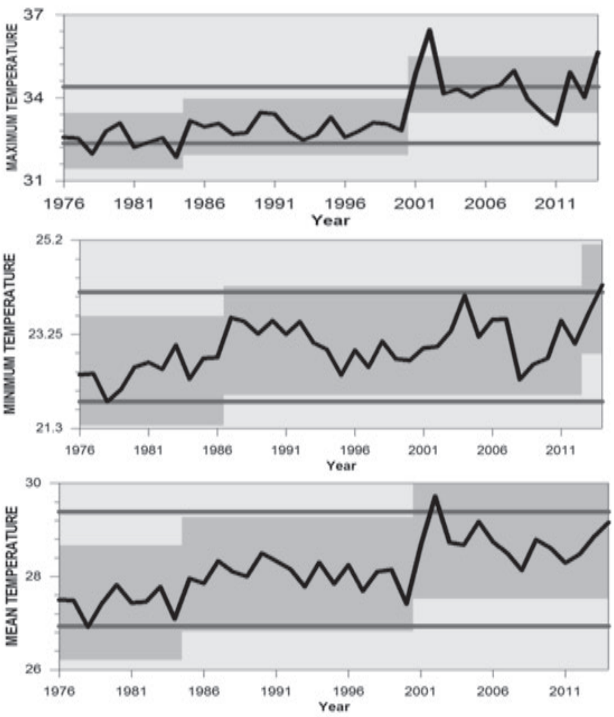

Fig. 3. Identifying change points for annual temperature.

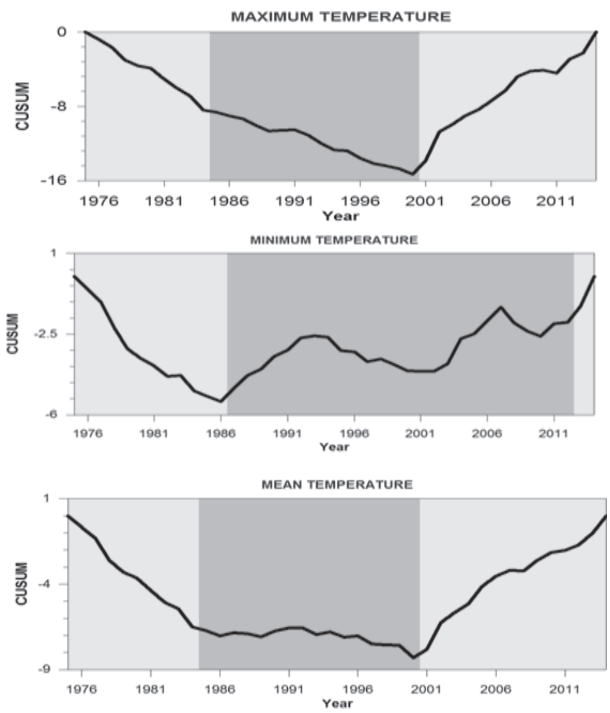

Fig. 5. CUSUM chart for annual temperature.

temperature change point occurred in 1985 and 2001 at a confidence level of 100% and 94% at levels 2 and 1, respectively. Before the existence of the change the mean maximum temperature was 32.94°C during 1985, and after the change the value was 34.46°C. In the case of minimum temperature, the change point appeared in 1987 and 2013 at 100% and 91% confidence interval at levels 1 and 3, respectively. Earlier to the change, the minimum temperature is 23.11°C and after the change, it had a value of 23.97°C. From the mean annual temperature, it is seen that the change point is present in 1983-1988 and 2000-2004 at 100% confidence interval at levels 4 and 3, respectively. The change point years are clearly shown in Fig. 4. The change point magnitude is computed using the ratio of average of climate data after the change point to the before the change point occurrence is found to be 0.99, 1.00, and 1.00, correspondingly.

The present study shows a statistical importance of change point that can be seen from the late 1980s at a confidence interval setting of 95% with 1,000 boot straps and a method of mean square of estimates. The process shifts estimation and generation of trends are well

	Year	Confidence Interval	Conf. Level	From	To	Level
Maximum Temperature	1985	(1980, 1989)	94%	32.438	32.943	2
	2001	(2001, 2004)	100%	32.943	34.465	1
Minimum Temperature	1987	(1985, 1993)	100%	22.494	23.119	1
	2013	(1997, 2013)	91%	23.119	23.978	3
Mean Temperature	1985	(1983, 1988)	100%	27.437	28.048	4
	2001	(2000, 2004)	100%	28.048	28.754	3

Fig. 4. Estimated change point years for annual temperature.

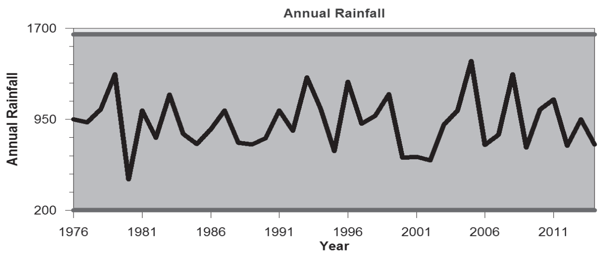

Fig. 6. Estimated change point years for annual rainfall.

indicated using CUSUM charts. The CUSUM chart of maximum, minimum, and mean temperatures obtained by the boot-strapping technique has a noticeable change at α = 0.05, which is depicted by modified background color in Fig. 5. A clear upward trend is represented in CUSUM charts and a sudden temperature change is found in the late 1980s and 2000s. The increasing trend continues until 2014. The estimated change point years of annual rainfall is shown in Fig. 6. The results of annual rainfall change point years shows no major change, which is due to the characteristic of highly erratic and inter annual variability.

Conclusions

The variability of rainfall and temperature due to probable human involvement or change in climate is essential for planning and managing water resources at a regional level. Different non-parametric tests were used for trend analysis and change point detection. The results show that all monthly, seasonal, and annual maximum, minimum, and mean temperatures have a significant greater rising trend. The magnitude of increasing trends in NEM and SWM are greater than those of summer and winter seasons for almost all the rain gauge stations. The previous studies also validated that the river basin in the Northern part of Tamil Nadu is experiencing an increase in temperature and rainfall, and a decrease in rainy days. The maximum temperature and minimum temperature change points are identified in 1985 and 2001, and 1987 and 2013, respectively. From the mean annual temperature, it is seen that the change point is present in 1983-88 and 2000-04 at 100% confidence interval. The important change points observed in maximum, minimum, and mean temperatures implies that there is an influence of fast-growing industrial activities in the basin and also the increase in temperature occurred by change in land use pattern, which is caused by the effect of excessive stream flow during monsoon season and thereafter a long dry period prevailed in the basin. The present study is very helpful in framing climate change scenarios and it is based on the revealed characteristics of climate variables at the regional level.

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