A Detailed Statistical Analysis of Rainfall of Thoothukudi District in Tamil Nadu (India)

Sathyanathan Rangarajan, Deeptha Thattai, Abhishek Cherukuri, Tanmoy Akash Borah, Joel Kuncheria Joseph and Arun Subbiah

Abstract The adverse change in climate in recent years influences different meteorological variables like precipitation, temperature and evapotranspiration. Agriculture and other related sectors which depend on the monsoon and timed irrigation schedules are seriously affected due to the changing pattern of rainfall. Thoothukudi, one among the four mega cities of Tamil Nadu, is a major driver of industrialisation, and the impact due to industrialisation on meteorological variables is unknown. In the present study, statistical analysis is carried out to ascertain possible trend in monthly, seasonal and annual historical time series of rainfall of Thoothukudi district in Tamil Nadu between the years 1901 and 2002. A detailed statistical analysis is performed by adopting most commonly used methods like Mann–Kendall's test, Sen's slope, departure analysis, rainfall anomaly index and precipitation concentration index. The north-east and south-west monsoons contribute more than 73% to the annual rainfall. A significant decreasing trend was observed for January, and no significant trend was found for other months and seasons. About 72% of the years received normal amount of rainfall; with no scanty and no rain category observed for the past 102 years. Moderate concentration of annual rainfall is witnessed with the mean PCI value about 15.

Keywords Tuticorin · Percentage departure · RAI · Mann–Kendall test
Sen's slope · Frequency analysis and probability distribution · PCI

1 Introduction

Rainfall, being a major component of the water cycle, is an important source of freshwater on the planet and contributes around 2,16,000 m^3 of freshwater. According to the scientific evidence collected globally over a period of 100 years, climate

S. Rangarajan (✉) · D. Thattai · A. Cherukuri · T. A. Borah · J. K. Joseph · A. Subbiah
Department of Civil Engineering, SRM Institute of Science and Technology,
Kattankulathur 603203, Tamil Nadu, India
e-mail: sathyanathan.r@ktr.srmuniv.ac.in

and temperature have begun to change globally beyond normal averages, and as a result, change in trend of rainfall has been detected. Reports show that there is a probability of global climate change in this century itself [1]. Variations in the global hydrological cycle influence the development of organisms [2]. A proper knowledge and understanding of variability of rainfall that occurs over a wide range of temporal scales can help with better risk management practices. Various researches indicate that precipitation patterns have been altered leading to increase in extreme weather events as result of global warming [3–6]. The global monsoon precipitation had an increasing trend from 1901 to 1955 and a decreasing trend later in the twentieth century [7]. While analysing precipitation trend and change point detection, nonparametric methods are usually preferred [8–10].

In a mainly agricultural country like India, which is dependent on the monsoon, rainfall data is necessary to plan and design water resource projects. Guhathakurta and Rajeevan pointed out the importance of studying the trend in monsoon rainfall in India [11]. Joshi et al. [12] attempted to study annual rainfall series of subregions of India to identify the climate changes. Sarkar and Kafatos [13] analysed the Indian precipitation pattern and its relationship with ENSO. Parthasarathy and Dhar studied the annual rainfall from 1901 to 1960 and found an increasing trend in and around Central India and a decreasing trend in some regions of eastern India [14].

Pal and Al-Tabbaa [15] predicted a decrease in pre-monsoon extreme rainfall and increased frequency of no rain days for Kerala, which could lead to water scarcity. Thomas and Prasanna Kumar observed a decreasing trend in south-west monsoon season and an increasing trend for the other seasons in Kerala [16].

Tamil Nadu experiences four monsoon seasons in a year, viz. north-east (NEM), south-west (SWM), pre-monsoon (Pre-mon) and winter. The aim of the present study is to analyse precipitation trends if any by various statistical methods for a 102-year rainfall data (1901–2002) of Thoothukudi district, Tamil Nadu.

1.1 Study Area

Thoothukudi (also called Tuticorin) district is situated along the Coromandel Coast of the Bay of Bengal, centred at 8.906°N latitude and 78.019°E longitude (Fig. 1). The district is located about 590 km south of Chennai, the state capital. The bounding districts are Virudhunagar, Ramanathapuram (north) and Tirunelveli (south and west). The Gulf of Mannar borders on the east. Tuticorin port is one of the fastest growing ports in India. The 4621 km^2 district has a coastline of 121 km. As of 2011, the population was 1,750,176. The minimum and maximum ambient temperatures in the area as per IMD Tuticorin are 19.4 °C (January) and 38.3 °C (May), respectively. The relative humidity varies from 52 to 90%. The normal annual rainfall in the region is 625.8 mm. The site falls under seismic zone II.
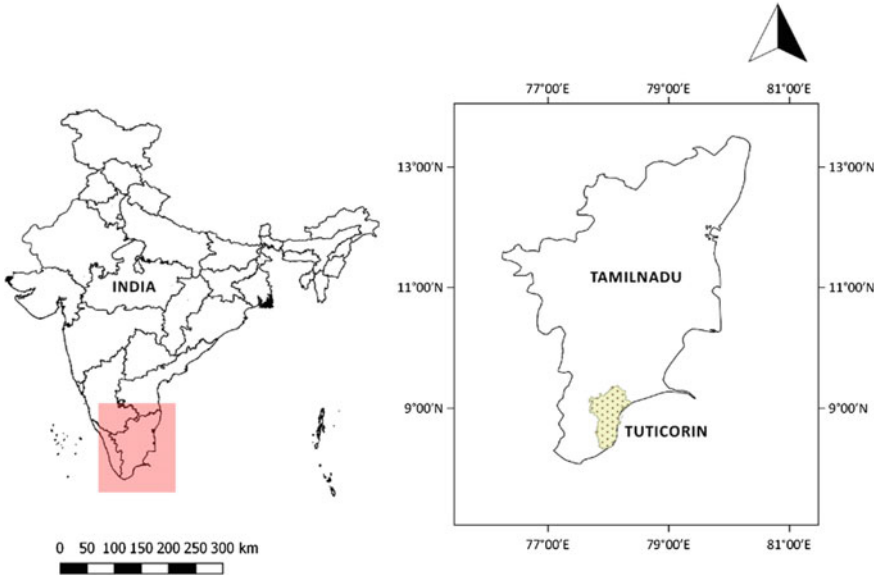
Fig. 1 Location map of Thoothukudi (Tuticorin) district

2 Methodology

2.1 Mann–Kendall Trend Test

Mann–Kendall's test is a rank-based nonparametric test to analyse time series data for consistently increasing or decreasing trends. In this test, the null hypothesis (H_o) is that there has been no trend in precipitation over time; the alternative hypothesis (H_a) is that there has been a trend (increasing or decreasing) over time [17, 18]. The test statistic S is defined as:

$$\sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sig}(X_j - X_i) \tag{1}$$

where n is the total length of data, X_i and X_j are two generic sequential data values, and function $\text{sign}(X_j - X_i)$ assumes the following values

$$\text{sign}(X_j - X_i) = \begin{cases} +1 & \text{if } (X_j - X_i) > 0 \\ 0 & \text{if } (X_j - X_i) = 0 \\ -1 & \text{if } (X_j - X_i) < 0. \end{cases} \tag{2}$$

2.2 Sen's Slope

The slope of n pairs of points is calculated by

$$Q_i = \frac{(X_j - X_k)}{(j - k)} \quad \text{for} \quad i = 1, 2, \ldots, N \tag{3}$$

where x_j and x_k are data values at times j and k ($j > k$), and the median of the value of Q_i is Sen's estimator slope.

$$\beta = \text{Sen's Estimator} = \begin{cases} Q_{n+1/2} & \text{if } N \text{ is odd} \\ \left(\frac{1}{2}\right)\left(Q_{\frac{n}{2}} + Q_{\frac{n+2}{2}}\right) & \text{if } N \text{ is even} \end{cases} \tag{4}$$

A positive value of β implies that there is an upward slope while a negative value of β indicates a downward slope [19, 20].

2.3 Frequency Analysis and Probability Distribution

From a frequency analysis, the rainfall or the return period for a design can be obtained. The first step in the frequency analysis is to sort the rainfall data in the descending order, and the serial rank number ranging from 1 to n is assigned. The Weibull distribution analysis [21] is performed to arrive at the probability of exceedance and return period.

$$\text{Weibull's estimate of probability of exceedance} = \frac{r}{n + 1} \times 100 \tag{5}$$

where $r =$ order of rank of the event and $n =$ number of events.

2.4 Departure Analysis of Rainfall

The percentage departure ($D\%$) of annual rainfall is calculated to understand the trend of drought years. Equation 6 computes the values as [16]

$$D\% = \frac{X_i - X_m}{X_i} \times 100 \tag{6}$$

where $X_m =$ Mean annual rainfall and $X_i =$ Annual rainfall of the given year.

The percentage departure of annual and monthly rainfall and the excess, normal, deficit, scanty and no rainfall years is derived from Table 1.

Table 1 Classification of regional rainfall distribution based on percentage departure (after Indian Meteorological Department)

Terminology	Definition
Excess	Percentage departure of realised rainfall from normal rainfall is +20% or more
Normal	Percentage departure of realised rainfall from normal rainfall is between −19 and 19%
Deficit	Percentage departure of realised rainfall from normal rainfall is between −20 and −59%
Scanty	Percentage departure of realised rainfall from normal rainfall is between −60 and −99%
No rain	Percentage departure of realised rainfall from normal rainfall is −100%

In India, "drought" as adopted by the Indian Meteorological Department (IMD) is a situation when the deficiency of rainfall in an area is 25% or more than the long-term average (LTA) in a given period. This term is further divided into "moderate" and "severe". The drought is considered as "moderate" if the deficiency of rainfall is between 26 and 50% and "severe" if it is more than 50% [22].

2.5 Rainfall Anomaly Index (RAI)

Van Rooy [23] designed the rainfall anomaly index (RAI) in the year 1965. The RAI considers the rank of the precipitation values and helps to determine the magnitude of positive and negative precipitation anomalies for the given period.

$$\text{RAI} = \pm 3 \frac{P - \bar{P}}{\bar{E} - \bar{P}} \tag{7}$$

where $P =$ Measure of precipitation, $\bar{P} =$ Mean precipitation and $\bar{E} =$ Average of 10 extrema (min and max).

The range of RAI values is divided into nine categories: extremely wet, very wet, moderately wet, slightly wet, near normal, slightly dry, moderately dry, very dry and extremely dry as shown in Table 2.

2.6 Precipitation Concentration Index (PCI)

The precipitation concentration index (PCI) is estimated on seasonal and annual distributions, variations and trends [24]. The seasonal estimations were based on four seasons (i.e. NEM, SWM, Winter and Pre-mon). The PCI is analysed at different timescales to identify the rainfall patterns (Table 3).

Table 2 Classification of RAI values

Range of values	Classification
≥3.00	Extremely wet
2.00 to 2.99	Very wet
1.00 to 1.99	Moderately wet
0.50 to 0.99	Slightly wet
0.49 to −0.49	Near normal
−0.50 to −0.99	Slightly dry
−1.00 to −1.99	Moderately dry
−2.00 to −2.99	Very dry
≤−3.00	Extremely dry

Table 3 Classification of rainfall according to the PCI values

PCI value	Distribution of rainfall
PCI ≤ 10	Low precipitation distribution
11–15	Moderate precipitation concentration
16–20	Irregular distribution
PCI > 20	Strongly irregular distribution

The PCI is calculated by the following equation:

$$\text{PCI}_{\text{annual}} = \frac{\sum_{i=1}^{i=12} P_i^2}{\left(\sum_{i=1}^{i=12} P_i\right)^2} \times 100 \tag{8}$$

where P_i is the monthly rainfall for the ith month. In addition to this, PCI for the seasonal scales was also computed.

3 Results and Discussions

3.1 General Analysis

Various statistical analyses were conducted for the precipitation data for Tuticorin district for the years 1901–2002. The annual rainfall varied from 645.96 to 1388.94 mm, and the average normal rainfall was 981.78 mm. The standard deviations for the individual months varied between 28.10 and 80.46 mm. The coefficient of variation (CV) was calculated to determine the spatial pattern of interannual variability of monthly precipitation in the district. The CV varied from 42.28% in October to 124.37% in February. The CV of the annual precipitation over the study period was around 16.33%. However, the relatively low CV for annual rainfall (16.33%) shows the less interannual variability of annual rainfall in Tuticorin. For January–March, CV values

Table 4 Monthly and seasonal mean of rainfall, standard deviation, coefficient of variance and percentage distribution from 1901 to 2002

Month	Average	SD	% CV	% Contribution
Jan	24.98	28.1	112.51	2.54
Feb	33.59	41.78	124.37	3.42
Mar	29.35	33.18	113.06	2.99
Apr	85.5	55.77	65.23	8.71
May	86.1	58.3	67.71	8.77
Jun	111.76	79.15	70.82	11.38
Jul	63.15	52.45	83.06	6.43
Aug	56.75	36.8	64.85	5.78
Sep	63.36	36.81	58.1	6.45
Oct	190.3	80.46	42.28	19.38
Nov	166.66	75.05	45.03	16.98
Dec	70.27	56.44	80.32	7.16
Annual	81.81	13.36	16.33	100
NEM	427.23	124.78	29.21	43.63
SWM	295.02	112.88	38.26	29.89
Winter	58.57	48.89	83.46	6.06
Pre-mon	200.95	83.16	41.38	20.42

were >100%; whereas for October and November, CV values were lower (around 45%). This indicates lesser variability in winter and larger variability in summer. The NEM and SWM contribute the maximum to the annual rainfall (>73%). The NEM caters to around 43% of the annual precipitation, whereas the SWM contributes around 30%. The winter monsoon contributes the least to the annual rainfall, around 6% (Table 4).

3.2 Long-Term Patterns in Mean Annual and Seasonal Precipitation

The annual and seasonal precipitation data were used to study the variation in the time series. Figure 2 shows the time series of rainfall over Tuticorin for the entire period. Figure 3 shows the time series over the four seasons.
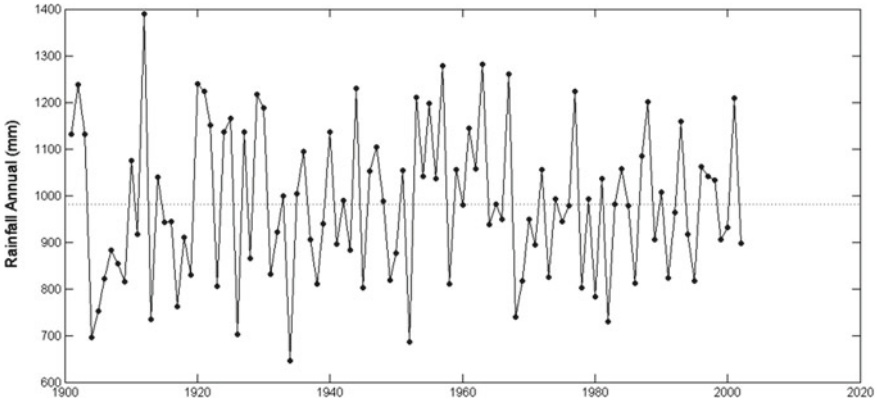
Fig. 2 Annual rainfall over Tuticorin (1901–2002). The dashed line is the average
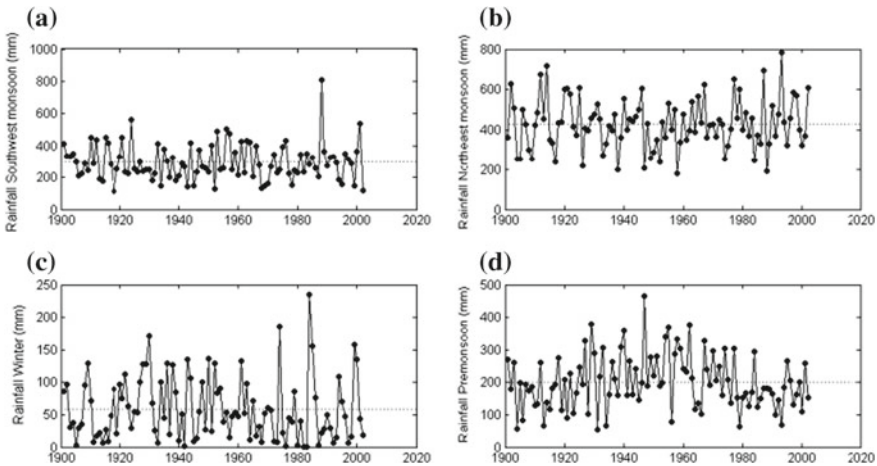

Fig. 3 Seasonal time series of rainfall **a** south-west monsoon, **b** north-east monsoon, **c** winter and **d** pre-monsoon. The dashed line is the average

3.3 Results of Mann–Kendall's and Sen's Slope Test

The results of the Mann–Kendall's and Sen's slope test are presented in Table 5. A positive value (β) indicates an increasing trend and negative value (β) indicates a decreasing trend in Sen's slope analysis. For Mann–Kendall's test statistic, $z > 1.96$ confirms a significant rising trend, while $z < -1.96$ confirms falling trend at 95% confidence level. A decreasing trend was observed only for January, and no significant trend was found for the other months and seasons. Sen's slope values also indicated no trend.

Table 5 Results of Mann–Kendall's test and Sen's slope values (1901–2002) for Tuticorin

Month	MK value (Z-value)	Sen's slope (β-value)
Jan	−2.559	−0.121
Feb	1.090	+0.070
Mar	−0.466	−0.016
Apr	−0.040	−0.007
May	−0.173	−0.033
Jun	−1.284	−0.308
Jul	1.498	+0.180
Aug	−0.827	−0.093
Sep	0.416	+0.041
Oct	−0.301	−0.073
Nov	0.364	+0.088
Dec	0.752	+0.115
Annual	0.237	+0.122
NEM	0.150	+0.046
SWM	−0.393	−0.144
Winter	−1.035	−0.126
Pre-mon	−0.294	−0.083

3.4 Results of Weibull's Frequency Distribution

Using the Weibull's frequency distribution method, the probabilities of exceedance of the ranked annual rainfall data at 50, 75 and 90% were calculated (Table 6).

3.5 Results of Departure Analysis

Table 7 depicts the departure analysis of rainfall. It shows the number of years with excess, normal, deficit, scanty or no amount of rainfall.

Tuticorin district of Tamil Nadu has had no "no rain" or scanty year in the study period (Fig. 4). This indicates that there was no severe drought for the past 102 years. According to the drought classification of IMD [25, 26], Tuticorin experienced 11 "deficit" years during the first 51 years (1901–1951) and nine during the last 51 years (1952–2002). Both the severity of drought and excess of rainfall have a decreasing trend. The data of the last two decades (1981–2002) shows only one "deficit" year and zero "excess" rainfall year. The decade-wise departure of annual rainfall indicates the first decade (1901–1910) as the driest decade, having a maximum of three "deficit" years and the last decade as the wettest (1991–2002) having only one "deficit" year. In the history of 102 years, it is found that Tuticorin has mostly experienced normal rainfall for 72 years, "deficit" for 20 years and "excess" rainfall for 9 years.

Table 6 Probabilities of exceedance of the ranked annual rainfall data estimated with Weibull's distribution

Month	50%	75%	90%
Jan	14.57	3.87	0.65
Feb	15.81	3.26	0.53
Mar	16.87	5.62	1.30
Apr	78.30	42.18	21.07
May	74.15	38.26	11.74
Jun	90.18	51.18	24.15
Jul	44.60	24.18	12.54
Aug	50.84	25.90	16.81
Sep	59.97	34.74	22.71
Oct	184.15	129.58	92.89
Nov	155.81	121.68	66.02
Dec	53.91	25.19	11.32
NEM	424.88	349.09	254.32
SWM	269.64	224.64	153.13
Winter	47.57	16.98	6.85
Pre-mon	189.59	137.55	99.02
Annual	979.79	832.04	783.24

Table 7 Departure analysis of annual precipitation

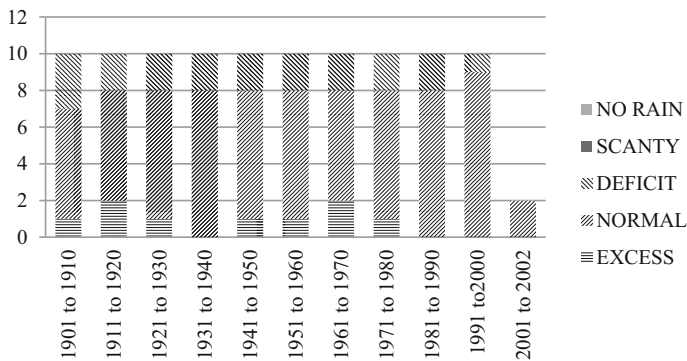| Terminology	Number of years (1901–2002)	Number of years (1901–1951)	Number of years (1952–2002)
Excess	9	5	4
Normal	73	35	38
Deficit	20	11	9
Scanty	0	0	0
No rain	0	0	0

Fig. 4 Decade-wise distribution of annual rainfall

Table 8 Rainfall anomaly index

Range of values	Classification	Number of years (1901–2001)	Number of years (1901–1951)	Number of years (1952–2002)
≥3.00	Extremely wet	4	1	3
2.00 to 2.99	Very wet	12	7	5
1.00 to 1.99	Moderately wet	13	10	3
0.50 to 0.99	Slightly wet	13	1	10
0.49 to −0.49	Near normal	19	7	12
−0.50 to −0.99	Slightly dry	11	5	6
−1.00 to −1.99	Moderately dry	17	10	7
−2.00 to −2.99	Very dry	9	5	4
≤−3.00	Extremely dry	4	3	1

3.6 Results of Rainfall Anomaly Index (RAI)

The rainfall anomaly index from 1901 to 2002 (Table 8) shows the classification of different categories of rainfall anomalies and the number of years of occurrence.

Four extremely dry and extremely wet years were observed during the study period. Three out of four extremely dry years occurred during the first five decades, which indicates that 1901–1951 was drier than the next 51 years. The dry years (from extremely dry to slightly dry) follow a decreasing trend, and a reduction of 21.73% is seen over the period of 102 years. A total of 23 dry years were recorded for the first 51 years, while the number of dry years decreased to 18 years for the remaining period (Fig. 5). Tuticorin mostly enjoys a normal amount of rainfall ranging from −0.49 to 0.49. The number of wet years in the recent 51 years (1952–2002) also increased when compared to the initial years (1901–1951). Though the initial five decades have many dry events, they rarely extend beyond three consecutive years and a balance in number of wet and dry years is noticed in the last six decades till 2002.

3.7 Results of Precipitation Concentration Index (PCI)

The mean PCI for Tuticorin is 15, which shows that the annual rainfall is of moderate concentration (Fig. 6). Strong irregularity was observed only for three years. Since NEM is significant over Tuticorin, such irregularity can be associated with it. The PCI is between 16 and 20 for 31 years, indicating lesser contribution of NEM towards the annual precipitation (Fig. 7). The NEM contribution was still lower for the years which had PCI between 11 and 15. The rainfall concentration of pre-monsoon season showed higher variability, implying inconsistency in rainfall.
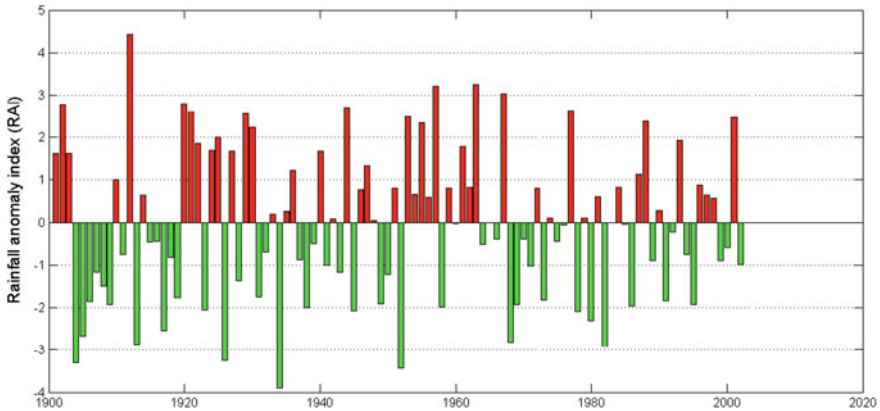
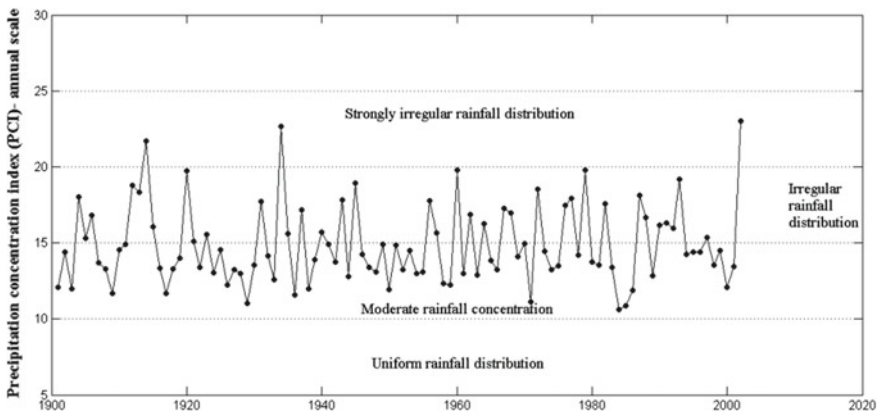**Fig. 5** Rainfall anomaly index for Tuticorin during 1901–2002

Fig. 6 Precipitation concentration index (PCI) of annual rainfall (1901–2002)

4   Conclusions

In this study, various statistical analyses were done to determine the rainfall trends and patterns in Tuticorin district, Tamil Nadu, for 102 years (1901–2002). The annual rainfall in this area varied from 646 to 1389 mm, with a normal annual rainfall of 982 mm. The north-east monsoon has a large contribution (43%), and the least contribution (6%) is realised during winter monsoon. Mann–Kendall's and Sen's slope tests showed no significant trend for all months except January. The precipitation concentration index indicates that the rainfall concentration in the Tuticorin district is moderately concentrated. Some significant irregularities in annual precipitation were observed for all the monsoon seasons. The departure analysis suggests a decreasing trend in extreme climate, and no severe drought was found over the past 102 years. The rainfall anomaly index shows that Tuticorin mostly enjoys a normal amount of
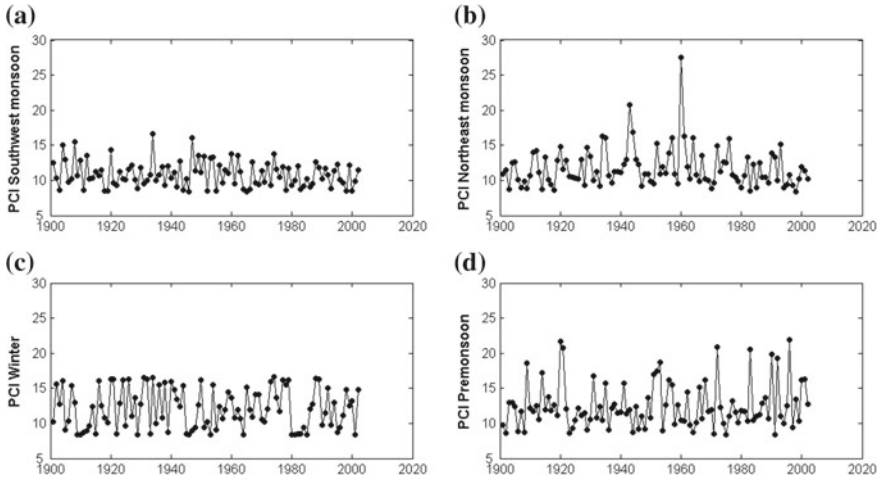
Fig. 7 Precipitation concentration index (PCI) of seasonal rainfall **a** SWM, **b** NEM, **c** Winter and **d** Pre-monsoon

rainfall ranging from −0.49 to 0.49. After analysing the trend of rainfall for the past 102 years, it can be predicted that this region will face no major change in trend in the near future.

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