Maheswaran Rathinasamy
S. Chandramouli · K. B. V. N. Phanindra
Uma Mahesh *Editors*

Water Resources and Environmental Engineering II

Climate and Environment

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Foreword

Judicious management of water resources is fundamental for achieving sustainable management of natural resources and ensuring environmental integrity. Technologies, such as remote sensing, navigation, space communication, geospatial tools, and Internet of things, are extremely useful in developing newer applications and tools for scientific data management and decision-making.

The international conference organized by the Department of Civil Engineering, MVGR College of Engineering (A), Vizianagaram, from 30 March to 01 April 2017, provided a much-needed platform to discuss the emerging technologies and opportunities in water, environment and climate change facets.

The effort of the organizers in bringing out a scientific book on conference deliberations and a compendium of papers needs a special compliment.

I strongly believe that the technical insights presented in this book will enrich the scientific community, provide inspiration to readers and lead to newer technological applications that would support human society in coping up with the challenges posed by impending climate change.

I wish the organizing committee of the conference a grand success.

Hyderabad, India

Y. V. Krishna Murthy
Director
National Remote Sensing Centre

Preface

With an ever-increasing demand for the development, the stress on water resources and environment is increasing day by day. The changing climate is further amplifying the effect resulting in severe drought, flood and pollution problems. In order to provide a platform for eminent scientists, researchers and students to discuss the emerging technologies in mitigating the problems related to water and environment, the International Conference on Emerging Trends in Water Resources and Environmental Engineering (ETWREE-17) was conducted by MVGR College of Engineering, Vizianagaram, Andhra Pradesh, India, from March 2017 to April 2017. About 100 participants from three different countries attended ETWREE-17. ETWREE-17 was organized by the Department of Civil Engineering, MVGR College of Engineering, and was sponsored by the Science and Engineering Research Board (SERB) and the National Remote Sensing Centre (NRSC).

The proceedings of this conference contain 60 papers which are included as two volumes. The response to ETWREE-17 was overwhelming. It attracted quality work from different areas related to water resources, environmental engineering and climate. From a total of 120 abstracts, we selected around 80 papers for presentation through a rigorous peer review process with the help of our programme committee members and external reviewers.

Dr. Y. V. N. K. Murthy, Director, NRSC, Hyderabad, conducted a special session on “Application of Remote Sensing in Water Resources”. Professor Rakesh Khosa, IIT Delhi, conducted a special session on “Enigma of Climate”. Professor D. Nagesh Kumar, IISc Bangalore, delivered a lecture on “Remote Sensing, GIS and DEM for Water Resources Assessment of a River Basin”. Professor Uma Mahesh, NIT Warangal, gave a lecture on “Non-Stationarity in Rainfall Intensity”. Dr. Brijesh Kumar Yadav, IIT Roorkee, conducted a session on “Engineered Bioremediation”. Dr. K. B. V. N. Phanindra, IIT Hyderabad, delivered a keynote on “Modeling Soil–Water–Disease Interactions of Flood-Irrigated Mandarin Orange Trees”.

Dr. Shishir Gaur, IIT BHU, conducted a special session on “Application of Simulation Optimization Model for Management of Groundwater Resources”. Dr. L. Suri Naidu, NUS, Singapore, delivered a lecture on “Food, Water and

Energy Nexus". Professor G. V. R. Srinivas Rao, Andhra University, conducted a session on "Multivariate Statistical Analysis of River Water Quality". Professor T. V. Praveen, Andhra University, delivered a lecture on "Salinity Intrusion Modelling". Dr. Y. R. S. Rao, NIH Kakinada, provided a lecture on "River Bank Filtration".

These sessions were very informative and beneficial to the authors and delegates of the conference. We thank all the keynote speakers and the session chairs for their excellent support in making ETWREE-17 a grand success. The quality of a contributed volume is solely due to the reviewers' efforts and dedication. We thank all the members of the advisory board of the conference for their support and encouragement.

We are indebted to the programme committee members Mr. A. V. S. Kalyan, Mr. Varaprasad and Mr. Sridhara Naidu for extending their help in preparing the manuscript.

We express our heartfelt thanks to chief patrons, Sri Ashok Gajapathi Raju, Chairman, MANSAS, and patron and Prof. K. V. L. Raju, Principal, MVGR College of Engineering, for their continuous support and encouragement during the course of the convention. We also thank all the faculty and administrative staff for their efforts.

We would also like to thank the authors and participants, who have made it for the conference. Finally, we would like to thank all the student volunteers who spent assiduous efforts in meeting the deadlines and arranging every detail to make sure smooth running of the conference. All the efforts are worth if the readers of this contributed volumes find them inspiring and useful. We also sincerely thank the press, print and electronic media for their excellent coverage of this convention.

Vizianagaram, India — Dr. Maheswaran Rathinasamy
Vizianagaram, India — Dr. S. Chandramouli
Hyderabad, India — Dr. K. B. V. N. Phanindra
Warangal, India — Prof. Uma Mahesh
December 2017

About This Book

This book covers a variety of topics related to water, climate and environment. The topics mainly focus on but not limited to hydrological modelling, water resources management, water conservation practices, applications of recent techniques for solving water-related issues, land use impact on water resources, climate change impacts, wastewater treatment and recovery, advances in hydraulics in rivers and ocean. This book is a collection of the best papers submitted in the First International Conference on Emerging Trends in Water Resources and Environmental Engineering held from 28 March 2017 to 1 April 2017 at MVGR College of Engineering, Vizianagaram, Andhra Pradesh, India. It was hosted by the Department of Civil Engineering, MVGR College of Engineering, with the support of Science and Engineering Research Board, India.

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About the Editors

Dr. Maheswaran Rathinasamy is currently Associate Professor in the Department of Civil Engineering, MVGR College of Engineering, Vizianagaram. He received his bachelor's and master's degrees from Anna University, Chennai, and BIT Mesra, respectively. He obtained his Ph.D. from IIT Delhi. He is a recipient of INSPIRE Fellowship from the Department of Science and Technology, India, and Humboldt Fellowship from Alexander Von Humboldt Foundation, Germany. He has postdoctoral experience in the University of Minnesota, USA, and Potsdam Institute of Climate Impact Research, Germany. He is the principal investigator of funded research projects of the order of 1.5 crore rupees. He has around 30 international journal publications and 25 international conference publications. His research interests include stochastic hydrology, hydrological modelling, hydro-meteorological forecasting.

Dr. S. Chandramouli currently serves as Professor and HOD in the Department of Civil Engineering, MVGR College of Engineering, Vizianagaram. He received his M. Tech. in water resources engineering as specialization from REC, Warangal, in 2002. He obtained his Ph.D. in civil engineering from Andhra University, Visakhapatnam, in 2013. He worked in several organizations such as CES(I) Pvt. Ltd., Hyderabad; GVP College of Engineering, Visakhapatnam; and GMRIT, Rajam, for a period of 10 years. Currently, he is working in MVGR College of Engineering since 2011. He published more than 50 technical papers in various reputed journals and conferences. He has attended more than 60 professional training programmes organized by the prestigious institutions in India. He is Life Member of ISTE and IEI. He has completed one DST project as a co-principal investigator. He has reviewed many journal papers published by prestigious journals and conferences. He has organized many faculty development programmes and student training programmes.

Dr. K. B. V. N. Phanindra currently serves as Assistant Professor in the Department of Civil Engineering, IIT Hyderabad, India. He received his master's degree in hydraulics and water resources engineering from IIT Kanpur and Ph.D. in water resources engineering from New Mexico State University (NMSU). He also holds a graduate minor degree in GIS from NMSU. To his credit, he has nine journal publications of international repute, three technical reports, one monograph and one chapter. He has completed three research projects funded by various ministries from the Government of India to the tune of about 1.6 crore rupees. His research interests include hydrogeologic characterization, groundwater flow and transport modelling, soil–water–crop interactions, remote sensing and GIS applications in groundwater.

Prof. Uma Mahesh is currently serving as Professor in the Department of Civil Engineering, National Institute of Technology, Warangal, Telangana, India. He has earlier served as Head of the Department from July 2008 to June 2010, as Dean, Students' Welfare, from July 2012 to March 2013 and as Dean, Planning & Development, from April 2013 to June 2014. His area of specialization is water resources with a focus on water resources systems, hydrologic modelling, irrigation management, water quality modelling and management, applications of soft computing techniques and modelling impacts of climate change. He is a recipient of the Jalamitra Award by the Government of AP in 2003 for successful implementation of Watershed Development Project in Warangal District, G M Nawathe Award for the paper presented at Hydro 2004 (annual conference of the Indian Society for Hydraulics) and Central Board of Irrigation and Power (CBIP) Award. Eight Ph.D. students have been graduated with him as their advisor. He is currently advising six Ph.D. students at NIT Warangal. He has published more than 60 papers in various reputed journals and conferences.

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

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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.

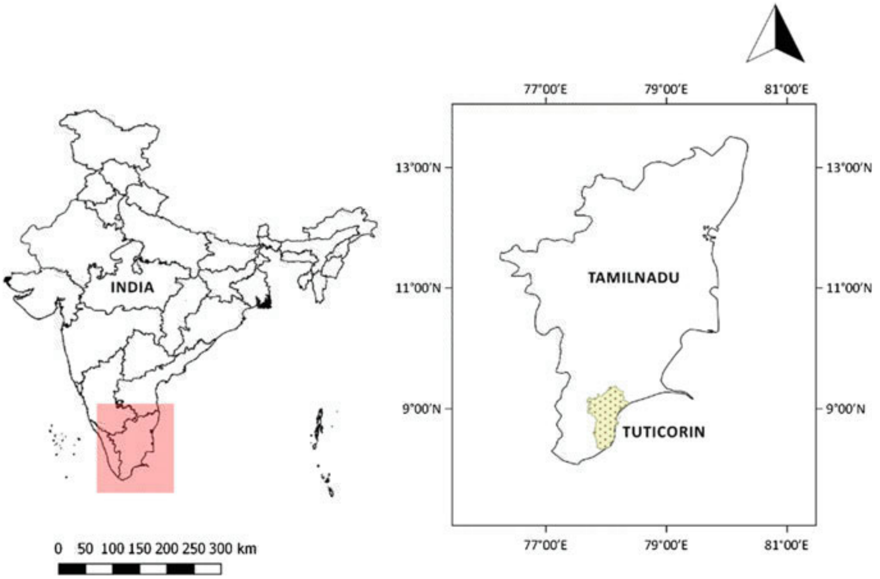

Fig. 1 Location map of Thoothukudi (Tuticorin) district

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:

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

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

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

2.2 Sen's Slope

The slope of n pairs of points is calculated by

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

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.

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

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:

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

where P_{i} is the monthly rainfall for the *i*th 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.

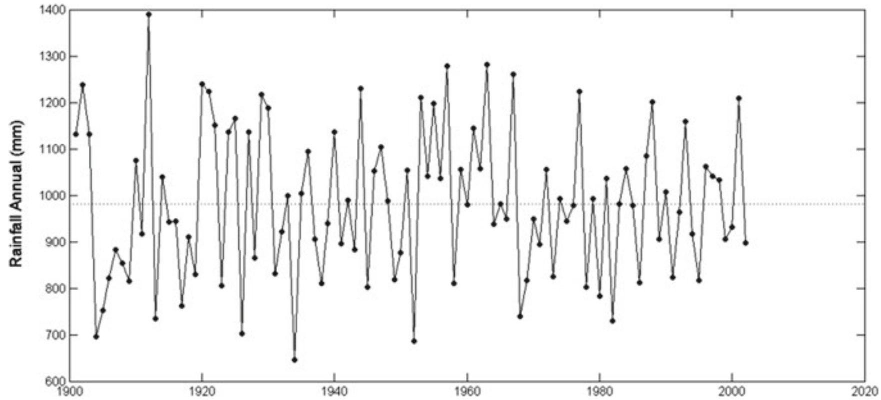

Fig. 2 Annual rainfall over Tuticorin (1901–2002). The dashed line is the average

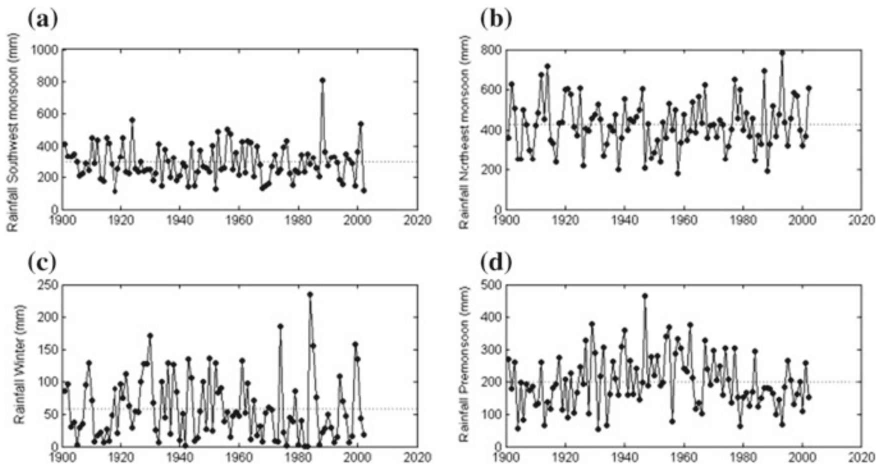

Fig. 3 Seasonal time series of rainfall **a** south-west monsoon, **b** north-east monsoon, **c** winter and **d** pre-monsoon. The dashed line is the average

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.