ANALYSIS OF LONG TERM SPATIO-TEMPORAL TREND OF RAINFALL IN TAMIL NADU, INDIA

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Abstract. In recent decades, the escalation of human activities has played a pivotal role in driving substantial global climate change. This research primarily centers its attention on the assessment of changes occurring in the spatio-temporal distribution of rainfall in Tamil Nadu over a 40-year period. The study area comprises 32 districts of Tamil Nadu, India and a comprehensive dataset spanning four decades (1981-2020) of monthly precipitation of each district was acquired from both the Tamil Nadu Agricultural University and the India Meteorological Department. Subsequently, various statistical methodologies were employed to analyze this extensive rainfall data. The Seasonal Precipitation Concentration Index (SPCI) was scrutinized for both the southwest and northeast monsoon. The findings revealed that SPCI values < 10 indicated a relatively uniform distribution of rainfall during the southwest monsoon, while values > 10 indicated more extreme weather conditions during the northeast monsoon. Statistical analyses, including the Mann–Kendall non-parametric test, were conducted using trend analysis software for both monsoon seasons. Notably, a significant upward trend in rainfall was observed during the southwest monsoon in locations such as Coimbatore (1.8 mm/season/year), Erode (2.1 mm/season/year), Perambular (2.1 mm/season/year), Theni (2.0 mm/season/year), and Tirunelveli (2.4 mm/season/year). Conversely, a significant decrease in rainfall was noted in Namakkal (2.5 mm/season/year) during the same period. In contrast, the northeast monsoon displayed a significant increase in rainfall in areas like Kancheepuram (2.4 mm/season/year), Tuticorin (2.6 mm/season/year), and Villupuram (2.0 mm/season/year).
Keywords: *SPCI, Mann–Kendall, south west, north east, rainfall distribution*

Introduction

The distribution of rainfall has significant repercussions for agriculture, impacting factors like soil conditions, hydrology, and the health of crops within agricultural systems (Dourte et al., 2013). The shifting patterns of rainfall resulting from climate change pose challenges for water resource managers and hydrologists (Gajbhiye et al., 2015). In India, substantial research has been conducted to investigate the importance of rainfall events, particularly in the context of monsoon variations and global warming (Balachandran et al., 2006). Notably, there has been a change in the recent dry season during the Indian summer rains, with a 27% increase from 1981 to 2011 compared to 1951-1980, accompanied by more intense rainfall spells (Krishnan et al., 2020).

India’s history marked by recurring droughts and fluctuations in rainfall underscores the paramount significance of employing rigorous methodologies for conducting

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extended trend and variability investigations. These approaches are vital for collecting essential insights into the alterations that have transpired over the past few decades, ensuring a deeper understanding of the evolving climatic conditions (Murugan et al., 2008). Consequently, an accurate assessment of the spatial and temporal distribution of precipitation, along with the monitoring of its trends, is essential for ensuring sustainable agricultural production (Ayalew et al., 2012).

In the pursuit of elucidating the temporal aspects of rainfall distribution, numerous meteorologists have proposed various methods for measuring seasonal rainfall intensity. The concept of rainfall stabilization, denoting the rate of temporal rainfall distribution within an area, can be observed through various models such as the Gini (GI) indicator, concentration index (CI) (Monjo and Martin-Vide, 2016, and Yin et al., 2016), and the precipitation concentration index (PCI) (Oliver, 1980). The precipitation concentration index (PCI) is employed to assess both the temporal and seasonal precipitation distribution (Zhang et al., 2019).

A trend signifies a substantial change in a random variable over time, which can be detected through statistical parametric and non-parametric approaches. Long-term climate data can be statistically analyzed to explore the temporal and spatial variability of climatic characteristics (Patle et al., 2013). Parametric and non-parametric statistical techniques can be applied to analyze climate variability in time series data. Parametric methods assume that data follows a regular distribution and is devoid of outliers, while non-parametric methods make no such assumptions. When data exhibits a skewed probability distribution, the non-parametric Mann–Kendall test possesses greater power than the parametric t-test (Hamed and Rao, 1998). Furthermore, the Mann–Kendall non-parametric test, at a given confidence level, can establish the presence of a positive or negative trend.

The study focused on investigating spatio-temporal changes in precipitation in Tamil Nadu, utilizing monthly precipitation data spanning a substantial time frame. The findings suggested that the weakening of monsoon circulation characteristics induced by global warming appears to be the primary driver of the observed changes. Inter-annual variability is a crucial indicator for assessing the reliability of rainfall. Therefore, understanding the regional trends in rainfall based on historical data is vital for agriculture, as the success or failure of crops in a rainfed environment is distinctly linked to rainfall patterns.

Hence, the primary goal of this study was to discern the temporal and spatial behavior and seasonal concentration of rainfall using the Seasonal Precipitation Concentration Index during both the southwest and northeast monsoons in Tamil Nadu. To investigate the trend in rainfall for Tamil Nadu, a non-parametric statistical technique known as the Mann-Kendall test was employed, with the intention of assisting farmers in implementing suitable agricultural practices, soil and water conservation, and flood/drought management.

Materials and methods

Study area and data source

The study area covers a geographical co-ordinate of 1,35,100 km^2 between 76°15’ and 80°20’ east longitudes and 08°05’ and 13°35’ north latitudes. Over 40 years (1981-2020) of monthly data has been collected from Agro Climate Research Centre, Tamil Nadu Agricultural University and India Meteorological Department, New

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Delhi. Data quality checking and validation were performed using the procedure described in Yadav et al. (2021). Tamil Nadu receives a greater amount of rainfall during the South West Monsoon Season (June-September) and the North East Monsoon Season (October-December). The Location of the rainfall stations and their details were represented in *Figure 1* and *Table 1*. The spatial variability of rainfall received in Tamil Nadu for SWM, NEM and annual period ranged from 69.3 mm (Tutucorin)/277.8 mm (Krishnagiri)/558.8 mm (Tutucorin) to 772.8 mm (The Nilgiris)/825.9 mm (Nagapattinam)/1466.8 mm (The Nilgiris) respectively (Kokilavani et al., 2021a).

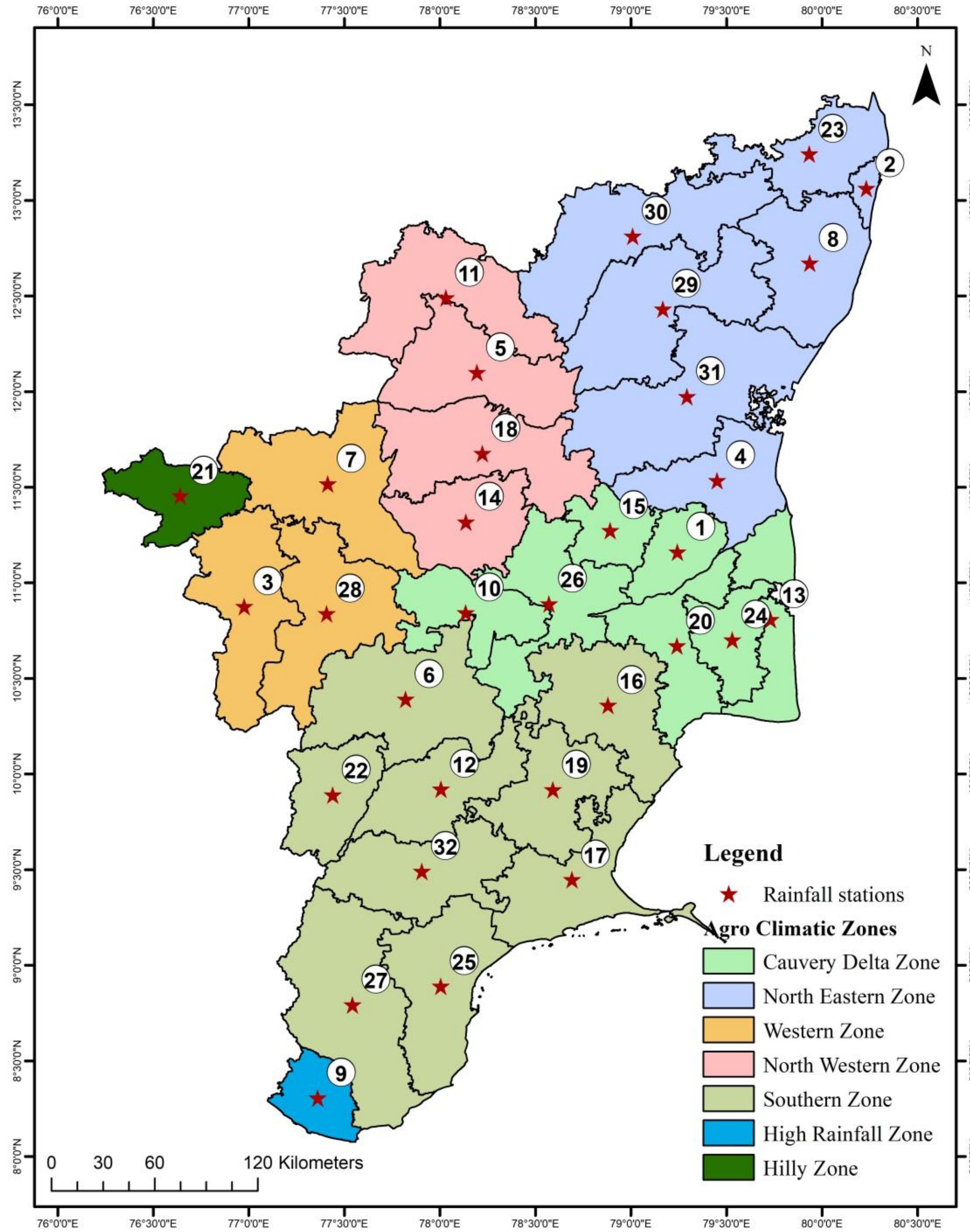

Figure 1. *Study and Location of rainfall stations over the agro climatic zones of Tamil Nadu*

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Table 1. *Details regarding the rainfall stations*

Station No.	District	Longitude	Latitude	Elevation (m)
1	Ariyalur	79.242	11.162	107.4
2	Chennai	80.232	13.063	35.3
3	Coimbatore	76.976	10.878	353.5
4	Cuddalore	79.450	11.536	41.5
5	Dharmapuri	78.193	12.101	583.0
6	Dindigul	77.820	10.392	335.1
7	Erode	77.413	11.518	246.5
8	Kancheepuram	79.935	12.673	48.3
9	Kanniyakumari	77.360	8.307	385.3
10	Karur	78.135	10.844	177.7
11	Krishnagiri	78.031	12.491	726.8
12	Madurai	78.005	9.923	186.0
13	Nagapattinam	79.729	10.809	32.6
14	Namakkal	78.136	11.319	216.9
15	Perambalur	78.890	11.275	161.7
16	Pudukkottai	78.879	10.360	123.7
17	Ramanathapuram	78.691	9.449	43.2
18	Salem	78.223	11.678	329.3
19	Sivaganga	78.591	9.919	112.3
20	Thanjavur	79.241	10.671	64.8
21	The Nilgiris	76.640	11.456	2158.0
22	Theni	77.438	9.892	364.2
23	Thiruvallur	79.933	13.244	55.2
24	Thiruvarur	79.529	10.703	34.1
25	Thoothukkudi	78.004	8.891	74.8
26	Tiruchirappalli	78.570	10.891	96.9
27	Tirunelveli	77.542	8.794	106.6
28	Tiruppur	77.407	10.839	328.4
29	Tiruvannamalai	79.166	12.432	202.8
30	Vellore	79.009	12.814	719.7
31	Villupuram	79.292	11.975	103.6
32	Virudhunagar	77.905793	9.4922148	114.1

Data analysis

Precipitation concentration index (PCI)

In this study, the seasonal rainfall variability has been computed using the Precipitation Concentration Index (PCI). PCI is used to examine the variability (heterogeneity pattern) of rainfall at different scales. The seasonal scale of Precipitation Concentration Index was calculated using equation.

$$PCI_{seasonal} = \frac{\sum_{i=1}^{3} p_i^2}{\left(\sum_{i=1}^{3} pi\right)^2} \times 25 \quad \text{(Eq.1)}$$

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PCI values of less than 10 indicates uniform monthly distribution of rainfall (low precipitation concentration), values between 11 and 15 denote moderate concentration, values from 16 to 20 indicates high concentration, and values of 21 and above indicate very high concentration (Zamani et al., 2018).

Mann-Kendall test

The analysis of seasonal rainfall trend in both the Southwest Monsoon (SWM) and the Northeast Monsoon (NEM) seasons was analyzed using a non-parameter Mann-Kendall statistical test, which finds trends in time series and is widely used in precipitation analysis (Ahmad et al., 2015). One of its advantages is that it does not require the data to be distributed normally (Song et al., 2015).

This method tests whether there is a trend in the time series data. It is a non-parametric test. The n time series values (X1, X2, X3,…, Xn) are replaced by their relative ranks (R1, R2, R3,…, Rn) (starting at 1 for the lowest up to n).

The Mann-Kendall test statistic is calculated according to

$$S = \sum_{i=1}^{n-1} \left[\sum_{j=i+1}^{n} \text{sgn}(R_j - R_i \right] \qquad \text{(Eq.2)}$$

where sgn(x) = 1 for x > 0; sgn(x) = 0 for x = 0; sgn(x) = -1 for x < 0.

If the null hypothesis H_0 is true, then S is approximately normally distributed with:

$$\mu = 0$$

$$\sigma = n (n – 1) (2n + 5) / 18$$

The z-statistic is therefore (critical test statistic values for various significance levels can be obtained from normal probability tables):

$$z = \frac{|S|}{\sigma_{0.5}} \qquad \text{(Eq.3)}$$

A positive value of S indicates that there is an increasing trend and vice versa. Mann-Kendall Test (non-parametric) was applied to detect trend magnitude using Trend change detection software.

Results

Seasonal precipitation concentration index

The precipitation concentration index (PCI) serves as a critical element in water resource planning, risk prediction associated with droughts and floods, and the management of natural resources. In *Table* 2 and *Figure* 2, we provide a summary of the seasonal precipitation indices for both the South West Monsoon (SWM) and North East Monsoon (NEM) in seven Agro Climatic Zones (ACZ) within Tamil Nadu.

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Table 2. *Seasonal precipitation concentration index (PCI) values for SWM*

Zone/season	SWM/PCI values		% No. of years with PCI > 10
	<10 No. of years	10–15 No. of years	
Cauvery Delta zone			
Ariyalur	31	9	23
Karur	16	24	60
Nagapattinam	35	5	13
Perambalur	23	17	43
Thanjavur	35	5	13
Tiruvarur	33	7	18
Trichy	30	10	25
Western zone			
Coimbatore	33	7	18
Erode	33	7	18
Tiruppur	28	12	30
North Western zone			
Dharmapuri	32	8	20
Namakkal	35	5	13
Krishnagiri	31	9	23
Salem	37	3	8
Southern zone			
Dindigul	27	13	33
Madurai	35	5	13
Pudukottai	38	2	5
Ramanathapuram	26	14	35
Sivaganga	38	2	5
Theni	31	9	23
Tirunelveli	33	7	18
Tutucorin	24	16	40
Virudhunagar	29	11	28
North Eastern zone			
Chennai	40	0	0
Cuddalore	38	2	5
Kancheepuram	40	0	0
Thiruvallur	40	0	0
Tiruvannamalai	37	3	8
Vellore	40	0	0
Villupuram	37	3	8
Hilly zone			
Nilgiris	40	0	0
High rainfall zone			
Kanyakumari	37	3	8

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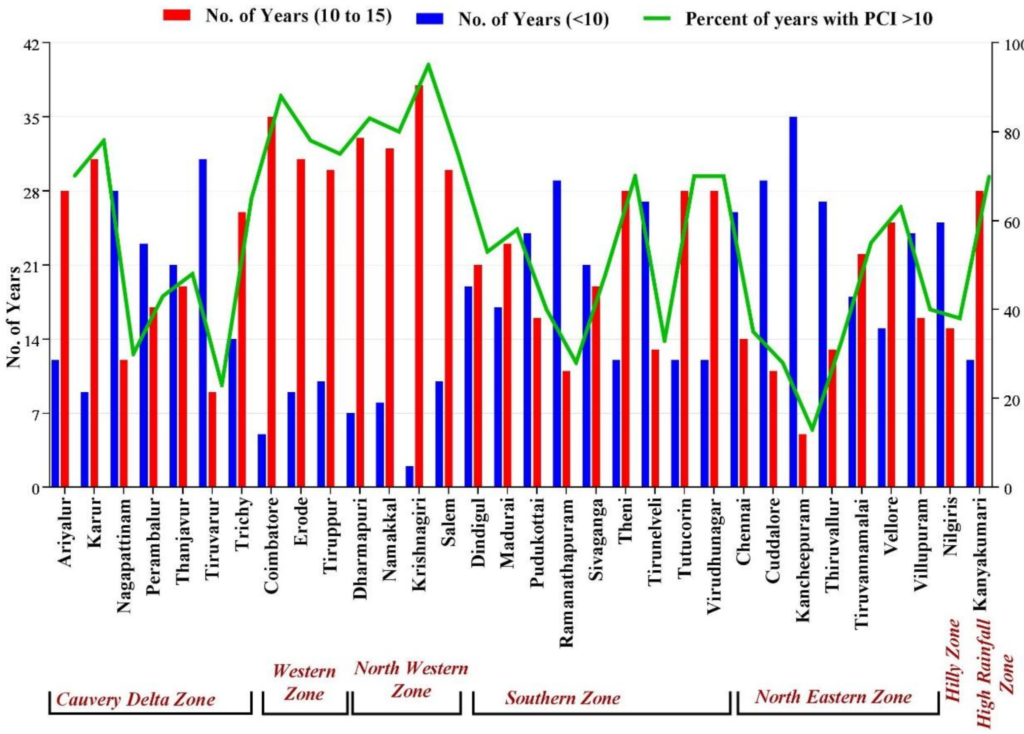

Figure 2. *Seasonal precipitation concentration index (PCI) values for NEM*

In the context of the South West Monsoon (SWM) and based on 40 years of seasonal PCI data for the Cauvery Delta Zone (CDZ), it was observed that precipitation distribution remained uniform for over 30 years in the zone, with the exceptions of Karur (16) and Perambalur (23). The Western Zone (WZ) exhibited uniform SPCI values for more than 30 years, except for Tiruppur (28), while the North Western Zone (NWZ) maintained uniform SPCI values for all its districts over the same period. In the Southern Zone (SZ), SPCI values remained uniform for over 30 years, with the exceptions of Dindigul (27), Ramanathapuram (26), Tutucorin (24), and Virudhunagar (29). In the North Eastern Zone (NEZ), the SPCI values were uniform for 40 years, except for Cuddalore (38), Tiruvannamalai (37), and Villupuram (37). The Hilly Zone (HZ) of The Nilgiris had uniform SPCI values for 40 years, and the High Rainfall Zone (HRZ) in Kanyakumari exhibited uniform SPCI values for 37 years. Concerning the North East Monsoon (NEM), findings from a comprehensive analysis of 40 years of seasonal Precipitation Concentration Index (PCI) data for the Cauvery Delta Zone (CDZ) revealed that Ariyalur (28), Karur (31), and Trichy (26) consistently experienced a moderate distribution of precipitation. On the other hand, the Western Zone (WZ) and North Western Zone (NWZ) displayed consistent SPCI values for over 30 years, while the North Eastern Zone (NEZ) recorded uniform SPCI values with moderate precipitation distribution in Tiruvanamalai (22) and Vellore (25). Lastly, Kanyakumari in the High Rainfall Zone (HRZ) exhibited uniform SPCI values for 28 years.

Long-term and seasonal trends in southwest and northeast monsoon rainfall

The analysis of time series data for precipitation included monthly and seasonal assessments for both the South West Monsoon and North East Monsoon in Tamil Nadu. The Mann-Kendall (MK) test was applied to this data to evaluate trends and variations.

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The MK test significance level was computed as 10%, 5% and 1% significant level for the data series to analyze anomalies during the monsoon period in Tamil Nadu. A positive trend value signifies a positive increase or a monotonic upward trend in a specific month of the area, while a negative trend value indicates the opposite.

Rainfall trend observed during southwest monsoon

Thr trend in rainfall during the months of June to September and in southwest monsoon season is illustrated in *Figure* 3*a-e*. During the southwest monsoon, several regions displayed notable trends. Coimbatore exhibited a significant increasing trend of 1.8 mm per season per year at a significance level of 1%. Erode and Perambalur also showed increasing trends at a significance level of 5%, with rates of 2.1 mm per season. Theni experienced a significant increasing trend of 2.0 mm per season per year at a significance level of 1%, while Tirunelveli showed an increasing trend of 2.4 mm per season per year at a significance level of 5%. In contrast, Namakkal district had a significant decreasing trend of 2.5 mm per season per year at a significance level of 5%.

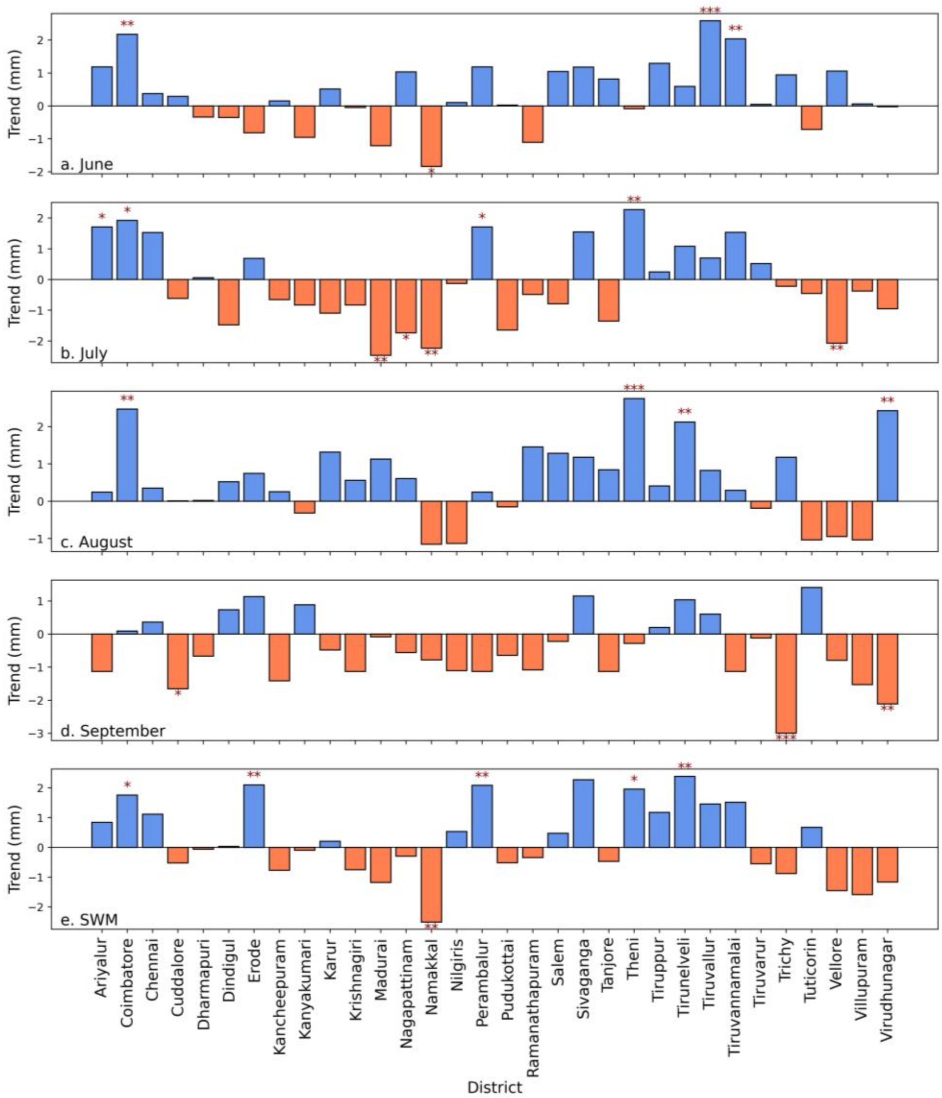

Figure 3. (a-e) *Rainfall trend for southwest monsoon season (*, ** and *** represents significant at 10%, 5% and 1% level)*

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The increase in the southwest monsoon rainfall in Coimbatore was particularly remarkable, supported by significant increasing trends in June (2.2 mm per season per year at a significance level of 5%), July (1.9 mm per season per year at a significance level of 1%), and August (2.5 mm per season per year at a significance level of 5%). The percentage contribution of the southwest monsoon to annual rainfall of Coimbatore showed an increasing trend from the 1990s (29.9) to the 2010s (44.8) (Kokilavani et al., 2021b). Moreover, the frequency of wet spells during El-Nino events in Coimbatore was reported to be higher (Kokilavani et al., 2017).

Similarly, in Theni, the months of July (2.3 mm per season per year at a significance level of 5%) and August (2.8 mm per season per year at a significance level of 10%) exhibited increasing trends, influencing the overall southwest monsoon season. The occurrence of extreme rainfall events over the past decade likely contributed to the overall increase in southwest monsoon rainfall.

On the other hand, Namakkal experienced a decreasing trend in June (1.8 mm per season per year at a significance level of 1%) and July (2.2 mm per season per year at a significance level of 5%), resulting in reduced rainfall during the southwest monsoon. This pattern had adverse effects on the Kharif cropping season in Namakkal district. The magnitude of the rainfall and temperature trends was estimated using Sen's estimator of the slope, while the statistical significance was assessed through the Mann-Kendall test for India. The findings revealed both positive and negative trends in the region (Jain et al., 2012).

Rainfall trend observed during northeast monsoon

The trend in rainfall during the months of October to December and in northeast monsoon season is illustrated in *Figure 4a-d*. In the North East Monsoon, significant increasing trends were observed at three locations: Kancheepuram exhibited a trend of 2.4 mm per season per year at a 5% significance level, Tuticorin showed an increasing trend of 2.6 mm per season per year at a 10% significance level, and Villupuram displayed an increasing trend of 2.0 mm per season per year at a 5% significance level. Similar to the Southwest Monsoon, significant increases in October (1.8 mm per season per year at 1% significance) and December (1.9 mm per season per year at 1% significance) contributed to the greater quantum of rainfall during the North East Monsoon in Villupuram.

Discussion

In the present study, it was observed that Krishnagiri district experienced irregular rainfall distribution, with PCI values exceeding 10 during 95% of the study period, particularly in the northeast monsoon period. A similar pattern emerged in various agricultural climate regions, such as the Prakasam area in Andhra Pradesh, where PCI values exceeded 16 for 62% of the year during the northeast monsoon (Manickam et al., 2013). Across all agro-climate regions, the seasonal PCI values ranged from 13 to 95%, indicating a moderate distribution of rainfall and the presence of more extreme weather conditions during NEM. This complexity suggests that PCI not only influences local rainfall but also exhibits a connection to the global atmospheric characteristics of the region, with seasonal changes being localized (Chatterjee et al., 2018).

An analysis of the seasonal Precipitation Concentration Index (SPCI) reveals that during the South West Monsoon (SWM), rainfall is uniformly distributed, emphasizing

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the suitability of cultivating short-duration crops, typically lasting fewer than 100 days, to maximize production. This approach can include the cultivation of short-term and low-water-demand crops that enjoy high market demand, providing potential financial returns (Sivajothi et al., 2018).

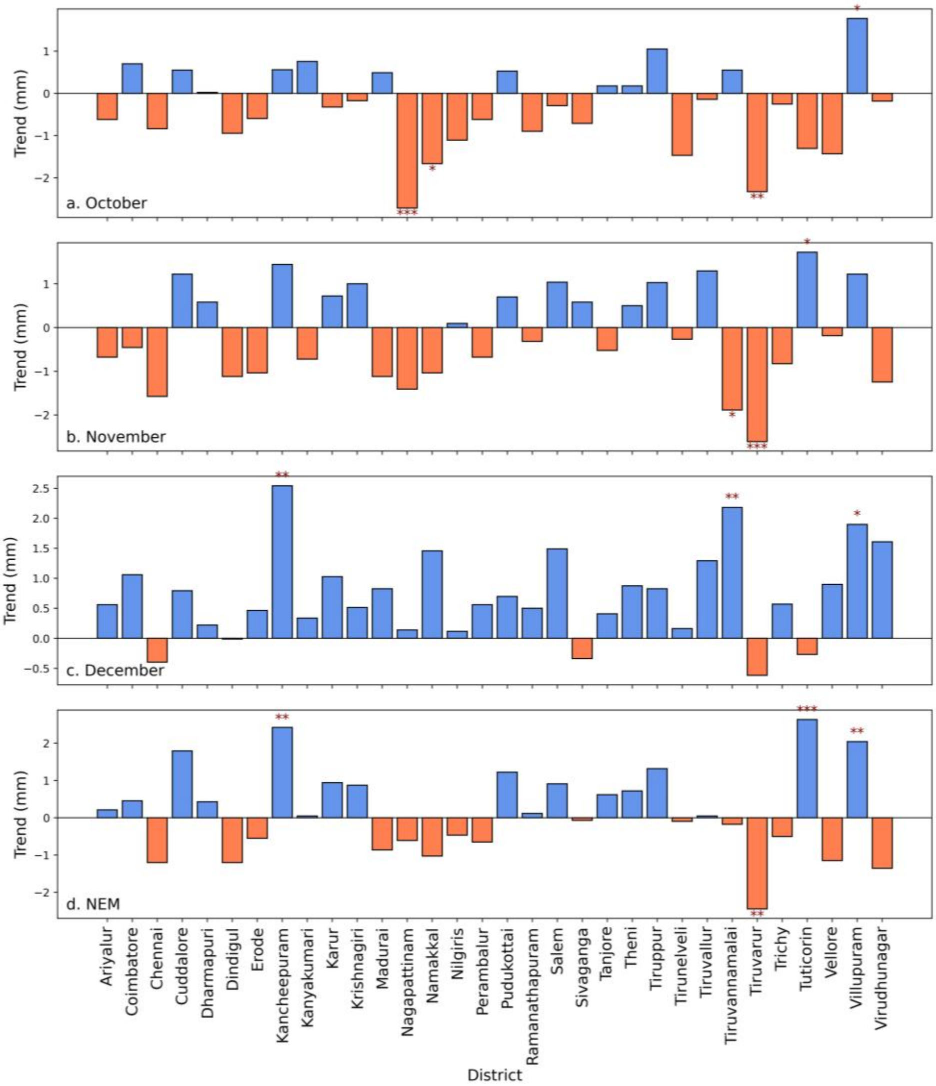

Figure 4. (a-d) *Rainfall trend for northeast monsoon season (*, ** and *** represents significant at 10, 5 and 1% level)*

Conversely, during the North East Monsoon (NEM), heavy rainfall occurs from the 3rd week of October to the 3rd week of November. Farmers can strategically plan the sowing window for rice crops to ensure they reach the tillering stage during this peak rainfall period. Alternatively, delaying the sowing of rice crops to the Navarai season in December-January is also a viable option. This flexibility in crop planning is critical for optimizing agricultural yields in response to seasonal precipitation patterns.

The trend analysis of both monsoons suggests that the implementation of cisterns can be an effective strategy to mitigate the challenges posed by irregular rainfall distribution. These storage structures can collect rainwater during the monsoon season

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and subsequently provide a reliable source of irrigation water during critical crop growth stages. Furthermore, the practice of mulching can be employed to conserve stored soil moisture.

Moreover, diversifying the cropping pattern to include water-efficient crops can enhance overall water use efficiency in agriculture. Additionally, transitioning from conventional irrigation methods to micro irrigation systems can significantly contribute to more effective groundwater management practices. These measures collectively aim to address water scarcity issues and improve agricultural sustainability in the face of variable monsoon patterns.

Conclusion

The extensive analysis of hydro-meteorological data spanning from 1981 to 2020 for Tamil Nadu has provided valuable insights into the dynamic nature of precipitation patterns during the Southwest and Northeast monsoons. The utilization of the Seasonal Precipitation Concentration Index (SPCI) and the Mann-Kendall test has shed light on critical trends and variations in rainfall distribution. The findings suggest that during the Southwest Monsoon, significant increasing trends in rainfall were observed in certain regions, while a decreasing trend was noted in others. Conversely, the Northeast Monsoon displayed its own set of trends, with significant increases in precipitation in specific areas.

As changing precipitation patterns pose challenges to agriculture and water resource management, the importance of well-informed decision-making cannot be overstated. Moreover, the uniform distribution of rainfall during the Southwest Monsoon, contrasted with a more moderate distribution during the Northeast Monsoon, emphasizes the need for adaptive strategies. In this era of changing climate patterns, the study highlights the importance of proactive measures in maintaining sustainable agricultural practices and water resource management. By recognizing and adapting to these trends, Tamil Nadu can effectively address the challenges posed by evolving precipitation patterns, ensuring the long-term resilience and productivity of its agricultural sector.

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