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Regional Rainfall Variability and Trends in Tamil Nadu: An Assessment using Non-parametric Tests

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Abstract: The drastic changes in traditional rainfall patterns have created a need to study trends in climatic variables, especially rainfall. In this paper, annual and seasonal trends of rainfall in Tamil Nadu as a whole, as well as Agro-climatic zone-specific patterns for the period of 24 years (2000-2023) have been analysed using non-parametric tests ideal for non-normal hydro-climatic time series: the Mann-Kendall test for monotonic trends and Sen's slope estimator for magnitude - this analysis mirrors methodologies in the referenced works. The results reveal spatially heterogenous rainfall trends across Tamil Nadu's Agro-Climatic Zones. Especially, the Southern Zone showed a decreasing trend of -0.55mm/year during the winter season while Western Zone showed significant increasing trend of +2.13mm/year during the monsoon season. In contrast, there was no significant monotonic trend in rainfall statewide and in other zones which implies that variations are likely due to natural variability rather than a systematic increase or decrease.

Keywords: Trend, Rainfall, Non-parametric test

1. INTRODUCTION

Rainfall is the primary source of fresh water and a vital element of all forms of life to meet their daily needs and demands. Agricultural activities in any region mainly depends on both time of occurrence and amount of rainfall that the area receives. Studying changes in rainfall trends and patterns is therefore crucial. Seasons analysed in this study include winter (January–February), pre-monsoon (March–May), monsoon (June–September) and post-monsoon (October–December). For a more comprehensive analysis, districts of Tamil Nadu are classified into seven

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Agro-climatic zones: North Eastern zone, North Western zone, Cauvery Delta zone, Southern zone, High rainfall zone and Hilly and High-Altitude zone.

This study addresses research gaps in prior works by Hussain et al. (Northern Punjab Province, Pakistan), Kamal and Pachauri (nine North-Eastern states of India), Kamble et al. (Parola tehsil), Shaha and Kirnab (Ghotki Feeder Canal, Sindh), and Duttarganvi (North-Eastern dry zone of Karnataka), which analyzed trends in climatic variables in these localized, non-Tamil Nadu contexts. It fills those gaps by comprehensively analyzing rainfall trends across Tamil Nadu.

2. MATERIALS AND METHODS

2.1. Data Description

This study used rainfall (in mm) data of the districts of Tamil Nadu for a period of 24 years (2000-2023), which was sourced from the Department of Economics and Statistics, Tamil Nadu. Tamil Nadu's monthly rainfall data from all districts were aggregated into seven Agro-Climatic Zones: North Eastern (Kancheepuram, Tiruvallur, Cuddalore, Villupuram, Vellore, Tiruvannamalai); North Western (Dharmapuri, Salem, Namakkal); Western (Coimbatore, Erode, Karur, Dindigul, Theni); Cauvery Delta (Tiruchirappalli, Perambalur, Pudukkottai, Thanjavur, Thiruvarur, Nagapattinam); Southern (Madurai, Sivagangai, Ramanathapuram, Virudhunagar, Tirunelveli, Thoothukudi); High Rainfall (Kanniyakumari); and Hilly & High Altitude (Nilgiris).

2.2. Mann-Kendall test

The Mann-Kendall test (Mann,1945; Kendall,1975; Gilbert,1987) is a non-parametric statistical method used to detect whether a variable shows a monotonic upward or downward trend over time. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, although the relationship between the variable and time does not have to be linear.

The test statistic S is defined as,

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} sign(x_i - x_j) \tag{1}$$

Where, n is length of data,

x i and *x j* are sequential data in the series and

$$sign(x_i - x_j) = \begin{cases} -1 \; if \; (x_i - x_j) < 0 \\ 0 \; if \; (x_i - x_j) = 0 \\ 1 \; if \; (x_i - x_j) > 0 \end{cases}$$

Mean of S, E(S)=0 and Variance is

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p-1}^{q} tp(tp-1)(2tp+5)}{18}$$

where, tp is number of ties of p value

Standardized test statistics Z is

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

To test for monotonic trend at α significance level, the null hypothesis of no trend is rejected if the absolute value of Z is greater than $Z_{1-\alpha/2}$, which is obtained from the standard normal cumulative distribution tables.

2.3. Sen's slope Estimator

The Mann-Kendall test shows whether there is a positive or negative trend. Sen's slope calculates the strength of a trend and is given by

$$b_{sen} = Median \left[\frac{y_i - y_j}{i-j}\right] \text{ for all } j<i$$

Where, y_i and y_j are data at time i and j respectively.

The positive and negative sign of the test statistic indicates increasing and decreasing trends respectively.

3. RESULTS AND DISCUSSION

3.1. Converting District wise variables to Agro-Climatic Zones data

The monthly rainfall data of the districts of Tamil Nadu are converted to seven Agro-Climatic Zones (North Eastern Zone, North Western Zone, Western Zone, Cauvery Delta Zone, Southern Zone, High Rainfall Zone, and Hilly and High-Altitude Zone) data by aggregation of respective districts' rainfall data.

3.2. Descriptive Statistics of Rainfall

The descriptive statistics of rainfall in Tamil Nadu and its Agro-Climatic Zones from 2000 to 2023 is shown in table 1.

Table 1: Descriptive Statistics of Rainfall

Season		*Tamil Nadu*	*North Eastern*	*North Western*	*Western*	*Cauvery Delta Zone (CDZ)*	*Southern*	*High Rainfall*	*Hilly and High Altitude*
ANNUAL	MAX	225.78	1318.64	158.77	179.52	284.94	247.86	324.37	297.67
	MIN	43.67	68.81	31.91	43.62	62.68	60.95	51.50	61.73
	MEAN	86.34	223.28	92.20	110.61	173.97	145.14	150.55	152.55
	SD	37.30	234.88	29.44	32.12	49.63	41.55	59.72	52.88
WINTER	MAX	59.77	66.23	12.28	31.36	87.08	77.66	47.50	96.80
	MIN	1.38	0.01	0.00	1.40	0.00	1.70	0.30	0.75
	MEAN	13.35	12.99	3.26	7.59	17.70	17.46	15.06	16.57
	SD	12.62	17.68	3.37	6.96	22.65	15.67	14.58	19.62
PRE MONSOON	MAX	277.68	873.96	127.67	102.61	111.30	123.47	159.40	168.50
	MIN	15.24	7.00	31.06	23.57	6.21	10.47	28.00	16.50
	MEAN	53.65	64.00	61.34	52.09	39.01	47.24	76.95	79.72
	SD	50.03	169.66	23.88	21.21	22.98	24.37	35.55	36.90
MONSOON	MAX	333.52	1177.11	129.13	158.29	106.67	75.59	144.95	474.63
	MIN	46.34	55.44	48.42	28.07	42.23	24.66	19.23	7.58
	MEAN	91.22	152.38	83.17	66.78	66.59	46.45	97.12	206.04
	SD	55.63	222.71	17.27	28.00	16.77	12.66	32.86	96.02
POST MONSOON	MAX	412.25	1318.64	158.77	179.52	284.94	247.86	324.37	297.67
	MIN	59.14	68.81	31.91	43.62	62.68	60.95	51.50	61.73
	MEAN	162.30	223.28	92.20	110.61	173.97	145.14	150.55	152.55
	SD	66.18	234.88	29.44	32.12	49.63	41.55	59.72	52.88

From table 1 the mean of annual rainfall in the seven Agro-climatic zones are 223.28mm, 92.20mm, 110.61mm, 173.97mm, 145.14mm, 150.55mm, 152.55mm respectively. Mean of pre-monsoon season rainfall in the zones are 64mm, 61.34mm, 52.09mm, 39.01mm, 47.24mm, 76.95mm, 79.72mm respectively. Similarly, mean of other seasonal rainfall have been presented in the above table.

3.3. Converting Monthly variables to season and annual variables

The monthly data of rainfall are converted to annual and seasonal data. Here, four seasons such as winter (January, February) pre-monsoon (March-May), monsoon

(June-September) and post-monsoon (October-December) have been used. To calculate annual and seasonal rainfall, aggregation of monthly rainfall has been used.

3.4. Trend analysis using non-parametric tests

Results of Annual Rainfall Trend

To analyse trend of rainfall, non-parametric tests like Mann Kendall test and Sen's Slope estimator have been used and the result is presented in table 2 and 3. Mann Kendall shows whether there is trend or not by given hypothesis

H_0: There is no significant monotonic trend

H_1: There is an increasing (decreasing) trend

Sen's slope estimator has been used to identify change per unit time of climate variable (rainfall).

Table 2: Annual rainfall in Tamil Nadu and its Agro-Climatic Zones

Zones	*Mann-Kendall*		*Sen's slope*
	Z test	*Result*	
Tamil Nadu	-1.22	0.224	-0.76
North eastern	-1.166	0.244	-1.03
North western	-0.620	0.535	-0.26
Western	0.868	0.385	0.56
Cauvery delta zone (CDZ)	-1.811	0.070	-0.89
Southern	-0.422	0.673	-0.26
High rainfall	0.372	0.710	0.27
Hilly and high altitude	0.670	0.503	0.73

Table 2 data reveals that none of the annual climate variable(rainfall) is significant. So, by accepting null hypothesis it is concluded that there is no significant monotonic trend in the variables. The sign in Z test shows whether there is increasing or decreasing trend. This means observed changes in rainfall, such as the suggested slight decrease(increase) from the negative(positive) Z-statistic could probably from random year-to-year variability rather than a consistent upward or downward shift over time. It implies that, the annual precipitation remains roughly stationary, with no reliable long-term increase or decrease.

Results of Seasonal Rainfall Trend

Similarly, trends of seasonal climate variables have been calculated using non parametric tests like Mann Kendall and Sen's slope estimator and the resulting trend estimates and their statistical significance are presented in table 3.

Table 3: Seasonal rainfall trends in Tamil Nadu and its Agro-Climatic Zones

Season	*Winter*			*Pre monsoon*			*Monsoon*			*Post monsoon*		
Test	*Mann-Kendall Test*		*Sen's slope*	*Mann-Kendall Test*		*Sen's slope*	*Mann-Kendall Test*		*Sen's slope*	*Mann-Kendall Test*		*Sen's slope*
Zones	*Z test*	*Result*		*Z test*	*Result*		*Z test*	*Result*		*Z test*	*Result*	
Tamil Nadu	-1.12	>0.05	-0.28	-0.57	>0.05	-0.33	0.77	>0.05	0.57	-1.02	>0.05	-1.59
North Eastern	-1.22	>0.05	-0.34	-0.97	>0.05	-0.33	0.47	>0.05	0.29	-1.02	>0.05	-1.98
North Western	0.57	>0.05	0.05	1.02	>0.05	0.52	0.07	>0.05	0.07	-0.72	>0.05	-0.62
Western	-0.47	>0.05	-0.04	-0.17	>0.05	-0.26	2.65	S	2.13	-0.67	>0.05	-0.98
Cauvery delta zone (CDZ)	0.87	>0.05	0.37	-0.97	>0.05	-0.52	1.02	>0.05	0.50	-1.91	>0.05	-2.13
Southern	-2.01	S	-0.55	-1.46	>0.05	-0.87	1.81	>0.05	0.81	-0.02	>0.05	-0.02
High rainfall	-1.12	>0.05	-0.36	-0.37	>0.05	-0.20	1.51	>0.05	1.82	1.41	>0.05	2.55
Hilly and high altitude	-0.57	>0.05	-0.15	0.12	>0.05	0.25	1.56	>0.05	3.18	0.12	>0.05	0.29

From table 3, it is clear that only winter season rainfall in Southern Zone and monsoon season rainfall in Western Zone are significant. So, by rejecting null hypothesis it can be concluded that there is increasing (decreasing) trend in rainfall. From the sign of Z test, it is clear that winter season rainfall in Southern Zone has a decreasing trend and monsoon season rainfall in Western Zone has increasing trend. Sen's slope estimator shows the change of unit, like there will be decrease of 0.55mm/year winter season rainfall in Southern Zone and there will be increase of 2.13mm/year monsoon season rainfall in Western Zone. For the entire Tamil Nadu and remaining zones, the p-values are greater than 0.05, indicating no significant monotonic trend and hence, we conclude that variations are likely due to natural variability rather than a systematic increase or decrease.

Time series plots of rainfall Trend

Time series plot of annual and seasonal climatic variable (rainfall) of Tamil Nadu has been presented in figure 1 and 2 respectively.

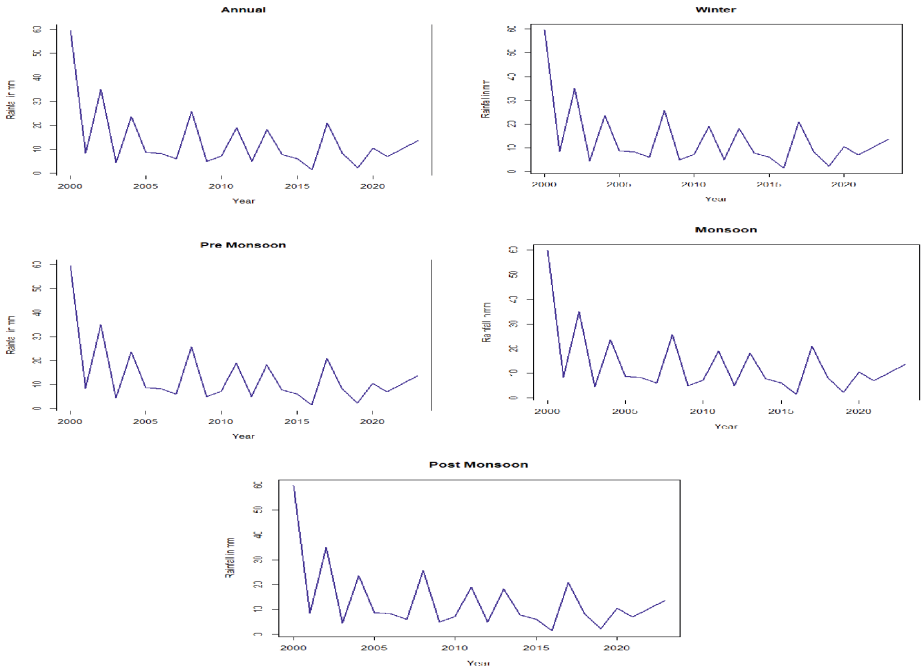


Figure 1: Plots of Rainfall Trend in Tamil Nadu

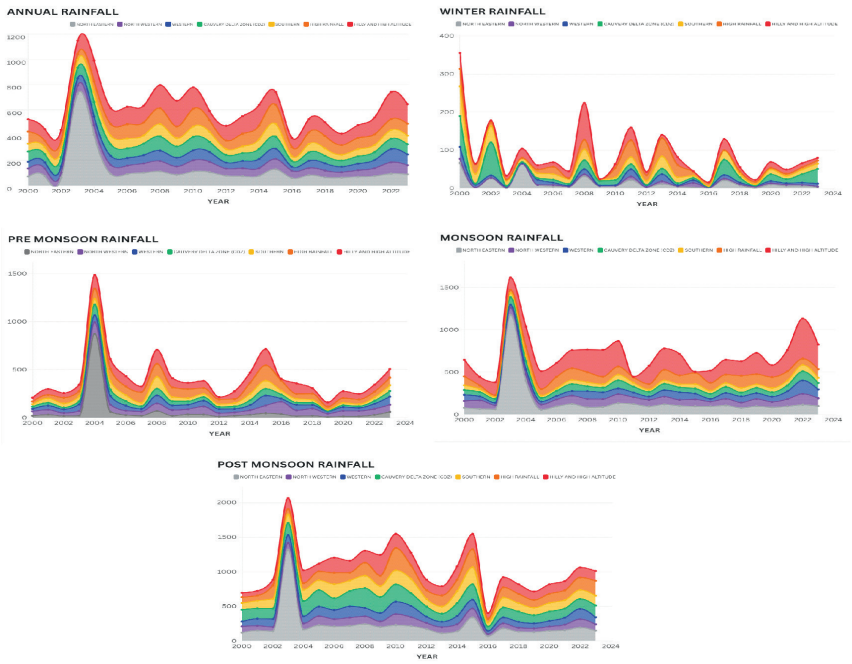


Figure 2: Plots of Rainfall Trend in Agro-climate Zones

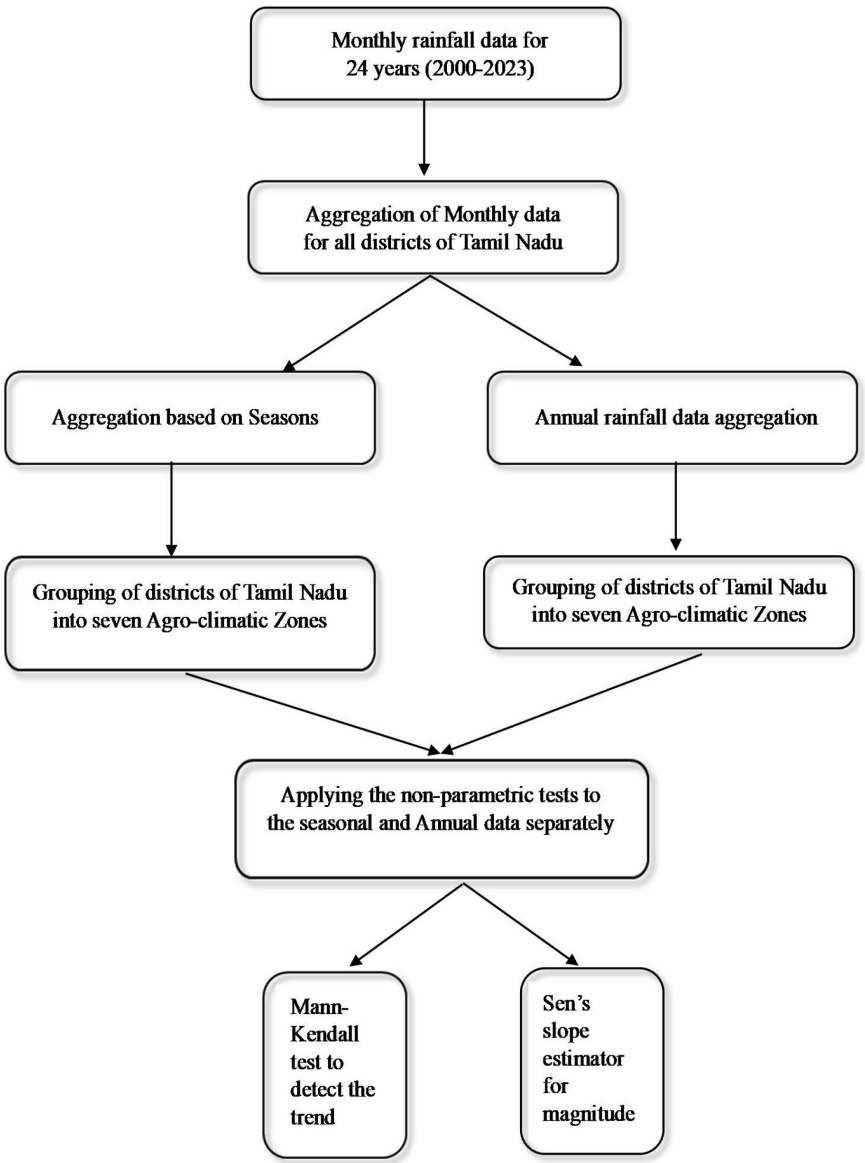


Figure 3: Flowchart for Methodology

4. CONCLUSION

The results clearly indicates that the variability in the rainfall pattern is primarily due to natural causes rather than systematic increase or decrease. The findings of the study suggest that these trends would help policymakers of the Tamil Nadu government to take informed decisions, particularly in the agricultural sector for

optimized cultivation practices—such as crop selection and sowing schedules and in water management strategies to mitigate risks from excessive or deficient rainfall. By integrating these insights into adaptive frameworks, authorities can enhance food security, reduce drought and flood vulnerabilities, and promote sustainable development amid changing climatic conditions.

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