



Crop planning using innovative trend analysis of 62-years rainfall data

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ABSTRACT

The success of climate-smart agriculture in high rainfall zone lies in understanding the rainfall trend and planning or modifying the cropping system for maximum yield. Moisture stress in critical crop growth stages is detrimental to the crop and drastically reduces the yield. Udhagamandalam region in Western Ghats is a high rainfall area and is largely cultivated by vegetable crops. Rainfall trend based crop planning would enhance the crop yield without water stress. A study was carried out at ICAR-Indian Agricultural Research Institute, Dhemaji, Assam focused on assessing the long-term seasonal and monthly rainfall trends of Udhagamandalam region, Tamil Nadu using non-parametric tests and Innovative Trend Analysis (ITA). Daily rainfall of 62 years from 1960–2021 was analyzed with non-parametric tests, viz. Mann-Kendall and modified Mann-Kendall and ITA to find the seasonal rainfall characteristics. Mann-Kendall (3.055) and modified Mann-Kendall (3.055) tests showed a significantly increasing trend in the annual and seasonal monsoonal rainfall. ITA revealed either a significant positive or a negative trend in all the months except February, with the highest trend in June (2.625). In contrast to standard non-parametric tests, ITA detected a significant positive trend in all seasons and annual rainfall, except in cold winters where the trend is negative. The long-term trend analysis results suggest that the ITA is more precise for rainfall trend analysis than standard non-parametric tests and can be used to evaluate hidden variations of rainfall trends. Hence, ITA is recommended for analyzing rainfall trends for crop planning in high-rainfall regions. IT analysis of 62 years of rainfall data of Udhagamandalam suggested that vegetable crop planning can be done by farmers from August–November months as the rainfall trend during this period is assured as an increasing trend of rainfall pattern was observed.

Keywords: Innovative trend analysis, Mann-Kendall test, Non -Parametric tests, Rainfall, Sens's slope

Rainfall is the primary water source and a crucial factor determining the success of rainfed agriculture in any agro-ecological region. Although 70% of the total rainfall occurs during the monsoon period, meagre is stored in the soil for crops (Manivannan *et al.* 2016). However, rainfall variations within the season are unpredictable, causing frequent floods and droughts (Kaur *et al.* 2022). In the current century, drought occurrences are more frequent in some years due to reduced rainfall and drastically reduced crop yield (IPCC 2013). Researchers have characterized rainfall distribution for sustainable crop planning in various agro-climatic regions (Mohanty *et al.* 2000, Manivannan *et al.* 2010). A long-term rainfall trend analysis showed 6% increase trend per decade with increased frequency of very heavy rain events (>150 mm/day) over central India

(Rajeevan *et al.* 2008). Still, decreased precipitation is predicted in the Himalayan region (Basistha *et al.* 2009).

Comprehensive knowledge of long-term rainfall patterns at a regional scale is vital for scientific crop planning and designing water harvesting structures (Yadav *et al.* 2014, Caloiero *et al.* 2017). Pradhan *et al.* (2020) proposed an ideal crop planning of early sowing of rice during 15–25 May and millet sowing from 25th June–1st July based on long-term trend analysis increased the yield in Baster region, Chhattisgarh. Yadav *et al.* (2016) recommended similar crop planning for *rabi* pulses and oil seeds. Dharani *et al.* (2022) suggested a change in the cropping pattern of Theni District, Tamil Nadu, from a double to single rice crop followed by pulses, maize/minor millets due to a predicted decreasing trend in annual mean rainy days.

Udhagamandalam is one of the hilly areas in the Western Ghats where agriculture solely depends on rainfall. Although the Nilgiris hill range receives higher rainfall, it still experiences water scarcity during summer, as the maximum rainfall is received during monsoons (June–December). Many researchers detected the rainfall trend at the national and regional levels using non-parametric analysis methods that highly depend on sample size and

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data distribution (Yue S and Wang 2004). ITA is reliable for trend detection (Gedefaw 2018), can delineate hidden trends, and is not sensitive to the serial correlation of data (Bora *et al.* 2022). The Nilgiris is a typical rainfed region where most vegetable crops, like potato, carrot, beans, cauliflower, beetroot, cabbage, broccoli, etc., are cultivated throughout the year. Therefore, trend analysis at the local level is more relevant for planning vegetable crops and water harvesting measures to mitigate the effects of climate change in Nilgiris. With this background a study was employed with an objective to compare the trend analysis by non-parametric and ITA, and recommend suitable trend analysis methods for crop planning in high-rainfall regions.

MATERIALS AND METHODS

Study area and data used: Daily rainfall data for 62 years (1960–2021) recorded at the meteorological observatory located in Udhagamandalam (11°24' N and 76°41' E, 2200 m amsl) was collected from ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Udhagamandalam, Tamil Nadu. The study area covers a geographical area of 87900 ha in Udhagamandalam block and falls under agro-climatic zone-10 Southern Plateau and Hills region. Major land uses in Udhagamandalam block are dense forest (51163 ha) followed by tea plantations (21150 ha) and vegetable crops (12319 ha), namely potato, cabbage, radish, carrot, cauliflower and broccoli. An area of 3268 ha has been put under non-agricultural land uses. The region receives an average rainfall of 1208 mm annually, of which more than 50% is distributed from June–September. The daily rainfall data were cumulated for monthly and seasonal rainfall analysis. The seasons were classified as cool winter (January–March), hot summer (April–May), south-west monsoon (June–September) and north-east monsoon (October–December) and seasonal rainfall patterns were analyzed using non-parametric and ita methods using 62 years of rainfall data.

Non-parametric trend analysis: In the current investigation, non-parametric tests such as Mann-Kendall, modified Mann-Kendall, and Wallis and Moore phase-frequency tests for randomness were employed to detect trends in rainfall time-series data. Furthermore, Sen's slope test and Spearman's rank correlation were also employed to determine the trend's magnitude with R software (version 4.1.2).

Mann-Kendall (MK) and Modified Mann-Kendall (MMK) test: The Mann-Kendall test is a robust and non-parametric rank test that detects significant trends in meteorological parameters in time series (Mann 1945, Kendall 1975). Positive and negative standardized Mann-Kendall test values indicate an increasing and decreasing trend. The modified Mann-Kendall test using the Hamed and Rao (1998) variance correction method was used for serially correlated data.

Randomness test: The non-parametric Wallis and Moore phase-frequency test was performed to test the H_0 -hypothesis, that the series comprises random data against

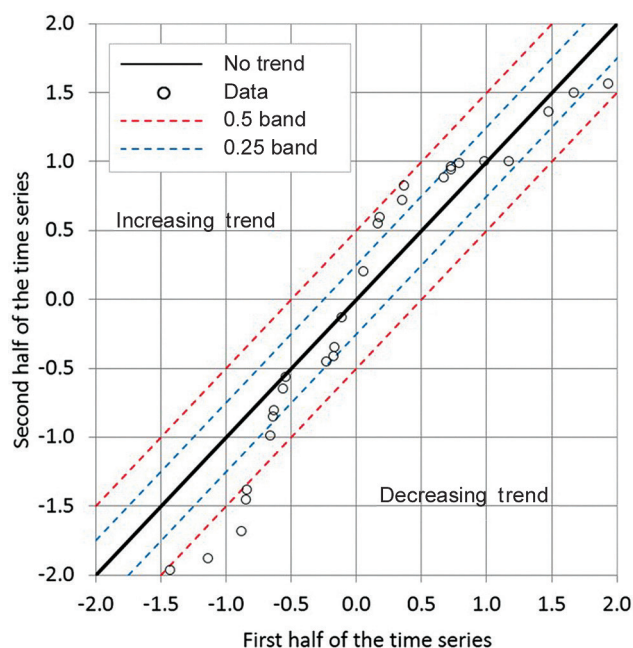


Fig. 1 Graphical illustration of the innovative trend analysis.

the HA-hypothesis that the series is significantly different from randomness (two-sided test) (Wallis and Moore 1941).

Sen's slope and Spearman's rank correlation: To verify the magnitude of trend in rainfall time-series data, non-parametric methods, viz. Sen's slope test (Sen 1968) and Spearman's rank correlation were employed (Lehmann and D'Abnera 1975). In both test statistics, positive and negative values depict the magnitude of the increasing and decreasing trend, respectively.

Innovative trend analysis: The ITA method, proposed by Sen (2012), was used to detect rainfall trends. It divides the daily rainfall data into two equal sub series, and then both sub series are sorted in ascending order (Fig. 1). Subsequently, the first sub series (x) is placed on the X-axis and the second sub series (y) on the Y-axis, according to the Cartesian coordinate system. If the data points accumulate in the top triangle, it indicates a positive trend, and the data points in the bottom triangle indicate a negative trend of the analyzed data. If the data points lie on a 1:1 line, it indicates that the data has no trend.

RESULTS AND DISCUSSION

Monthly rainfall statistics of the study area: From 1960–2021, the mean monthly rainfall was highest in July (194.9 mm), followed by June (161.1 mm) (Table 1). This indicates that the rainfall is concentrated in south-west monsoon season. However, July (16.3%), October (13.6%), and June (13.2%) had higher contributions to the annual rainfall, whereas January and February contributed the least (0.7%) towards annual rainfall. Though July had the highest contribution (16.3%) of rainfall, exceptionally in 1964, the highest monthly rainfall of 632.2 mm was recorded during August. Hence, preparatory works for water harvesting can be taken up before June month, and nursery preparation for

Table 1 Results of non-parametric tests for the monthly rainfall

Month	Mann-Kendall	Modified Mann Kendall	Randomness	Sens's slope	Spearman's rho
January	-0.830	-0.926	1.834*	0.000	-0.090
February	0.013	0.013	1.529	0.000	-0.004
March	1.422	1.847*	0.00	0.156	0.191
April	1.093	1.191	0.306	0.275	0.143
May	-0.443	-0.443	0.611	-0.220	-0.041
June	3.055***	3.055***	0.306	1.869***	0.384***
July	-1.215	-1.215	0.306	-0.877	-0.146
August	1.743*	1.493	0.611	0.939*	0.210
September	1.239	1.239	0.611	0.529	0.164
October	1.312	1.312	0.306	0.696	0.167
November	1.020	1.020	0.917	0.580	0.116
December	-0.419	-0.526	0.306	-0.104	-0.049

*Significance at $P \leq 0.1$; **significance at $P \leq 0.05$; ***significance at $P \leq 0.01$.

rabi (August–November) crops like cabbage, broccoli and radish can be taken up in July with sufficient and assured rainfall (Manivannan *et al.* 2016). In terms of variability, the highest variability was found in February (188.69%), followed by January (161.78%) and March (139.54%), indicating that the farmers should efficiently use the water for irrigating the vegetable crops grown in the cool winter season with the harvested rainwater. The rainfall in October (47.92%) has the least variability, indicating assured rainfall.

Seasonal rainfall statistics of the study area: During the study period, a mean annual rainfall of 1208 mm was recorded, with a coefficient of variation of 23.17% and a standard deviation of 279.89 (Fig. 2). Out of the 62 years, in 30 years, the annual rainfall was below the average. In contrast, in the remaining 32 years, it was above the average, indicating the unstable nature of rainfall over the years. Over this period, the highest mean rainfall was recorded during the south-west monsoon (649.9 mm), contributing 54% to the area's annual rainfall, followed by the north-east monsoon 324.8 mm and 27%, respectively (Table 2). In contrast, hot summer and cold winter seasons contributed only 18% and 1% to the annual rainfall. Similar to the rainfall contribution, the lowest rainfall variability was noticed with the southwest monsoon (31.63%) showing assured rainfall

for crop cultivation during the season. The farmers must be cautious in taking up the sowing or planting operations during January–February as the highest rainfall variability occurred in cold winter (122.82%). Farmers can use this period to construct small water harvesting structures like ponds. However, in all seasons, the rainfall variability percentage was higher than the annual rainfall percentage.

Trend analysis

Monthly rainfall trend: The statistical trend analysis of monthly rainfall (mm) using various tests from 1960–2021 in Udthagamandalam are presented in Table 3, Fig. 3. In June, a significant ($P \leq 0.01$) positive rainfall trend was observed, as indicated by the Mann-Kendall (3.055) and modified Mann-Kendall (3.055) test values. Similarly, a significant ($P \leq 0.01$) increasing magnitude of the trend was also explained by Sens's slope (0.384) and Spearman's rho values (1.869). The Mann-Kendall (1.743) test values for August also showed a significant ($P \leq 0.1$) positive trend in rainfall, with a magnitude of 0.939 (increasing trend), as indicated by Sens's slope. However, the Wald-Wolfowitz test of randomness (1.834) and modified Mann-Kendall test results (1.847) showed significant ($P \leq 0.1$) positive rainfall trends in January and March, respectively. On the

Table 2 Results of non-parametric tests for the seasonal and annual rainfall

Season	Test				
	Mann-Kendall	Modified Mann Kendall	Randomness	Sens's slope	Spearman's rho
Cold winter	0.000	-0.180	1.834*	0.000	0.003
Hot Summer	1.820*	1.736*	0.00	0.893*	0.236*
SWM	2.041**	2.010**	2.446**	3.399**	0.261**
NEM	1.215	1.537	0.917	1.317	0.136
Annual	2.520**	2.346**	2.140**	5.464**	0.322**

*Significance at $P \leq 0.1$; **significance at $P \leq 0.05$; ***significance at $P \leq 0.01$. SWM, South-west monsoon; NEM, North-east monsoon.

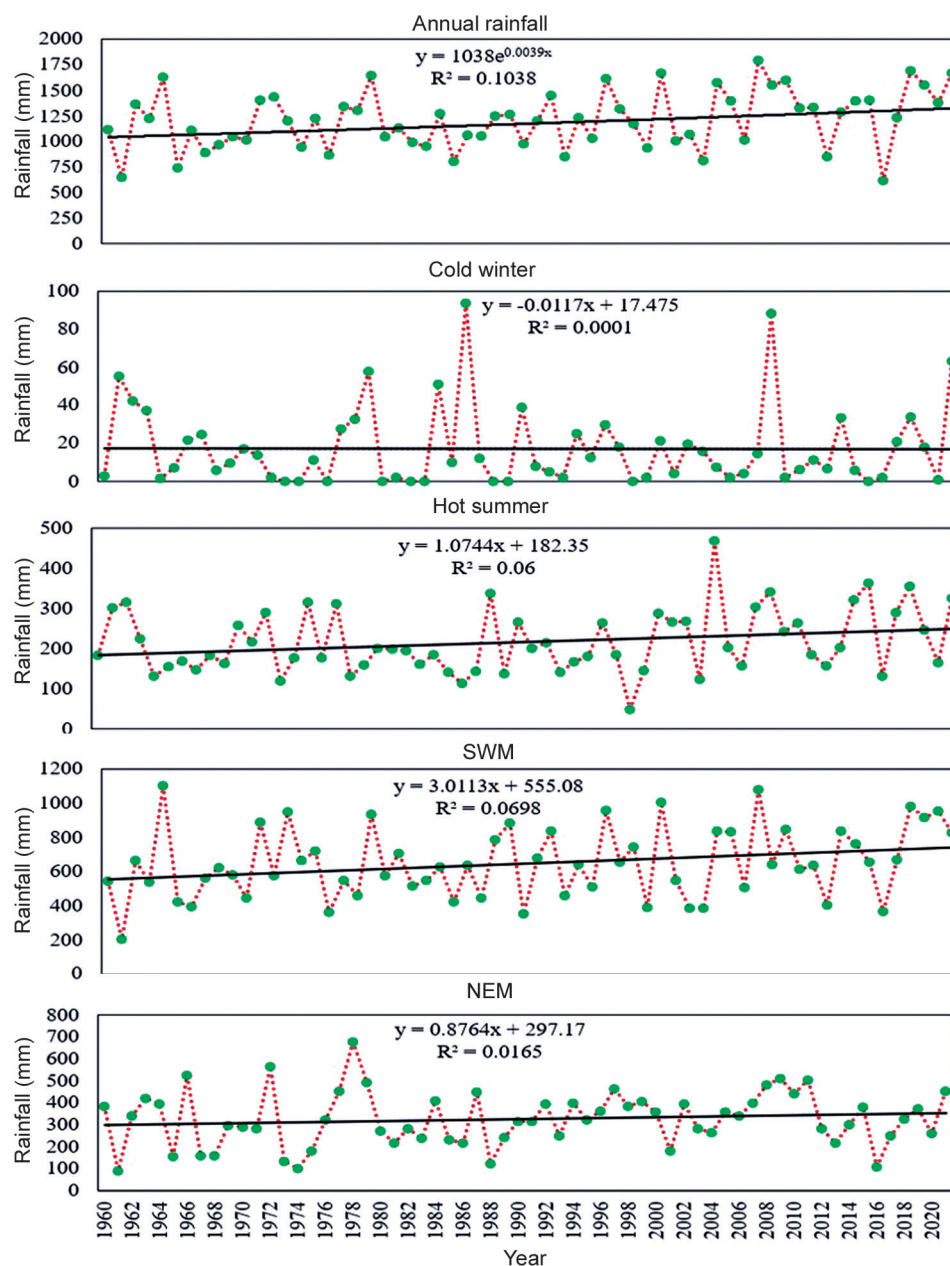


Fig. 2 Mean rainfall distribution during 1960–2021.

SWM, South-west monsoon; NEM, North-east monsoon.

other hand, both Mann-Kendall and modified Mann-Kendall tests reported a non-significant negative trend in January, May, July, and December. However, the region's rainfall

patterns may change if the trend continues. A significant decreasing rainfall trend in July and September was also reported by Remya *et al.* (2015) in the Kolli Hills of Tamil Nadu. Anand and Karunanidhi (2020) also confirmed a negative trend in January in the lower Bhavani basin, Tamil Nadu with 33 years of rainfall data (1983–2015).

Seasonal rainfall trend:

The monthly rainfall data were converted into seasonal (cold winter, hot summer, south-west monsoon, and north-east monsoon) and annual rainfall, and the linear trend and intensity of the trend were tested. Mann-Kendall, modified Mann-Kendall, and Wald-Wolfowitz tests of randomness for the south-west monsoon (2.041, 2.010, 2.446) and annual rainfall (2.520, 2.346, 2.140) revealed a significantly positive trend. This was evidenced by the increasing magnitude, as shown by Sens's slope (3.399 and 5.464) and Spearman's rho values (0.261 and 0.322), respectively. Similarly, rainfall during the summer showed a positive trend in the Mann-Kendall and modified Mann-Kendall tests with increasing magnitude. However, a significantly positive trend was reported

only with the Wald-Wolfowitz test of randomness for the cold winter season rainfall. In contrast, in the north-east monsoon, a non-significant positive trend was noted with all

Table 3 Seasonal results for innovative trend test of long-term rainfall data

Month	Slope	Slope SD	Correlation	Significance @ $P<0.1$		Significance @ $P<0.05$		Significance @ $P<0.01$	
				Lower CL	Upper CL	Lower CL	Upper CL	Lower CL	Upper CL
Cold winter	-0.098***	0.024	0.960	-0.040	0.040	-0.048	0.048	-0.063	0.063
Hot Summer	1.047***	0.097	0.955	-0.159	0.159	-0.190	0.190	-0.250	0.250
SWM	2.969***	0.244	0.958	-0.401	0.401	-0.478	0.478	-0.628	0.628
NEM	1.384***	0.153	0.954	-0.252	0.252	-0.300	0.300	-0.394	0.394
Annual	5.303***	0.291	0.968	-0.478	0.478	-0.569	0.569	-0.748	0.748

*Significance at $P\leq 0.1$; **significance at $P\leq 0.05$; ***significance at $P\leq 0.01$. SD, Standard deviation; CL, Confidence limit; SWM, South-west monsoon; NEM, North-east monsoon.

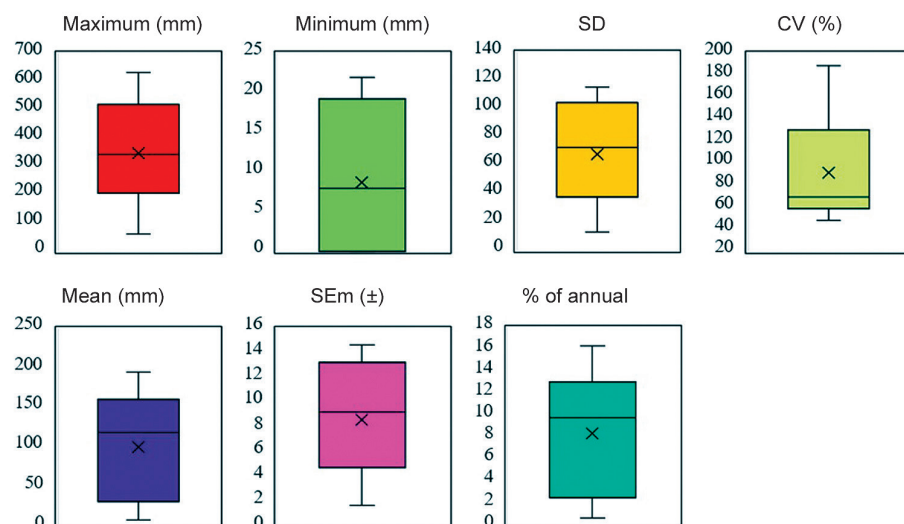


Fig. 3 Box and Whisker plot of overall monthly rainfall characteristics at Udhagamandalam during 1960–2021.

test statistics. Similar to our results, a significant ($0 < 0.05$) positive trend of the southwest monsoon and annual rainfall was reported in Erode district of Tamil Nadu (Kokilavani *et al.* 2017). In contrast to our results, Remya *et al.* (2015) detected a significant negative and positive trend with the south-west and north-east monsoon rainfall in the Kolli Hills of Tamil Nadu. Venkatesan *et al.* (2015) analyzed the long-term annual rainfall trend (1951–2012) of Tamil Nadu and reported no abrupt fluctuations in rainfall until 2000 but a significant negative trend thereafter. A slight decreasing trend in the annual rainfall over Tamil Nadu was also reported from 1989–2018 by Guhathakurta *et al.* (2020).

Innovative Trend Analysis

Monthly rainfall trend: The monthly trend analysis results of rainfall for Udhagamandalam were performed using ITA for all 12 months for the period of 62 years from 1960–2021. Positive values dominated slope values, most significant at either 5% or 1% level. During the 12 months, a significant trend was not detected for February month. Meanwhile, in seven months (March, April, June, August, September, October, and November), a significant increasing trend was noted at a 1% level of significance, with the highest magnitude of a trend noted in June (2.625), followed by October (1.349). In contrast, January, May, July, and December showed a significant negative trend ($P \leq 0.01$ or $P \leq 0.05$), with a decreasing magnitude ranging from 0.106–0.599. Furthermore, the trend explained by the slope values in different was strongly evidenced by the strong correlation values ranging from 0.877–0.979.

Seasonal rainfall trend: The slope value of 5.303 for annual rainfall indicated a significant positive trend at 1% level of significance, which was strongly supported by the correlation value of 0.968. In three seasons-hot summer, south-west monsoon, and north-east monsoon-a significant ($P \leq 0.01$) positive trend was observed, with the south-west monsoon season showing the highest magnitude of 2.969. In contrast, the cold winter season showed a significant

($P \leq 0.01$) negative trend, with a magnitude of 0.098. In all seasons, the correlation values were > 0.95 , indicating a trend change from 1960–2021. Singh *et al.* (2021) reported a significant ($P < 0.01$) negative trend in winter rainfall in Tamil Nadu from 1901–2019, as indicated by the slope of linear regression (-0.31) and Sen's slope values (-0.24). Overall, the seasonal and monthly rainfall findings using ITA have discovered more significant increasing or decreasing trends that were not discovered by non-parametric test statistics; these findings would be useful for precisely evaluating the hidden variation trends of rainfall

in Udhagamandalam. Praveen *et al.* (2020) reported effective trend analysis for seasonal rainfall over India, including Tamil Nadu, with ITA. A similar opinion was recorded by Sonali and Kumar (2013), Kisi *et al.* (2014) and Cui *et al.* (2017) in their studies conducted in India, Turkey, and China, respectively.

The study comparing non parametric trend analysis and ITA of monthly rainfall data showed that the seasonal and monthly rainfall findings using ITA have discovered more significant increasing or decreasing trends that were not found by non-parametric trend analysis. ITA deducted a significant positive trend in seven months (March, April, June, August, September, October, and November), with the highest magnitude in June (2.625), followed by October (1.349). In contrast, January, May, July, and December showed a significant negative trend with a decreasing magnitude ranging from 0.106–0.599. Furthermore, the trend explained by the slope values was evidenced by the strong correlation values ranging from 0.877–0.979. ITA revealed a significant increasing trend in the annual and seasonal rainfall except during the cold winter season (December–February). Hence, the cold winter must be utilized for harvesting unseasonal rainfall. Even though an increased trend was observed in June, the farmers should not go for sowing as July is experiencing a negative trend, and crops would fail due to water stress. Vegetable crops, namely potato, carrot, cabbage, radish, cauliflower, broccoli etc. can be grown effectively without being subjected to rainfall deficits in Udhagamandalam during the southwest monsoon (August–November) due to the increasing rainfall trend.

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