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Assessment of rainfall trend over Periyar Vaigai Command area of Tamil Nadu

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सार – जलवायु परिवर्तन के प्रभावों का अध्ययन करने के लिए वर्षा प्रवृत्ति विश्लेषण महत्वपूर्ण है। बेसिन स्तर पर जलवायु परिवर्तन को समझने का सबसे महत्वपूर्ण पहलू यह है कि यह जल उपयोग, योजना और विकास को कैसे प्रभावित करेगा। इस अध्ययन में 1982 से 2021 (40 वर्ष) तक पेरियार वैगई कमांड क्षेत्र में वार्षिक और मौसमी वर्षा के आंकड़ों की प्रवृत्ति का विश्लेषण करने का प्रयास किया गया है, जिसमें विभिन्न प्रवृत्ति विश्लेषण विधियों का उपयोग किया गया है, यानी प्रवृत्ति महत्व के लिए मान-कैंडल परीक्षण, प्रवृत्ति की शुरुआत और समाप्ति के आकलन के लिए अनुक्रमिक मान-कैंडल परीक्षण, प्रवृत्ति परिमाण के लिए सेन का ढलान परीक्षण, प्रवृत्तियों के संयोजन के लिए अभिनव प्रवृत्ति विश्लेषण और प्रवृत्ति का पता लगाने के लिए रैखिक प्रतिगमन विश्लेषण। सभी तरीकों का उपयोग करके गर्मियों के मौसम में सांख्यिकीय रूप से सकारात्मक प्रवृत्ति का पता चला, जबकि वार्षिक और SWM वर्षा ने सांख्यिकीय रूप से महत्वपूर्ण घटती प्रवृत्ति दिखाई। सर्दियों और NEM वर्षा में कोई खास प्रवृत्ति नहीं दिखाई। इस अध्ययन के परिणाम विभिन्न जल प्रबंधन आचरणों को अपनाने में मदद करते हैं और नीति निर्माताओं के लिए उचित शमन रणनीति तैयार करने में उपयोगी हैं।

ABSTRACT. Rainfall trend analysis is critical for studying the effects of climate change. The most crucial aspect of understanding climate change at the basin level is, how it will affect water usage, planning and development. The present study has been attempted to analyze the trend of annual and seasonal rainfall data over Periyar Vaigai Command area from 1982-2021 (40 years) employing different trend analysis methods *i.e*., Mann-Kendall test for trend significance, Sequential Mann-Kendall test for assessment of start and end of trend, Sen's slope test for trend magnitude, Innovative Trend Analysis for combination of trends and linear regression analysis for trend detection. Statistically positive trend was detected in summer season using all methods whereas, annual and SWM rainfall showed a statistically significant decreasing trend. Winter and NEM rainfall resulted with no significant trend. The results from this study helps to adopt various water management practices and useful for policy makers to prepare appropriate mitigation strategies.

Key words - Rainfall, Trend analysis, Periyar vaigai command area.

1. Introduction

Climate change is the major worldwide environmental problem considering rainfall and temperature as fundamental physical parameters (Pytrik *et al*., 2010) which can affect agricultural productivity (Panthi *et al*., 2015). Among different meteorological variables, rainfall is the key variable that is studied for planning socio-economic development strategies in the country (Singh and Kumar, 2022; Dharani *et al*., 2023). Due to industrialization and urbanization in India, the rainfall distribution has changed hastily (Kumar *et al*., 2021) and the GDP of India is dictated by monsoonal rainfall (Kokilavani *et al*., 2016). Rainfall has high variability on both temporal and spatial scales (Phukan and Saha, 2022) and proper rainfall estimation is needed for crop planning because 60 per cent of the agricultural area is under rainfed conditions in India (Kaur *et al*., 2021).

Trend analysis of rainfall is important to study the impact of climate change for water resources planning and management (Feizi *et al*., 2015). Understanding climate

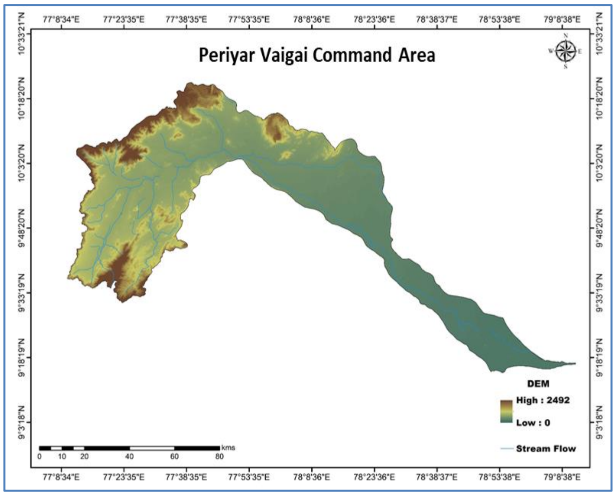

Fig. 1. Study area map of Periyar Vaigai Command area.

change at the basin scale is most important for the usage, planning, and development of water (Singh *et al*., 2008) Rainfall trend analysis studies had been carried out by many researchers in worldwide and also in India (Kumar and Jain, 2010; Panthi *et al*., 2015; Tabari *et al*., 2015; Wu *et al*., 2016; Langat *et al*., 2017; Fentaw *et al*., 2017; Gao *et al*., 2019; Dharani *et al*., 2022). The seasonal and mean monthly trend analysis using MK test resulted in decreasing trend for rainy days and rainfall (Khavse and Chaudhary, 2022). Trend analysis in the Sabarmathi basin showed statistically significant decreasing trends for annual, winter, pre-monsoon & monsoon rainfall (Krishn *et al*., 2022). For seasonal rainfall, the trend of winter & summer rainfall was insignificantly positive, whereas the trend of the Southwest & Northeast monsoons was insignificantly negative in Thanjavur Delta region of Tamil Nadu (Pavithrapriya *et al.*, 2022) & the trend of Northeast monsoon rainfall had increased (Ramaraj *et al*., 2017).

The current study focuses on seasonal & annual rainfall analyses over the period of 1982-2021 (40 years) to examine long-term patterns in precipitation for Periyar Vaigai Command area. The trend analyses were done by (*i*) using Mann-Kendall test for trend significance (*ii*) using Sen's slope estimator for trend magnitude estimation (*iii*) using innovative trend analysis for aiding the results of trend analyses (*iv*) using Sequential Mann-Kendall test for start and end of trend detection & (*v*) also using linear regression method to identify the trend in rainfall data.

2. Data and methodology

2.1. *Description of study area*

The Periyar river flows westward and is channelled into the eastern slopes of the Western Ghats by the tunnel. The transferred water from Periyar Lake joins the rivers Vairavanar and Suruliar eventually joining the river Vaigai, which originates in the Varushanad hills. The Periyar Vaigai Command (PVC) area includes five Tamil Nadu districts *i.e*., Theni, Dindigul, Madurai, Sivagangai, and Ramanathapuram and drains into the Palk Strait (Fig. 1). The PVC region is located between the latitudes of 9°15' N to 10°20' N and the longitudes of 77°10' E to 79°15' E, encompassing an area of 7741 sq. km with a length of 258 km. The primary reason for diverting water is to give irrigation facilities to rain shadow regions that receive a limited quantity of rainfall during the Southwest monsoon.

2.2. *Weather data*

The daily rainfall data of Periyar Vaigai Command area comprising of 28 raingauge stations for 40 years (1982-2021) had been collected from PWD, Periyar Vaigai Basin Division, Madurai. The daily data were converted into seasonal and annual data for analysis as per the India Meteorological Department (IMD) guidelines. The year was separated into four seasons for seasonal trend analysis: Winter (January - February), Summer (March - May), Southwest monsoon (June - September), Northeast-monsoon (October - December) as adopted in Verma and Kale (2018).

2.3. *Trend analysis*

2.3.1. *Mann-Kendall (MK) test*

The Mann-Kendall test is a non-parametric test that evaluates the relative magnitudes of data rather than the actual data values in order to discover patterns in time series (Gilbert, 1987). The advantage of this test is that the data does not have to correspond to any specific distribution. Each data value in the time series is compared to all subsequent values in this test. S is initially believed to be zero, and if a data value in a subsequent time period is greater than a data value in a prior time period, S is increased by one, and vice versa. The sum of all such increments and decrements results in the ultimate value of S.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sign\ (X_j - X_i)$$

where, n is data series length, X_i and X_j are the successional data in the series and

$$Sign\ (X_j - X_i) = \begin{cases} 1\ for\ (X_j - X_i) > 0 \\ 0\ for\ (X_j - X_i) = 0 \\ -1\ for\ (X_j - X_i) < 0 \end{cases}$$

A positive S number implies an upward trend, whereas a negative one suggests a downward trend. However, statistical analysis is required to determine the significance of the pattern. Kendall (1975) describes the test technique for the normal - approximation test. This test assumes that the data collection contains few tied values. The variance (S) is calculated by the following equation:

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

where n, is the number of data points, p is the number of tied groups and tj is the number of data points in the j^{th} group. The normal Z- statistics is computed as:

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

If Z is negative and the computed Z - statistics is more than the z - value corresponding to the 5% level of significance, the trend is considered to be falling. If the Z is positive and the computed Z - statistics is more than the z - value corresponding to the 5% threshold of significance, the trend is considered to be growing. There is no trend if the calculated Z - statistics is smaller than the z - statistics equivalent to the 5% level of significance.

2.3.2. *Sen's slope estimator (SS)*

Sen's slope estimator is a powerful tool for developing linear relationships and is mostly used to measure slope magnitude (Sen, 1968). Sen's slope is calculated by taking the average of all pairwise slopes between each pair of points in the dataset. Sen's slope has an advantage over regression slope in that it is unaffected by large data mistakes and outliers.

$$b_{sen} = median\left[\frac{X_i - X_j}{(i-j)}\right] \text{ for all } i > j$$

where, i and j are time points and Xi and Xj are the respective data at these time points. If n is the tally of data points in series, then (n(n-1)/2) will be the slope estimates and median of these slope estimates is the b_{sen}. An increasing trend is denoted by positive sign of b_{sen} and declining trend is denoted by negative sign of b_{sen} (Sonali and Kumar, 2013).

2.3.3. *Innovative trend analysis (ITA)*

The principle of this technique is that for two identical time series, their plot on Cartesian coordinates against one another shows a 1:1 line (straight line of 45°), despite the fact that this does not hold true for all postulations about distribution, length of sample, and serial correlation. If all of the data points are on the 1:1 line, there is no trend in the time series. The location of scatter points below or above the 1:1 line indicates diminishing or growing monotonic trends in this approach. If scatter points appear on each side of the 1:1 line, it indicates the presence of a growing and declining trend of non-monotonic nature masked at distinct time scales in the provided data series (Sen, 2012; Sonali and Nagesh Kumar, 2013; Kale, 2020).

2.3.4. *Sequential Mann- Kendall test (SQMK)*

The Sequential form of Mann-Kendall test might be seen as an effective method of determining the beginning year(s) of a trend (Partal & Kahya, 2006). Similarly the last point of intersection will denote the ending of the trend (Kale, 2018). Thus, the SQMK test was used to determine the start and end of a trend (assuming one exists in the supplied time series) & it is a Change point assessment tool.

2.3.5. *Linear regression analysis*

Linear regression analysis is a parametric model that is used to find trends in data sets (Kaur and Kaur, 2019). By fitting a linear equation to the observed data, this model builds a link between two variables (dependent and independent). The data is initially examined to see whether there is a link between the variables of interest. The scatter plot may be used to do this. The linear regression model is broadly defined by the equation:

$$Y = mX + C$$

where, Y is the dependent variable, X is the independent variable, m is the line's slope and C is the intercept constant. The model's coefficients (m and C) are found using the least-squares approach, which is the most often used method. At the 5% significance level, the t-test is performed to evaluate if the linear trends are substantially different from zero

3. Results and discussion

3.1. *Annual rainfall*

The result from the trend analysis for annual rainfall over PVC area using the linear regression analysis, the rate of change is defined by the slope of regression line which is about -9.15 mm/year for annual rainfall and a

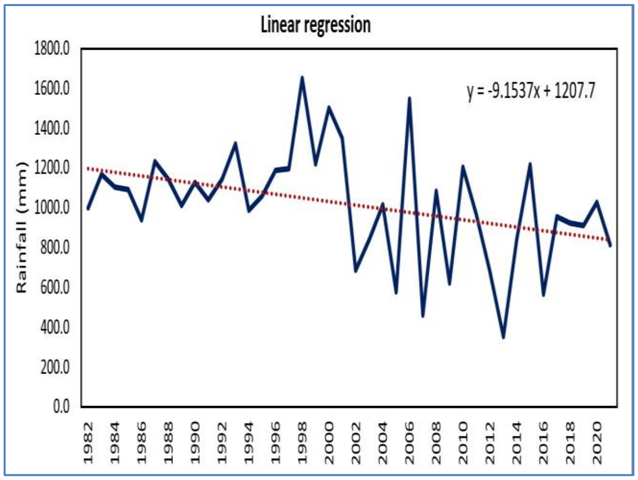

Fig. 2. Trend analysis using linear regression method for annual rainfall over PVC area.

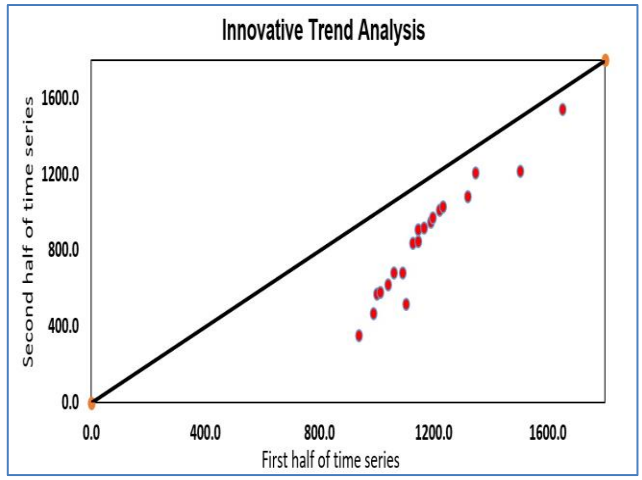

Fig. 3. Trend analysis using ITA plot method for annual rainfall over PVC area.

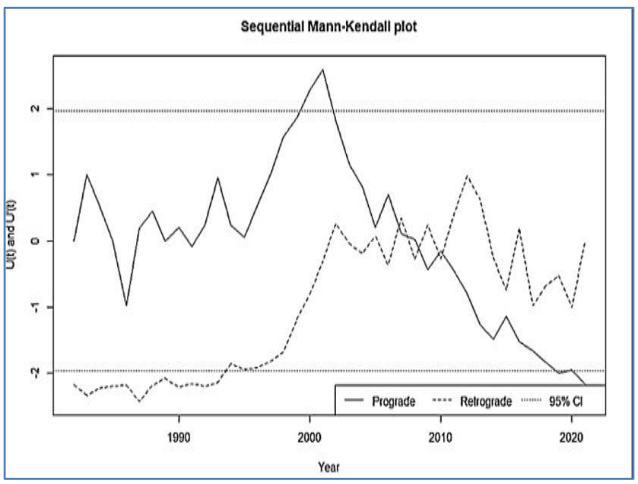

Fig. 4. Trend analysis using SQMK test for annual rainfall in PVC area.

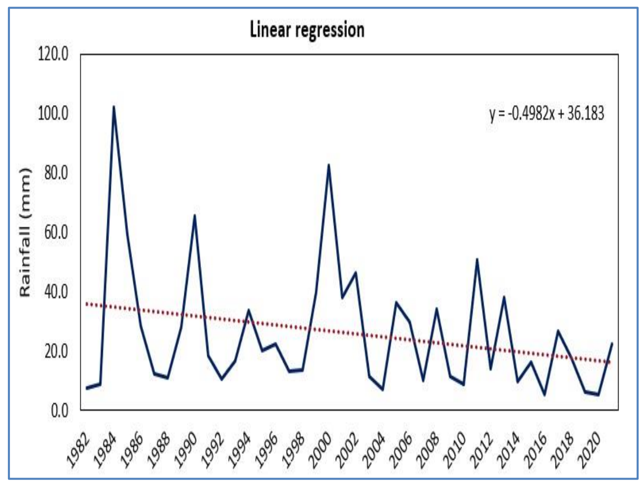

Fig. 5. Trend analysis using linear regression method for winter rainfall over PVC area.

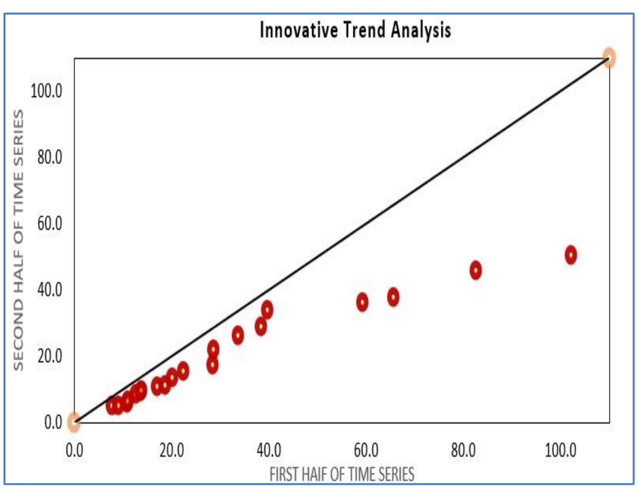

Fig. 6. Trend analysis using ITA plot method for winter rainfall over PVC area.

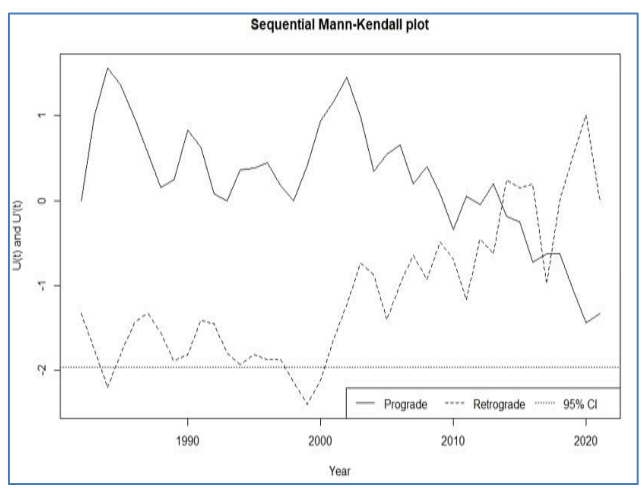

Fig. 7. Trend analysis using SQMK test for winter rainfall in PVC area.

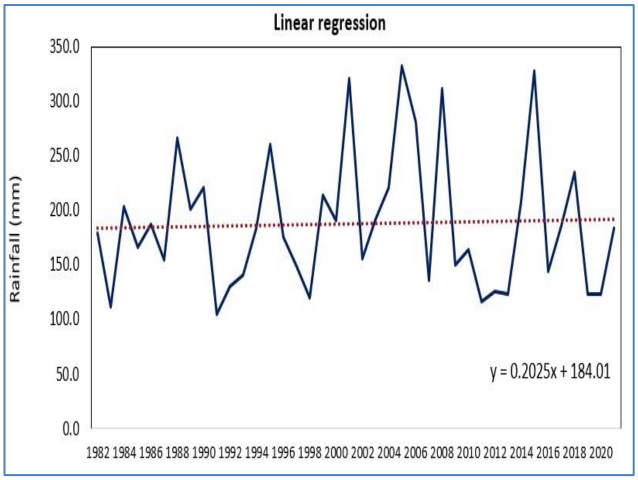

Fig. 8. Trend analysis using linear regression method for summer rainfall over PVC area.

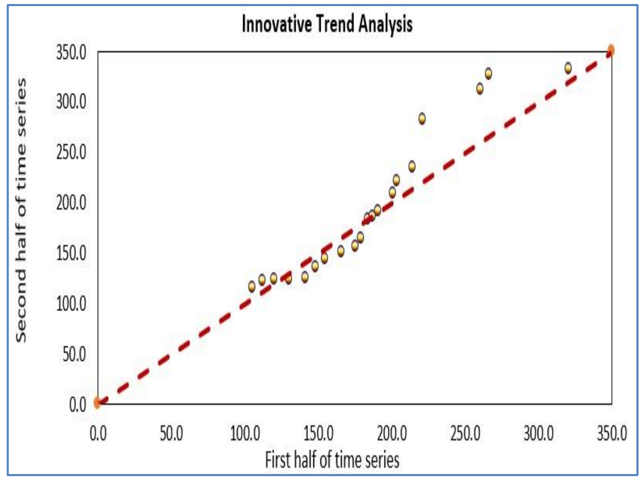

Fig. 9. Trend analysis using ITA plot method for summer rainfall over PVC area.

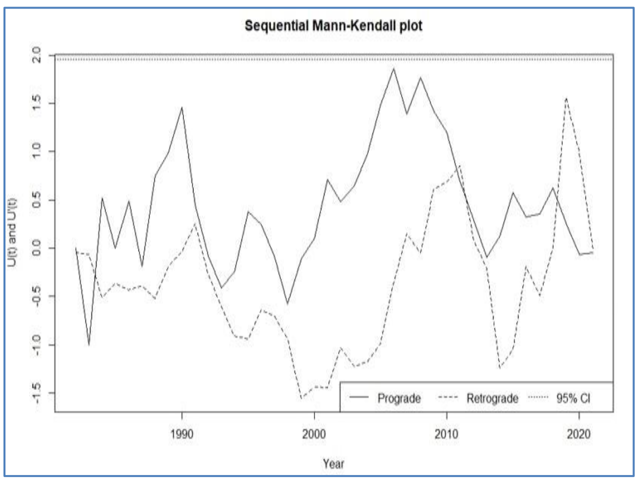

Fig. 10. Trend analysis using SQMK test for summer rainfall in PVC area.

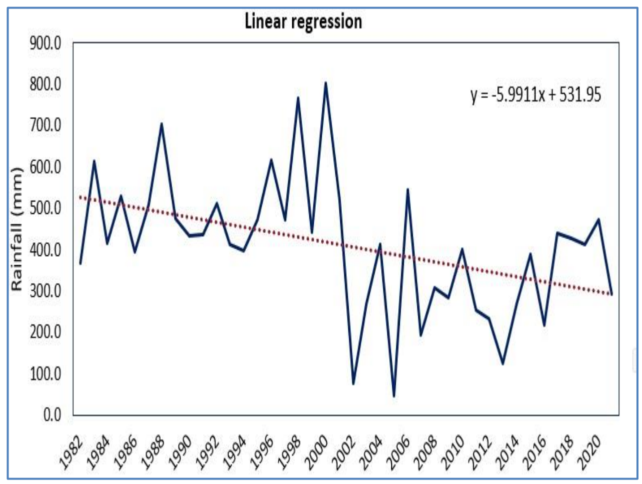

Fig. 11. Trend analysis using linear regression method for SWM rainfall over PVC area.

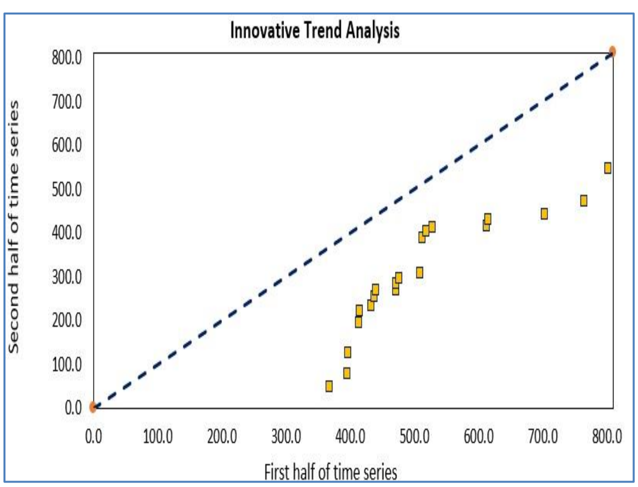

Fig. 12. Trend analysis using ITA plot method for SWM rainfall over PVC area.

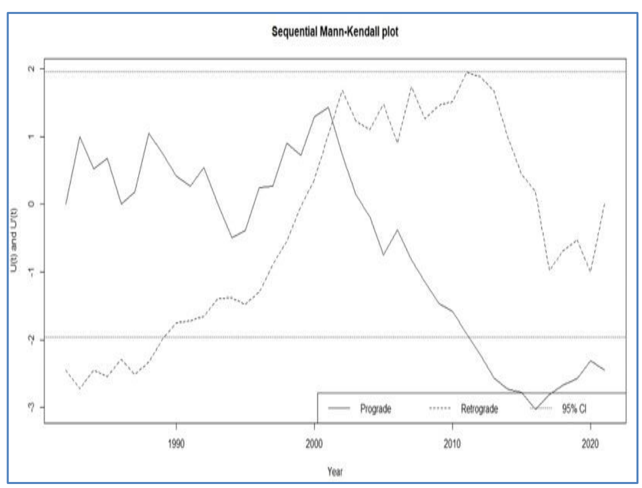

Fig. 13. Trend analysis using SQMK test for SWM rainfall in PVC area.

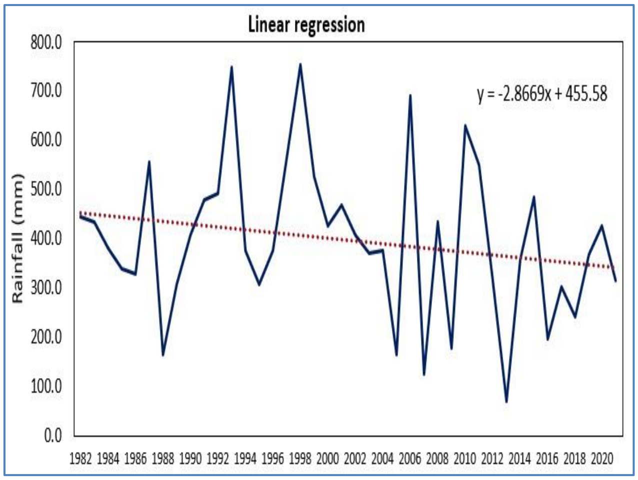

Fig. 14. Trend analysis using linear regression method for NEM rainfall over PVC area.

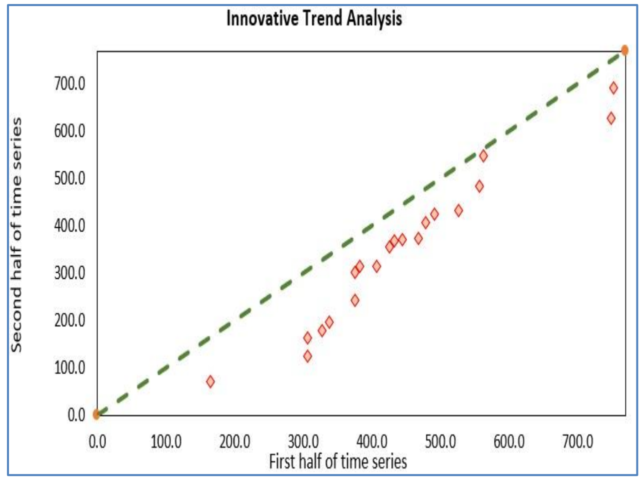

Fig. 15. Trend analysis using ITA plot method for NEM rainfall over PVC area.

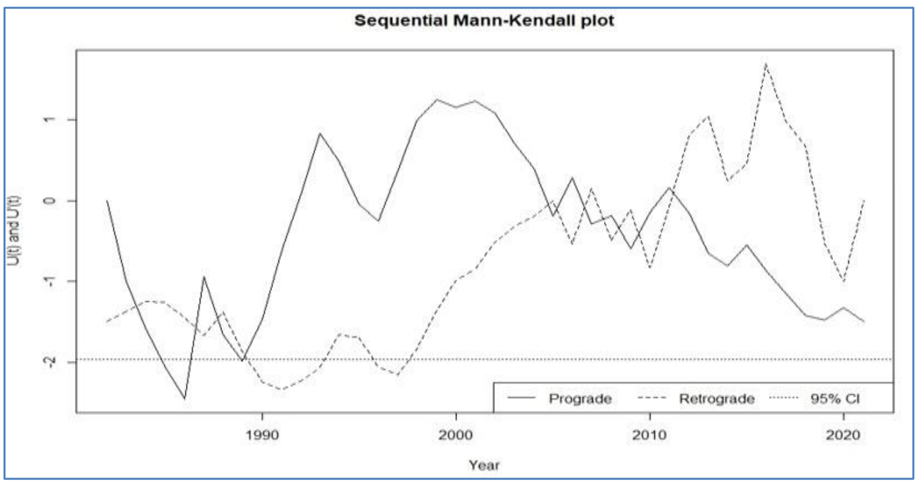

Fig. 16. Trend analysis using SQMK test for NEM rainfall in PVC area.

TABLE 1

SS, MK and SQMK test results for annual and seasonal rainfall trend analysis in PVC area from 1982-2021 (40 years)

Variables	SS Test	Trend at 5 % Significance level	
		MK Test	SQMK test
Annual	-7.18	Significant	Yes
Winter	-0.28	NS	No
Summer	-0.02	NS	No
South-West Monsoon	-5.41	Significant	Yes
North-East Monsoon	-2.68	NS	No

decreasing trend with statistical significance at 5% was found in annual rainfall respectively (Fig. 2). The innovative trend analysis for annual rainfall showed a monotonous decreasing trend (Fig. 3), while there was a negative magnitude of -7.18 mm / year of rainfall estimated from Sen's Slope test. The results from the Mann-Kendall showed a significant trend (p-value = 0.031) in annual rainfall over Periyar Vaigai Command area for 40 years (1982 - 2021) (Table. 1) and Sequential Mann-Kendall analysis resulted with more significant variability in the beginning and ending of trend in annual rainfall (Fig. 4).

3.2. *Seasonal rainfall*

3.2.1. *Winter rainfall*

Results of trend analyses for winter rainfall over the Periyar Vaigai Command area for 40 years (1982-2021) are interpreted in this section. From the linear regression analysis, the winter seasonal rainfall is statistically significant with decreasing trend at a rate of 0.5 mm/year (Fig. 5) which was supported by ITA test resulted with a monotonous decreasing trend (Fig. 6), however, there was no significant trend observed through Mann-Kendall test (p-value = 0.188) and using SQMK test, trend begins in 2014 and ends in 2017 and again begins in 2018 was estimated (Fig. 7). Sen's slope analysis found a negative magnitude of winter rainfall with 0.28 mm/year reduction (Table. 1).

3.2.2. *Summer rainfall*

The summer rainfall trend analysis from 1982-2021 (40 years) resulted in rate of increase of 0.20 mm/year with a statistically significant trend which is highly supported by the results from ITA plot with non-monotonous increasing trend (Figs. 8 & 9). There was no significant trend observed through Mann-Kendall test (p-value = 0.972) and a higher variability in winter rainfall resulted in more exposure of starting and ending points of trend by SQMK test (Fig. 10). From the Sen’s slope analysis, a magnitude of 0.22 mm/year of summer rainfall was found (Table. 1).

3.2.3. *South West Monsoon (SWM) rainfall*

The graph shows the results of trend analysis for SWM rainfall across the Periyar Vaigai Command region over the last 40 years (1982-2021). According to the linear regression analysis, the SWM rainfall is statistically significant with a lowering trend at a rate of 6.0 mm/year (Fig. 11), which was corroborated by the ITA test (Fig. 12) and start of trend estimated by SQMK test was from 2002 (Fig. 13). Mann-Kendall test showed a statistically significant trend (p-value = 0.014) and Sen's slope study revealed a negative magnitude of SWM rainfall with a 5.41 mm/year (Table.1).

3.2.4. *North East Monsoon (NEM) rainfall*

The trend analysis results for NEM rainfall across the PVC region using linear regression analysis, the rate of change is characterized by the slope of the regression line, which is around -2.86 mm/year for NEM rainfall (Fig. 14) is highly supported by Sen’s slope estimation with a negative magnitude of 2.68 mm/year and a declining trend with statistical significance of 5% was discovered in annual rainfall. The ITA for NEM rainfall revealed a monotonous declining trend (Fig. 15). The Mann-Kendall analysis revealed a non-significant trend (p-value = 0.139) in NEM rainfall across the Periyar Vaigai Command area over 40 years (1982-2021), and the Sequential Mann-Kendall analysis revealed more no significant trend point detection in the NEM rainfall (Fig. 16).

4. Conclusion

The present study shows the rainfall trend in Periyar Vaigai Command area in Tamilnadu. The rainfall pattern of this region was analyzed using linear regression analysis, Innovative trend analysis, Mann-Kendall Trend analysis, Sequential Mann-Kendall Trend analysis and Sen’s slope estimator for annual and seasonal rainfall of time series data from 1982-2021 (40 years) showed a statistically significant positive trend in summer seasonal rainfall in all the different types of trend analysis methods adopted in this study. A negative trend was observed in annual, winter, SWM and NEM rainfall. Agriculture is the predominant occupation in this region, if the rainfall decreasing trend continued, it will ultimately affect the crop growth and final crop production. As a result, water management approaches should be implemented in this region to reduce the risk of crop failure.

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