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Analysing Micro-Level Rainfall Trends: Implications for Water Conservation in Paravanar River Basin

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Abstract: High-intensity, short-duration rainfall resulting in flood hazards is one of the significant challenges now. On the other hand, this basin is affected by drought in the subsequent years because of the lack of conservation of floodwater and high elevation difference. Rainfall analysis is the preliminary study for suggesting the type of water conservation measures. This study analyzes the trend and change point at a micro-scale with its village boundaries for the Paravanar River basin. One hundred forty-eight villages under six blocks have increasing trends, 28 towns in the summer season using rain gauge dataset show decreasing trends which are considered negligible, and the rest of the villages have no trends. It is identified that; trend analysis works well with the extended data record. 1991 is the trend change point for gridded data, and 1995 is for the rain gauge data. The main aim of this study is to analyze the rainfall trends and their change point at a micro level and suggest mitigation measures with the indigenous facilities.

Key words: Village-level trend analysis, annual and seasonal analysis of rainfall.

Introduction

One of the significant components of hydrology is rainfall, which is adequate to maintain an environmental flow and ecological balance. The distribution of water plays a vital role and varies with space and time (Mishra et al., 2023). Hence, this study is a piece of evidence that insists on the improvement of water harvesting structures. Many applications and methods are available for analysing rainfall. Trend prediction is advisable for studying rainfall data behaviour (Malarvizhi and Ravikumar, 2021). The presence of completed open-cast mines evoked the choice of the Paravanar River basin for this study. The main idea is to prove that the rainfall will increase in these regions.

This basin experiences flood frequently, but since the floodwater had not been harvested and left to join the sea, the basin experienced drought in the subsequent years. The solution is to combine innovative infrastructures with traditional water harvesting methods (Nirban Laskar, 2022).

Trend analysis demands nonparametric tests (Kisi and Ay, 2014). Many Indian studies have followed these nonparametric methods for trend analysis (Abhishek et al., 2018). Many trend prediction methods are available such as Sen's slope (Sen, 1968), Spearman's Rho, (Yue et al., 2002), the Mann-Kendall (MK) trend test (Kendall, 1938), (Mann, 1945); these techniques try to identify monotonic trends within a given time, (Alifujiangli and Ge, 2021). Mann-Kendall and Spearman's Rho test successfully predicts the trend of annual, monthly, and seasonal series of data (Malarvizhi and Ravikumar, 2021; Palanichamy and Sankaralingam, 2020). One of the essential studies along with trend

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analysis is the change point of the trend (Patakamjri et al., 2020). Few researchers have a note on the time of trend change in their research (Sonali and Nagesh Kumar, 2013).

Changepoint identification is vital in studying hydro-meteorological data such as rainfall and temperature data (Patakamjri et al., 2020). The present study uses two nonparametric tests, such as Cumsum and Cumulative deviation, to analyse the change points.

Study Area

The study region, Paravanar river basin is situated in the Cuddalore district with 191 villages (Figure 1). Also, these villages are classified into six blocks: Cuddalore, Panruti, Kurinjipadi, Kammapuram, Mel Bhuvanagiri, and Parangipettai. The precipitation of this area is cyclonic and tends to develop a low-pressure region in the Bay of Bengal (Shankar et al., 2010). Even though the basin receives moderate to heavy precipitation, water scarcity and water quality problems exist (Shankar et al., 2010). This study basin falls under one of the low-lying coastal zones; even in 2004, Tsunamis had a much higher impact in this region (Saxena et al., 2012). Most of the study area is a flat plain, sloping very gently towards the sea on the east. The elevation of the Paravanar basin is higher at the dump yard from the mines and the lowermost ridge at the open-cast mines. So, the study area consists of three open-cast lignite mines with three thermal power plants. The

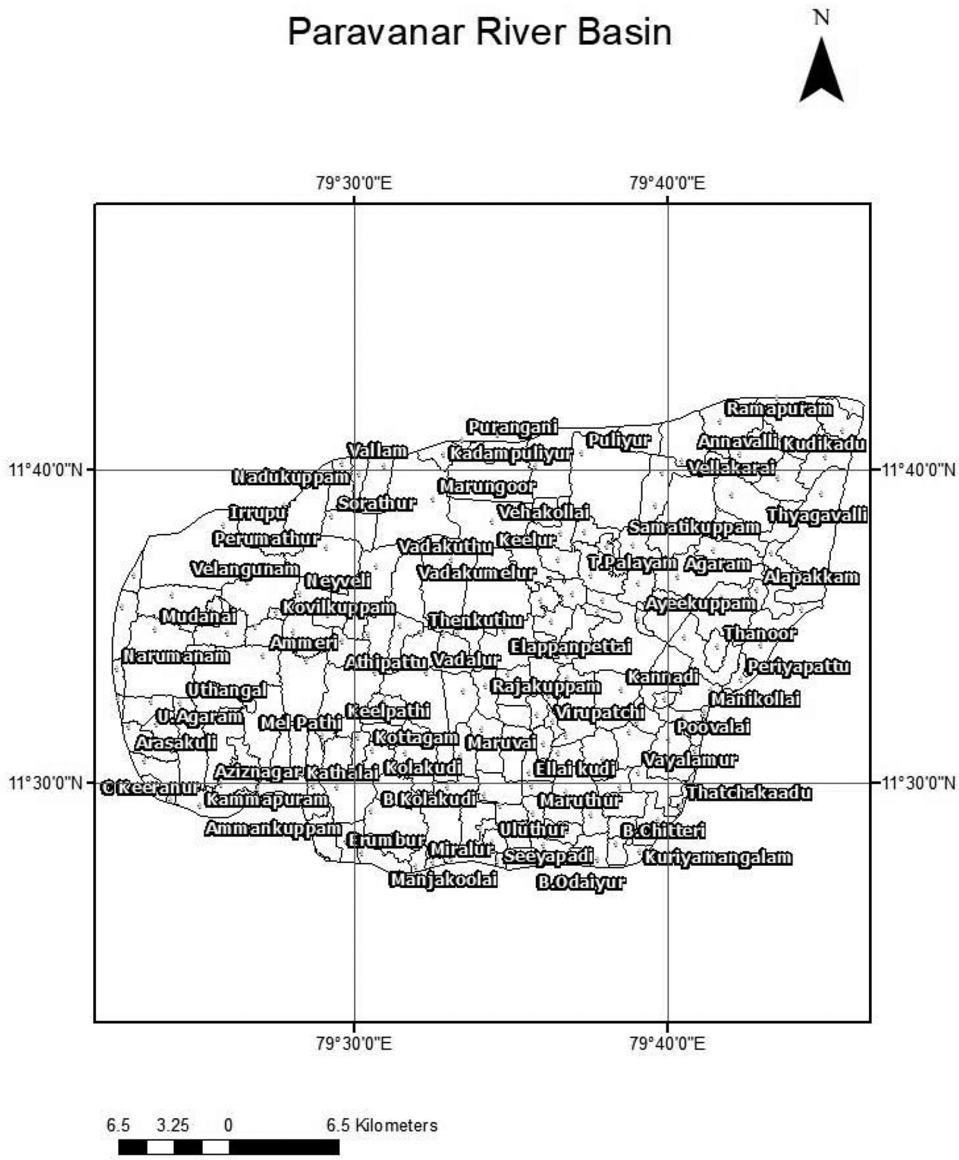

Figure 1: Paravanar River with village boundaries.

average annual precipitation is 1369 mm, with most of the contribution from the northeast and the lesser from the southwest monsoons (Khan and Arif, 2023).

Since it is a coastal basin, it lies in the heavy wind and cyclone zone. The number of depressions and cyclones is around 124 (Zakullah et al., 2012). Figure 2 illustrates the floods and droughts in the consecutive years. In 2015, the number of rainy days was 36, and the magnitude was 2194 mm, but in the next year, 2016, the number of rainy days was 21, and the magnitude was 937 mm. The above analysis insists on the significance of floodwater harvesting.

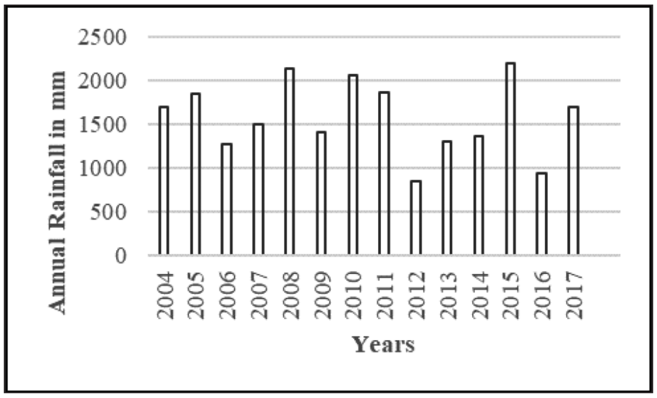

Figure 2: Illustration of consecutive floods and droughts for Mine I RG station.

Materials and Methods

Data Used

The trend analysis and the change point detection use trend software from the e-water toolkit. Two data sets were used in this study, the rain gauge (RG) data from 12 stations (Figure 3) and the satellite-gridded dataset (Figure 4) with four grid points covering the basin. We collected the daily rainfall data from the RG stations for 44 years (1971–2015) from the Institute for Water Studies, and the gridded data set from 1901 to 2021 from the IMD website with 0.25° grids(Pai et al., 2014), and with four grids all over the basin.

The study basin is delineated and overlayed with the village boundaries with block details for micro-level analysis using the data from the NIRT website.

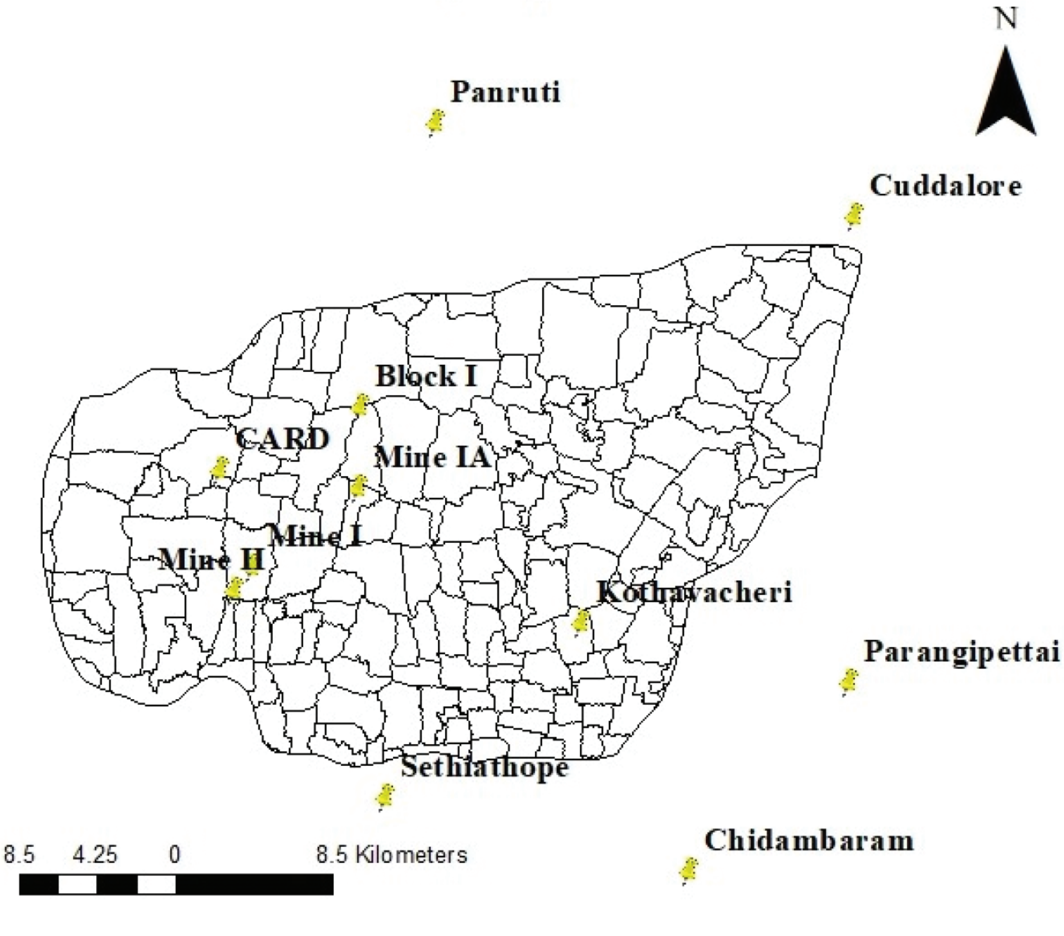

Figure 3: RG stations.

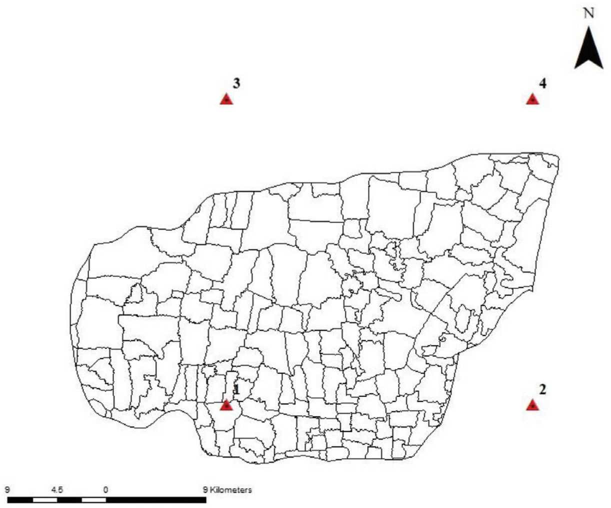

Figure 4: IMD grid points.

Rainfall Analysis

Statistical Trend Analysis

Mann Kendall Test

Mann Kendall is a non-parametric test used to identify the behaviour of the data, such as increasing, decreasing, or no pattern. Among many fields, meteorology also uses this test predominantly. The primary use of this test is to detect monotonic trends in long-time series data (Neel Kamal and Pachauri, 2018). This test is applicable only if the time series is assumed to obey the following model

$$x_i = f(t) + \varepsilon_i \tag{1}$$

x_i = data values of a time series, $f(t)$ = continuous monotonic function of time and ε_i = residual. This analysis uses the following test statistic to calculate the Mann-Kendall test static Z,

$$Z = \begin{cases} \frac{s-1}{\sqrt{\mathrm{Var(s)}}}, S > 0 \\ \frac{s+1}{\sqrt{\mathrm{Var(s)}}}, S < 0 \end{cases} \tag{2}$$

The positive value of Z denotes an increasing trend, whereas the negative value of Z indicates a decreasing trend. 0.01, 0.05, and 0.1 are the three different intervals used for trend analysis.

Spearman's Rho Test

Spearman's Rho test is a correlation test that analyses the statistical dependence between two variables. It is a nonparametric measure for data analysis, and Rho (ρ) is its test statistic. This test is similar to Mann Kendall; instead, replace the ranks of the time series in order. The test statistic (ρ) follows the following equation (Malarvizhi and Ravikumar, 2021),

$$\rho = \frac{s_{xy}}{\sqrt{s_x s_y}} \tag{3}$$

$$S_x = \sum_{i=1}^{n} (x_i - \bar{x})^2 \tag{4}$$

$$S_y = \sum_{i=1}^{n} (y_i - \bar{y})^2 \tag{5}$$

$$S_{xy} = \sum_{i=1}^{n} (x_i - \bar{x})^2 (y_i - \bar{y})^2 \tag{6}$$

The test statistic values for various significance levels are similar to the Mann-Kendall test.

Change Point Detection

The change point is estimated using Cumsum and Cumulative Deviation analysis. The change point will vary quietly, but highly repeated and is considered as the change year. The result divides the data period into two sub-periods based on the identified change point and calculates the mean annual rainfall. Also, it infers the percentage change in one sub-period over the other sub-period.

CUMSUM Method

Cumulative Sum (CUMSUM) is a sequential analysis technique for monitoring change points in a time series data. The following is the equation for the Cumulative Sum method (Wayne and Taylor, 2000):

$$S_i = S_i - 1 + (x_i - \bar{x}) \tag{7}$$

i = 1 to n, $\bar{x}$ is the average. The values are calculated and plotted for time series data, and the change point is detected using the graphs.

Cumulative Deviation Method

The period deviation added to the initial value is the basic concept behind cumulative deviation. It is similar to the incremental sum method, with the graphs plotted using the values and detecting the change point from the graph.

Results and Discussion

Spatial Distribution of Rainfall

Two data sets, gridded and RG rainfall, are studied for spatial distribution. The grided rainfall is collected and analysed for 121 years, so the analysis is more accurate than the RG data. However, since only four grid points cover the basin, the spatial distribution is low compared to the RG data. The RG data is quite good in spatial distribution but has low data records. Hence this study uses both datasets.

The gridded data shows that the southeast and northwest region of the basin receives a high amount of rainfall, whereas the other two areas receive medium rainfall. The RG data shows high rainfall in southeast and northwest regions, and the other regions are not very low, but they are comparatively lower (Figure 5). The inference above shows a correlation between gridded and RG data sets in spatial distribution.

Trend Analysis

Annual Trend Variations of Rainfall

The annual rainfall of gridded and RG data is analysed with Mann-Kendall and Spearman's test with three significance levels, as shown in Tables 1 and 2 and Figure 6.

The gridded data set shows increasing trends with a 1% significance level (0.01) in around 50 villages, from Cuddalore to Samatikuppam in the downstream and Vadakkumelur to Kammapuram on the upstream side of the basin. Mines I and II fall in Ammeri village, and mine IA in Kovilkuppam village; all these villages have increasing rainfall trends.

The RG data results show villages with increasing and no trends. The total downstream of the basin is falling under an increasing trend which covers the area with Cuddalore, Kuriyamangalam, Maruvai, and Puliyur villages in all four directions, and villages with mines are also showing increasing trends as same as the gridded data. The Cuddalore and Kothavacheri stations showed trends with 10% significance levels (0.1), and Mine I and Vridhachalam showed a 5% significant increasing trend (0.05).

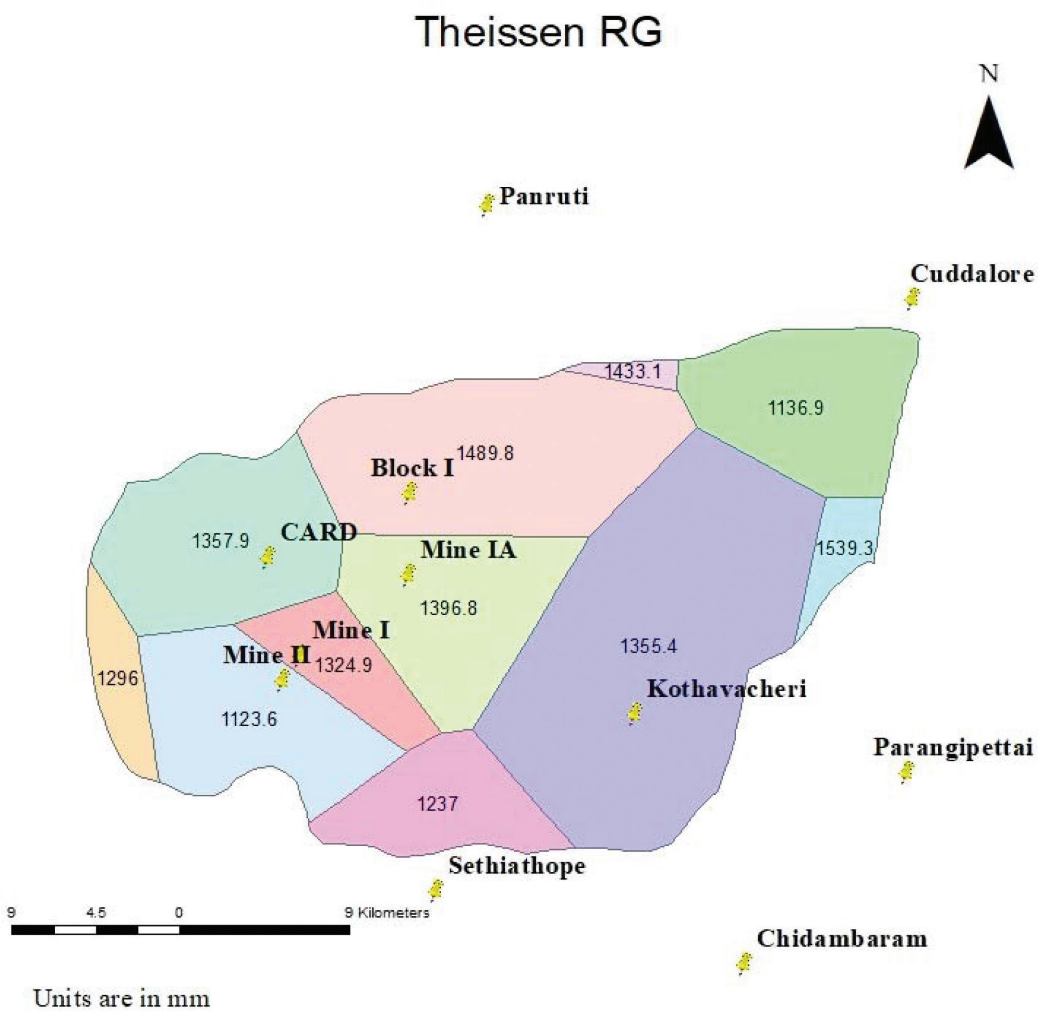

Figure 5a: RG dataset rainfall.

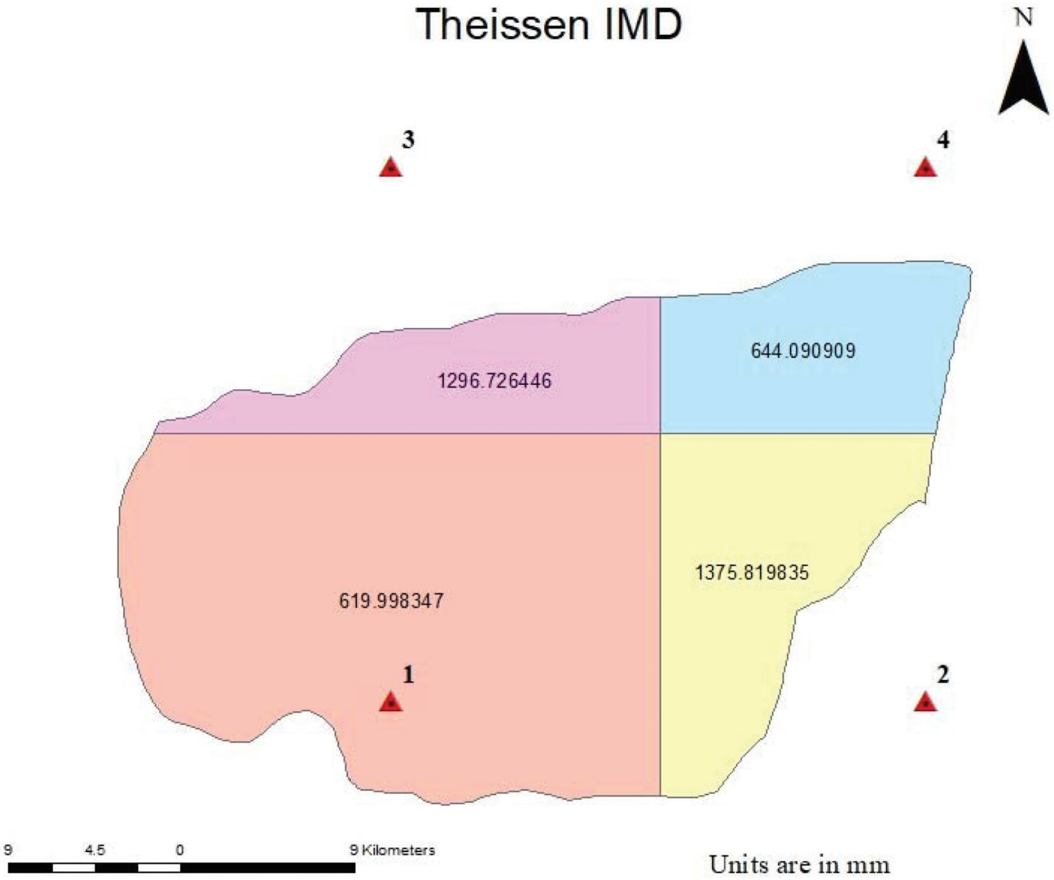

Figure 5b: Gridded dataset rainfall.

Table 1: The annual trend of RG stations

Station Name	*Annual*		Trend
	Z	*P*	
Block I	-0.393	-0.025	N
CARD	0.928	0.165	N
Chidambaram	0.616	0.1	N
Cuddalore	1.673***	0.274***	I
Kothavacheri	1.888***	0.265***	I
Mine I	2.248**	0.409**	I
Mine II	1.463	0.276	N
Mine IA	-0.219	-0.103	N
Panruti	0.753	0.064	N
Parangipettai	1.399	0.231	N
Sethiathope	1.516	0.243	N
Vridhachalam	1.966**	0.312**	I

(N=No trend, I=Increasing and D=Decreasing, *=0.01, **=0.05 and ***=0.1)

Table 2: The annual trend of grid points

Grid points	*Annual*		*Trend*
	Z	P	
1	4.684*	0.437*	I
2	0.468	0.043	N
3	0.007	0.004	N
4	5.258*	0.494*	I

(N=No trend, I=Increasing and D=Decreasing, *=0.01, **=0.05 and ***=0.1)

Seasonal Trend Variations of Rainfall

The seasonal analysis groups the data into four seasons; with the gridded dataset, the study shows increasing trends in Northeast monsoon, southwest monsoon, and winter, and there is no significant trend in the summer rainfall. All three seasons showed trend maps that are precisely similar to the annual trend of the gridded dataset but with different test statistic values at different significant levels, as shown in Table 3a and 3b and Figure 7. The RG dataset shows significant trends only

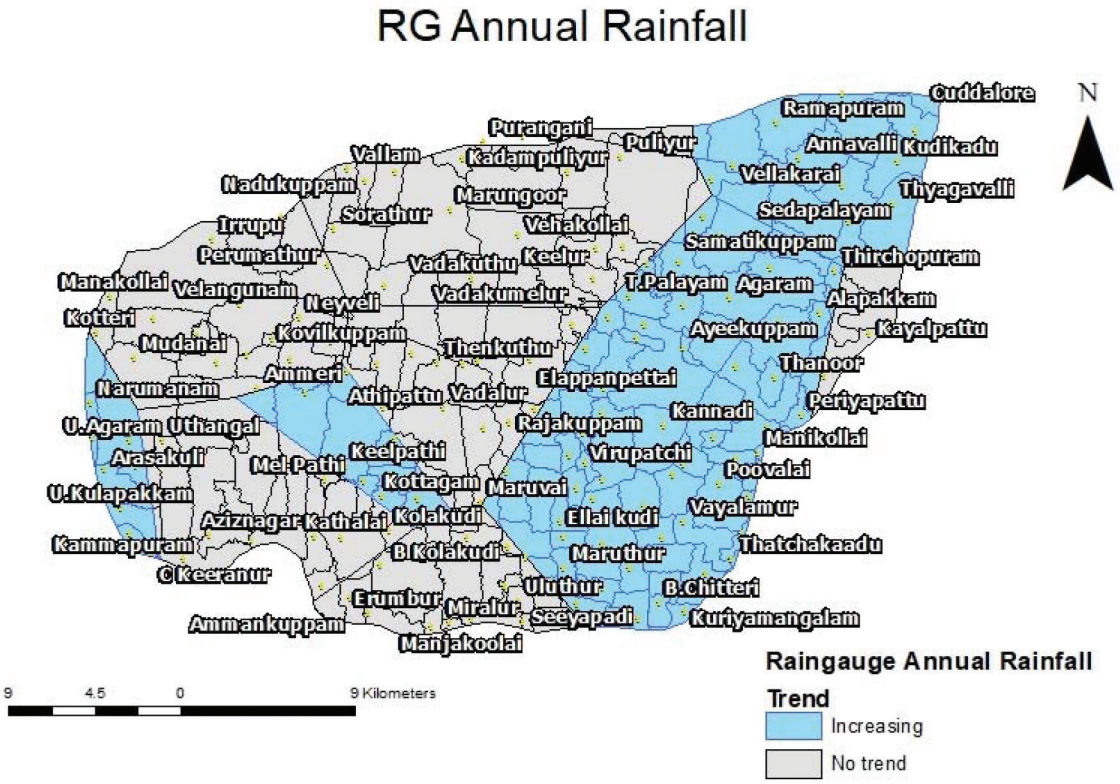

Figure 6a: Annual dataset trend.

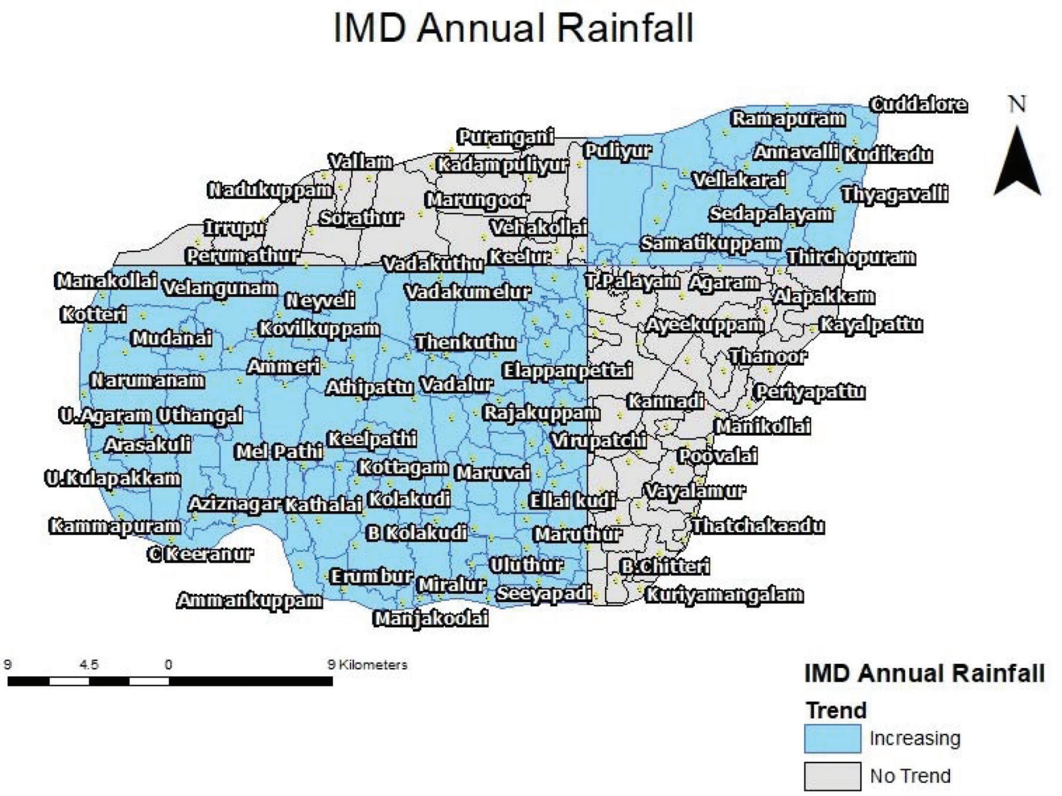

Figure 6b: Gridded dataset trend.

Table 3a: Winter and summer seasonal trends for grid points

Grid Points	*Seasonal*					
	Winter		*Trend*	*Summer*		*Trend*
	Z	P		Z	ρ	
1	2.449**	0.258*	I	-0.087	0.002	N
2	0.401	0.034	N	0.269	0.035	N
3	-0.007	0	N	0.246	0.017	N
4	2.946*	0.308*	I	0.547	0.048	N

(N=No trend, I=Increasing and D=Decreasing, *=0.01, **=0.05 and ***=0.1)

Table 3b: SWM and NEM Seasonal trends for grid points

Grid points	*Seasonal*					
	SWM		*Trend*	*NEM*		*Trend*
	Z	P		Z	ρ	
1	1.682***	0.166***	I	6.232*	0.987*	I
2	-0.896	-0.077	N	0.757	0.059	N
3	0.385	0.029	N	0.41	0.039	N
4	3.909*	0.353*	I	6.206*	0.987*	I

(N=No trend, I=Increasing and D=Decreasing, *=0.01, **=0.05 and ***=0.1)

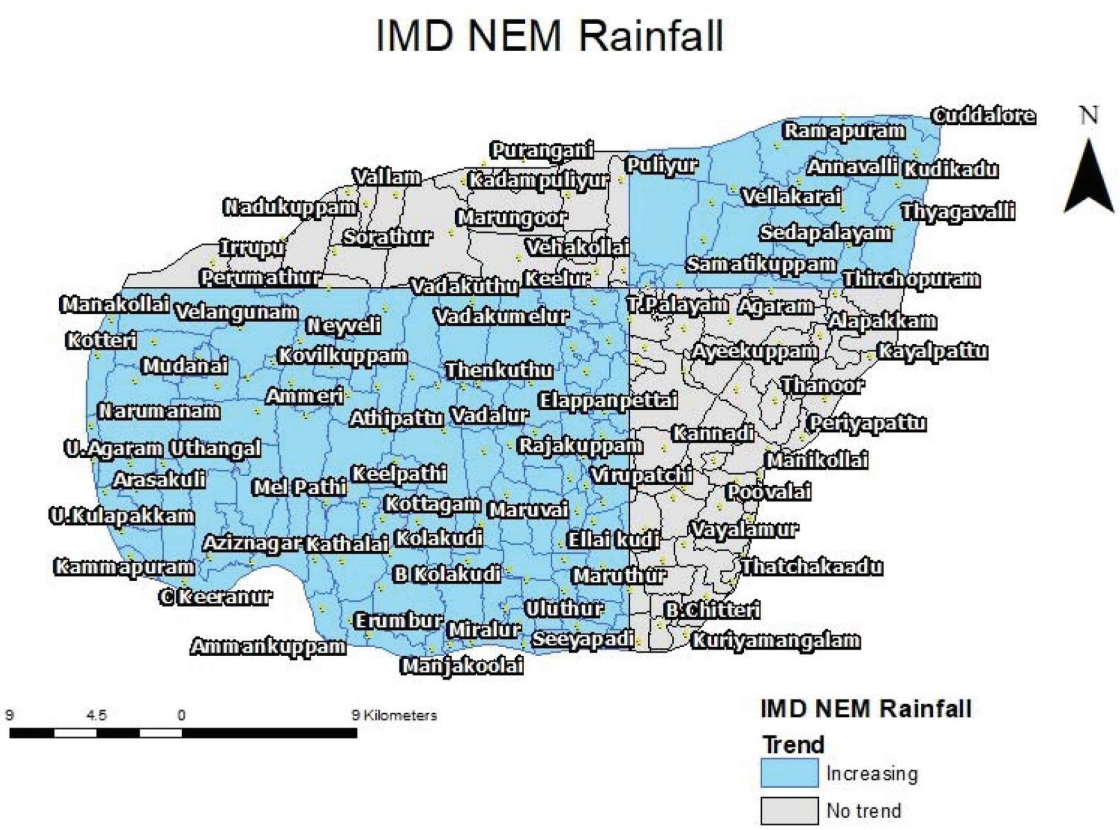

Figure 7a: Northeast monsoon rainfall trend.

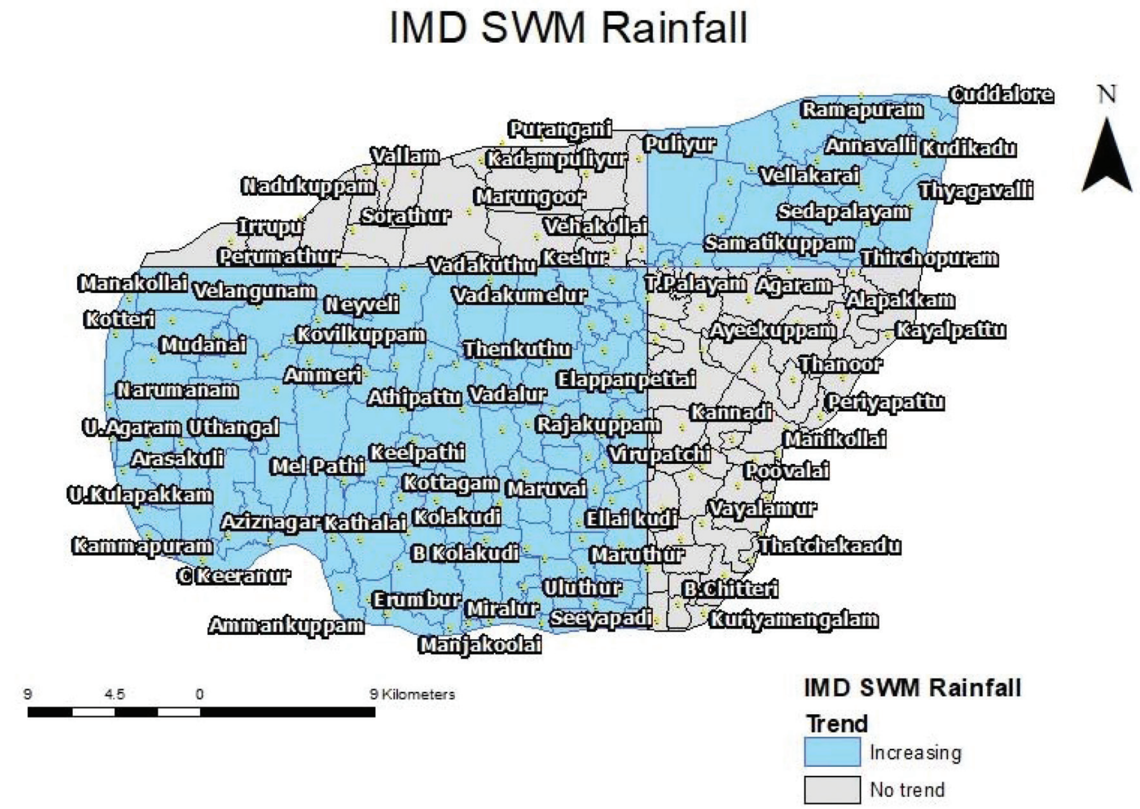

Figure 7b: Southwest monsoon rainfall trend.

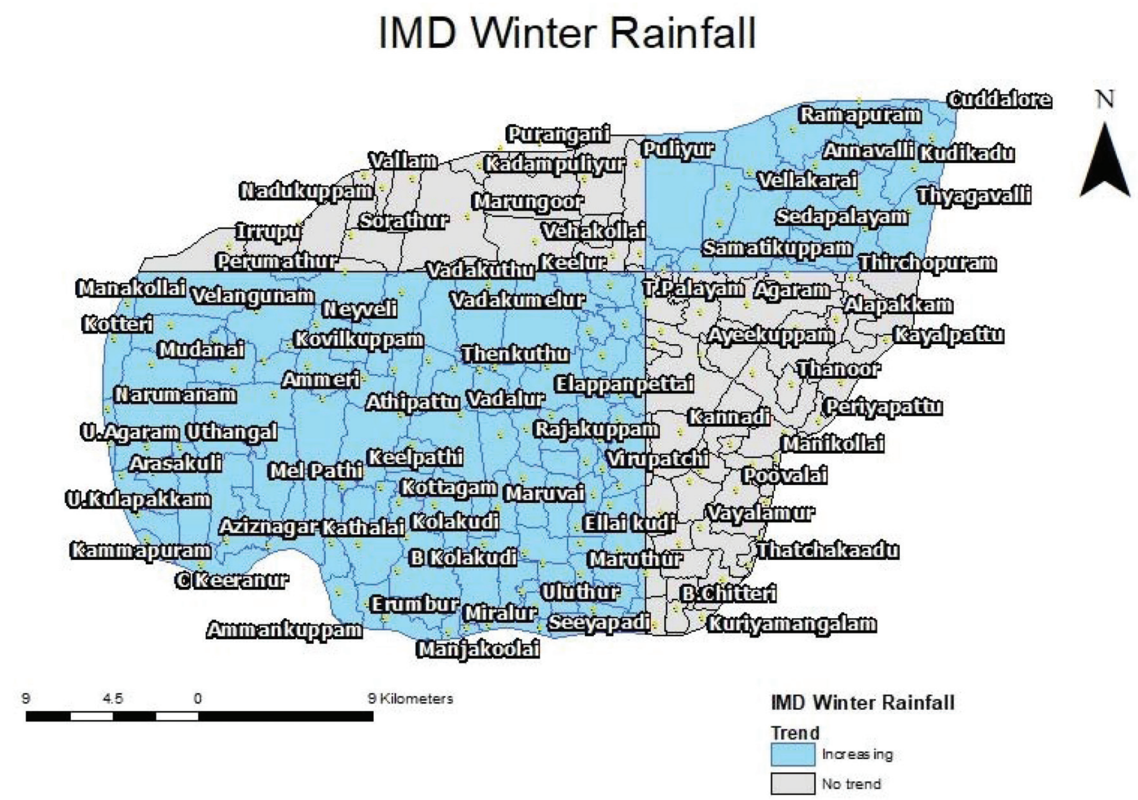

Figure 7c: Winter rainfall trend.

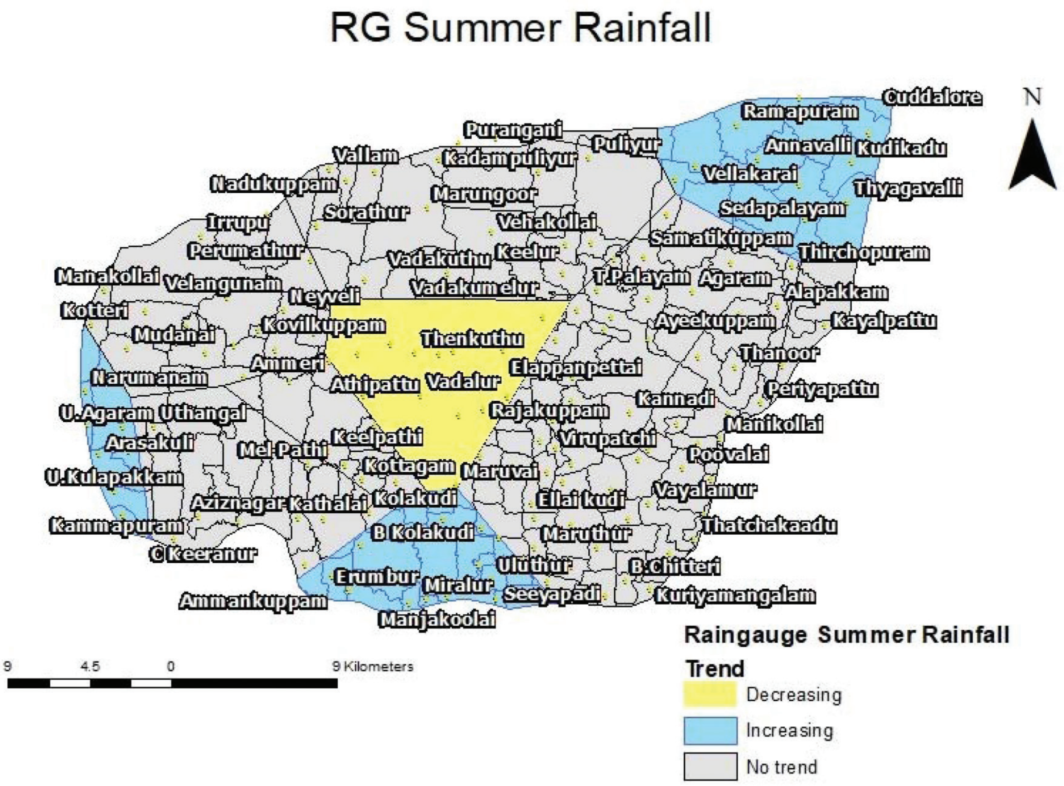

Figure 8a: Summer rainfall trend.

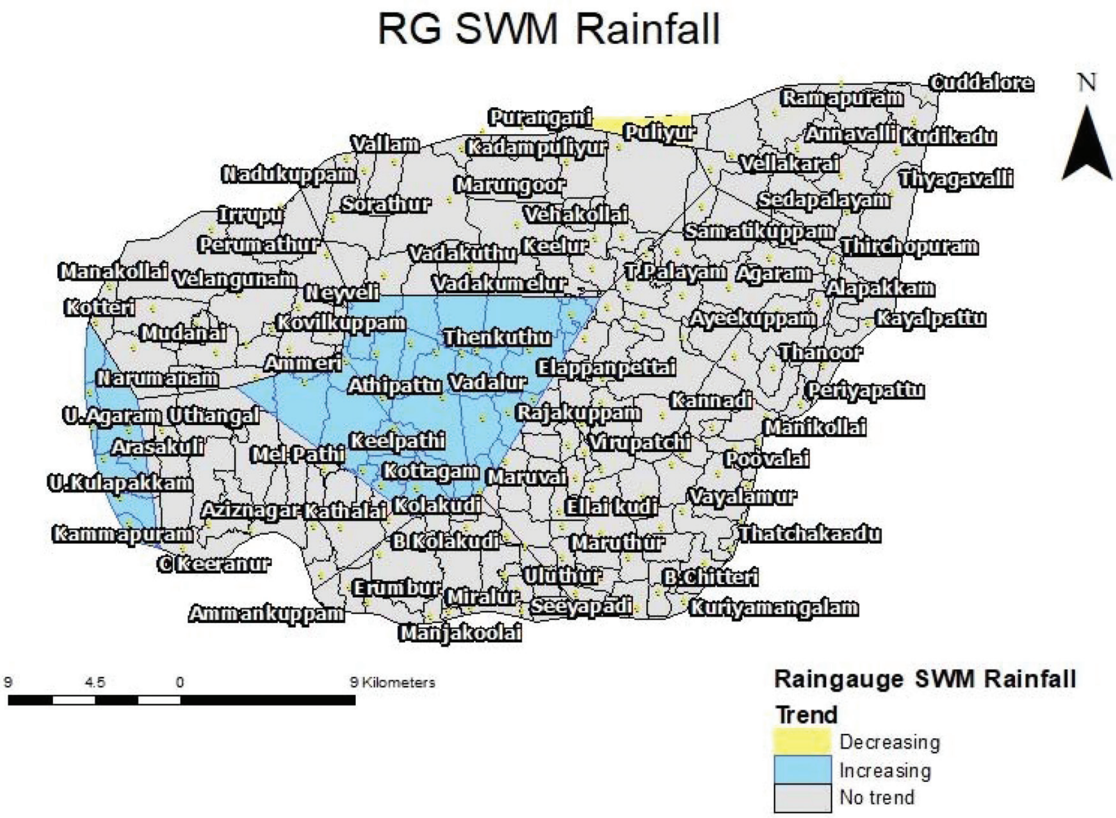

Figure 8b: Southwest monsoon rainfall trend.

in summer and southwest monsoon seasons. In the southwest monsoon, Narumanam, U.Agaram, Arasakuli, U.Kulapakkam, and Kammapuram villages, situated in the upstream end, showed an increasing trend due to the impact of Vridhachalam RG station with 10% significance level as shown in Table 4a and 4b and Figure 8.

Also, the middle part of the basin, which covers Neyveli, Vadakumelur, Kolakudi, and Ammeri villages in all four directions, showed increasing trends due to the impact of Mine I and Mine IA RG stations with a 1% significance level. Only the Puliyur village shows a decreasing trend due to the Panruti RG station's effect with a 1% significance level. The summer rainfall showed a similar increasing trend in the upstream end. In addition, the impact of rainfall of the Cuddalore RG station showed increasing trends in the villages starting from Cuddalore to Sedapalayam with a 5% significance level.

Table 4a: Winter and Summer Seasonal trends for RG stations

Station Name	*Seasonal*					
	Winter		*Trend*	*Summer*		*Trend*
	Z	*P*		*Z*	*P*	
Block I	0.996	0.271	N	-0.332	-0.052	N
CARD	0.731	0.216	N	0.5	0.1	N
Chidambaram	1.428	0.316	N	2.015**	0.316**	I
Cuddalore	0.646	0.14	N	2.563**	0.37**	I
Kothavacheri	1.223	0.356	N	1.233	0.208	N
Mine I	1.409	0.292	N	1.409	0.264	N
Mine II	0.553	0.096	N	0.856	0.184	N
Mine IA	0.931	0.292	N	(-)1.861*	(-)0.508*	D
Panruti	0.196	0.295	N	0.949	0.169	N
Parangipettai	1.086	0.324	N	0.577	0.14	N
Sethiathope	0.959	0.356	N	2.084**	0.319**	I
Vridhachalam	0.616	0.306	N	1.761***	0.279***	I

(N=No trend, I=Increasing and D=Decreasing, *=0.01, **=0.05 and ***=0.1)

Table 4b: SWM and NEM seasonal trends for RG stations

Station Name	*Seasonal*					
	SWM		*Trend*	*NEM*		*Trend*
	Z	*P*		*Z*	*ρ*	
Block I	1.782	0.383	N	-0.695	-0.131	N
CARD	0.428	0.079	N	0.607	0.09	N
Chidambaram	-1.428	-0.235	N	0.245	0.053	N
Cuddalore	-0.812	-0.136	N	1.555	0.241	N
Kothavacheri	-0.049	-0.027	N	1.37	0.193	N
Mine I	3.14*	0.558*	I	0.535	0.093	N
Mine II	1.606	0.252	N	0.856	0.145	N
Mine IA	2.409*	0.662*	I	-0.766	-0.279	N
Panruti	(-)3.923*	(-)0.546*	D	1.751***	0.237	N
Parangipettai	-0.538	-0.089	N	1.614	0.242	N
Sethiathope	-1.467	-0.243	N	1.575	0.244	N
Vridhachalam	1.859***	0.639*	I	1.34	0.228	N

(N=No trend, I=Increasing and D=Decreasing, *=0.01, **=0.05 and ***=0.1)

The impact of Sethiathope RG station shows an increasing trend with a 5% significance level in the villages starting from Kolakudi to Manjakoolai. On the contrary, the Panruti RG station shows a decreasing trend in the middle of the basin with a 1% significance level. Since there is no decreasing trend in the overall analysis, this contradiction might be the low data record.

Determination of Change Point of Rainfall

The change point is determined using Cumsum and Cumulative deviation methods for the RG data (Table 5) and gridded data (Table 6). The change point identified varies, but 1995 is the most significant change year identified over time for the RG dataset. This analysis compares the mean for two periods (1971-1995) and (1995-2015) and estimates the change percentage. The maximum change percentage is 47.7, identified in Mine I with a 50% significance level.

The gridded data sets show 1991 as the change point; the maximum change percentage is 243 with a 1% significance level which offers a sudden jump in rainfall which indicates climate change. Further study will analyze the reason for this sudden jump. Still, with the preliminary analysis, the cause is identified as the heat island effect created by the initiation of mines and thermal power plants during the 1960s. Thus, the increasing rainfall trend is evident in the southwest and northeast parts of the basin.

Suggested Mitigation Measures

There is a rising trend in rainfall, characterised by the intense and short duration of rainfall. It is recommended to transform the existing open-cast mines in this region into reservoirs as a means of mitigating the impacts of floods and recurrent droughts. One of the key factors in determining the feasibility of converting open-cast

Table 5: Change point detection for RG stations

Station Name	*Cumsum*		*Cumulative deviation*		*Change percentage*
	Year	*Maximum Deviation*	*Year*	*Q/√n*	
Block I	2003	5	2003	0.605	-
CARD	1992	5	2003	0.704	18.15
Chidambaram	1995	7	1976	0.581	5.13
Cuddalore	2003	9***	1995	1.302**	21.4
Kothavacheri	2002	10**	2002	0.963	16.7
Mine I	1995	8**	1995	1.321**	47.7
Mine II	1995	6	2003	1.033	18.9
Mine IA	2011	2	2011	0.665	-
Panruti	1992	8	2010	0.992	15.3
Parangipettai	2004	6	1982	1.198***	15.4
Sethiathope	2003	11*	1995	1.066	19.2
Vridhachalam	1995	9***	1995	1.371**	22.7

(N=No trend, I=Increasing and D=Decreasing, *=0.01, **=0.05 and ***=0.1)

Table 6: Change point detection for grid points

Grid points	*Cumsum*		*Cumulative deviation*		*Change percentage*
	Year	*Maximum deviation*	*Year*	*Q/√n*	
1	1980	26*	1991	3.789*	234.592
2	2003	13	2003	0.803	4.66002
3	2003	9	1946	0.785	6.97691
4	1991	31*	1991	4.005*	243.927

(N=No trend, I=Increasing and D=Decreasing, *=0.01, **=0.05 and ***=0.1) mines into reservoirs is the capacity of the mine void. In the case of the mine proposed for conversion in the Paravanar River Basin, the estimated capacity is 1125M cft, which is significantly higher than the capacity of the prevailing tanks in the region (Arunya et al., 2023). The depth of the mine plays a crucial role in providing a larger storage capacity. With the ability to store a substantial volume of water, the converted mine will serve as both a floodwater harvesting structure and a drought mitigation measure. This mine alone can store approximately 5.8% of the average volume of runoff in the basin. The potential for converting the other two mines, currently under operation, should also be explored to further enhance water storage capacity. If all three mines are converted, the total storage capacity can reach 17.4% of the average volume of runoff. The conversion of open-cast mines into reservoirs offers several benefits, including increased water storage capacity, flood prevention, and drought mitigation. By harvesting floodwater and storing it during periods of excess rainfall, the reservoirs can provide a reliable water source during dry spells. However, there are challenges to consider, such as the need for proper maintenance and management of the reservoirs, as well as potential environmental impacts.

Conclusion

The RG and gridded datasets showed significant results in trend analysis and revealed many sudden changes in climate through change point analysis. Since the study deals with village boundaries, it shows that the villages within Manakollai to Keelur, Kammapuram to Seeyapaadi in the southwest part of the basin, and Puliyur to Cuddalore, T. Palayam to Thiruchopuram in the northeast past will be facing increasing trends in the rainfall with an average increase of 20%. The change point is between 1991 and 1995, and the most extended data record revealed a vital aspect called the heat island effect, which is evident for climate change in the basin and insists the need for flood water harvesting. The village Ammeri which consists of two open-cast mines, falls under an increasing trend in all the analyses with both data sets. The mines are intended to be transformed into a water storage facility.

Data Availability Statement

The gridded data set of rainfall is downloaded from Climate Monitoring and Prediction Group (imdpune.gov.in). The rain gauge data sets were collected manually at different sites and will be provided on request by the corresponding author. The village boundaries are available at www.nirt.in.

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