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Integrating Climate Trends for Sustainable Water Resource Management in the Periyar River Basin

Rehan Khan[1]*, Mohammed Sharif[2] and Mohammad Shakeel[3]

Department of Civil Engineering, Jamia Millia Islamia Central University, New Delhi, India

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ABSTRACT

In order to evaluate the sustainability of the water resources in the Periyar River Basin in the face of climate change, this study provides the analysis of climatic trends. By examining rainfall and temperature patterns over 123 years (1901 to 2023), key trends and their impact on the basin's hydrology are identified. The analysis reveals shifting rainfall patterns, particularly during the monsoon season, and rising temperatures, notably in the winter and pre-monsoon periods. While most months show no clear rainfall trends, a linear increase is observed during August and September, with a decrease noted in January, February, June, July, November, and December. Simultaneously, continuous increases in both maximum and minimum temperatures suggest gradual regional warming. These climatic shifts significantly affect the hydrological cycle, influencing water quantity and quality. Spatial and temporal analyses provide deeper insights into these hydrological processes. In order to protect ecosystems and livelihoods, these combined findings emphasise the necessity of adaptive water resource management policies, resilient agricultural practices, and conservation initiatives. This research highlights the need for proactive actions in the Periyar River Basin and similar regions globally to effectively manage climate change consequences while maintaining sustainable development, serving as a roadmap for policymakers and stakeholders.

Key words: *Climate change, Trend analysis, Periyar River Basin, Sustainable development*

Introduction

India, being a tropical country, is increasingly vulnerable to the effects of climate change, particularly in the context of rising temperatures and altered precipitation patterns. According to IPCC (2014), the net annual temperatures in India in the 2030s will increase from 1.7 °C to 2.2 °C based on 1970 data. Extreme temperatures are expected to rise by 1°C to 4 °C with a higher increase in coastal regions. The coastal region of Kerala is experiencing reduced crop yields due to rising temperatures (Ramachandran *et al.,* 2017), with the highest temperature recorded in northwest India in 2016. The severity of heat waves is increasing, impacting coastal regions like Kerala. Moreover, extreme rainfall events are on the rise, especially during the Indian monsoon season, leading to increased risks of flooding in several regions, including the Periyar River basin. Trend Analysis of rainfall is important to understand the climate change effect on water resources. As per the IPCC (2007) report, water availability and annual average runoff will decrease by 10 to 30 % over certain dried-out regions and increase by 10 to 40 % in some wet tropical areas. Understanding temperature and rainfall patterns is crucial for hydrological processes and improving discharge control methods. Long-term analysis

([1] Research Scholar, [2]Professor, [3]Professor)

helps water resource managers make informed decisions, evaluate climate change impacts, and adjust water resource systems for sustainable management (Cunderlik and Burn, 2004). Meeting the various demands of stakeholders and preserving ecological balance depend on monitoring and regulating discharge levels (Katimon *et al.,* 2003). Excessive discharge during the monsoon causes floods, while insufficient discharge during the dry spell affects hydropower generation, agriculture, and other industries by creating a water shortage (Behzad *et al.,* 2012).

Several studies have been carried out for detecting the trend and variability of rainfall in various regions (Frei and Schar, 1998; Fawcett, 2004; Smith, 2004; Cannarozzo *et al.*, 2006; Goswami *et al.,* 2006; Joshi and Rajeevan, 2006; Fu *et al*., 2008; Kampata *et al.,* 2008; Kiem and Verdon-Kidd, 2010). Archer and Fowler (2004) investigated rainfall trends in the Himalayas Regions. Annual and Seasonal data analysis did not show any significant trend in the Himalayas region from 1893 to 1990 (Pant *et al.,* 1999). Increasing and decreasing rainfall trends were observed at some stations in the Kosi basin (Chadha and Sharma, 2000). Xu *et al*. (2010) investigated the trends of rainfall and runoff in major Chinese rivers to determine the human intervention in the trend from 1951 to 2000. Jiang *et al.* (2007) studied the annual and seasonal trend of precipitation using Mann-Kendall and linear regression methods. Rana *et al.* (2012) investigated the long-term rainfall trend using linear regression and Mann-Kendall statistics in Mumbai and Delhi. Chandniha *et al.* (2016) studied the trend of precipitation using autocorrelation and modified Mann-Kendall test in the Jharkhand state. However, no detailed study on rainfall trend analysis has been found for the Bagmati River basin in the literature.

The Periyar River basin in Kerala, India, faces significant discharge regulation and flood control challengesof its complex hydrological dynamics. Strong monsoon rains and the rough topography of the area cause frequent floods that endanger lives, property, and the surrounding ecosystems (Omar *et al.,* 2019). In order to protect the infrastructure and residents in this heavily populated area, flood mitigation measures are essential.

The primary objective of this study is to climate trend analysis to promote sustainable water resource management in the Periyar River basin. The study aims to: analyse historical trends of climatic variables such as rainfall and temperature within the basin project future rainfall and temperature patterns under different Shared Socioeconomic Pathways (SSPs), including SSP 126, 245, 370, and 585 and to assess the impact of climate change on high streamflow extremes under these SSP scenarios.This research aims to provide actionable insights for adaptive water resource management, infrastructure planning, and environmental conservation, helping mitigate the adverse effects of climate change on the basin's ecosystems.

Methodology

By analysing long-term rainfall and temperature trend analysis patterns and variations in precipitation and temperature, researchers and water resource managers can gain valuable insights into the dynamics of river systems (Omar *et al.,* 2019).By identifying long-term trends and patterns, water managers can make informed decisions regarding water allocation, flood control measures, and drought management strategies (Arora *et al*., 2005). Furthermore, rainfall and temperature trend analysis assist flood forecasting (Cunderlik and Burn, 2004). By studying historical data and identifying trends, researchers can develop models and tools to predict and mitigate the impacts of extreme precipitation events, thus enhancing flood preparedness and response.

This study involves trend analysis of two parameters in the Periyar River basin, i.e. rainfall and temperature. The Mann-Kendall test and the Sen-Slope method have been adopted for the two parameters. Detailed methodology adopted for both the parameters have been discussed below:

Rainfall Trend Analysis

Data Collection: Historical rainfall data spanning 120 years was obtained from the Indian Meteorological Department, focusing on the study area.

Data Preparation: Daily rainfall data was aggregated into yearly and monthly averages for trend analysis.

Calculation of Kendall's Tau: Kendall's Tau statistic was computed to determine the significance and direction of rainfall trends.

Computation of Standardized Test Statistic: The Z value, derived from Kendall's Tau, was used to assess the statistical significance of trends.

Trend Interpretation: Positive Kendall's Tau values indicated increasing trends, negative values indicated decreasing trends and values near zero suggested no discernible trend.

Temperature Trend Analysis

Data Collection: Historical temperature data covering 69 years was gathered from the Indian Meteorological Department, considering the study area.

Preprocessing: Temperature data was organised based on monthly maximum and minimum averages.

Time Series Analysis: Data was plotted as a time series to visualise temperature patterns over time.

Sen Slope Calculation: The Sen slope method was applied to estimate temperature trends, calculating median pairwise slopes.

Statistical Significance: The Mann-Kendall test determined the significance of computed Sen slopes.

Trend Interpretation: Positive Sen slopes indicated rising trends, negative slopes indicated falling trends, and the slope magnitude reflected the rate of change.

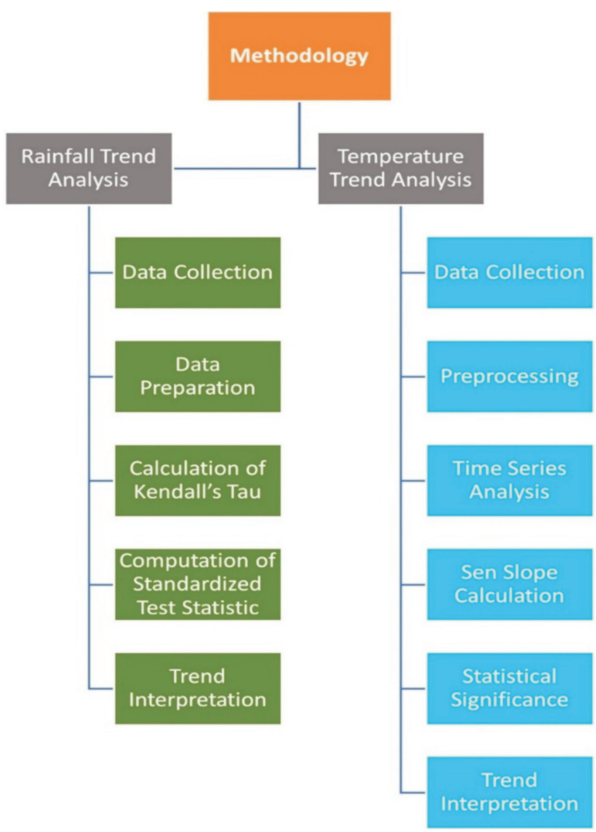

Fig. 1. Flow Chart of Methodology

Study Area and Data Collection

Kerala, in southern India, is home to the Periyar River Basin, which is important from an environmental and cultural standpoint. The basin, named for the Periyar River that supports the surrounding populations and ecosystems is around 5,398 square kilometres in size. The river rises in the biodiverse Western Ghats and empties into the Arabian Sea through various landscapes. The research region's index map is shown in Figure 2.

Gridded Rainfall Data

123-year (1901 to 2023) daily gridded rainfall data have been downloaded from IMD, and grids are selected based on the study area. A spatial variation of 0.25° is there in rainfall grids. Table 1 shows the location of grids that fall under the study area.

Table 1. Location of Rainfall Grids in Study Area

S. No.	Latitude	Longitude
1	9.25°	77.25°
2	9.5°	77°
3	9.5°	77.25°
4	9.75°	77°
5	9.75°	77.25°
6	10°	76.25°
7	10°	76.5°
8	10°	76.75°
9	10°	77°
10	10°	77.25°
11	10.25°	76.25°
12	10.25°	76.5°
13	10.25°	76.75°
14	10.25°	77°
15	10.25°	77.25°

Monthly rainfall data has been computed based on daily data, and annual data has been analysed for 123 years.

Gridded Temperature Data

Seventy-three years (1951 to 2023) of daily gridded temperature data with 1° spatial variation has been downloaded from IMD. Table 2 indicates the location of grids considered for the study area.

Average monthly maximum and minimum data have been processed from the daily data, and trend analysis has been done for both data sets.

Rainfall Trend Analysis

Mann-Kendall test has been used to analyse rainfall

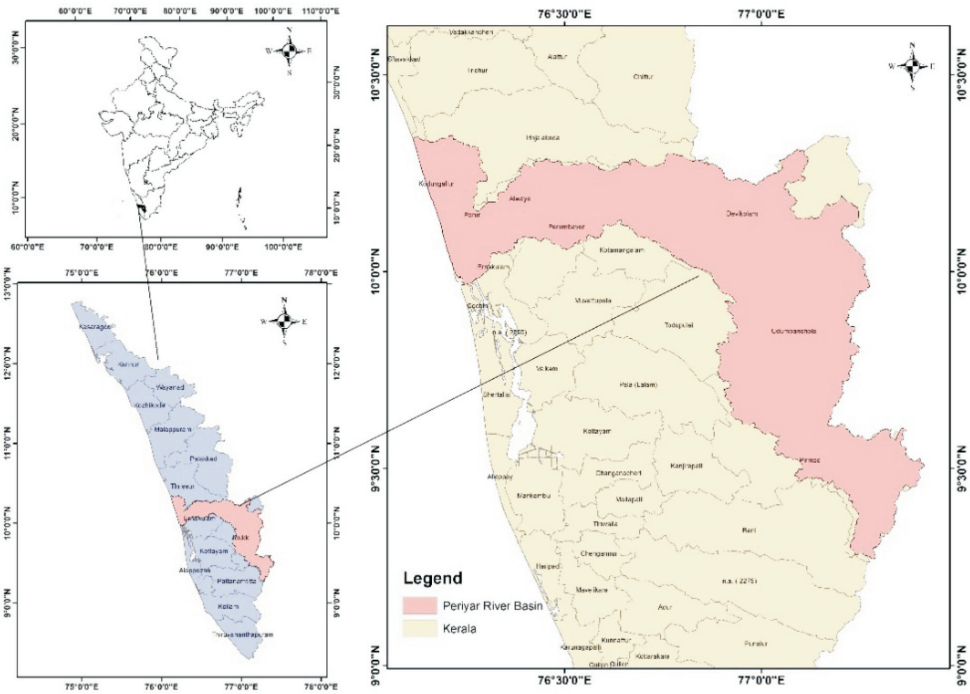

Fig. 2. Index Map of Study Region

Table 2. Location of Temperature Grids in Study Area

S.No.	Latitude	Longitude
1	9.5°	76.5°
2	9.5°	77.5°
3	10.5°	76.5°
4	10.5°	77.5°

trends (Kendall, 1975). Given as follows is the Mann-Kendall statistic S:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} Sign(T_j - T_i) \quad .. (1)$$

The trend test is applied to two-time series: xi, which has a ranking from i = 1, 2, ...n-1, and xj, which is ranked at j = i+1, 2, ...n. Every point of data xi is used as a benchmark andcompared to the remaining data points xj in order to:

Sign $(T_j - T_i)$ =

$$\{1\ if\ Tj - Ti > 0 0\ if\ Tj - Ti = 0 - 1\ if\ Tj - Ti < 0 \quad (2)$$

According to the results of this test,The MK test Z Statistics depend on the alpha value. In our case, alpha=0.05 means only a 5% chance of failure of the calculated trend.

If p < 5%, it means some trend is found in the data series

If p > 5%, it means no trend is found in the data series

The variance statistics are given as follows:

$$Var[S] = \frac{n(n-1)(2n+5) - \sum t(i)(i-1)(2i+5)}{18} \quad .. (3)$$

Table 3 displays the calculated linear trend for the rainfall data. Figures 3 to Figure 5 provide monthly trend analysis and annual trend analysis.

Temperature Trend Analysis

Sen's estimator is utilised to determine the magnitude of the trend. The slope (Ti) for each data pair is calculated according to the methodology proposed by Sen (1968).

$$T_i = \frac{X_j - X_k}{j - k} \text{ For, i = 1, 2, 3, ...N} \quad (4)$$

The data values at time points j and k (where j > k) are denoted as X_j and X_k, respectively. The Sen's estimator of slope, which represents the median of N values of T_i, is computed as follows:

endsQ_i =

$$\{T_{\frac{N+1}{2}} N\ is\ Odd \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right)\ N\ is\ even$$

Depending on whether N is an odd or an even

Table 3. Trend Analysis of Rainfall Data

Month	Min	Max	Mean	Std. deviation	Kendall S 's tau	Var (S)	p-value	alpha	Trend /No	Trend	Linear Trend
Jan	0.0	177.3	24.2	33.9	-0.20	-1423	199182.33	0.001	0.05	Trend	Decreasing
Feb	0.0	99.1	21.2	22.4	-0.11	-813	199221.33	0.069	0.05	No Trend	Decreasing
Mar	0.0	282.7	44.0	38.8	-0.02	-148	199244.67	0.742	0.05	No Trend	No Trend
Apr	22.3	237.2	106.2	45.4	-0.05	-382	199246.67	0.393	0.05	No Trend	No Trend
May	46.7	464.1	167.0	92.5	-0.02	-176	199244.67	0.695	0.05	No Trend	No Trend
Jun	81.2	686.3	371.5	122.7	-0.07	-483	199245.67	0.280	0.05	No Trend	Decreasing
Jul	96.1	1106.5	421.8	147.6	-0.07	-544	199246.67	0.224	0.05	No Trend	Decreasing
Aug	80.4	783.6	301.3	121.6	0.15	1057	199245.67	0.018	0.05	Trend	Increasing
Sep	33.2	573.0	202.3	101.1	0.12	847	199245.67	0.058	0.05	No Trend	Increasing
Oct	80.1	489.1	265.3	80.5	-0.08	-599	199243.67	0.180	0.05	No Trend	No Trend
Nov	25.8	467.5	185.4	95.0	-0.10	-721	199245.67	0.107	0.05	No Trend	Decreasing
Dec	0.0	239.6	63.9	53.4	-0.07	-526	199240.67	0.240	0.05	No Trend	Decreasing
Annual	1362.1	3071.7	2174.2	335.1	-0.01	-64	199246.7	0.888	0.05	No Trend	No Trend

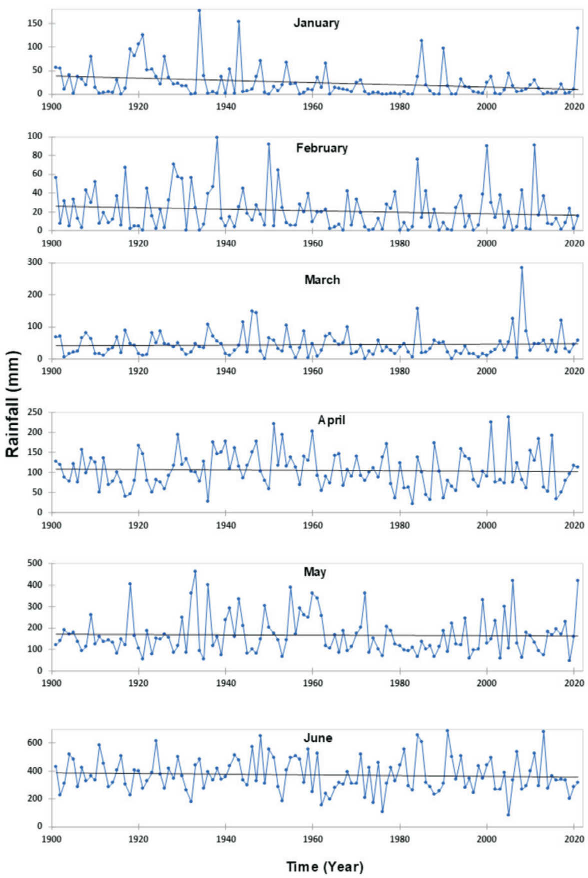

Fig. 3. Rainfall Trend graph of January to June

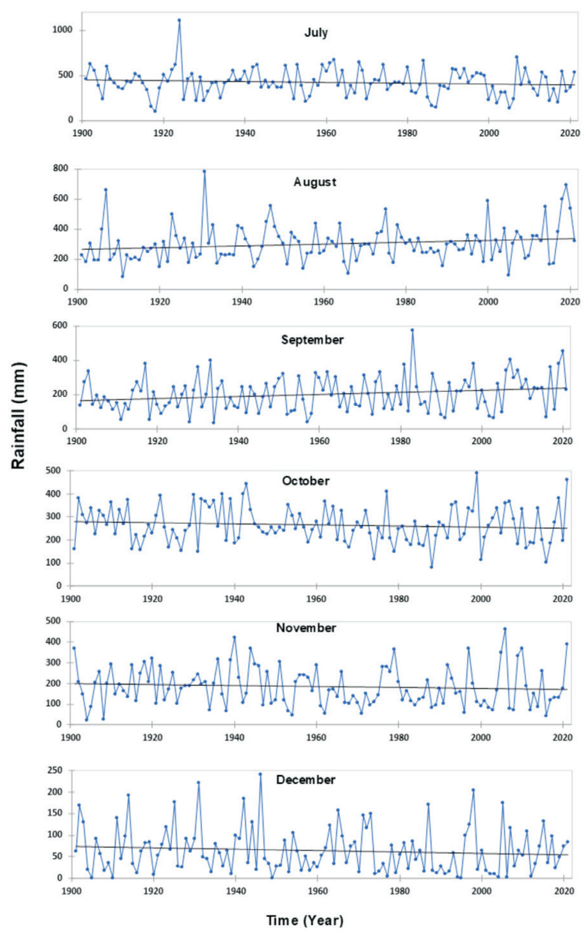

Fig. 4. Rainfall Trend graph of July to December

number, multiple formulae must be used to calculate Sen's estimator. The estimator is computed as $Q_{med} = T((N+1)/2)$ if N is an odd number. If N is even, on the other hand, the estimator is $Q_{med} = [T(N/2) + T((N+2)/2)]/2$. To determine the genuine slope, the resultant Q_{med} value is then put through a two-sided test with a 100(1- á) % confidence interval. A positive value of Qi denotes an upward or growing trend in the time series, whereas a negative

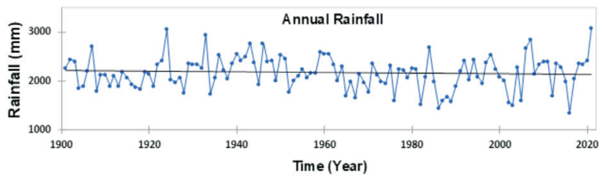

Fig. 5. Trend graph of Annual Rainfall

value of Qi shows a downward or decreasing pattern(Mondal et al., 2012).Temperature trend analysis results for average maximum temperature have been shown in Table 4, and graphs have been shown in Figures11 and 12.

Results and Discussion

Figure6-12shows the graphical representation of the trends in rainfall and temperature datasets found in the Mann-Kendall test and graphically represented by the Sen-Slope method. A brief discussion of each dataset is given below.

Rainfall Trends

Figure 6-10shows the historical trends of annual maximum rainfall of the best-fit GCM model, i.e. NorESM2-LM and IMD gridded data for 30 years, i.e. from 1985 to 2014. As can be seen from the graphs, the model data set shows a negligible trend during pre-monsoon, a slightly increasing trend during monsoon and increasing during the post-monsoon period. On the other hand, the historical dataset of IMD gridded data shows an increasing trend during pre-monsoon, slightly increasing during monsoon and post-monsoon. As evident fromthe figures, similar trends can be seen during the monsoon and post-monsoon periods of model and IMD historical data.

Figure 7 (a) to (f) shows the annual maximum rainfall trends of GCM model scenario 1 (SSP126) of the NorESM2-LM dataset. As evident from the graphs, there is a slightly increasing trend during

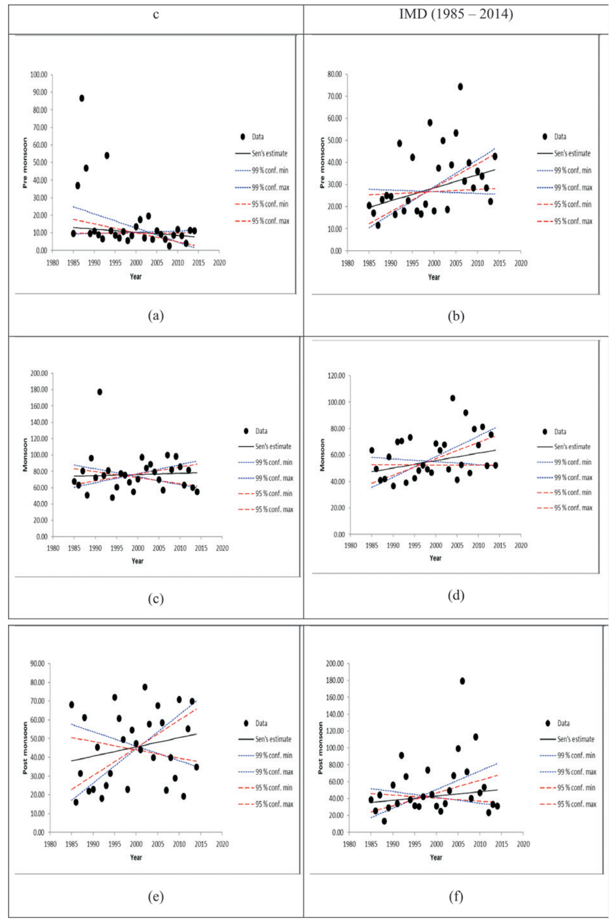

Fig. 6. Historical trends of Model and IMD Rainfall data

Table 4. Trend Analysis of Average Maximum Temperature

Time series	First-year	Last Year	n	Test Z	Signific.	Q	Qmin95	Qmax95	B	Bmin95	Bmax95
January	1951	2019	69	6.09	***	0.017	0.013	0.023	28.76	28.92	28.61
February	1951	2019	69	5.78	***	0.020	0.015	0.026	30.18	30.35	29.96
March	1951	2019	69	4.79	***	0.020	0.013	0.027	31.83	32.09	31.53
April	1951	2019	69	4.50	***	0.025	0.014	0.035	32.20	32.50	31.85
May	1951	2019	69	3.78	***	0.020	0.009	0.030	31.76	32.21	31.34
June	1951	2019	69	3.71	***	0.017	0.009	0.027	29.64	29.88	29.17
July	1951	2019	69	6.71	***	0.025	0.020	0.032	28.26	28.47	28.08
August	1951	2019	69	5.54	***	0.019	0.013	0.024	28.69	28.94	28.51
September	1951	2019	69	5.21	***	0.021	0.015	0.028	29.13	29.34	28.92
October	1951	2019	69	5.48	***	0.020	0.014	0.027	28.70	28.888	28.5355
November	1951	2019	69	4.38	***	0.013	0.007	0.019	28.273	28.435	28.0659
December	1951	2019	69	4.83	***	0.016	0.011	0.023	28.125	28.391	28.0046

monsoon periods of Near-end and Far-end Future of the scenario and the post-monsoon period of NEF, while all other seasonal variations show no or negligible trend.

Figure 8 (a) to (f) shows the annual maximum rainfall trends in GCM scenario - 2 (SSP245) of NEF and FEF of NorESM2-LM. As can be seen from the figures, the Near End Future show an increasing trend during pre-monsoon and monsoon periods while decreasing trends during the post-monsoon period. Meanwhile, the Far End Future shows no trend during pre- and post-monsoon periods, with a decreasing trend during the monsoon period.

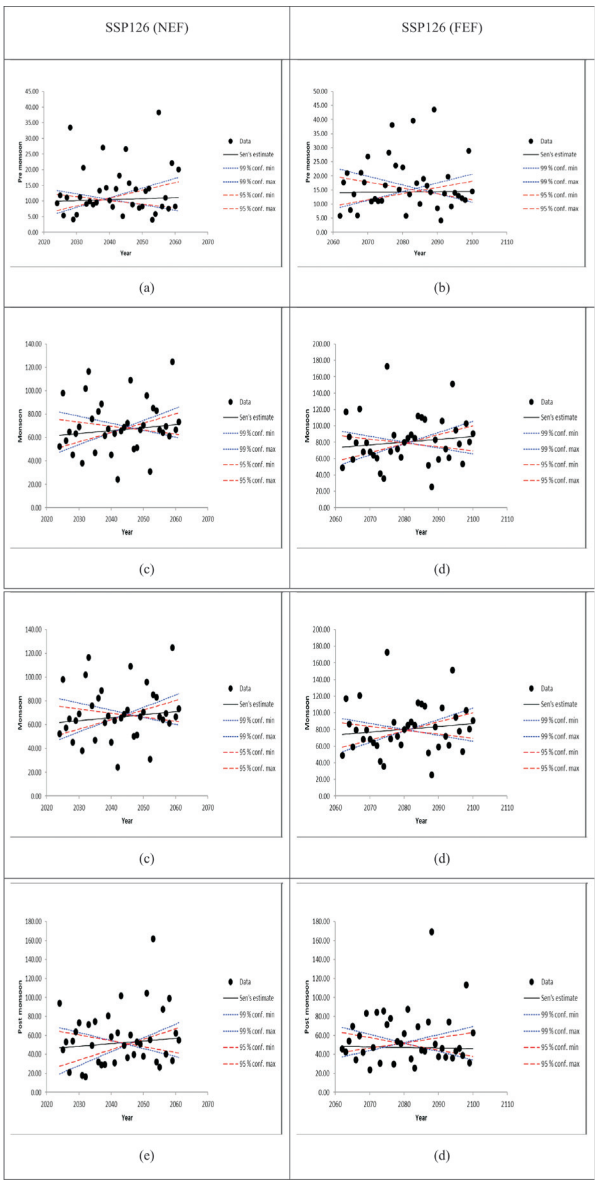

Fig. 7. Rainfall trends of Model data Scenario -1

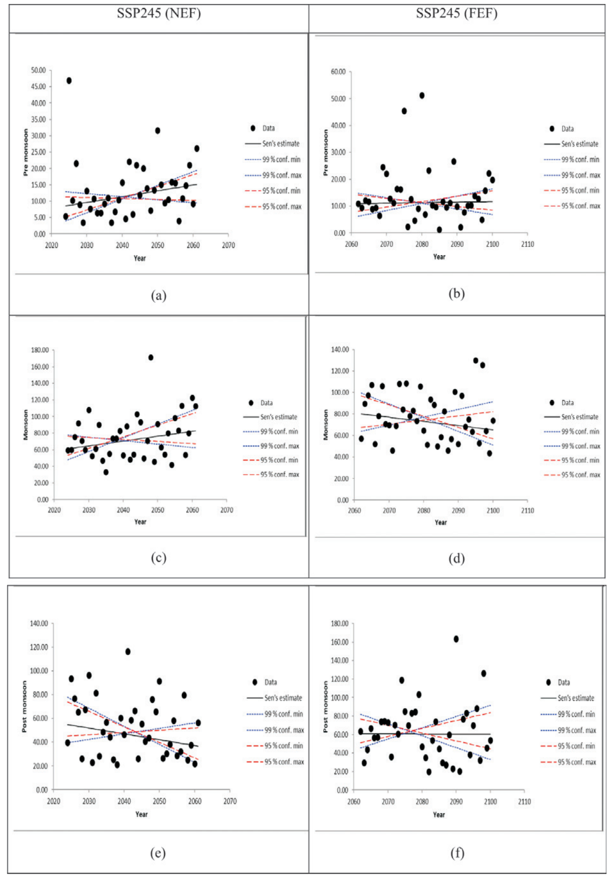

Fig. 8. Rainfall trends of Model data Scenario – 2

Figure 9 (a) to (f) shows the annual maximum rainfall trends in the Near End and Far End Future for the GCM NorESM2-LM scenario – 3 (SSP370). It can be seen that there is no trend during the pre-monsoon and monsoon periods of NEF, while the post-monsoon period shows a decreasing trend. The Far End Future, on the other hand, show increasing trends in all the seasonal periods of that period.

Figure 10 (a) to (f) depict the annual maximum rainfall trends in the Near End and Far End Future states of NorESM2-LM GCM sustainability scenario- 4 (SSP585). It can be seen that the NEF shows increasing trend in pre-monsoon period and decreasing trends in the other two. The FEF shows no or negligible trend in the pre-monsoon period and increasing trends in the monsoon and post-monsoon periods.

Temperature Trends

Figures 11 (a) to (f) show the maximum daily average temperature trends of the historical IMD gridded dataset and best-fit GCM NorESM2-LM for

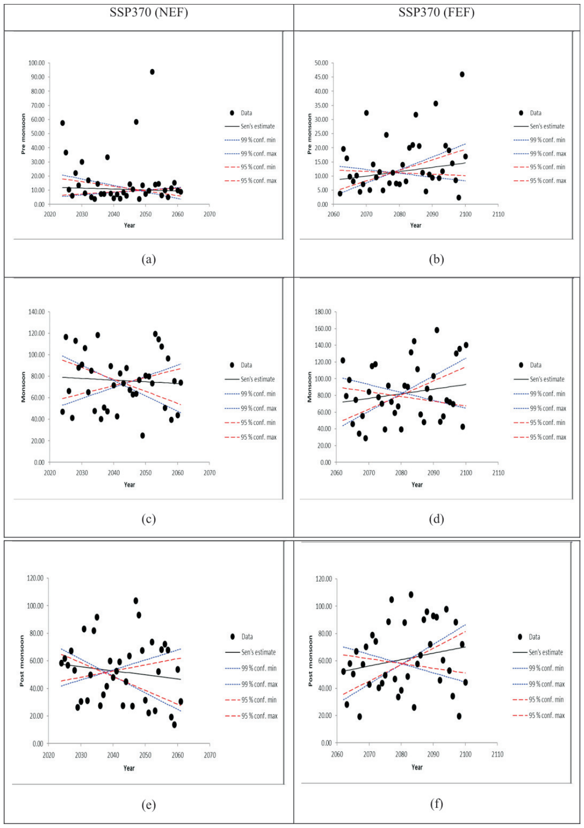

Fig. 9. Rainfall trends of Model data Scenario – 3

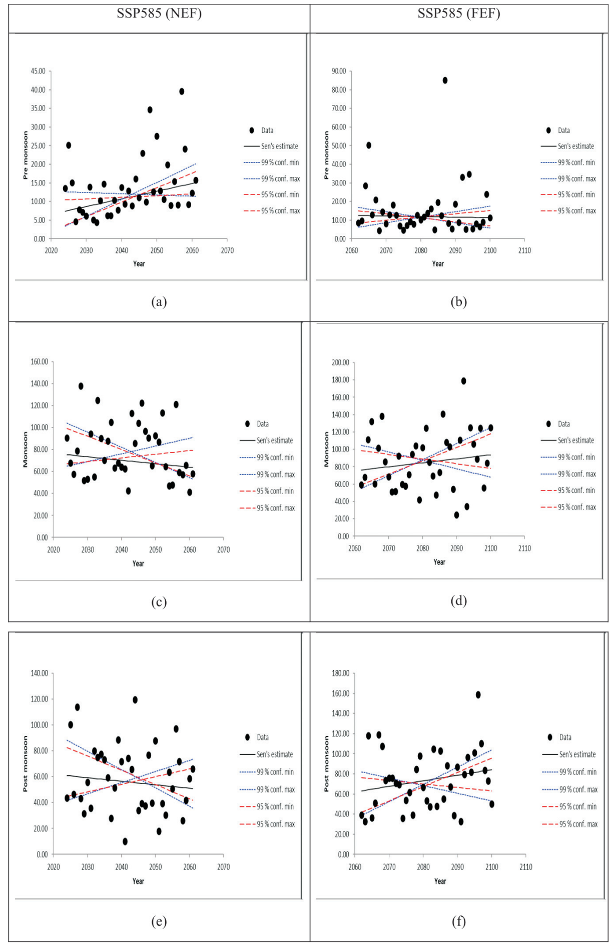

Fig. 10. Rainfall trends of Model data Scenario – 4

the seasonal variations between 1985 and 2014. The GCM dataset shows increasing trends during monsoon and post-monsoon periods while slightly increasing during the pre-monsoon period. The IMD dataset shows a decreasing trend in the pre-monsoon period while increasing trends during the monsoon and post-monsoon periods. The graphical representation shows similar trends in historical IMD and GCM datasets.

Figures 12 (a) to (f) show the minimum daily average temperature trends of the historical IMD gridded dataset and best-fit GCM NorESM2-LM for the seasonal variations between 1985 and 2014. It can be observed that there are similar trends in both datasets -no or negligible trends during pre-monsoon and increasing trends during monsoon and post-monsoon periods.

Conclusion

The analysis of rainfall and temperature trends in the Periyar River Basin reveals that while no discernible long-term rainfall pattern emerges, August and September exhibit a linear increase, whereas months like January, February, June, July, November, and December show declining trends. Over the study period, both maximum and minimum temperatures consistently rise, indicating the gradual warming of the region. Key findings from the study include:

Rainfall Trends: Historical IMD data and the NorESM2-LM GCM model show similar rainfall trends, with slight increases during the monsoon and post-monsoon periods.

- Scenario 1 (SSP126): Slightly increasing rainfall trends in the monsoon for both Near-End Future (NEF) and Far-End Future (FEF). Post-monsoon rainfall also shows an increasing trend in NEF.
- Scenario 2 (SSP245): NEF experiences increasing trends in pre-monsoon and monsoon periods, but decreasing post-monsoon trends. FEF shows decreasing monsoon trends.
- Scenario 3 (SSP370): No significant trends in

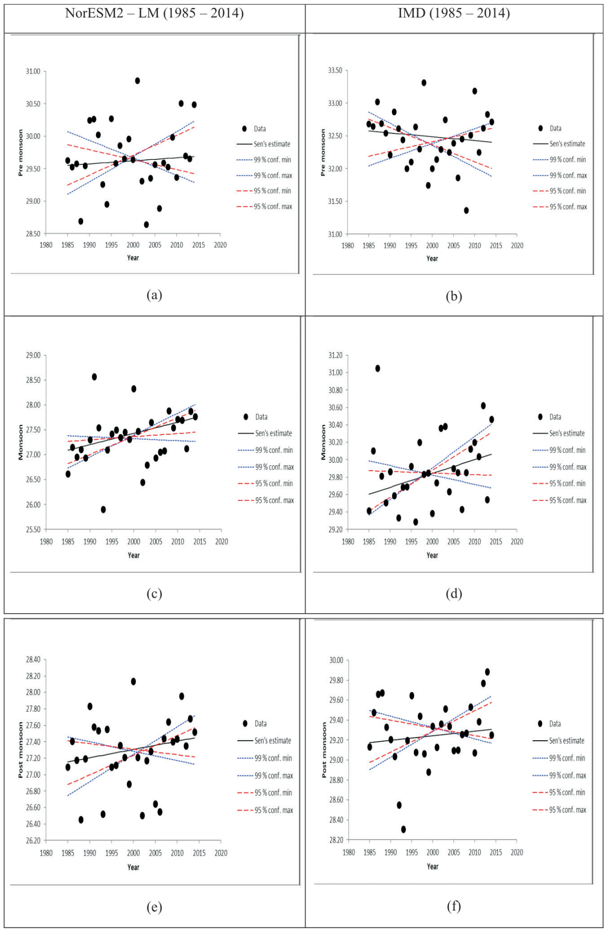

Fig. 11. Historical trends of Model and IMD Temperature data (T_{max})

NEF pre-monsoon and monsoon periods, but FEF shows increasing rainfall across all seasons.

- Scenario 4 (SSP585): NEF sees an increase in pre-monsoon rainfall, while other seasons decline. FEF shows rising rainfall during monsoon and post-monsoon periods.

Temperature Trends

- Maximum Daily Average Temperature: Both the IMD dataset and GCM NorESM2-LM exhibit increasing trends during the monsoon and post-monsoon periods, with a decreasing trend in the pre-monsoon period for the IMD dataset.
- Minimum Daily Average Temperature: Similar trends are observed, with negligible changes during the pre-monsoon period and increasing temperatures during the monsoon and post-monsoon periods.

The convergence of these findings highlights the intricate relationship between climate change, land use, and hydrological processes in the Periyar River Basin. Addressing these challenges requires proactive management strategies that ensure the sustainability of water resources, maintain agricultural productivity, and safeguard ecosystem health.

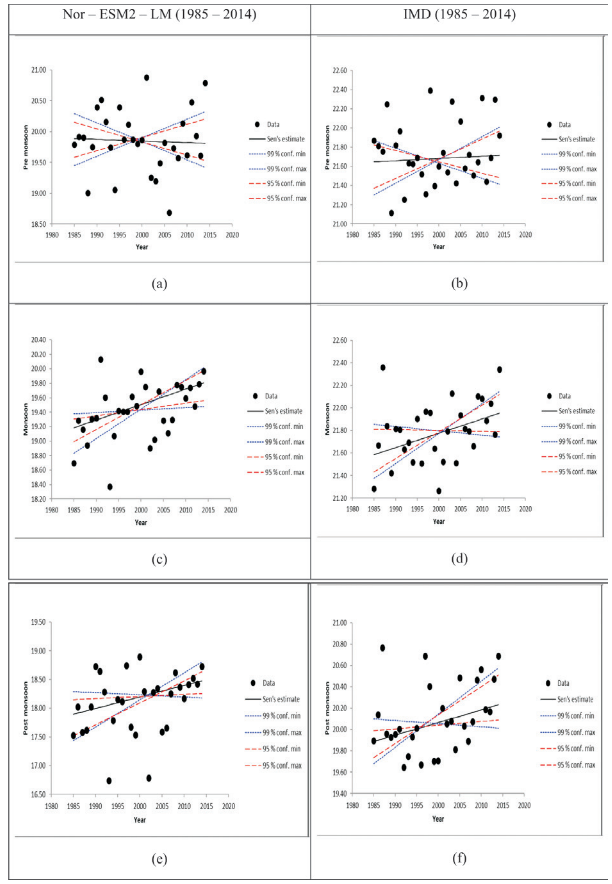

Fig. 12. Historical trends of Model and IMD Temperature data (T_{min})

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