

SPATIAL AND TEMPORAL ANALYSIS OF HISTORICAL RAINFALL PATTERNS AND ITS CLIMATE CHANGE IMPACT ON PEECHI DAM CATCHMENT AREA.

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Abstract - This comprehensive research project delves into the spatial and temporal analysis of historical rainfall patterns within the Peechi Dam catchment area, primarily focusing on assessing the impact of climate change. The study spans two pages and commences by establishing the significance of understanding historical rainfall dynamics in the context of water resource management and climate change adaptation. It meticulously outlines the methodology, incorporating advanced spatial and temporal analysis techniques, to discern patterns and trends in historical rainfall data. The research rigorously examines the spatial distribution of rainfall across the catchment area over an extended time frame, providing an in-depth exploration of how precipitation varies across different geographical regions. Simultaneously, the temporal analysis investigates trends and fluctuations in rainfall patterns over multiple decades, aiming to identify potential shifts attributable to climate change. A critical component of the study is the integration of climate change impact assessment. Utilizing sophisticated modeling and statistical tools, the research endeavors to quantify the influence of climate change on historical rainfall patterns. It scrutinizes whether observed variations align with established climate change projections, elucidating the potential implications for the region's water resources. The project also considers the broader environmental and socio-economic consequences of altered rainfall patterns, emphasizing the importance of developing adaptive strategies. The implications extend beyond mere hydrological changes, encompassing ecological shifts, agricultural impacts, and potential consequences for communities dependent on the Peechi Dam catchment area. In conclusion, this research not only contributes to the scientific understanding of historical rainfall dynamics and climate change impacts but also offers actionable insights for policymakers, water resource managers, and local communities. The comprehensive two-page exploration serves as a valuable resource for addressing the challenges posed by evolving precipitation patterns in the context of climate change and sustainable water resource management in the Peechi Dam catchment area.

Key Words: Spatial and temporal analysis, Modelling and statistical tools, Adaptive Strategies, Community resilience

1.INTRODUCTION

The hydrological cycle is one of the important components of the weather and climate system that is significantly affected by the precipitation and evaporation processes. Understanding historical rainfall patterns provides a baseline for assessing climate change effects and identifying precipitation shifts, aiding in forecasting future climate scenarios. The study of historical rainfall patterns and their evolution over time is a critical aspect of understanding the impacts of climate change on hydrological systems. The Peechi Dam catchment area, a vital water resource in Kerala, India, has experienced significant changes in rainfall distribution, which have profound implications for water availability, agricultural productivity, and ecosystem sustainability. This project aims to conduct comprehensive spatial and temporal analysis of the historical rainfall data to assess the impact of climate change on the Peechi Dam catchment area and forecast future trends.

The Mann-Kendall Tau Test is a statistical method used to detect trends in time series data. This method is particularly useful when the distribution of the data is unknown or abnormal. The test compares the ordering of data points to determine if there is a consistent upward or downward trend over time[20]. The test assumes that there is no trend in the data as the null hypothesis. On the other hand, the alternative hypothesis indicates either a positive or negative trend. One of the key advantages of this test is its resilience to missing data and abrupt changes. This is because of its non-parametric nature. In this case, the test will be used to analyze rainfall patterns, providing insights into long-term trends that may be associated with climate change. Sen's Slope Estimator Test, also known as Theil-Sen Estimator, is a non-parametric method that is used to measure the magnitude

of a trend in a time series[7]. This estimator is often used in conjunction with the Mann-Kendall Tau Test. Unlike parametric tests, which assume a specific data distribution, Sen's Slope Estimator is resistant to outliers and does not require data to follow any particular distribution. The estimator calculates the slope as the median of all slopes between paired data points, providing a robust measure of trend magnitude. In the context of the Peechi Dam catchment area, Sen's Slope Estimator will provide a reliable estimate of the rate at which rainfall patterns are changing, thus contributing to a more accurate prediction of future scenarios. The combination of these two tests will allow for a detailed analysis of historical rainfall data, providing insight into the changes in rainfall patterns over time and how they relate to indicators of climate change.

Trend analysis is a critical component of climatic research, providing insights into the historical and potential future states of various meteorological parameters. Our study, spanning from 1983 to 2022, delves deep into the climatic elements that shape the environmental narrative of a specific region. By dissecting data into monthly, annual, and seasonal segments, we capture the intricate fluctuations of climate that define periods such as Summer, Winter, and Monsoon seasons. The parameters chosen for this analysis are not arbitrary; they are the linchpins of meteorological science. Minimum and Maximum Temperatures offer a window into the thermal behavior of the region, influencing phenomena from evaporation rates to the survival of local flora and fauna. Relative Humidity measures the saturation of water vapor in the air, a determinant of precipitation patterns and a key player in the water cycle. Wind Speed affects the dispersal of seeds, the erosion of soil, and the spread of weather systems. Lastly, Precipitation is the culmination of these factors, a tangible measure of the climate's ebb and flow-renowned for its statistical prowess and graphical capabilities, to conduct the Mann-Kendall Tau test and Sen's Slope Estimator Test.

The positive or negative values of Sen's slope, denoted as Q, are particularly telling. A positive Q indicates an upward trend, a signal that a particular parameter, such as temperature or precipitation, is on the rise. Conversely, a negative Q suggests a decline, a warning that could have significant implications for water management, agriculture, and overall ecological balance.

1.1 Objective

- Collecting historical rainfall data for the region of interest.
- Selection of parameters for seasonal, annual, and monthly past rainfall patterns in trend analysis.
- Analyze the trend using the Mann-Kendall tau test and Sen slope test

1.2 Scope of study

The study will focus on specific geographical regions to provide a detailed examination of historical rainfall patterns and future forecasting. These regions will be chosen based on their ecological significance and potential impact on local communities. The temporal scope encompasses a substantial period, allowing for a comprehensive analysis of historical rainfall data. This extended timeframe aims to capture long-term trends, cyclical variations, and potential shifts in precipitation patterns. The project will leverage a variety of reliable data sources, including meteorological stations, satellite imagery, and climate databases, to ensure a comprehensive and accurate representation of historical rainfall patterns.

2. METHODOLOGY

2.1 General

The flowchart for the methodology is shown in **Fig 1**. The study area under consideration is Peechi, a region located within the Thrissur Forest Division of the Thrissur district in the state of Kerala. Encompassing an expansive area of approximately 108 km², Peechi is characterized by its geographical coordinates, falling between latitudes 10°30' and 10°40' N and longitudes 76°15' and 76°25' E. [26]. A range of parameters that are essential for the analysis were selected. The choices were driven by the necessity to encompass vital environmental elements that have a significant influence on our research area. These parameters include precipitation, Minimum and maximum temperatures, Relative humidity, and wind speed. The monthly parameters of the past 40 years of data from 1983 to 2023 were taken from NASA's power data access viewer website [32].

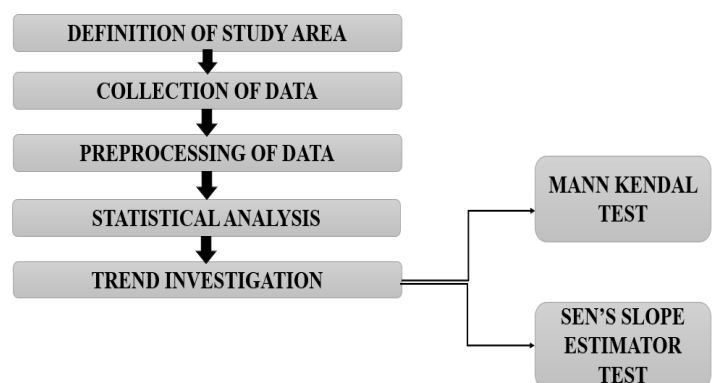


Fig 1 Methodology Flowchart

The data is then pre-processed which involves a series of steps to organize and clean the raw data before analysis. Initially, the collected rainfall data may contain inconsistencies, errors, or missing values that could affect

the accuracy of subsequent analyses. The monthly data of each parameter is then categorized into 4 seasons. (1) Summer which starts from the month March to May, is also referred to as the pre-monsoon season. (2) The South-southwest monsoon starts in June and ends with the month September. (3) Northeast monsoon in October and November. (4) Winter season from December to February [20]. Also, the 12 months are grouped to determine the annual data. Therefore, analysis is done for monthly, seasonal, and annual data for each parameter.

2.2 STATISTICAL ANALYSIS [7]

Statistical analysis involves evaluating data to identify patterns and trends. It helps remove bias and provides numerical insights. In this preliminary stage, we focus on eight key factors: minimum, maximum, mean, median, standard deviation, variance, skewness, and kurtosis. These factors are particularly relevant for analyzing hydrological parameters like precipitation, maximum temperature (Tmax), minimum temperature (Tmin), relative humidity (RH), and wind speed. The goal is to draw meaningful conclusions from raw data and facilitate decision-making based on past trends.

2.3 TREND ANALYSIS [7] [20]

Our study's investigation into rainfall trends unfolds in three methodical stages. Initially, we apply Kendall's Tau test to detect any consistent trends in rainfall, serving as a dependable method for revealing any persistent increases or decreases in the data. Subsequently, in the second stage, we utilize Sen's slope estimates to measure the extent of these rainfall trends, offering a precise gauge of the changes in precipitation levels. The final stage is dedicated to the graphical depiction of the observed rainfall trends, encapsulating the data in a visual format. This step-by-step approach ensures a comprehensive and detailed examination of the rainfall patterns throughout the study.

2.3.1 MAN KENDAL - TAU TEST [7]

In our study, we utilized Kendall's tau test, a non-parametric approach, to evaluate the presence of trends within a sequence of data points. The test assesses whether there is a statistically significant monotonic (consistently increasing or decreasing) trend. The test's design focuses on the signs of differences between pairs of observations, rather than their actual magnitudes, which enhances its robustness against outliers. The resilience of Kendall's tau test to outliers is a key feature, as it evaluates the sign differences between variables, not their precise values. The tau value that results from this test quantifies the strength of the association between two variables, X and Y, reflecting the extent of their correlation.

In essence, it measures the degree to which variables X and Y are related in terms of their directional movements.

The calculation of Kendall's tau value is as follows:

$$\tau = \frac{S}{\frac{n(n-1)}{2}}$$

Here, S is the sum of the sign differences from the Mann-Kendall statistical principle, and n is the number of data points. (X1, X2, ..., Xn) represent the data points, and (Xi, Xj) are the data points at times (i) and (j).

The computation of S involves summing up the sign differences between all pairs of data points:

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

The sign function is defined as:

$$\text{Sign}(X_j - X_i) = \begin{cases} -1, & \text{if } (X_i - X_j) < 0 \\ 0, & \text{if } (X_i - X_j) = 0 \\ +1, & \text{if } (X_i - X_j) > 0 \end{cases}$$

A tau value of zero suggests no trend, while a non-zero tau value indicates a trend. A negative tau value implies a negative correlation, with Y tending to decrease, and a positive tau value indicates a positive correlation, with Y tending to increase.

The Mann-Kendall Test is instrumental in discerning the existence of trends, signaling whether they are ascending or descending. However, it does not quantify the size of these trends. To complement this, Sen's Slope estimates are used to measure the degree of the identified trends. Thus, while the Mann-Kendall Test reveals the trend's direction, Sen's Slope provides a quantification of how significant the trend is, whether it's an increase or a decrease.

2.3.2 SEN'S SLOPE ESTIMATOR TEST [7]

Sen's Slope Estimator Test is a robust statistical tool used to measure the rate of change in a dataset over time, complementing the directional trend information provided by Kendall's tau test. This method is particularly useful when the data exhibits a linear trend, as it accurately quantifies the rate at which the variable is increasing or decreasing.

Consider a dataset with n observations, denoted by X1, X2,Xn, let Xi, Xj represent the observations at times i and j respectively, with (j > i).

The individual slope Ti between each pair of observations is calculated as follows:

$$T_i = \frac{X_j - X_i}{j - i}$$

Where,

$i = 1$ to $(n-1), j = 2$ to n .

If there are n values of X_j , the estimates of slope will be,

$$N = \frac{n(n-2)}{2}$$

Sen's Slope Estimator is calculated as the median of all the individual slopes between data points in a dataset. The median was determined as,

$$Q = \begin{cases} T_i \frac{(N+1)}{2}, & N \text{ is odd} \\ \frac{1}{2} \left(T_i \frac{N}{2} + T_i \frac{(N+1)}{2} \right), & N \text{ is even} \end{cases}$$

Where Q is the Sen's slope.

A positive value of Q suggests a rising trend, whereas negative Q values indicate a decreasing trend in the temporal data. Q represents the slope magnitude per year.

The linear trend line equation is then expressed as:

$$Y = Q * t + B$$

where Q is the Sen's Slope, B is the intercept, and t is time. The intercept is calculated as the median of the differences between the observed values and the product of Sen's Slope and time.

Trend analysis was conducted using R software, a powerful tool for statistical computing and graphics. R's extensive package ecosystem and data manipulation capabilities allowed for sophisticated analysis of temporal data. R's programming environment is designed for data analysis, making it an ideal choice for handling the complexities of trend analysis. The use of R software ensured a high level of accuracy and reproducibility in our trend analysis process.

3. RESULTS AND DISCUSSIONS

3.1 Statistical analysis

The result of the statistical analysis for all the parameters from the year 1981 to 2022 is provided in Table 1.

Precipitation

Among the months, June exhibits the highest mean rainfall of 458.18 mm, while January experiences the lowest mean rainfall at 13.34 mm. Additionally, June has the highest standard deviation (SD) of 145.71 mm, indicating greater variability in rainfall during that month. The variance also follows a similar pattern, with June having the highest variance of 21231.06 mm² and January having the lowest variance of 714.05 mm². Furthermore, March displays the highest positive skewness of 4.44, suggesting a right-skewed distribution with more extreme high rainfall

events. In terms of kurtosis, March exhibits the highest value of 24.08, signifying a heavy-tailed and peaked distribution. Conversely, the summer months have the lowest kurtosis of 1.25, implying a less heavy-tailed distribution compared to other months. Notably, both January and December record a minimum rainfall of 0 mm, while June boasts the maximum rainfall of 922.85 mm.

Minimum and Maximum Temperature

Among the months, May exhibits the highest standard deviation (SD) of 1.63, indicating high variability in maximum temperatures across different years within that month. This suggests that the maximum temperatures in May vary significantly from year to year, possibly due to diverse weather patterns or climatic conditions. Conversely, August has the lowest standard deviation of 0.53, indicating relatively low variability in maximum temperatures across different years within that month. This implies that the maximum temperatures in August tend to be more consistent or stable from year to year compared to other months. Additionally, variance measures the spread of data points around the mean. Months with higher variance have more spread-out data points, indicating greater variability in maximum temperatures. Similar to the standard deviation, May also has the highest variance, reflecting its high variability in maximum temperatures. Conversely, August has the lowest variance, indicating more consistent maximum temperatures compared to other months. Whereas, October exhibits the highest standard deviation (SD) of 0.95, indicating significant variability in minimum temperatures across different years within that month. This suggests that the minimum temperatures in October vary considerably due to diverse weather patterns or climatic conditions. Conversely, August has the lowest standard deviation (SD) of 0.39, implying more consistent or stable minimum temperatures from year to year. Additionally, variance measures the spread of data points around the mean. Similar to the standard deviation, October also has the highest variance, reflecting its high variability in minimum temperatures. Conversely, August has the lowest variance, indicating more consistent minimum temperatures compared to other months. Skewness measures the asymmetry of the distribution of data points. Positive skewness indicates a longer tail on the right side of the distribution, while negative skewness indicates a longer tail on the left side. Kurtosis measures the "tailedness" of the distribution. Positive kurtosis indicates a sharp peak and heavy tails, while negative kurtosis indicates a flatter peak and lighter tails.

Relative humidity

June has the highest standard deviation of 1.955146, indicating high variability in relative humidity across different years within that month. This suggests that the relative humidity in June varies significantly from year to

year, possibly due to changing weather patterns or environmental conditions. August has the lowest standard deviation of 0.853942, indicating relatively low variability in relative humidity across different years within that month. This implies that the relative humidity in August tends to be more consistent or stable from year to year compared to other months. Variance measures the spread of data points around the mean. Months with higher variance have more spread-out data points, indicating greater variability in relative humidity. Similar to the standard deviation, June also has the highest variance, reflecting its high variability in relative humidity. August has the lowest variance, indicating more consistent relative humidity compared to other months. The values of skewness and kurtosis for each month provide insights into the shape and characteristics of the relative humidity distribution for that month.

Wind speed

The month with the highest mean wind speed is June (5.676905), followed closely by July and August. These months typically experience higher values compared to others. The month with the lowest mean is March (3.114762), followed by February and November. Months with higher standard deviation and variance tend to have more variability in their data points, indicating greater fluctuations from the mean. In this dataset, June has the highest standard deviation and variance, suggesting more variability in the data, while December has relatively lower standard deviation and variance. Skewness measures the symmetry of the distribution. November has the highest skewness (0.863565), indicating a right-skewed distribution. June has the lowest skewness (-0.56149), indicating a left-skewed distribution. Kurtosis measures the tails of the distribution. November has the highest kurtosis (1.376597), indicating heavy tails. July has the lowest kurtosis (-0.47951), indicating lighter tails. The month with the minimum wind speed is February (2.59), and the month with the maximum wind speed is June (6.98).

Table 1

Statistical Analysis Result

PARAMETER	STATISTICAL FACTORS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN	SUMMER	SW	NE	WINTER
PRECIPITATION	Mean (mm)	13.33595	13.08857	28.93976	81.1081	189.3164	458.1771	398.7267	302.0102	208.5605	266.246	136.8826	33.65143	2130.043	99.7881	341.8686	201.5643	214.407
	Standard deviation (mm)	26.72166	24.32483	41.21318	58.98698	127.2577	145.7088	144.4505	125.2421	129.081	124.874	72.80485	33.3427	407.1611	49.40381	81.19119	78.20474	44.61381
	Variance (mm ²)	714.0472	591.6975	1698.526	3479.464	16194.52	21231.06	20865.93	15685.58	16661.91	15593.51	5300.546	1111.736	165780.2	2440.737	6592.009	6115.981	1990.392
	Skewness	2.579682	2.280376	4.437344	0.871008	1.574436	1.205789	0.214505	0.791854	0.397821	0.179058	0.997511	1.471125	0.030548	0.733734	0.361128	0.376024	0.080595
	Kurtosis	6.010045	4.656173	24.07951	0.169807	3.783932	1.858832	0.134064	0.580143	-0.72746	-0.79683	0.83365	2.36985	-0.73466	1.253737	-0.45002	0.173823	-0.53174
	Minimum (mm)	0	0	0	0	5.27	25.8	121.29	121.29	21.09	26.37	26.37	0	1368.91	5.27333	218.848	39.55	130.957
	Maximum (mm)	110.74	100.2	258.4	237.3	659.18	922.85	759.38	664.45	500.98	490.43	347.74	142.38	2921.48	244.3367	529.98	409.78	304.605
TMAX	Mean (mm)	34.87476	37.1481	38.24095	37.61833	34.67476	30.69143	28.84238	28.81262	29.61143	30.69143	30.82667	32.20786	38.51524	36.84468	29.48946	30.75905	34.74357
	Standard deviation (mm)	1.032083	0.85782	0.776719	1.483082	1.632503	1.629524	0.707585	0.530775	0.709966	0.994479	0.88078	1.390407	0.744663	1.01005	0.568653	0.833111	0.667524
	Variance (mm ²)	1.065196	0.735855	0.603292	2.199531	2.665065	2.655349	0.500677	0.281722	0.504052	0.988988	0.775774	1.933232	0.554523	1.020201	0.323367	0.694075	0.445589
	Skewness	-0.07123	-1.08216	-0.37723	-0.99975	0.617476	0.960743	1.020621	0.543771	0.290166	1.056794	0.932774	0.077023	-0.03708	-0.2367	0.088319	0.976001	0.138691
	Kurtosis	0.333676	1.93869	0.061619	1.499605	0.294165	0.724219	1.800918	0.005635	-0.21856	3.66408	0.474948	-0.58658	-0.76917	0.43869	-0.46575	1.283382	-0.63336
	Minimum (mm)	32.59	34.32	36.2	33.09	32.07	27.87	27.67	27.79	28.14	28.57	29.68	29.42	36.83	34.08333	28.2575	29.26	33.51
	Maximum (mm)	37.56	38.52	39.79	39.93	39.14	35.28	31.19	30.1	31.27	34.38	33.34	35.29	39.93	38.81667	30.605	33.25	36.23667
TMIN	Mean (mm)	18.99643	20.38643	22.74786	24.88071	24.59167	23.525	22.84643	22.6931	22.71738	22.37167	20.49214	18.85786	18.24857	24.07341	22.94548	21.4319	19.41357
	Standard deviation (mm)	0.973951	1.172192	1.293229	0.650802	0.538552	0.545926	0.489608	0.391311	0.46861	0.946536	1.296285	1.133379	0.735502	0.675249	0.3598	0.881485	0.716274
	Variance (mm ²)	0.94858	1.374033	1.672442	0.423543	0.290359	0.298035	0.239716	0.153124	0.219595	0.895931	1.680354	1.284549	0.540964	0.455962	0.129456	0.777016	0.513049
	Skewness	0.137942	0.165873	-0.24122	0.106144	0.773012	-0.02565	-0.61549	-0.28794	-0.22372	-2.06468	0.001298	0.463301	0.430361	0.280209	-0.13252	0.131465	0.060131
	Kurtosis	-0.47652	0.089644	0.293568	0.84951	-0.17692	-0.16067	0.01024	-0.12311	-0.03274	6.128614	-0.27014	-0.41638	-0.12303	0.689198	-0.41508	-0.32664	-0.47507
	Minimum (mm)	16.98	18.18	19.63	23.17	23.69	22.37	21.66	21.87	21.58	18.55	17.83	17.06	16.98	22.4	22.12	19.815	18.06667
	Maximum (mm)	21.32	23.41	25.44	26.64	25.75	24.67	23.77	23.53	23.58	23.66	23.14	21.49	19.92	25.56333	23.535	23.305	20.89667
RELATIVE HUMIDITY	Mean (mm)	64.01905	59.15929	62.12548	72.24333	80.08286	87.68762	90.36167	90.51976	88.83833	86.44786	81.74381	73.82714	78.20762	71.48389	89.35185	84.09583	81.64386
	Standard deviation (mm)	5.668442	4.977556	3.463512	4.803588	4.010213	1.955146	1.259663	0.853942	1.203594	2.101662	3.085726	4.988276	1.508164	3.043094	0.858009	2.253676	1.338074
	Variance (mm ²)	32.13123	24.77607	11.99592	23.07446	16.08181	3.822594	1.586751	0.729217	1.448639	4.416983	9.521702	24.88289	2.27456	9.260423	0.736179	5.079055	1.790441
	Skewness	-0.08119	0.256339	0.386887	-0.06884	-0.46379	-1.35319	-1.32154	-1.34917	-0.1202	-0.38658	0.015726	-0.05498	-0.24884	-0.42847	-0.97193	-0.21616	-0.3212
	Kurtosis	-0.27269	-0.60182	0.456346	-0.88283	0.071195	1.740284	1.798213	3.730306	-1.21448	-0.04849	-0.36219	-0.91634	0.268395	-0.13868	0.641097	-0.06946	-0.1004
	Minimum (mm)	52.81	49.06	54.81	62.62	70.81	81.81	86.38	87.62	86.62	81.44	75.38	63.38	64.46	87.015	78.41	78.28417	
	Maximum (mm)	76.88	69.44	71.19	80.56	88.5	90.5	92	92	90.81	91.06	88.19	83.44	81.75	78.16667	90.765	88.625	84.02139
WIND SPEED	Mean (mm)	3.609524	3.21881	3.114762	3.414048	4.444524	5.676905	5.607857	5.220714	4.39119	3.413571	3.183333	3.967381	4.110238	3.657778	5.224167	3.298452	3.598571
	Standard deviation (mm)	0.312377	0.243512	0.221367	0.454216	0.362727	0.647402	0.600547	0.466997	0.414771	0.432419	0.423537	0.486197	0.230636	0.264408	0.396641	0.313277	0.274146
	Variance (mm ²)	0.084034	0.081142	0.064401	0.210137	0.186347	0.358519	0.294749	0.198217	0.150299	0.172263	0.163515	0.21541	0.045812	0.087906	0.133648	0.088601	0.063807
	Skewness	1.032429	-0.11384	0.188309	0.36969	0.008842	-0.56149	0.133666	-0.31152	-0.0031	0.010535	0.863565	0.27852	-0.28711	0.098891	-0.4213	-0.28299	0.527626
	Kurtosis	1.322944	-0.72741	1.037123	0.280042	0.13042	0.891429	-0.47951	0.157248	0.112805	0.180031	1.376597	-0.03776	-0.2576	0.853377	-0.56723	-0.16075	0.14621
	Minimum (mm)	3.19	2.59	2.45	2.6	3.38	3.87	4.52	4.23	3.42	2.48	2.39	3.15	3.59	2.966667	4.3725	2.56	3.113333
	Maximum (mm)	4.49	3.72	3.78	4.74	5.47	6.98	6.77	6.23	5.17	4.35	4.48	5.07	4.53	4.423333	5.8075	3.82	4.25

3.2 Trend analysis

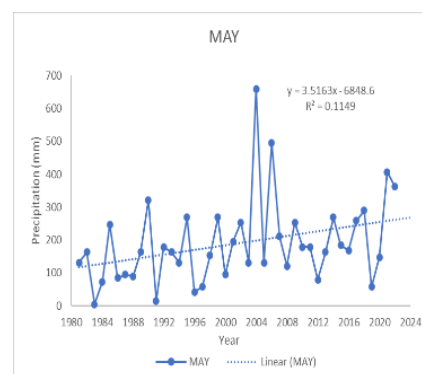
Trend analysis for precipitation

Annual, monthly, and seasonal precipitation trends from 1983 to 2022 were investigated individually. An increase in significant trends was observed annually with MK test value of 251 and Sen’s slope value of 1.1614. For monthly precipitation, a statistical increase in trend was observed for May, September, and November. For May MK test value shows 238 with Sen’s slope of 3.2018. September gives MK value of 172 with Sen’s slope of 2.9289. At the same time. November gives an MK value of 195 with Sen’s slope of 1.4381. Only the month of June showed a significant decrease in the trend with Mk value -238 along with Sen’s slope -4.5703. The seasonal analysis showed a positive trend for Northeast monsoon and Winter. For the Northeast monsoon, the MK test gives S value of 176 with Sen’s slope Q value of 1.9586. Winter gives the value 259 with the Mk test and 1.6141 for Sen’s slope. The trend analysis indicates a significant increase in a certain parameter during May, September, November, the northeast monsoon season, and annually. Conversely, a decreasing trend is observed for June. This pattern suggests a seasonal variability with higher values during the northeast monsoon and winter months, which could be attributed to increased rainfall during these periods. For the Peechi Dam catchment area, these trends could have several implications. The significant increases during the monsoon and winter months could lead to higher water inflow into the dam, potentially improving water availability for irrigation, power generation, and domestic use. However, it also raises concerns about the dam’s capacity to handle potential flood events and the need for effective water management strategies. The observed decrease in June, typically a monsoon month, is unusual and may indicate changes in climatic patterns or other environmental factors. This could affect the water balance in the catchment area, possibly leading to water scarcity issues during what is traditionally a replenishment period. Overall, the analysis suggests that while there is an overall annual increase, the monthly variability, especially the decrease in June, could pose challenges for water resource management in the Peechi Dam catchment area. It highlights the importance of continuous monitoring and adaptive management to mitigate potential risks associated with these trends.

Table 2 Analysis of precipitation

TEST	MK TEST VALUE (S)	SEN’S SLOPE VALUE (Q)	TREND
JAN	18	0	N
FEB	140	0	N
MAR	115	0.2027	N
APR	115	1.0547	N
MAY	238	3.2018	+S
JUNE	-238	-4.5703	-S
JUL	32	0.6129	N
AUG	69	1.5512	N
SEPT	172	2.9289	+S
OCT	121	2.4338	N
NOV	195	1.4381	+S
DEC	106	0.3907	N
ANNUAL	251	1.1614	+S
SUMMER	258	0.09489	N
SW	61	0.9039	N
NE	176	1.9586	+S
WINTER	259	1.6141	+S

(Note: N = No significant trend, +S = Significant increase in trend, -S = significant decrease in trend, SW= southwest monsoon, NE = northeast monsoon.)



(a)

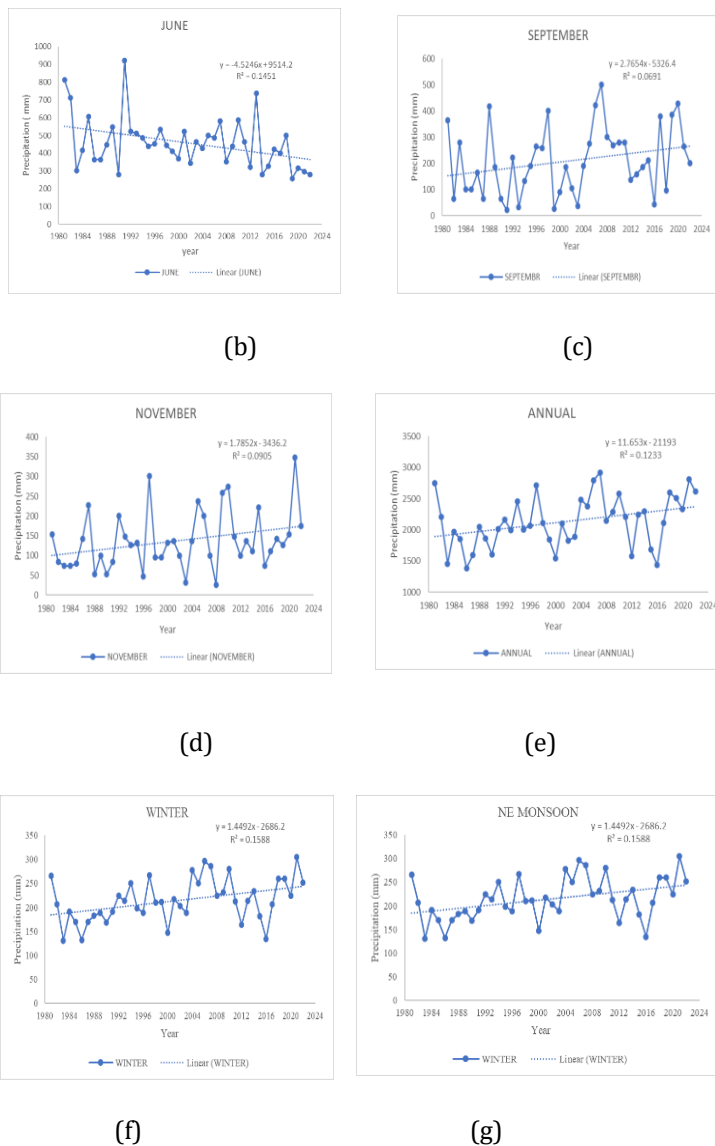


Fig 2 Time series graph of Precipitation for (a) May (b) June (c) September (d) November (e) Annual (f) Northeast Monsoon (g) Winter

Trend Analysis for Minimum and Maximum Temperature

MK test value and Sen’s slope value for minimum and maximum temperature are shown in Table 2

Table 2 Trend analysis for Tmax and Tmin

TEST	Tmax			Tmin		
	MK TEST VALUE (S)	SEN’S SLOPE VALUE (Q)	TREND	MK TEST VALUE (S)	SEN’S SLOPE VALUE (Q)	TREND
JAN	-44	-0.005	N	99	0.0105	N
FEB	106	0.01357	N	-7	-0.0010	N
MAR	-44	-0.0073	N	75	0.0161	N
APR	15	0.0020	N	33	0.0042	N
MAY	110	-0.02714	N	61	0.0033	N
JUNE	62	0.01348	N	208	0.0167	+S
JUL	282	0.02727	+S	308	0.0208	+S
AUG	363	0.02467	+S	290	0.0150	+S
SEPT	345	0.0333	+S	246	0.0156	+S
OCT	-20	-0.0018	N	126	0.0126	N
NOV	-1.0	0	N	20	0.0056	N
DEC	-126	-0.02958	N	83	0.0161	N
ANNUAL	-4.0	-0.0003	N	134	0.0164	N
SUMMER	-55	-0.008	N	80	0.007826	N
SW	273	0.0227	+S	369	0.01906	+S
NE	-1000	0.0000	N	134	0.01687	N
WINTER	-35	0.0036	N	51	0.007937	N

(Note: N = No significant trend, +S = Significant increase in trend, -S = significant decrease in trend, SW= southwest monsoon, NE = northeast monsoon.)

MK test value and Sen’s slope value for minimum and maximum temperature are shown in Table 4.2. Annual Tmin showed no significant trend in the analysis. A significant increase in trend is observed for June, July, August, and September. June gives MK value of 208 with Sen’s slope value of 0.0167. For July Mk test gives the value of 308 and Sen’s slope gives the value of 0.0208. August month also shows a positive trend with MK test value of 209 and Sen’s slope value of 0.0150. Similarly, the month of September also shows an increasing trend with the Mk test value of 246 and Sen’s slope value of 0.0156. Seasonal analysis of the Tmin time series shows an increase in significant trend for Southwest monsoon with Mk test value 369 and Sen’s slope value 0.0190. The trend analysis for maximum temperature (Tmax) in the Pechi catchment area indicates that there is no significant trend

annually However, there is a significant increasing trend during July, August, and September, as well as during the Southwest monsoon season. shows a positive trend with MK test value 282 and Sens slope value 0. 02727. Similarly, the month of August also gives an MK test value of 363 and a Sens slope value of 0.02467 September MK test gives a value of 345 and Sen's slope gives a value of 0.0333. seasonal analysis for maximum temperature shows a significant increase in trend only for southwest monsoon with Mk test value 273 and Sen's slope value 0.0227

changes in water storage, runoff patterns, and soil moisture levels. Additionally, the local ecosystem, including flora and fauna, may be affected by altered climatic conditions, potentially impacting biodiversity and agricultural practices.

Trend analysis for Relative humidity

The trend analysis for relative humidity in the catchment area shows a significant annual increase, highlighted by a Mann-Kendall (MK) test value of 246 and a Sen's slope of 0.056. This upward trend is particularly pronounced during May, July, and December, and is also evident during the summer season. Specifically, May exhibits an MK value of 249 and a Sen's slope of 0.1572, indicating there is more moisture in the atmosphere, which can lead to a higher potential for rainfall. This could result in changes to the rainfall patterns, such as more frequent or intense precipitation events, particularly during the months and seasons identified. For the catchment area,

this could mean changes in water storage due to increased runoff, impacts on the local ecosystem, and potential challenges for water resource management steep increase. July and December also show significant increases, with MK values of 220 and 241its Sen slope suggest that relative humidity is rising, especially during these months, which could lead to more moisture in the atmosphere and potentially more rainfall. An increasing trend in relative humidity suggests that there is more moisture in the atmosphere, which can lead to a higher potential for rainfall. This could result in changes to the rainfall patterns, such as more frequent or intense precipitation events, particularly during the months and seasons identified. For the catchment area, this could mean changes in water storage due to increased runoff, impacts on the local ecosystem, and potential challenges for water resource management.

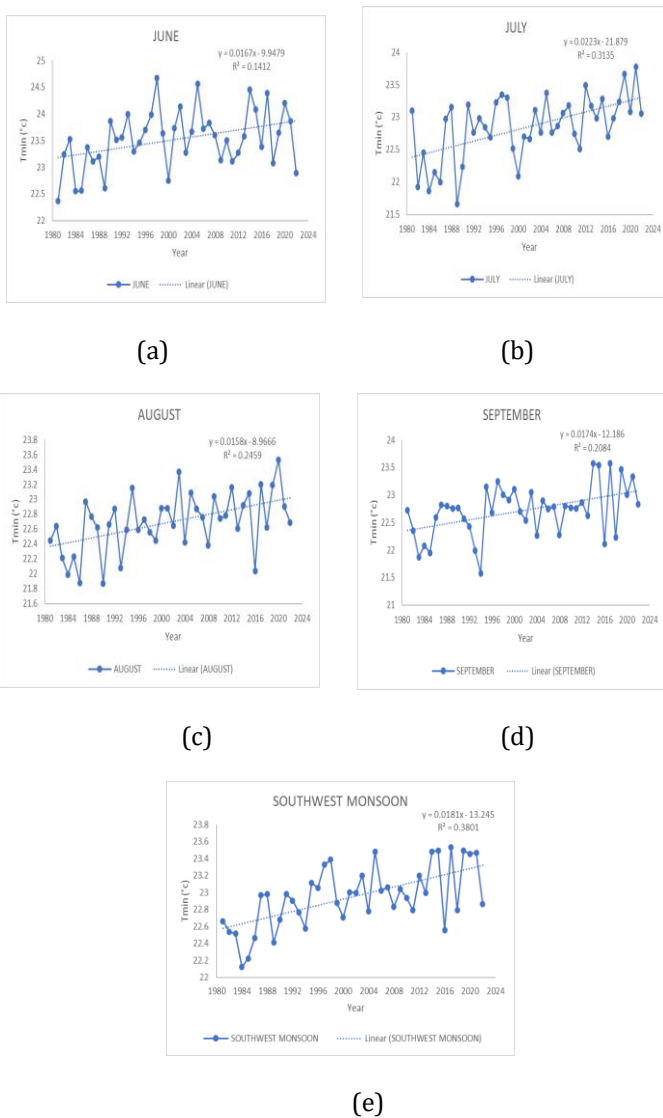
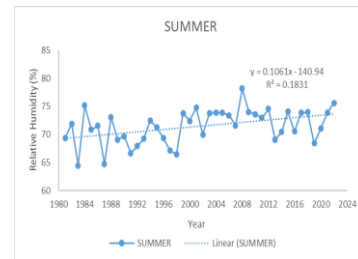


Fig 4 Time series graph of Maximum temperature for (a) July (b) August (c) September (d) Southwest Monsoon

These temperature trends can significantly impact rainfall patterns and the catchment area. Higher minimum and maximum temperatures during the monsoon months can lead to increased evaporation rates, potentially intensifying the hydrological cycle. This can result in more pronounced rainfall The catchment area may experience

Table 3 Trend analysis for relative humidity

TEST	MK TEST VALUE (S)	SEN'S SLOPE VALUE (Q)	TREND
JAN	146	0.1167	N
FEB	-34	-0.0179	N
MAR	112	0.04863	N
APR	142	0.0900	N
MAY	294	0.1572	+S
JUNE	-4	0.000	N
JUL	220	0.0300	+S
AUG	112	0.0124	N
SEPT	122	0.0260	N
OCT	1.5	0.0060	N
NOV	115	0.0060	N
DEC	241	0.1875	+S
ANNUAL	264	0.0562	+S
SUMMER	258	0.09489	+S
SW	181	0.01948	N
NE	86	0.0308	N
WINTER	291	0.05518	N



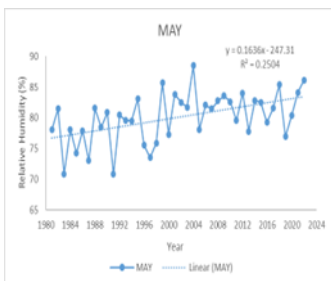
(e)

Fig 5 Time series graph of Relative Humidity for (a) May (b) July(c) December (d) Annual (e) Summer

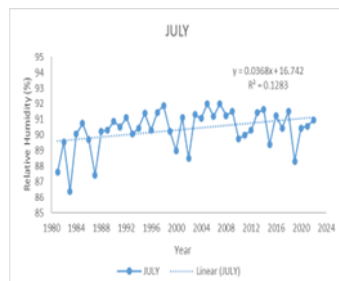
Trend analysis for wind speed

The trend analysis for wind speed from 1983 to 2022 reveals a significant annual decrease, with an MK test value of -361 and a Sen's slope of -0.0113. Monthly trends also show a decrease, particularly from March to August, with the most notable declines in March (MK -309, Sen's slope -0.0197), April (MK -291, Sen's slope -0.0195), July (MK -351, Sen's slope -0.02636), and August (MK -341, Sen's slope -0.01929). Seasonally, the Southwest monsoon and summer seasons exhibit a decreasing trend in wind speed.

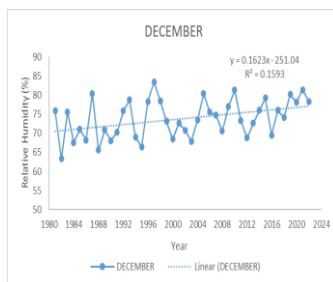
A decrease in wind speed during the monsoon and summer seasons could have several implications for precipitation rates. Lower wind speeds may lead to reduced evaporation rates, potentially increasing relative humidity and the likelihood of precipitation. This could result in more consistent and possibly heavier rainfall during the monsoon season, affecting the hydrology of the catchment area. For agriculture, changes in wind speed and subsequent rainfall could necessitate adjustments in irrigation practices and crop planning. Additionally, the local ecosystem could experience shifts in species distribution and behavior due to changes in water availability and climate conditions.



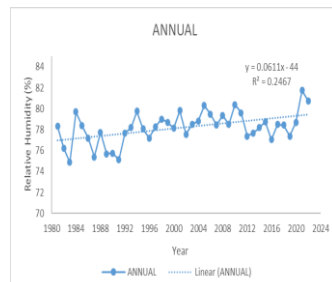
(a)



(b)



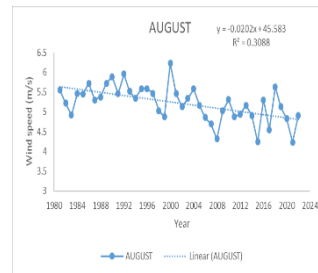
(c)



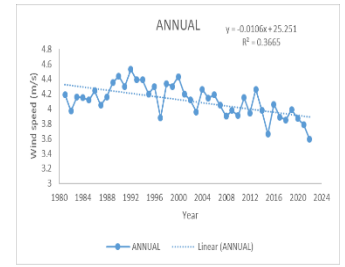
(d)

Table 4 Trend analysis for Wind speed

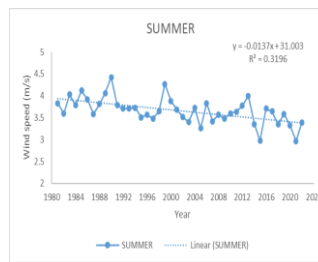
TEST	MK TEST VALUE (S)	SEN'S SLOPE VALUE (Q)	TREND
JAN	23	0	N
FEB	66	0010	N
MAR	-309	0.0024	-S
APR	-291	-0.0197	-S
MAY	-197	-0.0195	-S
JUNE	-351	-351	-S
JUL	-257	-257	-S
AUG	-341	-341	-S
SEPT	-130	-130	N
OCT	-37	-37	N
NOV	-43	-43	N
DEC	84	84	N
ANNUAL	-361	-361	-S
SUMMER	-358	-0.0129	-S
SW	-358	-358	-S
NE	-21	-21	N
WINTER	-37	-37	N



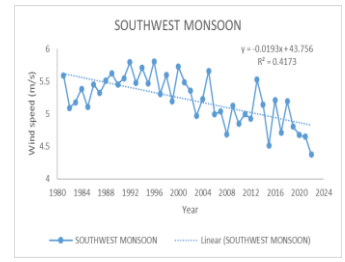
(e)



(f)



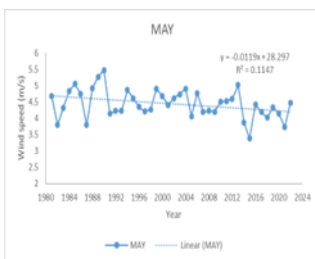
(g)



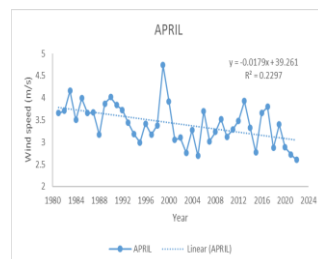
(h)

Fig 5 Time series graph of wind speed for (a) April (b) May (c) June (d) July (e) August (f) Annual (g) Summer (h) Southwest monsoon

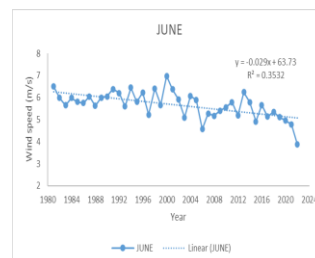
(Note: N = No significant trend, +S = Significant increase in trend, -S = significant decrease in trend, SW= southwest monsoon, NE = northeast monsoon.)



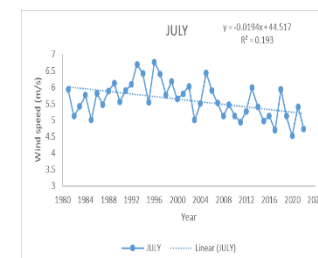
(a)



(b)



(c)



(d)

4. CONCLUSIONS

The study investigated historical rainfall patterns and their climate change impact in the Peechi Dam area. Key findings include an increase in precipitation during specific months, such as May, September, November, the northeast monsoon, winter, and annually. Conversely, June experienced a decreasing trend in precipitation. Temperature trends revealed rising minimum and maximum temperatures during June, July, August, September, and the southwest monsoon. Relative humidity showed an upward trajectory in May, July, December, and for the annual average and summer. Wind speed exhibited a declining pattern during March, April, May, June, July, August, the southwest monsoon, summer, and annually. These trends directly impact the Peechi Dam catchment area. Increased precipitation affects water availability, while rising temperatures and humidity levels impact ecosystems. Efficient reservoir management strategies are crucial to mitigate evaporation losses. In summary, adaptive measures are essential to address dynamic climate shifts in the Peechi Dam area.

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