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Frequency and Trend Analysis of Rainfall Data for Kochi, Kerala, India

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Abstract

Rainfall is a crucial component of many engineering designs, including hydraulic structures, water conservation structures, bridges and culverts, canals, storm water sewers, and road drainage systems. To estimate the relevant input value for crop planning as well as engineering structure design and analysis, a thorough statistical analysis of each region is necessary. The current study includes statistical analysis, namely frequency analysis of Kochi's seasonal rainfall data. Weibull's method is used to evaluate the designed value of rainfall based on daily rainfall data collected over a 20-year period. The mean, standard deviation, and coefficient of variation are computed to estimate the fluctuation in rainfall. The moving average method and probability distribution method are used to analyze the rainfall trend in annual and monthly time series. Over the course of these 20 years, September had the lowest mean monthly rainfall (59.16 mm), while June had the highest mean monthly rainfall (899.13 mm). June had the lowest coefficient of variation (CV), followed by July, while September had the highest coefficient of variation (CV). For the entire time period under consideration, it was found that the monthly rainfall for the selected Kochi was lower in September than in the other months. June and July had higher monthly rainfall than any other month over the whole study period.

Keywords: Frequency analysis: Rainfall variation: Probability distribution: Weibull's formula

Introduction

Rainfall is a vital component of India's hydrological cycle, sustaining ecosystems, water resources, and agriculture. Nearly 80% of the nation's yearly rainfall comes from the southwest monsoon alone, and its seasonal concentration between June and September frequently results in water scarcity and unequal distribution. However, rainfall patterns are becoming progressively disrupted by climate change and rising urbanization, which increases the likelihood of droughts, floods, and agricultural instability. Kerala, which is located on the windward slopes of the Western Ghats, gets about 3000 mm of rain a year, mostly from the northeast and southwest monsoons. Due to its location and urban growth, Kochi, a heavily populated coastal city in Kerala, is especially susceptible to monsoon fluctuation. Planning for sustainable water resources, watershed management, and adapting to climate change all depend on an understanding of Kochi's particular rainfall patterns. This study uses statistical methods like Sen's slope estimator and the Mann-Kendall test to examine seasonal rainfall trends in Kochi between 2001 and 2020. In order to evaluate rainfall reliability, which is essential for infrastructure design and agricultural decision-making, it also integrates frequency analysis.

Significant temporal and spatial changes in rainfall patterns have been reported by numerous studies conducted throughout India. According to Rajeevan et al. (2008), inter-annual and inter-decadal variability as well as Indian Ocean SST anomalies are responsible for the 6% annual rise in extreme rainfall occurrences over central India. Singh et al. (2008) discovered a 2–19% increase in relative humidity and annual rainfall in nine river basins, with significant increases in rainfall pre and post the monsoon, a decrease in winter rainfall, and fewer rainy days, especially in the Mahanadi basin. Numerous studies carried out across India have found significant temporal and spatial changes in rainfall patterns. According to Kothawale et al. (2010), there has been a general increase in hot days and nights throughout India, along with a decrease in cold events and a decrease in seasonal variability. While monsoon rainfall declined and off-season rainfall increased, Kumar et al. (2010) observed varied monthly trends and no significant national trend after analyzing 135 years of data from 30 subdivisions. Using spectral analysis, Joshi and Pandey (2011) revealed Madden-Julian oscillations and short-term rainfall cycles (10–50 days), with interdecadal variability linked to Atlantic and Pacific phases.

In the Andaman and Nicobar Islands, Kumar et al. (2012) found a decrease in annual rainfall and rainy days, a rise in heavy rain events, and a reduction in cyclonic disturbances. According to Duhan and Pandey (2013), Madhya Pradesh experienced a −2.59% decline in annual rainfall, with a key change point in 1978 and different patterns in the western and eastern parts of the state. In Rajasthan's urban centers, Pingale et al. (2014) observed mixed rainfall trends, with significant annual and monsoon rainfall declines, slight increases in non-monsoon rainfall, and consistent warming. According to Taxak et al. (2014), the Wainganga basin experienced an 8.45% decline in annual rainfall, with stable pre- and post-monsoon rainfall and shifts from increasing to decreasing trends post 1948. When estimating one-day maximum rainfall using probability distributions, Kumar and Bhardwaj (2015) found that Log Pearson Type-III was the most appropriate for infrastructure design.

In Kerala, Thomas and Prasannakumar (2016) observed decreasing southwest monsoon rainfall and increasing off-season rainfall, with ENSO-linked irregularity and a higher risk of drought. Weibull and Chi-squared models were found to be the most appropriate when Kumar et al. (2017) examined rainfall distributions in Uttarakhand, where 82% of rainfall occurs during the monsoon. According to Sai and Joseph (2018), Pattambi exhibits seasonal variability, with notable increases in summer rainfall and decreases in monsoon and yearly rainfall. Significant rainfall trends in West Bengal were found by Kundu and Mondal (2019), with notable regional differences and turning points in 1952, 1956, and 1967. Malik et al. (2020) used a variety of statistical techniques to examine rainfall in Uttarakhand, mapping geographical variability for climate risk assessment and identifying both positive and negative trends. According to Venkatesh et al. (2021), severe rainfall occurrences above 50 mm decreased in both the southern and northern regions, whereas rainfall and rainy days decreased in the central and coastal Western Ghats. Mehta et al. (2022) discovered that while pre-monsoon and seasonal rainfall exhibited growing trends, suggesting climatic change, July–October rainfall in Surat significantly decreased, impacting monsoon seasons. In line with this context, the present study proposes to study rainfall variation of Kochi by using various statistical parameters.

Materials and Methods

Study Area

Kochi is located on India's southwest coast (9°58′ N, 76°13′ E) and covers 94.88 square kilometers with a tropical monsoon climate (Am). It experiences considerable humidity and little variance in temperature (23–31°C) because of its equatorial and coastal position (Fig. 1). The geographic area has frequent southwest monsoon rains (June–September) and moderate northeast monsoon rains (October–

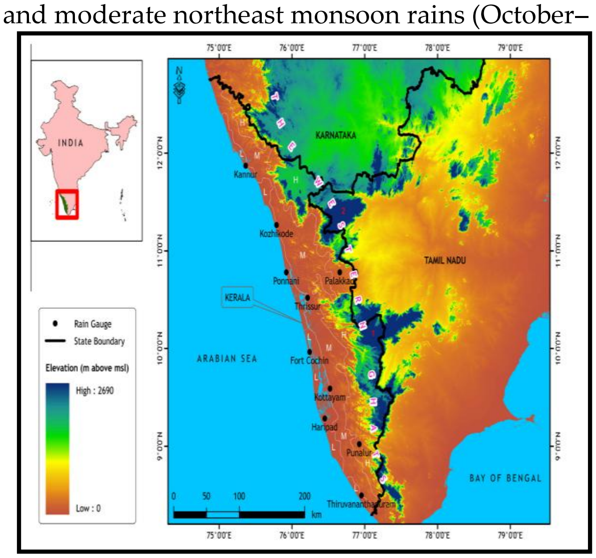

Fig.1 Location of Kerala State (highlighted in the index

map) India

December), average 3,014.9 mm yearly throughout 124 rainy days. Brown sands, alluvium, and aquatic marine kinds are among the soils found next to wetlands.

Data Collection and Analysis

The study focuses on Kochi, a coastal Kerala city with 2.12 million populations according to the 2011 Census. It is known for its diverse religious and cultural demography, balanced gender ratio, and high literacy rate of 96.5%. Kochi experiences a tropical monsoon climate with high humidity (70–90%) and temperatures ranging 23°C and 33°C. It receives approximately ~3,054 mm of rain on average annually, with the southwest monsoon (June–September) comprising 80% of this total and the winter and summer months experiencing a smaller amount. Rice, coconut, rubber, spices, fruits, vegetables, and other products are grown in the nearby rural areas due to the region's red, laterite, alluvial, and coastal soils. NASA's POWER data portal, accessible via https://power.larc.nasa.gov/data-access-viewer, provides precipitation data from 2001 to 2020. For statistical analysis, including conditional formulations, Microsoft Excel was used. Trend variability and mean rainfall patterns were analyzed using daily rainfall data. Each station's monthly rainfall series were calculated and averaged to generate district-level data, and then aggregated using area-weighted values to generate the state-level rainfall series.

a. Rainfall Variation: - Agriculture is significantly affected by variations in rainfall, which have an influence on crop success and irrigation demands, especially throughout the monsoon. Statistical measures such as mean, standard deviation, and coefficient of variation were used to assess the impact.

b. Mean (X_m):-The mean, which is calculated by dividing the sum of all values by their amount, is a measure of central tendency.

$$X_m = \frac{\sum_{i=1}^{N} X_i}{N} \qquad \dots (1)$$

where, X_m = Mean, X_i = Variables, N = Total number of variables

c. Standard Deviation (σ):-Standard deviation measures dispersion, giving more weight to extreme values than those near the mean.

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}(X_i - X_m)^2}{N-1}} \qquad \dots (2)$$

where, σ = Standard Deviation, X_i = Variables, X_m = Mean, N = Total number of variables

d. Coefficient of Variation (CV):- The coefficient of variation expresses relative variability by representing the standard deviation as a percentage of the mean.

$$CV = \frac{\sigma}{X_m} \times 100 \qquad \dots (3)$$

where, CV = Coefficient of Variation, σ = Standard Deviation, X_m = Mean

e. Hazen's Formula :-

$$P = (m-0.5) / N \qquad \dots (4)$$

where, P = probability of occurrence of rainfall, m = position of that rainfall, N = total number of years

f. Recurrence Interval (return period):- Recurrence interval is the estimated time between events of equal or greater rainfall.

$$T = \frac{1}{P} \qquad \dots (5)$$

where, T = return period, P = probability of occurrence of rainfall

g. Probability Analysis: - Hazen's formula and other statistical distributions and historical data are used in probability analysis to predict future rainfall events. The return period (TX) or probability of exceedance (PX) represents acceptable risk and potential damage for design purposes. Based on expected frequency, rainfall is classified for management as either low (PX = 80%), normal (PX = 50%), or humid (PX = 20%). Longer time series increase accuracy in frequency analysis, which is predicated on the consistency of past and future data. In most instances, a 30-year dataset is sufficient, but additional records may be required for severe event analysis.

Results and Discussion

Temperature, humidity, solar radiation, precipitation, and other variables are frequently used in climate change studies. Such variation makes expected adaptation measures challenging in areas like Kochi, where rainfall is high and erratic. Changes in rainfall patterns placed food and environmental security at risk, making rain-fed agriculture extremely vulnerable. Statistical analysis of rainfall data was performed using mean for central tendency and standard deviation and coefficient of variation for dispersion, as shown in the Table 2. Rainfall data for Kochi, based on a single station over 20 years, showed the highest mean monthly rainfall in June (494.2 mm) and the lowest in September (293.5 mm). The average seasonal rainfall was 386.8 mm, ranging from 173.8 mm to 711.3 mm.

Monthly mean, standard deviation, and coefficient of variation are detailed in Table 1.

Table 1 Monthly mean, standard deviation, and coefficient of variation.

Time Series	Mean Rainfall (mm)	Max. Rainfall (mm)	Min. Rainfall (mm)	S.D.	C.V.
June	494.2	899.1	306.7	143.1	28.9
July	438.7	752.2	216.3	149.5	34.1
August	349.7	692.3	157.9	156.1	44.6
September	293.5	593.5	59.2	148	50.4
October	357.7	619.4	128.9	153.5	42.9
Seasonal Average	386.8	711.3	173.8	150	40.2

Table 2 Statistical analysis of rainfall data.

Year	June	July	August	September	October
2001	678.9	372.6	157.9	273.7	404
2002	391.5	216.3	512.4	147.1	479.1
2003	495	389.1	318	59.2	515
2004	443.9	314.2	264.7	237.5	619.4
2005	623.8	494.2	208.5	364.1	466.3
2006	538.2	448	424.2	496.1	554
2007	593.1	752.2	342.4	593.5	380.7
2008	356.1	411.1	278.9	374.9	347.7
2009	513.8	624.3	175.3	320.2	128.9
2010	595.9	491	251.7	339.9	531.7
2011	494.8	356.9	367.4	316.2	163.5
2012	307.9	223.9	339.5	176.1	211.8
2013	899.1	579.9	277.9	200.9	213.1
2014	306.7	477	654.6	228.9	324.2
2015	415.2	231.2	178.8	264	277.2
2016	477.8	431.3	182.9	60.6	143.8
2017	457.9	308.1	379.6	385.7	239.8
2018	566.7	707	547.3	99.6	329.2
2019	329	423.8	692.3	429.8	571
2020	398.4	522.2	439.2	502.6	254.2
Mean	494.2	438.7	349.7	293.5	357.7
Max.	899.1	752.2	692.3	593.5	619.4
Min.	306.7	216.3	157.9	59.2	128.9
S.D.	143.1	149.5	156.1	148	153.5
C.V.	28.9	34.1	44.6	50.4	42.9

Return period of various rainfall amount for the month of June, July, August, September and October from year 2001 to 2020. Figure 2 shows June rainfall from 2001 to 2020, with a maximum of 899.1 mm (return period: 40 years) and a minimum of 306.7 mm (return period: 1 year). Similarly, this was calculated for upto October month.

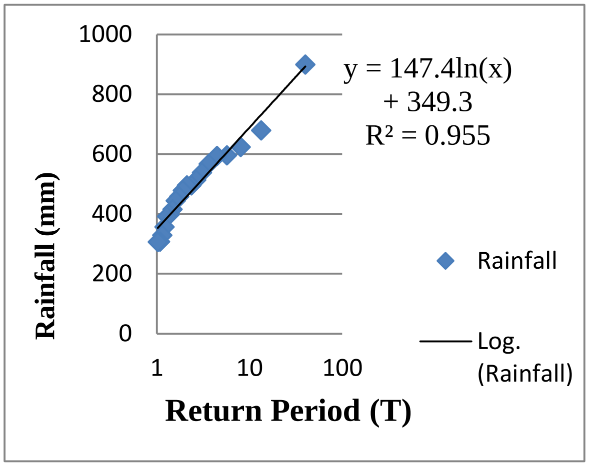

Fig. 2 Return period of various rainfall amount for month June

June regularly records the most rainfall compared to July, August, September, and October below in Table 3, according to rainfall estimates made using graphical regression for return periods of 20, 35, and 50 years. There is a definite upward trend in rainfall depth with longer design return periods, according to the examination of return-period rainfall from June to October. The total seasonal rainfall rises by around 20% between 20- and 50-year events, from 3,448.2 mm at the 20-year return period to 3,869.2 mm at the 35-year return period and then to 4,137.7 mm at the 50-year return period.

All months have higher rainfall during longer return times, according to a month-by-month analysis; the percentage increase varies from roughly 17% in June to nearly 23% in September. This implies that during the late monsoon season, extreme rainfall occurrences become more intense. Late-season months like August and September exhibit a proportionally bigger rise in rainfall for higher return durations, indicating a shift towards heavier late-monsoon events, even if June continues to be the wettest month and September the driest in absolute terms.

These modifications have significant planning and hydrological ramifications. Because inflow peaks are projected to move between August and September, reservoir operations may need a larger late-season flood cushion. In a similar vein, increased rainfall in the later stages of the monsoon must be taken into consideration for urban drainage, road networks, and flood protection infrastructure. In addition to suggesting more saturated fields, a higher risk of waterlogging, and possibly postponed agricultural operations, the heavier rainfall in October also suggests a delayed withdrawal of monsoon conditions. This implies that field drainage needs might rise while post-monsoon irrigation demand might somewhat decrease in terms of irrigation planning. From the standpoint of disaster management, the increased tail-end rainfall suggests that reservoir-spillway readiness and flood preparedness must continue past September. The rainfall pattern highlights the growing importance of designing water resources infrastructure and cropping systems to accommodate late-season extreme rainfall events and a longer active monsoon window.

Table 3 Predication of rainfall for return period of 20, 35 and 50 years

Return Period (Years) / Month	20	35	50
	Predicted Rainfall (mm)		
June	790.9	873.4	925.9
July	741.2	825.3	878.9
August	673	762.9	820.3
September	587.1	668.7	720.8
October	656	738.9	791.8

Rainfall depth gradually drops from the highest rated event (Rank 1) to the lowest (Rank 20), according to the rainfall frequency study for June, July, and August. This reflects normal diminishing extremes during return periods. The highest recorded rainfall in June is approximately 899 mm at a 40% probability (T = 3 years), progressively declining to approximately 307 mm at a 1% probability (T ≈ 100 years). Similar trends may be seen in July, with peak rainfall for the highest rank being close to 752 mm and falling to about 216 mm at the lowest probability (Table 4). August has relatively lower rainfall totals, with the most frequent extreme occurring at around 692 mm and the rarest event occurring at about 158 mm. The monthly rainfall intensity gradually decreases as the monsoon advances, with June typically showing the largest rainfall extremes, followed by July and ultimately August. September typically received the least amount of rainfall, while June and July recorded the most, according to monthly rainfall trends for Kochi, which were calculated using the five-year moving average method over a 20-year period in Figs. 3 and 5 below. With the exception of August, which has a noticeable rising trend, time series analysis for annual and monthly data (June to October) reveals a major declining trend in rainfall for every month.

Table 4 Probabilities of exceedance for June, July and August

	June			July			August		
Rank (m)	Probability Percentage (%)	Return Period (T)	Rainfall	Probability Percentage (%)	Return Period (T)	Rainfall	Probability Percentage (%)	Return Period (T)	Rainfall
1	3	40	899.1	3	40	752.2	3	40	692.3
2	8	13.3	678.9	8	13.3	707	8	13.3	654.6
3	13	8	623.8	13	8	624.3	13	8	547.3
4	17	5.7	595.9	17	5.7	579.9	17	5.7	512.4
5	23	4.4	593.1	23	4.4	522.2	23	4.4	439.2
6	27	3.6	566.7	27	3.6	494.2	27	3.6	424.2
7	33	3.1	538.2	33	3.1	491	33	3.1	379.6
8	37	2.7	513.8	37	2.7	477	37	2.7	367.4
9	43	2.4	495	43	2.4	448	43	2.4	342.4
10	48	2.1	494.8	48	2.1	431.3	48	2.1	339.5
11	52	1.9	477.8	52	1.9	423.8	52	1.9	318
12	58	1.7	457.9	58	1.7	411.1	58	1.7	278.9
13	63	1.6	443.9	63	1.6	389.1	63	1.6	277.9
14	68	1.5	415.2	68	1.5	372.6	68	1.5	264.7
15	73	1.4	398.4	73	1.4	356.9	73	1.4	251.7
16	77	1.3	391.5	77	1.3	314.2	77	1.3	208.5
17	83	1.2	356.1	83	1.2	308.1	83	1.2	182.9
18	88	1.1	329	88	1.1	231.2	88	1.1	178.8
19	93	1.1	307.9	93	1.1	223.9	93	1.1	175.3
20	98	1	306.7	98	1	216.3	98	1	157.9

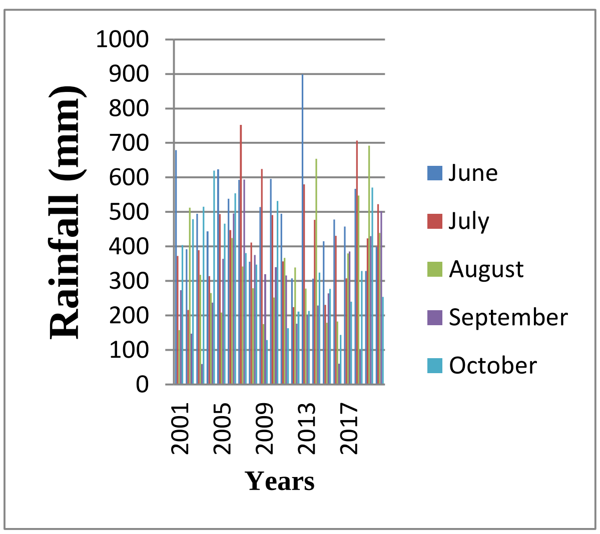

Fig. 3 Rainfall trend from June to October

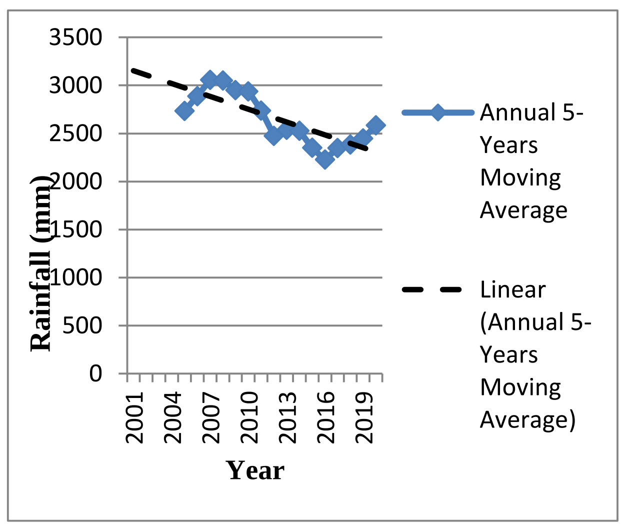

Fig. 4 Annual time series analysis

Conclusions

This study evaluated rainfall variability and trends in Kochi using daily data, Hazen's plotting position formula, and a 5-year moving average. Seasonal rainfall totals were derived from daily values, and key statistical parameters (mean, standard deviation, and coefficient of variation) were computed to understand variability. Results showed that June and July receive the highest rainfall with the lowest variability, while September exhibited the highest coefficient of variation, indicating greater fluctuation during the late monsoon period. Frequency analysis indicated that the maximum observed rainfall corresponds to a return period of about 40 years, and predicted rainfall for 20-, 35-, and 50-year return periods consistently showed June as the wettest month, followed by July, August, October, and September. Probability of exceedance values were also estimated for monsoon months to support hydrological design applications. Trend analysis revealed that while August showed an increasing rainfall trend, June, July, September, and October exhibited decreasing trends, and overall annual rainfall demonstrated a significant decline, suggesting a long-term reduction in rainfall over Kochi and highlighting the importance of climate-adaptive water resource planning.

Data Availability Statement

The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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