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Comparative Analysis of Flood Estimation using Log-Pearson Type III and Gumbel Max Models in the Cauvery River, India

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Abstract:- Flooding is one of the most destructive global disasters in scale, geographical extent, property and life loss, and population displacement. The Cauvery River is one of the flood vulnerable rivers in the Peninsular region of India. At-site flood frequency analysis is performed using flow data obtained at the Kodumudi gauged site in the Cauvery River. Log Pearson Type III and Gumbel Max distribution models are used in the present study to estimate peak floods for different return periods. The Central Water Commission provides the annual maximum discharge for the Kodumudi gauged site over 39 years (1980-2018). The goodness of fit test employing the Kolmogorov-Smirnov and Anderson-Darling tests, reveals that Log-Pearson Type III best estimates peak floods in the study area. The peak floods predicted by Log-Pearson Type III for return periods 2, 5, 10, 25, 50, 100, 200, and 500 years are approximately 929, 1886, 2998, 5303, 8002, 11929, 17633, and 29228 cumecs. Hydraulic structures can be designed in the region based on 100-year flood. The present research could help with flooding management approaches, vulnerability analyses, and hydraulic structure design in the study region.

***Keywords**:- Cauvery River; Flood Frequency Analysis; Goodness of Fit Test; Gumbel Max; Log-Pearson Type III.*

I. INTRODUCTION

Floods are one of the most destructive types of natural disasters, with the potential to result in large numbers of fatalities and financial losses [1]. When a body of water rises to the point where it breaches artificial levees or its natural banks, flooding happens and the surrounding area is submerged [2]. Floods are the most prevalent disasters to cause both human and financial losses in the heavily populated South Asian region [3]. India remains one of the most extremely suffering nations in Asia because of the floods. A total of 40 million hectares, or 12% of the total geographical land area, is subjected to different types of flooding [4]. Despite large investments and constant attempts to control flooding, India continues to experience socioeconomic losses and fatalities from flooding. The flood magnitudes and frequencies in the peninsular rivers are generally lower than those in the north and northeastern rivers of the Indian subcontinent. This is because, in comparison to the northern Indian region, fewer cyclonic disturbances occur in this area during each monsoon season. The lee side of the Western Ghats is where the majority of river basins originate. However, every year during the monsoon season, flood events happen in peninsular rivers like the Cauvery River.

To protect people and property from flooding, it is necessary to implement both structural and non-structural measures in areas that are vulnerable to flooding. Understanding the extent and frequency of flooding in the area will help to control flood events. Accurate data and knowledge of the frequency and severity of flood occurrences in the area are necessary for the design of structures like dams, bridges, and culverts in areas susceptible to flooding [5].

Flood estimation is necessary for flood hazard zoning for different flood-related studies [6]. Flood frequency analysis is therefore necessary for the analysis, forecasting, and zoning of areas susceptible to flooding. Applying a probability model to a sample of an annual flood peak observed for a region over a predetermined period is known as flood frequency analysis [7]. Extreme events over a long return period can be predicted by the model parameters. As a result, using the results of the flood frequency analysis, an extreme event within a large recurrence interval can be predicted. Thus, determining the estimated flood magnitude for a given return period is the main goal of a flood frequency analysis [8].

The return period represents a measure of the length of the interval between events of similar magnitudes. Hydraulic structures like spillways, dams, weirs, and bridges require precise estimation of flood peaks at the intended return period for design, construction, and maintenance. Flood estimation therefore contributes to the reduction of vulnerability caused by flooding. Various flood frequency analysis techniques are employed to study flood frequency using two types of time series discharge data: annual maximum series and partial duration series [9]. A defined threshold is used to select and tabulate the yearly peak discharge and gauge level in the partial duration series, whereas the yearly maximum discharge and gauge level values are recorded and tabulated in the annual maximum series [10]. Floods with a higher magnitude occur less

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frequently than those with a lower magnitude [11]. Nevertheless, floods with a return period of no more than five years, in particular, cannot be predicted using annual maximum series [12]. Peak discharges are usually used to analyse the frequency of floods; however, rainfall data series are also utilised when a watershed lacks a long history of discharge gauge data [8]. An acceptable duration for flood frequency analysis is 30 years of continuous Annual Maximum Series (AMS) data. Flood frequency analysis can be performed using two distinct approaches: (i) at-site analyses and (ii) regional analyses. The most direct approach, which needs a fair amount of streamflow data that has been recorded over an extended period, is at-site flood frequency analysis. Hydrologists commonly use regional flood frequency analysis to derive reliable estimates of flood occurrence and magnitude for ungauged catchments [13]. However, at-site flood frequency analysis can offer more precise information for the design of hydraulic structures for a specific and accurate prediction of peak floods. Hydrological events are highly uncertain, resulting in statistically fit distribution models a more accurate method of determining peak floods than deterministic, physical-based approaches [14]. There is not a single magnitude-frequency probability distribution technique that is accepted universally. It has remained difficult for many hydrologists to select the best parameter estimation method and probability distribution model. The normal, log-normal (LN), generalised extreme value (GEV), Gumbel's extreme value (EV-I), Weibull, Log-Pearson type III, Pearson type III, or gamma (3-parameter) distributions are among the most commonly employed probability distributions for fitting the flood data series. In India, the study of flood frequency in various river catchments is generally carried out using the Gumbel Max model and Log Pearson Type III. The Gumbel Max distribution model is applied by Mandal et al. [15] in the lower Ganga basin; Gulap & Gitika [16] in the Lohit River, Assam; and Bhagat [17] in the lower Mahi Basin. Vivekanandan [18] attempted to apply the six Gumbel distribution parameter estimation techniques to model the seasonal and yearly rainfall of the Krishna and Godavari River basins. Vivekanandan [19] applied the Gumbel model to estimate the peak flood runoff for Yamuna River ungauged catchments. In the Indian upper Krishna River basin, Sathe et al. [20] applied the Log-Pearson Type III distribution. The effectiveness of the Log Pearson type III probability distribution was assessed by Pawar & Hire [21] for flood series data from four locations along the Mahi River and its tributaries. Bhat et al. [2] reported that Log Pearson type III is suitable for the flood frequency analysis of the Jhelum River in the Kashmir valley. Kumar [22] conducted a flood frequency analysis in the Rapti River basin using the Gumbel Extreme Value-1 and Log Pearson Type III methods. Madhusudhan et al. [23] attempt to use the Gumbel extreme value, Log Pearson III, and Lognormal to determine the flood magnitude at Kabini dam, Cauvery River, for different return periods. Based on Gumbel Extreme Value Type I and Log Pearson Type III, Anwat et al. [24] used annual maximum series data to determine the size and frequency of floods in the Damanganga Basin. To determine the nature of flood frequency in the Mayurakshi River basin, Islam & Sarkar [25] developed the Gumbel method and Log-Pearson Type III. A limited study that focused on the flood frequency estimation in the Cauvery River is found. The present study focuses on at-site flood frequency analyses at the Kodumudi gauge site in the Cauvery River basin. The main aim of the present study is to estimate the peak floods for return periods 2, 5, 10, 25, 50, 100, 200, 300, and 500 years based on the Gumbel Max distribution model and Log Pearson III and to test which distribution model is best fit in the observed data recorded at the Kodumudi gauge in the Cauvery River.

II. MATERIAL AND METHODS

A. Study Area:

The Cauvery River rises in the Brahmagiri hills in the Western Ghats region of South India. It flows through the states of Kerala, Karnataka, Tamil Nadu, and the Union Territory of Pondicherry. Its latitudes range from 10°05' N to 13°0' N and its longitudes from 75°30' E to 79°45' E (Fig. 1). A total of 81,155 km^2, or 2.7% of the total land area of India, is being drained by the Cauvery River [26]. Its maximum width is 245 km, and its maximum length is approximately 560 km. The daily maximum and minimum temperatures in the Cauvery River basin vary from 19.5 to 33.7°C and 9.1 to 25.2°C, respectively. The Cauvery River basin experiences a tropical climate [27].

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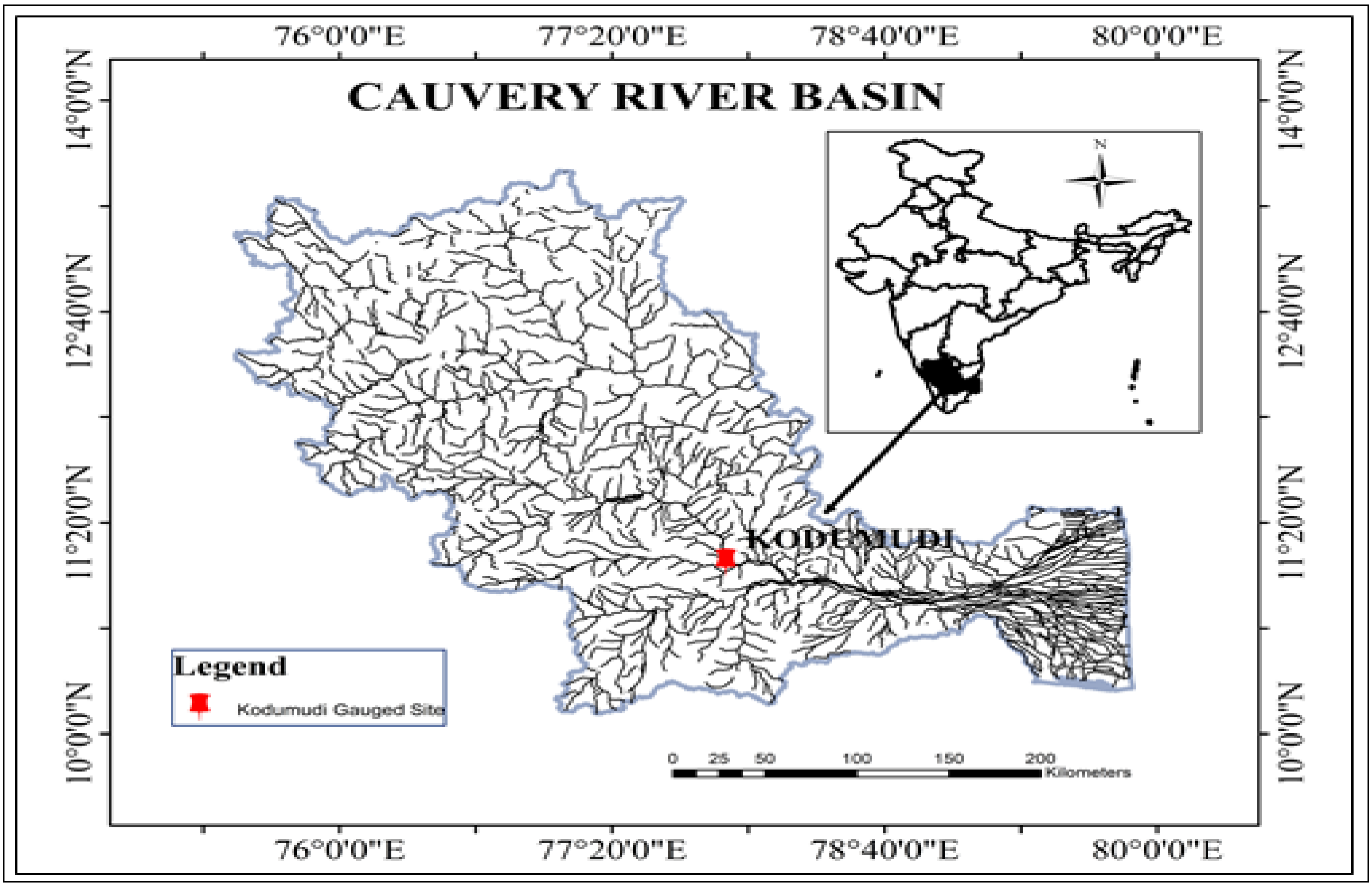

Fig. 1 Map of the Cauvery Basin and Kodumudi Gauged Site

B. Data:

The India-Water Resource Information System (India-WRIS) portal provides daily flow data for the Cauvery River. The Central Water Commission, Government of India, State Water Commissions, and the India Meteorological Department record data in a standardized national GIS framework for the India-WRIS, a single window for hydro-metrological database management in time and space, which is managed by the National Water Informatics Centre (NWIC) [29][30]. The Cauvery basin has a limited number of gauges where flow data is available for a longer duration. Therefore, the Kodumudi gauged site in the Cauvery River is selected for the analysis according to data availability. Annual Maximum Series data for Kodumudi is collected for the period 1980–2018 from the India-WRIS portal.

C. Methodology:

The present study analyses the annual maximum discharge of the river for 39 years (1980–2018) and estimates the peak floods for the 2, 5, 10, 25, 50, 100, 200, and 500-year return periods by conducting at-site flood frequency analysis using Log Pearson Type III probability distribution models and Gumbel Max or Gumbel's extreme value. Return period (T) is a regularly used parameter to define the intended flood and is the inverse function of probability (P).

➢ *Probability (P) of an Event is Expressed as:*

$$P = \frac{m}{(N+1)} \quad \text{..................(1)}$$

Where
N = number of events (years),
m = order number of the event.

- *Gumbel's Method:*

Gumbel [31] introduced the extreme value distribution, which is also known as Gumbel's distribution or Gumbel Maximum. It is widely used in hydrologic and meteorological studies to predict flood peaks, maximum rainfall, and other meteorological data. The largest flood flow that occurs in a given year, known as the annual maximum flood, is analyzed using the Gumbel method. For discharge data that is less than 50 years old, the Gumbel extreme value distribution also works well [32]. According to this theory of extreme occurrences, the probability of an event happening is greater than or equal to a certain number, x_0 [33].

The following describes the step-by-step process for determining the flood frequency using Gumbel extreme value distribution model:

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- Step 1: From 1980 to 2018, the total annual discharge is tallied in descending order and designated with an order number ranging from 1 to 39.
- Step 2: The mean (x̄) and standard deviation (σ_x) of the total yearly discharge flood data for N years are calculated as follows:

$$\bar{X} = \frac{1}{N}\sum_{i=1}^{N} X_i \quad \text{.....(2)}$$

$$\sigma_x = \sqrt{\frac{1}{(N-1)}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad \text{.....(3)}$$

- Step 3: From Gumbel's extreme value distribution table, the values of (Y_n) and S_n are obtained depending on the sample size. Referring to the Gumbel distribution table, for N = 39, (Y_n) and Sn values are 0.5430 and 1.1388 respectively.

- Step 4: The flood frequency function (K) is computed using table values of (Y_n) and S_n after which the reduced variate (Y_t) is computed from the specified return period T as follows:

$$Y_T = -\left[ln.\,ln\left(\frac{T}{T-1}\right)\right] \quad \text{.....(4)}$$

$$K = \frac{Y_T - \overline{Y_n}}{S_n} \quad \text{.....(5)}$$

- Step 5: The magnitude (X_t) of the flood for the return period (T) of 2, 5, 10, 25, 50, 100, 200 and 500 years is calculated using Gumbel's equation:

$$X_T = \bar{X} + K.\sigma_x \quad \text{.....(6)}$$

- *Log Pearson Type III:*

With a logarithmic transformation of the variables, Log Pearson Type III is a three-parameter gamma function [34]. The technique varies from other distribution models due to the fact it describes the distribution using three parameters: the mean, the standard deviation, and the coefficient of skewness. This method involves first transforming the variate into logarithmic form (base 10), after which the data has been transformed and examined. To estimate peak discharge for a given return period, the mean logarithm, the standard deviation of the logarithm, and the skewness coefficient are calculated [6]. The log-Pearson Type III distribution has the drawback of having multiple possible shapes, involving the establishment of a distinct probability scale for each shape [35].

➢ *Steps for Log Pearson Type III Frequency Analysis:*

- Step 1: The annual maximum series of discharges is converted into logarithms.
- Step 2: The Mean ($\bar{X}$), standard deviation (σ_n) and skewness coefficient (G) are computed using the following equations:

$$\bar{X} = \frac{1}{N}\sum_{i=1}^{N} log\,(X_i) \quad \text{.....(7)}$$

$$\sigma_x = \sqrt{\frac{1}{(N-1)}\sum_{i=1}^{n}(log\,x_i - log\,\bar{x})^2} \quad \text{.....(8)}$$

$$G\,(\text{skewness}) = \frac{\sum_{i=1}^{N}(X_i - \bar{X})^3}{(N-1).(\sigma_x)^3} \quad \text{.....(9)}$$

- Step 3: The frequency factor K of the return periods 2, 5, 10, 25, 50, 100, 200 and 500 years are determined from the Log Pearson Type III Distribution table based on the skewness coefficient value.
- Step 4: The logarithms of flood discharges, Log (X_i), for the different return periods are computed using the following equation:

$$Log\,X_i = \bar{X} + K_T.\sigma_x \quad \text{.....(10)}$$

Where X and σ_x are the mean and standard deviation of the logarithms of discharges, K_t is the frequency factor based on the skewness coefficients of the different return periods.

- Step 5: The expected flood discharge is computed by the anti-logarithms of Log X_i.

➢ *Goodness of Fit (GoF) Test:*

The goodness of fit tests Ais used in flood frequency analysis to help choose a better probability distribution model rather than rule out alternative models. The Anderson-Darling (A-D) and Kolmogorov-Smirnov (K-S) tests are used to assess how well the chosen model fits the observed data. The maximum vertical difference between the observed and hypothetical cumulative distribution functions is compared using the nonparametric K-S statistic. The observed and expected cumulative distribution functions (CDFs) are compared using the A-D test. Compared to the K-S test, the A-D test method gives the distribution tails more weight. Since the Chi-square test is not a high-power quantitative method of goodness-of-fit [32], it is excluded in some studies [36][37]. The GoF tests used to obtain the best-fit distribution model are carried out using Easyfit software (https://mathwave.com/).

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III. RESULT AND DISCUSSION

Flood frequency analysis is a statistical tool for studying hydrological behavior of rivers. The analysis computes statistical data, including mean values, standard deviations, and skewness, using observed annual peak flow discharge data. Frequency distributions are constructed using these statistical characteristics, which show the probability of different discharges as a function of exceedance probability. A flood frequency analysis is carried out in Kodumudi gauge located in the Cauvery River using Gimbel's extreme value distribution model and the Log Pearson Type III model. Annual maximum series data of 39 years duration at the gauge is used in the flood estimation. The graph of annual maximum series data at the Kodumudi gauge is shown in Fig. 2. The graph shows that there are peak floods in 1980, 2000, 2005, 2007, 2013, and 2018.

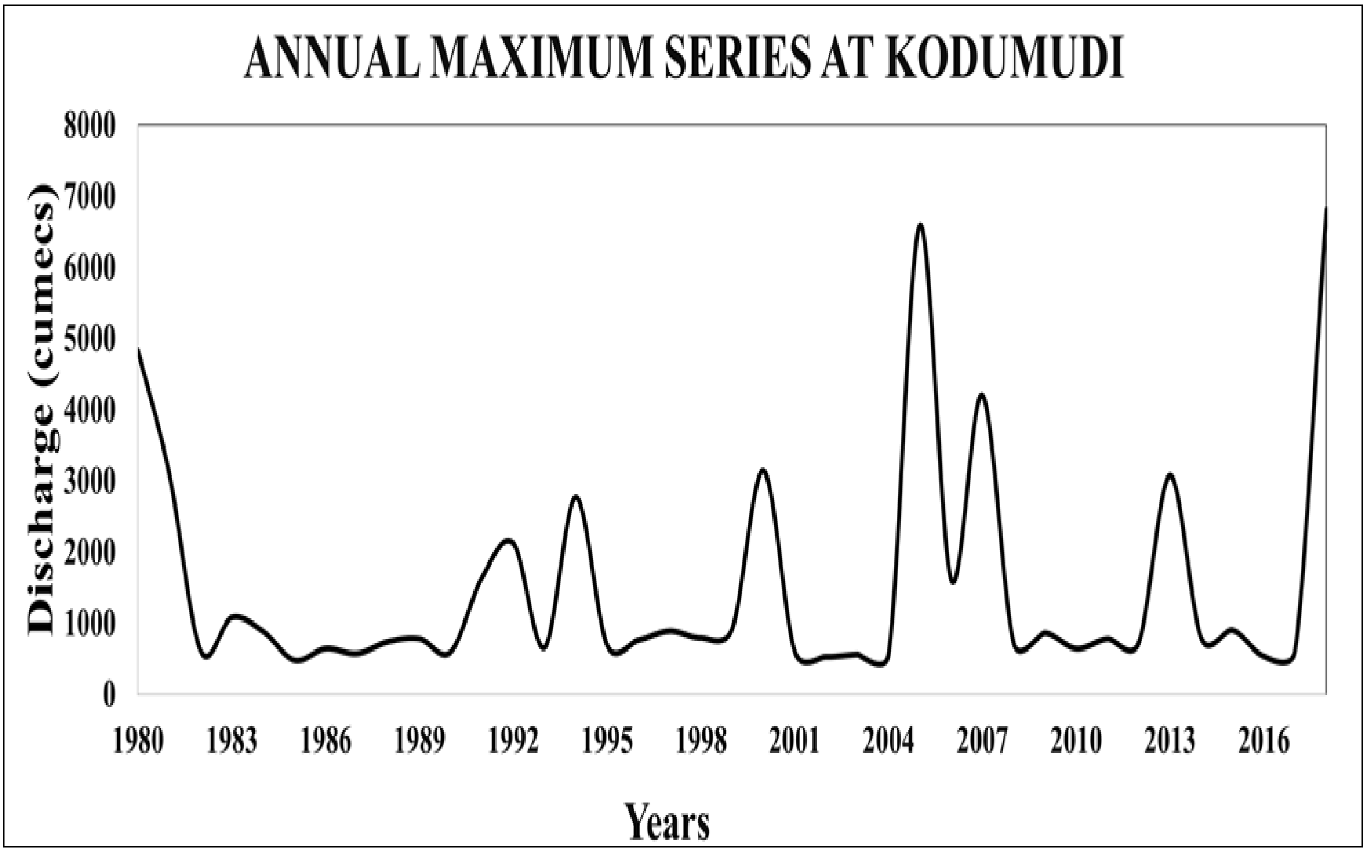

Fig 2: Annual Maximum Series of Discharge (Cumecs) at Kodumudi

The maximum peak flood is recorded at 6808 cumecs in 2018, and the minimum discharge is recorded at 480.2 cumecs in 1985. The mean value and standard deviation of the flood data are 1534.22 cumecs and 1622.54 cumecs, respectively. The coefficient of variation of the data is 105%, which indicates that there is large variation in the data series (Table 1). The high level of variation obtained may result from changes in the volume of rainfall and the number of rainy days. [28] found that the climate in the Cauvery basin is dry except in monsoon months, with large variability in rainfall and temperature across the basin.

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Table 1: Computational Table of Gumbel Extreme Value and Log Pearson Type III

Year	AMS (X_i)	Descending order (X_i)	Rank	P	T	Reduced Variate (Y_t)	Log (X_i)
1980	4828.7	6808	1	0.03	40.00	3.676247	3.83302
1981	3100	6584.92	2	0.05	20.00	2.970195	3.818551
1982	617	4828.7	3	0.075	13.33	2.55154	3.68383
1983	1081.5	4201.82	4	0.1	10.00	2.250367	3.623437
1984	884.9	3140	5	0.13	8.00	2.013419	3.49693
1985	480.2	3100	6	0.15	6.67	1.816961	3.491362
1986	644.1	3074.24	7	0.18	5.71	1.648325	3.487738
1987	573	2766	8	0.2	5.00	1.49994	3.441852
1988	739.8	2122	9	0.22	4.44	1.366914	3.326745
1989	781	1643	10	0.25	4.00	1.245899	3.215638
1990	596.8	1612.91	11	0.27	3.64	1.134498	3.20761
1991	1643	1081.5	12	0.3	3.33	1.03093	3.034027
1992	2122	924	13	0.32	3.08	0.933837	2.965672
1993	657.2	903.02	14	0.35	2.86	0.842151	2.955697
1994	2766	890.4	15	0.37	2.67	0.755015	2.949585
1995	689.3	884.9	16	0.4	2.50	0.671727	2.946894
1996	761.7	864.08	17	0.42	2.35	0.591701	2.936554
1997	890.4	793.5	18	0.45	2.22	0.514437	2.899547
1998	793.5	783.7	19	0.47	2.11	0.439502	2.89415
1999	924	781	20	0.5	2.00	0.366513	2.892651
2000	3140	779.99	21	0.52	1.90	0.295122	2.892089
2001	602.4	761.7	22	0.55	1.82	0.225011	2.881784
2002	529.5	739.8	23	0.57	1.74	0.155875	2.869114
2003	562	726.5	24	0.6	1.67	0.087422	2.861236
2004	565.76	719.82	25	0.62	1.60	0.019357	2.857224
2005	6584.92	689.3	26	0.65	1.54	-0.04862	2.838408
2006	1612.91	657.2	27	0.67	1.48	-0.11683	2.817698
2007	4201.82	644.1	28	0.7	1.43	-0.18563	2.808953
2008	719.82	642.54	29	0.72	1.38	-0.2554	2.8079
2009	864.08	623.47	30	0.75	1.33	-0.32663	2.794816
2010	642.54	617	31	0.77	1.29	-0.39989	2.790285
2011	779.99	602.4	32	0.8	1.25	-0.47588	2.779885
2012	726.5	596.8	33	0.82	1.21	-0.55559	2.775829
2013	3074.24	573	34	0.85	1.18	-0.64034	2.758155
2014	783.7	565.76	35	0.87	1.14	-0.7321	2.752632
2015	903.02	562	36	0.9	1.11	-0.83403	2.749736
2016	535.59	535.59	37	0.92	1.08	-0.95176	2.728832
2017	623.47	529.5	38	0.95	1.05	-1.09719	2.723866
2018	6808	480.2	39	0.97	1.03	-1.30532	2.681422

N	39	Mean of Log (X_i)	3.032599
Max. Discharge (Q_{max})	6808	Standard Deviation of Log (X_i)	0.331531
Min. Discharge	480.2	Skewness Coefficient (G)	1.2
Mean (Q_{mean})	1534.22		
Standard Deviation (Q_{std})	1622.54		
Q_{if} (=Q_{mean} + Q_{std})	3156.76		
Coefficient of Variation	105%		

The reduced variate and frequency factor related to various return periods are calculated using table values of the reduced mean and the reduced standard variation of the sample size. Estimations of peak floods for return periods 2, 5, 10, 25, 50, 100, 200, and 500 years are estimated based on Gumbel's extreme value model and Log Pearson Type III and given below in the Table 2.

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Table 2: Estimation of Peak Floods by Gumbel Max and Log Pearson Type III

Return Period (T) Years	Gumbel Max Model			Log Pearson III Model		
	Reduced Variate (Y_T)	Frequency Factor (K)	Expected Discharge (X_T)	Frequency Factor (K_T)	Log Discharge (Y_T)	Expected Discharge (X_T)
2	0.366513	-0.15498	1282.76	-0.195	2.96795	928.86
5	1.49994	0.840306	2897.64	0.733	3.275611	1886.3
10	2.250367	1.499269	3966.84	1.34	3.47685	2998.13
25	3.198534	2.331871	5317.77	2.087	3.724503	5302.77
50	3.901939	2.949542	6319.97	2.626	3.903198	8001.99
100	4.600149	3.562653	7314.77	3.149	4.076588	11928.57
200	5.295812	4.173527	8305.93	3.661	4.246332	17633.24
500	6.213607	4.979458	9613.59	4.323	4.465805	29228.41

For the estimation of peak floods by the Log Pearson Type III model, the mean and standard deviation of the logarithms of the discharges are computed. The expected discharge of return periods 2, 5, 10, 25, 50, 100, 200, and 500 years is computed by the antilog of the log discharge. The expected peak floods based on Gumbel's extreme value are 1282.76 cumecs, 2897.64 cumecs, 3966.84 cumecs, 5317.77 cumecs, 6319.97 cumecs, 7314.77 cumecs, 8305.93 cumecs, and 9613.59 cumecs for the return periods 2, 5, 10, 25, 50, 100, 200, and 500 years, respectively. The predicted peak floods based on Log Pearson Type III for the return periods 2, 5, 10, 25, 50, 100, 200, and 500 years are 928.86 cumecs, 1886.3 cumecs, 2998.13 cumecs, 5302.77 cumecs, 8001.99 cumecs, 11928.57 cumecs, 17633.24 cumecs, and 29228.41 cumecs, respectively.

Fig. 3 shows that the expected discharge computed by Log Pearson Type III for large return periods of 50, 100, 200, and 500 years is more predicted than the estimation based on Gumbel's extreme value. But Gumbel's extreme value model estimated a larger peak flood than the Log Pearson Type III in the lower return periods of 2, 5, 10, and 25 years. Overall, Log Pearson Type III is found to be overestimating the predicted discharge compared to the Gumbel model at Kodumudi for different return periods. This result is in disagreement with the findings of [2].

The reduced variance and flood magnitude are plotted to confirm if the observed flood data gathered in the gauge follows the Gumbel distribution (Fig. 4). The Gumbel distribution fits the observed flood data the best if the discharge points become straight lines.

The obtained value of r^2 value is 0.7977, which indicates that the Gumbel distribution is good but not the best fit for the observed data. Therefore, in order to select the best fit model among the models adopted in the present study, a goodness of fit test based on the Kolmogorov-Smirnov (K-S) and Anderson-Darling (A-D) tests is conducted in the EasyFit software 5.5 Professional. The results of goodness of fit are summarized in the Table 3. The critical values of Kolmogorov-Smirnov and Anderson-Darling determined at significance level $\alpha = 0.05$ (95% confidence level) are 0.21273 and 2.501755, respectively.

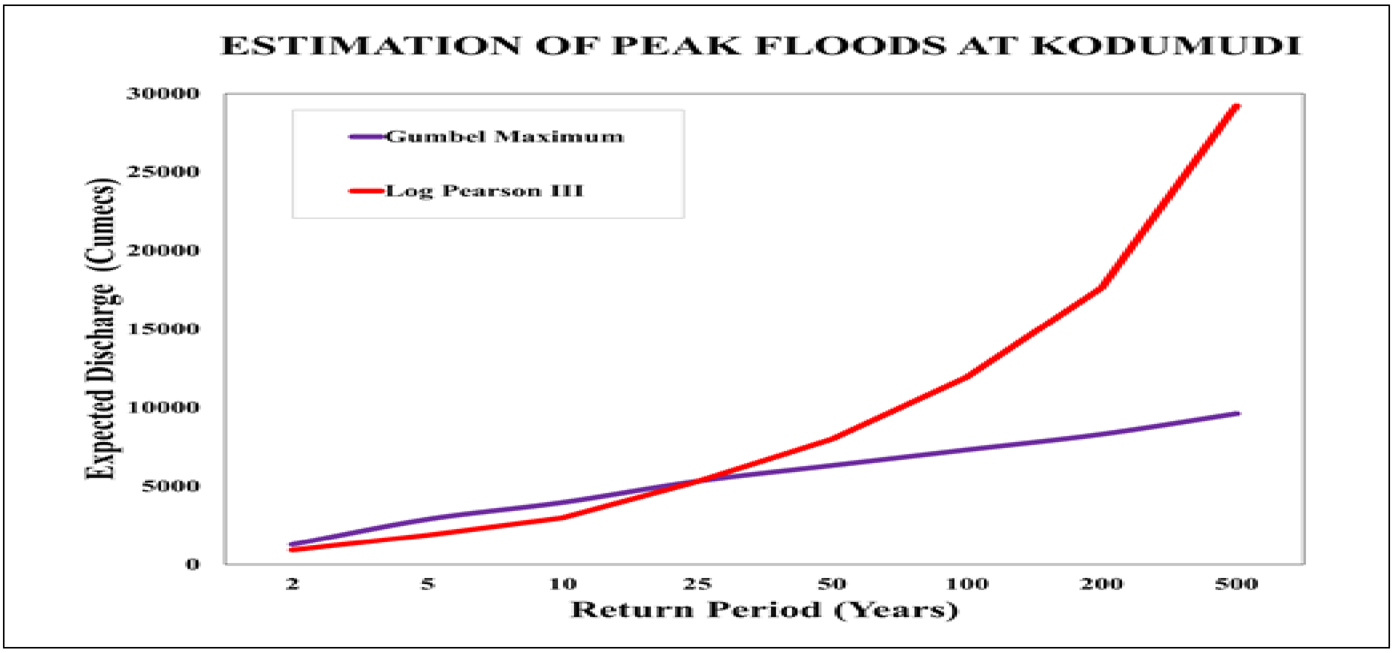

Fig 3: Estimation of Peak floods based on Gumbel Model and Log Pearson III at Kodumudi gauge in the Cauvery River Basin

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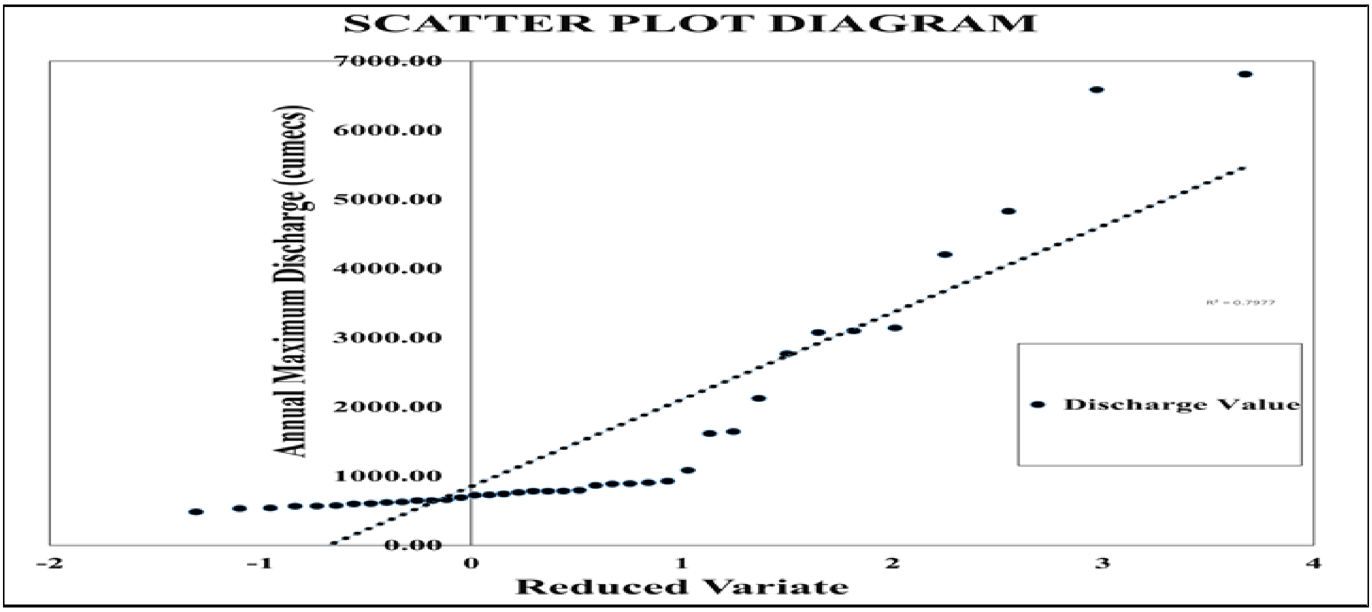

Fig 4: Scatter Plot Diagram of Reduced Variate and Annual Maximum Series of Discharge Based on the Gumbel Model

Table 3: Goodness of Fit Test for Gumbel Model and Log Pearson Type III

Test Methods	Kolmogorov-Smirnov (Critical value at 0.05 = 0.21273)			Anderson-Darling (Critical value at 0.05 = 2.501755)		
	Statistics	Reject	Rank	Statistics	Reject	Rank
Gumbel's extreme value	0.28957	Yes	2	4.33591	Yes	2
Log Pearson Type III	0.19506	No	1	1.61468	No	1

The results of the goodness of fit test show that Gumbel's extreme value is rejected in the Kolmogorov-Smirnov and Anderson-Darling tests since the statistical values of both tests are larger than critical values. But the Log Pearson Type III is not rejected in both test methods and became ranked 1. The Log Pearson Type III method is more appropriate and reliable than those computed by Gumbel's extreme value method. This result is in contrast with [23] but agrees with [22][24][25]. Therefore, Log Pearson III is best suited to estimate the peak floods at the Kodumudi gauged site in the Cauvery River basin. The estimation of peak floods based on Log Pearson Type III is displayed in the Fig. 5.

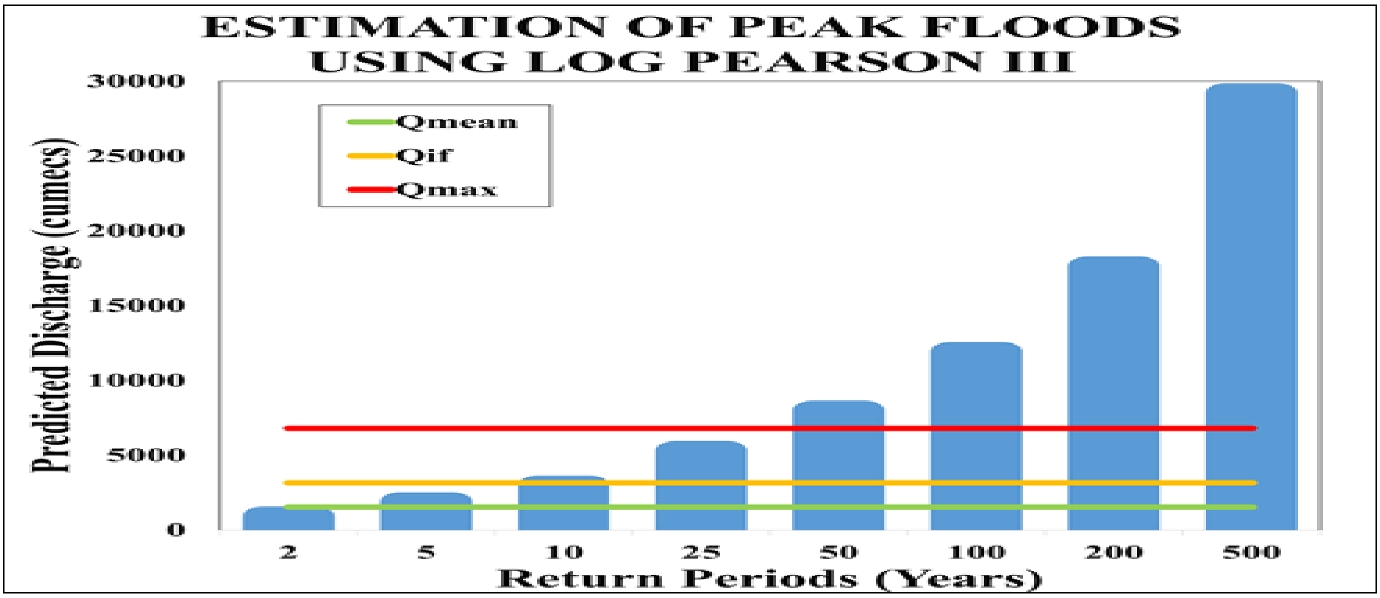

Fig 5: Estimation of peak floods based on Log Pearson III for different return periods and comparison with Maximum (Q_{max}), Mean (Q_{mean}) and the Sum of Mean and Standard deviation (Q_{if})

The peak flood of the 2-year return period is less than the observed mean discharge. Q_{if} is found to be similar to the flood of the 10-year return period. The maximum discharge ever recorded in the gauge station is less than the predicted peak flood of 50 years. However, it is recommended to design hydraulic structures based on the 100-year flood in the region as a precaution against future unprecedented flood events.

IV. CONCLUSION

The Cauvery basin is a flood-prone area in the peninsular region of India. At-site flood frequency is performed to estimate peak floods of 2, 5, 10, 25, 50, 100, 200, and 500 years return periods at the Kodumudi gauged site. The peak floods are observed in 1980, 2000, 2005, 2007, 2013, and 2018. The large variation in the data series indicates the possibility of a large flood in the future. The high level of variation obtained may result from changes in the volume of rainfall and the number of rainy days. The Gumbel model predicts more discharge for lower return periods, whereas Log Pearson Type III predicts more discharge for higher return periods than the Gumbel model. Log Pearson Type III is found to be the most suitable to estimate the peak floods at the Kodumudi gauged site in the Cauvery River basin. The design hydraulic structures can be based on the 100-year flood in the region. The present study would be valuable in developing flood management strategies, assessing vulnerability, and designing hydraulic structures in the study area.

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