Original Research Article

Flood Frequency Analysis of a Sub-watershed in Meenachil River Basin Using Gumbels Extreme Value Distribution

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A B S T R A C T

The extreme flood events are always a chapter of concern in all river basins, accompanied by loss of property, lives and economics. Estimation of flood peak discharge for a desired return period is pre-requisite for river basin management, design and execution of structures like bridges, culverts, dams, etc. Hence flood frequency analysis is essential to predict the flood peaks of different return periods. The Gumbels extreme value distribution is one of the best probability distribution model used to model annual maximum flood discharge. This paper presents the results of the flood frequency analysis of Meenachil river basin in Kerala using Gumbels extreme value distribution. The analysis used 34 years of data (1985-2018) to model the annual maximum discharge. The flood peak values of return period 2, 10, 50 and 100 year were computed and further extrapolation could be done to find out the flood discharge of any return period. The R^2 values of the plots of return period versus stream flow and reduced variate versus flood peak showed that the Gumbels extreme value distribution is suitable for predicting the expected flood flow in Meenachil River.

Introduction

Flood is one of the devastating natural disasters which occur in India every year during the south west monsoon season. In planning and design of water resources projects, it is very important to determine the magnitude and frequency of flood that will occur in the project area. Flood frequency analysis is the method of fitting a probability model to annual flood peak data recorded over a period of observation at a catchment outlet. The model parameters thus established can then be used to predict the flood peaks of desired return period.

Gumbels extreme value distribution is a reliable method to estimate the annual maximum flood peaks which is essential for flood plain management and design and

location of hydraulic structures. Flood mitigation and risk management using both structural (obtained by river training, storage dams, weirs, etc.) and/or non-structural (obtained by forecasting and rescue operations) measures are important aspect regarding occurrence of flood (Solomon and Prince, 2013).

Estimation of flood return periods associated with flood peaks of different magnitudes from recorded historical floods using statistical techniques specially enhance the flood rescue operation (Mujiburrehman, 2015). There is no statistical distribution that has gained worldwide acceptance and is specific to a particular country (Nirman, 2017).

Even then, in order to ensure safety and economic hydrologic design in the catchment area, the Gumbel extreme value distribution which is commonly used for flood frequency analysis is selected for this study.

Meenachil River face the threat of wide spread illegal sand mining. Previously the banks of the river were very much enriched with sands. Now the banks of the river are filled with grasses and mud. The depth of river is increasing day by day due to this illegal sand mining.

The sewage pollution is also another menace of the river. This river is not exceptional to annual floods during monsoon and causing destruction to the public. Meenachil River is highly dangerous and wild during flood season due to the depth of river.

This river contributed vigorously to 2018 Kerala flood and major causality in the human history. In view of all the above facts a flood frequency analysis was carried out to find out the likely flow discharge to be expected in the river at various return periods based on observed stream flow data.

Details of the study area

Meenachil River located in Kottayam district of Kerala acts as a cradle for the development of culture for Travancore. The river experiences enormous impacts of losses in terms of both property and life during monsoon flood. Due to changes caused by urbanization, the stream flow record of Meenachil river basin in the humid tropical zone of Kerala State is remarkably changed.

These alterations in stream flow scenario was more specifically, an indicator of upstream-arena urbanization in a humid tropical river basin (Celine *et al.,* 2012). Watersheds in Meenachil basin are parts of Western Ghats, which is categorised into ecologically sensitive region (Vincy *et al.,* 2012). Meenachil River basin consists of 47 sub-watersheds and 114 micro watersheds.

The river finally drains into Vembanad Lake. The Pala sub-watershed which contributes a lot to the Kerala economy, situated at the upstream portion of Meenachil River basin is selected for the present study. The basin map of study area is shown in Fig. 1. The sub watershed lies between 9°38'56.89"N and 9°49'50.64"N latitude, and 76°36'57.57"E and 76°56'17.99"E longitude. The watershed covers an area of 444.115 Km² which is approximately 35 per cent of the total area of Meenachil river basin (about 1272 Km² of drainage area).

Materials and Methods

Data collection

The daily discharge data observed at Pala gauging station (76°41'2.40"E, 9°42'36"N) of Meenachil river basin for a period of 34 years from 1985 to 2018 was collected from the Irrigation Design and Research Board (IDRB) Trivandrum, Department of Irrigation, Kerala.

The annual maximum discharge data were used for flood frequency analysis.

Data analysis

Flow data are denoted in terms of exceedance probabilities and recurrence intervals. Considering, Q_i as the annual maximum flood in year i and the quantile $Q_i(F)$ as the value of Q_i expected to exceed with probability F, the following relation, P $(Q_i \geq Q_i(F))$ = F, during the year of concern is derived. Thus, there is an F % chance for Q ≥ Q (F) occurrence. In other way, there is a (1−F) % chance that events X <Q (F) occurs. The return period T of a flood, is the reciprocal of the probability of exceedance in one year computed as 1/ (F) (Haan, 1977; Mujere, 2011).

Gumbels distribution

Gumbel distribution also known as Generalized Extreme Value distribution Type-I is a statistical technique, generally used for predicting extreme hydrological events and climate variables (Zelenhasic, 1970; Haan, 1977; Shaw, 1983). The study adopted this model for flood frequency analysis due to following reasons: (1) peak flow data are homogeneous and independent hence lack long-term trends; (2) the river is less regulated, hence is not significantly affected by reservoir operations and diversions; and (3) flow data cover a relatively long record and is of good quality (Mujere, 2011; Mukherjee, 2013).

Gumbel distribution uses the following equation for fitting the observed series of flood flows at different return periods T (Chow, 1988; Chow, 1964; Beard, 1943):

$$x_T = \bar{x} + K\sigma_{n-1}$$

Where, x_T represents the magnitude of flood event at T return period; K represents the frequency factor; $\bar{x}$ represents the mean of the maximum instantaneous discharge; σ_{n-1} represents the standard deviation of the maximum instantaneous discharge.

The reduced variate is related as y_T = - $\left[\ln.\ln\frac{T}{T-1}\right]$. Frequency factor is denoted as $k = \frac{y_T - \bar{y}_n}{S_n}$, where, $\bar{y}_n$=0.5396 and $S_n = 1.1255$ are selected suitably from standard table (Subramanya, 2004).

Results and Discussion

The analysis of procured data using Gumbel's distribution was performed using the above relations and the results are shown in Table 1. The flood frequency curve, i.e., a graph of discharge versus return period, was depicted in Fig. 2. A graph of reduced variate versus flood peak was plotted for upper Meenachil River Basin, which is represented in Fig. 3.

The maximum instantaneous discharge of 894.09 m³/s was recorded in 2018 during which Kerala faced a devastating flood while the lowest discharge of 139.28 m³/s was recorded in 2012 which was the driest year. The 34-year mean instantaneous discharge value was found as 357.63 m³/s. In addition, the flood frequency curve resulted in R² value of 0.967, which is an acceptable value.
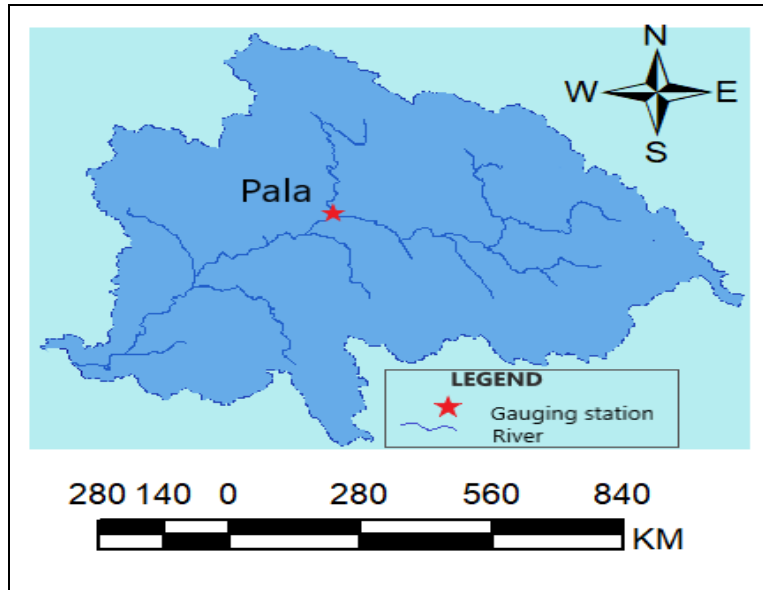
Gumbel's distribution was also used to compute the flood magnitude corresponding to different recurrence intervals T as shown in Table 2. Chi-square (χ 2) test was performed to find the goodness of fit between the observed and predicted discharge values. The test revealed a satisfactory fit between observed and predicted flood flow values that enabled prediction of flood frequency using Gumbel distribution.

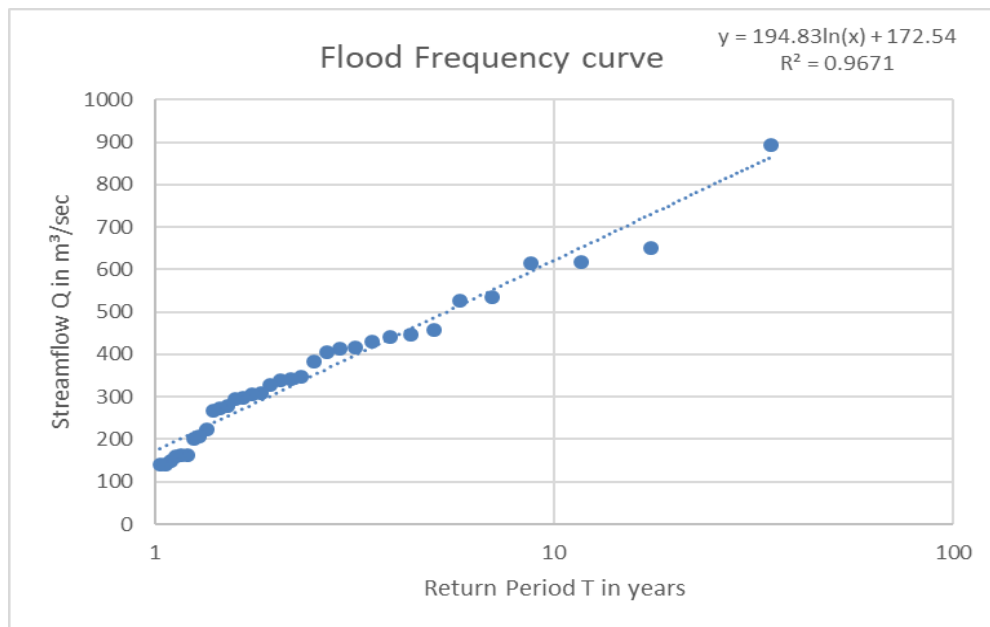**Table.1** Computation table of Gumbels distribution

Year	Peak flood (m³/s)	Peak flood in descending order (m³/s)	Rank (m)	Return period $T = \frac{n+1}{m}$	Reduced variate $y_T = -\left[\ln.\ln\frac{T}{T-1}\right]$
1985	616.6300049	894.0943453	1	35	3.540889304
1986	614.47	649.4799805	2	17.5	2.832924885
1987	430.980011	616.6300049	3	11.66666667	2.412264269
1988	414.9700012	614.47	4	8.75	2.108986882
1989	649.4799805	535.0900269	5	7	1.869824714
1990	307.4700012	525.41	6	5.833333333	1.671035528
1991	296.7900085	458	7	5	1.499939987
1992	383.0299988	447.58	8	4.375	1.348955435
1993	277.7600098	440.6532898	9	3.888888889	1.213176618
1994	525.41	430.980011	10	3.5	1.08923964
1995	458	414.9700012	11	3.181818182	0.974729942
1996	340.18	413.9700012	12	2.916666667	0.867848615
1997	305.91	406.25	13	2.692307692	0.767212305
1998	447.58	383.0299988	14	2.5	0.671726992
1999	268.0299988	348.1199951	15	2.333333333	0.580504824
2000	272.6700134	342.0799866	16	2.1875	0.492807132
2001	535.0900269	340.18	17	2.058823529	0.408003873
2002	163.9199982	327.25	18	1.944444444	0.325543568
2003	148.9499969	307.4700012	19	1.842105263	0.244929988
2004	201.9100037	305.91	20	1.75	0.165702981
2005	342.0799866	296.7900085	21	1.666666667	0.087421572
2006	224.1399994	295.730011	22	1.590909091	0.009647686
2007	295.730011	277.7600098	23	1.52173913	-0.068071098
2008	163.0500031	272.6700134	24	1.458333333	-0.146221719
2009	205.9600067	268.0299988	25	1.4	-0.225351487
2010	348.1199951	224.1399994	26	1.346153846	-0.306103956
2011	413.9700012	205.9600067	27	1.296296296	-0.389272391
2012	139.2799988	201.9100037	28	1.25	-0.475884995
2013	158.5299988	163.9199982	29	1.206896552	-0.567350706
2014	406.25	163.0500031	30	1.166666667	-0.665729811
2015	327.25	158.5299988	31	1.129032258	-0.77429099
2016	141.1078644	148.9499969	32	1.09375	-0.898833547
2017	440.6532898	141.1078644	33	1.060606061	-1.051590868
2018	894.0943453	139.2799988	34	1.029411765	-1.268452966
Sum		12159.45			
Average		357.6308			

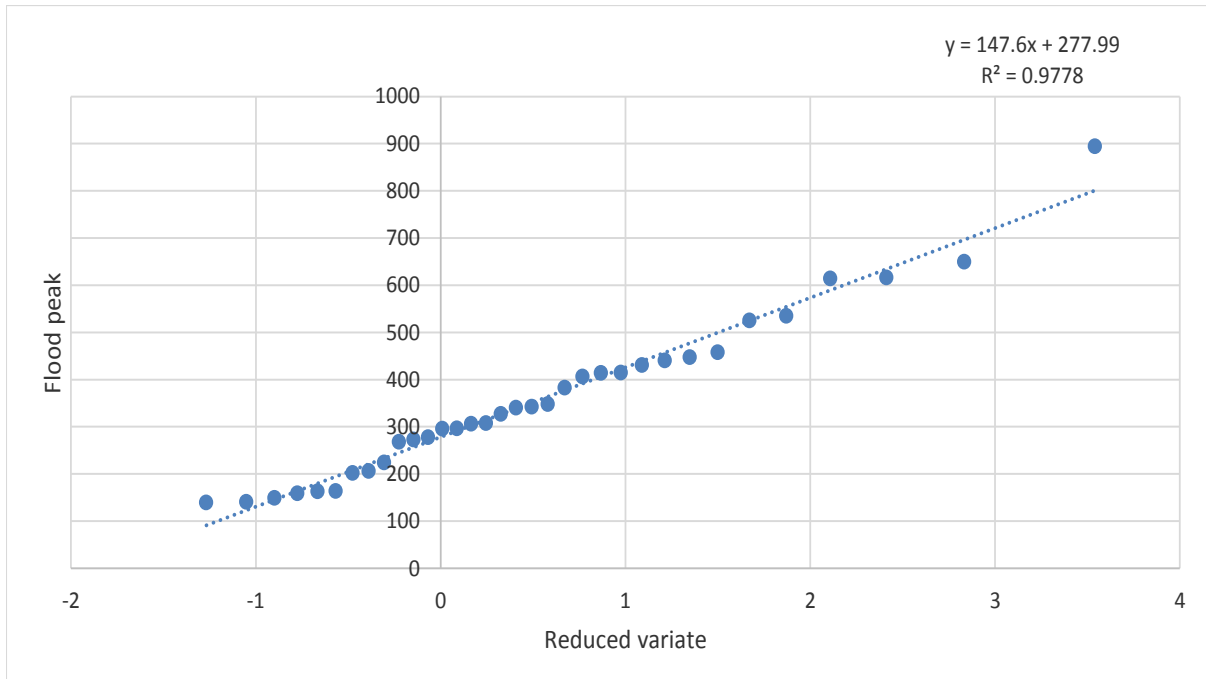**Table.2** Calculation of expected flood in Meenachil River

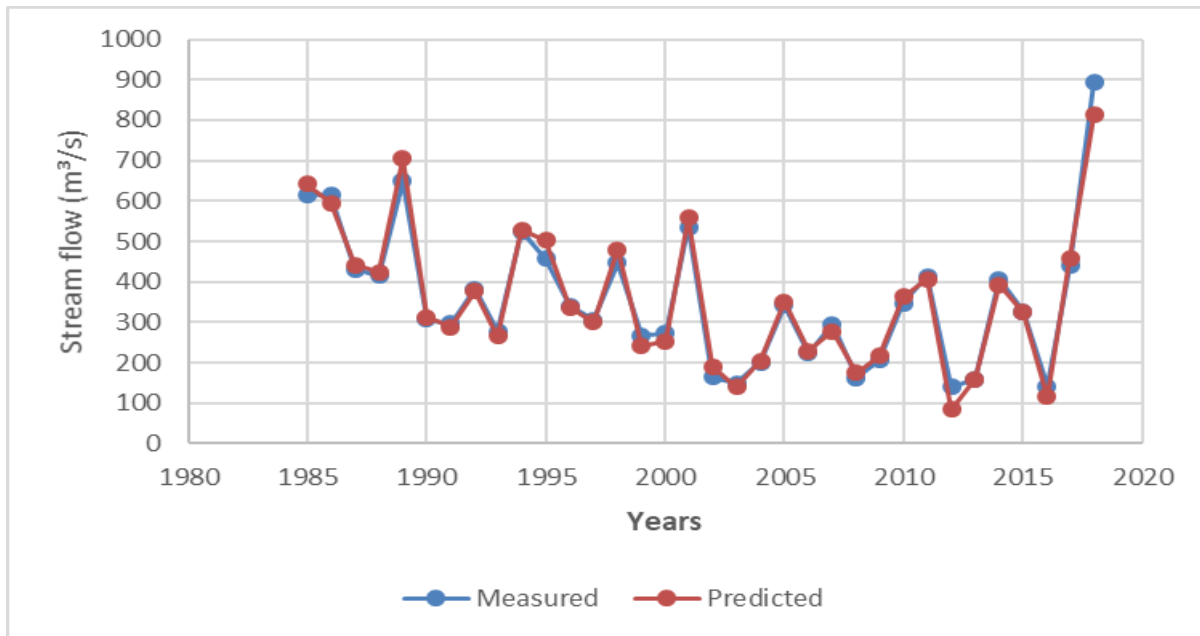| Return period T in years	Reduced variate $y_T = -\left[\ln.\ln\frac{T}{T-1}\right]$	Frequency factor $k = (y_T - \overline{y_n})/s_n$	Expected flood $x_T = \overline{x} + K\sigma_{n-1}$
2	0.366512921	0.153786832	331.41
10	2.250367327	1.52000651	616.84
50	3.901938658	2.987417733	867.08
100	4.600149227	3.607773636	972.87

Fig.1 Location of study area (Meenachil River Basin, Kerala)

Fig.2 Plot of streamflow versus return period (Frequency curve)

Fig.3 Plot of reduced variate versus peak flood

Fig.4 Plot of measured and predicted streamflow values

From the Gumbel's distribution, the expected estimated discharges for return periods of 2yrs, 10yrs, 50yrs and 100yrs were obtained as 331.41 m³/s, 616.84 m³/s, 867.08 m³/s and 972.87 m³/s respectively. These values can be adopted as a guide for storm water management in the region during flood. The predicted value and measured value of discharge showed good agreement without much variation as indicated in Fig. 4. Flood frequency analysis was carried out for Pala watershed, which lies in the upstream side of Meenachil River basin. The analysis used peak discharge data of 34 years from 1985-

2018. From the plot of the reduced variate versus peak flood, the trend line equation gives R² value of 0.9778. This showed that the pattern of the scatter is narrow and therefore Gumbel's distribution method is suitable for predicting expected discharge in the river. The frequency analysis also showed good capability of the Gumbel distribution to predict river flood magnitudes occurring in different return period.

There were no significant differences between the predicted and measured discharge values. Hence, the model can be reliably applied to predict the occurrence of floods in the catchment. This mathematical relation can also be considered for several extreme event distributions in the region where emergency evacuation of people could be done. This type of flood prediction can also be utilized in the designing of important hydraulic structures in the river reach.

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