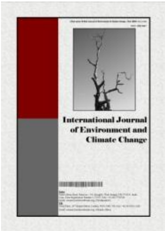

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Flood Frequency Analysis of Araniar Medium Irrigation Project in Chittoor District by using Gumbel's Distribution

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Flood frequency analysis is one of the most important statistical technique to understand the nature and magnitude of high discharge of floods in the river. The objective of flood frequency analysis was to relate the magnitude of floods and their frequency of occurrence through probability distribution. Flood frequency analysis is essential to reduce the impact of flood damage by predicting the floods by adopting the suitable flood prediction model. The Araniar reservoir was constructed across the Araniar river in the Chittoor district of Andhra Pradesh. The flood frequency analysis was conducted on the Araniar reservoir using Gumbel's extreme value distribution method in the year 2019-2020. Daily maximum inflow data from the Department of Water Resources, Andhra Pradesh, were collected for the period 1990-2019 and used for flood frequency analysis of Araniar Reservoir using

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Gumbel's extreme value distribution method. From the observations of Gumbel’s distribution, the R^2 value acquired from the trend line equation was 0.9803, indicating that Gumbel's extreme value distribution was suitable for estimating predicted reservoir flood flow. The estimated flood flow for upcoming years of 2 years, 10 years, 50 years, 100 years,150 years, 200 years, 300 years and 400 years were found to be 38.29 Mm^3/year, 66.96 Mm^3/year, 92.08 Mm^3/year, 102.71 Mm^3/year, 108.90 Mm^3/year, 113.29 Mm^3/year, 119.47 Mm^3/year and 123.85 Mm^3/year respectively. The mean instantaneous flow in the reservoir was 40.88149 Mm^3/year which was nearly equal to a return period of about 2 years. The estimated flood flows of the Araniar reservoir was useful for constructing important dam hydraulic structures, advising agricultural patterns in the command area, and protecting lives and property downstream of the catchment region.

Keywords: Araniar reservoir measured inflow; cropping patterns; flood frequency; gumbel’s extreme value distribution; hydraulic strictures; return period.

1. INTRODUCTION

A flood is an overflow of water on land, either from heavy rains or other natural disasters. Floods have been a recurrent phenomenon and cause huge losses to lives, properties, livelihood systems, infrastructure and public utilities. India’s high risk and vulnerability was assessed to be about 40 million hectares out of a geographical area of 3290 lakh hectares was prone to floods. On an average every year, 75 lakh hectares of land was affected, 1600 lives are lost and the damage caused to crops, houses and public utilities was Rs. 1805 crores due to floods. The maximum number of lives (11,316) which lost in the year 1977 (NDMA, New Delhi) [1]. The frequency of major floods was more than once in five years. Flood frequency analysis (FFA) is the estimation of how often specified flood events will occur. Before the estimation, analyzing of the stream or river flow data was important to obtain the probability distribution of flood (Ahmed, Shabri, and Zakara, 2011[2]). Because, one of the greatest challenges faced by hydrologists was to gain a better understanding of flood regimes.

While planning and designing the water resources projects, engineers and planners are usually focused on determining the magnitude and frequency of floods that will occur in project regions. In addition to the unit hydrograph method, rational technique and rainfall-runoff model it was found that the frequency analysis was one of the methods which was used to describe the relationship between the magnitude of an event and the frequency with which that event was exceeded [3]. The analysis of how often a specific event will occur is known as flood frequency analysis. Before carrying out the estimation, it was critical to analyse the inflow data in order to obtain a probability distribution of floods. Hydrologists and engineers all across the world use the Flood Frequency Analysis (FFA), which entails estimating flood peak volumes for a set of non-exceedance probability [4].

The fitting of a probability model to a sample of yearly flood peaks observed over a period of the fitting of a probability model to a sample of annual flood peaks observed over a period of examination for a watershed in a certain region is known as flood frequency analysis. The obtained model parameters can then be utilised to predict extreme events with a large recurrence interval. Floodplain management requires accurate flood frequency estimates in order to protect the public, reduce flood-related expenses to government and private organisations, build and locate hydraulic structures, and analyse risks associated with the development of flood plains [5].

Varies statistical distributions have been employed in research to estimate the likelihood and severity of floods, but none has received international approval and was specific to any country [6,7]. The Gumbel's extreme value distribution, a stochastic generating structure that generates random results, was used to predict the yearly peak inflows data of Araniar reservoir from 1990-2019. in order to provide security and cost-effective hydrologic design in the catchment area.

The main aim of the study was to carry out the Flood Frequency Analysis for the Araniar reservoir inflows data of reservoir. Based on the collected data, the results of the analysis obtained by the study provide precise information about the potential flood to be expected in the reservoir during various return periods. This data will be extremely useful for engineering applications, such as when developing structures in or near the reservoir that may be flooded, as well as when constructing the flood structure to prevent against the expected events [8]. This could include the design of dams, bridges, and flood control structures that will help the region's storm water management or reduce flood disasters in the catchment.

Several studies have been reported to be related to the investigation of the most suitable probability distribution for flood frequency analysis in different regions worldwide [9,10–16,17,18,3,10,8,11,7,9,5,6,4,12,1,13]. Ahilan et al. [19] compared the family of extreme value distributions using the data from 172 gauging stations in Ireland; they reported that the Gumbel distribution outperformed the other two types of extreme value distributions (i.e., Frechet, and Weibull).

2. MATERIALS AND METHODS

The Araniar River also known as Arani which flows through the states of Tamil Nadu and Andhra Pradesh. The Araniar medium irrigation project was constructed across the Araniar River near Pichatur village (latitude 13.35 to longitude 79.25), Pichatur Mandal, and Chittoor District in Andhra Pradesh in the year 1958. It has got 150 sq. miles and 2 sq. miles of free catchment and intercepted respectively gross capacity of the reservoir was 1.851 TMC. It irrigates a total ayacut of 3682.6 ha in Pichatur and Nagalapuram mandals of Chittoor district of Andhra Pradesh, in India. The daily inflows in to the Araniar reservoir was measured by the Department of Water Resources, Chittoor, A. P. and hence the measured inflow data of the same was considered for the study from the period of 1990-2019 for the flood frequency analysis [20].

The Gumbel extreme value distribution approach, which was employed in the current study for flood frequency analysis, was a statistical method for analysing extreme hydro-logical occurrences like floods [11]. Gumbel was the first to recognise that yearly flood peaks represent the extreme value of flood in each annual sequence of recorded flood or rainfall, which he did in 1941. As a result, floods should follow the distribution of extreme values [18]. The equation for Gumbel's extreme value distribution. as well as to the procedure with a return period T was given as, The equation for Gumbel's extreme value distribution. as well as to the procedure with a return period T was specified as,

X_T = X +$K.S_x$ . . .. (1)

X_T= Probable discharge with a return period of T years

$\overline{x}$ = Mean flood

S_x= Standard deviation of the Sample Size.

K - frequency can be modified as: $K_T = \frac{Y_{T-}Y_n}{\sigma n}$ (2)

In which, Y_T = Reduced Variate, Y_T = - [ln. ln $\frac{T}{T-1}$] (3)

The values of Yn and Sn are chosen from Gumbel's Extreme value Distribution considered depending on the sample size.

The steps to estimate the design flood for any return period using Gumbel's extreme value distribution. as given by Chow, V. T. 1988 is presented below:

Step 1: Annual peak flood data was collected from 1990 - 2019.

Step 2: From the maximum flood data for n years, the mean x and standard deviation σx are computing using:

$\sum_{i=1}^{n} X_i$ And $\sigma_x = \sqrt{\frac{1}{(n-1)} + \sum_{i=1}^{n}(x-\bar{x})^2}$ . . . . (4)

Step3: From the Gumbel's Extreme value distribution the table value Yn and Sn are taken as 0.5362 and 1.1124.

Step4: From the given return period T_r , the reduced variant Y_T was computed using equation (3).

Step 5: From Y_n, S_n and Y_T The flood frequency factor K was computed using equation (2).

Step 6: With use of Equation (1), the magnitude of flood was computed.

Before applying this method for flood frequency analysis, it was of great importance to recognize whether the input flood data series representing the catchment area satisfies the Gumbel's extreme value distribution or not [14,15].

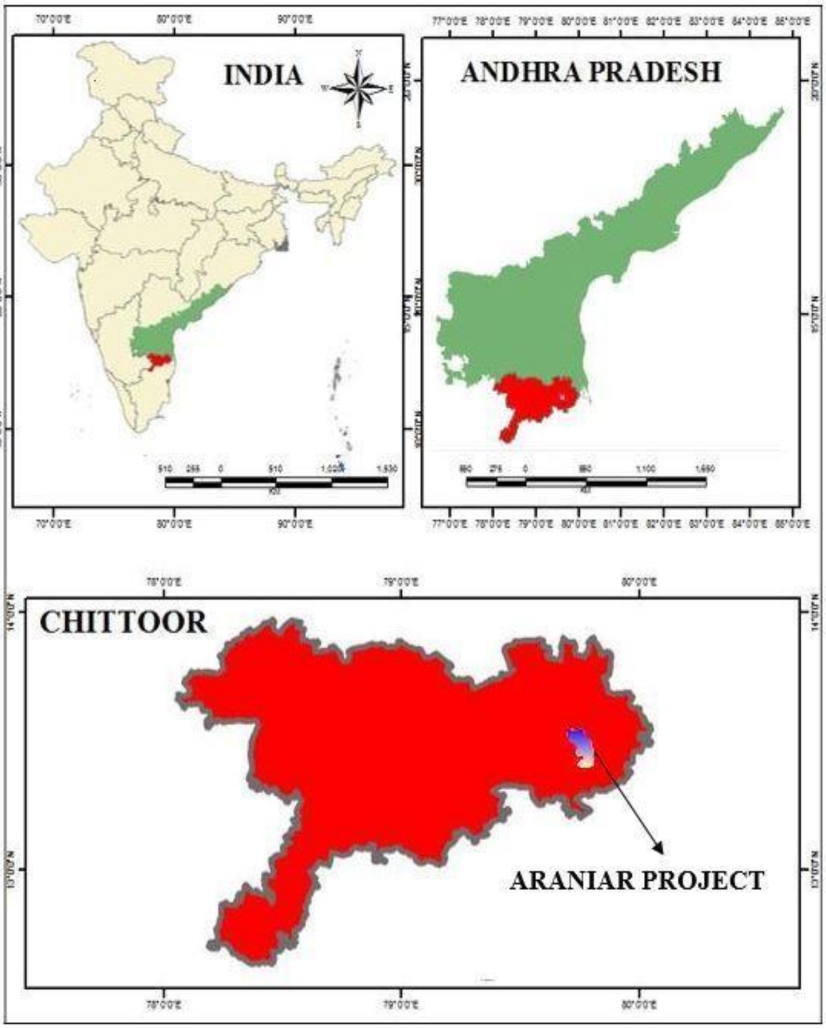

Fig. 1. Location of Araniar medium irrigation project command area

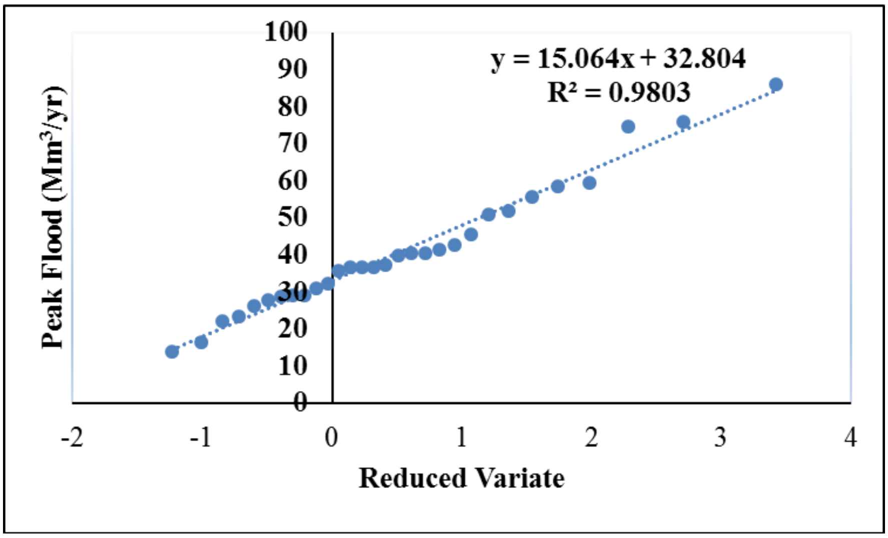

Fig. 2. Plot of Reduced Variate v/s Peak Flood for Araniar Project

Table 1. Gumbel's reduced mean variable and standard deviation based on data

Year	Flood peak (Mm^3)/year	Flood peak (Mm^3)/year In descending order	Order (m)	$sx^2 = (n-\bar{x})^2$	Return period $T_r = \frac{(n+1)}{m}$	Reduced Variate $Y_T = -\ln \ln \frac{(T_r)}{(T_{r-1})}$
1990	41.48	86.08	01	2043.19	31.00	3.41
1991	58.36	75.91	02	1227.51	15.50	2.70
1992	37.15	74.67	03	1141.76	10.33	2.28
1993	74.67	59.29	04	339.07	07.75	1.97
1994	42.75	58.36	05	305.53	06.20	1.73
1995	29.02	55.78	06	222.08	05.16	1.53
1996	51.90	51.90	07	121.51	04.42	1.36
1997	55.78	50.99	08	102.35	03.87	1.20
1998	23.24	45.53	09	21.64	03.44	1.07
1999	29.02	42.75	10	3.52	03.10	0.94
2000	40.60	41.48	11	0.36	02.81	0.82
2001	45.53	40.60	12	0.07	02.58	0.71
2002	27.63	40.37	13	0.25	02.38	0.60
2003	28.79	39.81	14	01.14	02.21	0.50
2004	36.64	37.15	15	13.91	02.06	0.41
2005	50.99	36.81	16	16.56	01.93	0.32
2006	31.09	36.72	17	17.26	01.82	0.22
2007	59.29	36.64	18	17.97	01.72	0.14
2008	75.91	35.60	19	27.88	01.63	0.05
2009	16.42	32.22	20	74.94	01.55	-0.03
2010	40.37	31.09	21	95.83	01.47	-0.12
2011	32.22	29.02	22	140.58	01.40	-0.21
2012	36.81	29.02	23	140.58	01.34	-0.30
2013	36.72	28.79	24	146.00	01.29	-0.39
2014	13.96	27.63	25	175.41	01.24	-0.49
2015	86.08	26.30	26	212.41	01.19	-0.60
2016	35.60	23.24	27	310.93	01.14	-0.71
2017	22.18	22.18	28	349.70	01.10	-0.84
2018	39.81	16.42	29	598.18	01.06	-1.00
2019	26.30	13.96	30	724.75	01.03	-1.23
	Sum	1226.44				
	Average	40.88				
			S. D	16.92		

Table 2. Computing expected flood in Araniar project

Return period (T)in year	Reduced variate $Y = -\ln \ln\left(\frac{T_r}{T_r - 1}\right)$	Frequency factor $K_{(T)} = \frac{Y_T - \overline{Y_n}}{\sigma_n}$	Expected Flood $X_T = \overline{X} + K_T S_X$
2	0.36	-0.15	38.29
10	2.25	1.54	66.96
50	3.90	3.02	92.08
100	4.60	3.65	102.71
150	5.00	4.01	108.90
200	5.29	4.27	113.29
300	5.70	4.64	119.47
400	5.99	4.90	123.85

To do this, the acquired data was organized in decreasing order (from highest to lowest) and each flood was given a return period. Equation (3) was used to calculate the reduced variate for each flood. A graph was illustrated with a plot of reduced variate and flood size; if the plot indicates a straight line, it was acceptable to conclude that the observed flood data follows the Gumbel's extreme value distribution and has a good fit. The expected flood for the return periods of 2 years, 10 years, 50 years, 100 years, 150 years, 200 years, 300 years and 400 years are estimated and presented in the results.

3. RESULTS AND DISCUSSION

The Gumbel's extreme value distribution analysis was performed using the approach described above, and the results are shown in Table 1. The highest annual inflow was 86.08 Mm^3/year in 2015 and the lowest annual inflow was 13.96 Mm^3/year in 2014. The return period ranges from 31 to 1.03. The average instantaneous peak flood over the last 30 years was found to be 40.88149 Mm^3/year. The standard deviation (S.D.) for this sample was estimated as 16.92. The decrease in inflow to the reservoir may be due to the abstractions of excess groundwater in the catchment and reservoir areas of the Araniar river. The increase in inflow during the year 2015 was due to the excess precipitation caused by ROVVANU cyclone that led to the increased inflows of flood which devasted many hydraulic structures which led to the flooding of agricultural land.

Fig. 2 indicates a plot of reduced variate v/s peak flood. From the trend line equation, R^2 gives a value of 0. 9803, showing the pattern of scatter was narrow and that Gumbel's extreme value distribution was found to be suitable for predicting expected inflow in the reservoir. The plot in Fig. 2 also gives the relationship between the anticipated flow and return period as: 15.064x+32. 804. By using this equation, the flood values may be extrapolated. These values obtained will be useful in the engineering design of hydraulic structures. Using the Gumbel's extreme value distribution analysis, the results agreed with the study of Bhaga [5] and Mukherjee MK [15].

Table 2 indicates the floods with various recurrence intervals that were computed. It shows the most essential flood frequency analysis parameters as well as the study's findings. It shows the many floods that are forecast, as well as their return periods. The results from the table shows the expected flood for the return periods of 2 years, 10 years, 50 years, 100 years, 150 years, 200 years, 300 years and 400 years are 38.29 Mm^3/year, 66.96 Mm^3/year, 92.08 Mm^3/year, 102.71 Mm^3/year, 108.90 Mm^3/year, 113.29 Mm^3/year, 119.47 Mm^3/year and 123.85 Mm^3/year respectively. The study's projected values are important in managing Araniar reservoir's extreme flood events. The same results are observed by Mukherjee M.K [15].

4. CONCLUSION

Using the 30 years of annual peak inflow data, flood frequency analysis was conducted for Araniar reservoir. From the results which depicts a representation of the reservoir's reduced variate and peak flood based on observed data. R^2 equals 0.9803 when the trend line equation was used. The value of R^2 = 0.9803 indicates that the scatter pattern was limited and that Gumbel's extreme value distribution. approach was appropriate for predicting projected reservoir flow. Also, the mean instantaneous flow in the reservoir was 40.88149 Mm^3/year which was nearly equal to a return period of about 2 years as shown in Table 2 and it was visible in the flood peak data also. This means that floods in the reservoir may be predicted accurately. This flood prediction can be used to construct essential hydraulic structures such as dams, spillways, sluices gates, weirs and flumes in the reservoir region. Emergency evacuations of people can also be carried out well in advance in the event of severe flooding. From this study it can be suggested that during floods, excess water may be pumped from Araniar reservoir to MALLEMADUGU Dam by constructing a lift irrigation project to lift water and to mitigate the floods during the period of excess precipitation and vice versa during droughts. Because the method utilised for the study was based on a standard formula, a similar investigation can be carried out in any other study region.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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