Research Article
Open Access
CrossMark

Flood frequency analysis of Asa River, Ilorin, Nigeria

Abstract

Flooding poses a risk to human lives, livelihoods, infrastructure, and the environment. Therefore, understanding the flood frequency patterns of the Asa River is crucial in developing effective flood management strategies. This study explores the statistical technique to understand the nature and magnitude of high discharge of floods in the Asa River, aiming at relating the magnitude of floods and their frequency of occurrence through probability distribution. The Gumbel Extreme Value Distribution method was used to analyze the 30 years (1991-2020) flood discharge data of River Asa which was collected from Lower Niger River Basin and Development Authority, Ilorin, and flood discharge for the return periods of 5 years, 10 years, 20 years, 30 years, 50 years, 100 years, and 150 years, was predicted. From the observations of Gumbel's distribution, the R^2 value acquired from the trend line equation was 0.9227, indicating that Gumbel's extreme value distribution is suitable for estimating predicted river flood flow. The expected flood discharge for the return periods of the upcoming 5 years, 10 years, 15 years, 20 years, 25 years, 50 years, 100 years, and 150 years, was estimated to be 43.19 m^3/s, 51.12 m^3/s, 55.60 m^3/s, 58.73 m^3/s, 63.11 m^3/s, 68.58 m^3/s, 75.96 m^3/s, and 80.27m^3/s respectively. The results obtained in this research would adequately serve as a planning guide for the decision makers on the development and flood risk management along Asa River, to achieve sustainable development and management, with a view of protecting lives and properties downstream of the watershed.

Keywords: flood frequency, return period, discharge, Gumbel's extreme value distribution

Volume 8 Issue 1 - 2024

HO Adebayo,[1] AO Ogunlela[2]

[1]University of Abuja, Abuja, Faculty of Engineering, Department of Agricultural Engineering, Nigeria

[2]University of Ilorin, Ilorin, Kwara State, Faculty of Engineering and Technology, Department of Agricultural and Biosystems Engineering, Nigeria

Correspondence: HO Adebayo, University of Abuja, Abuja, Faculty of Engineering, Department of Agricultural Engineering, Nigeria, Tel 08066191693, Email adebayohawa403@gmail.com

Received: January 23, 2024 | **Published:** February 12, 2024

Introduction

Flood Frequency Analysis is a statistical method used to estimate the likelihood and magnitude of floods that may occur at a specific location over a certain period. It involves analyzing historical flood data to develop probability distributions and models that help to predict the frequency and severity of future floods.[1] Bates et al.[2] stated that flood frequency analysis is a basic method for measuring extreme flood uncertainty and is of great significance for flood control management of river courses and water conservancy projects. Return period on the other hand is the average time or an estimated average time between flood events. The relationship between discharge and return period is typically established through statistical analysis of historical streamflow data. Hydrologists use various statistical models, such as the log-Pearson Type III distribution, to estimate the probability of different discharge magnitudes based on the available data. The application of statistical frequency curves to the flood was first introduced by Gumbel. Making use of the annual peak flow data that has been available for some years, flood frequency analysis can be used to calculate statistical information such as standard deviation, mean, and skewness which is further used to create frequency distribution graphs.

Hawant et al. (2020) focused on finding the best distribution to match the stream flow, calculation of magnitude and frequency of flow, therefore, they used several statistical distributions to find the best-fit distribution for stream flow and used flood frequency analysis techniques to find the magnitude and frequency of stream flow and non-exceedance probability of peak discharge for Burhi Gandak, River Basin. In their study, they considered Gumbel Extreme Value Distribution, Gamma distribution, Lognormal distribution, Galton distribution, Log Pearson Type III distribution, and generalized extreme values distribution to describe the annual maximum stream flow for desired return periods using the 50 years historical discharge data of each gauging stations.

Rao et al.[3] investigated the Flood Frequency Analysis of the Arainar medium irrigation project in the Chittoor District by using Gumbel's Distribution. In their work, Daily maximum inflow data from the Department of Water Resources, Andhra Pradesh, was collected for the period 1990-2019 and used for Flood Frequency Analysis of Araniar Reservoir they concluded that Gumbel's extreme value distribution is suitable for estimating predicted reservoir flood flow.

Solomon and Prince[4] carried out the Flood Frequency Analysis of the Osse River in Benin City, Nigeria, using Gumbel's Extreme Value distribution, they estimated the expected discharge for desired return periods and stated that Gumbel Extreme Value Distribution is suitable for predicting the expected magnitude of flow in the river. While planning and designing 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 method, and rainfall-runoff model, it was established that the frequency analysis was one of the methods which were used to describe the relationship between the magnitude of an event and the frequency with which that event was exceeded.[5]

Nirman[6] carried out the Flood Frequency Analysis for the Lower Mahi River, in India using 30 year's annual peak flow data of Wanakbori Weir using Gunmbel's Extreme Value Distribution, he presented detailed information on likely flow discharge to be expected in the river at the various return periods based on the observed data. Law and Tasker[7] opined that studies have adopted several statistical distributions to quantify the likelihood and intensity of floods, but none have gained worldwide acceptance and are specific to any country. Samantaray and Sahoo[8] estimated the Flood Frequency of the Mahanadi River Basin, India, using four statistical methods, namely Gumbel max, Log-Pearson III, Normal and General Extreme Value Distribution. The statistical methods were used to forecast the stream flow for, 10, 20, 30, 40, 50,60, 70, 75, 100, and 150 years from the monthly flow data collected from four different gauge stations from Mahanadi River. Samantaray and Sahoo[8] deduced that the goodness of fit test shows that the General Extreme Value Distribution method gives the best results at three different stations, which is closely followed by the Log-Pearson III method. Similarly, Mokwey and Audu[9] estimated the flood magnitude and frequency of occurrence of Escravos Bay in Delta State Nigeria for a return period of 2, 5, 10, 25, 50, 100, and 200 years of flow using Log-Pearson type III Distribution model fitted in fifteen years tidal record taken between 2000-2014 from Escravos Bay.

Adeniran et al.[10] examined the mapping and evaluation of flood risk areas along the Asa River in the Ilorin Metropolis using GIS and remote sensing. The author adopted geospatial data sets which include the Digital Terrain Model (DTM) which was converted to triangulated irregular network (TIN) format. The geometric data was obtained from TIN through the use of the United State Army Corps of Engineers, Hydrologic Engineering Centre, Geo River Analysis System (USACE HEC-geoRAS) in Geographic Information System. However, the map revealed that some areas in Ilorin which include Coca-Cola Road, Baba Ode, Unity Road, Taiwo Isale, Amilegbe, and others were prone to flood disasters.

Ogunlela and Adelodun[11] worked extensively on flood routing of the Asa River, Ilorin, Nigeria, using the Kinematic wave method. The United States Soil Conservation Service (SCS) method was used to develop the synthetic unit hydrograph using the computed peak discharge and time to peak of the river and the time of concentration was computed using Kirprich's formula. In their work, they reported that the kinematic wave method exhibited some level of accuracy when compared with other methods of flood routing also kinematic wave method took into consideration the watershed characteristics and other hydraulic properties of the channel while the time of concentration of Asa River was computed to be 0.32hr.

The main purpose of this study was to carry out the Flood Frequency Analysis of the Asa River along the Lower Taiwo Watershed using the discharge data of the Asa River. The result from this research provides comprehensive information on possible flow discharge to be expected in the watershed at various return periods based on the observed data. The results obtained would be useful when designing hydraulic structures to prevent predicted flood events.[12]

Methodology

Description of study area

Asa River originated from Oyo State, Nigeria which is the largest river that flows through the city of Ilorin, Kwara State, Nigeria in a South-North direction establishing a dividing boundary between Eastern and Western Ilorin. Asa River is 56 km long, with a maximum width of about 100 m (at the dam site). Asa River has its inlet at River Awon, which is one of the tributaries of River Niger, at 12,200 m North of Ilorin. It is merged with River Imoru and to the East by River Oyun. Afidikodi, Ekoro, and Obe are among the earliest tributaries of the Asa River while its tributaries in Ilorin include River Osere, Atikeke, Okun, Odota, Agba, and Aluko. Also, the Asa River is about 1040 km^2 in area and lies between latitudes $8^0 36'$N and $8^0 24'$N and longitudes $4^0 36'$E and $4^0 10'$E.[11,13] The map of Kwara state showing the study area is presented in Figure 1 and 2 respectively.

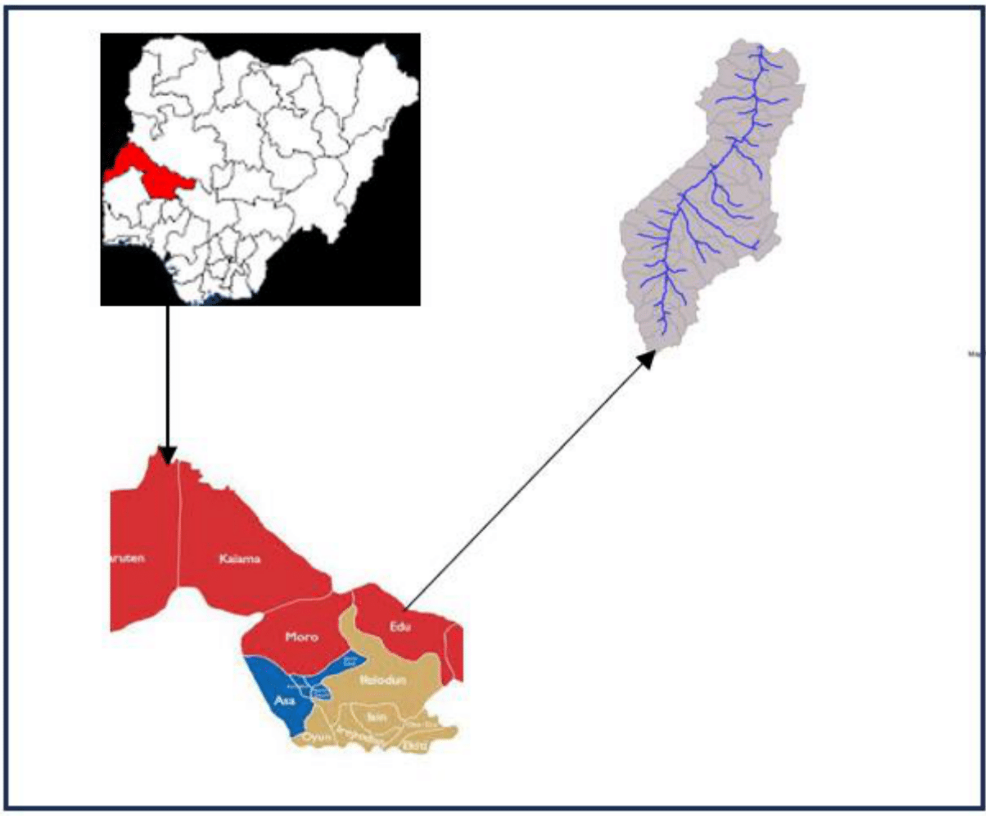

Figure 1 Map of Kwara State Showing the Location of the Study Area.

Source: (Google and Mapwindow SWAT Model).

Figure 2 Abridged Map of River Asa along Lower Taiwo, Ilorin.

Gumbel's extreme value distribution method

Gumbel's distribution is also acknowledged as the Extreme Value Type I distribution and it was introduced by Gumbel in 1945. It is often used in hydrology and other fields to model extreme events such as floods, but to define the designed flood, the criterion called return period (T) is usually used. Nevertheless, in this research, Gumbel's distribution was used to analyze the annual peak discharge data of Asa River, Ilorin, Nigeria from 1990-2020 which was collected from Lower Niger River Basin and Development Authority. The observed discharged data was used to predict the flood discharge for the return periods of 5 years, 10 years, 20 years, 25 years, 30 years yrs, 100 years, and 150 years. The plotting-position formula is;

$$P = \frac{m}{N+1} \tag{1}$$

Where;

P = plotting position/probability of exceedance

N = number of years of event /record

m = order number of the event

Therefore, the return period or recurrence interval is the inverse of the probability of exceedance and it is calculated as,

$$T_r = \frac{1}{p} \tag{2}$$

$$Y = -\ln .\ \ln \frac{T}{T_r - 1} \tag{3}$$

$$\bar{x} = \frac{\sum x}{n} \tag{4}$$

$$\bar{x}^2 = (\bar{x})^2 \tag{5}$$

$$\bar{X}^2 = \frac{\sum X^2}{n}$$

$$S = \sqrt{\frac{n}{n-1}}\left(\bar{X}^2 - \bar{x}^2\right) \tag{6}$$

$$K_T = \frac{Y_T - Y_n}{\sigma_n} \tag{7}$$

$$X_T = x + K_T . S \tag{8}$$

where,

Y_T = Reduce Variate

$\bar{x}$ = Mean

$\bar{x}^2$ = Squared mean

$\bar{X}^2$ Mean of squares

S = Standard deviations

K = Frequency factor

X = Expected flood (Gumbel distribution)

Results and discussion

The Flood Frequency Analysis of Asa River was done following the above procedure and the results obtained are shown in Table 1. Also, a plot of reduced variate against flood peak discharge was plotted for the Asa River, which is shown in Figure 3. However, the expected flood discharges of the study area for return periods of 5 yrs, 10 yrs, 15 yrs, 20 yrs, 30 yrs, 50 yrs, 100 yrs, and 150 yrs, were estimated to be 43.19 m^3/s, 51.12 m^3/s, 55.60 m^3/s, 58.73 m^3/s, 63.11 m^3/s, 68.58 m^3/s, 75.96 m^3/s, and 80.27 m^3/s respectively.

The computation of Gumbel's distribution was done and the results were analyzed in Table 1 and the Reduced Variate was plotted against the Observed Flood Peak discharge in Figure 3 using a scatter plot diagram to show the correlation between them. Also, the expected/estimated flood peak discharge was plotted against the return period in Figure 4 to analyze the flood frequency of the Asa River, Ilorin. The results revealed that the maximum flow of 56.11 m^3/s was recorded in the year 1995 while the lowest flow of 12.09 m^3/s was recorded in the year 2008. The 30-year mean instantaneous flood flow is 32.82 m^3/s. From the trend line equation, R^2 gives a value of 0.9447 which indicates a goodness of fit for the trend line equation and shows that Gumbel's distribution is suitable for predicting likely flood flow in a river or watershed, this conforms with similar studies of Samantaray and Sahoo.[8] The plot also gives the relationship between the anticipated flow discharge and return period as: 10.527x + 27.18 which will enable other values not shown in the chart to be estimated. These and other values obtained will be useful in the Engineering design of hydraulic structures such as reservoirs, culverts, and stormwater drains, to protect lives and properties downstream of the Asa River.

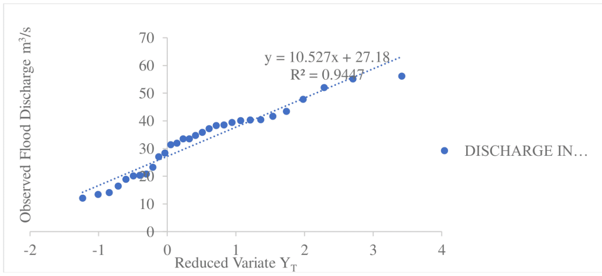

Figure 3 The Plot of Reduce Variate against Observed Discharge of Asa River.

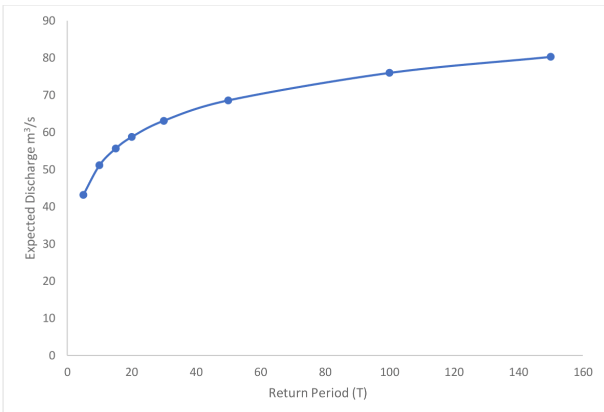

Figure 4 Flood Frequency Analysis of Asa River- Gumbel's Extreme Value Distribution Method.

The important parameters needed for the analysis were computed in Table 2, which shows the various discharges expected alongside their return periods. The results from Table 2 show that the expected stream discharge for return periods of 5 yrs, 10 yrs, 15 yrs, 20 yrs, 30 yrs, 50 yrs, 100 yrs, and 150 yrs, was estimated to be 43.19 m^3/s, 51.12 m^3/s, 55.60 m^3/s, 58.73 m^3/s, 63.11 m^3/s, 68.58 m^3/s, 75.96 m^3/s, and 80.27 m^3/s respectively. The trend line equation gives a better correlation when compared with the R^2 value of 0.954 obtained by Solomon and Prince[4] on Flood Frequency Analysis in Benin City. Also, the flood flow prediction and graphs obtained in this study conform with similar studies of Rao et al.[3] who investigated the flood frequency analysis of the Arainar medium irrigation project in Chittoor District, India, and obtained R^2 value of 0.9803 from the trend line equation, which reveals that Gumbel's extreme value distribution is suitable for estimating predicted reservoir flood flow.[14]

Table 1 Flood Frequency Analysis of Asa River by Gumbel Method (n = 30 years, period 1991-2020)

Year	Discharge	Discharge in descending order	Rank (m)	Probability (n)	Return Period T	Reduced Variate	Discharge X^2
1991	26.95	56.11	1	3.23	31	3.42	3148.33
1992	55.05	55.05	2	6.45	15.5	2.71	3030.5
1993	28.28	51.92	3	9.68	10.33	2.28	2695.69
1994	23.18	47.78	4	12.9	7.75	1.98	2282.93
1995	56.11	43.37	5	16.13	6.2	1.74	1880.96
1996	20.78	41.58	6	19.35	5.17	1.54	1728.9
1997	18.8	40.38	7	22.58	4.43	1.36	1630.54
1998	33.43	40.26	8	25.81	3.88	1.21	1620.87
1999	31.92	40.05	9	29.03	3.44	1.07	1604
2000	14.05	39.41	10	32.26	3.1	0.94	1553.15
2001	33.46	38.47	11	35.48	2.82	0.82	1479.94
2002	16.4	38.25	12	38.71	2.58	0.71	1463.06
2003	13.39	37.13	13	41.94	2.38	0.61	1378.64
2004	38.47	35.85	14	45.16	2.21	0.51	1285.22
2005	47.78	34.64	15	48.39	2.07	0.41	1199.93
2006	31.33	33.46	16	51.61	1.94	0.32	1119.57
2007	41.58	33.43	17	54.84	1.82	0.23	1117.56
2008	12.09	31.92	18	58.06	1.72	0.14	1018.89
2009	40.26	31.33	19	61.29	1.63	0.05	981.57
2010	43.37	28.28	20	64.52	1.55	-0.04	799.76
2011	38.25	26.95	21	67.74	1.48	-0.12	726.3
2012	34.64	23.18	22	70.97	1.41	-0.21	537.31
2013	20.31	20.78	23	74.19	1.35	-0.3	431.81
2014	40.38	20.31	24	77.42	1.29	-0.4	412.5
2015	35.85	20.12	25	80.65	1.24	-0.5	404.81
2016	20.12	18.8	26	83.87	1.19	-0.6	353.44
2017	40.05	16.4	27	87.1	1.15	-0.72	268.96
2018	39.41	14.05	28	90.32	1.11	-0.85	197.4
2019	51.92	13.39	29	93.55	1.07	-1.01	179.29
2020	37.13	12.09	30	96.77	1.03	-1.23	146.17
TOTAL		984.74				16.09	36678

Table 2 Computation of Expected Flood along Asa River

Return period (T)	Mean $\bar{x}$	Standard deviation (S)	Reduced Variate $Y_T = -\ln\ln\frac{T}{T-1}$	Frequency factor (K)	KS	$X = \bar{x} + KS$
5	33	11.76	1.5	0.87	10.19	43.19
10	33	11.76	2.25	1.54	18.12	51.12
15	33	11.76	2.67	1.92	22.6	55.6
20	33	11.76	2.97	2.19	25.73	58.73
30	33	11.76	3.38	2.56	30.11	63.11
50	33	11.76	3.9	3.03	35.58	68.58
100	33	11.76	4.6	3.65	42.96	75.96
150	33	11.76	5.01	4.02	47.27	80.27

Conclusion

The flood frequency analysis of the Asa River was carried out using Gumbel's extreme value distribution method. It shows that the outcomes of the analysis generated from the research give detailed data of possible flow discharge to be expected in the river at the various return periods based on the observed data. This information will be very useful for engineering purposes such as when designing structures in or near the river that may be affected by the flood as well as in designing the flood structure to protect against the expected events. The expected flood discharges of the study area for return periods of 5 yrs, 10 yrs, 15 yrs, 20 yrs, 30 yrs, 50 yrs, 100 yrs, and 150 yrs, were estimated to be 43.19 m^3/s, 51.12 m^3/s, 55.60 m^3/s, 58.73 m^3/s, 63.11 m^3/s, 68.58 m^3/s, 75.96 m^3/s, and 80.27 m^3/s respectively.

Acknowledgments

None.

Conflicts of interest

The author declares there is no conflict of interest.

References

1. Marsh N. *RAP River Analysis package: User guide, version 1.1*. CRC for catchment Hydrology, Australia. 2004.
2. Bates PD, Quinn N, Sampson C, et al. Combined Modeling of US fluvial, pluvial, and coastal flood hazard under current and future climates. *Water resource Res*. 2021;57(2).
3. Rao PS, Ramana MV, Madhusudhana RK, et al. Flood Frequency Analysis of Araniar Medium Irrigation Project in Chittoor District by using Gumbel's Distribution. *International Journal of Environment and Climate Change.* 2022;12(11):538–544.
4. Solomon O, Prince O. Flood Frequency Analysis of Osse River using Gumbel's Extreme Value Distribution, *Civil and Environmental Research*. 2015;3(10):1–6.
5. Bhuyan A. *A statistical study on flood frequency analysis of North-East India (Doctoral dissertation).* 2010;1–164.
6. Nirman B. Flood Frequency Analysis Using Gumbel's Distribution Method: A Case Study of Lower Mahi Basin, India. *Journal of Water Resources and Ocean Science*. 2017;6(4):51–54.
7. Law GS, Tasker GD. *Flood Frequency prediction methods for unregulated streams of Tennessee*. Water Resources Investigations Report 03-4176, Nashville, Tennessee. 2003.
8. Samantary Sandeep, Sahoo Abinash. Estimation of Flood Frequency using statistical methods: Mahanadi River Basin, India. *H2Open Journal*. 2020;3(1).
9. Mokwenye II, Audu HAP. Estimation of Flood Magnitude and Frequency of Escravos Bay in Delta State Nigeria using Log Pearson III Distribution. *FUPRE Journal of Scientific and Industrial Research*. 2020;4(1).
10. Adeniran KA, Ottawale AY, Ogunshina SM. Mapping and Evaluation of Flood Risk Areas along Asa River Using Remote Sensing and GIS Techniques. *FUOYE Journal of Engineering and Technology.* 2018;3(2).
11. Ogunlela AO, Adelodun B. Kinematic Flood Routing of Asa River, Ilorin, Nigeria. *International Journal of Engineering and Technical Research*. 2004;2(3).
12. Izinyon OC, Igbinoba E. Flood Frequency Analysis of Ikpoba River Catchment at Benin City using Log Pearson Type III distribution. *Journal of Applied Emerging Trends Engineering and Applied Science*. 2011;2(1):50–55.
13. Ibrahim KO, Okunlola IA, Abdurrahman A. Trace metal indices in the characterization of hydrogeochemical condition of surface water along Asa River, Ilorin, Kwara State, Nigeria. *International Journal of Geology, Earth and Environmental Sciences*. 2013;3(1):29–35.
14. Hanwat S, Pal K, Panda KC, et al. Flood Frequency Analysis for Burhi Gandak River Basin. *International Journal of Environment and Climate Change*. 2020;10(6):82–89.

Citation: Adebayo HO, Ogunlela AO. Flood frequency analysis of Asa River, Ilorin, Nigeria. *Int J Hydro.* 2024;8(1):15–19. DOI: 10.15406/ijh.2024.08.00368