ANALYSIS OF GUMBEL EXTREME VALUE DISTRIBUTION FOR PREDICTION OF EXTREME FLOOD EVENTS OF RIVER BENUE ALONG IBI, TARABA STATE, NIGERIA.

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Abstract

Prediction of flood frequency is vital for flood management and construction of hydraulic structures. It is on this basis that this study is set to analyse flood frequency of river Benue at Ibi using the Gumbel distribution method. The study applied a 40-year hydrological record of stage / discharge of river Benue at Ibi for the analysis to predict flood flows for return periods (T) 5, 10, 20, 30, 50, 60, 75 and 100 years. The modelled water level / flood flow magnitude obtained for the respective return period are as follows: 11.50m / 9, 864.10 cumecs, 14.20m / 11,481.00 cumecs, 16.80m / 13, 040.23 cumecs, 18.30m / 13,937.02 cumecs, 20.20m / 15,051.00 cumecs, 20.90m / 15,467 cumecs, 22.50m / 16,568.00 cumecs. The results revealed a gradual rise in both water level and flood flow magnitude with increase in return period. The result of goodness of fit test via non-parametric Chi square test returned insignificant, which indicates that the flood flow data fits Gumbel distribution and hence, can be used to predict the frequency of flood flow of river Benue at Ibi. The study recommends that Taraba State Emergency Management Agency (TSEMA) should note and be guided by both short and long term predictive floods of the return periods for appropriate flood response actions to safeguard communities, economic activities and infrastructure from flood dangers.

Keywords: Flood, Hazard, Frequency, River and Model

Introduction

Flooding is a general temporary condition of partial or complete inundation of normally dry areas from overflow of inland or tidal waters or from unusual and rapid accumulation or runoff (Oyatayo *et al*., 2018). Flooding phenomenon is considered the world's worst global hazard in terms of magnitude, occurrence, geographical spread, loss of life and property, displacement of people and socio-economic activities. At least one third of losses due to nature's forces can be attributed to flooding (Jeb and Aggarwal, 2008 cited in Oyatayo, 2021).

In Nigeria, the pattern is similar to the rest of the World. Flooding according to Olajuyigbe, Rotowa and Durojaiye (2012) is the most common environmental hazard in Nigeria. It has occurred in Ibadan (1973, 1985, 1987 and 1990); Yola (1999, 2003). The 2022 flooding events took place between the months of September and October 2022 in Nigeria, due to outflow from the Lagdo dam and Niger-Benue flooding. The worst affected states were Benue, Taraba, Adamawa, Kogi, Bayelsa, Jigawa and Anambra. This flood incident has been characterized as the most devastating since the last ten years. The flood submerged houses, severed transportation routes throughout the affected areas. Overall, an estimated 1.4 million people were displaced and about 603 people lost their lives. In addition, over 332, 327 hectares of land were affected (United Nations Audiovisual Library, 2022).

In the planning and design of water resources projects, engineers, hydrologist and planners are often interested to determine the magnitude and frequency of floods that will occur at the project area. Besides the rational method, unit hydrograph method and rainfall-runoff models method, frequency analysis is one of the main techniques used to define the relationship between the magnitude of an event and the frequency with which that event is exceeded (Bhagat, 2017). Flood frequency analysis is the estimation of how often a specified event will occur. Before the estimation is carried out, analysis of the stream flow data plays a very important role in order to obtain a probability distribution of floods (Bhagat, 2017).

Flood frequency analysis involves the fitting of a probability model to the sample of annual flood peaks recorded over a period of observation, for a catchment of a given region. The model parameters established can then be used to predict the extreme events of large recurrence interval. Reliable flood frequency estimates are vital for floodplain management; to protect the public, minimize flood related costs to government and private enterprises, for designing and locating hydraulic structures and assessing hazards related to the development of flood plains (Bhagat, 2017). Bearing this in mind, there exist paucity of research on flood frequency analysis of river Benue at Ibi watershed using the Gumbel extreme value distribution. This has made the application of Gumbel extreme value distribution to model annual peak level and flood flow magnitude necessary in Ibi watershed with a view to protect the public and enhance proper management of hydraulic structures in the study area.

Study Area

Location

Ibi local government is located on Latitude 8°10' 58 N of the Equator and Longitude 9° 44' 42 E of the Greenwich Meridian. It has an area of 2,672km2. The town is located on the south bank of the River Benue, opposite the influx of the much smaller Shamankar River. Both the River Taraba and River Donga flow into the River Benue within the Local Government Area (LGA). It shares boundary with Plateau state in the North, Nasarawa state in the west, Wukari Local Government Area (LGA) in the south, Gassol Local Government Area (LGA) in the East, while with Karim Lamido Local Government Area (LGA) in North East. It is located in the Southern part of Taraba State. Ibi is the headquarters of Ibi Local Government Area (Andokari, 2017).

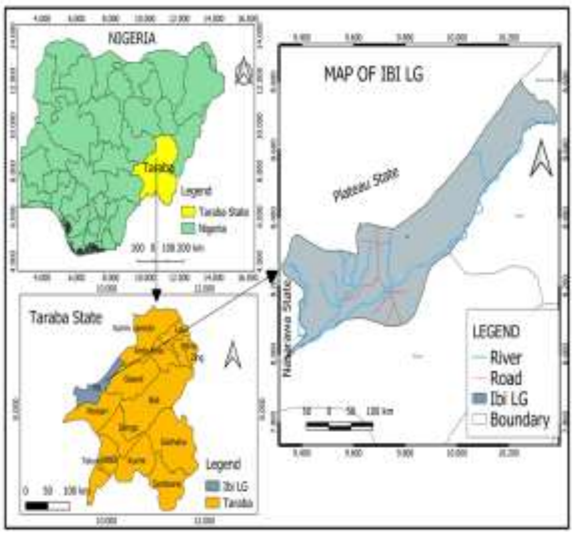

Figure 1.1: Map of Nigeria Showing Study Area
Source: Ministry of Land and Survey, Jalingo

Climate

The climate in Ibi is tropical, marked by wet and dry seasons. The climate here is classified as Tropical wet and dry (Aw) by the Koppen-Geiger system. The average annual temperature in Ibi is 27.2 °C. About 1,087 mm of precipitation falls annually. The rainy season spans between early May and late October, while the dry season starts from November to March. The rainy season reaches its peak in August and start retreating from late September (Andokari, 2017).

Vegetation

Ibi falls within the Southern guinea savannah zone. Vegetation is very vigorous during the wet season and the foliage winter in dry season, the vegetation cover consists of mainly trees, savannah with shrubs and grasses. This zone is characterized by the mixture of trees species; some of them loose their leaves for only a short period in the year (Andokari, 2017).

Geology and Soil

Ibi local government area is situated within the Benue trough which is almost 5,500M. The soil types are mainly ferruginous tropical soil which developed on crystalline acid rocks and sandy parent minerals (Andokari, 2017). Lateritic crust is widely spread in the west, the soils are deep well drained and medium to coarse textured (Andokari, 2017).

Population

Ibi Local Government Area has diverse ethnic groups which include Jukun, Chamba, Ichen, Hausa, Tiv and Fulani. According to the 2006 census figure released by the National Population Commission (NPC), Ibi local government area has a total population of 84,054 people (Andokari, 2017).

Economic and Human Activities

Most of people living in Ibi local government area engage in primary activities, such as fishing, farming, hunting e.t.c. Farm produce such as rice, yam, cassava, maize, groundnut, and beniseed among others are the major crops grown in the study area. The Nwonyo fishing festival is one of the major fishing festival in the area (Andokari, 2017).

Materials and Methods

In order to achieve the objectives of this study, the methodology adopted for this study is sub-divided into the following:

i. Reconnaissance survey
ii. 40 years hydro-logical record of river stage and discharge for river Benue at Ibi
iii. Method of data analysis

Reconnaissance Survey

This was embarked upon in order to have good understanding of the study area, and to give a real time site assessment and also to acquire information about the environment which may not be available on the topography map.

Hydrological Record of Stage / Discharge

In order to achieve the objectives of the study, the annual maximum river stage and discharge data of River Benue at Ibi from 1976 to 2016 was obtained from the archives of National Inland Water Authority (NIWA), Lokoja and Taraba State Water Board, headquarter, Jalingo.

Method of Data Analysis

Flood frequency analysis:

Flood frequency analysis to determine return periods of extreme flood events using observed annual peak flow from river stage and discharge data was conducted. Gumbel distribution is a statistical method often used for predicting extreme hydro-logical events such as flooding (Jeb and Aggarwal, 2008). In this study, it was applied because:

i. Peak discharge and stage data are homogenous and independent, hence, lack long term trends.
ii. The river is less regulated; hence, it is not significantly affected by reservoir operations and
iii. Flow data cover a relatively long record and is of good quality

Peak level gauge and discharge data for forty (40) years were used for the analysis. Gumbel defines floods as the largest of the 365 daily flows and the annual series of flood flows constitute a series of largest values flows. The equation is given as (Jeb and Aggarwal, 2008):

$$S_T = X + K \times SDV \quad - \quad - \quad (1)$$

Where

S_T = value of variate with a return period "T"
X = means of variate

SDV = standard deviation of the sample
K = Frequency factor expressed as
$K = (Y_t – Y_n)/S_n$
Y_t = reduced variate expressed by:
$Y_t = (LN \times LN)\ (T/T - 1)$
Where
T = return period
Y_n = reduced mean from table
LN = median
S_ns reduced standard deviation from table

Test of goodness of fit

The Chi-square (χ 2) test was carried out to find goodness of fit between the measured and predicted flood flows in Ibi watershed. It was applied to test the hypothesis that the flood data fit Gumbel distribution in river Benue at Ibi.

Results

Table 4.1 shows modeled water level and magnitude for Ibi drainage basin. Floods with 100, 75, 60, 50, 30, 20, 10 and 5-year recurrence interval will have 1.0%, 1.33%, 1.70%, 2.0%, 2.33%, 5%, 10% and 20% chance of occurrence in any given year. In Ibi catchment, 5, 10, 20, 30, 50, 60, 75 and 100 year flood flow would have the following river stage and magnitude: 11.50m / 9,864.10 cumecs, 14.20m / 11,481.00 cumecs, 16.80m / 13,040.23 cumecs, 18.30m / 13,937.02 cumecs, 20.20m / 15, 051 cumecs, 20.90m / 15,467.00 cumecs, 21.50m / 15,940 cumecs and 22.50m / 16,568m cumecs. The annual maximum stage and discharge data of river Benue at Ibi shows that the highest river stage and discharge of 10.21 meter /12,280 cumecs was recorded in the hydro-logical year 1997 and the least of 3.26 meter / 475 cumecs was recorded in the hydro-logical year 1999 as shown in appendix A. Table 4.1 shows that as the modeled river stage and magnitude increases, the recurrence interval increases, while exceedance probability reduces. This goes to show that flood flow with high recurrence interval have low exceedance probability and is accompanied by high river stage and magnitude. This flood flow does not occur frequently, but when it occurs, it inundates more land area and thus present higher risk (Oyatayo, 2021). The hydro-logical implication of this finding is that floods with 100, 75 and 50-year recurrence interval in Ibi drainage basin, have lower exceedance probability, but will have far reaching impact in low lying areas with gentle slope, because it is accompanied by flood flow with high river stage and magnitude. This confirms the works of Oyatayo *et al*. (2017) in Donga River Basin, Shakirudeen and Saheed (2014) in Lower Ogun River Basin whose research on flood frequency analysis reported that flood flows with higher recurrence interval and low exceedance probability have high river stage and magnitudes and thus posits that such flood flows constitute high risk when they occur, because it inundates more land area.

Table 4.1: Modeled Water Level and Magnitude

S/N	Recurrence Interval	Exceedance probability percent	Frequency Factor (K)	Mean Stage	STD	Stage Level (m)	Mean Magnitude (m^3/sec)	STD	Magnitude (m^3/sec)
1	5	20.00	0.829	8.1	4.15	11.50	7,799	2,491.08	9,864.10
2	10	10.00	1.478	8.1	4.15	14.20	7,799	2,491.08	11,481.00
3	20	5.00	2.104	8.1	4.15	16.80	7,799	2,491.08	13,040.23
4	30	2.33	2.464	8.1	4.15	18.30	7,799	2,491.08	13,937.02
5	50	2.00	2.913	8.1	4.15	20.20	7,799	2,491.08	15,051.00
6	60	1.70	3.078	8.1	4.15	20.90	7,799	2,491.08	15,467.00
7	75	1.33	3.268	8.1	4.15	21.50	7,799	2,491.08	15,940.00
8	100	1.00	3.520	8.1	4.15	22.50	7,799	2,491.08	16,568.00

Source: Field Work, 2022

Flood frequency analysis of this nature is a multi-dimensional tool used in the assessment of water resource potential as well as both hydro-logic and hydraulic measure that must be integrated in the engineering construction of structures that concern a defined water body. In addition, this measure is a tool of necessity to ascertain the extent of inundation based on hydro-logic data. It provides the data frame for inundation area mapping as well as for the assessment of flood hazard and risk within an area (Shakirudeen and Saheed, 2014). Okonofua and Ogbeifun (2013) reported that since man does a lot of activities on the flood plain, it has become important for him to protect it against flood. Some of the structures used by man to control flood are levees, reservoir and channel improvement. For an economic and efficient design of these measures, flood has been estimated with some level of accuracy. Once an estimate of maximum or peak flood which occur in a particular site can be estimated, an ideal solution can then be proffered by a hydraulic Engineer.

Flood Frequency: Test of Goodness to Fit

It is necessary to confirm if the observed flood data collected in river Benue at Ibi follows the Gumbel's distribution or not. The non-parametric statistic used to ascertain the goodness to fit is the Chi-square statistic. As observed by Shakirudeen and Saheed (2014), the Chi square distribution is an excellent measure of goodness to fit owing to its inherent statistical properties for test of association and homogeneity. Using Chi square distribution, the following null hypothesis was tested as shown in Table 4.2:

H_0: There is no significant difference between observed and expected flood flow data in river Benue at Ibi

Decision Rule

The Chi square calculated and tabulated values at 0.05 level of significance and 7 degree of freedom goes thus:

Calculated Chi square value = 5.02

Tabulated Chi square value = 14.07

From the foregoing, the null hypothesis is accepted; the Chi square test revealed a satisfactory fit between observed and estimated flood flows in river Benue at Ibi. This indicates that the flow data fit Gumbel distribution and hence, Gumbel distribution can be used to predict the frequency of floods of river Benue at Ibi. This corroborates the findings of Oyatayo (2021), who conducted a study on flood frequency analysis of river Benue at Makurdi and presented a result of measured and expected flood flows showing no differences, hence, a goodness to fit of the Gumbel distribution.

Table 4.2: Computation of Goodness to Fit for Gumbel Distribution

S/N	Return Period	Observed Gauge height (m)	Expected Gauge height (m)	(O – E)	$(O – E)^2$	$(O – E)^2/E$
1	5	11.50	18.24	-6.74	45.42	2.49
2	10	14.20	18.24	-4.04	16.32	0.24
3	20	16.80	18.24	-1.44	2.07	0.11
4	30	18.30	18.24	0.06	0.004	0.0002
5	50	20.20	18.24	1.96	3.84	0.21
6	60	20.90	18.24	2.66	7.08	0.39
7	75	21.50	18.24	3.25	10.63	0.58
8	100	22.50	18.24	4.25	18.15	1.00

X^2=1.024

Summary

This study has attempted to conduct flood frequency analysis using Gumbel extreme value distribution. The results of extreme value distribution analysis using the Gumbel statistics show that 5, 10, 20, 30, 50, 60, 75 and 100 year return periods have the following river stage and magnitude: 15.50m, 14.20m, 16.80m, 18.30m, 20.20m, 20.90m, 21.50m and 22.50m. The goodness to fit test attests to the fact that the Gumbel statistical distribution can be used to for the simulation of flood flow and magnitude in river Benue at Ibi.

Conclusion

A combination of annual maximum flood stage and discharge data enabled the estimation of river stage and magnitude of flood flow in Ibi watershed for different return periods. The study concludes that the model will give a reasonable estimate of peak flood discharge and river stage for any desired value of T, without any instrumentation and time consuming field work. Also, it can be concluded that as the modeled river stage and magnitude increases, the recurrence interval increases, while exceedance probability reduces in Ibi watershed.

Recommendations

Based on the findings of this study, the following are therefore recommended:

- Taraba State Emergency Management Agency (TSEMA) should note and be guided by both short and long term predictive floods of the return periods for appropriate flood response actions to safeguard communities, economic activities and infrastructure from flood dangers
- TSEMA should adopt emergency evacuation by propagating well advanced flood warning that may save thousands of live from the menace of flood in the study area.
- Taraba State Environmental Protection Agency should ensure full compliance of development guidelines for Ibi town as regards the encroachment of flood plains.
- Findings from this study should be adopted for the construction of hydraulic structures in the study area.

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APPENDIX A

s/n	Year	River Stage (m)	Mean	Standard Deviation	Discharge (m3/sec)	Mean	Standard Deviation
1	1976	9.4	8.1	4.15	10,558	7,799	2,491.08
2	1977	7.12	8.1	4.15	5506	7,799	2,491.08
3	1978	7.85	8.1	4.15	7106	7,799	2,491.08
4	1979	7.54	8.1	4.15	6462	7,799	2,491.08
5	1980	7.96	8.1	4.15	7320	7,799	2,491.08
6	1981	7.32	8.1	4.15	5917	7,799	2,491.08
7	1982	6.25	8.1	4.15	3850	7,799	2,491.08
8	1983	7.89	8.1	4.15	7221	7,799	2,491.08
9	1984	7.44	8.1	4.15	6247	7,799	2,491.08
10	1985	7.42	8.1	4.15	6132	7,799	2,491.08
11	1986	6.81	8.1	4.15	4886	7,799	2,491.08
12	1987	9.46	8.1	4.15	10660	7,799	2,491.08
13	1988	9.36	8.1	4.15	10320	7,799	2,491.08
14	1989	8.84	8.1	4.15	9436	7,799	2,491.08
15	1990	9.33	8.1	4.15	10320	7,799	2,491.08
16	1991	9.65	8.1	4.15	11000	7,799	2,491.08
17	1992	9.02	8.1	4.15	9657	7,799	2,491.08
18	1993	8.78	8.1	4.15	9215	7,799	2,491.08
19	1994	8.99	8.1	4.15	9657	7,799	2,491.08
20	1995	8.37	8.1	4.15	8314	7,799	2,491.08
21	1996	9.16	8.1	4.15	10116	7,799	2,491.08
22	1997	10.21	8.1	4.15	12280	7,799	2,491.08
23	1998	9.89	8.1	4.15	9674	7,799	2,491.08

24	1999	3.26	8.1	4.15	475	7,799	2,491.08
25	2000	7.85	8.1	4.15	7336	7,799	2,491.08
26	2001	8.17	8.1	4.15	7736	7,799	2,491.08
27	2002	9.73	8.1	4.15	9674	7,799	2,491.08
28	2003	7.91	8.1	4.15	9336	7,799	2,491.08
29	2004	8.61	8.1	4.15	9164	7,799	2,491.08
30	2005	6.56	8.1	4.15	4316	7,799	2,491.08
31	2006	8.52	8.1	4.15	9164	7,799	2,491.08
32	2007	8.29	8.1	4.15	8246	7,799	2,491.08
33	2008	8.67	8.1	4.15	9164	7,799	2,491.08
34	2009	7.71	8.1	4.15	7336	7,799	2,491.08
35	2010	6.36	8.1	4.15	4080	7,799	2,491.08
36	2011	5.88	8.1	4.15	3220	7,799	2,491.08
37	2012	8.28	8.1	4.15	8246	7,799	2,491.08
38	2013	7.25	8.1	4.15	5950	7,799	2,491.08
39	2014	7.08	8.1	4.15	5444	7,799	2,491.08
40	2015	8.86	8.1	4.15	9351	7,799	2,491.08
41	2016	9.01	8.1	4.15	9674	7,799	2,491.08