Gumbel Distribution-Based Flood Frequency Analysis for Coastal Flood Risk Assessment in Ugborodo Community, Niger Delta, Nigeria

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Flooding is a prevalent natural disaster affecting coastal regions worldwide. Flood frequency analysis is essential for understanding the frequency and magnitude of flood events within a catchment, providing critical insights for developing effective flood management strategies. This study aims to predict the magnitude and recurrence of flood events in the Ugborodo community. Gumbel distribution which is a statistical method was used in this study to predict flood occurrences in Ugborodo community, a coastal community in the Niger Delta region of Nigeria. The analysis reveals the magnitude, return period, and recurrence frequency of floods in the catchment, as well as estimates of flood discharge at various exceedance probabilities or recurrence intervals. Using the Gumbel distribution method, the findings show that the expected flood increases as the return period (T) in years increases. For 2yrs, 5yrs, 10yrs, 25yrs, 50yrs, 100yrs and 200yrs return periods, the expected flood are 9688.77m^3/s, 12081.13m^3/s, 13665.06m^3/s, 15666.39m^3/s, 17151.09m^3/s, 18624.82m^3/s, 20093.17m^3/s respectively. The results of this study contribute to informed decision-making and disaster preparedness in the Ugborodo community by strengthening resilience and minimizing the adverse impacts of flooding on the coastal region**.** The results of this study offer valuable contributions to informed decision-making and disaster preparedness in the Ugborodo community by enhancing resilience and reducing the adverse effects of flooding in this coastal region. The findings provide insights into the planning and design of flood control structures across the floodplain. Furthermore, the findings from this study serve as a resource for stakeholders, including policymakers, engineers, and community planners, to effectively assess flood risks and implement resilient infrastructure and targeted mitigation strategies tailored to the unique vulnerabilities of the area.
Keywords: Gumbel distribution, Flooding, Flood frequency analysis, Hydrological modelling, Return period, Ugborodo community

Introduction

Flood is a natural disaster the world is faced with (Gaume *et al.*, 2016; Onen & Bagatur, 2017), leaving negative impacts on humans and the environment (Hassan *et al.*, 2019; Ali & Rahman, 2022; Echogdali *et al.*, 2022). Because of global warming, flooding has become a worldwide problem and calls for concern to scientists, engineers, and environmentalists. Most flooding events can be attributed to weather-related hazards, and the effects of climate change on the earth (Gaume *et al.*, 2016), such as rise in sea level (Zamir *et al.*, 2021) as climate change is on the increase, coastal areas will always be affected due to rise in sea level (Runkle *et al.*, 2018; Toimil *et al.*, 2020), a well secured coastal area is an immensurable treasure to a country as activities done in the area can enrich the nation (Cetin, 2016). Floods happen when natural or artificial banks receive too much water than they can contain, either from heavy rain, snow, or other natural disasters (Lumbroso *et al.*, 2016), and the extent to the flood event determines its classification to be either flash or extreme (Turkington, *et al.*, 2016). Flash floods happen quickly, mainly from excess precipitation or dam malfunction (Pregnolato *et al.*, 2017; Marchi *et al.*, 2010), having severe consequences on the environment, destroying plants and damaging infrastructures (Hapuarachchi *et al.*, 2011). While extreme floods can be caused by a tsunami or a large storm that causes a storm surge, understanding the causes and occurrences of extreme floods is essential in managing flood events of a large magnitude in the future. (Lionello *et al.*, 2021; Fischer & Schumann, 2021). Extreme flooding can affect both developing and developed countries' economic activities. When this happens, a large amount of water overflows beyond its normal limits, spreading over a large area of land, which is termed a flood. It is one of the most pervasive in humans' activities (Allahbakhshian-Farsani, 2020) and requires flood defenses, evacuation, forecasting and management (Baidyaet *et al.*, 2020), lack of proper flood protection strategies and prevention structure can lead to a catastrophic situation for a country (Hickey & Salas, 1995). Flooding is a weather-related hazard (Taylor *et al.,* 2014; Val *et al.,* 2014) that occurs virtually anywhere around the globe, often because of heavy rainfall or melting snow, and can compromise water supplies (Howard *et al.,* 2010). Vast knowledge of the occurrence of floods will aid an engineer in constructing structures to best fit the environment (Dodangeh *et al.,* 2020), as adequate flood management will save the catchment from a destructive situation (Bhagat, 2017).

The act of forecasting flood occurrence is difficult but a way to manage floods of various magnitudes that affects communities (Jain *et al.,* 2018) as models are essential in predicting floods outcomes (Campolo, 1999) magnitude, frequency, occurrence, and peak discharge are the aim of flood frequency analysis (Rahman *et al.,* 2020). A safe and reliable way of predicting flood peak for a region/catchment (Bhagat, 2017), and is displayed as a flood frequency curve, important in hydraulic structures designed for flood prevention. Flood predictions can be achieved via different methods such as Gumbel distribution (Okonofua & Ogbeifun, 2013), Normal, Lognormal, Log-Pearson Type III Distribution (LP-III) (Pawar & Hire, 2018), L-Moments Method (de Souza *et al.,* 2021), and Logarithmic Method. Amongst the distribution methods for predicting flood occurrences, Gumbel distribution can be a good way to predict floods depending on the specific situation (Lawrence, 2020). As a result, it is used to predict the outcome of an extreme weather event over a period. (Onen, & Bagatur, 2017). The derived and statistical techniques are the two main techniques for flood frequency estimation. Derived technique is less concerned about historical data, while the statistical technique is the traditional method of fitting probability distributions to observed stream flow data. Often Gumbel distribution is used to predict large flow of floods (Lawrence, 2020). Some characteristics of floods are volume, duration, and peak flow (Mukherjee, 2013). Statistical probability aids in predicting flood occurrence, magnitude, and risk (Holmes & Dinicola, 2010) as flood flows at different recurrence intervals for a catchment are challenging (Law & Tasker, 2003). Accurate estimates of extreme flood events are essential for planning with knowledge of the return period for better design of hydraulic structures in a coastal area (Ehiorobo & Izinyon, 2013). Flood frequency analysis helps design flood control structures in a coastal area. This may include the design of bridges, dams, leaves, etc. (Han *et al.,* 2022) aiding in minimizing large extent of flood-related disasters, also assisting considerably in storm water management in the catchment with proper flood risk management program (England *et al.,* 2019) although proper flood estimation can be a tussle (Onen & Bagatur, 2017) as humans perform their activities on the flood plain and it is affected by flood, leading to loss of crops, animal and other disaster (Smakhtin *et al.,* 2015).

Climate change is a threat to the world (Brown *et al.,* 2007; Watts *et al.,* 2015; Forzieri *et al.,* 2017; Chan, 2018), having varying impacts on communities around the globe (Kerr, 2007). Low-income countries are more vulnerable to weather-related hazards as compared to high-income countries (Lumbroso *et al.,* 2016). Industrial activities are a leading cause of global warming, due to greenhouse gas emissions (Betts, 2011; Mohajan, 2017; Han *et al.,* 2022; Kamran *et al.,* 2023), leading to a reduction in economic activities (IPCC, 2018). Global warming threatens the environment (Song *et al.,* 2022), causing a rise in sea level and affecting communities close to the ocean, such as Ugborodo.

Flood risk assessment in Nigeria has received growing attention due to the increasing frequency and severity of flood events, particularly in coastal and deltaic regions. Prior studies, such as Ibitola (2009), explored hydrodynamic fluxes in the Escravos and Forcados basins, while Ojinnaka *et al.* (2021) and Ibeje, (2020) applied Log-Pearson Type III distribution for flood frequency analysis along the River Niger. Although GIS and Remote Sensing tools have been widely used (Komolafe *et al.,* 2015), they remain insufficient for fully capturing flood intensity and extent. Shuaibu *et al.* (2022) integrated GIS with Analytical Hierarchical Process (AHP) to assess risk in the Hadejia River Basin, revealing high vulnerability driven by physical and socio-economic factors. Recent advances using Sentinel-1 SAR imagery (Abubakar & Dodo, 2024) highlight the progression of flood geohazards, yet such methods are rarely applied to underrepresented coastal settlements.

Few studies have employed the Gumbel distribution model in Nigeria (e.g., Okonofua & Ogbeifun, 2013; Okonofua *et al.,* 2022; Adebayo & Ogunlela, 2024), and fewer still in Niger Delta Region. This study addresses that gap by applying Gumbel's model to Ugborodo, a flood-prone coastal community in the Niger Delta. By generating site-specific flood predictions from 12 years of tidal discharge data, it provides statistically robust insights essential for local infrastructure planning and early warning systems. Unlike broader or inland-focused studies, this research contributes a replicable approach for modelling flood risks in vulnerable Niger Delta region, supporting both academic and practical flood resilience efforts.

Study Area

Ugborodo is a coastal community located in Warri South-West Local Government Area of Delta State, in the Niger Delta region of Southern Nigeria. The community lies between the Atlantic Ocean to the south and the Escravos River to the north, and it is located adjacent to major oil and gas operations, including the Chevron Nigeria Limited facility at Escravos. Ugborodo comprises several sub-settlements, which are: Ajudaibo, Ijaghala, Madangho, Ode-Ugborodo, and Ogidigben (Jim-Dorgu *et al.,* 2022). Ugborodo community is situated approximately between latitudes 5.55° to 5.60° N and longitudes 5.17° to 5.31° E. This location is indicative of a broader area, as Ugborodo spans a linear coastal stretch with both residential and ecological significance. Its strategic location within the Niger Delta makes it a critical area for studying the environmental and socio-economic impacts of coastal flooding and oil exploration. The primary occupations of the indigenous people of the Ugborodo community include artisanal fishing, subsistence farming, and local trading.

Due to the community's closeness to the ocean, it has been threatened by high sea levels, which may result in the loss of lives and properties if urgent measures are not taken. Over the years, several oil spills have been recorded in the area, which have affected the environment and have left environmental pollution problems with visible physical destruction (Kadafa, 2012; Akinwumiju *et al.*, 2020). Oil exploration activities done within the area have polluted the brook, river, and ocean and brought negative effects on Indigenous people (Ukeje, 2004; Eriegha & Sam, 2020), including threatening the agricultural and economic activities within the community (Omatete, 2000; Eyitsede, 2010; Jim-Dorgu *et al.*, 2022).

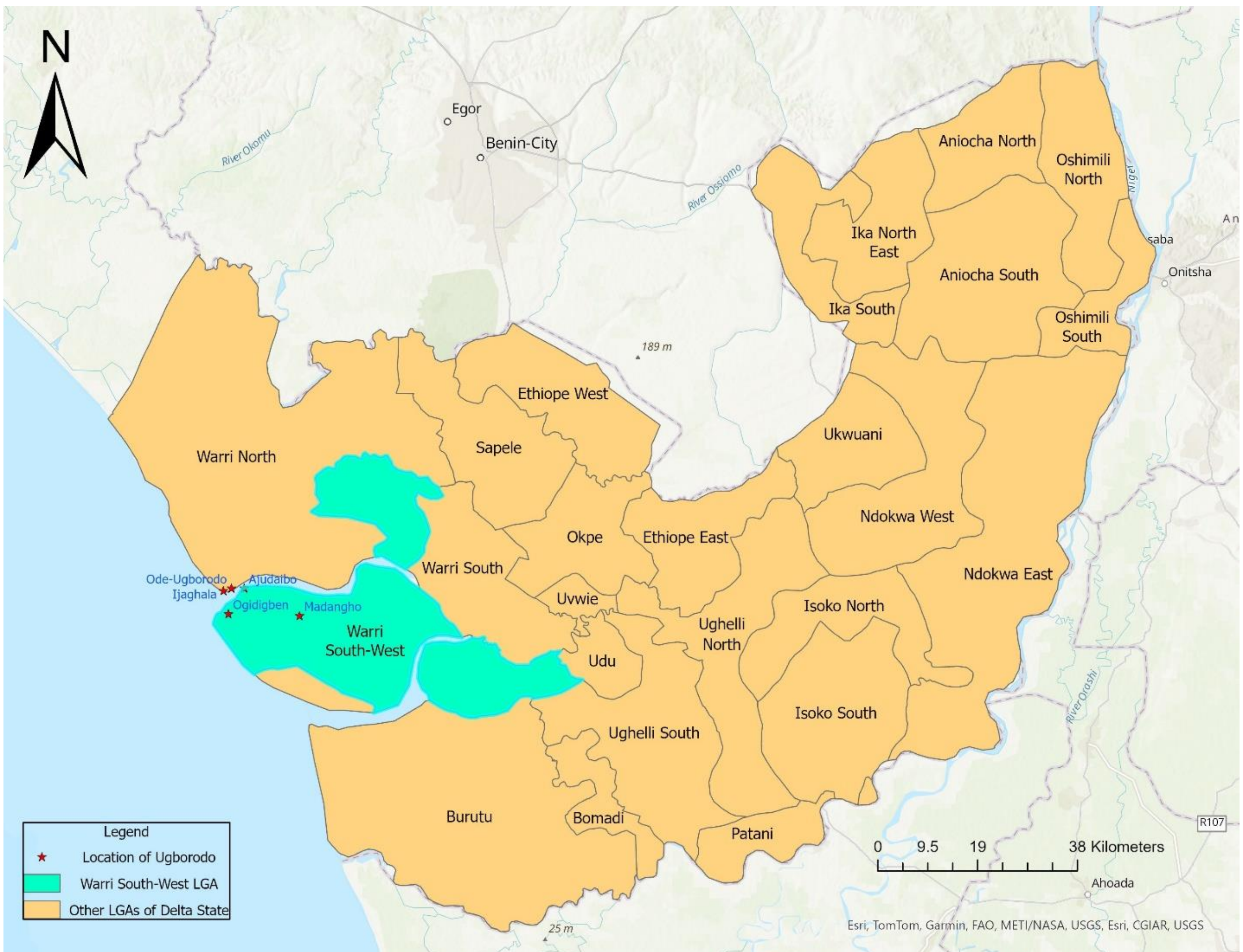

Figure 1: Map of the study area

Research Methodology

Theory of Gumbel distribution

Gumbel's distribution or EV-1 (Extreme value type 1) is a statistical method mostly used to analyse and predict the occurrence of hydrological events such as floods (Lawrence, 2020). Gumbel distribution is a widely used and dependable method for modelling extreme flood events, offering reliable flood prediction depending on the specific characteristics of the flood scenario (Onen & Bagatur, 2017). Gumbel stated that the probability of the occurrence of an event equal to or longer value X_o is expressed as (Shaw, 1983):

$$P(X \geq X_o) = 1 - e^{-e^{-y}} \quad \text{(Equation 1)}$$

As y is a dimensional variable

$$y = \alpha(X - \beta) \quad \text{(Equation 2)}$$

$$\alpha = \frac{1.28255}{S_x} \quad \text{(Equation 3)}$$

$$\beta = \bar{x} - 0.45005Sx \quad \text{(Equation 4)}$$

$S_{X=}$ Standard deviation (SD) for X

$$y = \frac{1.2825}{S_x}(X - \bar{X}) + 0.577 \quad \text{(Equation 5)}$$

The value of $\bar{X}$ for a given probability (p) is required for a given data.

$P(X \geq X_o) = 1 - e^{-e^{-y}}$ is transposed as $Y_{(p)}$

$Y_{(p)}$ = the value of variate y for a given probability (p) and taking logarithms on both sides to base two, will give

$$= -\ln[-\ln(1-p)] \quad \text{(Equation 6)}$$

$$p = \frac{1}{T}$$

Applying

$$Y_{(T)} = -[\ln.\ln\frac{T_r}{T_r - 1}] \quad \text{(Equation 7)}$$

Equation (2) becomes:

$$Y_{T} = \frac{1.2825}{S_x}[X_T - \bar{X}] + 0.577 \quad \text{(Equation 8)}$$

$X_{(T)=}$ Is the value of X for a return period of T

$$X_T = \bar{X} + K.S_x \quad \text{(Equation 9)}$$

$$K = \frac{Y_{(T)} - 0.577}{1.2825} \quad \text{(Equation 10)}$$

Frequency factor K, as N is smaller and of finite value,

$$K = \frac{Y_{(T)} - \overline{Y_n}}{\sigma_n} \quad \text{(Equation 11)}$$

$\overline{Y_n}$ is reduced mean and σ_n reduced standard deviation with 0.577 and 1.2825 as maximum values. Gumbel's Extreme value distribution is the table from which the values were obtained. The equations for the Gumbel distribution, as given by Okonofua and Ogbeifun (2013) were adopted.

Hydrological analysis using Gumbel's method

Data were obtained from the Escravos Bay tidal records in Ugborodo, which agreed with the findings of Ibitola (2009) on the hydrodynamic flux of Escravos and Forcados rivers. Present data on floods is needed to forecast future occurrences (Kamal, 2017). Gumbel's distribution was applied to the discharge maximum data of Escravos River at Delta state, Nigeria, from 2000-2011 (12 years' data).

The steps carried out in this study using Gumbel's distribution are given below.

Step 1: The Annual maximum flow data for Ugborodo River from the year 2000-2011 was used as shown in Table 1.

Step 2: The peak flow data was rearranged in descending order (highest to lowest) then the total sum and average flow were obtained.

Step 3: For n years maximum data of flood, the standard deviation (SD) σ_x and mean $\bar{X}$ are gotten with:

$\sum_{i=1}^{n} x_i$ and $\boldsymbol{\sigma_x} = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(x - \bar{x})^2}$

Step 4: Gumbel's Distribution reduced extreme table was used to obtain the value of $\overline{y_n}$, σ_n from n.

Step 5: For the return period ($\boldsymbol{T_r}$) given in years, equation (7) is used to compute the reduced variate.

Step 6: $Y_{(T)}$, $\overline{y_n}$, σ_n were used to obtain the frequency factor, K_T using equation (11).

Step 7: The Expected flood is obtained using equation (9).

Results and Discussion

Table 1 annual maximum discharge records from Escravos Bay tidal gauge (2000–2011), used for flood frequency analysis using the Gumbel distribution.

Table 2. Statistical analysis of annual peak discharge values, including descending order ranking, standard deviation (S.D.) components, return period (T), and reduced variate (Y) for flood frequency estimation.

Table 1: Record from Escravos Bay tidal gauge

Year	Annual Maximum flow (m^3/s)
2000	12358
2001	9865
2002	11321
2003	5893
2004	12300
2005	9562
2006	11721
2007	6986
2008	9851
2009	12001
2010	7565
2011	10201

Table 2: The calculation table

Year	Flood peak (m^3/s)	Descending order (m^3/s) of flood peak	Order (m)	$s_{x^2 = (n-\bar{x})^2}$	Return period $T_{r = \frac{n+1}{m}}$	Reduced variate $Y = -[\ln \ln \frac{T_r}{T_r - 1}]$
2000	12358	12358	1	5664796.672	13	2.525194941
2001	9962	12300	2	5392071.005	6.5	1.789437659
2002	11321	12001	3	4092866.172	4.333333	1.33802133
2003	5893	11721	4	3038339.506	3.25	1.000420501
2004	12300	11321	5	1803872.839	2.6	0.722559893
2005	9562	10201	6	49766.17346	2.166667	0.4795868798
2006	11721	9962	7	253.3402884	1.857143	0.2572307256
2007	6986	9865	8	12750.17369	1.625	0.04550853732
2008	9865	9562	9	172986.6739	1.444444	-0.1643745421
2009	12001	7565	10	5822166.842	1.3	-0.3827675012
2010	7565	6986	11	8951565.342	1.181818	-0.6269021498
2011	10201	5893	12	16686544.18	1.083333	-0.9419401743
SUM		**119735**		**51687978.93**		
AVERAGE		**9977.916667**				
S.D.				**2167.696283**		

n = Total number of years recorded (12 years)

m = Arrangement in descending order the annual flood series, having the highest flood peak as 1

S.D. = Standard deviation

Figure 2 shows a Gumbel probability plot used to analyse the annual maximum flood peaks of the Escravos River in Delta State, Nigeria. The x-axis represents the reduced variate (Y), which is a transformation of the exceedance probability, while the y-axis shows the observed flood peak values. The blue dots indicate the empirical data, and the black line is a linear regression fit representing the relationship between the reduced variate and the flood peak. The regression equation $y = 1939.4x + 9008.2$ allows for the estimation of flood magnitudes corresponding to various return periods, which is essential for flood risk management and infrastructure planning. The coefficient of determination $R^2 = 0.8281$indicates a strong correlation, meaning that approximately 82.8% of the variation in flood peaks is explained by the Gumbel distribution model. Microsoft Excel (Version 16.0) was used for organizing and analysing the dataset.

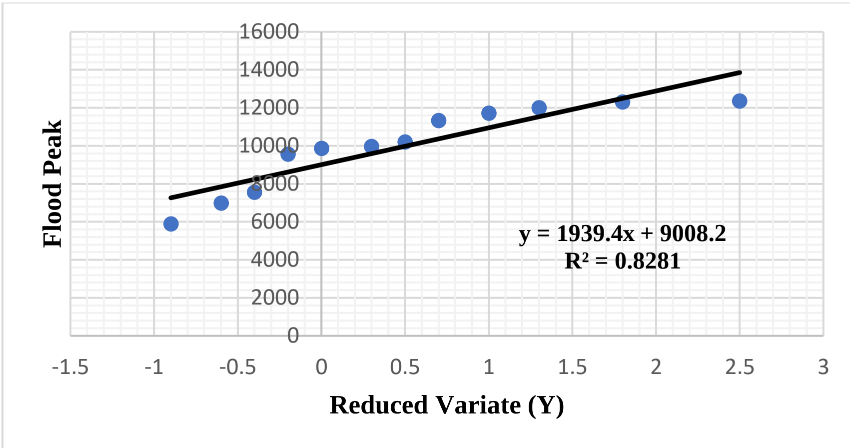

Figure 2: Plot of flood peak against reduced variate (Y) of Escravos River

Table 3, expected flood estimates for return periods (T) of 2, 5, 10, 25, 50, 100, and 200 years based on the Gumbel distribution. The table presents the corresponding reduced variate, frequency factor, and calculated expected flood values, illustrating the increasing flood magnitude with longer return periods. Using the Gumbel distribution method shows in the computation of the expected flood in Table 3, that as the return period (T) in years increases so the expected flood increases. For 2yrs, 5yrs, 10yrs, 25yrs, 50yrs, 100yrs and 200yrs return periods, the expected flood are 9688.77m^3/s, 12081.13m^3/s, 13665.06m^3/s, 15666.39m^3/s, 17151.09m^3/s, 18624.82m^3/s, 20093.17m^3/s respectively.

Table 3: Expected flood estimates for return periods using Gumbel distribution

Return period (T) (years)	**Reduced variate** $Y = -[\ln \ln \frac{T_r}{T_r - 1}]$	**Frequency factor** $K_{(T)} = \frac{Y_T - \overline{Y_n}}{\sigma_n}$	**Expected flood m^3/s** $X_T = \overline{x} + K_T . S_x$
2	0.3665129206	-0.1333847644	9688.779009
5	1.499939987	0.9702528998	12081.13027
10	2.250367327	1.700957064	13665.06197
25	3.198534261	2.624203712	15666.3933
50	3.901938658	3.309120818	17151.08556
100	4.600149227	3.988980602	18624.81509
200	5.295812143	4.666359693	20093.16723

Figure 3 presents the relationship between return period (T) and expected flood discharge based on Gumbel distribution analysis. The return period, shown on the x-axis, represents the average interval between flood events of a given magnitude, while the y-axis indicates the predicted flood discharge. The plotted data reveal a logarithmic trend, as represented by the fitted regression curve $y = 2234.4In(x) + 8374.1$, with a high coefficient of determination ($R^2 = 0.9986$), indicating a strong correlation between the return period and expected flood flow. As the return period increases, the magnitude of expected flood discharge also rises, but at a decreasing rate.

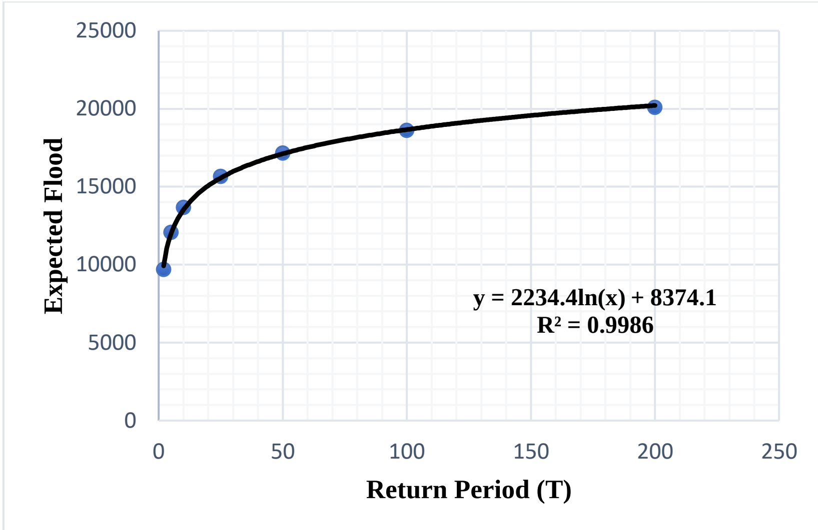

Figure 3: Plot of predicted flood flow

Conclusion

This study applied the Gumbel flood frequency analysis to assess flood risks in Ugborodo, a coastal community in the Niger Delta region of Nigeria. The findings indicate a clear and alarming trend: as the return period increases, so does the expected flood magnitude. This pattern, visually shown in Figure 3, underscores the growing vulnerability of the community to extreme flood events, particularly over longer time horizons. The significant rise in predicted flood flows for a 200-year return period highlights the urgent need for proactive and adaptive flood risk management strategies in this community.

By examining the hydrological behaviour specific to Ugborodo, this research enhances our understanding of flood dynamics in coastal catchments of the Niger Delta region. It provides a valuable case study that can inform broader regional planning and flood mitigation efforts. The results advocate for targeted government interventions, including the development of flood control infrastructure such as sea walls, levees, and dams. Special attention should be given to Indigenous communities, ensuring they receive sufficient resources and support to cope with the increasing threats posed by climate change. Also, maintaining accurate and accessible hydrological records is important for future research and planning. Such data will play a vital role in enabling evidence-based decisions and long-term resilience strategies for flood-prone areas across the region.

This study is limited by its use of a 12-year dataset and reliance on the Gumbel distribution, which assumes stationarity and does not account for changing climate conditions. It also lacks climate projections, socio-economic context, spatial analysis, community input, and cross-validation with other methods, which could enhance the accuracy and applicability of the findings.

Future research can study how climate change might affect flooding in the future by including climate projections in flood models. This will help predict how floods could occur under different environmental conditions. It is also important to study how social and economic factors make some people more vulnerable to floods. Working with local communities to find ways they can adapt, and using tools like real-time flood monitoring, can give a better picture of the flood risks and how to reduce them in coastal areas of the Niger Delta.

Acknowledgement

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Conflict of interest

The authors declare no conflicts of interest.

Data availability statement

Data for Benin, Escravos, and Forcados rivers are very difficult to access. Annual peak flow data of the Escravos Bay tidal gauge of 12 years were used in the study, which agrees with the findings of Ibitola's (2009) research.

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