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Flood Frequency Analysis at the Downstream of Ogbese Catchment: A Life-Threatening Environmental Hazard

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Abstract

Flood is a global natural disaster that has great effect on the environment and it is a threat to lives and properties. This study is on a comprehensive flood frequency analysis of the Ogbese River catchment, located in Ondo States, south-western Nigeria. The specific objectives are to provide quantitative estimates of flood magnitudes for various return periods and the associated environmental and health hazards/challenges in the river catchment. The study analyzed annual discharge data from 1989-2019 obtained from Benin-Owena River Basin and the Nigeria Meteorological Agency (NiMet) office, Akure. It adopted the Gumbel's distribution technique - a probability distribution model for river discharge – and carried out a linear regression analysis to establish a relationship between discharge and reduced variate. Results revealed annual maximum discharges ranging from 284.77 m³/s (1990) to 713.19 m³/s (1995), with a mean of 450.77 m³/s and standard deviation of 88.87 m³/s. High flood magnitudes dominated the early–mid 1990s, with record events in 1991 (665.17 m³/s), 1992 (582.14 m³/s), and 1995 (713.19 m³/s). Conversely, 2000–2019 recorded lower average magnitudes, though significant floods occurred in 2003 (517.88 m³/s), 2010 (577.10 m³/s), 2014 (554.42 m³/s), and 2019 (524.18 m³/s). This temporal pattern suggests possible non-stationarity in the flood series, potentially influenced by climate variability and land use changes. The sharp contrast between the lowest and highest values highlights strong inter-annual variability typical of tropical monsoon systems. The Gumbel distribution provided an excellent fit, with regression analysis yielding $R^2 = 1.0$, confirming model reliability. The flood destroyed houses, farmlands, displaced residents, caused food insecurity and health challenges like waterborne diseases (typhoid, cholera, and diarrhea), vector-borne diseases (malaria), trauma and hypothermia. The study underscores significant flood variability and provides critical baseline data for hydraulic infrastructure design and flood risk planning. It emphasized the need for government and community adoption of modern hydrological techniques, proactive land use management, and sustainable flood prevention strategies to protect lives and property in the study area.

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Keywords: Flood frequency analysis, Ogbese River Catchment, Gumbel distribution, Climate variability, Flood risk management

1.0. Introduction

Flood is a global natural disaster that occurs due to excess volume and flow of water on the earth surface. It has great effect on the environment and it is a threat to lives and properties. Floods are regarded as the most ubiquitous natural disaster that affects people and urbanization in different dimensions globally (Elagib *et al.*, 2021; Bernet *et al.*, 2018; Wilby and Keenan, 2012; Abolade e*t al.*, 2022). The United Nations Environmental Programme (UNEP, 2016) estimated that adapting to climate change and coping with damages will cost developing countries $140-300 billion annually by 2030 and between $280-500 billion annually by 2050. It was reported that economic losses from flooding in the United States in 2019 were estimated at $20 billion (Adam, 2020), $609 million in India, followed by $19 million in Bangladesh, and $4 million in Nepal (Nandi *et al*., 2017).

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usually According to the United Nations (2018), world population is expected to grow from 3.6 billion in 2011 to 6.7 billion in 2050 this implies that more properties and surge population are considerably affecting the urban regions. Nkwunonwo (2016) opined that over the period 1985–2014, flooding in Nigeria has displaced more than 11 million lives, with a total of 1100 deaths recorded and property damage exceeding US$17 billion.

Flooding in Nigeria can be dated back to 1963 and has recently become an annual event that occurs in the form of coastal floods, river floods, flash floods, and urban floods (Adegbola and Jolayemi, 2012). Over the last few decades, for instance, many states and cities have witnessed unusual and devastating flood disasters, which have weakened the government's capability to prevent such disasters (Adegbola and Jolayemi, 2012; Agbola *et al.*, 2012). The effects of river floods and storm surges in urban areas include deaths, displacements, acute health impacts, and huge economic losses. From 1970 to 2008, over 95 percent of deaths from natural disasters occurred in developing countries (IPCC, 2012).

Flood disasters in Ondo State are becoming more frequent, intense, and destructive owing to urbanization and climatic change factors such as lack of planned rapid settlement development, uncontrolled construction of buildings and land use changes, excessive rainfall, and temporal hazard patterns (Obiora, 2019; Ojigi, 2012; Bello *et al.*, 2014). River flooding is among the most devastating water-induced natural disasters in the world, claiming more lives and causing more property damage than any other natural disaster (Bernet *et al.*, 2018). This problem is commonly experienced in areas with low elevation in relation to mean sea level, such as Ogbese village located in Akure North Local Government Area of Ondo State, Nigeria (Olorunlana and Ogunade, 2022). It is one of the fastest-growing economically important communities in Ondo State, which hosts a considerable number of micro-industries such as the very popular Ogbese market and timber business, coupled with unique agricultural practices that have drawn people from several cultural backgrounds in the country (Oladele and Ajayi, 2009).

The Ogbese area of Nigeria experiences problems of flood hazards and risks of different magnitudes attributed to both surface water and river flooding during the rainy season. This is due to torrential rainfall that causes most rivers in the area to overflow their banks and inundate the low-lying areas (Sahara reporters, New York (2019); Dada (2019); Sowole (2019)) including some environmental and social factors. Flood events have occurred several times in this study area, but one in 2019 was the most devastating in the history of floods in the place, destroying crops, homes, and other infrastructure (Sahara reporters, New York (2019); Dada (2019); Sowole (2019)). The destruction happened after consistent rainfall, which caused the Ogbese River to overflow its bank and inundate the surrounding communities, leaving residents counting their losses (Sahara reporters, New York (2019); Dada (2019); Sowole (2019)). Managing floods requires decision-making based on up-to-date and reliable hydrological information and effective modeling to mitigate their disastrous effects (Li *et al.*, 2018; Das, 2019; and Els, 2013)

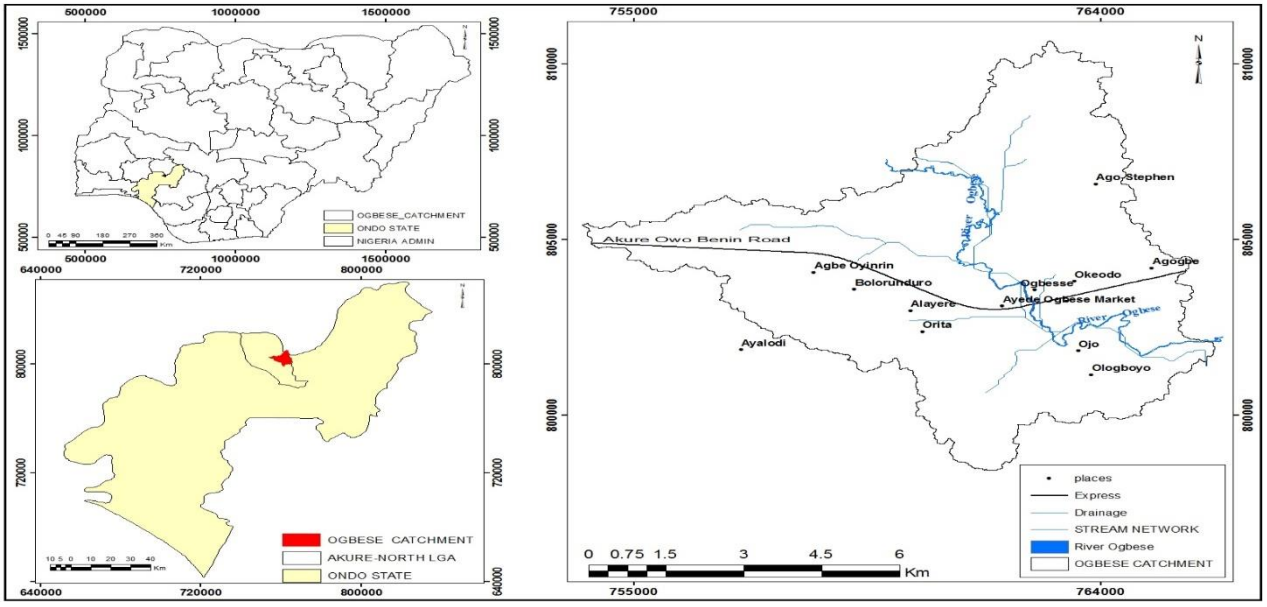


Figure 1. Study Area

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To avert the flood hazards with its environmental health challenges, detailed information on the past, present and future of flood and river discharges are pertinent. Thus, this study is aimed at analysing flood frequency of river Ogbese catchment thereby determining the annual peak discharge of the Ogbese River (1989–2019), predicting flood design for return periods and identifying the associated environmental health impacts. The inaccuracy of meteorological forecasts has led to false alarms and a decrease in public confidence in flood forecasting. Statistical methods like flood frequency analysis are used to predict extreme events based on annual flood peak observations for specific watersheds or catchments. Therefore, in order to ensure safety and economic hydrologic design in the catchment area, the Gumbel distribution, a stochastic generating structure that produces random outcomes, was used to model the annual peak discharge data of the Ogbese catchment at Ayede-Ogbese from 1989 to 2019 (31years). `

2.0. Methodology

2.1. Study Area

The Ogbese watershed is in Ogbese town, Akure North Local Government area of Ondo State. The watershed runs through Ayede-Ogbese, Agbe-Oyirin, and Asolo villages, which are about a few kilometers from Akure town. The Ogbese River is a major tributary of the Ose River in the southwest region of Nigeria. The Ogbese watershed lies within latitudes 6° 43' 00"N to 7° 45' 00"N and longitudes 5° 45' 00"E to 6° 34' 00"E (Figure 1). From a hydrological point of view, the Ogbese River took its source from Apata Hill in Awo Ekiti in Ekiti State (Odedeyi, 2018; Olawusie *et al*., 2014). It then flows for about 22 kilometers from its source to meet the Ose River, which is about 300 kilometers long and discharges into the Atlantic Ocean through a series of creeks and lagoons (Odedeyi, 2018; Olawusi *et al*., 2014). The total area coverage of the basin is 2039.65km^2. Ogbese town is characterized by a tropical rainforest climate zone subjected to both wet and dry seasons. The southwesterly wind current gives rise to a cooler rainy season from April to October with an annual rainfall of about 1600mm to 2100mm, although there may be a short dry spell in August (Obiora, 2019; Odebiyi, 2018). The northeasterly wind currents give rise to a hot, dry season from November to March. The months of August to October recorded the highest value of rainfall, which is associated with peak discharge, water stage, and runoff of the river (Otuaga and Philip, 2015).

The mean daily maximum temperature ranges from 30°C to 35°C, while the mean daily minimum temperature ranges from 21°C to 26°C (Otuaga and Philip, 2015; Obiora, 2019). Ogbese town is a gently undulating terrain situated within the Ogbese river valley from the bank of the river. The land rises gradually towards the east and west with an average slope of 4%. The local relief is about 1200 feet (365.76 meters), with the lowest portion being about 1050 feet (320.04 meters) (Benin Owena River Basin, 2013). Ogbese town is underlain by crystalline rocks, mainly undifferentiated Precambrian basement complexes (Ashaye and Jaiyeola, 1972; Oladele and Ajayi, 2009). It consists of gneisses and migmatites. Except for a small portion of less than 0.04 hectare in the extreme northwest where there is a rock outcrop, the entire bedrock is covered by superficial deposits consisting mainly of gravel, laterite from concretions, sand, silt, and clay materials (Oladele and Ajayi, 2009). These soils were termed latosol under the World Great Soil Group (Ashaye and Jaiyeola, 1972); furthermore, in the third approximation of the soil map of Africa (1960), the area was mapped as having a complex of ferrisols and ferrallitic soils.

Ogbese town is one of the major communities in Ogbese region, with a population of 5,396 out of the total estimate of 8,635 for the entire region, which include Ogbese town, Elemo Camp, Benin Camp, Owode Camp, Araromi Camp, and Lisa Camp (NPC, 2006). It covers a total land area of about 5 km^2. The people in Ogbese are predominantly Yoruba.
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2.2. Data Collection

In this study primary and secondary data sources were used. The data from primary sources is soil sample while the secondary data included an administrative map of Ondo State, Landsat imageries (OLI-TIRS ETM±7), Advanced Land Observing Satellite (ALOS) DEM, rainfall data (meteorological) and Topographical map. Data were obtained from two different meteorological stations (Benin-Owena River Basin and the NiMet Office, Airport, Akure). However, only Akure station has a good record of a 24-hour interval as Benin-Owena River Basin data was not up to date due damage of equipment (e.g. tidal gauge). ALOS PALSAR (Advance Land Observing Satellite Phase All L-band Synthetic

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Aperture Radar) data was used to generate the Elevation, drainage network, slope and contour map. Landsat (8 OLI and ETM ±7) of January, 2019 and August, 2022 was used to extract the classes of land use /land cover layer, while soil data was used to extract the soil type of the study area and their hydrological condition. Google earth was employed to extract infrastructure dataset. Rainfall data (NiMet 1989-2019) was used for production of rainfall spatial map. The study's method involved the integration of the Analytic Hierarchy Process (AHP) with the weighted overlay result of the factors considered thereby producing the final vulnerability map in GIS environment. Table 1 shows the details of Ogbese river gauging station while Table 2 describes the **data** sources and characteristics.

2.3. *Estimation of Flood Peak Discharge*

The Gumbel probability distribution was used to estimate the peak discharge value for a flood of a given return period applying the already computed discharge from Annual mean rainfall data collected from NiMet Akure office for 1989-2019 (31 years flood data) using rational method formula, Discharge (Q) = 0.278*C*I*A, (FMWDHM, 2013; ASCE, 1992; Rossmiller, 1980), where:

C= Coefficient of run-off expressed as a percentage of the imperviousness of the watershed surface (0.8)
I = Intensity or rate of rainfall expressed in millimeter per hour
Constant =0.278
A = Area of the watershed in hectares (203965hectares)
The discharge computed was later used in flood frequency analysis, applying the Gumbel distribution.
According to Mujere (2006), Gumbel's distribution is usually applied when;

i. The river is less regulated, i.e., not affected by human water demand such as reservoirs, diversions, and urbanization.
ii. Maximum flow data are homogeneous and independent.

The observed flow data was more than 10 years with good quality.

2.4. Flood Frequency Analysis

In The flood frequency was determined through different phases. Thus, the steps involved in flood frequency analysis using Gumbel, according to VenTe Chow's (Chow, 1988) are presented as follows:
(i) List and arrange annual floods (x) in descending order of magnitude.
(ii) Assign rank 'm', m = 1 for highest value and so on.
(iii) Calculate return period (T) and/or probability of exceedance (P) by equations n + 1/m and m/n +1, respectively. These values, together with the respective flood magnitude, give plotting positions.
(iv) Using tabular form, calculate x^2 and $\sum x$ and $\sum x^2$
(v) Now calculate mean x; squared mean x^2; mean of squares x^2 and standard deviation S.
(vi) Determine reduced mean (Y_n) and reduced standard deviation (S_n) using Gunnel's extreme value.
(viii) Find frequency factor 'K' using equation $k= (Y_T - Y_N/S_N)$
(ix) Using relation x = x + KS, calculate flood values for various return periods.
(viii) A plot of the reduced variate and magnitude of flood is made on ordinary graph paper.

2.5. *Health implications of Flood Hazards*

The health implications of flood in the study area over time are illustrated using previous information on flood occurrence.

3.0. Results

3.1. Flood Peak Discharge and Frequency Analysis

The flood frequency analysis research carried out for Ogbese river basin using 31 years annual peak discharge data, the maximum discharge is recorded in the year 1995 with 713.189 m^3/s while minimum flood discharge is recorded in the year 1990 with 284.771 m^3/s (Table 3). The 31-year average peak discharge of 450.768 m^3/s suggests a moderate long-term rise in flood risk (Table 2). This aligns with the results from Clement (2012) and Oyatayo *et al*. (2021), who also experienced an upward trend on historical peak floods in Makurdi. They concluded that increasing discharge levels are a factor contributing to the heightened extreme flood inundation observed in the study area.

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The 31-year mean peak discharge of 450.7684m^3 /s with return period of 2-years indicated high risk and long-term effect. The Gumbel Distribution can be used for flooding prediction in the region, while other values not shown in chart can be extrapolated and be useful in the Engineering design of hydraulic structure such as storm water drains, culverts and reservoirs with a view to protect lives and properties downstream of the river. The results align with previous studies by Hycienth (2019); AlHassoun (2011).

Table 1: Ogbese River Gauging Station Details

Station Location	State	Latitude	Longitude	Drainage Area (Km^2)	Staff Gauge
Ogbese River at Ogbese village	Ondo	7° 16' 00"	5° 23' 00"	2039.65	91.28m

Table 2: Data Sources and Characteristics

Data	Acquisition Date	Scale / Resolution	Sources	Type of Data	Usefulness for the Thesis
ALOS PALSAR DEM	2020	12.5mX12.5m	Alaska Satellite Facility website https://vertex.daac.asf.alaska.edu	Spatial	Delineation of drainage, relief, slope, and contour
Landsat 8 OLI-TIRS, Land sat 7 ETM±7	September 2019 August, 2002	30mx30m Path 190 Row 55	United States Geological Survey Website: http://earthexplorer.usgs.gov/	Spatial	Extraction of land use/cover in the catchment
Google Earth Imagery				Spatial	Extraction of the Infrastructural dataset/validation
Akure Sheet 264 NE	1966	1:50,000	OSGOF	Spatial	Extraction of rivers, waterbody place names, and Contour/ DEM validation
Rainfall Data	1989-2019	Station: point data (Daily precipitation of Akure Airport)	NiMet/Owena-River Basin	spatial	Map showing rainfall pattern
Soil Map	Field work	Sample		Spatial	Determine the type of soil and its hydrographic condition in the study area
Ground Trothing	Field work 2021			Spatial	Validate land use within the floodplain
Administrative map of Nigeria	2013	1:3,000,000	OSGOF	Spatial	Extraction of the Akure North LGA boundary

3.2. Setting of the Study and Case Selection

The relationship between flood peak/discharge (XT) with reduced variate (YT) shows a resulting linear relationship (Y=88.869X + 403.04), suggesting a strong correlation with a high coefficient of variability R^2=1 (Figure 2). This indicates that the Gumbel distribution accurately models Ogbese catchment flood peak data. The correlation implies that

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the catchment's flood risk is predictable as it follows a consistent pattern, with higher flood peaks corresponding to more extreme events. This is in agreement with Eke *et al*. (2020), Adebayo and Ogunlela (2024), who reported that the Gumbel distribution is suitable for predicting the expected flow, especially when discrete data is involved. The effect of return period can cause an increase in rainfall intensity received within an area and, consequently, velocity and flow depth changes according to the river channel and floodplain characteristics. Considering the return period of flooding is necessary as it can cause important changes in hazard mapping, mainly on high-hazard zone areas.

From the trend line equation, R^2 gives a value of 1, indicating that the pattern of the scatter is narrow and that Gumbel's distribution is suitable for predicting expected flow in the river (Fevzi and Tamer, 2015). The inferential statistic of the computed variables indicates that the flood peak discharge mean, standard deviation of the peak discharge, reduced mean (Y_n), and reduced standard deviation (S_n) were 450.77, 99.17, 0.5371, and 1.12 respectively. Table 4 presented the computed required parameters.

Table 3: Flood Frequency Analysis by Gumbel Method (n=31 from 1989-2019)

YEAR	Annual Peak Discharge (m^3/s)	Order Number (m)	Return Period (T) =n+1/m	Probability (p)=m/n+1	x^2
1995	713.189	1	32	0.03	508638.5497
1991	665.171	2	16	0.06	442452.4592
1992	582.14	3	10.67	0.09	338886.9796
2010	577.1	4	8	0.13	333044.41
2014	554.422	5	6.4	0.16	307383.7541
2009	530.481	6	5.33	0.19	281410.0914
2019	524.181	7	4.57	0.22	274765.7208
2003	517.881	8	4	0.25	268200.7302
1999	506.543	9	3.56	0.28	256585.8108
2005	488.9	10	3.2	0.31	239023.21
2015	469.999	11	2.91	0.34	220899.06
2007	457.398	12	2.67	0.38	209212.9304
2016	456.138	13	2.46	0.41	208061.875
1996	453.618	14	2.29	0.44	205769.2899
1997	438.5	15	2.13	0.47	192282.25
2008	428.417	16	2	0.50	183541.1259
1994	424.637	17	1.88	0.53	180316.5818
2018	424.637	18	1.78	0.56	180316.5818
2013	422.117	19	1.68	0.59	178182.7617
2011	406.996	20	1.6	0.63	165645.744
2012	398.176	21	1.52	0.66	158544.127
2001	389.356	22	1.45	0.69	151598.0947
2006	381.795	23	1.39	0.72	145767.422
1989	379.275	24	1.33	0.75	143849.5256
2000	378.015	25	1.28	0.78	142895.3402
2004	372.975	26	1.23	0.81	139110.3506
1998	362.895	27	1.19	0.84	131692.781
2002	362.895	28	1.14	0.88	131692.781

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2017	320.053	29	1.1	0.91	102433.9228
1993	301.15	30	1.07	0.94	90691.3225
1990	284.771	31	1.03	0.97	81094.52244
Total	13973.821				6593990.106

Table 4: Computed Required Parameters

Peak Discharge Mean x = ∑X/n	Standard Deviation= √n/n-1 (X^2- X)	Reduced mean (Y_n)	Reduced standard deviation (S_n)
450.7684194	99.16869496	0.5371	1.1159

3.3. Flood Prediction

Table 5 shows the expected floods in the river reach for return periods of 2 years, 5 years, 10 years, 25 years, 50 years, 100 years, 200 years, 400 years, 500 and 1000 years. The result shows that a 2-year flood with a discharge of 435.6086m3/s has a 50% probability of exceedance. This indicates that a flood of this magnitude is very likely to occur frequently within the said year, posing a significant risk to the surrounding communities and farmland. Furthermore, the analysis also revealed that a 100-year flood with a discharge of 536.3349m^3/s rare chance of flood occurrence, with a probability of exceedance of 1% (Table 5). The occurrence of such event is usually common within the study area.

Table 5: Gumbel Flood Prediction along Ogbese River

Return Period (T)	Reduced Variate Y_T= -ln(ln(T_r/T_r-1))	Frequency Factor K(T) =Yt-Yn/Sn	Expected Flood XT= x+KS (m^3/s)	Exceedance P=(1/T)X100
2	0.366513	-0.15287	435.6086	50
5	1.49994	0.862837	603.0244	20
10	2.250367	1.535323	687.2869	10
25	3.198534	2.385011	749.7976	4
50	3.901939	3.015359	811.8467	2
100	4.600149	3.641051	536.3349	1
200	5.295812	4.264461	873.6695	0.5
400	5.990213	4.88674	935.3801	0.25
500	6.213607	5.086932	955.2328	0.2
1000	6.907255	5.708536	1016.876	0.1

The flood frequency (Figure 3) shows that as the return period increases, the expected magnitude of the flood also increases. A 2-year return period, for instance, has an expected flood magnitude of approximately 435.609 m^3/s, while a 100-year return period flood is expected to reach about 536.335 m^3/s. This in agreement with the research carried out by Falade *et al.* (2023).

3.4. Associated Environmental and Health Hazards

The occurrence of floods results in several environmental menaces and health implications, causing loss of economic activities, infrastructures, and lives, particularly aquatic animals and sometimes human beings. Plate 1 shows the flood in the study area. Over time flood occurrence in the study area has destroyed houses and farmlands, displaced residents, caused food insecurity and health challenges like waterborne diseases (typhoid, cholera, and diarrhea), vector-borne diseases (malaria), trauma and hypothermia. Plate 2 depicts submerged Houses, Vehicles and Displaced Residents in the Study Area.

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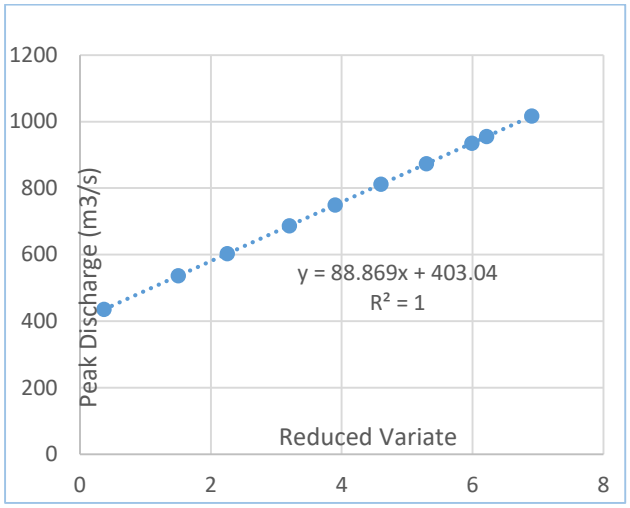


Figure 2: Reduced Variate against peak Annual Discharge for Ogbese River Catchment

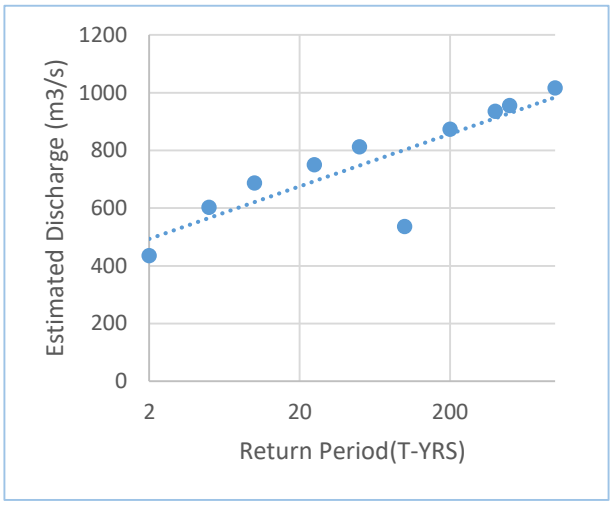


Figure 3: Flood Frequency Analysis by Gumbel's Extreme Value Distribution Method



Plate 1: Building and Children immerged in Flooded Water



Plate 2: Submerged Houses, Vehicles and Displaced Residents in the Study Area

Nigeria experienced severe flood-related casualties in some states (Anambara, Bayelsa, Cross River, Delta and Rivers in Southern Nigeria and Abuja, the Federal Capital Territory, Central Nigeria) as of October, 2022, with 2 million people forced to flee their homes, 612 people lost their lives, 200,000 dwellings were damaged, and 7,483 individuals contracted cholera or other waterborne illnesses (United Nations, 2023). Ondo state was not exempted from this national flood catastrophe. Studies (Nwigwe and Emberga, 2014); Etuonovbe, 2011) affirmed that floodings do not only damage properties and endanger the lives of human and animals but also affect the health of the people like with outbreak of diseases such as cholera and malaria. Study on floods in Akungba-Akoko, Ondo State by Olorunlana (2022) revealed

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that 10% of the respondents reported that flooding leads to outbreak of diseases. The health of the people is usually affected by flood due to contamination of potable water from overflowing waste pits. About seven percent (6.9%) of the respondents classified their loss to be the loss of relatives and loved ones.

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4.0. Conclusion

This study explores rainfall distribution estimation of thirty-one (31) years (31) in Ogbese River catchment using the Gumbel distribution approaches for flood frequency analysis and prediction. It provides estimates for different durations and return periods, ranging from 2 to 1000 years. The application of the Gumbel technique proved adequate in flood analysis as it showed suitability for predicting expected flow in the study area. The findings indicated a tendency for environmental and health implications of flood occurrence in the study area. This study underscores significant flood variability and provides critical baseline data for hydraulic infrastructure design and flood risk planning. It is expedient that the government and community take adequate measures by adopting modern hydrological techniques, proactive land use management, and adequate flood prevention strategies for a sustainable environment, protection of lives and properties in the study area.

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