FLOOD FREQUENCY ANALYSIS USING GUMBEL'S DISTRIBUTION METHOD: A CASE STUDY OF LUGBE TRADEMORE ESTATE FLOOD IN FCT ABUJA

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ABSTRACT

For the significance of checking the rate of flash flooding in Abuja and environs, Trademore estate where flash flood was experienced was picked with rainfall daily data of 1982 to 2022 and subsequent prediction, various probability distribution models were fitted to various rainfall in Lugbe part of Abuja in Nigeria. This is to evaluate the model that is best suitable for the prediction of their values and subsequently using the best model to predict for the expected yearly maximum daily-rainfall at some specific return periods. Many models were evaluated for the rainfall runoff and the best model was selected based on the statistical goodness of the fit test. The Normal distribution model was found most appropriate for the prediction of yearly maximum daily-rainfall of 98 mm. The analysis of the Lugbe peak flow data suggests that the region is susceptible to extreme flood events. The data is skewed to the right, with a longer tail on the high end of the distribution, which means that extreme flood events are more likely to occur than would be expected if the data were normally distributed. The correlation between the peak flow and the return period is also strong and positive, which suggests that extreme flood events in Lugbe are becoming more frequent over time.

***Keywords*:** Flood Frequency Analysis, Gumbel's Distribution Method, Lubge Trade More Estate, Flood Inundation, Hydrological Extremes, Rainfall Intensity

Introduction

Extreme meteorological events-induced disasters are among the largest contributors to natural disasters worldwide as per the Emergency Event Database (EM-DAT). Because of its tremendous volatility. Precipitation is the principal meteorological variable that directly influences life and civilization (Limsakul and Singhruck, 2016). Precipitation can have a considerable impact on both human society and the environment. Extreme changes in rainfall typically lead to either droughts or severe rainfall events with attendant flood risk. Floods have increased in severity and frequency over recent years, prompting serious concern on a global scale. In studies from the Inter-governmental Panel on Climate Change (IPCC) (such as IPCC, 2013) and in literature, the socioeconomic effects of floods and other extreme weather and climate events are widely documented.

A common environmental problem in Nigeria is flood and it is said to occur when a body of water moves over and above an area of land which is not normally submerged. It could also be seen as the inundation of an area not normally covered with water, through a temporary rise in +level of stream, river, lake or sea. Nelson (2001) viewed flood as a natural consequence of stream flow in a continually changing environment. Sada (1988) defines flooding as unusually high rates of discharging; often leading to inundation of land adjacent to streams, and it is usually caused by intense or prolonged rainfall. The occurrence of flood represents a major risk to riversides populations and floodplains, in addition to causing substantial impacts on the environment, including aquatic fauna and flora, and bank erosion. Flooding is becoming an increasingly severe and more frequent problem in Nigeria. Unfortunately, the impact is more felt by the urban poor in such a way that recovery is unlikely to be achieved without external aid (Blaikie 1994). Furthermore, floods can lead to the loss of human life and other (non-lethal) human health effects (Hajat *et al*., 2005).

As population structures change and the degree of urbanization increases, more people will be exposed to flash floods (Hapuarachchi et al., 2011; Kleinen and Petschel-Held, 2007). Urbanization and reductions in rural land areas have led to declines in drainage capacity and increased numbers of flash floods (Mustafa and Szydlowski, 2020).

There are two basic types of floods: flash floods and the more widespread river floods. Flash floods generally cause greater loss of life and river floods generally cause greater loss of property, (Armah et Al., 2010). River flooding is generally more common for larger rivers in areas with a wetter climate, when excessive runoff from longer-lasting rainstorms and sometimes from melting snow causes a slower water-level rise over a larger area. Floods also can be caused by ice jams on a river or high tides, but most floods can be linked to a storm of some kind.

A flash flood occurs when runoff from excessive rainfall causes a rapid rise in the water height (stage) of a stream or normally-dry channel, (Kotzee & Reyers, 2016). Flash floods are more common in areas with a dry climate and rocky terrain because lack of soil or vegetation allows torrential rains to flow overland rather than infiltrate into the ground, Ashley & Ashley (2008).

Flash floods impose extensive damage and disruption to societies, and they are among the deadliest natural hazards worldwide. Several studies have assessed the impacts of flash flood events around the world with regards to substantial financial losses, destruction of infrastructures, displacement, and fatalities (Kotzee & Reyers, (2016); Cutter, (2017).

The main objective of the study was to carry out the Flood Frequency Analysis for Trademore estate, Lugbe in Abuja, the results of the analysis generated from the study gives detailed information of likely 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, Izinyon, and Igbinoba (2011). This may include the design of dam, bridges and flood control structures which will reduce flood disaster in the catchment or assist considerably in storm water management in the region.

Fofana et al. (2022) conducted a comprehensive study on urban flash floods and extreme rainfall trends in Bamako, Mali, emphasizing the impact of climate change on increased rainfall intensity and frequency, leading to elevated flooding risks. Analyzing data from 1982 to 2019, the study utilized rainfall observations from the Mali Meteorological Agency and Climate Hazards Group Infrared Precipitation, alongside flood ground information from the Mali Civil Protection Service. Results indicated an upward trend in all five extreme rainfall indices, signifying heightened intensity and frequency, with flood events showing a consistent increase in Bamako. The study underscores the urgent need for adaptive and mitigative measures in the face of escalating flood risks in Mali.

Umaru and Adedokun (2018) conducted a thorough investigation into flood risk and vulnerability along the River Benue Basin in Kogi State, Nigeria. Despite timely flood alerts from the Nigeria Meteorological Agency, the lack of specific information on vulnerable zones posed a challenge. Employing geospatial methods and quantitative techniques, the researchers used GIS software to analyze DEM data and Landsat TM images. Results indicated a 6-kilometer radius around the River Benue as highly susceptible to flooding, with urban areas like Abejukolo facing significant risks due to water proximity and high vulnerability factors. Recommendations included land use directives, continuous vulnerability mapping, dam construction, and collaborative efforts to enhance risk communication and potential community relocation.

Study Area & Data Collection

Lugbe is an urban settlement in FCT Abuja with the coordinate 8.9581N, 7.3683E, it experiences a tropical climate characterized by distinct wet and dry seasons, the wet season typically lasts from April to October, with peak rainfall occurring in July and August. Average annual rainfall in Lugbe ranges between 1,000 and 1,500 millimetres. Rainfall patterns can vary significantly within the city and are influenced by factors like topography and proximity to bodies of water. The region experienced flash flood incidence in in recent time, including the flash flood on 26th June, 2023, which therefore necessitated this research. For the purpose of this research a field work was carried out residents interviewed and assessment of area.

Below are some plates from the flood and the field work.

Plate 1. Showing the flash flood incidence in June, 2023

Plate 2. Showing the damage and the inadequacy of the Triple Box culvert.

Based on the field work carried out on the 4th July, 2023, it was gathered that rainfall of high intensity was experienced twice in three days at average of five hours duration, the culvert was skewed and the channel narrowed there by obstructing the flow at inlet of the culvert, the channel was widen after the outlet, the channel was not desilted there by causing blockage and obstructing the flow, also the elevation of most building at the floodplain areas all contributed, to mention just a few. During the visit desilting work was ongoing.

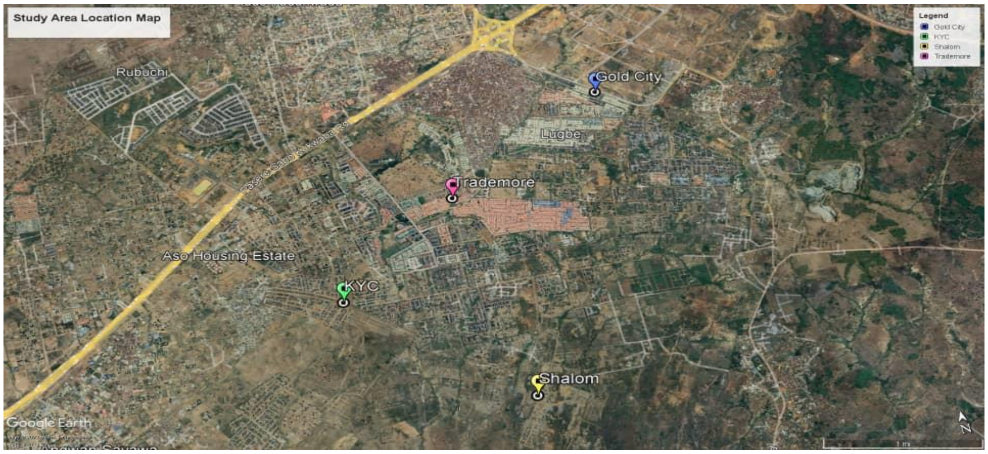

Figure 1: Aerial Imagery of Lugbe Abuja

Gumbel's Method

Gumbel's Method is a widely used statistical technique for analyzing extreme value data, particularly in hydrology and meteorology. It is based on the Extreme Value Type I (EV1) distribution, which describes the behaviour of maximum values (e.g., flood peaks, annual maximum rainfall) in a series, Shaw, (1983). In this study it has been applied for flood frequency analysis because (a) the river is less regulated, hence is not significantly affected by reservoir operations, diversions or urbanization; (b) flow data are homogeneous and independent hence lack long-term trends; and (c) peak flow data cover a relatively long record (more than 10 years) and is of good quality (d), there is no majot tributary of the river whose inflow can affect the flood peak.

The equation for Gumbels distribution as well as the procedure with a return period of T is given by

$$X_T = \bar{X} + K.\sigma_x \quad (1)$$

Where

$\sigma_x = Standard\ deveition\ of\ the\ sample\ size$

K=Frequency factor, which is expressed as $K = \frac{Y_t - \overline{Y_n}}{S_n}$ (2)

In which $Y_{T=}$ Reduced variate, $Y_{T=}\left[Ln.Ln.\left(\frac{T}{T-1}\right)\right]$ (3)

The values of $\overline{Yn}$ and S_n are selected from Gumbels extreme values distribution considered depending on the sample size.

Methodology

The maximum rainfall data of Lugbe from 1982 to 2022 (41 years of flood data) were considered for the flood frequency analysis applying the Gumbel's distribution.
The steps to estimate the design flood for any return period, given by [2] is as follows:
Step I: Annual peak flood data was assembled from 1981 to 2022

Step II: From the maximum flood data for n years, the
Mean $\bar{X}$and standard deviation σx are computed using:

$$\sum_{i=n}^{n} Xi \ and\ \sigma_x = \sqrt{\frac{1}{(n-1)}\sum_{i=1}^{n}(x-\bar{x})^2} \quad (4)$$

StepIII: From the Gumbel's Extreme Value distribution table, the value $\overline{Yn}$ and S_n are taken as 0.5362 and 1.1124.
Step VI: From the given return period Tr, the reduced variate YT is computed using Equation (3).
Step V: $\overline{Yn}$, S_n and YT, the flood frequency factor K is computed using Equation (2
Step VI: With use of Equation (1), the magnitude of flood is computed.
It is of great importance to confirm if the observed flood data collected in the catchment follows Gumbel's distribution or not. In order to achieve this, the observed data is arranged in descending order (the highest coming first) and assigning the return period for each flood; the reduced variate corresponding to each flood is computed using Equation (3). A plot of the reduced variate and magnitude of flood is made on ordinary graph paper. If an eye fits to this plot suggest a straight line, then it is reasonable to conclude that the Gumbel's distribution is a good fit for the observed flood data.

Results

The Gumbels distribution analysis was done using the methodology stated above and the result obtained is showed in Table 1. A plot of the reduced variate v/s flood was plotted as shown in Figure 2.

Table 1: Gumbels Distribution Analysis of Lugbe FCT Abuja Precipitation

Year	Lugbe	Peak flow rearanged	order (m)	Sx2(n-mean)^2	Tr=(n+1)/m	Reduced variate (Y)=-ln.lnTr/Tr-1
1981	60	98	1	2500.00	43	3.749457937
1982	38	85	2	1369.00	21.5	3.044333427
1983	52	70	3	484.00	14.33333333	2.626645415
1984	66	69	4	441.00	10.75	2.326483708
1985	32	66	5	324.00	8.6	2.090591828
1986	32	66	6	324.00	7.166666667	1.895240399
1987	48	61	7	169.00	6.142857143	1.727764474
1988	38	60	8	144.00	5.375	1.580597552
1989	37	58	9	100.00	4.777777778	1.448852589
1990	32	57	10	81.00	4.3	1.329186299
1991	40	56	11	64.00	3.909090909	1.219207556
1992	40	53	12	25.00	3.583333333	1.117144215
1993	42	52	13	16.00	3.307692308	1.021643653
1994	45	51	14	9.00	3.071428571	0.931647329
1995	46	50	15	4.00	2.866666667	0.846308604
1996	34	50	16	4.00	2.6875	0.764936996
1997	30	48	17	0.00	2.529411765	0.68695921

1998	66	48	18	0.00	2.388888889	0.611891134
1999	46	46	19	4.00	2.263157895	0.539317206
2000	46	46	20	4.00	2.15	0.468874827
2001	61	46	21	4.00	2.047619048	0.400242277
2002	51	46	22	4.00	1.954545455	0.333129082
2003	28	45	23	9.00	1.869565217	0.267268074
2004	32	45	24	9.00	1.791666667	0.202408593
2005	42	43	25	25.00	1.72	0.138310385
2006	45	42	26	36.00	1.653846154	0.074737801
2007	50	42	27	36.00	1.592592593	0.011453953
2008	40	40	28	64.00	1.535714286	-0.051785592
2009	35	40	29	64.00	1.482758621	-0.115240059
2010	56	40	30	64.00	1.433333333	-0.179192298
2011	50	38	31	100.00	1.387096774	-0.243960147
2012	69	38	32	100.00	1.34375	-0.309911784
2013	29	37	33	121.00	1.303030303	-0.377487371
2014	70	35	34	169.00	1.264705882	-0.447231002
2015	43	34	35	196.00	1.228571429	-0.519840016
2016	58	32	36	256.00	1.194444444	-0.596245216
2017	46	32	37	256.00	1.162162162	-0.677749567
201	57	32	38	256.00	1.13157894	-0.766287136

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2019	85	32	39	256.00	1.102564103	-0.864957754
2020	98	30	40	324.00	1.075	-0.979298517
2021	48	29	41	361.00	1.048780488	-1.121043137
2022	53	28	42	400.00	1.023809524	-1.324738086

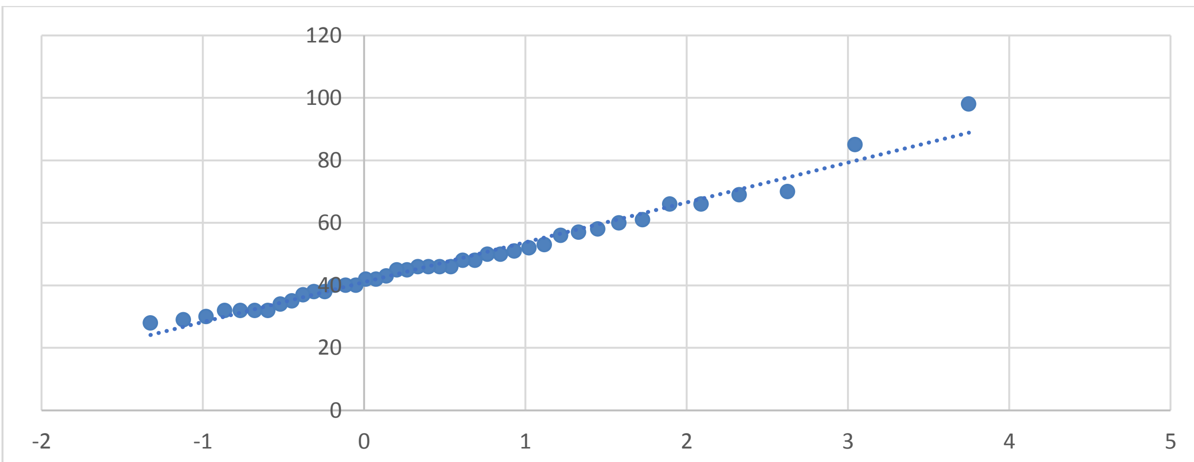

Figure 2: Plot of the reduced variate v/s flood for Lugbe FCT Abuja

From the above results, the minimum flow of 28m^3/s was recorded in the year 2003 while the maximum flow of 98m^3/s was recorded in the year 2020, also an average rainfall of 48.00m^3/s. using the Gumbels distribution analysis, the flood recurrence is computed as shown in Table 2.

Table 2: Computation of Expected Flood in Lugbe FCT Abuja

Tr	Reduced variate (Y)=-ln.lnTr/Tr-1	Frequency Factor K	Expected flood Xt
5	1.499939987	0.833600966	60.47076178
10	2.250367327	1.488538425	70.26869792
50	3.901938658	2.9299517	91.83239844
100	4.600149227	3.539316833	100.9485676
200	5.295812143	4.146458494	110.0314734

The table provided shows the results of a study on the relationship between the frequency factor and the speed of flood. The highest speed of flood is 110.0314734, which corresponds to a frequency factor of 5.295812143, also the lowest speed of flood is 60.47076178, which corresponds to a frequency factor of 1.499939987. it could be deduced that, the frequency factor is a factor that affects the speed of flood, while the speed of flood is a factor that affects the frequency. The table shows that the frequency factor has a positive correlation with the speed of flood. This means that as the frequency factor increases, the speed of flood also increases. The table also shows that the speed of flood has a positive correlation with the return period. This means that as the speed of flood increases, the return period also increases. For example, at a speed of flood of 60.47076178, the return period is 43, while at a speed of flood of 110.0314734, the return period is 18.

The flood observed in the study region could be as a result of longer duration of rainfall, as prolonged rainfall events can saturate the soil and increase runoff, leading to faster and more severe floods. Also, from interview of residents and site investigations, it was discovered that entry and exit of surface water provided by an existed culvert was not enough to take care of the flow thereby restricting the flow of water and increase flood velocity. Conversely, wider channels with natural meanders can slow the floodwaters down.

Conclusion

The analysis of the Lugbe peak flow data suggests that the region is susceptible to extreme flood events. The data is skewed to the right, with a longer tail on the high end of the distribution, which means that extreme flood events are more likely to occur than would be expected if the data were normally distributed. The correlation between the peak flow and the return period is also strong and positive, which suggests that extreme flood events in Lugbe are becoming more frequent over time.

Recommendations

The following recommendations are made based on the findings of this study:

1. Flood risk maps can be used to identify areas that are at risk of flooding and to develop appropriate mitigation measures.

2. Improved flood forecasting can help to warn people of impending floods and give them time to evacuate or take other protective measures.

3. Flood control structures, such as dams, levees, and floodwalls, can be used to reduce the risk of flooding in vulnerable areas.

4. Sustainable land management practices, such as afforestation and wetland restoration, can help to reduce runoff and slow down floodwaters.

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