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Rainfall Frequency Analysis of Some Cities in Niger Delta Region of Nigeria

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ABSTRACT: Rainfall frequency analyses for four cities namely Benin City, Port Harcourt, Calabar and Uyo in Nigeria's Niger Delta area were carried out utilizing daily rainfall data from the yearly maxima series for 48 years (1965 – 2012) at each location. The study's goal was to identify the probability distribution model that fit the data the best and applicable to each location from among six candidate probability distribution models namely: Pearson Type III (PIII), log Normal (LN), log Pearson Type III, Generalized Extreme value (GEV), Extreme value type I (EVI), and Generalized Pareto (GPA). The method of moments (MOM) was used to estimate the distributions' parameters applying the outcomes of seven goodness of fit tests, the most optimal fit distribution model was chosen for each site namely Root Mean Squared Error (RMSE), Relative Root Mean Square Error (RRMSE), Maximum Absolute Derivation Index (MADI), Chi–Square etc. The best distribution model at each location was utilized to predict rainfall of desired return periods. Based on our findings, PIII for Benin City, GEV for Port Harcourt, GEV for Calabar and EVI and LN for Uyo are the distribution models that suit the data the best., The Best Fit Probability Distribution Model predicted rainfall return values (R_T) at 200 years return period ranging from192.92mm at Uyo, 185mm at Port Harcourt; 218mm for Benin City; and 245 mm at Calabar.. The study's findings are helpful in the planning, designing, and maintaining of hydraulic structures for preventing flood damage and mitigating floods at the locations

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Key words: Maximum rainfall; Probability distribution; Goodness of fit, Distribution parameters, Return level

The design and construction of certain projects such as dams and urban drainage systems, management of water resources and prevention of flood damage require an adequate knowledge of extreme events of high return periods (Tao *et al.*, 2002; Olofintoye *et al.*, 2009). Most of the time, return periods of interest do not always match the length of records that are accessible, making it impossible to extract them straight from the recorded data. Therefore, if available sample data could not be used to compute the parameters of a given frequency distribution, current engineering practice estimates extreme rainfall depths by drawing on maximum precipitation records, and conducting a statistical frequency study. Further stimulation for the study, resulted from recent presentation by NIMET of evidence of climate variation especially on the trend of maximum rainfall in 2012 (Okoloye *et al.*, 2013). Accurately estimating extreme occurrences, such as the maximum frequency of rainfall, is becoming increasingly important due to

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climate change since it will help in the design of safer and more effective hydraulic systems. There are many probability distribution models used to analyze hydrological data, but very few of them have been used or employed in earlier research projects carried out by Nigerian scholars. Since no single model is thought to be better than another as far as is feasible, WMO (2008) advised screening available models based on the nature of the data that is available and the problem that needs to be solved. Consequently, it is required to evaluate candidate distributions to choose the one that best fits the data at a given place.

MATERIALS AND METHOD

The Study Area: The map of the study area is presented in Figure 1

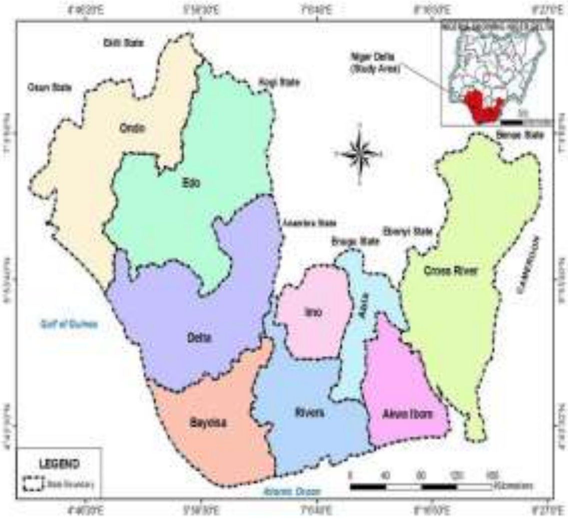

Fig 1: Map of Niger Delta, Nigeria (Source: Oweikeye (2017)

The Atlantic Ocean borders the Niger Delta region to the south and it is situated in the center of Southern Nigeria. This area contains 500 kilometers of shoreline that stretches from the mouth of the Benin River to the Imo River Estuary. The research area stretches along the coast of the Niger Delta. from (5˚2′47.10″ E and 5˚46′57.06″ N) west of the Benin River in Edo State to (7˚41′26.00″E and 4˚29′56.37″N) close to the Imo River in Akwa-Ibom State (Adegoke *et al*.,2010).

The region is made up of the following states: Delta, Bayelsa, Rivers, and Akwa-Ibom States, which are in the South-South region of Nigeria. Ibe and Anitia (1983) identified the Niger Delta's wetlands, which span an area of over 9,000 square kilometers and are primarily made up of dense mangrove vegetation, tidal flats, and flood plains that are located between mean low and high tides.

The selected cities is presented in Table 1.

Table 1: Co-ordination of the cities that have been chosen

S/N	Selected Location	State	Longitude	Latitude	Years of available data
1	Benin City	Edo	5.31ºE	6.20ºN	48
2	Port Harcourt	Rivers	7.10ºE	4.40ºN	48
3	Uyo	Akwa Ibom	7.53ºE	5.10ºN	32
4	Calabar	Cross River	8.20ºE	4.57ºN	48

Analysis of Data: In this study, a frequency analysis of the chosen cities' yearly maximum series of daily rainfall depths is conducted. The four (4) cities selected are: Benin City, Port Harcourt, Uyo and Calabar. The Nigerian Meteorological Agency (NIMET), Oshodi, Lagos provided the selected cities' daily rainfall statistics over the 48-year period between 1965 and 2012. These data were utilized to determine the stations' annual maximum series. Rainbow Software to test for homogeneity and HEC-SSP Software help to identify outliers in the annual series data for every station was examined.

Methodology: The procedure adopted in this study is depicted by the flowchart in Figure 2

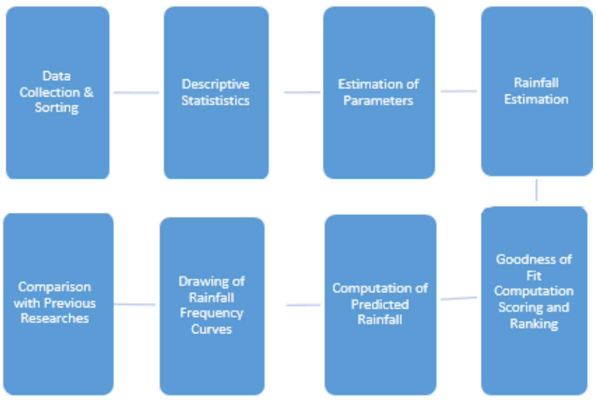

Fig. 2. Flowchart of the Methodology (Source: The Researcher)

The yearly maximum series data for each location were fitted with the following six probability distribution models: Pearson type III, log Pearson type III, Gumbel or Extreme Value type 1 (EVI), Generalized Extreme Value (GEV), Generalized Pareto (GPA), and Log-Normal.

The method of moments (MOM) was utilized to estimate the parameters of the fitted distribution. The model that suited the data the best at a particular site was identified by applying a score and ranking system and analyzing the results of goodness of fit tests. This model was then used to forecast rainfall return levels for return periods of engineering design significance, which ranged from 5 to 200 years.

The details of quartile functions and parameter estimates of some of the probability distributions are as presented in Table 2.

Performance of Probability distribution models at Locations: The performance of the probability distribution models at the study locations were evaluated by means of Goodness of fit tests:

Table 2. Quartile function and parameters of probability distribution (Vivekananda, 2020, 2021)

S. No.	Distribution	quartile function (R_T)	Parameter by MOM
1	EV1	$R_T = \xi - \alpha \log(-\log F)$	$\xi = \bar{R}$ - 0.5772157α $\alpha=(\sqrt{6}/\pi)\, S_R$
2	GEV	$R_T = \xi + \alpha(1-(-\log F)^k)/k$	$\xi = \bar{R} + (\alpha\ (\Gamma(1+k)-1)/k)$ $\alpha = S_R\ \lvert k\rvert / \{\Gamma(1+k) - \Gamma(1+k)^2\}^{1/2}$ $\Psi = (\text{sign } k) \frac{\Gamma(1+3k)+3\Gamma(1+k)(1+2k)-2\Gamma(1+k)^2}{\{\Gamma(1+k)-\Gamma(1+k)^2\}^{1/2}}$
3	GPA	$R_T = \xi + \alpha(1-(1-F)^k)/k$	$\bar{R} = \xi + \alpha/(1+k)$; $S_R = \alpha^2/(1+2k)-(1+k)^2$ $C_s = 2(1-k)(1+2k)^2/(1+3k)$

Goodness of fit tests (GOF): The GOF tests utilized for checking the adequacy of fit of the probability distribution to the observed annual maximum rainfall data are as presented.

1 Root Mean Squared Error (RMSE*):* This is defined statistically as:

$$RMSE = \left[\sum \frac{(R_o - R_f)^2}{n-m}\right]^{½} \quad (1)$$

Where: R_o, R_f, n, m are observed maximum annual rainfall, predicted annual rainfall, number of observations and number of estimated parameters.

2. Relative Root Mean Square Error (RRMSE): This is defined mathematically as:

$$RRMSE = \left[\sum \frac{\left(\frac{R_o - R_f}{R_o}\right)^2}{n-m}\right]^{½} \quad (2)$$

3. Maximum Absolute Derivation Index (MADI): This is defined mathematically as:

$$MADI = \frac{1}{n}\sum \left|\frac{R_o - R_f}{R_o}\right| \quad (3)$$

4. Maximum Absolute Error (MAE): This is mathematically defined as:

$$MAE = Max(\lvert R_o - R_f \rvert) \quad (4)$$

5. Chi – Square (X^2): is statistically defined by

$$X^2 = \sum \frac{(R_o - R_f)^2}{R_f} \quad (5)$$

6. Probability Plot Correlation Coefficient (PPCC): This is mathematically defined as:

$$PPCC = \frac{\sum\{(R_o - R_m)(R_f - R_{fm})\}}{[\sum(R_o - R_m)^2 \sum(R_f - R_{fm})^2]^{½}} \quad (6)$$

Where R_m, R_{fm} = mean of observed maximum rainfall and mean of forecasted rainfall

7. D – Index is the diagnostic test that is used in the choice of an appropriate probability distribution to estimate rainfall return values. This is mathematically defined as:

$$D - Index = \frac{1}{R_m}\sum_{i=1}^{6}(\lvert R_o - R_f \rvert) \quad (7)$$

When assessing a the performance of a probability distribution model in a certain location, the distribution is considered better with lower the value of the Goodness-of-fit test result, with the exception of the PPCC criterion, which considers that the distribution is better the closer the value is to 1 numerically.

Scoring and ranking scheme: Using the goodness of fit test results as a basis, a scoring system where the top test criterion has a score of six (6) points and the least one (1) point was adopted. The distribution model deemed most effective at the station is the one with the highest overall score at a given location. This model was employed to forecast the amount of rainfall for different return periods.

RESULTS AND DISCUSSIONS

Table 3 gives the summary statistics of the Annual Maximum Rainfall (AMR) recorded at the stations under study. The values in the Table were further used to analyze the parameters of estimation of the distribution models. The basic estimation parameters for the probability distribution models are K-shape, α= scale and ε = Location. These were given in Table 2. This facilitated the easier and quicker computation of the parameters. Using the formula in Table 2 and data of the parameter estimator, the six probability distribution models were estimated for the four stations .Six goodness of fit tests and diagnostic test. D – Index, in equations 1-7 were used to determine the best fit probability distribution of each location. Table 4 gives the values obtained for these tests by applying equation 1-7 Goodness-of-Fit Test Results for the Distributions at Port Harcourt, Rivers State, Nigeria.

Table 3: Descriptive Statistics of Annual Maximum Rainfall (AMR)

S/N	Location	Mean	SD	Skewness	Kurtosis
1	Benin City	103.53	48.79	-0.25	0.78
2	Port Harcourt	99.14	42.87	-0.64	0.82
3	Uyo	98.54	25.66	0.64	0.03
4	Calabar	111.73	49.47	-0.58	0.72

Table 4. Results of the Goodness-of-Fit Tests for the Port Harcourt Distribution

S/ N	Distribution	RMSE	RRMSE	MADI	MAE	PPCC	CHI-SQ	D-INDEX
1	EVI	17.14	2.99	0.88	43.05	0.9479	53.67	0.91
2	GEV	13.19	1.45	0.05	32.4	0.9645	103.9	0.61
3	GPA	39.49	7.72	2.45	95.16	0.952	698.6	2.96
4	LN	17.50	4.05	1.278	59.5	0.969	241	0.34
5	P111	17.85	4.16	1.285	53.1	0.94	249	0.51
6	LP111	21	4.69	1.46	57.9	0.9075	290	0.86

Table 5: Rainfall Estimates by Six Probability Distributions Estimated Rainfall (mm) Port Harcourt

Return Period Years	EVI	GEV	GPA	LN	PIII	LPIII
5	129.98	143.728	113.05	135	136.7	133.6
10	155.062	159.171	114.23	157.3	161.2	159.4
25	186.755	165.98	114.91	178.4	184.3	185.9
50	210.17	172.2	115.13	205.6	213.2	223.0
100	233.503	176.53	115.24	226	234.4	253.2
200	256.73	179.56	115.3	246.5	255.1	285.4

Evaluation of Probability Distribution Models through the Calculation of Goodness of Fit Test Score: valuation of Probability Distribution Models through the Calculation of Goodness of Fit Test Score the Port Harcourt Distributions' Goodness-of-Fit Test Results was obtained. Each distribution model receives a test score in-between one and six (1–6), with the distribution model that received the highest rating being selected as the optimal distribution model for the data of a specific city. The distribution that a test finds to be the strongest is given a score of six (6), followed by a score of five (5) for the second best distribution, nd so forth in decreasing order. Using the scoring scheme outlined, Tables 6 were worked out. Tables 6 present the results of the overall ranking. The chosen model for the peak rainfall and the goodness of fit test is presented in Table7. Table 8 presents the predicted rainfall return level of the best suited probability distribution model for every station as well as the rainfall return levels (mm) for chosen return periods ranging from five years to 200 years

Table 6 Scoring and Ranking Scheme for Distribution at Port Harcourt

DIST	RMSE	RRMSE	MADI	MAE	PPCC	CHI - SQUARE	D - INDEX	TOTAL	RANK
EVI	5	5	5	5	3	1	2	26	3
GEV	6	6	6	6	5	6	4	39	1
GPA	1	1	1	1	4	2	1	11	6
LN	4	4	4	2	6	5	6	31	2
P111	3	3	3	4	2	4	5	24	4
LP111	2	2	2	3	1	3	3	16	5

Table 7: The chosen model for the peak rainfall and the goodness of fit test.

	Location	Best Fit Model	Total Max Score	Second Best Fit Model	Total Max Score
1	Benin	Pearson III	36	GEV	35
2	Port Harcourt	GEV	39	Log-Normal	31
3	Calabar	GEV	36	Log-Normal	36
4	Uyo	GEV	38	Pearson III	36

Table 8: Predicted rainfall return levels (mm) at the study locations

Location	Best-fit distribution	Return Period (years) 5	10	25	50	100	200
Benin	PIII	142.20	164.41	183.60	197.38	208.4	218.2
Port Harcourt	GEV	143.7	159.17	171.90	179.11	182.43	185.00
Calabar	GEV	150.33	174.04	199.86	216.42	230.95	243.77
Uyo	EVI	116.99	131.96	149.39	165.03	179.99	192.92
	LN	115.33	127.5	138.52	152.05	161.81	171.28

Rainfall Frequency Curves (RFCs): For the probability distribution models, the AMR estimations acquired in Table 2 were used to develop the RFCs and presented in Figures 3. The required optimum rainfall value for each return period for design can be read off from the graph in Figure 3.

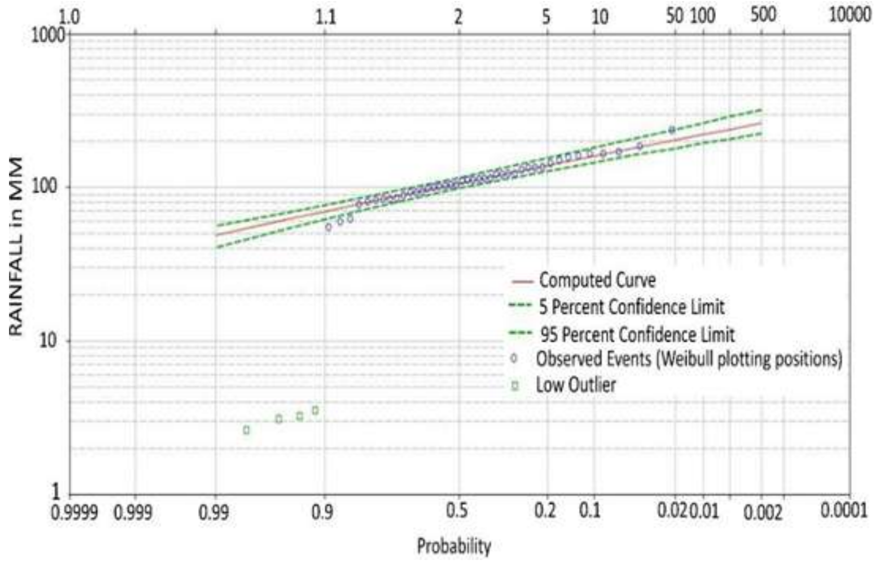

Fig 3: Rainfall frequency curve (RFC) for Benin City

Table 9; Comparison of Best-Fit Probability Distribution Model Obtained in This Study with Previous Studies Made By Olofintoye *et al.* (2009)

S/N	Location	Observations and Comments
1	Benin City	PIII was considered best as against LPIII recommended by them. Forecasted rainfall for Rt (50) were (197.38mm, 175.96 mm).
2	Port Harcourt	GEV considers best fit was not used by them.
3	Calabar	GEV considered best fit was not used by Olufintoye *et al*. Forecasted rainfall for return period of 50 years were (165.03mm, 207.25mm).

The comparison of Best-Fit Probability Distribution Model obtained in this study with previous studies made by Olofintoye *et al*. (2009 is presented in Table 9. Rainfall frequency analysis is crucial for understanding and managing water resources, agricultural planning, and infrastructure development in Nigeria's Delta region. Here are a few ways in which rainfall frequency analysis is useful in this context:

1. Water Resource Management: Rainfall frequency analysis helps in estimating the amount of water available for various uses. In the Delta region, where water resources are vital for agriculture, aquaculture, and domestic consumption, understanding the frequency and intensity of rainfall events is essential for effective water resource management. By analyzing rainfall frequency, water authorities can better plan for water storage, distribution, and usage, thus helping to ensure a sustainable water supply for the region.

2. Flood Risk Assessment and Mitigation: The Delta region is susceptible to flooding, and rainfall frequency analysis plays a key role in assessing flood risks. By understanding the frequency and intensity of rainfall events, authorities can better predict potential flood occurrences and plan mitigation measures such as constructing flood control infrastructure, establishing early warning systems, and developing land use planning regulations that account for flood risk.

3. Agricultural Planning: Agriculture is a primary economic activity in the Delta region. Rainfall frequency analysis provides valuable information for farmers, agricultural planners, and policymakers to make informed decisions regarding crop selection, irrigation planning, and watershed management. By understanding the historical rainfall patterns and frequency of extreme events, farmers can optimize their planting schedules and irrigation practices, leading to improved crop yields and enhanced food security.

4. Infrastructure Design and Maintenance: Infrastructure development in the Delta region, including roads, drainage systems, and buildings, must consider the frequency and intensity of rainfall events to ensure resilience against heavy rains and potential flooding. Rainfall frequency analysis aids in designing infrastructure that can withstand the expected rainfall patterns, reducing the risk of damage and ensuring the long-term functionality of constructed assets.

5. Climate Change Adaptation: With the growing impacts of climate change, including shifts in rainfall patterns and increased frequency of extreme weather events, rainfall frequency analysis is vital for understanding how these changes may affect the Delta region. By analyzing historical rainfall data and projecting future trends, stakeholders can develop adaptation strategies to cope with potential climate-induced shifts in rainfall patterns, thereby enhancing the region's resilience to climate change.
6. Environmental Management: Rainfall frequency analysis is essential for assessing its impact on the natural environment. It helps in understanding the distribution of rainfall, which in turn affects the local flora, fauna, and ecosystems. By understanding rainfall frequency, authorities can effectively manage and protect the Delta's unique and diverse ecosystems, including wetlands, rivers, and mangrove forests, which are crucial for biodiversity conservation and ecological sustainability**.**

Conclusions: In this study the best fit probability distribution model applicable to each location were selected for four cities in the Niger Delta region of Nigeria from seven Suitable probability distributions and utilized to forecast the amount of rainfall return levels that is important for the location's engineering. The study's findings are helpful in the planning, designing, construction and maintaining of hydraulic structures for preventing flood damage and mitigating floods at the locations. With the projected trends of rainfall, stakeholders can make informed decisions that contribute to the sustainable development and resilience of the Delta region of Nigeria.

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