

## PAPER 36 – FLOOD FREQUENCY ANALYSIS OF RIVER NIGER AT LOKOJA GAUGE STATION: A MORPHODYNAMIC APPROACH

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### ABSTRACT

Flood frequency analysis is used by water resources professionals to estimate the probability of exceedance associated with a flood of a given magnitude. The estimation of flood frequencies is important because they are used for the planning and design of hydraulic structures. This study was carried out to understand the flood-generating processes and establish the reliability of different probability distribution models in predicting the bank-full discharge for selected return periods based on the available hydrometric dataset. The designed bank-full discharge and experimental results of the sampled bed materials at different chainages along the river reach being used to characterize the river bed materials by comparing the Egelund & Hansen method, and Meyer-Peter & Muller method with their established criteria and finally obtain the sediment transport capacity of the River Niger at Lokoja. The results show that the flood magnitude is highly dependent on the sediment transport capacity of the river.

**KEYWORDS:** Bank-full discharge, Flood frequency, sediment transport capacity, morphodynamics, Probability distribution models

### 7. INTRODUCTION

Floods are the consequence of natural water exceeding the capacity of removal by the river channel or reservoirs (Knapp, 1979). Flood discharge in tropical regions is known to be a factor of intensity, extent and duration of rainfall, and the runoff characteristic of the basin. During precipitation, rainwater is absorbed by the soil, a part is lost through evapotranspiration and the remaining part is transported as runoff into rivers, streams, and reservoirs. The capacity of the drainage system of the catchment area to contain the excess runoff water in river channels, the catchment extent, the velocity of downstream discharge and the presence or absence of retention basins, determine if the flood water will overspread the natural banks and cause damage to adjoining areas. In the work of Busari et al. (2013), the Normal distribution model was found most appropriate for the prediction of yearly maximum daily rainfall in the Evaluation of Best Fit Probability distribution models. Another important aspect of the research presented here is the impact of deposition and erosion on the flow process. Prediction of the described process with its entire complexity requires the application of sophisticated mathematical models with several empirical or subjective assumptions (Brunner, 2016a; Kolarski, 2018; Parker, 2004; Popek, 2006; Wu, 2007). The most important assumptions seem to be the empirical formulae applied to complete the mathematical models of sediment routing (Beckers et al., 2018; Osidele et al., 2003; Parker, 2004; Popek, 2006; Radecki-Pawlik, 2014; Schmelter et al., 2012; Wu, 2007; Yang, 1996). Considerations of morphodynamical processes in the context of flood hazards are not very frequent. The rare examples found in the literature have been focused on short-term analyses of direct morphological responses to flood events. These are single-event computations based on simple deterministic modelling (Lane et al., 2008; Lane et al., 2007; Nones, 2019; Radice et al., 2013; Radice et al., 2016).

Hydrometric and climatic data are not enough for flood modelling and prediction. A good knowledge of land use patterns and the behaviour of our river systems is essential. The understanding of a riverbed material and its hydrology along with the selection of adequate modelling tools will yield a flood prediction of relatively low uncertainty.

### 8. THEORETICAL ANALYSIS

Sediment transport is the movement of solid particles driven by fluids like water or wind in rivers, lakes, reservoirs, and coastal waters. In the real world, the flow is unsteady like flood waves, tidal waves and wind waves as steady and uniform flows are very rare in reality. In the literature, many formulae use the boundary shear stress  $\tau$  ( $= \rho ghS$ ) to express sediment transport discharge, like Meyer – Peter and Muller, and Engelund and Hansen (Shu-Quing Yang, 2020). The maximum amount of sediment transported by a river as bed material load is the Sediment Transport Capacity (STC) and is related to the stream velocity,  $u$ . The general STC formula has the form:

$$qs = mu^b \quad (1)$$

where  $q_s$  is the amount of bed material load per meter of river width ( $m^2/s$ ),  $m$  is the proportionality coefficient,  $u$  is the local stream velocity and  $b$  is the exponent (values larger than 3). Meyer - Peter & Muller (MPM) equation is given as:

$$q_{sb} = 8\sqrt{\Delta g D_m^3} \sqrt{(\mu\theta - 0.047)^3} \quad (2)$$

where  $q_{sb}$  is the amount of sediment transported as bedload per meter of river width ( $m^2/s$ ),  $D_m$  is the mean sediment grain size (m),

Bedform factor,  $\mu = \sqrt{(C/C')^3}$   
 $C = \text{Chezy's coefficient } (m^{1/2}/s)$  (3)

$C'$  is the grain-related Chezy's constant given as:  
 $C' = 18\log(12h/D_{90})$  (4)

where  $D_{90}$  grain size of 90% passing (m).

Criteria for the characterisation of riverbed materials are given as

- (a)  $\frac{\omega s}{u_*} > 1$  ; where  $\omega s = \text{fall velocity } \left(\frac{m}{s}\right)$ ,  $u = \text{shear velocity } \left(\frac{m}{s}\right)$
- (b)  $D_m > 0.4\text{mm}$ ;  $D_m = \text{mean sediment grain size (m)}$
- (c)  $\mu\theta < 0.2$  for Gravel – bed;  $\mu = \text{bed factor}$  and  $\theta = \text{Shields parameter}$ .

For Engelund and Hansen (E-H) equation. In equation (1),  $b = 5$  and  $m$  is given by:

$$m = \frac{0.05}{C^3 \left(\frac{\rho_s - \rho}{\rho}\right) D_{50} \sqrt{g}} \quad (5)$$

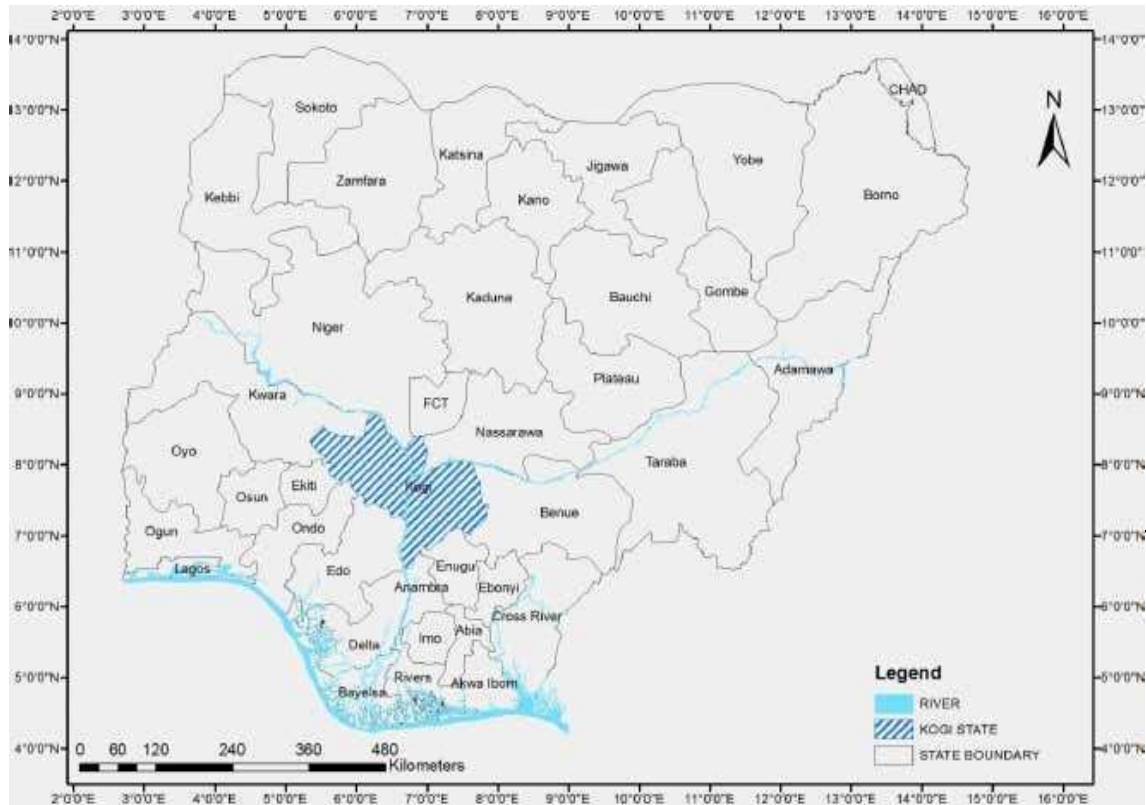
where  $C$  is Chezy's coefficient ( $m^{1/2}/s$ ),  $\rho_s$  is sediment density ( $kg/m^3$ ) and  $D$  is median sediment grain size (50% of sediment material has a smaller diameter) (m). Criteria for the characterisation of riverbed materials are given as:

- (a)  $\frac{\omega s}{u_*} < 1$ ;
- (b)  $0.19 < D_{50} < 0.93\text{mm}$ ;
- (c)  $0.07 < \theta < 6$  for Sand-bed.

## 9. MATERIALS AND METHODS/METHODOLOGY/EXPERIMENTAL PROCEDURE

### 3.1 Study Area

Lokoja is the capital city of Kogi State in the north-central part of [Nigeria](#). It presents a very important hydro-geological feature and covers a land area of approximately 3180  $km^2$ . The gauging station from which the data for this study was extracted is located along River Niger in Lokoja. Geographically, it is located at the following coordinates (08°40'N, 05°20'E and 07°20'N, 05°20'E, 07°20'N, 06°44'E) North of the equator and East of the meridian.



A total of twelve (12) bed material samples were collected from different locations at 50 m intervals downstream along the riverbed longitudinal profile commencing from the Lokoja Slipway herein designated as chainage 0 + 000. The soil samples were collected at an average depth of 0.5m by disturbed sampling method in accordance with BS 1377:1 (2016) standard procedure for sample collection. Water samples were also collected from the riverbed at 50m intervals along the river reach and the following tests were carried out: (a) Specific gravity, (b) Density of bed material and (c) Soil particle size distribution.

Calculation of Recurrence Interval  $T_p$

The annual maximum flood discharge values have been arranged in descending order and the plotting position for the recurrence interval  $T_p$  for each discharge is obtained as:

$$T_p = \frac{N+1}{m} = \frac{22}{m} \quad (6)$$

Where  $m$  = order number and the discharge magnitude  $Q$  plotted against the corresponding  $T_p$  on EasyFit probability software shown in Figure 2.

The discharge and return period relationship is given in the plotted graph in Figure 2. The fitting equation (7) is shown as follows:

$$Q = -1.3194(T_p)^2 + 712.19(T_p) + 16476 \quad (7)$$

The degree of correlation between the parameters is high ( $R = 0.871$ )

Substituting the following return periods (30, 40, 50, 60, 70, 80, and 100)  $T_p$  values in equation (7) we have the maximum flood discharge ( $Q_{max}$ ) corresponding to each return period.

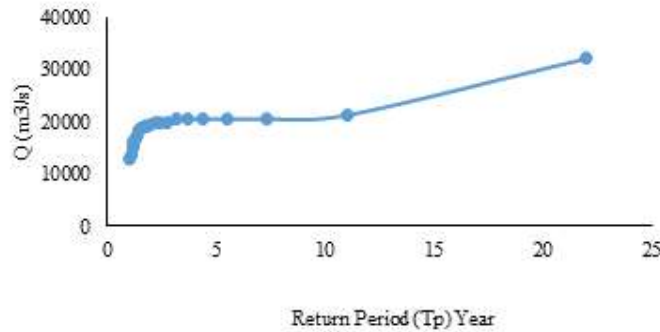


Figure 2. Graph of Discharge and Return Period

**Table 1: (Q -Tp) Relationship**

Return Period (Tp) years)	30	40	50	60	70	80	100
Flood discharge Q (m <sup>3</sup> /s)	36654	42853	48787	54458	59864	65007	74501

## 10. RESULTS AND DISCUSSION

### 4.1 Results

Particle size analysis was conducted on the twelve (12 Nos.) material samples taken from the Lokoja gauge station, and the result so obtained for particle size ( $D_{50}$ ) and Specific Gravity (GS) is presented in Table 2.

**Table 2: Experimental results of soil sample**

Samp le No.	0+00	0+050	0+050	0+10	0+150	0+150	0+20	0+250	0+250	0+30	0+35	0+40
	0	A	B	0	A	B	0	A	B	0	0	0
$D_{50}$	0.35	0.35	0.35	0.35	0.28	0.35	0.35	0.35	0.35	0.35	0.35	0.35
SG	2.44	2.75	2.42	2.6	2.66	2.67	2.52	2.68	2.21	2.63	2.63	2.62

The hydrometric dataset used in the research was extracted from the Nigerian Inland Water Authority (NIWA) and is presented under Appendix 1. The probability distribution function for the dataset comparing Cauchy, Gen. Logistic, Log-Logistic, Log-Logistic (3P), Log-Pearson 3 and Wakeby methods, is presented in Figure 3.

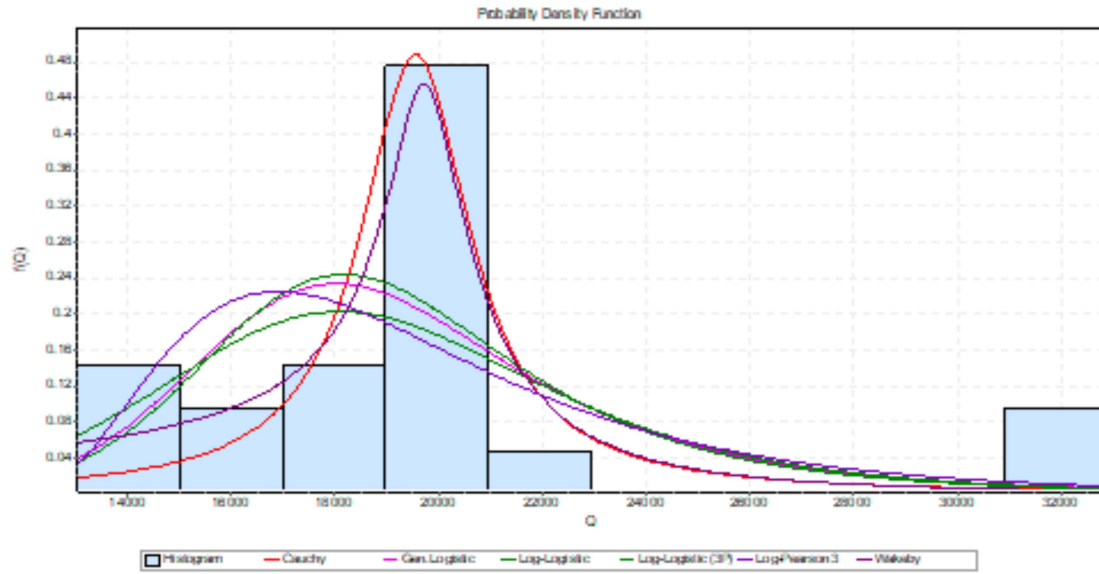


Figure 3: Probability distribution function for six (6) methods

Parameters for calculating the sediment transport and characterizing the riverbed channel by comparing the methods of Engelund & Hansen and Meyer-Peter & Muller with their established criteria are presented in Appendix 2. While the computed STC for the selected return periods and some river reaches is presented in Appendix 3.

#### 4.2 Discussion of Results

The result of particle size distribution carried out on the 12 soil samples from the Lokoja gauge station shows that the bed materials are predominantly Sandy as a greater percentage of the materials fall within the region.

For the hydrometric data, the probability distribution for the selected recurrence intervals ( $T_p = 30, 40, 50, 60, 70, 80,$  and  $100$  years) was plotted for six (6) models; Cauchy, Gen. Logistic, Log-Logistic, Log-Logistic (3P), Log-Pearson 3 and Wakeby. The reliability of the probability distribution as a fitting model has been tested using the statistical tests known as goodness of fit and found to be significantly correct. The statistical tools prescribed in the Easy Fit software have been used for the statistical analysis. The generated variables were used to determine how well the correlation coefficient and coefficient of determination best fit the models. From Figure 3, the best-fit model for the Lokoja gauge station is the Cauchy distribution model.

The parameters for calculating the sediment transport capacity (STC) were computed and presented in Appendix 2 for the selected recurrence intervals (return periods) and for the chainages according to the river reaches where samples were collected. For ( $T_p = 30$ ) return period, the critical parameters for characterizing the river channel by methods of Eugelund & Hansen and Meyer-Peter & Muller with their established criteria are as follows:

$\omega s/u^* = 0.4720 < 1$ ;  $D_{50} = 0.35 > 0.19$  and  $< 0.93\text{mm}$ ;  $\theta = 3.8588 > 0.17$  and  $< 6$ . These parameters satisfy the Eugelund & Hansen criteria for all the river reaches (chainages). Similarly, other selected return periods of 40, 50, 60, 70, 80, and 100 years also satisfy the E-H criteria and hence the channel is classified as a Sand-bed. Conversely,

the riverbed materials did not comply with MPM criteria.

From Appendix 3, the relationship between the selected return periods which is a function of the discharge,  $Q$  and the calculated sediment transport capacity is linear and therefore clearly indicates that the flood magnitude is highly dependent on the sediment transport capacity of the river.

## 5. CONCLUSION

Flooding in a river system can be better described by understanding the morphodynamics (bed-level formations and changes). With this research paper as reference material, a full understanding of fluvial flooding in Nigeria based on the morphodynamics of our river system is assured under the present-day climate change scenario. The results obtained from the computations show that the river flood magnitude is highly dependent on the sediment transport capacity of the river.

To understand the behaviour of our river system viz a viz the rainfall magnitude and discharge, it is worth noting that mining activities especially sand mining in our river channels cause a change in slope and thereby alter the behaviour of the river system. While erosion of the riverbed will translate to some advantage against flooding, the reverse is the case for huge and long-term deposition on the river floor bed which tends to reduce the river depth and by extension the carrying capacity of the river channel and thus leading to flooding.

Detailed studies are recommended on all the major rivers in Nigeria to characterize each river channel based on their discharge, slope, and bed materials (whether it is gravel-bed or sandy-bed material). With this, we can fully estimate the sediment transport capacity of our rivers, predict erosion (or accretion), and deposition due to upstream release of water and propose viable river engineering measures rather than assuming dredging as usual. Flood intervention measures should be based on short and long-term assessments of the morphodynamics of the rivers, not by a mere assumption.

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**APPENDICES**

**Appendix 1.** Annual Maximum Discharge (cumecs)

Year	July	August	September	October	November	December
2000	8188	14640	18225	16531	6073	3201
2001	0	0	17713	18885	7863	3364
2002	0	0	14939	13003	3201	3227
2003	9000	12123	18106	19025	13003	4265
2004	8625	13818	16098	15292	6724	2811
2005	7079	11062	13026	13792	9120	3392
2006	5422	8923	17599	19389	10710	3742
2007	7044	15650	19831	19831	10855	4110
2008	6759	14366	20426	19695	9920	4265
2009	9960	15140	19695	20534	15650	6481
2010	8311	14199	19806	21272	17940	5345
2011	4416	9080	16830	17340	14150	3915
2012	14102	18080	29815	32150	16079	4850
2013	8809	9120	15727	16396	9560	3582
2014	7560	14660	17512	19941	11376	4356
2015	7079	11062	13026	13792	9120	3393
2016	12079	17571	18225	19279	5826	3201
2017	8694	18139	19941	19941	10855	4110
2018	10360	18106	19695	20534	15446	6481
2019	10421	15652	32441	32860	16646	5171
2020	10887	14725	19520	20534	15650	3960

Source: Extracted from NIWA's gauge record in Lokoja and Adjusted with Rating Curves

**Appendix 2.** Parameters for calculating STC

TP (yrs)	$u = Q/Bh^2$	$C = u/\sqrt{hi}$	$\mu$	$\omega s/u^*$	$D_m$	$\mu\theta$	$D_{50}$	$\theta$
30	24.766	203.577	3.8909	0.4720	0.0035	142791	0.35	3.8588
40	25.707	199.103	3.7004	0.4107	0.0035	14.2791	0.35	3.8588
50	26.443	194.675	3.5271	0.4227	0.0035	12.9117	0.35	3.6607
60	27.026	190.392	3.3698	0.4045	0.0035	13.4726	0.35	3.9980
70	27.498	186.371	3.2290	0.3892	0.0035	13.9475	0.35	4.3194
80	26.443	194.675	3.5271	0.4227	0.0035	12.9117	0.35	3.6607
100	28.478	176.078	2.8919	0.3550	0.0035	15.0104	0.35	5.1905

**Appendix 3.** STC (m<sup>2</sup>/s) for Selected Return Periods and Reaches

TP	River Reaches (Chainages)							
	0+000	0+050A	0+050B	0+100	0+150A	0+150B	0+200	0+250A
30	0.1255	0.2120	0.1396	0.1772	0.1526	0.1931	0.1399	0.1954
40	0.1617	0.2189	0.1441	0.1830	0.1182	0.1994	0.1544	0.2018
50	0.1992	0.2941	0.1937	0.2459	0.2117	0.2679	0.2219	0.2711
60	0.2375	0.3281	0.2160	0.2742	0.2361	0.2988	0.2646	0.3023
70	0.2761	0.4077	0.2684	0.3408	0.2935	0.3713	0.3076	0.3757
80	0.1992	0.2941	0.1937	0.2459	0.2117	0.2679	0.2219	0.2711
100	0.3900	0.4262	0.2806	0.3563	0.3068	0.3881	0.4346	0.3928