Flood Frequency Analysis and Inundation Mapping of Lower Ogun River Basin

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***Abstract*- Flood frequency analysis and inundation mapping of lower Ogun River basin was implemented using the Gumbel probability distribution method. This method was however tested with Log Pearson Type III to ascertain the best fitting statistical measure for hydrological fluxes using Chi Square. Basin delineation data was extracted from the topographic maps of Ilaro SE 1, 2, 3 & 4 which covers the study area while gauge height data at Adiyan intake was used as the principal data for flood frequency assessment and inundation modelling based on (T_r) return periods 2, 5, 10, 25, 50 and 100 years. The results showed modelled water level values of 2.22 metres, 2.24 metres, 2.28 metres, 2.38 metres, 2.55 metres, and 2.90 metres for each of the return periods. Consequent upon this, the inundated area is projected to increase to almost 30% of the area from an initial 23% for most of the scenarios. These findings provide clearer picture for the pattern of hydrological fluxes of the lower Ogun River Basin. Sustainable planning and developmental measures that consider the modelled pattern of hydrological fluxes of the study area were recommended for decision making on urban areas.**

Keywords- Flood estimation; Flood modelling, Floodplain; Gumbel distribution; Log Pearson Type III and Return period.

I. INTRODUCTION

Globally, flooding is regarded as the most ubiquitous natural disaster that affects people in different dimensions [1]. The 20th century witnessed an unprecedented rate of flood occurrence within most drainage basins in the world. Specifically, the yearly flood evaluation showed that in the past fifty years, flood incidences have increased by almost 10-fold from about 20 in 1945 to almost 190 in 2005 [2]. It has also been estimated that about a third of the total landscape of the earth is flood-prone, consequently affecting close to 82% of the world's population [3]. Similarly, the United Nations [4] has stated that about 170,000 flood-related deaths were recorded worldwide within a period of two decades, further between 1980 and 2000. More specifically, the World Meteorological Organisation (WMO) claimed that between 1970 and 2012, about 89% of the reported global disasters were due to flooding and storms, resulting in deaths of millions and huge economic losses [5]. These statistics portray the fact that flooding is a global environmental issue that requires consistent and continuous assessment through a scientifically suitable methodology.

In Nigeria, flood occurrence is connected to different anthropogenic activities and occurs within its spatial dimensionalities. This dimensionality is connected to a location where river flooding, urban flooding and coastal flooding with concomitant losses in lives and properties are the common types. River flooding, coupled with urban development, however, intensifies the rate of flooding in the lower section of the Ogun River basin in southwest Nigeria. A key issue considered in the choice of this study area is the paucity of information concerning the probability of flood occurrence and the flood extent in the area. This necessitates the estimation of flood frequency assessment and inundation mapping.

Flood frequency analysis is the universal method used for the estimation of recurrent interval of any hydrological event [6, 22]. Flood frequency analysis is pivotally essential for the management of flood with respect to design, planning and operations through the use of fundamental knowledge of flood characteristics in terms of peak flow, volume and duration. [7] state that flood estimation via flood frequency analysis provides a basic standard for flood risk evaluation especially in areas that are close to floodplains [8]. More precisely, [6] affirms that return periods associated with annual maximum flood peaks are modelled using flood frequency analysis.

This gives room for prediction of such extreme events (especially river runoff) since they are unpredictable and difficult to estimate spatiotemporally. Flood frequency analysis has been used extensively by hydrological scientists and hydrological engineers [9]. Scientists and researchers find flood frequency analysis a useful tool for the estimation of the contribution of precipitation to stream flow and river runoff to flood occurrence. As a hydrological tool, flood frequency analysis is useful for the estimation of design flood that forms a pivot for designing hydrological structures. Such structures are commonly designed based on the statistical flood history of the entire drainage area [10]. [11] affirm that the choice of a method of statistically estimating flood scenarios using any of the available methods should be based on the following;

1. Variability of the documented records concerning water level and stream flow; and
2. Suitability of the method to the geographical area in view.

Concerning the study area, the observed lack of consistent hydrologic data on river runoff presents a herculean task for inundation modelling, hence, the need to subject available data to appropriate methods and validation. Consequently, log Pearson Type III and Gumbel Distribution method would be appropriate for estimating the extent of probable flood and water levels expected in the area.

Flood inundation mapping is a process-based task that follows the pattern of the outcome of flood frequency analysis within a defined catchment. It has been referred to as mapping of areas that are prone to flooding, i.e. areas likely to be flooded [12]. The key considerations in flood inundation mapping are restricted to issues concerning areas forecasted to be inundated by water, depth of forecasted floodwaters and geovisualisation of extent of anticipated flooding. In addition, it relies on values computed from extreme hydrologic and hydraulic modelling. Clear knowledge about inundation mapping entails understanding the underlying philosophies about the concept;

1. It is a practical reference point for decision-making concerning the management of water and land.
2. It is not a regulatory instrument or tool for policymaking, but it could be integrated as a mechanism for proper management of floodplains and associated areas based on their relative land use and land cover characteristics.
3. It is a typical input into the general planning of a piece of land; thus, issues regarding legal or political or any other governmental instruments are not attached to the mapping procedure. It is more of a guide to proper resource management than a restrictively-centred mechanism for land management. This is necessary as water level fluctuates relative to water-input and water-output within the catchment.

The use of satellite remote sensing and Geographic Information Systems (GIS) techniques is a novel methodology over the traditional crude calculation-based procedure [13]. The mapping advantage provides a spatial synoptic overview of the extent of flooding in an area, provides mechanisms for flood warning and emergency preparedness as well as flood protection planning [12, 22]. Integration of spatial tools of GIS to flood inundation mapping has made it possible to delineate water level, particularly water level spatially and overlay with the land use and land cover data to generate areas that will be inundated. This procedure has been widely used [14]. For instance, [15] utilised the tools of GIS to develop spatial flood inundation maps for regional and sub-regional scales of south-western part of Bengal State of India. The result shows the space-based level of flood severity in the different levels of governance under study. Using a DEM of 5-metre resolution as the principal data along with soil, geology and land use maps of Makkah city, [14] developed GIS-based flood inundation maps to show the probable flood extent of the study area. Log Pearson Type III flood extreme computation technique was used to capture the gauge and stream flow of the catchment and rainfall data. The final result was suggested to be used in re-designing the flood history of the study area for appropriate urban planning.

However, studies [16, 17, and 18] have shown a geometrical increase in the built-up area of the Lower Ogun River basin and a significant loss of the wetlands to other impervious land uses in the area. [16] in a study of change detection and hydrological implication in the Lower Ogun flood plain, Southwest Nigeria, reveals that within the Lower Ogun area, wetland decreases at the rate of 0.44×10^6 ha per annum while built up area increases at the rate of 0.2775×10^6 ha per annum between 1965 and 2005. The consequences of the continuous loss of wetland, especially in the urban setting, are degradation of the environments in various forms [17] leading to flooding and erosion [16]. The implication is that, due to changes in land use and land cover, with significant conversion of wetlands to built-up area, degradation processes of flooding and erosion prevail in many parts of the lower Ogun River basin [16]. Though [18] had identified these factors for Greater Lagos, the current rate and magnitude of flooding phenomenon in the Lagos end of the lower Ogun River basin is unprecedented. Consequently, this study aims at estimation of flood frequency of the lower Ogun River basin at Adiyan intake with a view to developing inundation maps for different return periods 2, 5, 10, 25, 50 and 100 years using Gumbel and Log Pearson Type III methods.

II. STUDY AREA

The study area falls within the lower hydrologic landscape of River Ogun, referred to as Lower Ogun Basin [16, 18]. It lies within two states in southwest Nigeria; Ogun State (Ifo, Sagamu, and Obafemi-Owode local government areas) and Lagos State (Ikeja, Ifako-Ijaiye, Kosofe and Ikorodu local government areas) (Fig. 1). The study area is geographically located within longitude 3º22´E to 3º39´E and latitude 6º31´N to 6º39´N occupying an approximate catchment area of 361.02 km^2.

The water level (gauge height) station – Adiyan Intake (see Fig. 1) is located at the central point of the hydrologic catchment. It is geographically located within longitude 3º22'57.63"E and latitude 6º31'45.45"N. It is the only station designed for the collection and maintenance of water resource information within the Lower Ogun basin. It is sited at a central point within the basin with representative data for the entire basin, hence, its suitability for flood inundation modelling. The location of the Adiyan Intake thus captures the hydrologic and morphologic characteristics of the basin at both the upper and lower section of the Ogun River. Thus, the runoff and flow characterisation of the Ogun River at this level provides a representative outlook of the entire Lower Ogun River basin. The Lagos State Water Corporation manages the Adiyan Intake facility.

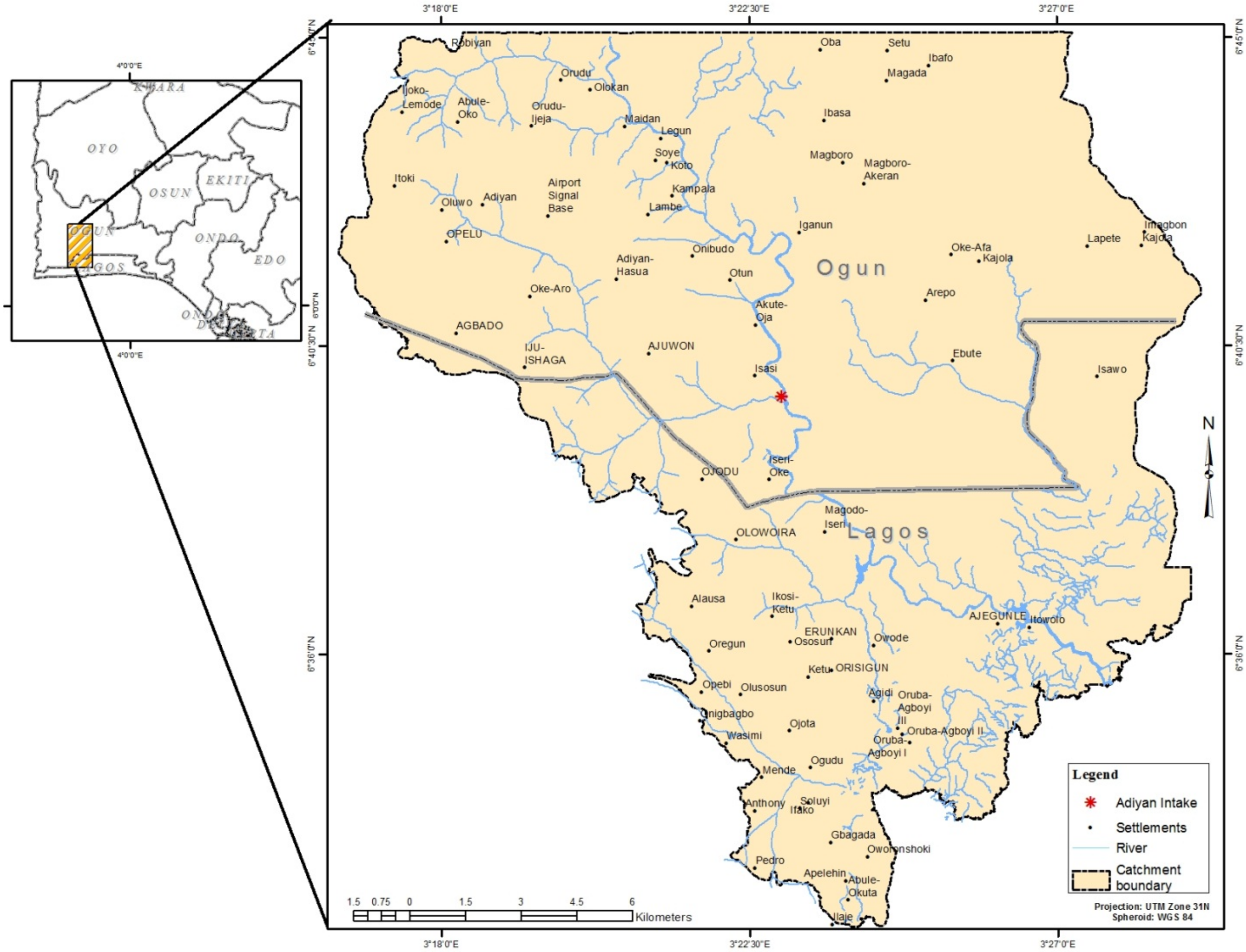

Fig. 1: The study area (indicating the Adiyan Intake, drainage networks and major settlements within the catchment) in context of southwest Nigeria

Topographically, the area is low-lying with traces of undulating landscape. There are also micro scale rugged areas with gentle slopes and gorges. Due to the presence of the Ogun River, the Lagos Lagoon as well as other tributaries of the river, the altitude of the study area varies from sea level to about 15 metres above sea level. Hydrologically, the sinuous Ogun River indicating the old stage of the river traverses the study area. There are traces of connecting streams, wetlands, coastal marsh and hydrophytes, which testify to the river stage. The basin is composed mainly of 4^{th} order stream – Ogun River indicating the presence of short streams that feed the main river all year round. The drainage pattern is dendritic in morphology as it captures the expected traits of a river at old stage (Fig. 2). Apart from the sinuosity of the Ogun River, there are two different hydrologic zones differentiated by drainage characteristics and elevation. The westward side of the basin indicates a series of watersheds (Adiyan, Iju and Iya-Alaro) running from the highly elevated areas into the Ogun River. These watersheds, chiefly dominated by the Adiyan watershed, form the principal point for the location of the water level measurements i.e. the Adiyan Intake. Shallow rivers and tributaries of the Ogun River dominate the eastern fringe. Elevation provides a synoptic overview of the relief structure of the basin. It also provides an overview of the outlay of the river, the extensive eastern floodplain and the rugged relief areas of the northwest axis.

The climate of the area is influenced by two air masses, namely; Tropical maritime and the Tropical continental air masses. The tropical maritime air mass, which is warm and wet, originates from the Atlantic Ocean. The tropical continental air mass is warm, dry and dusty and originates from the Sahara desert. Hence, the climate of the area is similar to that of the other coastal regions of the tropical West Africa with tropical sub-equatorial climate. The temperature is seasonal, relatively high and ranges between 22^{o}C and 32^{o}C.

Annually, two seasons are distinguishable in Lower Ogun basin, dry season from November to March and wet season between April and October. Overall, mean annual rainfall ranges from 900 mm in the north to 2000 mm towards the south. The estimates of total annual potential evapotranspiration fluctuate between 1600 mm and 1900 mm. The two major vegetation zones that can be identified on the watershed are the high forest vegetation in the north and central part, as well as swamp/mangrove that cover the southern coastal and floodplains proximate to the Lagos lagoon.

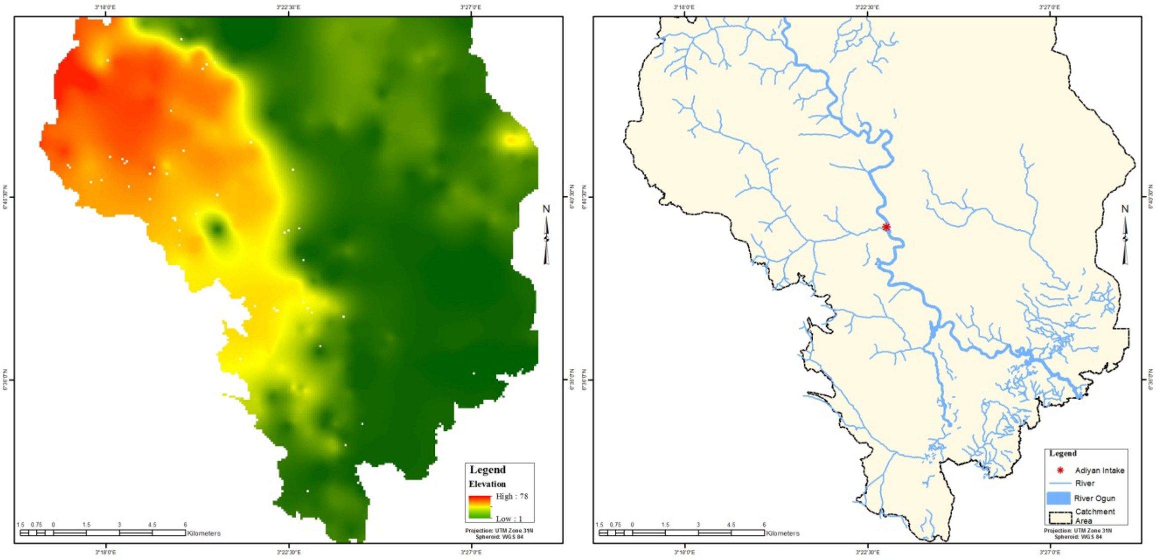

Fig. 2: Physical descriptors of the study area elevation and drainage maps

Land use pattern within the catchment is mostly urban with traces of scattered cultivation at the northern fringes. The southern part of the study area is almost completely urbanised despite its shallow water end with marshlands and swamps. In settlements such as Oregun, Alausa, Opebi the urban landscape is dense with commercial activities while others are mere residential areas. Conversely, the northern areas are mostly residential with semi-urban or rural landscape characterised by low economic activities and high-end urban sprawl. Human settlement at this point is close to the water as most of the settlements are situated within the extensive floodplain of Ogun River.

III. METHODOLOGY

A. Data sources and characteristics

The data used for the flood frequency analysis were sourced from the Lagos State Water Corporation and the Federal Surveys Department. The data include the daily average water level at Adiyan Intake (see Fig. 1). These daily averages were aggregated and collated into annual water level values which were presented for public usage. The 1:25,000 topographic map sheets was the main data source for the extraction of elevation data via onscreen digitizing of contour values and spot heights. Also, settlement names were extracted via point-based heads-up digitizing process. Synoptically, the data used for the study are itemized in Table 1.

TABLE 1: DATA SOURCES AND CHARACTERISTICS

Serial Number	Data	Data Scale and Resolution	Data extracted	Data Source
1	Ogun River Stage Height Data (Adiyan Intake at River Ogun)	Point-based	• Annual average water level	Lagos State Water Corporation (LSWC)
2	Topographic maps of Ilaro SE 1, 2, 3 & 4	1:25,000	• Elevation data from contours and spot heights • Settlement names and locations, • Basin catchment area delineation	Federal Surveys Department, Lagos

B. Flood Frequency Determination from Hydrologic Data

The methodological procedure used for the study is presented in Fig. 3. It describes the stepwise procedure employed in the determination and assessment of the flood frequency analysis and by extension the production of the inundation maps. As indicated in the flowchart, two flood frequency methods were used for the study – Gumbel Distribution and Log Pearson Type III. The choice of these methods was based on two cogent reasons. The first is the lack of appropriate river runoff data, which makes it inevitable to utilize the most ecologically and hydrologically-fit measure. The second is the need to provide a suitable hydrologic inundation procedure that will generate the fundamental water level threshold for flood mapping purposes [19].

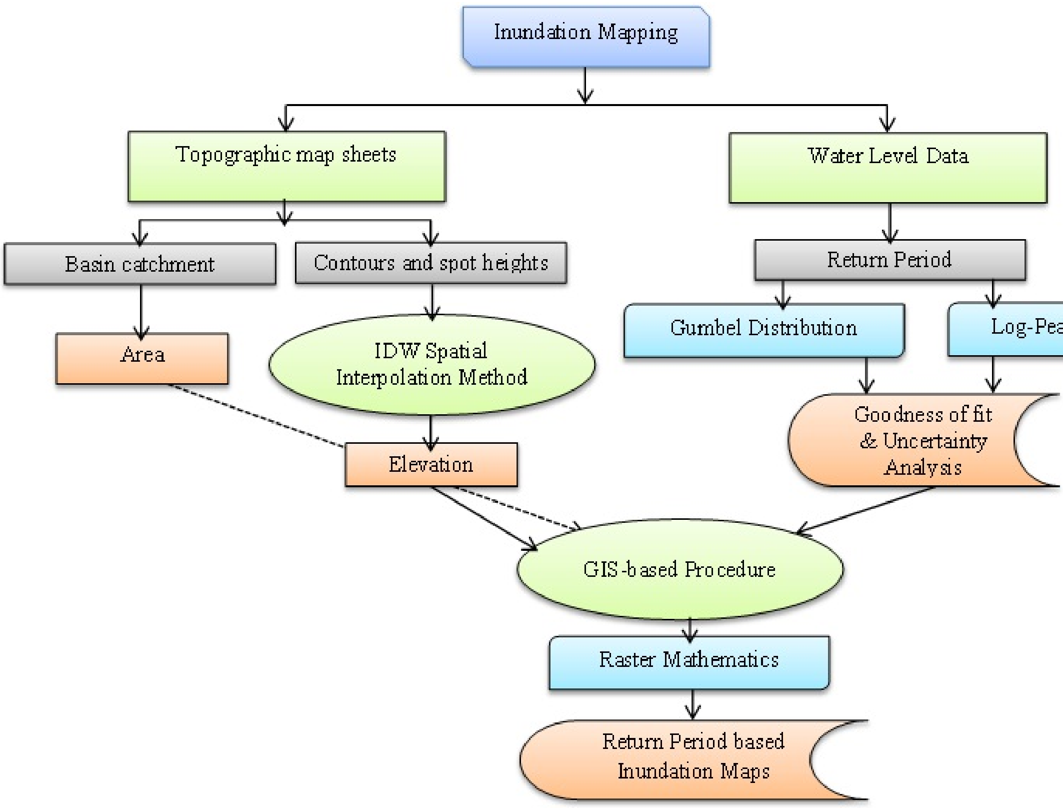

Fig. 2: Methodological Flowchart of Flood Frequency Analysis

Usually, the Gumbel method analyses the annual maximum flood, which is the largest flood flow during a year. The general characteristics of the Gumbel extreme-value distribution are; the mean flow occurs at the return period of T_r = 2.33 years and it has a positive skew (i.e., it is skewed towards the high flows or extreme values). Despite the positive skew of the Gumbel distribution, it has some drawbacks [20]. First, it does not account directly for the computed skew of the data although it predicts the high flows reasonably well. The entire curve fit is not much better than that obtained with the normal distribution, indicating that the peak flow series is not distributed according to the double-exponential distribution equation. In recent years, Gumbel extreme value analysis has been used as a general model of extreme events including flood flows, particularly in the context of regionalization procedures [19, 21]. In this study however, the mathematical description of the Gumbel function is stated in equation (1), thus;

$$X_T = X_{av} + K * SDV \quad (1)$$

where;

X_T = value of variate with a return period

X_{av} = mean of the variate

SDV = Standard deviation of the sample

K = Frequency factor expressed as $K = (y_T – 0.577)/1.2825$; y_T = reduced variate expressed by $y_T\ (T – 1) = - (L_N * L_N)$; T = return period

The log-Pearson Type III describes a random variable whose logarithms have a Pearson Type III distribution. The distribution is a three-parameter gamma function with a logarithmic transform of the variable. It is widely used for flood analyses because the data quite frequently fit into the assumed population. The log-Pearson Type III distribution differs from most other distributions methods in that three parameters (mean (Z_a), standard deviation (SDV), and the coefficient of skew (k)) are necessary to describe the distribution. A limitation of the log-Pearson Type III distribution is that it can assume a variety of shapes requiring a separate probability scale for each different shape. This distribution has found wide use in modelling flood frequencies with concomitant recommendations [20].

The designed Log Pearson Type III for this study is expressed in equation (2), thus;

$$Z_T = Z_a + K_z * SDV \quad (2)$$

where,

K_z = Frequency factor taken from table with values of coefficient of skew "Cs" and recurrence interval 'T'.

SDV = Standard deviation of the '*Z*' variate sample.

Cs = Co-efficient of skew of variate 'Z' $Z = N\sum \{(Z - Z_a)^3\} / \{(N-1)(N-2)\}$

Z_a = Mean of the 'z' values

N = Number of years of observation

C. Goodness of Fit Measure – Chi-Square Test

The non-parametric statistic used to ascertain the fitness of either Gumbel distribution or Log Pearson Type III flood frequency measure is chi-square statistic for inundation mapping. Chi-square was used owing to its inherent statistical properties for test of association and homogeneity which is the fundamental basis for validation of the two measures considered for the study. The Chi-Square formula used is expressed in equation (3) as;

$$X^2 = \sum (O - E)^2 / (E) \quad (3)$$

Where X^2 is the Chi-Square statistic, *O* is the observed water level (computed values) and is the *E* expected water level (expected constant average water level value).

The derived Chi-Square statistic was further subjected to probability values based on degree of freedom *(df)*, and 0.995 significance level (α). Degree of freedom *(df)* is mathematically defined as $(c-1)(r-1)$, *c* represents the column and *r* denotes the row. The null hypothesis designed for the statistic is that the distribution with the least probability at 0.995 significance level (α) is suitable for flood inundation mapping.

D. Inundation Area Mapping

Inundation mapping approach adopted in this study is based on the spatial association between elevation and water levels. The methodology stipulated for the creation of inundation maps is based on the swathing computed water levels (estimated values computed from the return periods flood frequency analysis) in the Ogun River over the elevation of the basin (Fig. 3).

The digitised contours and spots heights were converted to points. The derived point data was spatially collocated and IDW (Inverse Distance Weighted) interpolation algorithm embedded in ArcGIS 9.3 was used to derive a unified contour values. The derived contours were converted finally to a raster dataset that eventually formed the elevation. This procedure was effected using Spatial Analysis Tool embedded in ArcToolBox of ArcGIS 9.3. On the other hand, the outcome of Chi-Square validated water level flood frequency analysis was used as the input data for water level. This was based on return period across the prior defined periods of 2, 5, 10, 25, 50 and 100 years.

The two datasets – elevation and the return period based water levels arranged as input into Raster Mathematics module of Spatial Analysis Tools in ArcGIS 9.3. The GIS based procedure defined for this approach is based on creation of blank raster and the usage of Raster Mathematics Tools Raster Mathematics Tool. Blank raster data with cell values that corresponds to each of the return period water level values was created while the elevation data was already prepared in raster data format. Subtraction operation was implemented by taking away the values of the water level from the elevation values. The outcome was mapped with null values indicating the flood/inundated area while the remaining values indicating the non-flood area. In total, six inundation maps were created for each of the return periods.

IV. RESULTS AND DISCUSSION

A. Flood Frequency Analysis of Lower Ogun

Flood frequency is a multidimensional tool used in the assessment of water resource potential as well as a measure of both hydrologic and hydraulic measure that must be integrated in the engineering construction of structures that concern a defined water body. In addition, this measure is a tool of necessity to ascertain the extent of inundation based on available hydrologic data. It provides the data frame for inundation area mapping as well as for the assessment of flood hazard and risk within an area. The general characteristics of the water level values for the Lower Ogun showed non-linear characteristics with positive co-efficient of regression (R^2 = 0.32) and a polynomial expression ($y = 0.03x^2 - 0.29x + 2.42$). This characteristics is applicable to the two extreme events measures – Gumbel and log Pearson Type III distributions.

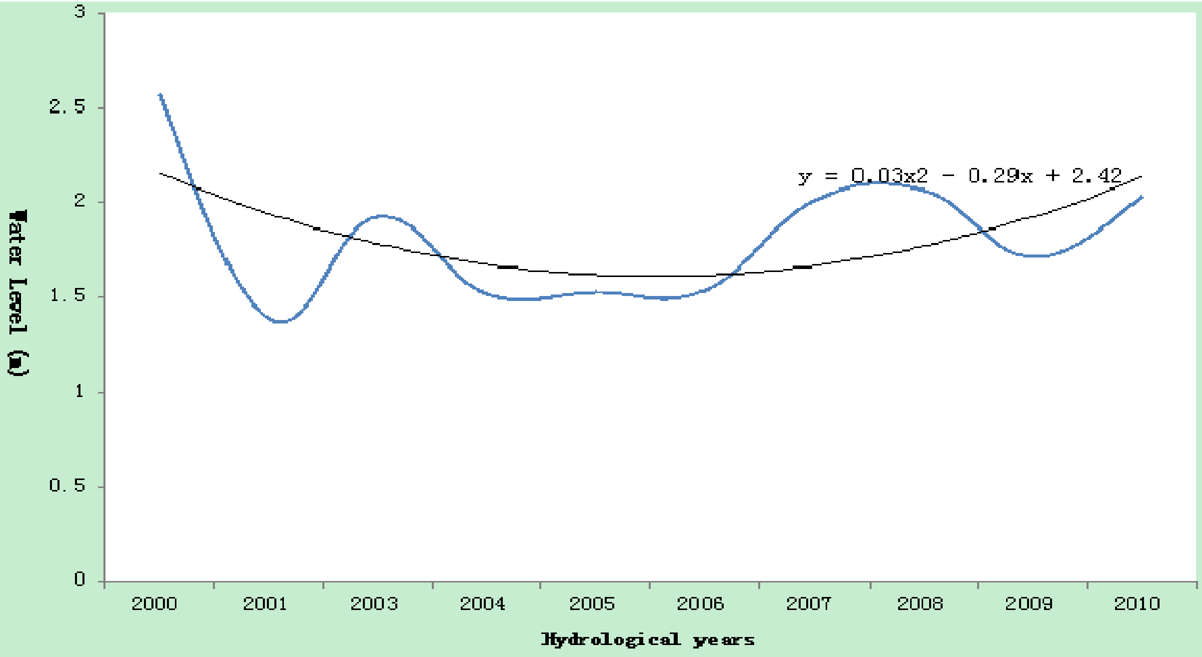

Fig. 4: Ogun River Gauge Level between 2000 and 2010

B. Gumbel Distribution of Lower Ogun River

The stepwise procedure for the computation of Gumbel distribution is presented in Table 2 with the respective statistical parameters (return period, plotting position and plotting probability). The overall mean () of the distribution is 1.83 m, and the standard deviation is 0.30 m. The return period computations showed that the highest water level (2.57 m) was recorded in the hydrological year 2000. Expectedly, it returned the highest recurrent interval of 18 years. Conversely, the least water level (1.39 m) was recorded in hydrological year 2001 with an annual return period. The entire distribution showed that water level 1.92 m could be experienced biennially in the basin. However, the remaining parameters tabulated are important to the estimation of the extreme values as stated in equation (1) above.

TABLE 2: OGUN RIVER AT ADIYAN INTAKE; COMPUTATION OF GUMBEL EXTREME VALUES STATISTICAL PARAMETERS

Year	**Water level (metres)**	**Rank**	***Return Period (years)**	****Plotting Probability**	$(x/\bar{x})$	$(x/\bar{x}-1)$	$(x/\bar{x}-1)^2$	$(x/\bar{x}-1)^3$
2000	2.57	1	18.07	0.06	1.41	0.41	0.16	0.07
2008	2.07	2	6.49	0.15	1.13	0.13	0.02	0.00
2010	2.03	3	3.95	0.25	1.11	0.11	0.01	0.00
2007	2.01	4	2.84	0.35	1.10	0.10	0.01	0.00
2003	1.92	5	2.22	0.45	1.05	0.05	0.00	0.00
2009	1.71	6	1.82	0.55	0.94	-0.06	0.00	0.00
2006	1.53	7	1.54	0.65	0.84	-0.16	0.03	0.00
2005	1.53	8	1.34	0.75	0.84	-0.16	0.03	0.00
2004	1.52	9	1.18	0.85	0.83	-0.17	0.03	0.00
2001	1.39	10	1.06	0.94	0.76	-0.24	0.06	-0.01
Sum							0.35	0.04
Mean	1.83							

*Return Period [$T_r = (n+0.12)/(m-0.44)$]
**Plotting Probability is defined mathematically as $Pr = 1/T_r$

C. Log Pearson Type Iii of Lower Ogun River

The statistical properties of Log Pearson Type III with respect to return period, plotting position and probability position are outlined in Table 3 with mean value of 1.83 m, standard deviation of 0.36 m, and coefficient of skewness of 0.03 m. This indicates that the distribution is slightly skewed towards the high water levels i.e. the properties indicate the likelihood of hydrological extremes in the basin. Statistical parameters for return period described previously under the Gumbel distribution are also true for the Log Pearson Type III. The remaining parameters tabulated are paramount to the estimation of the extreme values as stated in equation (2) above. Hence, similar outputs and interpretation are put forward. However, the observed differences in the computation of statistical values are tabulated in Table 3.

TABLE 3: OGUN RIVER AT ADIYAN INTAKE; COMPUTATION OF STATISTICAL PARAMETERS FOR LOG PEARSON TYPE III

Year	Rank (*m*)	Water level (*x*)	*Return period	$y = \log_{10} x$	$(y - \overline{y})^3$	**P_r=1/T_r	***Weibull Plotting Position
2000	1	2.57	18.07	0.41	0.00374	0.06	0.09
2008	2	2.07	6.49	0.32	0.00022	0.15	0.18
2010	3	2.03	3.95	0.31	0.00015	0.25	0.27
2007	4	2.01	2.84	0.30	0.00012	0.35	0.36
2003	5	1.92	2.22	0.28	0.00002	0.45	0.45
2009	6	1.71	1.82	0.23	-0.00001	0.55	0.55
2006	7	1.53	1.54	0.19	0.00034	0.65	0.64
2005	8	1.53	1.34	0.18	0.00035	0.75	0.73
2004	9	1.52	1.18	0.18	0.00038	0.85	0.82
2001	10	1.39	1.06	0.14	0.00140	0.94	0.91
Sum					0.00177		
Mean		1.83		0.25			

*Return Period [T = (*n+0.12)/ (m-0.44)*].
**Plotting Probability is defined mathematically as $Pr = 1/T_r$.
***Weibull Plotting Position is defined mathematically as *(m) / (n+1)*

The overall flood frequency estimation is tabulated in Table 4 showing Gumbel and Log Pearson Type III computations. For each of the modelled return period, the exceedence probability reduces establishing the fact that the chances of occurrence of the extreme events reduces with increasing time. The statistical computation of Log Pearson Type III specifies that the flood level will increase from return of 2 years with 1.79 m water level to 100 years flood of 2.88 m. Conversely, Gumbel distribution shows that flood level will increase to 2.22 m at the 2-year return period and it will increase marginally to 2.55 m by the 100-year return period. Therefore, there are contrasting increases in the response of the water level at different hydrological years based on the return period. Although, the Log Pearson Type III indicates a small increase in water level at the 2-year return period, it postulates that the increase will be monumental within the next century. However, the reverse is the postulation of the Gumbel distribution for the same period of assessment.

TABLE 4: ESTIMATED WATER LEVELS OF LOWER OGUN BASIN FOR LOG PEARSON TYPE III AND GUMBEL VALUES

Return period (yrs)	Exceedence Probability	Log Pearson Type III			Gumbel Distribution			
		*Frequency factor (k)	Y_i = log m (Y_i =ŷ+k*Sy)	X_T	**Frequency factor (k) [when g = 0.8]	X_{av}	SDV	X_T
2	0.5	-0.03	0.25	1.79	1.30	1.83	0.30	2.22
5	0.2	0.83	0.32	2.11	1.37	1.83	0.30	2.24
10	0.1	1.3	0.36	2.30	1.49	1.83	0.30	2.28
25	0.04	1.82	0.41	2.54	1.83	1.83	0.30	2.38
50	0.02	2.16	0.43	2.71	2.40	1.83	0.30	2.55
100	0.01	2.47	0.46	2.88	3.53	1.83	0.30	2.9

*Frequency factor (k) is a function of the coefficient of skew g. For Log Pearson Type III g = 0.2 (approximated value from 0.18).
** Frequency factor (k) is a function of the coefficient of skew g. For Gumbel Distribution g = 0.8.

D. Flood Frequency: Assessment of Uncertainty and Goodness of Fit

With different figures and postulations from the flood frequency measures of Log Pearson Type III and Gumbel distribution as shown above, it is germane to compute the extent of uncertainty and assess the fitness of the data for the inundation mapping. The output of the analysis is presented in Table 5 showing the Chi-Square computations. The computed

Chi–Square statistics for log Pearson Type III is 0.3431 and Gumbel Distribution is 0.0645. With the degree of freedom (*df* = 5) and 0.995 significant level, Chi-Square returned the value 0.0412. By implication, Gumbel distribution falls within the designed threshold as stated in the null hypothesis. In addition, it is thereby accepted as the principal measure for flood inundation mapping.

TABLE 5: COMPUTATION OF GOODNESS OF FIT FOR LOG PEARSON TYPE III AND GUMBEL DISTRIBUTION

Return Period	Log Pearson Type III Distribution				Gumbel Distribution			
	Observed	Expected	$(O-E)^2$	$(O-E)^2/E$	Observed	Expected	$(O-E)^2$	$(O-E)^2/E$
2	1.79	2.39	0.36	0.1506	2.09	2.22	0.018	0.0081
5	2.11	2.39	0.08	0.0335	2.10	2.22	0.015	0.0068
10	2.30	2.39	0.01	0.0042	2.12	2.22	0.010	0.0045
25	2.54	2.39	0.02	0.0084	2.19	2.22	0.001	0.00005
50	2.71	2.39	0.11	0.0460	2.30	2.22	0.007	0.0032
100	2.88	2.39	0.24	0.1004	2.52	2.22	0.093	0.0419
	2.39		0.82	0.3431	2.39		0.822	0.0645

Chi Square statistics; Log Pearson Type III = 0.3431, Gumbel Distribution = 0.0645
At degree of freedom (*df* = 5) and significant level (α) 0.995, Chi-Square (x^2) returned the value 0.0412

E. Flood Inundation Area Mapping

A two-dimensional flood inundation mapping is adopted for this study based on the outcome of the flood frequency measure and the subsequent goodness of fit and uncertainty analysis. The 2-D flood inundation maps of the basin with respective return periods are presented in Figs. 5–10. Area and proportional analysis of the spatial extent of inundated and non-flooded area within the basin is estimated in Table 6 below for each of the flood inundation maps. It shows that 78.64 km^2 (23.1%) of the basin will be inundated in 2 years. This will increase in 5 years to 79.04 km^2 (23.22%). 81.32 km^2 will be inundated in 10 years. The inundation trend will persist up to 100 years whereby 96.7 km^2 of the basin (28.41%) will be completely flooded.

TABLE 6: INUNDATED AREA UNDER DIFFERENT RETURN PERIODS

Return period (years)	Water Level (metres)	Flooded Area		Non-Flooded Area	
		Area (km^2)	(%)	Area (km^2)	(%)
2	2.22	78.64	23.10	261.75	76.90
5	2.24	79.04	23.22	261.35	76.78
10	2.28	81.32	23.89	259.07	76.11
25	2.38	85.33	25.07	255.06	74.93
50	2.55	95.24	27.98	245.15	72.02
100	2.9	96.70	28.41	243.69	71.59

Although less than a third of the basin is anticipated to be inundated, the implication of this outcome is huge when compared to the nature and extent of anthropogenic activities and the importance of the floodplain in regulating the natural hydrological fluxes in the basin. The likelihood of exposure to flood risk might be higher going by the fact that road infrastructure and other hydrologic engineering structures within the basin are connected to human activities that are located close to the Ogun River.

A closer examination of the spatial trend of the inundation could be measured based on the annual land area that is anticipated to be inundated using the derived estimations from Table 6. Table 7 shows the range of spatial changes expected within the basin using the return periods as a base. The result presents a simple relation that the shorter the years (return period) the more obvious the inundation and vice versa. Consequently, it portrays the fact that Lower Ogun basin flood has a high capacity and probability to expand to the entire floodplain as the years go by. The consequence of this observation is the gradual emergence of a nascent landscape with more areas liable to flood being observed.

TABLE 7: SPATIAL CHANGES EXPECTED WITHIN THE BASIN

Return period (years)	Expected Inundated area (km^2)
2	39.32

5	15.81
10	8.13
25	3.41
50	1.91
100	0.97

In addition, the modelled trend of inundation extent depicts a meager increase in the land area inundated. This manifests as a consequence of the increase in elevation on the northern part of the basin in addition to the reduction in the water surface modelled for the area. Essentially, inundation of this area is based on the anticipated water surface level. Also, the coastal areas as well as areas along the River Ogun corridor possesses high naturally-inherent susceptibility to flood occurrence coupled with low elevation that makes the area directly flood-prone.

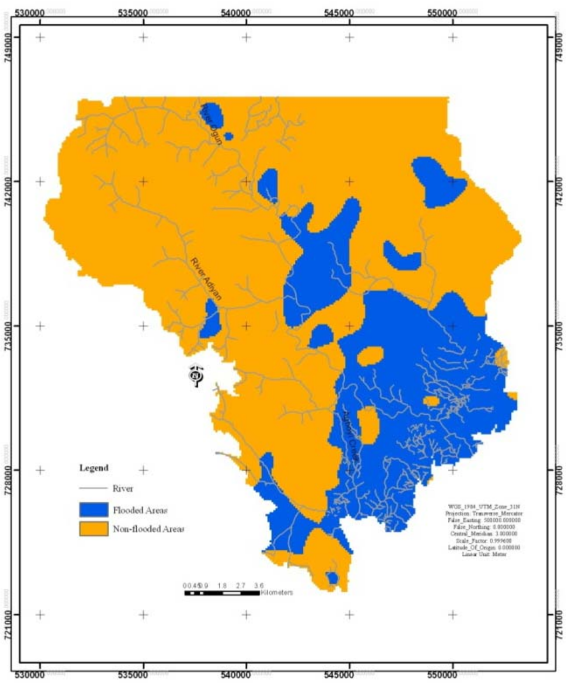

Fig. 5: 2-year return period flood inundation

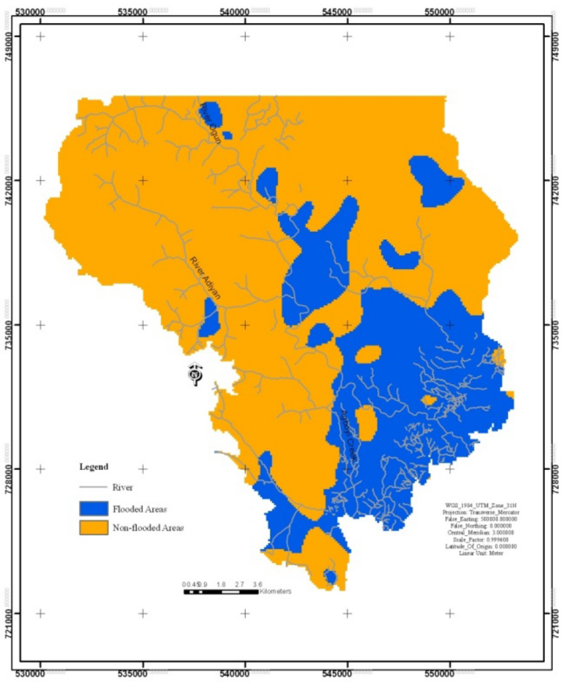

Fig. 6: 5-year return period flood inundation

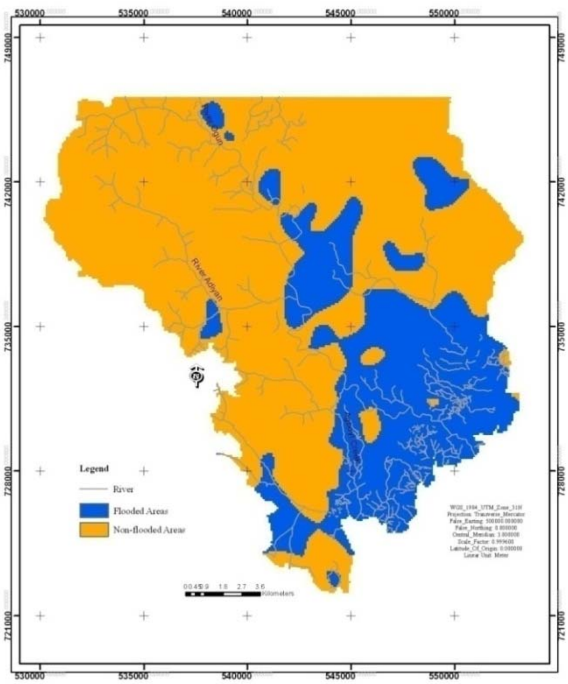

Fig. 7: 10-year return period flood inundation

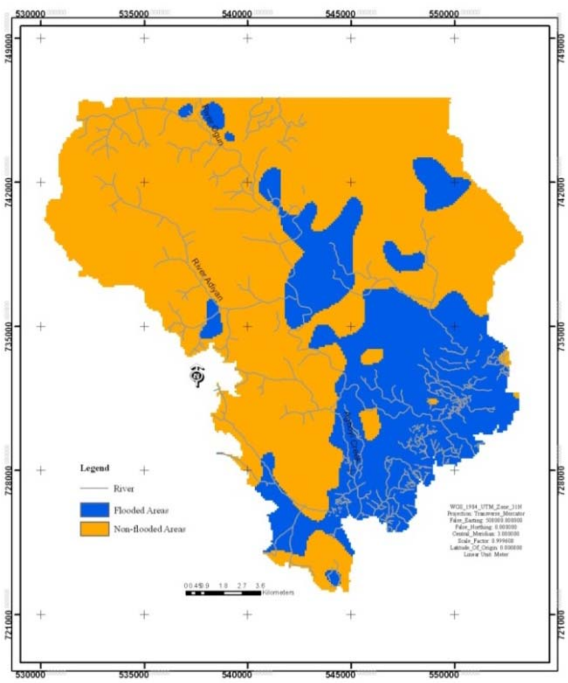

Fig. 8: 25-year flood inundation

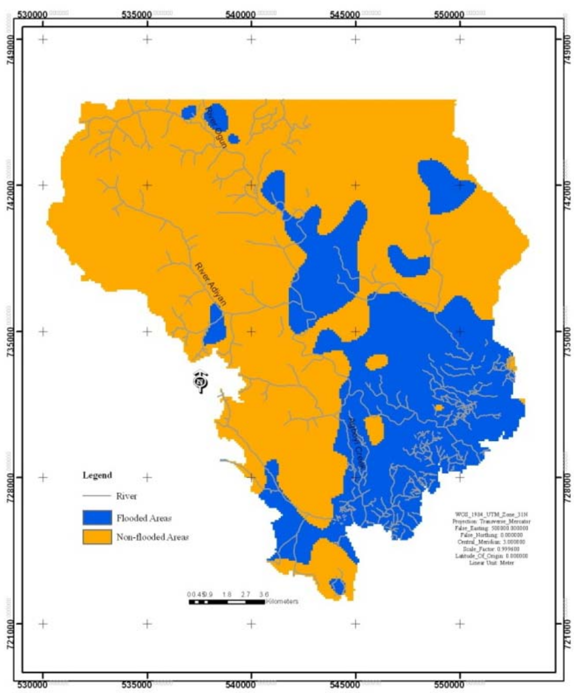

Fig. 9: 50-year return period flood inundation

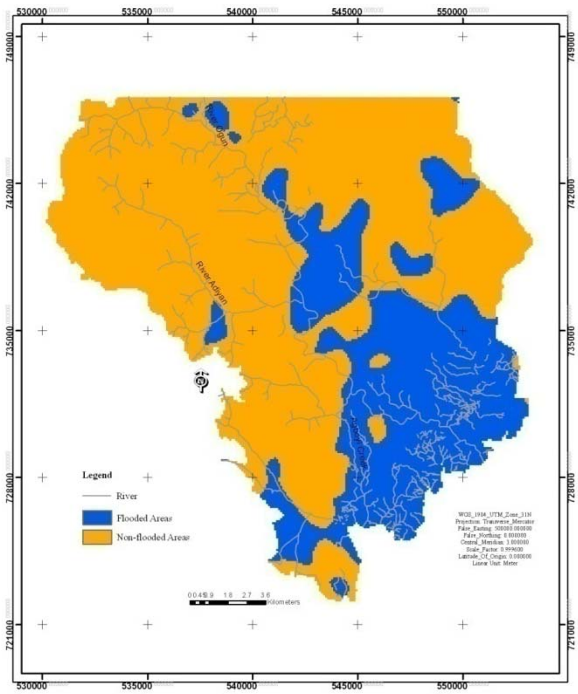

Fig. 10: 100-year flood inundation

V. CONCLUSION

Flood assessment and monitoring is crucial for environmental sustainability, particularly within areas traversed by river floodplain. This study has shown the need to compute flood frequency analysis and the usefulness of geographic information system (GIS) as a spatial tool for inundation mapping within an ungauged basin. Also, the study has demonstrated the importance of depicting the frequency of occurrence of flood to the production of the aforementioned GIS-based flood inundation mapping. However, one of the most challenging issues in hydrology is the choice of suitable flood frequency analysis. This challenge is further intensified by the extent of uncertainties and variability in river behaviours particularly water level measurement and discharge computations. This challenge has been surmounted in this study with simultaneous examination of two established and widely used methods of flood frequency analysis. The flood inundations analysis, however, shows that there is the likelihood of an increased flood frequency, especially if continuous expansion of the impervious areas into the Lower Ogun floodplain is considered. Since the area is an emerging urban environment typical of Nigeria and Africa at large, one possible long-term solution is a combination of structural approach with sustainable urban drainage systems, SUDS [23]. The SUDS will involve a sustainable planning and developmental measures that consider the modelled pattern of hydrological fluxes of the study area. The SUDS, in addition to helping relieve the flooding problem, bring benefits including water quality protection and enhancement; encouragement of natural groundwater recharge and the elimination of possible salt-water intrusion to water supply wells; and the promotion of healthy habitat for wildlife. In the long run, the SUDS will help in adjusting the changes in the hydrological fluxes to expanding urban landscape particularly within ungauged basins. This is inevitable particularly for Nigeria and Africa at large where urbanization has been on the rise and most of the rivers are not gauged.

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