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Streamflow Models of Imo River for Regional Water Resources Allocation

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Abstract
Developed Streamflow Models for Imo River is presented based on the statistical method of least squares. Four streamflow models of Imo River are developed to assist allocation of water resources within the South-East region of Nigeria mostly concern by the river basin, using streamflow data from Umuna, Obigbo, Umuopara and Ndimoko streamflow gauging stations. The models represent nonlinear relationship between annual maximum discharge and annual maximum stage. High and positive values of correlation coefficients (r) ranging between 0.953 to 0.998 and coefficients of determination (r^2) ranging between 0.908 to 0.997 were obtained indicating good curve fitting. The models developed will serve the useful purpose of predicting streamflow events and in turn flood prediction, erosion and sedimentation control, drainage, water resources allocation and management, design and operation of hydraulic structures, irrigation, habitat protection, recreational use of water, and pollution abatement. The four streamflow models of Imo River can also be used to predict similar river characteristics with that of Imo River. The research will play an important role in ensuring that future allocation of water resources in the localities are scientifically based and efficiently used so as to satisfy the needs of both human and natural systems.

Key Words: *Streamflow, Stage, Discharge, Water Resources Allocation, Correlation Coefficient, Coefficients of Determination and Standard Error Estimate.*

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I. INTRODUCTION

Hydrologic systems models are analyzed by using mathematical models. In most parts, mathematical models are designed to describe the way a system's elements respond to some types of stimulus (input). The models may be empirical or statistical, or founded on known physical laws. They may be used for such simple purpose as determining the rate of flow that a roadway grate must be designed to handle, or they may be used to guide decisions about the best way to develop a river basin for a multiplicity of objectives (Viessman, and Lewis, 2008).

Hydrologic data are the building blocks for modeling hydrologic processes. Many sources of data may be accessed to support model development and verification, statistical analyses, and other studies (Viessman, and Lewis, 2008). The unavailability of long term hydrological data such as streamflow measurements and invariably lack of streamflow models has been the major difficulties encountered by engineers and hydrologists in design and planning of water resources structures in developing countries like Nigeria and other underdeveloped countries (Ojha et al., 2008; Viessman and Lewis, 2008; Raghunath, 2006 and Sonuga, 1990.) In the developed countries such as United States of America, France, Britain to mention but a few, hydrological data such as rainfall data, stream flow data, climatological data, hydrometeorological data, etc. may abound up to and beyond one hundred years duration.

For the analysis and design of any hydrologic project adequate data and reasonable length of records are necessary (Raghunath, 2006). It is generally accepted that hydrological data and hydrologic modeling are indispensable in the planning and design of water resources development programmes. Water yield from basin - its occurrence, quantity and frequency, etc. is necessary for the design of dams, the size of storage reservoirs, municipal water supply, flood estimation, water power, river navigation, etc. (Raghunath, 2006; Ojha et al., 2008). The knowledge of streamflow is important for estimating groundwater recharge rates.

Barlow and Leake (2012) explained that one of the primary concerns related to the development of groundwater resources is the effect of groundwater pumping on streamflow. Groundwater and surface-water systems are connected, and groundwater discharge is often a substantial component of the total flow of a stream. Groundwater pumping reduces the amount of groundwater that flows to streams and, in some cases, can draw streamflow into the underlying groundwater system. Streamflow reductions (or depletions) caused by pumping have become an important water-resource management issue because of the negative impacts that reduced flows can have on aquatic ecosystems, the availability of surface water, and the quality and aesthetic value of streams and rivers.

Hydrologic models have widely been used to explain and predict complex behaviors associated with the management of environmental systems and Land Use/Cover (LULC) of the watershed changes (Bronstert et al., 2002; Croke et al., 2004; Siriwardena et al., 2006; Lin et al., 2007; Kalin and Hantush, 2009). Land Use/Cover (LULC) of the watershed effects and soil characteristics on water quantity have been addressed in the context of estimating streamflows in unmonitored watersheds as well as predicting changes in streamflow in response to Land Use/Cover (LULC) changes (Isik et al, 2012). There is strong experimental evidence that local water balance can be affected by Land Use/Cover (LULC) changes (van Dijk et al, 2011; Nagy et al, 2011). Reliable predictions of water availability and streamflow characteristics, and the impact of climate and land use change on water availability, are central to water resources planning and management (Zhao at al., 2012). Realistic and accurate streamflow forecasts are essential for water resources planning and management. In many regions, agricultural, municipal, and environmental water uses increase demands on limited freshwater resources (Harshburger et al., 2012).

The physical characteristics of floods and management adaptations to flood hazards in Imo river basin were studied by Ezemonye and Emeribe, (2011). The pre and post flood disaster is a yearly event. The extent and time of commencement usually differ in each flood seasons being between July, August and September when rainfall is at its peak. It was observed that flood duration in the sampled communities last for as much as three to four months. The velocity of the flood waters under peak discharge usually between August and September was observed to be sluggish, while being faster during recession in mid-October. It was concluded that Engineering control of the major tributaries of the Imo river system is required to reduce impact of flooding on the settlements, while land use zoning will serve as effective adaptation and disaster management option in the area.

Nwaogazie and Okah (2003) studied the upper reaches of Imo river system between Nekede and Obigbo hydrological stations (a stretch of 24 km) for purpose of water quality and streamflow modeling. Model's application on water supply to Nekede and Obigbo connunities were equally explored with the development of mass curve. Possible sources of contamination of Imo river system within Nekede and Obigbo hydrological stations watershed were traced. Trend analysis, consistency tests and modeling of water quality constituents and river flow characteristics at upstream Nekede station and downstream Obigbo station show linear and nonlinear relationships for water quality models against total dissolved solids (TDS), Total Suspension Sediments (TSS), chlorine, pH and sulphate; and non-linear relationship for streamflow and water quality transport models. Microsoft Excel Software on multiple regressions was applied to the data yielding values of model coefficients and those of correlation coefficients ranging from 0.9296 to 0.9999.

Water allocation is the allocation of certain rate of flow of water to various water using sectors. It is used as a basis for designing the distributaries and water courses (Suresh, 2008).The distribution of water from water sources, such as rivers, reservoir etc. to the outlet comes under the management of government agency. Klemis (1973) defined the water management as a discipline that seeks the water balance between the demand and availability of water with the satisfaction of economic, political, sociological, ecological and environmental consideration. Compared to other natural resources, water is not stationary and does not respect administrative borders. Thus drainage basin's boundaries are not necessarily identical to political boundaries resulting in the existence of International River Basins. Within the basin, (surface) water can be distributed unequally which might lead to conflict among the riparian states about transboundary waters especially surface waters (*Wolf et al.*, 2003a). To prevent conflict and to manage the existing natural resource adequately, the partition of river flow can be regulated by bilateral or multilateral water allocation agreements (*Matthews & St. Germain*, 2007).The relationship between stage (m) and the corresponding discharge (m^3/s) is an exponenti al function (Ojha et al., 2008). Strong nonlinear bivariate and multivariate correlations are common in hydrology and various mathematical models are used to describe the relationships, such as parabolic, exponential, hyperbolic, power, and other forms that provide better graphical fits than straight lines. In this study, regression modeling was adopted to fit streamflow data from four streamflow gauging stations along Imo River for eleven years duration (1978-1988). The approach was to utilize the original data in model calibration and using coefficient of correlation, coefficient of determination and standard error of estimate as evaluation parameters for good curve fitting.

II. METHODOLOGY

2.1 Study Area and Data Collection

Imo River constitutes the study area. Imo River is the major river within the South Eastern States of Nigeria. The stream flow data utilized in this research where obtained from Anambra Imo River Basin Development Authority (AIRBDA) which is located at Agbala along Owerri -Aba road in Imo State Nigeria. Stream flow data from four stream flow gauging stations were collected from 1978 to 1989 (see Fig. 1).

The four stream flow gauging stations along Imo River from where data are obtained are:

- Ndimoko stream flow gauging station located on latitude 05´52' N and longitude 07° 15′ E and catchment area of 160 sq km.
- Umuna stream flow gauging station on latitude 05° 47' N and longitude 07° 18′ E and catchment area of 490 sq km.
- Umuopara stream flow gauging station on latitude 05´33' N and longitude 07° 25′ E and catchment area of 1450 sq km.
- Obigbo stream flow gauging station on latitude 04´52' N and longitude 07° 11′ E and catchment area of 5600 sq km.

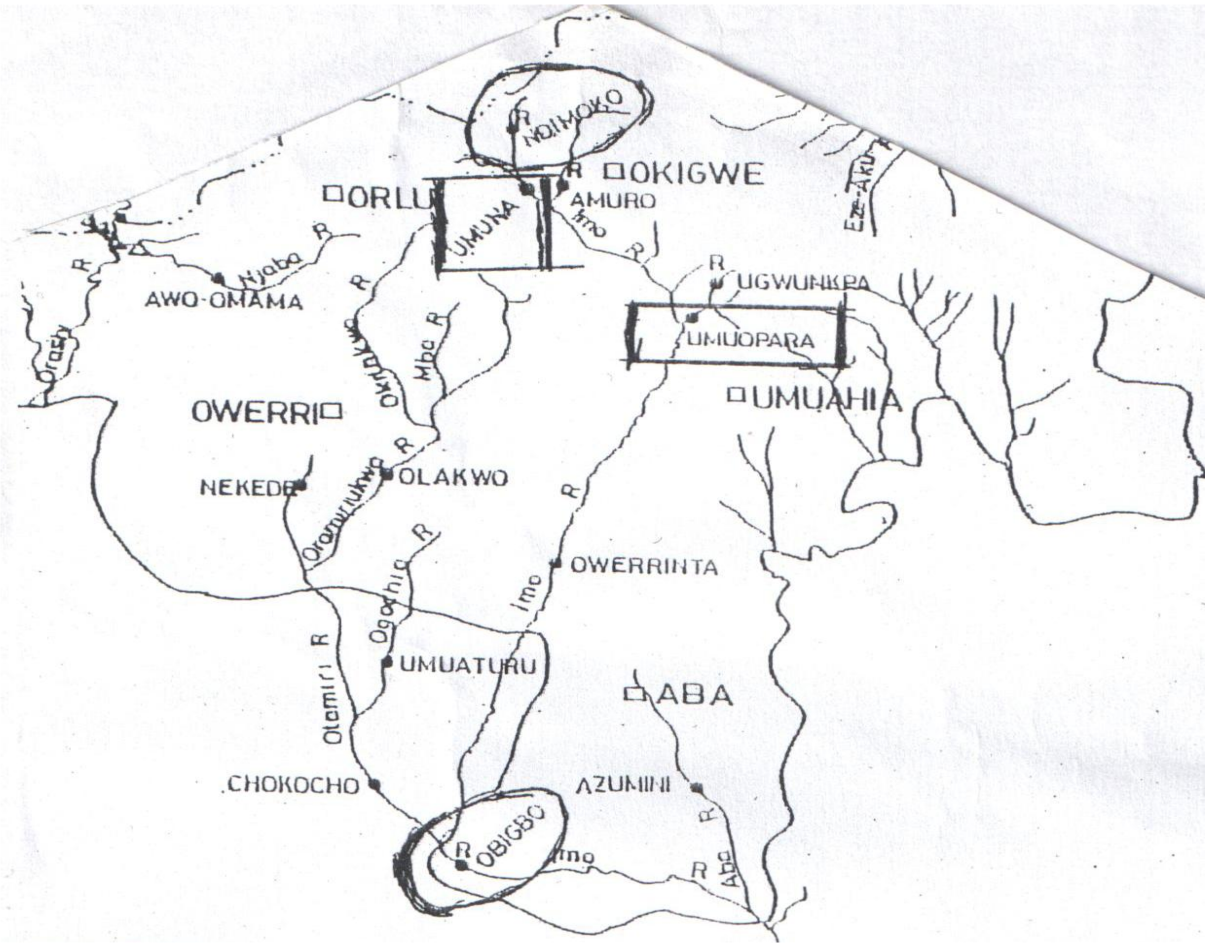

Fig. 1 Imo River Basin – Showing Gauging Stations
(Source: AIRBDA, 1989)

2.2 Model Development and Calibration

2.2.1 Mathematical Representation

The mathematical representation of the relationship between the stage (h) and the corresponding discharge (Q) can be expressed as:

$$Q = k\,(h)^b \quad \ldots \quad (1)$$

where k and b are constants for any stream gauging station (Ojha et al., 2008; Reddy, 2008 and Arora, 2007). The above relationship is an exponential function which can be handled by transforming it to a straight line by using logarithms of the variables. Logarithmic transformation can also be avoided by fitting an exponential growth curve to actual data (Moore and McCabe, 1993).

III. RESULTS AND DISCUSSION

3.1 Streamflow Data Analysis and Results

The eleven years annual maximum discharge and annual maximum stage data from each of the four streamflow gauging stations (Table 1) were subjected to regression analysis.

Table 1

S/n	Year	Annual maximum stage (h) at Ndimoko (m)	Annual maximum discharge (Q) at Ndimoko (m^3/s)	Annual maximum stage (h) at Umuna (m)	Annual maximum discharge (Q) . at Umuna (m^3/s)	Annual maximum stage (h) at Umuopara (m)	Annual maximum discharge (Q) at Umuopara (m^3/s)	Annual maximum stage (h) at Obigbo (m)	Annual maximu m discharg e (Q) at Obigbo (m^3/s)
1	1978	3.02	25.00	4.48	77.50	5.66	270.00	2.06	246.00
2	1979	2.59	18.20	4.59	80.00	4.54	158.40	1.97	232.00
3	1080	3.30	27.50	4.84	96.00	3.95	118.00	2.14	261.50
4	1981	3.14	24.40	3.97	62.40	6.23	258.28	1.90	220.00
5	1982	3.16	18.90	1.99	17.00	4.75	187.50	1.91	240.80
6	1983	3.14	24.50	4.62	81.60	5.53	223.00	2.23	263.89
7	1984	3.00	22.84	4.18	68.40	3.22	126.20	1.54	176.40
8	1985	2.95	22.28	4.71	84.60	4.83	194.40	2.29	286.20
9	1986	2.79	20.49	4.87	89.10	3.00	115.00	1.75	200.00
10	1987	3.56	29.51	4.63	80.40	5.19	223.20	1.92	223.20
11	1988	3.52	29.02	4.89	89.70	1.32	42.85	2.40	306.80

The outputs of the Microsoft Excel progammes for regression are shown in Figures 2 to 5.

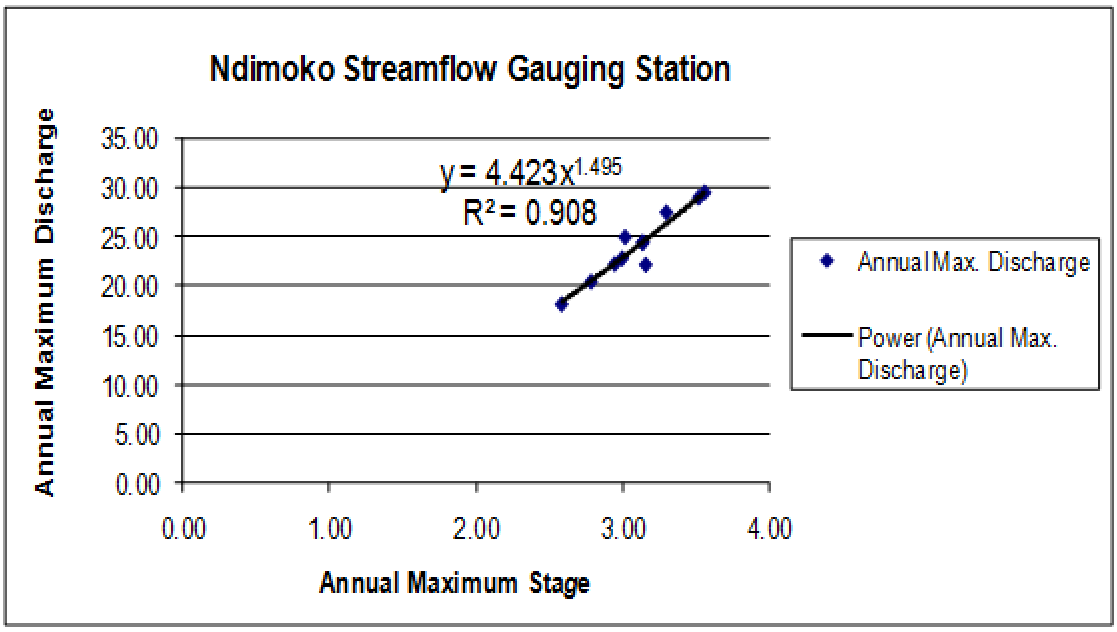

Fig. 2 Plot of annual maximum discharge versus annual maximum stage at Ndimoko.

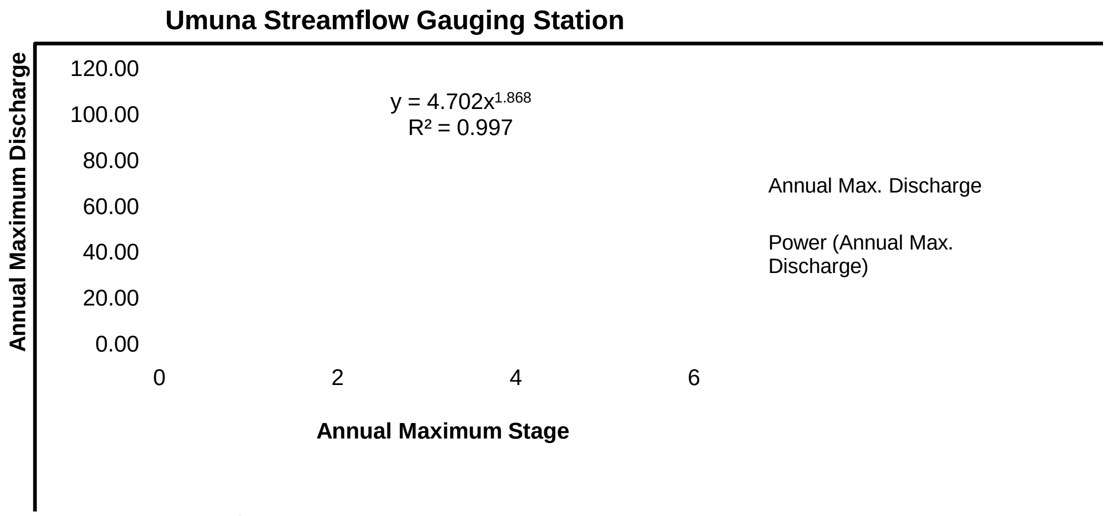

Fig. 3 Plot of annual maximum discharge versus annual maximum stage at Umuna.

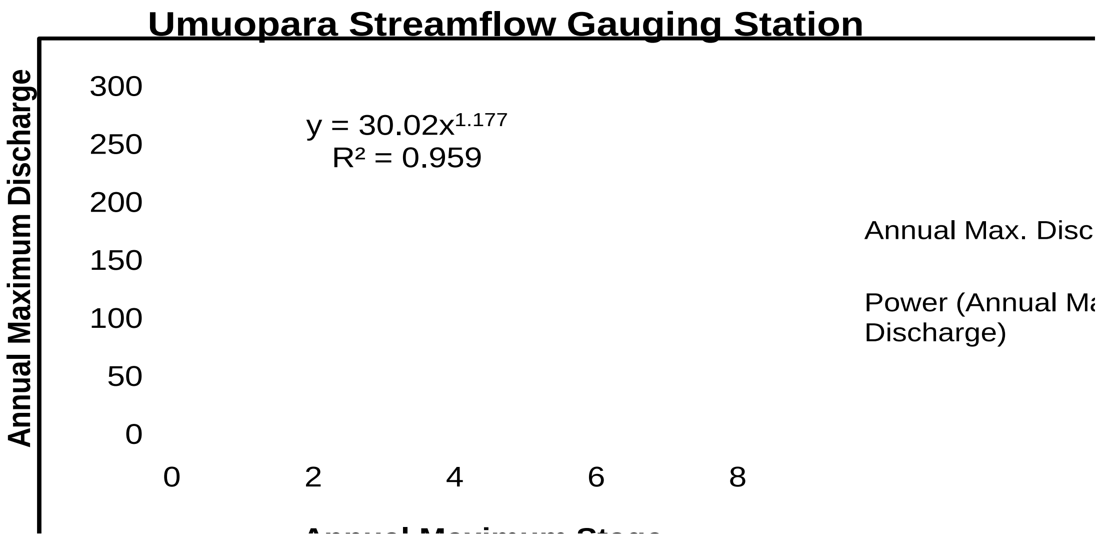

Fig.4 Plot of annual maximum discharge versus annual maximum stage at Umuopara.

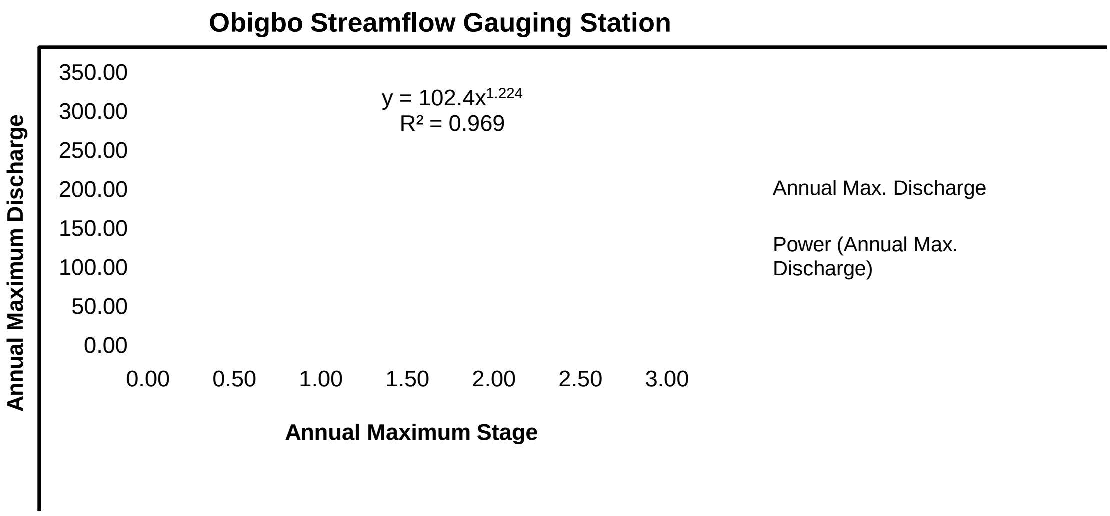

Fig. 5 Plot of annual maximum discharge versus annual maximum stage at Obigbo.

The streamflow models of Imo River at Ndimoko, Umuna, Umuopara and Obigbo obtained from Figures 2 to 5 (using annual maximum discharge versus annual maximum stage curve) are shown in Table 2

Table 2 Imo River Streamflow Models (using annual maximum discharge versus annual stage curve)

S/n	Streamflow gauging station	Streamflow Model + $Q = k (h)^b$	Model Performance Indicator *
1	**Ndimoko**	$Q = 4.423\ h^{1.495}$	$r^2 = 0.908$ $r = 0.953$ $S_{Q.h} = 1.82$
2	**Umuna**	$Q = 4.702\ h^{1.868}$	$r^2 = 0.997$ $r = 0.998$ $S_{Q.h} = 2.19$
3	**Umuopara**	$Q = 30.02h^{1.177}$	$r^2 = 0.959$ $r = 0.979$ $S_{Q.h} = 17.40$
4	**Obigbo**	$Q = 102.4\ h^{1.224}$	$r^2 = 0.969$ $r = 0.984$ $S_{Q.h} = 6.41$

+ Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)
*** Model Performance Indicator**
r^2 = Coefficient of determination
r = Coefficient of correlation
$S_{Q.h}$ = Standard error of estimate of discharge (Q) on stage (h)

IV. DISCUSSION

The result in Table 2 suggests that there is a good test of good fit of the regression analysis done using annual maximum discharge versus annual maximum stage. The coefficient of correlation (r) which summaries in one number the direction and the magnitude of correlation have very high values ranging from 0.953 to 0.998. The coefficient of determination (r^2) which accounts for or is able to explain a large percentage of the variation in the data has very high and positive values ranging from 0.908 to 0.997 which implies that from 91% to nearly 100% of the total variance is explained. The standard error of estimate ($S_{Q.h}$) which is a measure of the scatter about the regression line of discharge (Q) on stage (h) has small values ranging from1.82 to 17.40 indicating that the regression models fit the data. Therefore these models confirm the nonlinear relationship between stage and discharge. The streamflow models of Imo River developed at the various streamflow gauging stations (Table 2) are useful for water resources planning and allocation of water to the various water using sectors in the regions.

V. CONCLUSION

The streamflow models developed from the annual maximum discharge versus annual maximum stage from Umuna, Obigbo, Umuopara and Obigbo streamflow gauging stations along Imo River has high and positive values of correlation coefficients (r) ranging between 0.953 to 0.998 and coefficients of determination (r^2) ranging between 0.908 to 0.997.

The standard error of estimate (SQ.h) ranging from1.82 to 17.40 indicating good curve fitting and confirms the nonlinear relationship between stage and discharge. The models developed in this research can serve useful purpose in developing alternative water use futures, estimating water requirements for natural systems, developing more efficient systems for applying water in all water-using sectors, and analyzing and designing water management systems incorporating technical, economic, environmental, social, legal and political elements. The models will help in determining design inflows which are necessary in water control, water use and management.

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