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Review Article

Streamflow Modelling of River Niger at Lokoja and Onitsha in Nigeria for Water Resources Development and Management

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Abstract

This paper presents the streamflow modelling of River Niger at Lokoja and Onitsha streamflow gauging station in Nigeria based on least square regression technique. The flow calibration was performed for eleven years from 1998 to 2008 for River Niger at Lokoja streamflow gauging station and from 1980 to 1990 for River Niger at Onitsha streamflow gauging station. The models were also verified and they gave good results. The performance of the modelling effort was evaluated by calculating statistical measures such as Coefficient of Determination (R^2) ranging from 0.9983 and 0.9995, Coefficient of Correlation (R) ranging from 0.9991 and 0.9997, Nash-Sutcliffe model Efficiency (NSE) ranging from 0.9962 and 0.99996, Root Mean Square Error (RMSE) or Standard Error of Estimate (S_{yx}) ranging from 12.68 and 35.66, Mean of Residues (MR) or Mean Absolute Error (MAE) ranging from 7.042 and 33.03 and Mean Absolute Relative Error (MARE) ranging from 0.9981 and 0.9996 and then the measured (observed) state variables are compared with the predicted (simulated) state variables. The developed models can be used for hydropower electricity generation, water resources development and management within Lokoja and Onitsha towns and to study any post development scenario within the River Niger catchments and for further hydrological studies in the river basin.

Keywords: Water, Water Resources Development, Water Resources Management and Environment.

1.0 INTRODUCTION

Water is the most important natural resources, a vital resource for human survival and it is a basic necessity which is crucial for all life on earth (Reddy, 2008). Water is required for human and animal consumption and it is also needed for the growth of agricultural produce which sustain life on the earth. Water plays an essential role in human health, economy, food production and environment. Water covers 78% of the earth surface, yet water availability for human use is limited especially in the developing countries. In view of its occurrence and distribution pattern, water is not easily available to man in desirable quantity and quality. However, being a basic need of human development, health and well-being, the availability of drinking water has been internationally accepted human right (WHO, 2001 cited in Ogunwemimo, 2015) which has been enlisted as one of the ten targets in Millennium Development Goals (MDGs) (Fada and Bodiaga, 2014).

Safe drinking water is imperative for development and public health since 21 of the 37 primary diseases in developing countries are related to water and sanitation (W.H.O., 2010 cited in Abioye and Adamu, 2014). Clean water for drinking, washing, growing crops, cooking food and operating business is a priority throughout the developing world and currently, close to two billion people lack access to safe drinking water (European Report on Development (ERD), 2012 cited in Haruna *et al.*, 2014). In most urban and rural settlement areas in Nigeria, access to clean and potable water is a great challenge. The two main problems man contends with in Nigeria are the quantity and quality of water (Adeniyi, 2004 cited in Ogunwemimo, 2015). Water is used for various other purposes such as hydropower development, navigation and recreation. If the water is properly harnessed and utilized, it can be a boon and of immense value to humanity. However, if the water is not properly controlled, it may be a curse and cause destruction and misery. Water quality management is an important phase of the water-resources engineering, without which pollution may threaten its utility (Arora, 2007).

1.1 Water Resources Development and Environment

Water is a major component of that environment in which man occupies the centre-stage. Water is part of a large ecological system. All great civilization had grown around water and many had perished with water, perhaps not having realized the importance in its sustainable development. The ever-increasing need of water has brought into focus the fragility of environment and the need to guard it. The National Water policy (1987 cited in Sharma and Sharma, 2000) recognizes the importance of water in the environment. Water is a scarce and precious national resource to be planned, developed and conserved as such, and on an integrated and environmentally sound basis (Sharma and Sharma, 2000). Water resources development projects are not a purpose but a means to achieve the best use of water resources by storage of flood water in a reservoir for regulated use during dry season. Water resources development may create both beneficial and adverse impacts on the environment. Given the circumstances and needs, water resources development cannot be stopped merely for fear of destroying the ecological balance. Environmental considerations, at the same time, cannot be neglected entirely while planning for the future development.

1.2 Water Resources Management

According to Gada (2014), for a successful water resources management, appropriate decision making is crucial and this is even so when water resources is limited or when there is a spatial-temporal variability of the resource in an area. The growing population and recent droughts occurrence attributed to climate change leads to further variable changes and uncertainty putting the available water resources under pressure and calling for new approaches for water development planning and management to decision makers if escalating conflicts are to be avoided (Paul *et al*., 2008 cited in Gada, 2014; Friedrich *et al*., 2008 cited in Gada, 2014; Water Aid, 2007 cited in Gada, 2014; Parry *et al*., 2007 cited in Gada, 2014).

2.0 STUDY AREA

According to Olivry (2002, cited in Abrate *et al*., 2013), the River Niger is the third longest river in Africa (4200 km), after the Nile and the Congo, draining a basin of about 1 100 000 km2. The river has its sources on the Fouta Djallon massif in Guinea and, after a long arch through the Sahelian and Saharan regions, empties in the Gulf of Guinea with a large delta. Welcomme (1986) and Lae (1995) stated that the River Niger takes its source in the mountains of Fouta-Djalon in Guinea and crosses successively Mali, Niger, Benin and Nigeria where it’s ended into the Atlantic Ocean after crossing approximately 4200 km. River Niger is the largest river in West Africa and the third longest river on the continent after the Nile and the Congo (see Figure 1).

With a total length of 4,200Km, the Niger is the eleventh longest river in the world and 9th from the point of view of the size of its catchment area. Its active basin covers a surface of approximately 1,5 million km^2 shared by nine (9) countries gathered within the Niger Basin Authority (NBA), these are: Benin, Burkina Faso, Cameroun, Côte d'ivoire, Guinea, Mali, Niger, Nigeria and Chad. It has a total drainage area of 1,595,000km^2 out of which 482,300km^2 falls within the desert that produces no runoff. The major tributary Benue takes its source in Chad before crossing Cameroun to join the River Niger at Lokoja in Nigeria. Nigeria derives its name from the river, though only less than one-third of its length lies in its territory (Hydrological Bulletins, 2015).

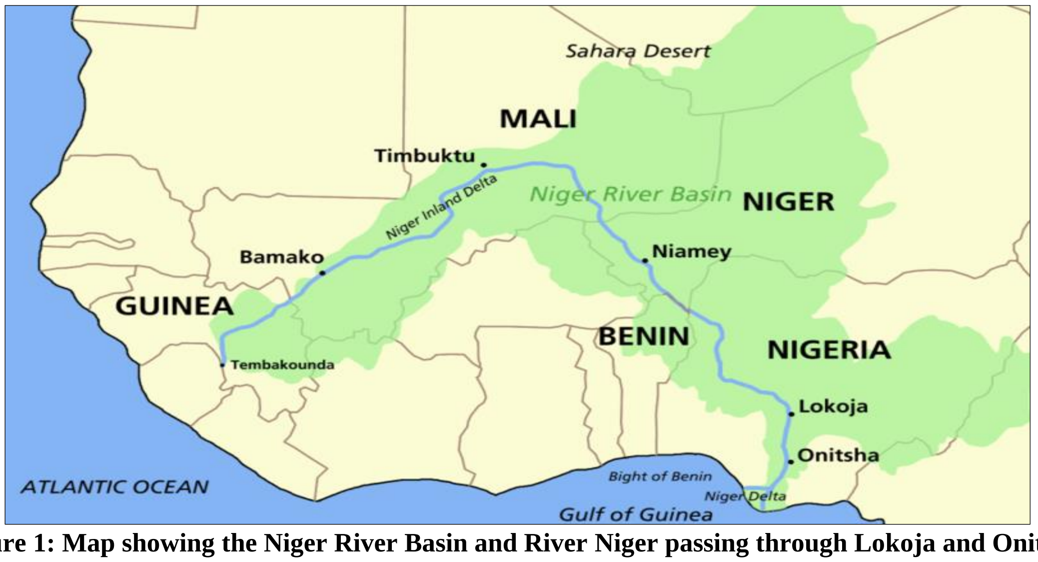

Figure 1: Map showing the Niger River Basin and River Niger passing through Lokoja and Onitsha
Source: https://commons.wikimedia.org/wiki/File:Niger_river_map.PNG

3.0 METHODOLOGY

3.1 Mathematical Representation of the Relationship between Stage and Discharge

The width of the river can be expressed as a power function of the depth of flow (Strelkoff and Clemmens, 2000, cited in Petersen-Øverleir, 2006):

$B = \beta h^N$ . . . . (1)

Where β and *N* are dimensionless scale and shape parameters. Arora (2011), Reddy (2008), Ojha *et al*., (2008) and Raghunath (2006) also stated that the relationship between the stage (h) and the corresponding discharge (Q) can be expressed as:

$Q = k\,(h)^b$ . . . . . . (2)

where,

k and b are constants for any stream gauging station.

h = gauge height or stage

Q = discharge or flow rate

3.2 Streamflow Model Calibration of River Niger at Lokoja Gauging Station

Sixteen years' record of streamflow measurements of River Niger at Lokoja gauging station was obtained. Eleven years' record of annual maximum stage and annual maximum discharge from 1998 to 2008 are used for streamflow model calibration, while the other five years' 2009 to 2011 and 2013 to 2014 are used for the verification of the streamflow model. The streamflow model is calibrated by fitting an exponential growth curve to actual data using Microsoft Excel Programme shown in Figure 2 (power model).

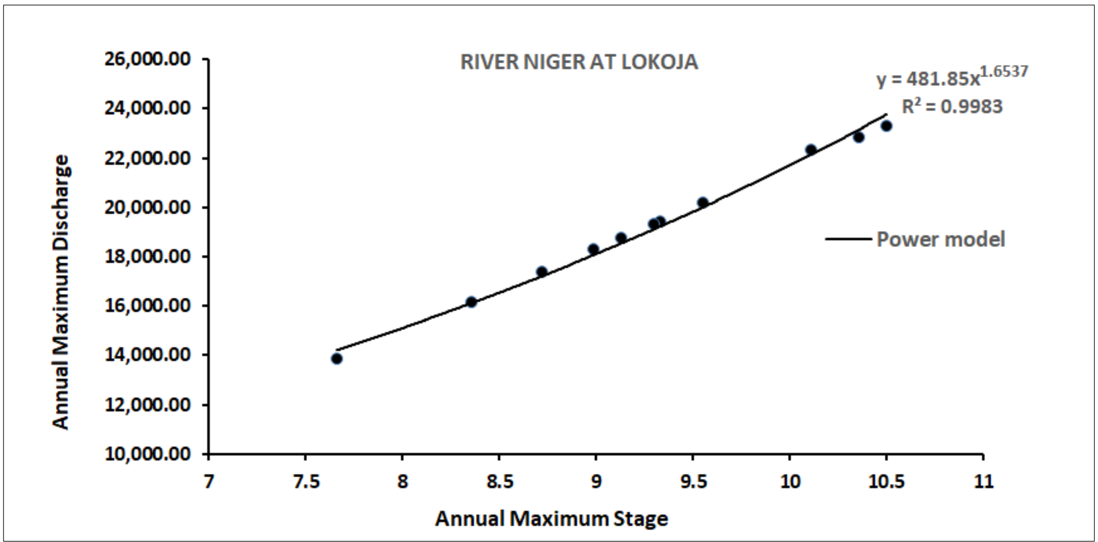

Figure 2: Plot of streamflow model calibration of River Niger at Lokoja gauging station (power model)

Source: Uzoukwu (2023)

3.3 Verification of Streamflow Model of River Niger at Lokoja Gauging Station

After calibration, model's verification was carried out for River Niger at Lokoja gauging station using stage and discharge data for the period of 2009 – 2011 and 2013 – 2014. The verification values are shown in Table 1.

Table 1: Verification of streamflow model of River Niger at Lokoja gauging station

S/N	Year	Annual Maximum Stage (h) (m)	Measured Annual Maximum Discharge (Q) (m^3/s)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Power Model)
1	2009	9.95	21,530.00	21,528.41
2	2010	9.79	20,986.00	20,958.93
3	2011	8.56	16,794.08	16,753.45
4	2013	8.45	16,430.00	16,430.65
5	2014	9.40	19,595.26	19,596.27

3.4 Streamflow Model Calibration of River Niger at Onitsha Gauging Station

Fifteen years' record of streamflow measurements of River Niger at Onitsha gauging station was obtained. Eleven years' record from 1980 to 1990 of annual maximum stage and annual maximum discharge are used for streamflow model calibration, while the other four years; 1991, 1995, 2000 and 2001 are used for the verification of the streamflow model. The streamflow model is calibrated by fitting an exponential growth curve to actual data using Microsoft Excel Programme shown in Figures 3.

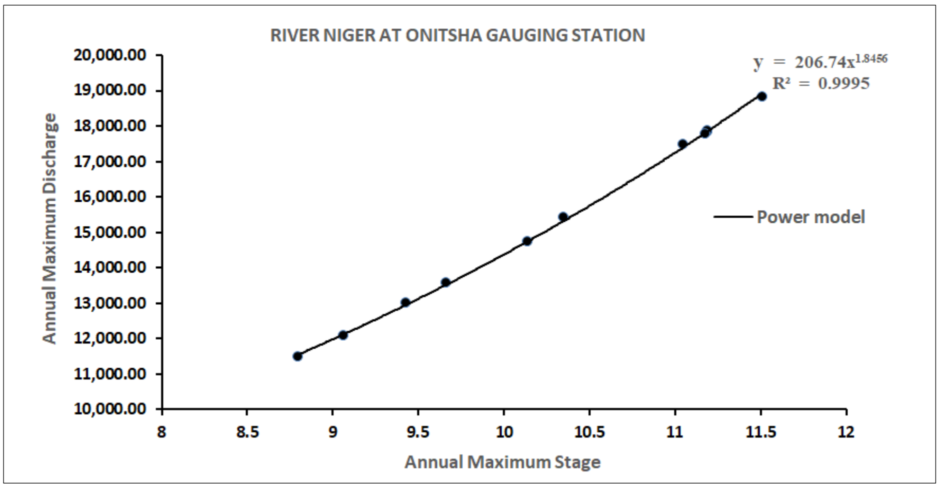

Figure 3: Plot of streamflow model calibration of River Niger at Onitsha gauging station (power model)
Source: Uzoukwu (2023)

3.5 Verification of Streamflow Model of River Niger at Onitsha Gauging Station

Verification of streamflow model of River Niger at Onitsha gauging station was carried out by using stage and discharge data for the period of 1991, 1995, 2000 and 2001. The verification values are shown in Table 2.

Table 2: Verification of streamflow models of River Niger at Onitsha gauging station

S/N	Year	Annual Maximum Stage (h) (m)	Measured Annual Maximum Discharge (Q) (m^3/s)	Predicted Annual Maximum Discharge (Q) (m^3/s) (Power Model)
1	1991	11.29	18,159.08	18,124.93
2	1995	10.91	17,025.82	17,015.08
3	2000	10.76	16,629.33	16,585.83
4	2001	10.87	16,943.85	16,900.12

The summary of the streamflow models of River Niger at Lokoja and Onitsha gauging stations obtained from Figures 1 and 2 and the models evaluation parameters are shown in Table 3.

Table 3: Summary of streamflow models of River Niger at Lokoja and Onitsha gauging station and the models evaluation parameters

River System	Streamflow Model +	Model Evaluation Parameters *					
		R^2	R	NSE	RMSE or S_{QH}	MR or MAE	MARE
River Niger at Lokoja gauging station	Power model $Q = 481.85h^{1.6537}$	0.9983	0.9991	0.99996	12.68	7.042	0.9996
River Niger at Onitsha gauging station	Power model $Q = 206.74h^{1.8456}$	0.9995	0.9997	0.9962	35.66	33.03	0.9981

+ Annual maximum stage is given in meter (m) and annual maximum discharge in cubic meter per second (m^3/s)

***Model Evaluation Parameters**

Coefficient of determination (R^2), Coefficient of correlation (R), Nash-Sutcliffe model Efficiency (NSE), Root Mean Square Error (RMSE) or Standard error of estimate of discharge on stage ($S_{Q.H}$), Mean Residue (MR), Mean Absolute Relative Error (MARE).

3.6 Application of the streamflow model of River Niger at Onitsha Streamflow Gauging Station in Hydropower Electricity Generation

Streamflow model of River Niger at Onitsha gauging station is used in hydropower electricity generation in Onitsha, Anambra State. The mean monthly water levels (stages) were calculated from the daily streamflow records of River Niger at Onitsha gauging station. Then with the help of the calibrated streamflow model of River Niger at Onitsha gauging station, the predicted mean monthly flows (discharges) were computed and then tabulated in Table 4.

The calibrated streamflow model (power model) of River Niger at Onitsha streamflow gauging station is $Q = 206.74h^{\mathbf{1.8456}}$

Table 4: Mean monthly streamflow data of River Niger at Onitsha s gauging station

Months	Mean monthly stage (m)	Predicted mean monthly discharge m^3/s
January 2001	3.76	2,382.27
February 2001	3.33	1,903.92
March 2001	3.13	1,698.25
April 2001	3.07	1,638.65
May 2001	3.37	1,946.34
June 2001	4.05	2,732.40
July 2001	5.32	4,520.30
August 2001	7.42	8,352.99
September 2001	9.69	13,670.48
October 2001	10.43	15,659.22
November 2001	5.91	5,488.66
December 2001	3.49	2,076.17

Computation for Flow Duration Curve (FDC) for River Niger at Onitsha streamflow gauging station is shown in Table 5.

Table 5: Computation for Flow Duration Curve (FDC) for River Niger at Onitsha streamflow gauging station

Months	Predicted mean monthly discharge (flow) m^3/s	Discharge (flow) arranged in descending order m^3/s	Rank m	Percentage of time discharge equaled or exceeded $\frac{m}{n} x\ 100\ \%$
Jan. 2001	2,382.27	15,659.22	1	8.33
Feb. 2001	1,903.92	13,670.48	2	16.67
Mar. 2001	1,698.25	8,352.99	3	25.00
Apr. 2001	1,638.65	5,488.66	4	33.33
May 2001	1,946.34	4,520.30	5	41.67
Jun. 2001	2,732.40	2,732.40	6	50.00
Jul. 2001	4,520.30	2,382.27	7	58.33
Aug. 2001	8,352.99	2,076.17	8	66.67
Sep. 2001	13,670.48	1,946.34	9	75.00
Oct. 2001	15,659.22	1,903.92	10	83.33
Nov. 2001	5,488.66	1,698.25	11	91.67
Dec. 2001	2,076.17	1,638.65	12	100.00

The flow duration curve is obtained by plotting discharge (flow) as the ordinate and the percent of time as abscissa as shown in Figure 4.

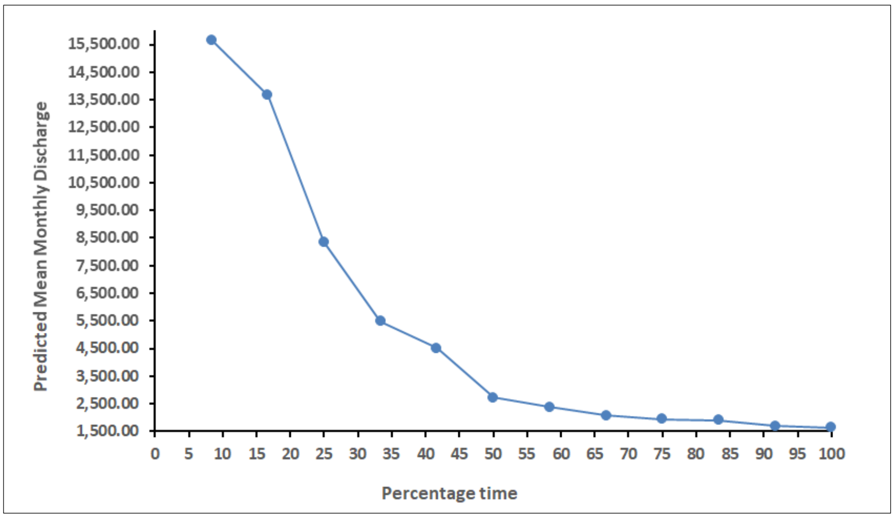

Figure 4: Flow duration curve for River Niger at Onitsha streamflow gauging station
Source: Uzoukwu (2023)

The discharge available 90 to 97 % of the time is used for estimating the firm power. 95 % dependable flow is adopted here. From flow duration curve the magnitude of the flow available 95 % of the time is 1674 m^3/s. Available head is 3m. Assuming an overall efficiency of 80 % for the turbine-generator system, the *firm power* (P) for a *run-of-the river plant* is calculated as follows:

$$P = \eta g Q H \quad (3)$$

Substituting the values in Equation 3

P = 0.80 x 9.81 x 1674 x 3

P = 39,412.66 kw

where, P = firm power

η = the overall efficiency of the scheme

g = acceleration due to gravity = 9.81 m^3/s

Q = dependable flow

H = available head

4.0 CONCLUSION AND RECOMMENDATIONS

4.1 Conclusion

The streamflow models developed from the annual maximum discharge versus annual maximum stage of River Niger at Lokoja and Onitsha gauging stations have high and positive values of coefficients of determination (r^2) ranging from 0.9983 to 0.9996 and correlation coefficients (r) ranging from 0.9991 to 0.9998. The models developed in this research can serve useful purpose in developing alternative water use futures, hydropower electricity generation, 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.

4.2 Recommendations

The following recommendations are made:

- This study which was limited to River Niger at Lokoja and Onitsha streamflow gauging stations should be extended to other rivers with similar characteristics in the country. This will help in water resources development and management in Nigeria.
- Institutions should sponsor continuous research work that will keep current data updated, for the primary reason of keeping up with environmental changes, such as the present day global warming effect that has caused overflow of rivers banks and flooding of cities and regions.

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