Fitting Rating Curves to Selected Streams in Southeast Nigeria

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Abstract: Lack of funds and political will have made continuous gauging of rivers in Nigeria impossible, thus stalling the development of surface water resources. In order to address this anomaly; this study is focused on developing discharge rating curve, for selected streams in Imo-Anambra river basin of southeast Nigeria, which is capable of predicting discharge from stage. Ten years monthly stage and discharge records, measured with stream gauges, for Rivers Adada in Enugu state, Ajali in Anambra state, Ivo in Ebonyi State, Otamiri in Imo state, and Ivo (Umupopara) in Abia state, were used in estimating the rating curve models using simple linear regression as: \( Q = 23.719S^{0.775}, \) \( Q = 9.605S^{0.2924}, \) \( Q = 10.123S^{−0.1455}, \) \( Q = 10.955S^{−0.0629} \) and \( Q = 35.923S^{−1.2446}. \) All the rating curve equations were validated using coefficient of determination which yielded values of 98.54%, 97.38%, 17.31%, 89.98% and 99.43%, but the empirical discharge-stage model of River Ivo was discarded as the model produced poor performance and lacked the features of a rating curve. The rating curve of Imo River predicted the highest discharge for equivalent input values of stage because of its large cross-section at the gauging station. The developed rating curve models are therefore recommended for discharge prediction in these catchment areas with limited streamflow records.

Keywords—fitting, rating curve, southeast Nigeria, stream discharge

1 INTRODUCTION

Stream gauging is a very important component of hydrologic design (Bjerklie et al., 2003). Hydraulic structures such as dams, storm water drains, erosion control structures and river training work all rely on accurate records of discharge. Possible collapse of these structures is eminent if correct and enough discharge records of the host river is not employed in their design. It is a huge task to continuously gauge streams in order to have sufficiently large discharge data required in hydrologic designs (Ashmore & Sauks, 2006). Hydrologic engineers circumvent this daunting problem by either regressing or plotting available discharge record against the stage at some permanent control section of the stream in order to obtain discharge-stage relationship (Ibeje, 2019). This plot is called the rating curve; it saves the risk of gauging streams continuously especially at high flows.

Booker (2010) opined that all the time, cost and skilled labour required for continuous stream gauging are avoidable using the rating curve. The rating curve is founded on the assumption that stream discharge is a function of a number of factors of the stream basin such as channel geometry and bed roughness (Muzzammil et al., 2015). However, a consummate quantification all the factors is mathematically unfeasible. Discharge rating curve simplifies the relationship between discharge and catchment characteristics with emphasis mainly on discharge-stage relation. According to Lee et al. (2010), the traditional rating curve plots the logarithm of the discharge against the logarithm of S-S0 and this makes it easy to fit a straight line through the plotted points. Thus, the relationship obeys a law of the form

\[ Q = C(S - S_0)^k \]  

where \( S_0 \) is a constant arbitrary value subtracted from stage, \( S \), \( k \) and \( C \) are constants obtained by solving simultaneous equations resulting from any three points on the rating curve where the values of \( S \) and \( Q \) are known (Singh, 2018).

Different analytical methods have been adopted to establish discharge rating curves. Regression analysis were utilized to develop discharge rating curves by Singh et al. (2018), Alfa et al. (2018), Krekeler & Siwale (2012), Braca & Grafiche Futura (2008), Booker (2010) and non-linear regression by Petersen-Øverleir (2006). Optimization techniques were performed to fit discharge rating curve by Kim et al. (2016), Muzzammil et al. (2015), Lee et al. (2010), Moyoed & Clarke (2005). The relationship between stage and discharge were fitted considering power function by Singh et al. (2018), Alfa et al. (2018), Krekeler & Siwale (2012), Muzzammil et al. (2015), Bjerklie et al. (2003) and polynomial function by Braca & Grafiche Futura (2008), Ibeje (2019). Stream width-discharge rating curve was used to predict discharge in a stream located in a remote area. Stream width - discharge rating curves were established by considering power function by Ashmore & Sauks (2006), Sun et al. (2010), Osterkamp & Hedman (1977), polynomial function by Booker (2010), Ashmore & Sauks (2006) and linear function by Ashmore & Sauks (2006).

Nigeria is a developing country confronted with eerie challenge of water resources development. Thus, the cost of establishing and maintaining a network of stream gauges is prohibitive (Alfa, 2018). Very few works have reported the evidence of established rating curves in Nigeria (Ibeje, 2019; Alfa et al. 2018; Olaniyi et al., 2018; Adeboye & Alatise, 2008). Adeboye & Alatise (2008) fitted a rating curve to River Osun at Apoje sub-basin Nigeria by plotting the gauge heights against their annual maximum discharges. However, Adeboye and Alatise did not produce any rating curve equation which is of great importance to the design engineer. But Olaniyi et al. (2018) developed a rating curve model for River Osun with 0.78 coefficient of determination. The rating curve equation was obtained as:

\[ Q = 0.487(G - 0.368)^{0.748} \]
The study was an improvement on the research reported by Adeboye & Alatise (2008) because the rating curve equation yielded more accurate prediction of discharge, $Q$, from stage height, $G$, than the interpolated values from the graphical rating. In another study, Alfa et al. (2018) developed the rating curve for Ofu River at Oforachi gauging station in Kogi state, Nigeria. The rating curve equation was evaluated as:

$$Q = 15.5410(H - 55.4139)^{0.6905}$$

The coefficient of determination yielded a value of 0.7120 which was a good fit. However, it was observed that trial and error approach was employed to estimate some of the parameters of the model. This was a major shortcoming of that rating curve equation. Ibeje (2019) reported a novel polynomial model for fitting the rating curve of Rivers Otamiri and Oramiriukwa in Imo State, Nigeria. This approach addressed the ambiguities of conventional rating curves. The polynomial model was a composite rating curve having a cubic function given by:

$$S = 0.187Q + 0.027Q^2 + 0.002Q^3 + 0.726$$

The model had improved accuracy in discharge prediction at a coefficient of determination of 0.999 and 0.005 standard error. Based on the foregoing, there is need to use simple linear regression to develop rating curves for many other rivers in Nigeria. Southeast Nigeria, like other regions of Nigeria, is faced with the problem of hydrological data gathering which has hampered the development of the needed rating curves necessary for discharge prediction. Rivers Adada, Imo, Otamiri, Ajali and Ivo are all located in the Anambra-Imo River basin of Southeast Nigeria. Unfortunately, in these rivers, obsolete discharge data existed only for a limited period from 1979 to 1989, after which no stream gauging was done again. It is therefore imperative that this study be focused on fitting rating curves to the stage-discharge data of these rivers using simple linear regression.

### MATERIAL AND METHODS

Monthly stage and discharge records that were used covered over 10 years for selected Rivers Adada in Enugu, Otamiri in Owerri, Imo state, Ivo in Ebonyi and Imo (umuopara) in Umuahia, Abia state (Table 1). The discharge data were obtained from Anambra-Imo River Basin Authorities. The observations were plotted on logarithmic paper, with stage on the ordinate and discharge on the abscissa. Straight lines were fitted to the scatter. Two different discharge data sets were used for calibration and validation of the rating curve models (Olaniyi et al., 2018). The coefficient of determination, $R^2\%$ was used to assess performance of the fitted models.

#### 2.1 STUDY AREA

Abia, Anambra, Ebonyi, Enugu and Imo states are the five Igbo-speaking states of Nigeria that make up the southeast geo-political zone of the country. It is located between latitudes $4^\circ 40'$ to $7^\circ 20'$ north of the equator and longitudes $6^\circ 00'$ to $8^\circ 20'$ east of the Greenwich Meridian. The area occupies about 50,000km² of Nigeria’s total area of 923,768 km² (Okeke et al., 2006). In the north, the

### Table 1. Geographical Locations of the Rivers

| STATE | RIVER | STATION | LAT. | LONG. | CATCHMENT AREA (Km²) | ZERO LEVEL OF GAUGE (m) | G.R.M LOCAL |
|-------|-------|---------|------|-------|----------------------|------------------------|-------------|
| IMO   | Otamiri | Nekede | 05°26’ | 07°02’E | 100                  | 97.71                   | 100         |
| Abia  | Abia   | Ukpu-Ngwa | 05°33’N  | 07°25’E | 1450                 | 86.50                   | 100         |
| Anambra | Adada | Umuokpu | 06°38’N  | 07°11’E | 890                  | NA                     | NA          |
| Enugu | Ajali  | Agnoobra-umunna | 07°19’N  | 07°13’E | 900                  | NA                     | NA          |

NA* = Not available
Source: Anambra-Imo River Basin Authority, Owerri

Fig.1: (a) Map of Nigeria showing the location of the states of the southeast region, (b) Map of Enugu state showing Rivers Adada and Ajali, (c) Map of Ebonyi state showing River Ivo, (d) Map of Imo State showing Rivers Otamiri and Ivo.
southeast Nigeria is bounded by Benue and Kogi states while River state is located at its southern border. Cross River and Delta states are at the eastern and western boundaries respectively. Anyadike (2002) reported the rainfall depth varied on the average between 1800mm and 1200mm, and the average air temperature of the region is 27°C.

3 RESULTS AND DISCUSSION

The descriptive statistics for the maximum discharge of the various gauging stations in Southeast Nigeria, considered in the study is presented in Table 2. The results of the descriptive statistics show that the mean discharge ranges from 131.315 m$^3$/s to 11.0468 m$^3$/s while the sample standard deviation ranges from 87.372 to 0.198. The maximum and minimum mean discharges of 131.315 m$^3$/s and 11.0468 m$^3$/s respectively were observed in Imo and Ivo rivers respectively. Discharge records of Rivers Adada and Ivo showed positive skewness with skewness coefficients of 0.918875 and 0.847137 respectively, which the discharge records of the other rivers are negative. River Adada had the highest positive kurtosis of 2.3232.

3.1 CALIBRATED RATING CURVES

The rating curves of selected rivers in southeast Nigeria at the various gauging stations are presented in Table 3. The rating curve of Otamiri River (Figure 2b) produced results typical of some other Rivers in Nigeria. In the rating equation of Otamiri River presented in Table 3, the exponent of stage was estimated as 0.6829 which is consistent with that of River Ofu in Kogi state reported by Alfa (2018). The implication is that the streamflow dynamics of Rivers Otamiri and Osun maybe similar although they are located in different regions of Nigeria. Thus, it is permissible to exchange morphological information between the two river catchments.
The value of the constant is %.

Singh et al., 2018, Alfa et al., 2008, Book 2018, Krekeler & Siwale, 2012, Braca & Grafiche Futura, 2018, RIVERS OSUN AND OFU BY OLANIYAN ET AL. (2018).

The exponent of stage for the rating curve of Adada River is inconsistent with conventional rating curves (Singh et al., 2018, Alfa et al., 2018, Krekeler & Siwale, 2012, Braca & Grafiche Futura, 2008, Booker, 2010). This is because discharge is known to be proportional to stage.

Obviously, this misnomer may have been due to faulty gauging equipment or erroneous discharge used in computing the rating curve equation. Thus, the rating curve equation evaluated for Ivo River in this study is not recommended for use in practical engineering sense.

Figure 3a shows the fitted rating curve of River Ajali. On visual inspection, the scatter plot shows very few outliers unlike that of River Otamiri. The value of the constant is 9.605 which lower than that of River Otamiri (10.95). However, a lower value of the stage exponent (0.4204) implies that equivalent stage values from the two streams would yield higher discharge value for River Otamiri (Table 3). Also, Table 3 shows that among all the Rivers considered in this study, rating curve of Imo River (Figure 4a) had the highest power coefficient (1.0246) for stage, while the rating curve of River Ivo (Figure 5a) had the lowest value of -0.1435. Highest value of exponent of stage in the Imo River rating curve means that Imo River would yield the highest discharge value for equivalent stage value among all the rivers studied in the Anambra-Imo River Basin.

This is because Imo River receives discharge from its tributaries including River Otamiri and it has the greatest section among all the rivers studied (Amangabara, 2015). Most of the other streams considered in this study except River Otamiri have no tributaries (Amangabara, 2015). The exponent of stage for the rating curve of Adada River (Figure 6b) is observed to be 0.945 (Table 3) which is a little higher than the values of 0.749 and 0.6905 evaluated for Rivers Osun and Ofu by Olaniyan & Alatise (2018) and Alfa et al. (2018). The negative exponent of stage in the rating curve equation of River Ivo is inconsistent with conventional rating curves (Singh et al., 2018, Alfa et al., 2018, Krekeler & Siwale, 2012, Braca & Grafiche Futura, 2008, Booker, 2010). This is because discharge is known to be proportional to stage.

3.2 VALIDATION OF RATING CURVE MODEL

The performance of the rating curves was evaluated using discharge and stage data which were not utilized in the curve fitting. Table 3 shows the coefficients of determination, R² % from the model validation of the fitted rating curves (Figures 2b, 3b, 4b, 5b and 6b). The coefficients of determination were computed as 98.54%, 97.38%, 17.31%, 89.98% and 99.43% meaning that rating curve models could only explain 98.54%, 97.38%, 17.31%, 89.98% and 99.43% variation in the discharge by the stage for the respective Rivers Adada, Ajali, Ivo, Otamiri and Imo. The values of coefficients of determination obtained for rating curve models of Rivers Adada, Ajali, Otamiri and Imo can be accepted as good fits since the values are close to 100%. It can be observed that the value of coefficient of determination for the rating curve model of River Ivo does not approximate to 100% which makes the model unacceptable for discharge prediction.

Also, the values of R² % for the respective rating curve models increased from 97.3%, 97.62%, 70.23% and 97.28% (calibration) to 98.54%, 97.38%, 89.98% and 99.43% (validation) for the respective Rivers Adada, Ajali, Ivo, Otamiri and Imo implying that in the rating curve models are sensitive to stage data applied to the models.

4 CONCLUSION

The rating curve models relating stream discharge and water level above datum were developed for selected streams in Imo-Anambra river basin of southeast Nigeria. It was deduced that the empirical models represent the rating curve equations of these streams after the performance of the models were validated using the coefficient of determination. However, the empirical discharge-stage model of River Ivo was discarded as the model does not possess the required qualities of typical discharge rating curve. The rating curve of Imo River predicted the highest discharge for equivalent input value
for stage because of its large cross-section at the gauging station. Further study is recommended in fitting discharge rating curves among other streams in southeast Nigeria. Verification of the developed models is recommended by comparing the present study with discharge-width rating curves of these rivers. The developed rating curve models are recommended for discharge prediction in these catchment areas with limited streamflow records.

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