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(Research Article)

Development of rating equation for lower river Ogun, South-Western, Nigeria

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Abstract

River discharge is a variable which is separated from other component of the system, it is directly influenced by surface and subsurface runoff but influences fresh water influxes into the ocean. The rating equation is widely adopted where the measurement of discharge is difficult most especially in developing countries. Most Rivers in Nigeria has frequent occurrence of flooding. This study developed a stage and discharge relationship for Lower River Ogun in Nigeria. The stage and discharge relationship was established using measured and collected data. The velocity of water flow was measured using flow meter and gauge were measured with automated stage level. The generated rating equation: Q = 169.1(G-a)0.099 m/s3 with coefficient regression 79%. The generated equation was calibrated and validated with discharge data collected from 2005 to 2018. The rating equation curve performed better at depth 3.63m with percentage variation between measured and simulated discharge of 5.43%. The rating equation can be adapted to other rivers with similar catchment and geological characteristics. The Lower River Ogun serve as the permanent control and the rating equation is reliable.

Keywords: Discharge; Rating Equation; Lower River Ogun; Regression; And Stage Gauge

1. Introduction

The Lower River Ogun is a major river running through the Abeokuta metropolis, which is the capital of Ogun state and eighth largest city in Nigeria (Oyegoke and Sojobi, 2012). It is a major outlet for the sub-basins of the watershed. Abeokuta is highly urbanised and the land has been institutionalised for the development of residential, industries, recreational grounds and educational establishments (Araffin, 2008). Due to Abeokuta's increasing population, land demand is an acute problem with residents using every available space along or on the bank of the river for personal use. Lower River Ogun is located in Abeokuta North local government of Ogun state with catchment area of about 9000 km2, the river has a length of 480 km. Ogun River has its origin in Oyo North as tributaries. The communities ravaged by the river flood include Eweko, and Obafemi/Owode local government areas in Ogun state (Babarudin and Bustan, 2007). The flooding of 2007, 2010, 2012, 2015, 2016 and 2018, is caused as a result of the poorly planned release of excess water where many lives and properties were lost. The unprecedented flooding incidence of July 8, 2018 led to displacement of no fewer than 1,928 residents, loss of valuable man-hours owing to deadlock traffic, erosion of bridges and road surfaces (Raji et al., 2014). There is a continued exposure to flood risk in the state capital of Ogun state, Abeokuta (Arora, 2004). However, this urbanisation pressure is expected to lead to increased runoff of waste pollution (Balselmo et al., 2009). River Ogun takes its source from Igaran hills and flows directly southwards before it discharges into the Lagos lagoon. The river is dammed at Oyan. The major tributaries of River Ogun are the River Ofiki and Opeki Rivers. This is more so because there is no contingency protection and drainage options for any excess water which may originate from within river Ogun (Benson, 2014). This calls for concerted effort to develop water budget models and flood mitigation measures in forms of flood warning and control system.

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The development of the rating curve for a particular gauging site requires measurement of discharge usually by a current meter or other methods and the corresponding stage values at the site usually from a staff gauge or any other method. This has been the common practice since the early 19th century (Brunner, 2016). (Barbetta et al., 2017) emphasized that a curve of discharge against stage can then be developed by fitting these data with a power or polynomial curve which can be used to transform stage data into discharge as long as the gauging control does not change.

Ayansina and Ogunbo (2009) outlined the most commonly used stage-discharge rating curves treat the discharge as a unique function of the stage which typically follows a power curve where the discharge Q (m3/s) is related with the stage it (m above mean sea level) as follows:

$$Q = K (H - h) m \quad 1$$

were

- Q = discharge (m3/s)
- H = observed stage (m)
- h = gauge height of zero flow (m)
- K and m = calibration coefficient for rating equation (Brunner, 2016).

Equation 2 is a parabolic equation which plots as straight line on double logarithmic graph sheet. Taking logarithms of both sides of equation 3 and obtain the relation:

$$\text{Log } Q = m \log (H-h) + \log K \quad 2$$

It takes the form of a straight-line equation,

$$y = mx + C \quad 3$$

were

- y = log Q
- x = log (H-h)
- c = log K (the intercept on the y-axis)
- m = slope of the straight line.

This implies that the coefficient K is the antilogarithm of the intercept C. The value of h was obtained by trial and error while the value K and m were obtained by linear regression analysis using Microsoft Excel, 2007). The value of h with the lowest standard error of estimate (Se) was accepted (Brunner, 2016).

2. Materials and Methods

2.1. Development of Rating Equation

Running and Graphical methods was used to established stage-discharge (G-D) relationship (Rating Curve). The measured stage on Lower River Ogun between May, 2019 to April, 2020 while the measured discharge between May to October, 2019. In the absence of stage and discharge record, the rating equation was developed using stage and discharge data measured on Lower River Ogun from May to October, 2019. The rating equation developed based on stage and discharge data measured for six (6) months was used to simulate discharge between November, 2019 to April, 2020 to complete the seasonal discharge data on Lower River Ogun. This method was used in line with (Brunner, 2016; Adegbola and Olaniyan, 2013). The combined effect of stage and discharge is termed control which is permanent, if it does not change with time. The general rating equation that was used is shown in equation 3 which can be further expressed as equation 4 and 5 (Subramanya, 2007).

$$Q = Cr (G - a) \beta \quad 4$$

were

- a = Stage for zero discharge (m)
- G = Stage depth (m)
- Cr and β are coefficients

$$\text{Log } Q = \beta \log (G-a) + \log Cr \qquad 5$$

It takes the form of a straight line

The Arc GIS software was used to establish stage-discharge relationships using running and graphical method, which involves drawing best of fit curve on plot discharge (Q) against gauge (G). The trial-and-error approach was used to fix unknown variables of rating equation by using collected gauging records. The developed rating equation were validated using measured discharge and gauge record.

2.2 Sampling Points Across Lower River Ogun

The coordinates of each sampling point (S1 to S6) were recorded with the aid of Germin Global Position System (GPS) with model GPS Map 78. The coordinate of the upstream were taken at Ago-Ika (S1), Enu-Gada (S2), while the mid-stream coordinate of Lower River Ogun was taken at Lafenwa Old Bridge (S3), Lafenwa New Bridge (S4) and the downstream coordinates of the river was taken at Mokoloki (S5) and Kara (S6). The coordinates of the sampling points across Lower River Ogun is presented in Figure 1

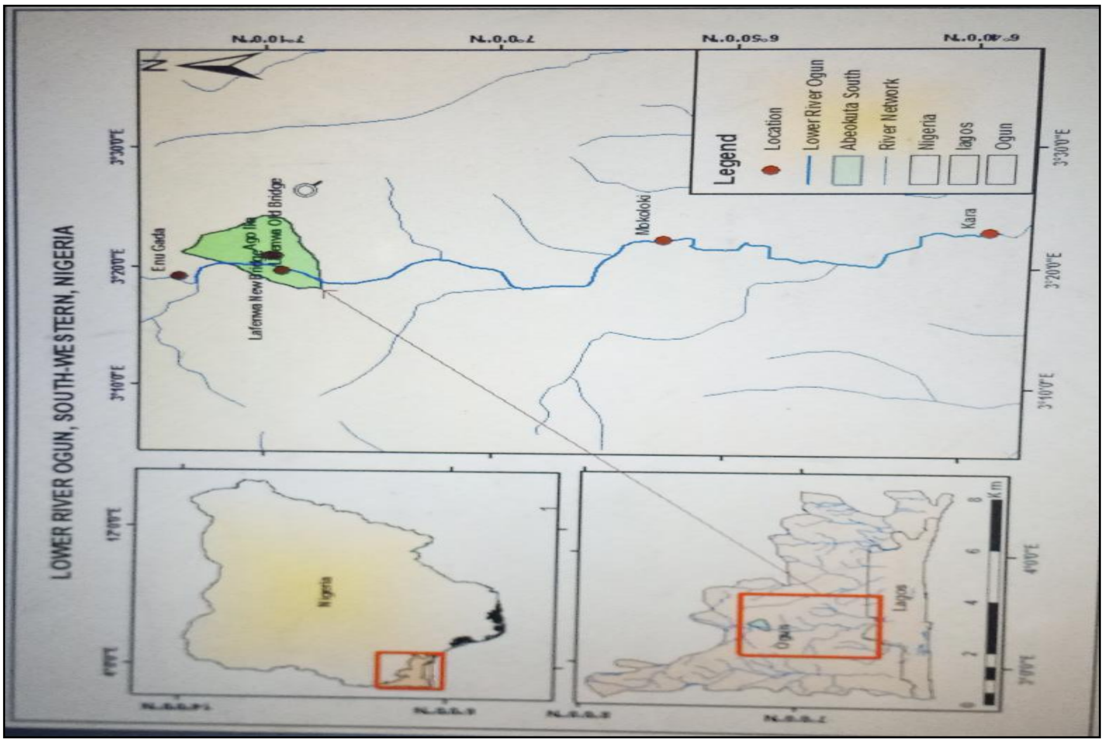

Figure 1 Hydrological Map of Sampling Points across Lower River Ogun State

3. Results and Discussion

3.1. Rating Curve Analysis

The rating equation on Lower River Ogun was developed and calibrated using measure gauge depth and discharge, the result is presented in Table 1. From the Table,

Ax = -3.1157

- Σy = 13.0620
- Σxy = - 6.3025
- Σx2 = 4.3141
- Σy2 = 28.5390
- a = 3.63

Using the following equation

6, 7 and 8

β = 0.099 6

Cr = 169.1 7

r = 0.791 8

The correlation is accepted because r falls within 0.70 – 100, thus the rating equation developed is:

Q = 169.1 (G-a)0.099 m3/s 10

The rating equation 10 developed was calibrated by comparing it with the measured discharge across Lower River Ogun. Table 2 shows the stage and discharge data used in developing the rating equation across the river. The rating equation developed was used to estimate discharge between November, 2019 and April, 2020. Figure 2 shows the relationship between the simulated and measured discharge with the coefficient of regression 79%. This implies a good correlation discharge depends on longitudinal slope of river, channel geometry, bed roughness etc. The measurement of these parameters at even and every time step and section is not possible, thus, there is need to establish the accurate relationship between stage and discharge. It is easier to measure the gauge depth of a stream than its discharge.

It can be observed from Table 3 that the developed rating equation performed well at S5 and S6. The percentage of variation at S5 and S6 ranges from (38.54 - 42.86) %. This can be attributed to the fact that there were little differences between the gauge measure in rainy season and dry season at the sampling points. The discharge percentage variation varies from (5.43-42.86) % across the river. It could be noted that below gauging depth of 3.63m, the rating equation cannot be used. This is in consonance with previous finding of Barbetta et al (2015).

Table 1 Analysis of Rating Equation

	Q	**(G-a)**	**x=log(G-a)**	**Y=log Q**	**XY**	**X^2**	**Y^2**
3.65	94.68	0.02	-1.6989	1.9763	-3.3375	2.8862	3.9058
3.83	121.90	0.20	-0.6989	2.0860	-1.4579	0.4885	4.3514
4.17	142.61	0.54	-0.2676	2.1541	-0.5764	0.0716	4.6401
4.61	151.00	0.98	-0.8774	2.1789	-1.9118	0.7698	4.7476
5.06	197.86	1.43	0.1553	2.2964	0.3566	0.0241	5.2734
5.50	234.86	1.87	0.2718	2.3708	0.6443	0.0739	5.6207
4.61	168.76	0.98	-0.0873	2.2272	-0.1944	0.0076	4.9604
2.83	165.73	0.80	-0.0969	2.2194	-0.2151	0.0094	4.9257
2.16	110.62	1.44	-1.5989	2.0438	-3.4722	2.8863	4.1771
1.76	90.11	1.87	-2.7103	1.9548	-3.9096	4.8100	3.8212
2.10	70.68	1.53	-0.1849	1.8493	-2.1358	1.3337	3.4199
3.16	100.26	0.47	0.3279	2.0011	-0.6562	0.1075	4.0044

Table 2 Comparison between Measured and Simulated Discharge on Lower River Ogun

Sampling Stations	Measured Discharge (m^3/s)	Simulated Discharge (m^3/s)	Discharge Percentage Variation (100%)
S_1	160.02	169.20	5.43
S_2	207.19	215.45	3.83
S_3	329.29	257.91	27.68
S_4	369.76	401.16	7.83
S_5	555.46	400.94	38.54
S_6	1185.03	682.36	42.86

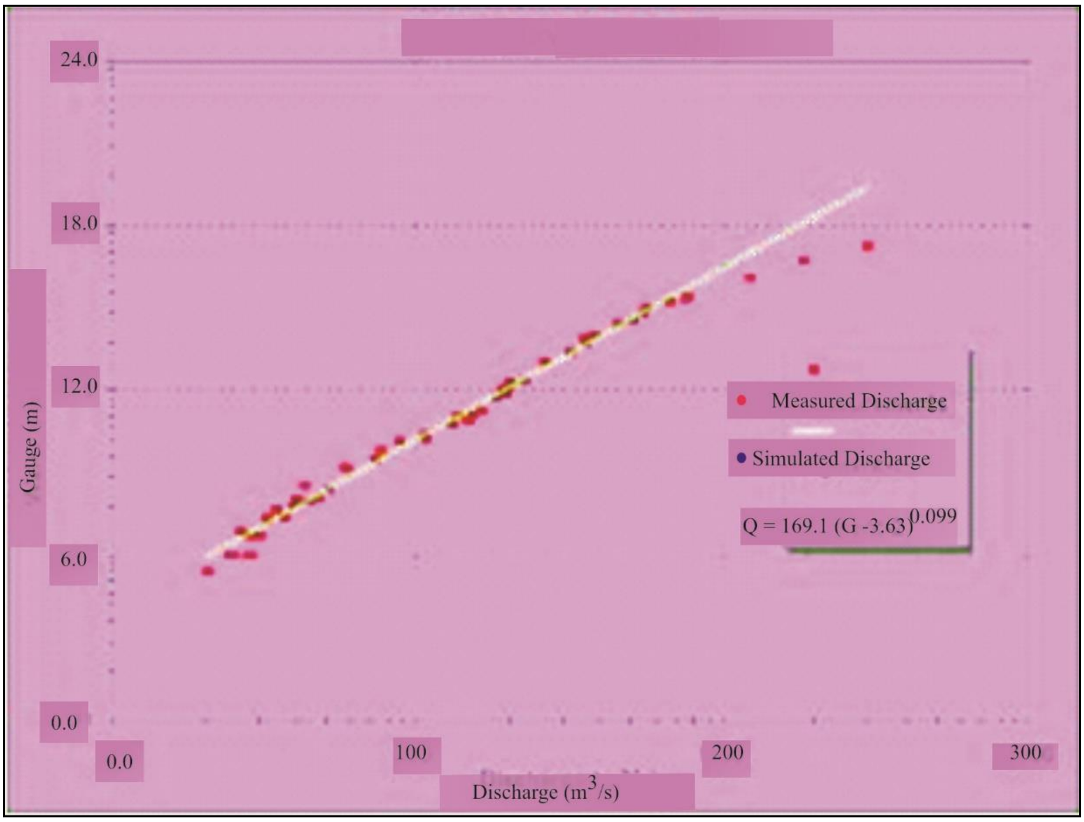

Figure 2 Rating Equation Validation Across Lower River Ogun

4. Conclusion

Based on the findings, the following conclusion were drawn

- The rating equation developed on Lower River Ogun was Q = 169.1(G-a)0.099 m/s3
- The rating equation solved problem of discharge data scarcity to predict flooding of the Lower River Ogun

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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