

# Development of Rating Curve for Ofu River at Oforachi Hydrometric Station

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**ABSTRACT:** The stage-discharge rating curve is widely used in the research for analysis of flow regime and design of hydraulic structure and river channel where the measurement of discharge is difficult especially in developing countries like Nigeria. This study sought to develop a stage-discharge relationship for Ofu River in Nigeria where water resources project planning has been limited by the unavailability of stream flow data. Discharge Measurement was carried out using Valeport Current meter while stage was measured using staff gauge at Oforachi Bridge hydrometric station from February, 2016 to January, 2017. The Stage and discharge results were used to determine the curve coefficient via regression analysis and finally the rating curve equation for the river at this station. The Oforachi Bridge serves as the permanent control, thus the curve is reliable.

**KEYWORDS:** Discharge, Efficiency, Ofu River, Rating curve, Hydrometric station.

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## I. INTRODUCTION

Measurement of surface water flow is an important aspect of hydrology related project such as water quality monitoring, flooding, geomorphology, and aquatic life support amongst others (Meals and Dressing, 2008; Gore and Banning, 2017; Barbetta *et al.*, 2017; Sikorska *et al.*, 2017). Accurate measurement of discharge of a basin therefore is the first and the most essential requirement for planning and management of any water resource project including flood forecasting (Patra, 2008; Borga *et al.*, 2011; Kiang *et al.*, 2017; Westerberg *et al.*, 2017). Discharge measurements are usually done once in a day during normal periods and on an hourly basis during floods. This continuous measurement is usually impractical and very expensive, especially in less developed and developing countries such as Nigeria, where the cost of establishing and maintaining a network of stream gauges is prohibitive (Patra, 2008; WMO, 2010).

The rating curve is a most frequently used methodology to overcome this difficulty (Leonard *et al.*, 2000; Patra, 2008; Maghrebi and Ahmadi, 2017) reducing the problem to a simple reading of river stage and then finding the corresponding discharge either from stage-discharge graph or equation established at the site (El-Jabi *et al.*, 1992; Meals and Dressing, 2008; Patra, 2008; Sadeghian *et al.*, 2016).

The rating curve is an empirical or theoretical relationship existing between the water level (stage) and the corresponding flow discharge in an open channel (Braca, 2008). The rating curve is a very important tool in surface hydrology because the reliability of discharge data values is highly dependent on a satisfactory stage-discharge relationship at the gauging site. It can be used to obtain an estimate of the discharge of a large flood where only the stage data is available, by extension of the rating curve (Patra, 2008; Mustafa and Yusuf, 2012). The preparation of rating curves is an essentially empirical task which requires a wide

theoretical background in order to create a reliable tool for transforming measured water level to discharge.

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 (Rantz, 1982a; Patra, 2008); Mustapha and Yusuf 2012; Meals and Dressing, 2008). 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.

Ofu River which takes its Origin from Ojofu in Dekina Local Government Area of Kogi State Nigeria and empties into the Anambra River falls within the Lower Benue River Basin Development Authority. Records of Stream flow for the river exist from 1955 to 1973 after which no measurement was done again. This makes all water resources development related to the river to rely on this obsolete record which has tendencies of leading to erroneous decisions.

It therefore becomes important for a stage discharge relationship to be developed for the river at the Oforachi Hydrometric station to provide basis for transforming the readily available stage values to discharge.

## II. MATERIALS AND METHODS

### A. Stage Measurement

Ofu River stage at Oforachi Bridge hydrometric station was measured from February 1, 2016 to January 31, 2017 using three recalibrated staff gauges at Oforachi, Kogi State, Nigeria. The location of the gauging site is shown in Figure 1. The selected site was firm and satisfies all the criteria for locating a gauging site as recommended by Meals and

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Dressing (2008) and Sauer and Turnipseed (2010). The stage measurement was taken twice daily and the average taken as the value for the day.

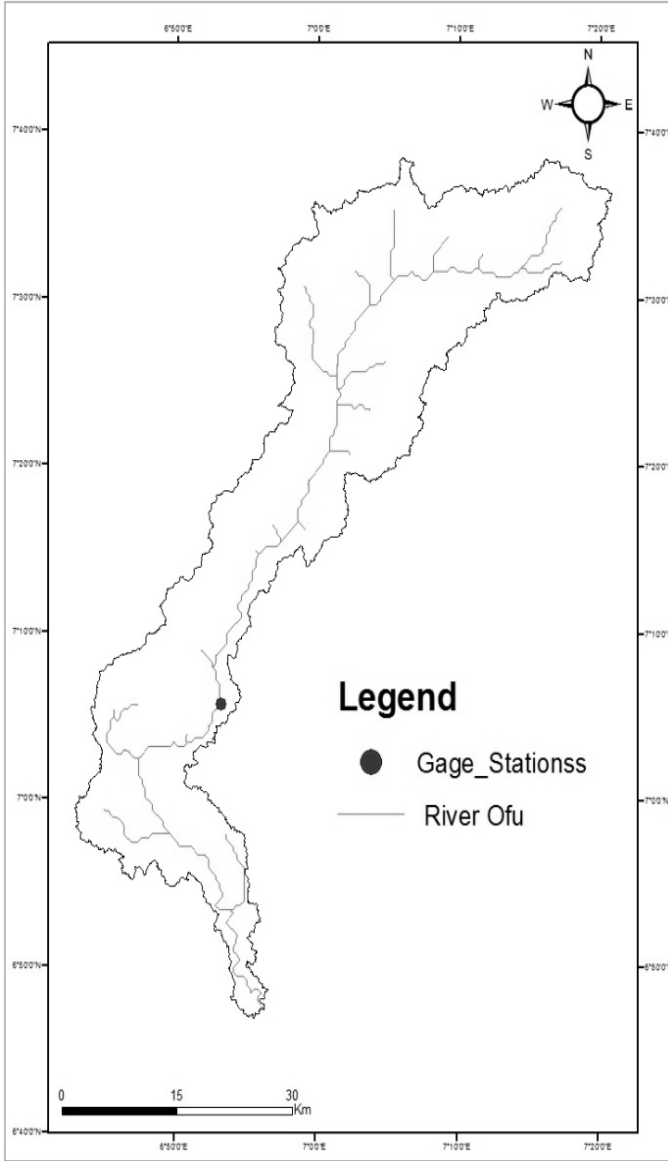


Figure 1: Ofu River catchment showing location of gauge stations.

**B. Discharge Measurement**

The discharge of Ofu River was measured for 12 months beginning from February, 2016 to January 2017 in order to generate data for the development of the rating curve. The discharge measurement adopted is the Velocity-Area method (Mid section) using a Valeport Impeller current meter model 0012B Version 4.01. Ofu River is a perennial river whose year round flow depth does not go below two meters at the centre thus making it difficult to apply the wading method. The bridge suspension method was therefore adopted incorporating some wading techniques to fit into the site peculiarities. The method of measurement has been described previously in Mays (2005), Patra (2008) and Mustapha and

Yusuf (2012). Limited number of discharge measurements (22 nos.) was carried out within the period for the development of the rating curve.

**C. Development, fitting and Extension of Ofu River Rating Curve at Oforachi Hydrometric Station**

Generally, 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  $Q$  ( $m^3/s$ ) is related with the stage  $H$  (m above mean sea level) as follows (Braca, 2008):

$$Q = K(H - h)^m \tag{1}$$

Where,  $Q$  is discharge ( $m^3/s$ ),  $H$  is the observed stage (m above sea level),  $h$  is the gauge height of zero flow (m above sea level),  $K$ ,  $h$  and  $m$  are calibration coefficients for the rating curve (Rantz, 1982b; Herschy, 1995; Braca, 2008; Patra, 2008).

Equation 1 is a parabolic equation which plots as a straight line on double logarithmic graph sheet. Taking logarithms of both sides of equation (1) we obtain the relation.

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

It takes the form of a straight line equation,  $y = mx + c$  where  $y = \log Q$  and  $x = \log(H-h)$  and  $c = \log K$ .  $M$  is the slope of the straight line while  $\log K$  is the intercept on the y axis. 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 of  $K$  and  $m$  were obtained by the linear regression analysis using the analysis tool park of Microsoft Excel 2007 as shown in Table 1. The value of  $h$  with the lowest standard error of estimate ( $S_e$ ) was accepted (Patra, 2008). The efficiency of the fitting of the curve was checked using the standard error of estimates, efficiency and the coefficient of determination (Patra, 2008). The efficiency,  $\eta$  was calculated using eqn (3).

$$\eta = \frac{\text{Variance of 15bserved discharge} - S_e^2}{\text{Variance of 15bserved discharge}} \times 100 \tag{3}$$

The standard error of estimates and coefficient of determination ( $R^2$ ) were both calculated using the regression analysis tool in Microsoft Excel. Maroof et al. (2015) used this approach to develop a stage-discharge relationship or rating curve for the Ero-Omola falls in Kwara State, Nigeria determining the calibration coefficients by method of least square. The simplicity and accuracy of the method as demonstrated by these authors informed its choice in this study.

Table 1: Estimation of rating curve calibration coefficients.

S/No	H (m asl)	Q <sub>o</sub> (m <sup>3</sup> /s)	H-h	X (log(H-h))	Y (log Q <sub>o</sub> )	Q <sub>c</sub> = K(H-h) <sup>m</sup>	(Q <sub>o</sub> -Q <sub>c</sub> ) <sup>2</sup>
1	55.43	0.1583	0.0001	-4.0969	-0.8005	0.0230	0.0183
2	55.46	0.2688	0.0301	-1.5217	-0.5707	1.3827	1.2408
3	55.52	4.2430	0.0891	-1.0502	0.6277	2.9261	1.7341

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S/No.	H (m asl)	Q <sub>o</sub> (m <sup>3</sup> /s)	H-h	X (log(H-h))	Y (log Q <sub>o</sub> )	Q <sub>c</sub> = K(H-h) <sup>m</sup>	(Q <sub>o</sub> -Q <sub>c</sub> ) <sup>2</sup>
4	55.52	4.2187	0.0911	-1.0406	0.6252	2.9713	1.5560
5	55.53	4.3853	0.0961	-1.0174	0.6420	3.0830	1.6959
6	55.52	4.8054	0.0881	-1.0551	0.6817	2.9034	3.6175
7	55.56	5.3853	0.1236	-0.9081	0.7312	3.6683	2.9484
8	55.55	6.6511	0.1197	-0.9217	0.8229	3.5893	9.3745
9	55.54	6.6311	0.1102	-0.9576	0.8216	3.3902	10.5036
10	55.66	7.9056	0.2311	-0.6362	0.8979	5.6513	5.0816
11	55.65	8.6407	0.2187	-0.6601	0.9366	5.4413	10.2364
12	55.60	6.6948	0.1692	-0.7715	0.8257	4.5579	4.5666
13	55.60	7.4216	0.1649	-0.7827	0.8705	4.4770	8.6709
14	56.31	13.4353	0.8783	-0.0564	1.1282	14.2086	0.5981
15	56.30	13.3080	0.8699	-0.0605	1.1241	14.1156	0.6521
16	56.39	14.6134	0.9553	-0.0199	1.1648	15.0576	0.1974
17	56.36	14.2385	0.9308	-0.0312	1.1535	14.7898	0.3040
18	55.65	7.6747	0.2207	-0.6563	0.8851	5.4742	4.8425
19	55.45	0.2099	0.0138	-1.8601	-0.6779	0.8074	0.3570
20	55.45	0.3150	0.0207	-1.6846	-0.5016	1.0672	0.5657
21	55.44	0.1781	0.0117	-1.9311	-0.7494	0.7211	0.2949
22	55.44	0.1683	0.0111	-1.9554	-0.7739	0.6938	0.2762
		<b>Σ</b>		-23.6753	9.8645		69.3324

### III. RESULTS AND DISCUSSION

The average daily stage hydrograph developed for Ofu River at Oforachi Bridge hydrometric station is shown in Figure 2.

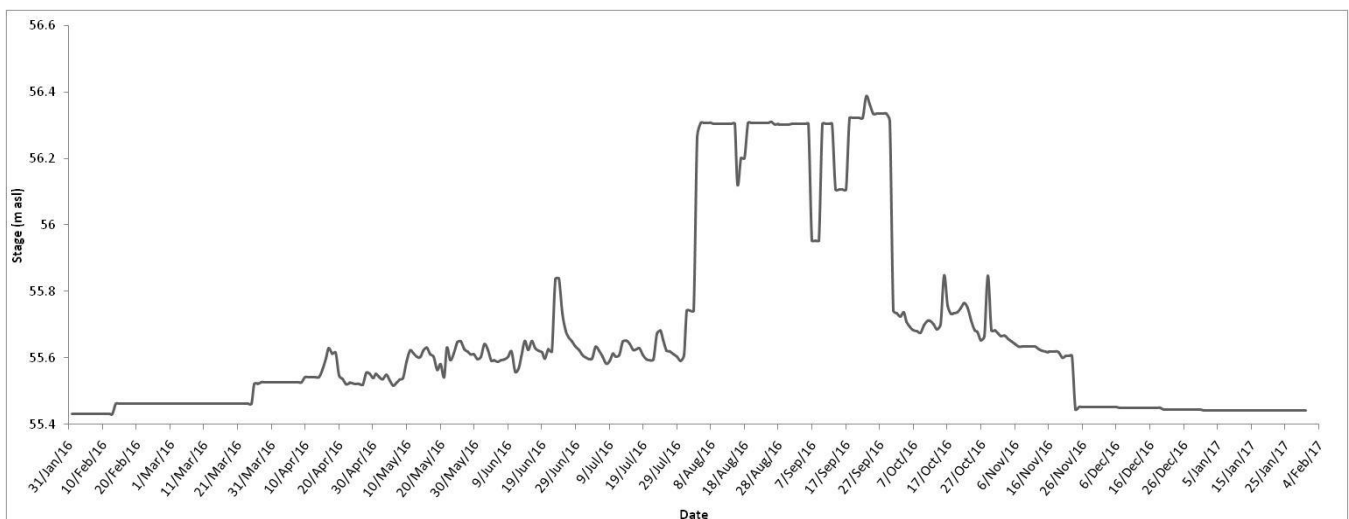


Figure 2: Average daily stage hydrograph of Ofu River at Oforachi Hydrometric Station.

The maximum water level observed was 56.39 m above mean sea level (asl) while the minimum value was 55.43 m above sea level. The variations in water level could be

explained by the 35-years average monthly rainfall of the study area presented in Figure 3.

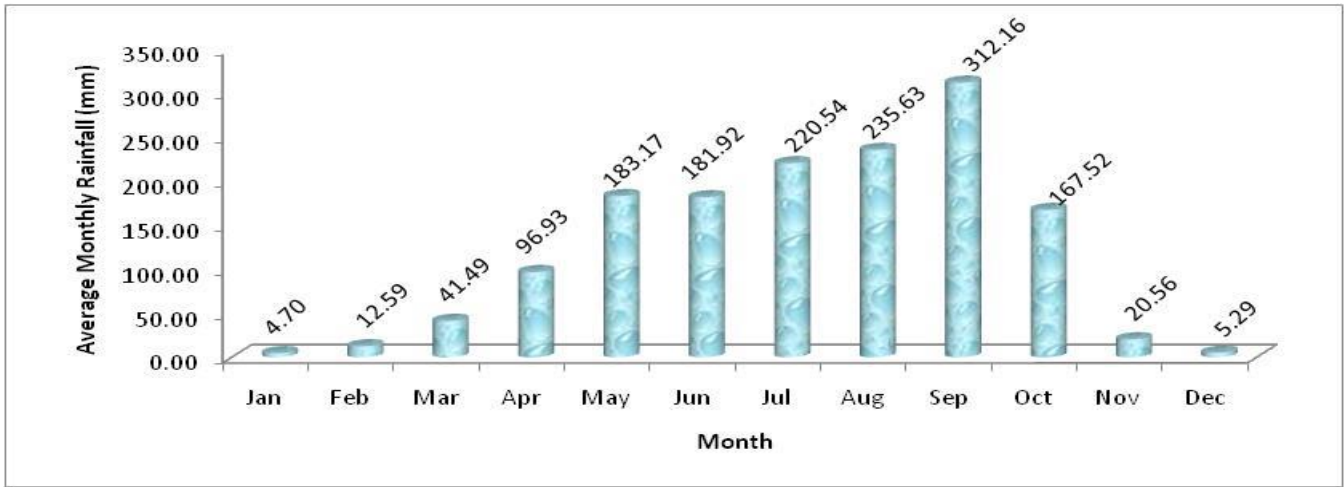


Figure 3: Average Monthly Rainfall Characteristics of Ofu River Catchment ([www.waterbase.org](http://www.waterbase.org)).

The average monthly rainfall showed a similar pattern to the water level (stage). September has the highest average monthly rainfall of 312.16 mm which is closely followed by August with an average monthly rainfall of 235.63 mm. These two months were the months during which highest

stage readings were observed (Figure 2). January has the least rainfall of 4.70 mm followed by December with 5.29 mm which correspond with the relatively lower stage readings (Figure 2). Furthermore, the discharge hydrograph developed from the observations is shown in Figure 4

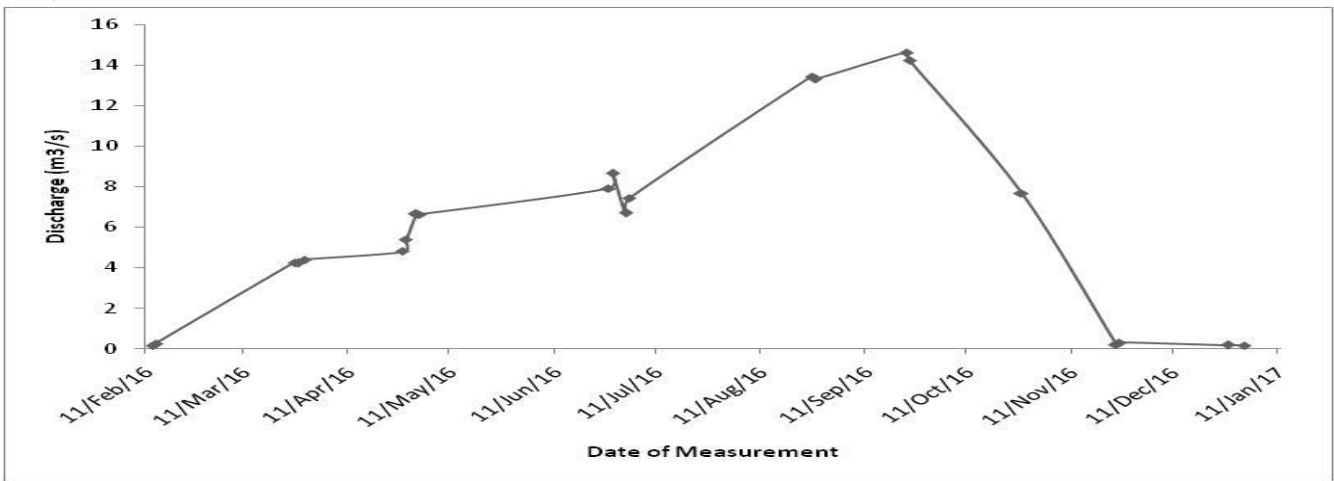


Figure 4: Observed discharge hydrograph for Ofu River at Oforachi Hydrometric Station.

The maximum discharge obtained during the period of measurement was 14.61m<sup>3</sup>/s recorded on 23<sup>rd</sup> September, 2016 while the minimum was 0.16 m<sup>3</sup>/s recorded on 13<sup>th</sup> February, 2016. The calibration coefficients *h*, *m* and *K* for the rating curve are presented in Table 2 while the coefficient of determination and efficiency used as validation parameters for the curve fitting process are presented in Table 3.

Table 2: Calibration Coefficients for Ofu River Rating at Oforachi Hydrometric Station.

Coefficient	Value
Height of zero flow, <i>h</i> (m)	55.4319 m
Slope, <i>m</i>	0.6910
<i>K</i>	15.5410

Table 3: Parameters for validation of curve fitting process.

Parameter	Value
R <sup>2</sup>	0.7257
Adjusted R <sup>2</sup>	0.7120
Efficiency, $\eta$ (%)	99.33

Table 3 shows that the coefficient of determination (R<sup>2</sup>) is 0.7257 (adjusted R<sup>2</sup> = 0.7120) which implies that about 72.57% variance in the curve fitting process was explained by the regression model (Nagelkerke, 1991). In as much as it is desirable that R<sup>2</sup> be close to unity as much as possible, the value obtained herein could be accepted as a good fit since

the efficiency of the fitting process is 99.33% (Patra, 2008). Thus the Final fitted rating curve equation for Ofu River at

Oforachi bridge hydrometric station is  $Q = 15.5410(H-55.4319)^{0.6905}$  (4)

The plot of effective depth of flow against the calculated discharge using the fitted rating curve is shown in Figure 5

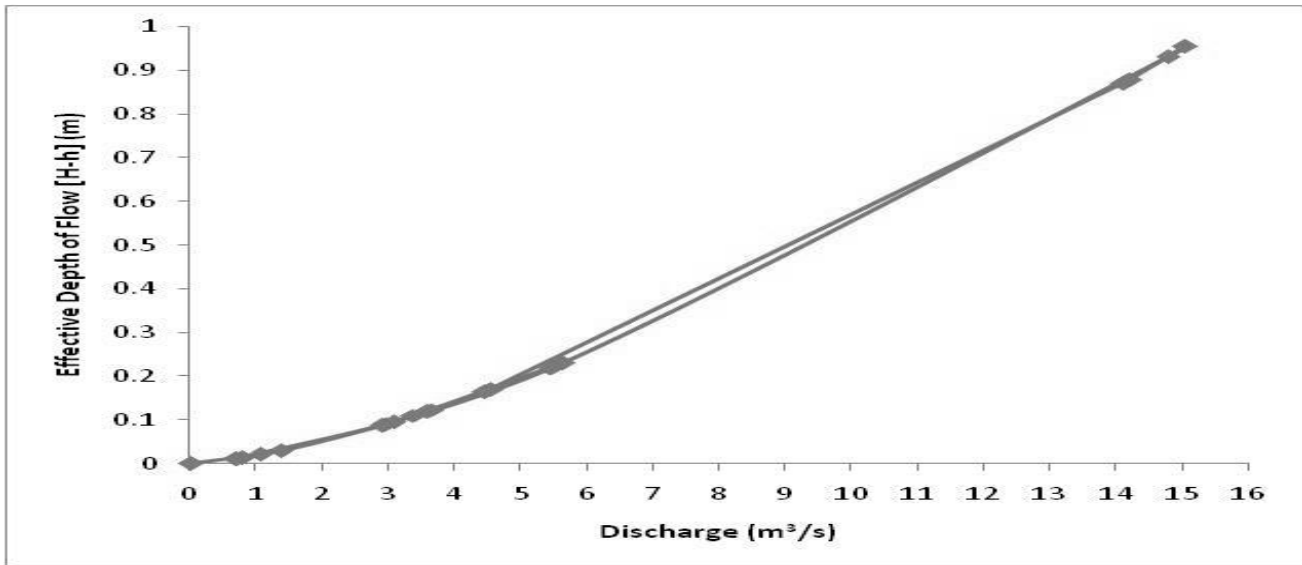


Figure 5: Fitted Rating Curve for Ofu River at Oforachi Hydrometric station.

The curve in Figure 5 shows that a very close loop was formed by the rising and falling stage which according to Mustafa and Yusuf (2012) is characteristic of an acceptable

rating curve. The rating curve was used to transform the one year stage measurement into discharge. The discharge hydrograph obtained is shown in Figure 6.

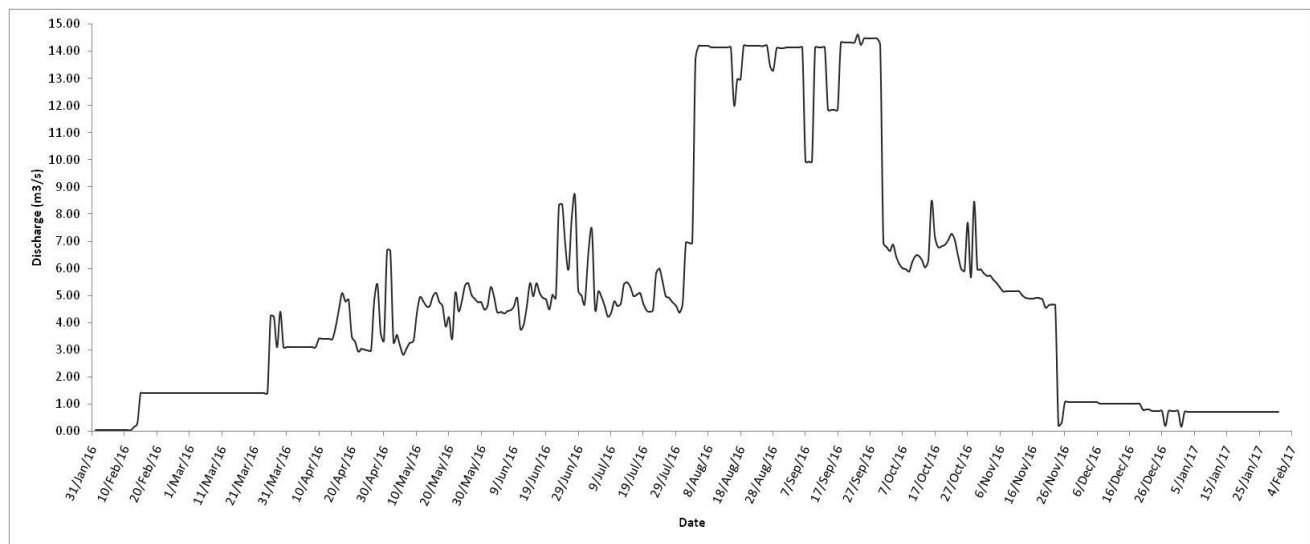


Figure 6: Discharge Hydrograph for Ofu River using fitted Rating Curve.

The discharge hydrograph shows a similar pattern to that of the stage hydrograph (Figure 2) which is also not unconnected with the variations in the average monthly rainfall for the study area (Figure 3).

IV. CONCLUSION

The rating curve equation relating discharge  $Q$  in  $m^3/s$  and stage  $H$  in m above mean sea level was developed for Ofu River at Oforachi Bridge hydrometric station. This curve equation can be used for the transformation of available stage

data into discharge since stage readings are readily available at the site. This will go a long way to solve the problem of discharge data scarcity for the river. The Oforachi Bridge serves as a permanent control structure which makes the developed curve reliable until there is a change in this control.

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