International Journal of Scientific & Engineering Research Volume 11, Issue 6, June-2020 123
ISSN 2229-5518

Empirical Correlation of Flow Characteristics of Ikpa-River Akwa-Ibom State, Nigeria

By
[1] T.G Leton , [2]Okon.B And [3] C F Ikebude

[1]Department of Civil and Environmental Engineering. University of Port Harcourt. Nigeria.

[2]Ministry of works, Uyo, Akwa-Ibom, State.
[3]Department of Civil and Environment Engineering University of Port Harcourt. Nigeria

ABSTRACT

This study present finding from the study conducted in Ikpa River in Uyo Local Government of Akwa Ibom State, in the South South of Nigeria. The method adopted for the study involved taking field measurement of the hydraulic geometry such as the depth and width of the river with a tape rule and a dumpy level. Other measurement taken was the velocity of the river using a current meter. The velocity of the river was taken at 5 depths (river bed level, 0.2d, 0.4d, 0.8d and 0.95d). The width of the river ranged from 18.49 – 31.31m while the depth of the river ranged from about 1.95 – 3.23m, which may be considered as a shallow river. The mean average velocity of the river ranged from 0.371- 0.545m/s while the cross sectional area ranged from 19.00- 49.14m^2. Five empirical model were developed relating the discharge of the river with the hydraulic variables (depth, average velocity, cross sectional area, width and average depth). The scatter plot guided our choice in using the power function to fit the relationship between the discharge and the hydraulic variable. The model relating the discharge and the width of the river gave the best R^2 value and the lowest RMSE of 0.9954 and 0.6415 respectively while the model relating the discharge and the average depth of the river gave the worst performing model among the five with an R^2 value and RMSE of 0.8939 and 3.067 respectively.

KEY WORDS: Discharge, Velocity, Dumpy level, Riverbed, Average depth, Model, Rmse.

1. Introduction

The significant number of flood occurrences happening currently is becoming a major challenge for most countries around the world. Majority of hydro-engineering problem such as flooding, coastal erosion, etc. are all related to open channel flow. In other to minimize problems such as flooding, coastal erosion, river studies should be conducted in other to help one have a good understanding of the hydraulic characteristics of the river. Hydraulic characteristic of a river refers to the processes of water and sediment movement in a natural channel in relation to the hydraulic geometry of the river such as the flow depth, mean channel depth, mean velocity, cross-sectional area, and wetted perimeter. Hydraulic characterization of river is not just useful in engineering, as it is a well important in other area of study. The combination of the hydraulic characteristic of the river and data of a given species can be used to estimate the amount of habitat in that given river. The wetted perimeter method is a threshold method that was developed to assess instream-flowrequirements for salmon (Gordon and others, 1992).

Hydraulic geometry analysis of stream channels was first described by Leopold and Maddock (1953), and since the various rivers studies have been conducted. Rivers studies conducted are aimed at correlating the hydraulic geometry of the river with the discharge. The hydraulic geometry such as width of the river, mean averagevelocity, mean depth of the river can be quantitatively related to discharge as a power function by the use of regression model. Limited river studies have been done in Nigeria, notable river studies was done by NEDECO on River Niger and Benue in 1959 (Jansen and others, 1979) and on the south west Nigeria Omi River (Adegbola and Olaniyan, 2012). Outside Nigeria, work has been done on East Fork River in the United states (Leopold and Emmet, 1976), Amurang River Estuary in Malaysia (Tendean and others, 2012), and Tapi River in India (Yadav and Samtani, 2008), among others. In this work presented, an attempt was made to empirically correlate the discharge of Ikpa River in Uyo Local Government of Akwa Ibom State, in the South South of Nigeria with the hydraulic geometry of the river.

2. Study Area

The river used for the study was the Ikpa- River in Uyo Local Government of Akwa Ibom State, in the South South of Nigeria. The Universal Transverse Mercator (UTM) coordinates for the study area lies on latitude 381286.00 m E and longitude561718.00 m N at an elevation of 18m above sea level. The river has its source in Ibiono Ibom Local Government Area of Akwa Ibom State and runs along four Local Government area namely Ibiono, Itu, Uyo and Uruan (Figure 1) before discharging into the Cross River at Oron close to the Cross River estuary with the Atlantic Ocean. The total Channel length of the river is about 52.5Km with a catchment area of approximately 516.5Km^{2}out of which about 14.8% is subjected to annual flooding during the rainy season. The drainage basin has a climate typical of rain forests. The average temperature of the place varies between 23.3^{o}C to 28.0^{o}C with a mean annual rainfall of 255.8cm

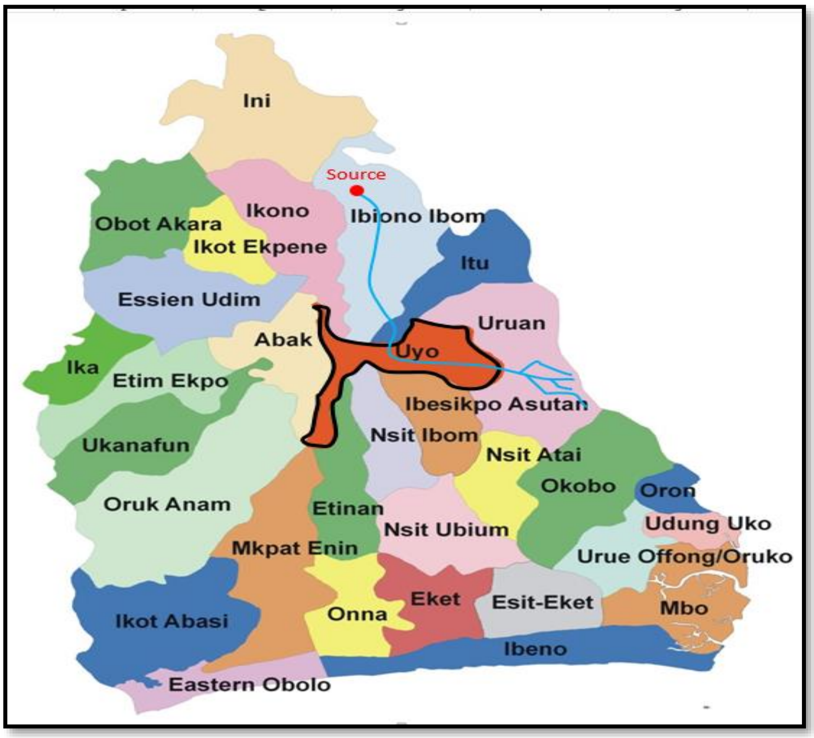

Figure 1: Maps showing the Local Government Area of Akwa Ibom

Figure 2: Google Earth Map showing Ikpa River in Akwa Ibom State

3. Material and Method

The methods used in this study was to determine the hydraulic feature of the Ikpa River and obtain the velocity of the river at different cross-section of the river.

3.1 Cross-Section Geometry

`The width and depth of the River was obtained with a 100 m tape and a dumpy level respectively. A 120 meter straight reach of Ikpa River was identify and selected for carrying out the study on the River. The selected length of the River was then divided into five unequal part and measurement was taken at each transect of the river. Each transect of the river was either divided into 6 vertical sections or 7 at bank full stage when the wider top width has been reached by flood water as shown in Figure 3. A steel rod was driven into the ground beyond the reach of maximum flood which served as the reference point. Using the 100m tape rule, the distance of from the reference point to each vertical was measured and recorded.

Because of the high risk of people tampering with any gauge installation, a dumpy level was used in taking measurement of the depth of the river. A temporary benchmark (TBM) was established at the pile cap of the bridge located near Ikpa River as shown in Figure 3. The staff was place at each vertical and measurement was taken, this was done for the five vertical, after which the reduced level was obtained by subtracting the staff reading at the TBM from staff reading at each vertical in other to obtain the depth at each vertical.

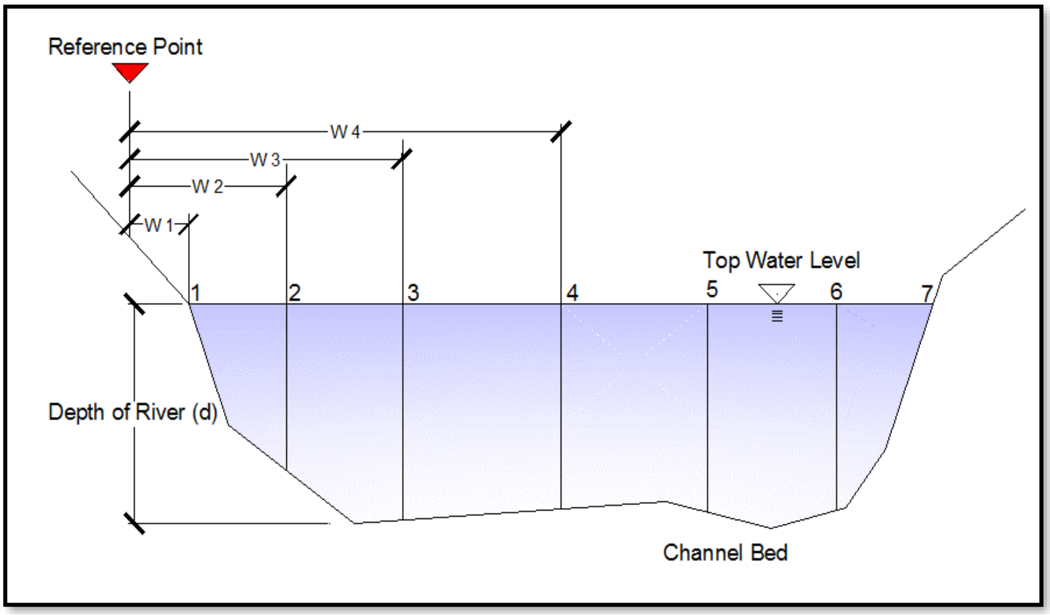

Figure 3: Diagram showing the measurement of the width of the rivers

3.2 Measurement of Velocity at Ikpa River

The velocity of the river was measured using the current meter, which is an instrument that consist of a small propeller mounted on a pole that is connected to a device that measure the frequency of the propeller rotation. Since the velocity of the river change from zero (no-slip condition) at the bottom of the river to a maximum value above a certain height from the bottom of the river, the velocity is measured at various depths along the cross section of the river. As shown in Figure 4, the velocity of the river was measured at the riverbed, at a distance of 0.2, 0.6 and 0.8 from the top of water level and also the velocity of the river was measured at the top of water level. This was done for the five vertical, and eight measurement was taken for each point during the duration of the study.

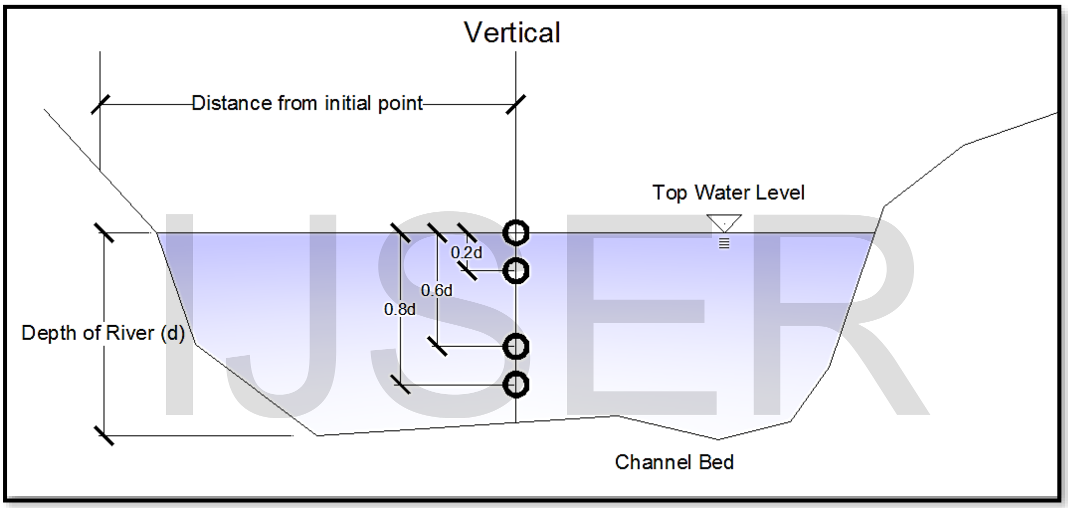

Figure 4: Diagram showing the measurement of the velocity of the rivers

3.3 Data Analysis

From the data obtained from the field measurement, the depth of the river was computed using the height of instrument method. Since eight measurement of velocity were taken at each point of the cross section, the mean velocity was obtained by taking the average of the eight data, which was then plotted with the depth to see the velocity profile at the cross-section. For computation of discharge, the discharge is found the integrating the product of the velocity and the change in area of the stream as given in Equation 1.

$$Q = \iint_{O}^{A} V dA \tag{1}$$

Where V = velocity component in the y-direction

Q = discharge or flow

The discharge was approximately be computed by dividing the rivers into different vertical sections (Figure 5) and summing the product of the average velocity and the area of all the vertical section, which is given by Equation 2. The velocity used to in Equation 2 is obtained by averaging the velocity at 0.2d and 0.8d from the top of the Top water level.

$$Q = \sum_{i=1}^{n} v_i d_i \Delta w_i \tag{2}$$

Where v_i = Average velocity at vertical

Q = discharge or flow

Δw_i = change in width $\left(\frac{W_{i+1} - W_{i-1}}{2}\right)$

d_i = depth of the vertical section

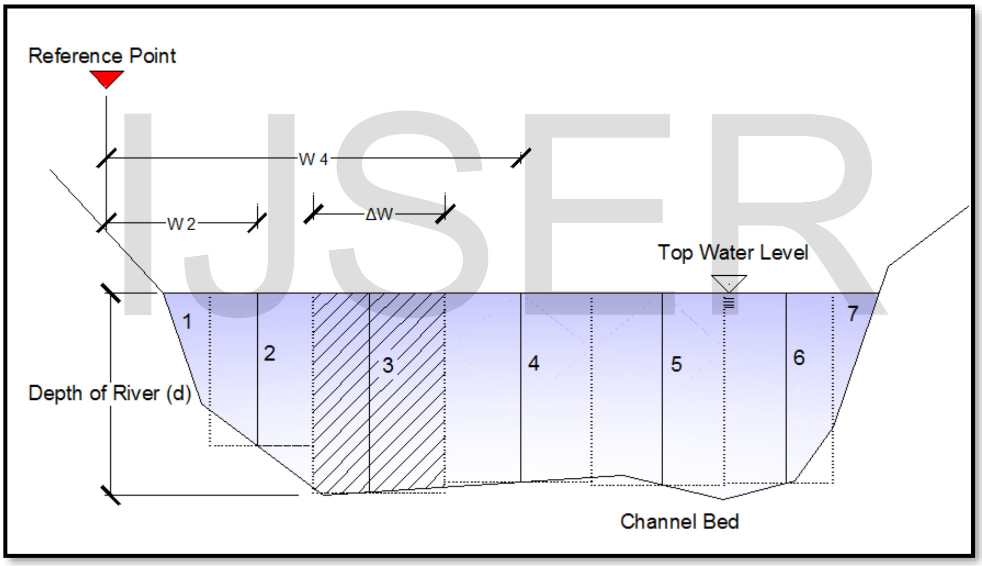

Figure 5: Diagram showing the measurement of the velocity of the rivers

Various empirical models that related the discharge of the river to variable such as width of the river, cross section area etc. were developed. Xlstat which is a statistical software package was used for developing the models.

4. Results and Discussion

4.1 Hydraulic Characteristic of Ikpa-River

The results of the measurement of the various hydraulic variables are presented in forms of figures. The measurement take at different days during the duration of the study are shown from Figure 6-13. Figure 6 showed the velocity profile of the river when the maximum depth of the river was 2.15m. It can be observed that the river velocity increased from zero velocity at the river bed (no-slip condition) to a maximum at the top of the river.

From the figure the maximum velocity of 0.64 m/s was recorded at the second vertical which is close to the bank of the river while the minimum velocity was recorded at the far end of the river. For the hydraulic characteristic of the river at 2.15m depth, the discharge of the river was computed to be 8.69m^3/s as shown in Table 1. Figure 7 also showed that the width of the river was 19.94m, with a cross sectional area of 22.45m^2,with an average velocity of 0.388m/s andan average depth of about 1.286m.

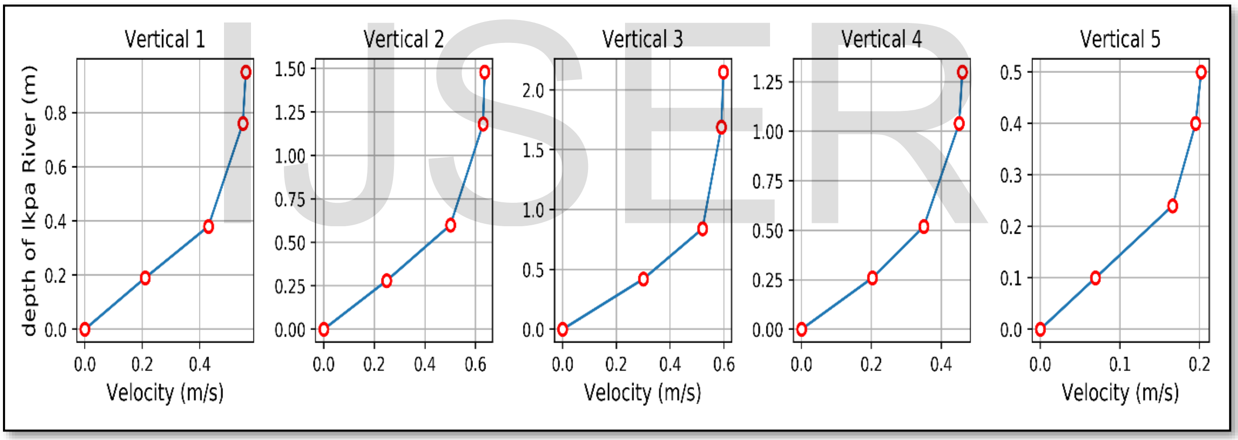

Figure 6: Velocity profile at the different verticalsat 2.15m max. depth

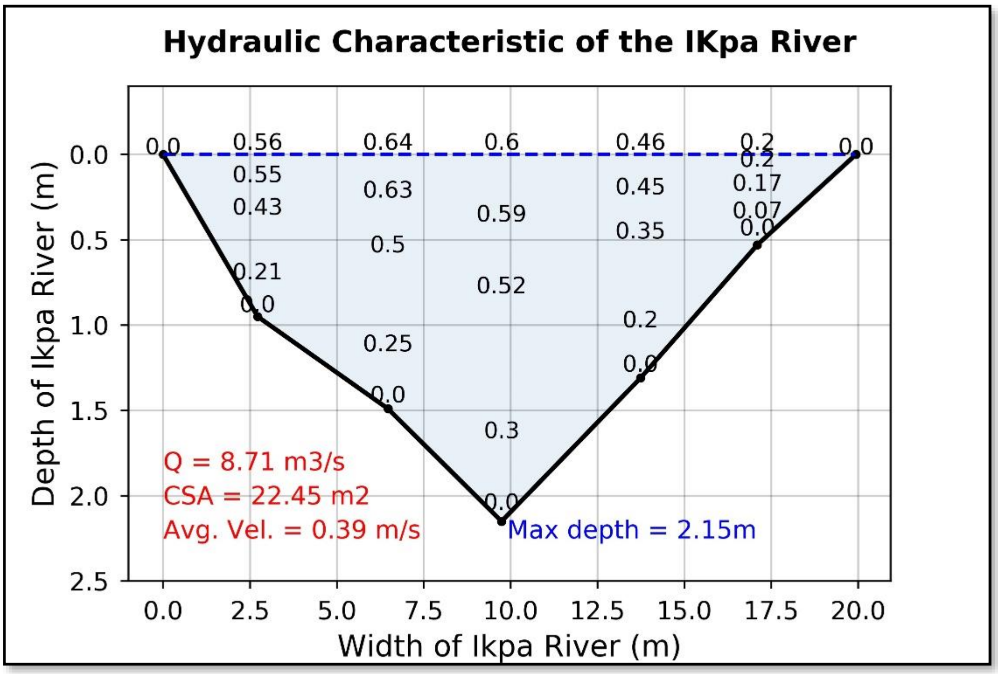

Figure 7: Cross section of hydraulic characteristic of Ikpa River at 2.15m max. depth

Table 1: Computation of the discharge at maximum depth of 2.15m

Computation of discharge from stream gaging								
Measurement Point (i)	**Distance from initial point**	**Width (m)**	**Depth (m)**	**Mean Velocities (m/s)**		**Average Mean Velocity (m/s)**	**Area (m^2)**	**Discharge (m^3/s)**
				at 0.2d	**at 0.8d**			
1	14.28	1.36	0	0	0	0	0	0
2	17	3.235	0.95	0.21	0.55	0.38	3.07325	1.167835
3	20.75	3.51	1.49	0.249	0.63	0.4395	5.2299	2.29854105
4	24.02	3.635	2.15	0.3	0.59	0.445	7.81525	3.47778625
5	28.02	3.68	1.3	0.203	0.451	0.327	4.784	1.564368
6	31.38	3.1	0.5	0.069	0.195	0.132	1.55	0.2046
7	34.22	1.42	0	0	0	0	0	0
						Total	22.4524	8.7131303

At maximum depth of 1.95m, the velocity profile as shown in Figure 8. The figure showed similar pattern with the velocity profile at 2.15m. The maximum velocity of 0.63m/s was recorded at the second vertical, with the minimum recorded at the far end of the river. From Figure 9, the computed discharge of the river was 7.053m^3/s, with an average velocity of 0.371m/s and a cross sectional area of 19.00m^2. The width of the river at that depth was found to be 18.49m

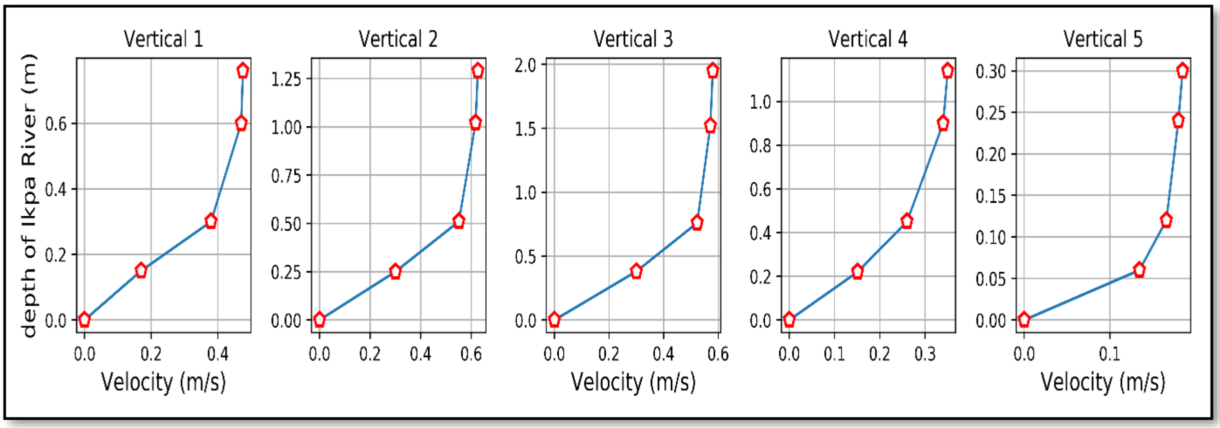

Figure 8: Velocity profile at the different verticals at 1.95m max. depth

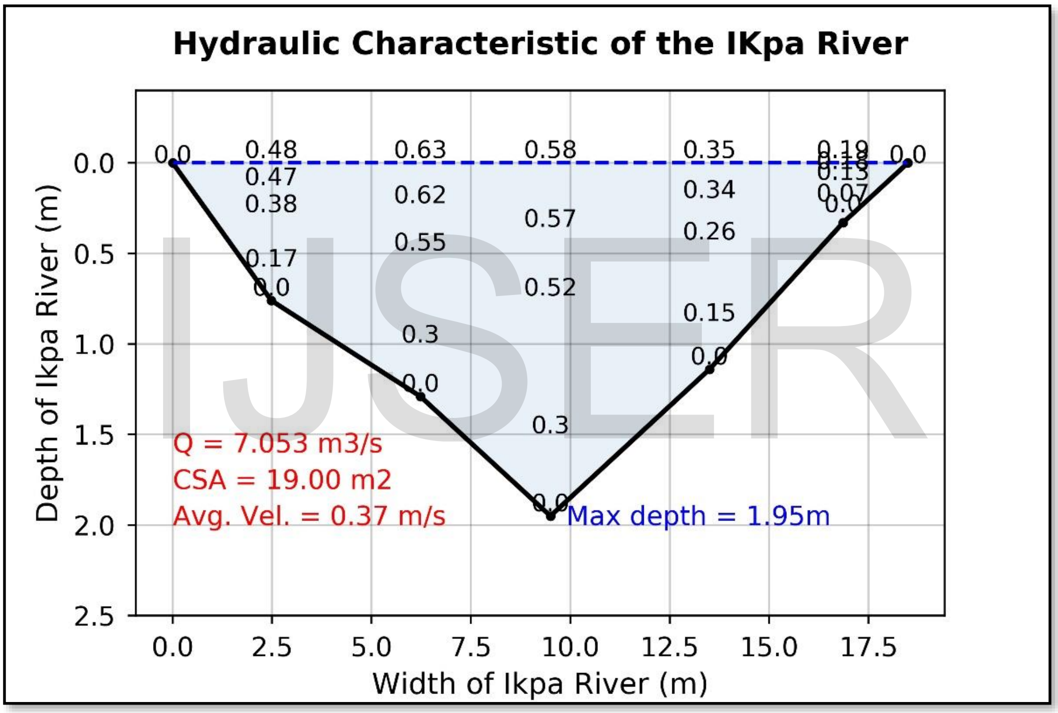

Figure 9: Cross section of hydraulic characteristic of Ikpa River at 1.95m max. depth

At maximum depth of 2.99m and 2.38m, the velocity profile took similar trends as previous velocity profile as recorded in other depths of the river. At depth 2.99m, the maximum velocity of 0.92m/s was recorded at the second vertical while for depth 2.3m, the maximum velocity 0.8m/s of the river was also recorded at the at the first vertical. Theses result indicate, that the velocity of Ikpa River is highest near the banks. For the hydraulic characteristic, it was observed from Figure 11 and 13, that the discharge of Ikpa River at depth of 2.99m was 20.118m^3/s while that of depth 2.38m was 11.821m^3/s. The relationship observed from the study confirmed that the cross sectional area of the River is directly related with the discharge of the river. Increase in one variable will cause the other variable to increase.

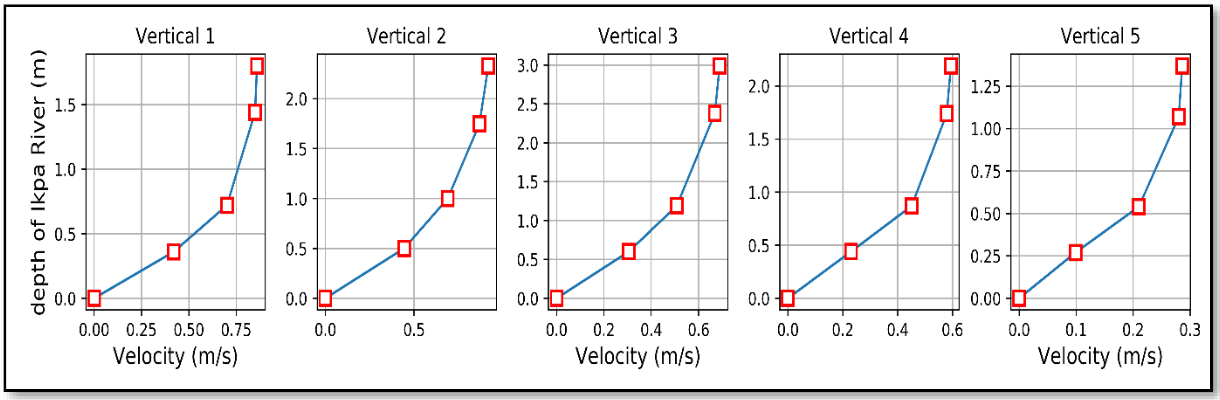

Figure 10: Velocity profile at the different verticals at 2.99m max. depth

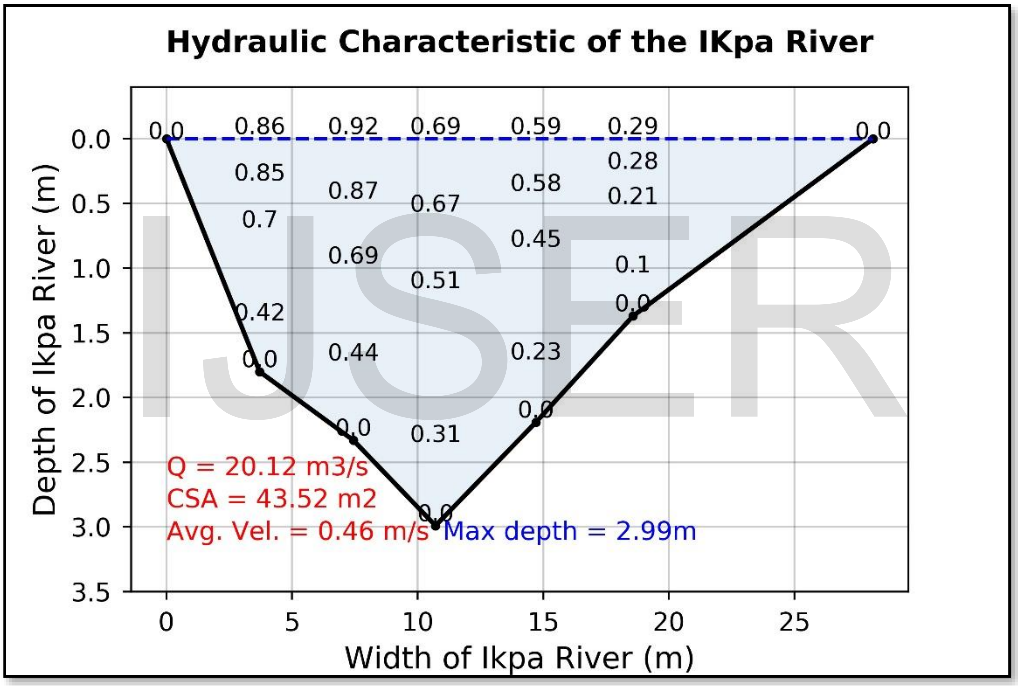

Figure 11: Cross section of hydraulic characteristic of Ikpa River at 2.99m max. depth

The average velocity recorded at depth 2.99m was 0.462m/s while the average velocity recorded at 2.38m was about 0.431m/s. For the cross sectional area, the area at depth 2.99m was 43.52m^{2}while the area for depth 2.38m was found to be 27.40m. The width of the river at depth 2.99m and 2.38m were 28.13m and 21.6m respectively. Summary of the hydraulic characteristic of the last station is presented in Table 2. The River studies done on Ikpa river confirmed that the discharge has correlation with all the hydraulic variables as reported by (Nidal, 2013). Summary of the hydraulic characteristic of the river are presented in Table 2.

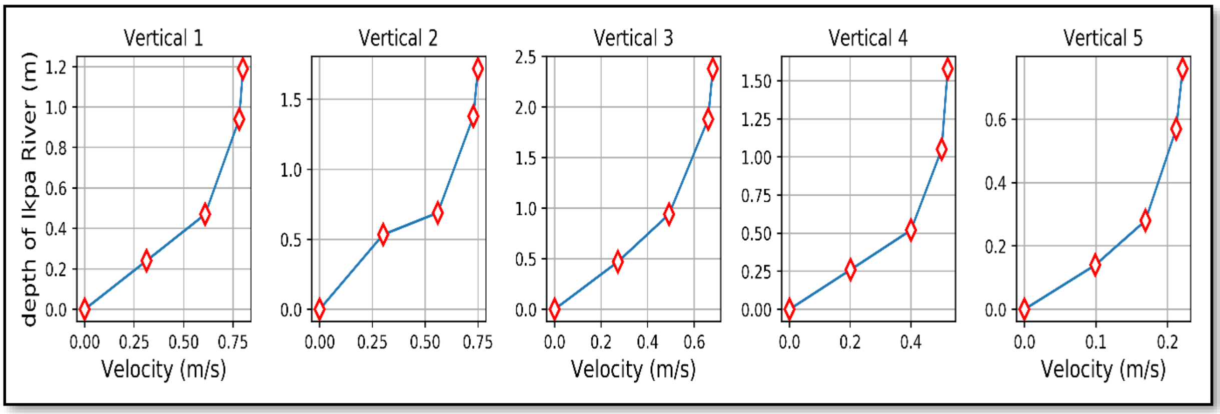

Figure 12: Velocity profile at the different verticals at 2.38m max. depth

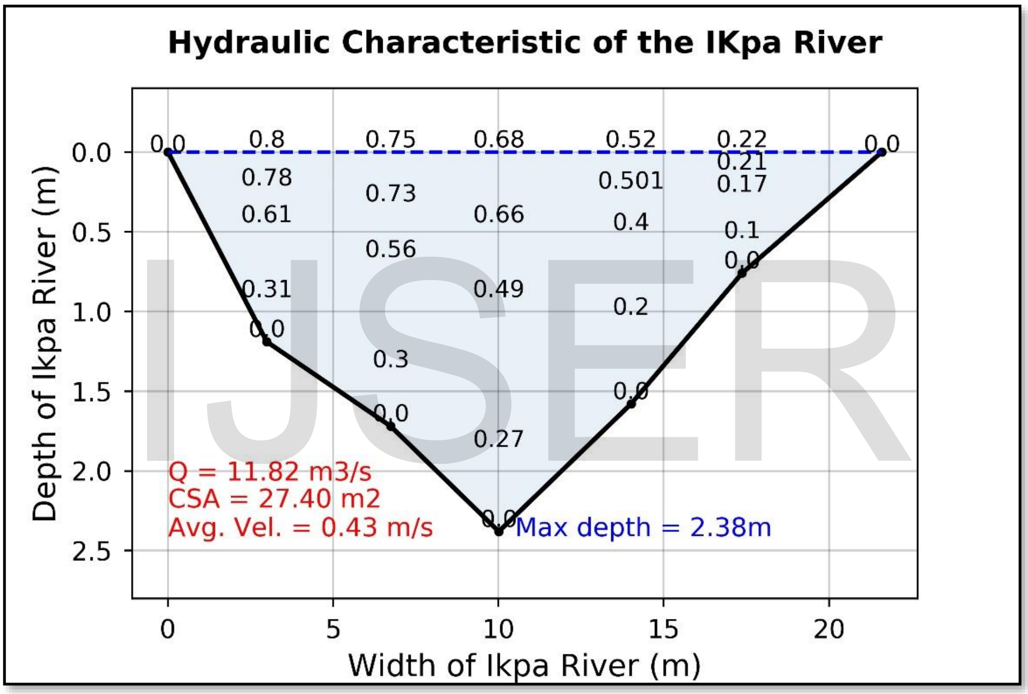

Figure 13: Cross section of hydraulic characteristic of Ikpa River at 2.38m max. depth

Table 2: Summary of hydraulic properties of Ikpa River

Maximum Depth (m)	Width of the River (m)	Cross Sectional Area (m^2)	Average Velocity (m/s)	Discharge (m^3/s)	Max Velocity (m/s)	Mean Depth (m)
3.23	31.31	49.139	0.545	26.280	1.02	2.08
2.99	28.13	43.52	0.462	20.118	0.92	2.14
2.38	21.60	27.40	0.431	11.821	0.80	1.53
2.15	19.92	22.45	0.388	8.713	0.64	1.29
1.95	18.49	19.00	0.371	7.053	0.63	1.094

4.2 Empirical Model

The discharge against flow characteristics of the river was investigated. It can be observed from the scatter plot, that a power model will best fit the data point, this was also observed by (Philip, 1998 and Jacobsen, 2016). The result of the model development are presented in Table 3.

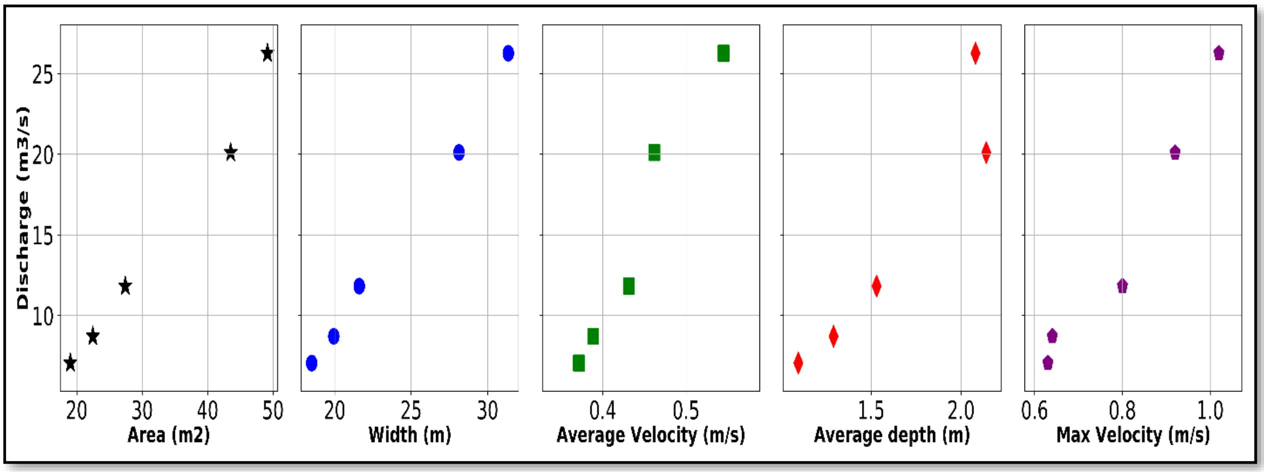

Figure 14: Scatter plot of the discharge against the cross section area of Ikpa River

From Table 3, it can be observed that the five model developed had a good fit. The model showing the relationship between discharge and Cross sectional area had an R^2 of 0.9892. This tell you that 98.92% of the variation in the discharge was explained by the variation in the cross sectional area of the river. The root mean squared root associated with the model was 0.9814, this value show the deviation of the error associated with the model. The discharge can be predicted to an accuracy of $\pm(2\times0.9814)$ of the actual value, this indicate that prediction of the discharge with this model is reliable. The model showing the relationship between the discharge and the width of the river, gave an $R^2$of 0.9954, showing that 99.54% of the variability in the discharge can be explained by the variation in the width of the river. The root mean square of the model was 0.6415, indicating that discharge can predicted to an accuracy of $\pm(2\times0.6415)$ of the actual value. The other model developed have high R^2 value and relatively low RMSE. From the five model develop, it can be observed that the model relating the discharge and the width of the river was the best as indicated by the R^2 and RMSE. The model relating the discharge and the average depth of the river, gave the least model in terms of performance. The root mean square of the model was 3.067, which indicated that the model will predict the discharge of the river to an accuracy of $\pm(2\times3.067)$ of the actual value. This shows that prediction of the discharge can be off by about 6.134m^3/s, which is relatively high compare to other model predictions.

Table 2 Empirical Correlation of discharge on the flow characteristics of Ikpa River

S/N	Model Type	Model Parameter	Goodness of fit
1	$Q = a_o CSA^{a_1}$	a_o = 0.1247 a_1 = 1.3647	R^2 = 0.9892 RMSE = 0.9814
2	$Q = a_o W^{a_1}$	a_o = 0.0076 a_1 = 2.3638	R^2 = 0.9954 RMSE = 0.6415
3	$Q = a_o {V_{avg}}^{a_1}$	a_o = 180.9075 a_1 = 3.1157	R^2 = 0.9287 RMSE = 2.5310
4	$Q = a_o {d_{avg}}^{a_1}$	a_o = 5.6015 a_1 = 1.8861	R^2 = 0.8939 RMSE = 3.067
5	$Q = a_o {V_{max}}^{a_1}$	a_o = 24.7339 a_1 = 2.7167	R^2 = 0.9822 RMSE = 1.266

5. conclusion

From the result from the study, it can be shown that the velocity of the river increases from zero at the bed of the river (no-slip condition) to a maximum about a certain distance of the river. It can also confirmed that as the discharge of the river increases, the hydraulic variables such as mean velocity, cross sectional area, width of the river etc also increase. The power function was confirmed to relate the variables of the discharge and the hydraulic variable, which lead to developing an empirical model between the variables and the hydraulic variables. Five model were developed, between the discharge of the river and the hydraulic variable of the river. The model relating the discharge of the river and the width of the river proved to be the best with an R^2 value of 0.9954 and a RMSE of 0.6415 while the model relating the discharge with the average depth of the river proved to be the least model with an R^2 value of 0.8939 and a RMSE of 3.067.

Reference

Adegbola, A. A., Olaniyan, O. S. (2012) Estimation of bed load transport in River Omi, South Westren Nigeria using grain size distribution. International Journal of Engineering Technology. Vol.2, No 9. pp 1-6.

Gordon, N.D., McMahon, T.A., and Finlayson, B.L., (1992) Stream hydrology: an introduction for ecologists:Chichester, England, John Wiley and Sons, 526 p.

Jansen, P., Van Bendegom, L., Devries, M. and Zanen, A (1979) Principles of River Engineering-The Non Tidal Alluvial River. 1ST Edition, VSSD, Delft. Pp. 147-150, 216-218.

Leton, T.G (2010) Elements of Civil Engineering Hydraulics. Reynolds Grit Publishing Co. Port Harcourt. pp. 172-175.

Leopold, B. L. (1994) A view of the River, Harvard University Press, Masschusset. pp. 6-39, 168-170.

Leopold, L. B., and Maddock, T. (1953). The hydraulic geometry of stream channels and some physiographic implications. U.S. Geological Survey, Professional Paper 252, Washington, DC: U.S. Department of the Interior, Geological Survey.

NidalHadadin (2013) Statistical Analysis to Describe the Complex Hydraulic Variability Inherent Channel Geometry. Journal of Hydraulic Engineering, 123: 73-80

Tendean, M., Bisri, Rayes, M.L, Tamod, R.Z (2012) Mathematical Modeling of Bed Load Transport Along the Estuary of RanoyapoAmurang River. Applied Scientific Research. Vol. 2, No 5. pp 1-10

Yadav, S. M., Samtani, B. K. (2008) Bed load Transport in Tapi River India. Global Journal of Environmental Research. Idosi Publication. Vol 2, No 2. pp 96 – 101