Sediment Dynamics and Rating Curve Development on River Osun, South-Western Nigeria

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ABSTRACT

Sediment transport rate hinge upon hydraulic flow, upstream sediment supply and bed composition. There is paucity of Information on sediment dynamics on River Osun. Landsat7 Imageries from African Regional Center for Space Science and Technology Engineering - Education (ARCSSTE-E), Obafemi Awolowo University, Ile-Ife, Osun State was used to produce land use map of the study area. The acquired image was layer stacked and sub setted using the study area boundary. The sub settted image was classified using maximum likelihood algorithm of supervised classified technique. Thereafter, the classified image was exported as raster layer to ArcGis 10.3 environment where the coordinate of the study area were overlaid on the exported land use classification. Stage and discharge were measured across River Osun was measured from July 2015- June, 2016. Rating equation was developed using stage and discharge records and was validated using three months stage –discharge record from March 2017 to May, 2017. The agricultural activities observed from the land use map are responsible for the highest suspended sediment concentration at the upstream while the urbanization contributes to the highest discharge recorded at the mid-stream. The discharge and cross sectional area across River Osun ranges between (0.53-17.46)m³/s and (3.83-47.46) m². The corresponding slope and depth ranged from (0.0032 - 0.0046) and (0.2-1.9) m, respectively. The flow area across the river in dry and wet season ranges between 3.83 – 19.2 m² and 13.5 - 47.5 m², respectively. The developed rating equation on River Osun was $Q = 0.467(G-0.368)^{.749}$ with 78% coefficient of regression between simulated and measured discharge values.

Keyword: Sediment Dynamics, Rating Curve, Development, River Osun & South-Western Nigeria

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1. INTRODUCTION

River Osun is the largest river in Osun State, the major tributaries of this river include Erinle River, Oba River and Omi Osun River. It was gauged where the tributaries were impounded for reservoir. For a scientific approach to different river problems, proper planning and design of water resources project, an understanding of the morphology and behavior of the river is a prerequisite. Morphology (of river) is an aspect of science that has to do with the change of river plan form and cross section due to sedimentation and erosion. In the field, dynamics of flow and sediment transport are the principal element. The morphological studies therefore play a crucial role in planning, designing and maintaining river engineering structure. There has been a growing awareness about the need for making up morphological study of river in the country, especially with particular reference to their unique problems (Adegbola and Olaniyan, 2013). Flood is the major natural disaster in Nigeria, Many lives and properties have been lost as a result of poor water management. The study of water behavior is very important in forecasting of future flooding occurrence. Sediment transport plays a vital role in water behavior. Hence, the study of sediment transport becomes important in reducing the menace of flood in Nigeria. Water supply is a basic requirement of life and it is important to sustain life.

The availability of quality water is one of the most important factors that determine our health. Therefore any study that is related to sustenance of human life is worthwhile.

2. METHODOLOGY

The data was collated on the river and it includes: discharge (Q), water-surface width (B), flow depth (Y_o), water-surface slope (S_o).

2.1 Brief Description of the Study Area

River Osun is a river that flows southwards through Central Yoruba land in Southwestern Nigeria into the Lagos lagoon and the Atlantic Gulf of Guinea. The origin of River Osun is at Ekiti State ($8^{\circ}20'N$ $5^{\circ}16'E$) while its mouth is at Lekki lagoon ($6.563210^{\circ}N$ $4.062032^{\circ}E$). It is one of the several rivers ascribed in local mythology to have a woman who turned into flowing water after some traumatic event frightened or angered her. Figure 1 shows the map of River Osun.

The river channel was divided into sub channels and the cross sectional geometrical variables such as area, wetted perimeter, channels top width were computed for each sub channel. The expressions were used to calculate the cross section in line with (Olaniyan, 2014).

$$A_i = 0.5 (y_i + y_{i+1}) dx_i \quad (1)$$

$$A_t = \sum_{i=1}^m A_i \quad (2)$$

$$P_t = (d \times 1^2 + (y_i - y_{i+1})^2)^{1/2} \quad (3)$$

$$T = \sum_{i=1}^N T_i \quad (4)$$

Figure 1: Map of the Study Area showing the Sampling Stations

Where:

A_i and P_i = area and wetted perimeter of a subsection

T_i = top width of a sub-channel

A , P , and T = Area, wetted perimeter and top width of the whole cross section, respectively:

m = number of subsections

N = number of computed sub-channels

Flow Area is the gross section of the river channel at the sampling point. Producing a cross section of a river channel is a basic river field work skill. Equipment used for this task (i) A rigid calibrated rope, (ii) Surveying pole for taking actual depth readily, (iii) A long waterproof tape for measuring the width of the river.

The width of the river was obtained by stretching a tape from one bank the other bank at 90° to the course of the river, the starting and finishing points for the measurement are the points at which the dry bank meets the water. In order to avoid drag induced by the tape making contact with the flowing water, and the consequent possible increase in distance to be measured due to the likely scotching of tape into a curve, it has to be stretched at about 20cm above water level. The ends of the section to be measured will be determined by observation from directly above the tape at 90° of the ground. Observation from directly above the tape is to ensure that the error is minimal (Olaniyan, 2014). The readings were taken at an interval of 4 meters. The tape was stretched from one bank to the other is to serve as a guide-to ensure that you take measurements in a straight line. It is also a convenient way of measuring the intervals between readings.

A calibrated rope was immersed in the water every 4m, until the concrete cube weight end touches the bed of the river. The depth measurements from the stream were recorded. The measured depths and distance were used to draw a chart of the stream shape. In other to examine the effect of human activities on River Osun, lands at 7 was acquired from global land use and land cover facility achiever. The acquired image was layer stacked and sub setted using the study area boundary. The sub setted image was classified using maximum likelihood algorithm of supervised classified technique. Thereafter, the classified image was exported as raster layer to ArcGis 10.3 environment where the coordinate of the study area were overlaid on the exported land use classification.

2.2 Rating Curve Development

Stage and discharge were measured across River Osun was measured from July 2015- June, 2016. Rating equation was developed using stage and discharge records and was validated using three months stage –discharge record from March 2017 to May, 2017. This rating equation developed was used to estimate discharge from February 2016 to June 2016 to complete the seasonal discharge data on River Osun.

Running method was used to develop the rating equation in-line with (Adegbola and Olaniyan, 2013). Three points A, B and C on the curve was selected such that their discharges are in geometrical progression i.e.

$$\frac{Q_A}{Q_B} = \frac{Q_B}{Q_C} \quad 5$$

This method assumed that the lower part of the stage-discharge curve is a parabola. The constant (a) can be estimated using equation:

$$a = \frac{G_1 G_3 - G_2^2}{(G_1 + G_3) - 2G_2} \quad 6$$

From Gauge-Discharge equation,

$$Q = C_r (G - a)^{\beta} \quad 7$$

$$\log Q = \beta \log (G - a) + \log C_r \quad 7(a)$$

$$Y = \beta X + b \quad 7(b)$$

Using equation 3.7(a) and 3.7(b) for the data, the unknown variables (β, b and r) can be determined by:

$$\beta = \frac{N(\sum XY) - (\sum X)(\sum Y)}{N(\sum X^2) - (\sum X)^2} \quad 7(c)$$

$$b = \frac{\sum Y - \beta(\sum X)}{N} = \log C_r \quad 7(d)$$

$$r = \frac{N(\sum XY) - (\sum X)(\sum Y)}{(\sqrt{N(\sum X^2) - (\sum X)^2})(\sqrt{N(\sum Y^2) - (\sum Y)^2})} \quad 7(e)$$

Note that $r = \log Q$, $X = \log(G - a)$

3. RESULTS AND DISCUSSION

3.1 Depth and Width Computation

The calculated flow areas for rain and dry season are shown in Table 1 and Table 2 respectively. The flow area across River Osun in dry season ranges between 3.83 – 19.2 m² while it ranges between 13.5 and 47.5 m². The highest flow area in dry season was recorded at upstream while the lowest was recorded at midstream. Also, the highest flow area in rain season was recorded at midstream while the lowest was recorded at downstream.

It was observed from the land use map at Figure 6 that farming activities and presence of forest at T₁ are the factors responsible for the highest measured SSC at sampling station T₁. Also the presence of little forest and woodland at sampling station T₄ as shown in Figure 6 is the factor responsible for the higher measured suspended sediment concentration at T₄. Sampling station T₂ and T₃ are within urban area as shown in Figure 6. The presence of road and drainage in urban area enhance movement of surface run off directly into the river. Hence, the highest discharge recorded at T₂ and T₃ during rainy season could be attributed to the high influx of surface run off entering directly to the water body.

Table 1: Rain Season Cross-sectional Flow Area Computation at Sampling Stations

Station	T ₁	T ₂	T ₃	T ₄
Area(cm ²)	192,000	38,340	46,865	75,000

Table 2: Dry Season Cross-sectional Flow Area Sampling Stations Computation

Station	T ₁	T ₂	T ₃	T ₄
Area (cm ²)	453,040	474,640	249,360	135,120

Figure 2: Slice through River Osun at T₁ for Dry and Rain Season

Figure 3: Slice through River Osun at T₂ for Dry and Rain Season

Figure 4: Slice through River Osun at T₃ for Dry and Rain Season

Figure 5: Slice through River Osun at T₄ for Dry and Rain Season

Figure 6: River Osun Land use Map

3.2 Wetted Perimeter

The wetted perimeter is relatively low in midstream at dry season; its average at midstream is 0.113m while the highest value was recorded at the upstream. It's important to note that the difference between wetted perimeter obtained in dry season and rain season at both upstream and downstream is relatively low compare to the difference between the wetted perimeters obtained in midstream. Table 3 and Table 4 show the respective wetted perimeter in dry and rain season.

Table 3: Wetted Perimeter at Dry Season

Distance (cm)	Wetted Perimeter (cm)			
	T ₁	T ₂	T ₃	T ₄
0	0	0	0	0
400	401.53	400.50	400.50	400.78
800	400.03	400.12	400.28	401.53
1200	400.78	400.00	400.04	400.50
1600	400.12	400.98	400.50	404.47
2000	400.03	0	0	0
2400	400.78	0	0	0
2800	400.78	0	0	0
3200	400.50	0	0	0
3600	402.00	0	0	0
	3605.80	1601.60	2001.82	2007.78

Table 4: Wetted Perimeter at Rainy Season

Distance (cm)	Wetted Perimeter (cm)			
	T ₁	T ₂	T ₃	T ₄
0	0	0	407.92	402.00
400	410.00	412.31	403.11	402.00
800	402.00	405.25	400.50	400.78
1200	400.50	400.50	401.12	401.53
1600	400.50	400.50	401.12	401.12
2000	400.00	400.00	402.00	402.00
2400	400.50	401.12	403.11	0
2800	400.50	400.50	0	0
3200	401.12	400.00	0	0
3600	403.11	400.50	0	0
4000	403.11	400.50	0	0
4400	0	401.12	0	0
4800	0	403.11	0	0
Σ	4021.34	4825.41	2818.89	2409.43

3.3 Rating Curve Analysis

The rating curve data is presented in Table 5. The correlation was acceptable because r fall within 0.6-1, therefore rating equation in equation 7 was developed

$$Q = 0.467(G - 0.368)^{.749} \quad 7$$

This rating equation in was calibrated by comparing it with the measured discharged across River Osun. Table 6 shows the stage and discharge data used in developing the rating equation across the river. The rating curve develop was used to estimate discharge between February 2016 to July 2016.

Table 5: Rating Curve Data

G	Q	A	G-a	$x=\log(G-a)$	$y=\log Q$	XY	X*X	Y*Y
1	2.056	0.368	0.632	-0.19928	0.313023	-0.06238	0.039714	0.097983
1.2	3.03	0.368	0.832	-0.07988	0.481443	-0.03846	0.00638	0.231787
1.7	7.7	0.368	1.332	0.124504	0.886491	0.110372	0.015501	0.785866
0.55	1.22	0.368	0.182	-0.73993	0.08636	-0.0639	0.547494	0.007458
0.5	0.96	0.368	0.132	-0.87943	-0.01773	0.015591	0.77339	0.000314
0.4	0.309	0.368	0.032	-1.49485	-0.51004	0.762436	2.234577	0.260142
0.7	0.98	0.368	0.332	-0.47886	-0.00877	0.004201	0.229309	7.7E-05
1.05	1.92	0.368	0.682	-0.16622	0.283301	-0.04709	0.027628	0.08026
1	2.065	0.368	0.632	-0.19928	0.31492	-0.06276	0.039714	0.099175
0.6	0.76	0.368	0.232	-0.63451	-0.11919	0.075625	0.402605	0.014205
0.7	0.451	0.368	0.332	-0.47886	-0.34582	0.165602	0.229309	0.119594
0.55	0.597	0.368	0.182	-0.73993	-0.22403	0.165763	0.547494	0.050188

Table 6: Comparison of measured and simulated discharge on River Osun

Sampling Station	Measured discharge (m ³ /s)	Simulated Discharge (m ³ /s)	Percentage Variation
T ₁	1.64	1.73	+5.2
	3.00	4.50	+33.0
T ₂	1.35	0.69	-44.0
	4.10	11.87	+65.0
T ₃	1.50	1.03	-31.0
	3.90	15.71	+75.0
T ₄	1.64	1.62	-1.2
	1.68	1.76	+4.5

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

Based on the findings from this study, the following conclusions can be drawn; the discharge and cross sectional area across River Osun ranges between $(0.53-17.46)\text{m}^3/\text{s}$ and $(3.83-47.46)\text{m}^2$. The slope and depth across river Osun range from $(0.0032-0.0046)$ and $(0.2-1.9)\text{m}$. The developed rating curve on River Osun was $Q = 0.467(G-0.368)^{0.749}$. The seasonal bed load across the river is 95.22% of the measured load which gives $2358.77 \times 10^3 (\text{kg}/\text{year})$.

4.2 Recommendation

Routine maintenance of waterways in Nigeria in other to provide easy access of researchers in taking field measurement for morphological studies.

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