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Simulation of Sediment Transport in River Ogunpa Using Winxpro Software

Olaniyan, O.S., Adegbola, A.A., Adeleke, W.O., Afolabi, L.A., Ayanlola, J.A. Ojo, E.O. and Adeyokunnu, A.T.

Abstract: The numerical modelling of sediment transport of a river has long been developed. Rivers across Nigeria has interdicted researchers on modelling sediment transport. The environmental problem makes sediment transport study an important area among morphological mechanisms. This research studied the Simulation and modelling of sediment transport in River Ogunpa using WinXspro software. Suspended Sediment concentration was measured from November 2015 to June 2016 across the upstream, midstream and downstream of River Ogunpa using standard methods. The values of manning's roughness factor used varied from 0.012 - 0.018. Sediment discharges (Q_S) were computed across the river using Acker and White approach. The average Suspended Sediment Concentration (SSC) across River Ogunpa varied from 2 - 64mg/L. The mathematical relationship for the sediment discharge value was Q_S = 64625Q + 12922. The estimated Qs varied from 0.00 - 23012kg/s. The variation in measured and validated discharge ranged between 0.95 - 4.19%. Sediment discharge across River Ogunpa was simulated using Winxpro software. The sediment discharge value can be a piece of useful information for dredging operation on River Ogunpa.

Keywords: Ogunpa, River, Sediment, Simulation and Winxpro

I. Introduction

Bedload is essential to the ecosystem through the process of a nutritional system. Sediment deposition could be anywhere in a river system [14]. The generally acceptable approach to analyse the principle of motion particles is not feasible because of the soil and slope of the river. [1];[7]

WinXSPRO is an integrated Window software package designed to assist watershed specialists in analyzing stream channels at the cross-section. The geometrical, hydraulic and sediment transport parameters are the input data. Although the program can be used with streams of any gradient, it has been specifically developed to handle channel geometry and hydraulic conditions for single transects in steep (gradient > 0.01) stream. Several resistance equations are supported, including those specifically designed for large roughness channels. Analysis options include developing stage-discharge relationships and depth computation which required an inundate valley floor surface. Both graphical and tabular output can be generated in WinXSPRO software package. It also assists hydrologists in analyzing streamflow parameters. They are used in performing hydraulic reconstructions, designing effective channel and riparian structures as well as monitoring channel changes. [13]

The importance amongst the interrelationships of flow, temperature geometry and hydraulics is paramount for remediating the shortcomings associated with a flow situation. In many channel stability

Olaniyan, O.S., Adegbola, A.A., Adeleke, W.O., Afolabi, L.A., Ayanlola, J.A. and Ojo, E.O. (Department of Civil Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria)
Adeyokunnu, A.T. (Department of Civil Engineering, Ajayi Crowther University,Oyo, Oyo State, Nigeria)
Corresponding Author: adeyokunnuat20@gmail.com
Phone Number:+2348065155439
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analyses, it is costumed to relate stream bed materials movement to some measure of stream power or average bed shear stress. If the relationship between streamflow and certain hydraulic variables such as mean depth and water-surface slope are known, it is easier to evaluate stream power and average bed shear at any given level of flow. Thus, a channel cross-section analysis makes it possible to estimate conditions of stream bed particle movement at various levels of streamflow. WinXSPRO also includes two sediment transport relations: The Parker model for gravel-bed rivers and the Ackers-White model for sand-bed channels. [5]

The advantage and limitation of Winxspro is that the mean velocity of streamflow in a cross-section can be estimated when certain discharge conditions are met. The essential criteria for discharge conditions are water surface elevation, bed slope and energy grid line. The terrain in the energy grid shows the extent at which the energy is conveyed through a frictional slope with the known topography. Different methods are allowed for the computation of velocity through the cross-section of the river or stream [8]. The only advantage of steady flow is stream line which is symmetrical [14]. The uniform flow rarely occurs in open channels, but the reason is approached in some river beds where the channel geometry is relatively stable. The disrupted condition of uniform flow consist of a change in cross-section of channel geometry, bends in the stream sides and obstruction to flow due to roughness coefficient. A resistant equation may be used to accept the non-uniform flow conditions. However, energy transition computation must be included in the analysis. The multiple transect numerical model is considered such as in HEC-2, HEC-RAS and Winxspro among others. [2]

WinXSPRO is very effective when using manning's equation for computing mean velocity across the section of the river. Manning's equation is valid for non-uniform flow that is invariably encountered in open channels, provided the energy gradient is adjusted to showcase only losses because of frictional slope [13]. The equation to compute velocity is presented as:

$$V = K/n\ R^{2/3}S^{1/2} \tag{1}$$

where:
V = mean velocity at river section (m/s)
k = 1.0 for metric units and 1.486 for English units,
n = Manning's roughness coefficient,
R= hydraulic radius (ft or meters), and
S= energy slope (m/m) (water-surface slope for uniform flow).

In Manning's equation, resistance to flow due to friction at the channel boundary is solved through the use of a roughness coefficient, n, supplied by the user of the equation. The roughness coefficient may be thought of as an index of the features of channel roughness that contribute to the dissipation of stream energy. WinXSPRO encouraged one bedload transport function appropriate for gravel-bed streams and one bed material load transport function appropriate for sand-bed streams. The bed load function estimates the quantity of material rolling, sliding or jumping (saltating) along the bed with the given cross-section. The bed material load function calculates the total bed material load being transported through the cross-section (i.e., bed load plus suspended bed material load). All the sediment transport calculations in winXSPRO used a single grain size for computation of sediment load. [5] and [8]. WinXSPRO software is a dimensional computer program that models the sediment transport of the rivers and other channels. The models were used over MIKE II, SWAT and SEDIMOA because of their high visual capability and complete output with details [4]. This study calls for immediate attention as the incessant inundation keeps claiming lives and properties.

II. Materials and Methods

A. Description of the Study Area

Ibadan is the largest city in West Africa and the second-largest in Africa with a land area size covering approximately 3010 km^2. It is located at an average height of 200m above sea level, drained by three major river basins. Ogunpa, Ona and Ogbere. The Ogunpa River is situated in Ibadan at a longitude of 03˚52'03" E and latitude 07˚17' 13" N, with a catchment area of 128 km^2.

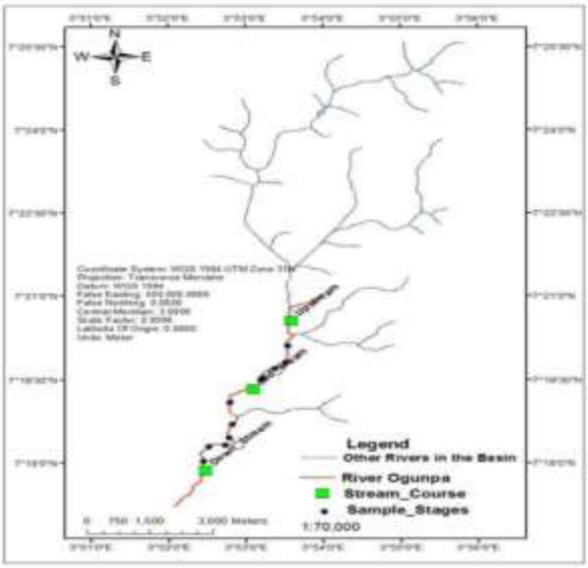

Figure 1: Hydrological Map of River Ogunpa showing Sampling Points

Ogunpa River takes its source from Ashi village in the Orita Basorun of Ibadan, with records of annual flooding in the flat or low, lying terrain Municipal waste and eroded soil sediments impart to the stagnation of the river, resulting in the propensity of flooding [6]. The Hydrological map of the study area is presented in Figure 1.

B. Suspended Sediment Concentration (SSC)

This was estimated as the weight of dry bed load divided by the weight of wetted bed load mixture using the analytical method (ASTM 1999). The initial weight of 0.4μm filter paper was measured by analytical weighing balance and used to filter a 100ml water sample taken at the middle depth across the sampling points. The moist paper filter was oven-dried, and its weight was measured and recorded. The suspended sediment concentration is the ratio of the difference between the final and the initial weight of filter paper with the volume of water in mg/l.

The input data used for winXSPRO software in this study are:

(i) Position Elevation – variables, (ii) Sediment mean size, (iii) Manning constant (iv) Stage Temperature- variables

The stage-discharge relationship was first generated from measured data using the Winxspro software. The stage-discharge relationship was then set as the input parameter to the software module. The effective particle size (d_{50}) and the corresponding water temperature were used as the input file for the Ackers-White method to estimate sediment load. The river temperature was measured with a thermometer.

III. Results and Discussion

A. Suspended Sediment Concentration (SSC)

The average values of SSC measured on River Ogunpa is presented in Table 1. The SSC increases as the rainfall intensity increasesThe value is higher during the rainy season than the dry season. Channel slope, human activities and river morphology also contribute to the measured values. The SSC values tend to increase from April 2016 in the rainy season. This is with previous work of [5] which suggests that sediment is trapped at the midstream.

Table 1: Summary of Average SSC across River Ogunpa

Month	Stream Course	Avg. SSC (mg/l)
Nov, 2015	Upstream	64
	Midstream	55
	Downstream	56
Dec, 2015	Upstream	64
	Midstream	55
	Downstream	56
Jan, 2016	Upstream	6
	Midstream	5
	Downstream	5
Feb, 2016	Upstream	7
	Midstream	5
	Downstream	5
March, 2016	Upstream	5
	Midstream	2
	Downstream	1
April, 2016	Upstream	28
	Midstream	29
	Downstream	15
May, 2016	Upstream	64
	Midstream	50
	Downstream	30
June, 2016	Upstream	56
	Midstream	54
	Downstream	49

Farming activities spread across the upstream through the midstream which could act as a source of the transported sediment. The SSC on the river varied from 2 - 64 mg/l. Data generated was input into the winXSPRO software. The values of manning's roughness factor used varied from 0.012-0.018. Ackers-white model equation for Total sediment load. The river temperature varied from (30-32)^{0}C in the morning and (24-29)^{0}C in the afternoon.

B. Position-Elevation (stage)

The results indicate that as the water warms, sediment transport decreases in line with inverse and non-linear law. Sediment transport is sensitive to changes in water temperature. The effects of water temperature on sediment transport are small under 6% over a range of temperature changes.

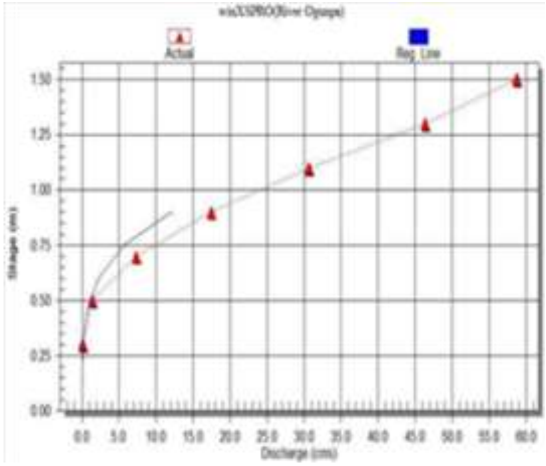

Figure 2: Upstream Stage–Discharge Relationship of River Ogunpa

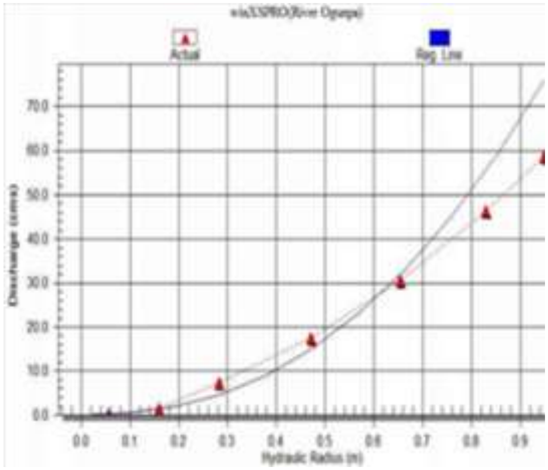

Figure 3: Discharge–Hydraulic Radius of River Ogunpa

Different simulation runs were taken to reflect the situation at both time frames.

C. Relationship

The stages and their corresponding horizontal elevations were plotted by winXSPRO software after input Mannings coefficient, channel slope together with high and low stages values. The upstream and downstream stage-discharge relationship is shown in Figures 2 and 3. The winXSPRO hydraulic and regression analysis on River Ogunpa estimated the stages and the corresponding hydraulic parameters.

Table 2: Winxpro Simulated Hydraulic Parameters at River Ogunpa

	Upstream				Downstream			
Stage (m)	Perimeter (m)	V (avg) m/s	Shear N/m	Froude	Perimeter (m)	V(avg) m/s	Shear N/m	F
0.1	2.77	0.47	1.62	0.64	2.77	0.49	1.73	0.66
0.3	7.24	1.21	4.68	0.97	7.24	1.25	5.00	1.00
0.5	10.93	2.36	8.29	1.41	10.93	2.44	8.84	1.45
0.7	11.13	3.32	13.85	1.52	11.13	3.43	14.77	1.57
0.9	11.33	4.13	19.21	1.59	11.33	4.27	20.49	1.64
1.1	11.53	4.85	24.38	1.64	11.53	5.01	26.01	1.70
1.24	11.67	5.30	27.90	1.67	11.66	5.44	29.49	1.73

The parameters include Area, Perimeters, Width, Hydraulic radius (R), Average velocity(m/s), Discharge Q(m^3/s), Shear, Froude number as shown in Table 2.

D. Stage-Discharge Relationship

The first data generated after the stage-elevation was input into the winXSPRO software, with Manning"s values of (0.018 - 0.012) and low and high stage of 0.1 and 1.24 m, respectively. The river channel slope of 0.003 was used in this study. A stage increment of 0.2 was used to generate the data for the stage-discharge relationship and other hydraulic parameters. The stage-discharge relationship on River Ogunpa is shown in Figure 2. It was established that the stage of the channel increases with increasing discharge. The hydraulic regression analysis of stage (Z) against discharge (Q) produced 97% coefficient of regression shown in equation 2.

$$Q = aZ^b \quad (2)$$

where: a=17.841059, b=4.141, $r^2 = 0.966264$ upstream, a=19.245510, b=4.141,r^2 =0.966264 midstream, a=18.692795, b=4.147, r^2 =0.966865, downstream

E. Discharge-Hydraulic Radius

The relationship of discharge and the hydraulic Radius resulted from the hydraulic and regression Analysis from river Ogunpa plotted by winXSPRO software as shown in Figure 3 for upstream. Hydraulic radius is a function of channel efficiency. The discharge increases with increase in hydraulic radius which invariably increases the channel efficiency. This shows that there is less possibility for flooding to occur along the downstream the river.

The hydraulics and regression analysis that gives the mathematical equation for discharge (Q) against hydraulic radius (R) is presented in equation 3.

$$Q = aR^b \quad (3)$$

where a=82.154449, b=2.328163, $r^2 =$ 0.985869 upstream, a=88.621674, b= 2.328164, $r^2 =$ 0.985869 midstream, a= 85.645439, b=2.327563, $r^2 =$ 0.985845 downstream

F. Sediment Transport Analysis

The sediment transport analysis was computed in the software by using Ackers and the white sediment transport function. In order to analyze and compute the sediment load across River Ogunpa, the data input includes stages, water temperature and effective sediment mean size (d_{50}).

The sediment discharge dynamics were related to flow through the river channel. The sediment transport analysis at the upper and lower course of River Ogunpa is presented in Tables 3 and 4. The sediment load increases with an increase in water discharge as analyzed by winXSPRO software.

The mathematical equation was developed and calibrated Sediment (as shown in Figure 4). Equation 4 shows the calibrated equation of sediment discharge developed using Ackers and White approach.

$$Qs = 6462.5Q + 12922 \quad (4)$$
$$R^2 = 0.8312$$

G. Comparison of Result Obtained with Previous Study

The results obtained from this study is compared with previous results on Kulim River and River Omi from Literature as presented in Table 5. [1] and [4] worked extensively on sediment transport and it was observed that their estimated d_{50}, rating equation and flow depth has above 90% as the determination of coefficient. The hydraulic relationship between hydraulic radius (R) and discharge (Q) in this present study had a 99% coefficient of determination from the regression analysis. The hydraulic radius on River Ogunpa channel is higher compared to other neighbouring rivers (e.g. River Omi). This is due to the channelization of the river Ogunpa by both Federal and State governments since 1999. This increase in hydraulic radius reduces the possibility of flooding occurrence within the study area of River Ogunpa.

G. Model Validation of the Result

The result obtained from the simulation using winXSPRO were compared with previous studies on Kulim River, and River Omi because of their similar catchment characteristics. The sediment mean diameter (d_{50}), discharge, length and hydraulic depth varies. The hydraulic radius and discharge of

Table 3: Estimated Sediment Transport at Upstream

Stage (m^3/s)	Discharge Q (kg/s)	Sediment Discharge Qs (m)
0.10	0.00	0.00
0.30	0.04	0.00
0.50	0.21	12953.13
0.70	0.51	18394.86
0.90	0.90	21114.43
1.10	1.36	22427.55
1.23	1.70	23012.69

Table 4: Estimated Sediment Transport at Down stream

Stage (m^3/s)	Discharge Q (kg/s)	Sediment Discharge Qs (m)
0.10	0.00	0.00
0.30	0.04	0.00
0.50	0.21	12078.89
0.70	0.50	17588.36
0.90	0.87	20328.52
1.10	1.32	21754.30
1.24	1.67	22393.18

Table 5: Comparison of Obtained Results with Previous Studies

Parameters	River Kulim	River Omi	River Ogunpa
Q (m^3/s)	0.73 - 9.98	0.05 - 0.4	0.00-1.67
d_{50} (mm)	1.0 – 2.0	0.4 - 0.6	1.8 - 2.0
Total Length (km^2)	14.4	14.1	21.5
Hydraulic Radius (m)	0.23 - 0.63	0.14 - 0.35	0.06 - 0.95
Flow depth (m)	0.20 - 0.58	0.20 - 1.25	0.10 - 1.24

Table 6: Validation of Result on River Ogunpa

Stage	Measured Discharge (m^3/s)	Simulated Discharge (m^3/s)	Percentage Difference
0.1	0.05	0.052	4.0
0.3	1.45	1.39	4.14
0.5	7.35	7.28	0.95
0.7	16.7	17.4	4.19
0.9	31.5	30.6	2.86
1.1	45.1	46.6	3.32
1.2	60.6	58.3	3.80

River Kulim and River Omi are higher than that of Ogunpa River. This may be as a result of rapid urbanization in Ibadan metropolis. The values of measured discharge and the simulated discharge at every cross-sectional stage across the river were recorded and the percentage differences were computed as shown in Table 6. The percentage difference in the measured discharge in all sample points across River Ogunpa varied from 0.95 - 4.19%.

IV. Conclusion

The following conclusions were made based on the results obtained from this study:

i. The river elevation is higher downstream, the river is steepest downstream and the temperature is lower downstream due to the land use pattern.
ii. The effective mean sediment size (d_{50}) varied across the river.
iii. The SSC is 15% higher upstream than other parts of the river.
iv. The sediment transport yield gives a higher hydraulic radius, which implied the capability of river Ogunpa to discharge the estimated sediment load downstream.

The following recommendations were made

i. Channelization of major rivers to reduce the possibility of incessant flooding.
ii. Measurement of sediment concentration and periodical de-siltation of the sediment should be encouraged for effective river management

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