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Predicting the Morphology of a Forested River Channel: A Case Study of Oji River in Enugu State, Nigeria

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ABSTRACT
The present study investigated the predictive capacity of the hydraulic parameters on the morphology of a forested river channel in southeastern Nigeria. The objective was to analyze the relationship between channel morphology, discharge, velocity, suspended sediment yield, and bed load sediment of the study river. Primary and secondary data are employed in this study. The Regression analysis statistics and ANOVA are used for data analysis. The findings revealed a significant correlation between the channel morphology and hydraulic variables. The correlation between channel morphology, discharge, velocity, suspended sediment, and Bed load sediment showed that discharge alone provided 95.3% explanations for variations in channel morphology of the Oji River while velocity provided 1.8% explanations for the variations. In conclusion, the study showed that what predicted the variability in the morphology of the Oji River channel are the hydraulic variables; hence the major predictors of channel changes are discharge and velocity. The author recommends the usage of appropriate conservation mechanisms to safeguard the river channel against erosion.
Keywords: Channel Morphology, Prediction, Hydraulic Variables, Oji River, Nigeria

INTRODUCTION

Channel morphology simply means channel shape. According to Leopold, Wolman, & Miller,(1964, p.198), 'The shape of a cross-section of a river channel at any location is a function of flow, the quantity and character of sediment movement through the section, and the character or composition of the materials making up the bed and banks of the channel which probably include vegetation.

Channel morphology is dynamic, changing both spatially and temporally in response to controlling factors such as changes in hydraulic discharge, sediment delivery, and stream bed and stream bank roughness (Beschta and Platts, 1986; Montgomery and Buffington, 1998). The channel can adjust to these changes in a number of ways including changes in channel width and depth, channel cross-section shape, channel gradient, bed material composition, channel sinuosity, and bedform composition. Factors controlling channel morphology can be divided into those that are imposed on the watershed (i.e., independent) and those that adjust to the imposed conditions (i.e., dependent). The independent landscape factors controlling channel morphology are geology, climate, and human. The geologic, climatic, and human conditions to which a watershed is subjected determine the dependent landscape variables of sediment supply, stream discharge, and vegetation (Montgomery and Buffington 1993; Buffington et al. 2003). Channel morphology is the result of the combined influence of the dependent landscape variables, and the channel responds to changes in these variables by adjustments in one or many of the dependent channel variables. Human alteration of the landscape can also significantly change watershed conditions. Therefore, channel morphology or channel shape is a reflection of the processes that formed it.

The fluvial dynamics at a given point along a stream are influenced by the various processes occurring in the watershed upstream. Classic conceptual models depicted channel morphology as primarily a function of stream-flow and sediment transport rate, where transport rate equals sediment supply for equilibrium conditions (e.g., Lane 1955; Blench 1957; Schumm 1971). However, these models did not explicitly address the role of vegetation or other boundary conditions, which often play a critical role in determining channel morphology. Many scholars have recognized the contribution of vegetation to river process and channel form. Nanson and Beach (1977) in their report explained the consequences of plant covering on channel geometry in northeastern part of British Columbia, where varying densities of floodplain vegetation are influencing overbank sedimentation rates. The character and plant species also affect channel geometry.

Zimmerman, Goodlet, and Comer (1967), observed that small flowing streams via sod may likely be more contracted and incised than streams under forest covering. Forested streams usually exhibit highly variable widths as a result of local disturbance. Keller and Swanson (1979), in their studies discover that enormous release of organic debris affects the morphology and river processes by providing sites for deposition, either locally reducing or enhancing deposition, erosion and dissipating stream energy.

Millar (2000), developed a model to predict stream channel geometry based on the riparian vegetation condition. This model was put to test on a section of Slesse Creek, a distributary of the River Chilliwack. The riparian section was extensively logged from the 1950s to 1960s, and has become parkland. The model's prediction showed that in the absence of dense riparian vegetation the Slesse Creek would form a braided channel, but in the presence of dense riparian vegetation, it would form meandering channel. These predictions were confirmed with the use of pre- and post-logging air photographs. Prediction of changes in base level and channel morphologies are important steps toward understanding future stream behaviors and attendant risks.

This present study is on the effects of the channel processes on the channel morphology of the Oji River. It looked at the influence of the variables that operate at the reach scale on the morphology of Oji River and statistically determined the predictors of the channel morphology. The study objective is to examine the influence of hydraulic parameters of discharge, velocity, bed load, and suspended sediment load on the channel morphology of the Oji River so as to identify the major factors controlling morphological change in the area. It intends to develop channel morphology predictive model from hydraulic parameters to identifying its role in sustainable flood disaster management.

Area of Study

The study area is within latitudes 6^0 31′ 30″N and longitudes 7^0 44′ 0″ E. The Oji River is the trunk stream in the Oji River Drainage Basin in Enugu State. It has its source in the famous Enugu-Awgu escarpment. From its source in Awgu escarpment in Obeagu, to where it empties into Mamu river in Anambra state, the Oji River is about 67.72km in length with a drainage basin area of about 927km^2.

The area is the humid tropical rainforest belt of Nigeria (Iloeje, 1979; Balogun, 2005), and has partially deforested northern parts which turned into derived Savanna grassland. It has a tropical savanna climate (Koppen: Aw). This area is characterized by relatively warm temperature days of 27^0C to 32^0C and moderately cool nights of 17^0C to 28^0C. It experiences two main distinct seasons, namely: the dry season and the rainy season. The underlying soils are of sedimentary origin, with sandstones and shales as the two dominant parent materials. The area has undulating relief with a high central zone lying above 370m mean sea level with some isolated peaks above 580m. The landforms are classified into cuesta, plains and lowland landscapes. The cuesta comprises the Nsukka - Okigwe cuesta, the Enugu and Awgu escarpments and the Udi - Nsukka plateau (Akamigbo, 1987). The geology of the study area can be broadly classified into shales, false-bedded sandstones and coal measures (Akamigbo, 1987). The Oji River Basin is underlain by three lithostratigraphic units, namely, Imo Shale, Nsukka Formation, and Ajalli Sandstone.

Method of Study

Extensive field studies and measurements were carried out on the Nyaba River channel. This was to help examine the influence of discharge, velocity, suspended sediment load, and bed load sediment on channel morphology. First, the channel lengths were gotten using fiber tape. The morphologic variables: the Mean

channel depths, widths, discharges, velocities, sediment yield measurements were carried out at 30 sampling points along the river channel (figure 1).

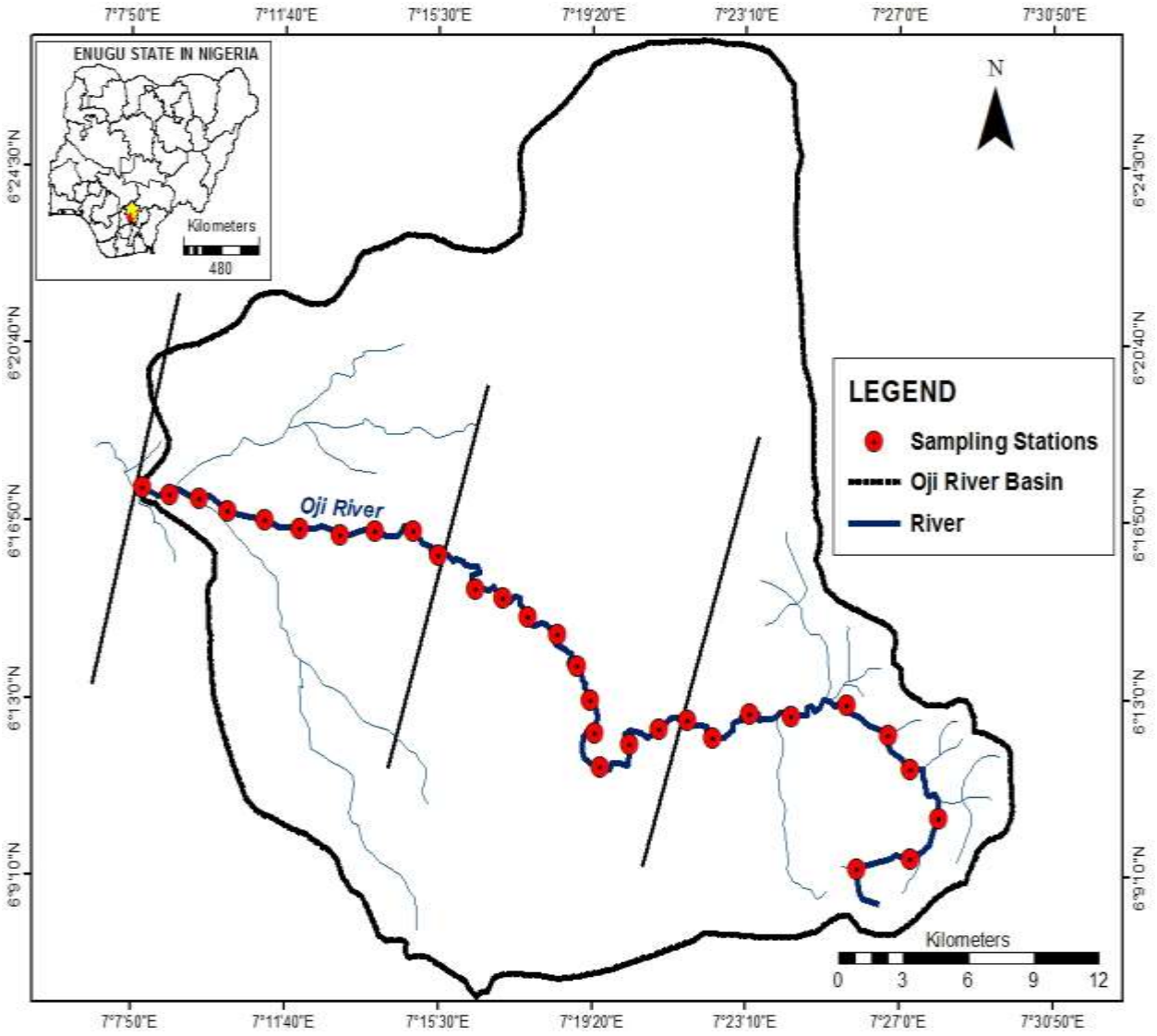

Figure 1: Oji River channel showing Sampling points

Velocity Determination

In measuring the flow velocity in the channel, different techniques of velocity measurement are used. In this present work the two point method was employed. This implied that velocity measurements were done both on top and beneath the stream surface exactly at 0.2m and 0.8m respectively. This was because the river flow depth is greater than 0.76m (USGS, 1980) as in Chukwu-Okeah (2012).

So velocity data were determined at 0.2 and 0.8m flow depth, d. The mean velocity was gotten by taking the average value of all the velocities determined at 0.2 and 0.8m of the flow depth. Hence the average velocity was:

$$V = \frac{(V_{0.2} + V_{0.8})}{2} \quad (1)$$

In this present work the velocities were gotten using a float along a known distance at three consecutive times taking the mean value.

Discharge determination

To determine channel discharge is to obtain the discharge per unit width (m^2/sec). This is to determine the product of mean velocity in the vertical per unit area. This method is the same whether the measurements are carried out under permanent or non-permanent flow conditions (Chukwu-Okeah, 2012). The total discharge of the channel was calculated from the measurement of velocity in the channel, noting that discharge per unit width q (m^2/sec), which is the product of the mean velocity in the vertical (m/sec) and the water depth (d) at the vertical at the moment of measurement.

Therefore discharge Q = VA (2)

Where V = mean velocity, A = cross sectional area

Bed load measurement

Bed load samples were taken with the aid of an improvised sediment trap. The sediment trap was made of a thick hollow pipe of a fixed length with a dead weight attached to aid in lowering it to the river bed. The instrument has an open receiving end that faces the direction of river flow to collect bed load sediment when lowered for about 10 minutes. The rear end has sieve material of minute pores can that only allow water to pass and not the sediments. It acts as a trap. The trap is withdrawn from the river bed after about 10 minutes of immersion for collecting sediments, and the trapped sediments weighed with an electronic device. Several formula have been put in place for the calculation of sediment transport, but here we used the formula put forward by Chang et al. (2000)

$$g_b = \frac{w_i}{(T,X\ h_s)}\ X\ b \qquad (3)$$

In which,

g_b = transport in kg/s

w_i = weight of bed load sample in kg.

T = sampling time in seconds.

h_s = width of sampler nozzle in meter

b = section width of the stream in meter

Suspended Sediment Load

To measure the suspended load at the sampling 30 points of each river channel, clean plastic bottles were used because we could not lay our hands on the initial proposed US DH-48 depth-integrating suspended-sediment sampler. This method is previously employed by Kithiia (2006), Kwamboka (2014), and Anya (2016), in their studying temporal changes of sediment dynamics in river sub-basins. Sediment sampling was done for the wet season only. This provides enough sediment to ascertain erosion and depositional processes for channels morphologic change. The sediment samples collected showed evidence of erosion from the catchment and the river channel. Suspended sediment load is used to estimate soil loss from river channel and catchment erosion. The collected suspended sediment samples were subsequently taken to the laboratory for analysis using appropriate methods and equipment.

Channel Morphology

The ultimate goal of the data collection process is basically to access the relationships between the various independent variables of discharge, velocity, bed load, and suspended sediment yield on the one hand and the channel morphology on the other hand. Within the context of the present study, channel morphology, which is the shape of the channel, refers to the cross-sectional area of the channel at various sampled points of the basin. Here, the average channel width and depths are measured and their products were taken and represented in square meters. This was done using Cuencia, as cited in (Chukwu-Okeah, 2012) formula for estimating cross-sectional area.

Area = width x depth …….. (4)

The cross-sectional areas of the thirty (30) sample points are determined. These were done by measuring the channel widths and channel depths at the sampling points. The cross-sectional area at each traverse was the product of the channel width and the mean channel depth.

Data Analysis

The data derived in this study are presented in tables and figures using means, percentages, charts, and graphical transformations for statistical analysis. The acquired data were after that processed and subjected to inferential analysis to give room for hypotheses testing.

Hypotheses Testing

Since a hypothesis is formulated for the study, which is;

$H_{O1:}$ There is no significant relationship between channel morphology and discharge, suspended sediment yield and bed load of the study basin.

This hypothesis is tested using a Correlation matrix and Multiple Regression analytical tools (bivariate and multivariate analytical techniques). The model equation of the step-wise multiple regression analysis is as follows:

$Y = a + b_1 X_1 + b_2X_2 + b_3X_3 + b_4X_4 + e$ (5)

Where:

Y = Channel Morphology

a, b_1 b_2 …… b_m are regression coefficients

e = error term

X_1 = velocity

X_2 = discharge

X_3 = suspended sediment yield

X_4 = bed load

RESULTS AND DISCUSSIONS

This section looked at the predictive capacity of the hydraulic parameters of velocity, discharge, suspended sediment yield, and bed load of channel morphology of Oji River using the SPSS multiple regression (R) statistical tools.

Below shows the Pearson correlation matrix of the independent variables; velocity, discharge, suspended sediment yield and bed load sediment and the dependent variable Channel morphology in Oji River (Table 1). The correlation between velocity and channel morphology reveals that a positive correlation exists between them, has correlation coefficient value of 0.344. The correlation is positive which implies that a positive correlation is between velocity and Channel morphology of Oji River.

A positive correlation exists between channel morphology and Bed load of Oji River, with correlation coefficient of 0.384 which is significant at 95% significance level.

The table showed that a negative correlation exists between Suspended sediment yield and Channel morphology in Oji River, with correlation coefficient value of -0.38 though not significant.

In conclusion this table also revealed a positive correlation existing between discharge and Channel morphology, with correlation coefficient of 0.976 which was not significant at 95% but at 99% significance level.

With the description, it was revealed that a positive correlation exists between morphology and velocity and bed load while an inverse relationship was observed between channel morphology and suspended sediment yield. With respect to discharge a direct relationship was observed with Channel Morphology which was 99% statistically significant.

Table 1: Correlation Matrix for Channel Morphology and Velocity, Discharge, Bed Load and Suspended Sediment Yield of Oji River.

		Channel morphology	Velocity	Bed load	Suspended sediment yield	Discharge
Channel morphology	Pearson Correlation	1	.344	.384*	-.038	.976**
	Sig. (2-tailed)		.063	.036	.844	.000
	N		30	30	30	30
Velocity	Pearson Correlation		1	-.047	-.471**	.472**
	Sig. (2-tailed)			.804	.009	.008
	N			30	30	30
Bed load	Pearson Correlation			1	.109	.411*
	Sig. (2-tailed)				.568	.024
	N				30	30
Suspended sediment yield	Pearson Correlation				1	-.088
	Sig. (2-tailed)					.643
	N					30
Discharge	Pearson Correlation					1
	Sig. (2-tailed)					
	N					

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 2 reveals that discharge and velocity entered the regression equation. Discharge solely provided accounted for 95.3% explanation for difference in channel form of Oji River while velocity accounted for 1.8%. Hence the two accounted for 97.1% explanation for variations in the morphology and are predictors of channel morphology in Oji River.

Table 2: Summary of multiple regression of channel morphology and hydraulic parameters of Oji River Channel

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics					Durbin-Watson
					R Square Change	F Change	df1	df2	Sig. F Change	
1	.976[a]	.953	.952	1.28782	.953	573.688	1	28	.000	
2	.985[b]	.971	.969	1.03243	.018	16.566	1	27	.000	2.021

a. Predictors: (Constant), Discharge

b. Predictors: (Constant), Discharge, Velocity

c. Dependent Variable: Channel morphology

The stepwise multiple regression in table 3 reveals that discharge and velocity explains the alterations in the channel form of Oji River. They accounted for 97.1% alteration in the channel form.

Table 3: Step wise multiple regression for Hydraulic parameters of Oji River Channel

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	1.416	.496		2.854	.008
	Discharge	.877	.037	.976	23.952	.000
2	(Constant)	10.786	2.336		4.617	.000
	Discharge	.941	.033	1.048	28.257	.000
	Velocity	-10.110	2.484	-.151	-4.070	.000

a. Dependent Variable: Channel Morphology

Thus, the hypothesized model developed by this study is of the form,

$Y = 4.415 + 0.995x_1 - 0.133x_2$ …… (6)

Where,

Y = Channel morphology

X_1 = Discharge

X_2 = Velocity

To ascertain the significance of this relationship ANOVA was used, as shown in table 4 below.

The ANOVA table shows that two variables significantly explained variation in Oji river channel morphology. They together provided approximately 97.1% explanation for change in the channel form of Oji river.

Since calculated value 454.587 > table 4.29 value of 3.35, it implies that discharge along with velocity affect the Oji river channel form. It implies that hydrological parameters (auto channel processes) determine the channel form.

Table 4. One way ANOVA for explanation of variation between hydraulic parameters and channel morphology of Oji river channel

Sources of Variation	Sum of Squares	df	Mean Square	F	Sig.
Regression	969.100	2	484.550	454.587	.000[c]
Residual	28.780	27	1.066		
Total	997.880	29			

Source: SPSS Computer programme.

*0.05 significance level

CONCLUSION AND RECOMMENDATION

The analysis revealed a positive correlation between discharge and channel morphology. The relationship was statistically significant at the 95% level. The multivariate technique employed in the SPSS computer programme of the step-wise multiple regression analysis showed that discharge was the most single predictor of the Oji River morphology as it is accountable for 95.3 % of the variation in the channel morphology of Oji River. From the analysis, the model developed assisted in the prediction of the channel morphology.

From the analysis, the model developed assisted in predicting the channel morphology with the use of velocity, discharge, bed load, and suspended sediment yield, which is of the form:

$Y = 10.786 + 1.048x_1 - 0.151x_2$ …….. (7)

Where,
Y = dependent variable (channel morphology)
X1 = discharge (independent variable)
X2 = velocity (independent variable)

The result of the study shows that discharge and velocity are the significant predictors of the Oji River channel morphologic change. It shows that the morphologic changes were resulting from autogenic processes. The implication of the high discharge and velocity rates can be felt on the channel boundaries of Oji River resulting in erosion hazards in the area. There is a very high tendency for high flows during the raining season, which can be destructive to the riparian structures.

We recommend that appropriate measures be introduced to control overland flow and encourage infiltration. Good farming practices could be introduced to this effect. Also, vegetation loss through deforestation ought to be managed as this leaves the soil bare. Construction companies within the riparian zones should embark on flood and erosion control measures.

Gabions, dykes and other flood protection mechanisms should be constructed in sections that are prone to erosion. Stream corridor assessments need to be done on a regular basis.

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