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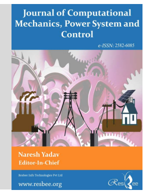

Predicting Channel Morphology of the Nyaba River from Hydraulic Variables

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Abstract: The study investigated the predictability of the hydraulic variables on the morphology of the Nyaba River channel in southeastern Nigeria. The study's objective was to analyze the relationship between channel morphology and hydraulic variables such as Discharge, Velocity, Suspended sediment yield, and Bed load sediment of the Nyaba River. Primary and secondary data sources are used in this study.The ANOVA and Regression analysis statistics are used for data analysis. The findings revealed a significant correlation between channel morphology and channel form processes. The correlation between Channel morphology, Discharge, Velocity, Suspended sediment, and Bed load sediment showed that discharge alone provided 97.8% explanations for variations in channel morphology of the Nyaba River while velocity provided 1.8% explanations for the variations.In conclusion, the study showed that the predicted variability in the geometry of the Nyaba River channel is the hydraulic variable.Hence the major predictors of channel changes are discharge and velocity. The author recommends employing appropriate conservation mechanisms to protect the river channel against erosion. The channel should be cleared of wood debris regularly as this may enhance over-flooding during the rainy season.

Keywords: Channel Morphology, Prediction, Hydraulic Variables, Nyaba River, Nigeria

Nomenclature

Abbreviation	Expansion
IIMI	International Irrigation Management Institute
USGS	United States Geological Survey
SPSS	Statistical Package for the Social Sciences

1. Introduction

The morphology of natural water ways varied through the resistance of the valley floor materials and the constant erosive potential of the river. The force that causes the water to flow (whether in a channel, rill, gully, or overland) in the down-slope component of gravity [7]. The channel form is dynamic, and changes spatiotemporally regarding controlling factors such as modifications in sediment transfer, stream bed, stream bank roughness, and hydraulic discharge [3][19].

The general relation between stream flow, sediment yield, and channel adjustment is evident but with diverse effects [9]. However, the degree and direction of changes in channel capacity or composition may differ with variables such as (a) Relative size of alterations in discharge. (b)Sediment yield supplied, and(c) Quality of supplied sediment [16]. The changes in the channel are adjusted in a variety of ways such as changes in Channel depth and width, Velocity, Channel cross-section shape, Roughness, Slope, Bed material composition, Channel gradient, Sediment size, Channel sinuosity, and Bed form composition [17].

According to the quantitative data of Nigeria, it is suggested that the changes in the channel involve a reduction in channel capacity rather than enlargement [11][20], and the changes in the magnitude are smaller than the temperate environments. However, a dramatic case of channel enlargement was documented along the Ekulu River a major tributary of the Nyaba River within the urban area of Enugu state (Capacity ratio = 1.91, Width ratio = 1.34, Depth ratio=1.65; [13]). Some other studies in Nigeria reported smaller urban river channels. The channel reductions in the Nigeria examples were accomplished principally in the depth dimension [11][20] and indicated aggradation of the stream bed in contrast to the degradation from Britain. This channel aggradation has been attributed to excessive sediment production and delivery in humid tropical environments, rapid deposition of suspended sediments, and low competence [11]. The processes of erosion and sediment transport result from an interconnected set of natural, human, and hydrologic factors within a river basin [15]. The natural

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factors responsible for erosion are topography, geology, and soils. The hydrological factors are climate and the amount and distribution of surface water runoff and groundwater discharge; while land use is the major human factor [22].

The impact of land use on discharge and the resultant land degradation is one of the most critical environmental problems of our time. Urbanization of a drainage basin could significantly affect its hydrology by increasing flood magnitudes and increasing lag times [5][1][30][20] and[24]. Urbanization of a drainage basin can lead to changes in the river channel size and form with time [17][10][26][24]. According to [18], urbanization has some severe impact on river basin response through variations in sediment yield, bank full discharge, and channel capacity.

This present study considers the hydraulic processes. It looked at the influence of the channel processes (hydraulic variables) on the morphology of Nyaba River and statistically determined the predictors of the channel morphology. So, 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 Nyaba River to identify the major factors controlling morphological change in the area. It intends to develop a channel morphology predictive model from hydraulic parameters to identify its role in sustainable flood disaster management.

The paper is organized as follows: Section 2 covers the literature review. Section 3 details the method of study, and 4 emphasizes hypothesis testing, Section 5 explains the results and discussion, Section 6 mentions the advantages and disadvantages of the proposed method and the conclusion is recapitulated in Section 7.

2. Literature Review

Determinants or predictors of channel morphology can be classified into external and internal factors. The external basin factors are Geologic, Climatic, and Human. These factors determine the internal dependent landscape variables of Discharge, Sediment, and Boundary conditions [19] [31]). Channel morphology results from integrated effects of the independent and dependent variables (Autogenic processes).The channel reacts to alterations in the variables by modifications in the dependent channel variables. Geomorphologists have always encountered the problem of identification of the predominant process accountable for the creation of a particular form.

The river dynamics at any location within the stream are influenced by the different processes that take place in the watershed upstream. Classic conceptual models showed channel form as a result of streamflow (discharge) and rate of sediment transport when the rate of transfer is the same as the supply of sediment for stable conditions [16][4] [32]. Some rivers' morphologies in the humid tropics were studied and predicted. They found that discharge and velocity are the primary determinants of the channel form in their study on channel form prediction of Chinda Creek, a tropical river creek. Discharge accounts for 59% of the variation in Chinda Creek's channel morphology [25]. In Port Harcourt, Nigeria's Ntawogba, a tropical creek, a noteworthy relationship has been found between discharge and channel size and morphology. In this instance, among some other variables, discharge served as the main determinant or predictor of channel shape [21]. According to[13],the basin's geology, an independent landscape variable, is a determining factor of channel morphology and size properties. Their research on the Rima basin showed that, in addition to criteria that determine discharge, basin shape, and size, geological characteristics of the channel evaluate the degree of caving and enlargement. [23] on the upper Ogunpa River's channel morphology prediction using the urbanization index, discharge, and sediment production. They discovered that discharge was a key factor in determining or predicting channel morphology and created a model for doing so.

2.1 Research Gap

Based on the Literature, we can understand river morphologies in the humid tropics, which suggests that there may be a lack of research in this specific geographical region. There is a need for further research on the role of these variables in shaping river morphology and the development of effective conservation mechanisms for river channels in the humid tropics, specifically in the Nyaba River system.

The study focuses on the predictability of hydraulic variables on the morphology of the Nyaba River channel, indicating a potential research gap in understanding the relationship between these variables and channel morphology in this specific river system. It also recommends employing appropriate conservation mechanisms to protect the river channel against erosion, indicating a potential research gap in exploring effective conservation strategies for river channels in similar environments.

3. Method of Study

The study was conducted in the Nyaba River Basin, southeastern Nigeria. Nyaba River is the trunk river in the basin with its source from Enugu- Awguescarpment (Udi Hills). Nyaba River flows through the southern section of Enugu, the State capital, and passes through various land use/land cover types. From its source to where it empties into the Aboine River in Ebonyi State, the Nyaba River is about 52.21 kilometers long with a drainage basin area of 921km^2[28]. Figure 1 portrays the view of the Nyaba River[29].

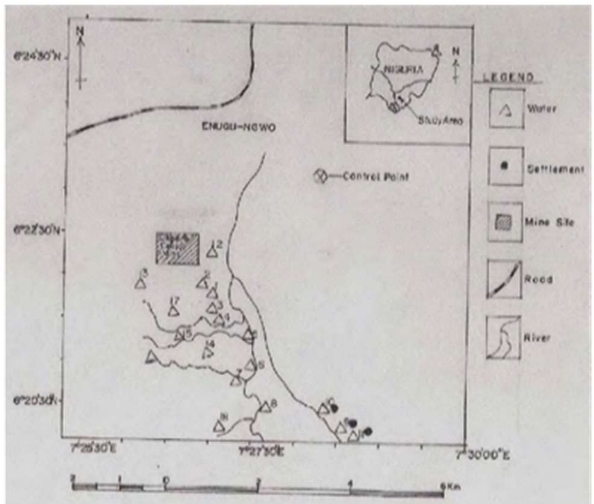

Fig 1.*Nyaba River [29]*

The study area is within latitudes 6^0 31′ 30″N and longitudes 7^0 44′ 0″ E [28]. The temperature of the study area ranges from 27^0C to 32^0C and high relative humidity of about 65% to 80% [28]. This study area lies within the humid tropical rainforest belt of Nigeria [12] [2].The soils in the area are of sedimentary origin. The landforms of the study area are cuesta, plains, and lowland landscapes. This study area is underlain by five geologic formations. Extensive field studies and measurements were carried out on the Nyaba River channel. This examines the influence of discharge, velocity, suspended sediment load, and bed load sediment on the channel morphology of the Nyaba River. Mean channel depths, widths, discharges, velocities, and sediment yield measurements were carried out at 30 sampling points along the river channel. The only challenge encountered was that we made use of improvised equipment during the suspended sediment load collection. This is because we cannot lay hands on the initial proposed US DH-48 depth-integrating suspended-sediment sampler. We got the expected results from our fieldwork and laboratory work.

3.1 Discharge Determination

The discharge per unit width (m2/sec) must be obtained to calculate channel discharge. The purpose of this is to calculate the mean velocity per unit area in the vertical direction. Whether the measurements are conducted in non-permanent or permanent flow circumstances, the methodology remains the same [8]. The velocity measured in the channel was used to compute the total discharge, keeping in mind that discharge per unit width q (m2/sec) is the product of the mean vertical velocity (m/sec) and the water depth (d) at the vertical at the time of measurement. Therefore

$$\text{Discharge } Q = VA \tag{1}$$

Where V =Mean velocity, and A= Cross-sectional area

3.2 Velocity Determination

Some velocity measurement techniques are identified to ascertain the flow velocity in a channel by the IIMI report no. T-7. The two-point approach is applied in this investigation. Here, velocity readings are obtained exactly at 0.2 and 0.8 meters below the water's surface at her than only on the surface. This occurred as a result of the river's flow depth exceeding 0.76 meters [8].

Consequently, measurements using a velocity meter were made at 0.2 and 0.8 meters below the flow depth. By averaging the velocities recorded at 0.2 and 0.8 meters below the flow depth, the mean velocity was calculated.

As a result, the reach's mean velocity was: $V = \frac{(V_{0.2} + V_{0.8})}{2}$ (2)

3.3 Bed Load Sediment 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 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 are weighed with an electronic device. Several formulas have been put in place for the calculation of sediment transport, but here we used the formula put forward by [6].

$$g_b = \frac{w_i}{(T_r X h_s)} Xb \tag{3}$$

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

3.4 Suspended Sediment Load

To measure the suspended load at the sampling 30 points along the 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 [14][15], in their study of 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 the channel's 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 channels and catchment erosion. The collected suspended sediment samples were subsequently taken to the laboratory for analysis using appropriate methods and equipment.

3.5 Channel Morphology

In essence, the main objective of the data collection method is to determine the correlations between the channel morphology and the many independent variables of discharge, velocity, bed load, and suspended sediment production. The form of the channel, or its cross-sectional area, is referred to as channel morphology in the context of this study as it relates to individual river sample locations. This is the measurement of average channel widths and depths, together with the extraction and representation of their products in square meters. The formula for estimating cross-sectional area, Cuencia [8], was used for this.

$$Area = width \ x \ depth \tag{4}$$

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.

3.6 Data Analysis

After statistical analysis, the data from this study are displayed in tables and figures employing means, percentages, charts, and graphical transformations. To allow for the testing of hypotheses, the collected data were processed and then made the topic of inferential analysis.

4. Hypotheses Testing

A systematic procedure for deciding whether the results of a research study support a particular method that applies to channel morphology. 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 sediment of the study river.

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:

$$Y = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + e \quad (5)$$

Where:

Y= Channel Morphology

a, $b_1 b_{2,\ldots,} b_m$ are regression coefficients.

e = Error term

X_1 = Velocity

X_z = Discharge

X_3 = suspended sediment yield

X_4 = bed load

5. Results and Discussions

Using SPSS multiple regression (R) statistical methods, this part investigated the predicting ability of the hydraulic parameters of discharge, velocity, suspended sediment yield, and bed load sediment of the Nyaba River's channel morphology.

The link between the independent variables of velocity, flow, bed load sediment, and suspended sediment yield and the dependent variable of channel shape is shown in the correlation matrix Table 1 below. The correlation between velocity and the channel morphology as revealed in the Table below shows that an inverse correlation exists between them, with a correlation coefficient of -0.84. However, reveals that in the Nyaba River, a negative correlation exists between velocity and channel morphology. In the correlation between channel morphology and bed load sediment of Nyaba River, it was revealed that a negative correlation exists between them with a correlation coefficient of -0.87. This relationship is inverse. However, This shows that in Nyaba River an inverse correlation exists between the Bed load sediment and Channel morphology. Table 1 shows a direct correlation between Suspended sediment yield and Channel morphology of the Nyaba River, with a correlation coefficient value of 0.14. The relationship, as observed is a positive one but not significant.

In conclusion, this table shows that a positive correlation exists between discharge and Channel morphology, with a correlation coefficient value of 0.989. The relationship as observed is a direct one though not significant at 95% but at a 99% significance level.

Table 1. *Correlation Matrix for Channel Morphology and the Process Variables of the Nyaba River*

		Channel morphology	Velocity	Bed load	Suspended sediment yield	Discharge
Channel morphology	Pearson Correlation	1	-.084	-.087	.014	.989**
	Sig. (2-tailed)		.661	.648	.940	.000
	N		30	30	30	30
Velocity	Pearson Correlation		1	-.054	-.152	.050
	Sig. (2-tailed)			.776	.422	.794
	N			30	30	30
Bed load	Pearson Correlation			1	.213	-.086
	Sig. (2-tailed)				.259	.652
	N				30	30
Suspended sediment yield	Pearson Correlation				1	-.015
	Sig. (2-tailed)					.939
	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).

From the description, it is observed that an inverse relationship exists between the channel morphology velocity and bed load. In contrast, a direct relationship is noted between the channel morphology and suspended sediment yield though not significant. Discharge has a direct correlation with the channel morphology, and is 99% statistically significant.

Table 2 below reveals that factors like discharge and velocity are featured in the regression equation. Discharge is solely responsible for the 97.8% difference in morphology of the Nyaba River channel, while velocity accounted for 1.8%. Thus the two variables provided a 99.6% explanation of the differences in the morphology and therefore are predictors in the Nyaba River.

Table 2. *Summary of multiple regression of channel morphology and hydraulic parameters of the Nyaba River Channel*

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics R Square Change	F Change	df1	df2	Sig. F Change	Durbin-Watson
1	.989a	.978	.977	.38902	.978	1234.250	1	28	.000	
2	.998b	.996	.995	.17823	.018	106.395	1	27	.000	1.698

a. Predictors: (Constant), discharge
b. Predictors: (Constant), discharge, velocity
c. Dependent Variable: channel morphology

Source: SPSS Analysis result

The stepwise multiple regression as shown in Table 3 below revealed that discharge and velocity accounted for the change in the channel morphology. Discharge is solely responsible for the 97.8% difference in morphology of the Nyaba River channel, while velocity accounted for 1.8%. Thus the two provided a 99.6% explanation of the differences in the morphology and therefore are predictors in the Nyaba River.

Table 3: *Step-wise multiple regression for Hydraulic parameters of Nyaba River Channel*

Model		Un standardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	-.006	.141		-.042	.967
	Discharge	1.038	.030	.989	35.132	.000
2	(Constant)	4.415	.433		10.186	.000
	Discharge	1.045	.014	.995	77.100	.000
	Velocity	-4.594	.445	-.133	-10.315	.000

a. Dependent Variable: channel morphology

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

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

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 shows that two parameters significantly explained variation in the Nyaba River channel morphology and are accountable for 99.6% variation in the morphology of the Nyaba River channel. As the value calculated2993.240 > 3.35, the table value implies process variables discharge and velocity (autogenic channel processes) determine the morphology of the Nyaba River channel.

Table 4: *One-way ANOVA for the explanation of the difference in hydraulic parameters and channel morphology of theNyaba River channel*

Source of Variation	Sum of Squares	df	Mean Square	F	Sig
Regression	190.164	2	95.082	2993.240	.000c
Residual	.858	27	.032		
Total	191.022	29			

Source: SPSS Computer program
*0.05 significance level.

The results of the investigation showed that channel shape and discharge were positively correlated. At the 95% confidence level, the connection was statistically significant. Because discharge accounts for

97.18% of the variation in the channel morphology of the Nyaba River, the multivariate technique used in the SPSS computer program of the step-wise multiple regression analysis demonstrated that discharge was the most significant single predictor of the Nyaba River morphology. From the analysis, the model developed assisted in the prediction of the channel morphology with the use of velocity, discharge, bed load, and suspended sediment yield, which is of the form:

$$Y = 4.415 + 0.995X_1 - 0.133X_2 \quad (7)$$

Where,

Y= dependent variable (channel morphology)

X_1= discharge (independent variable)

X_2= velocity (independent variable)

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

6. Advantages and Disadvantages

Advantages

- The study provides insights into the predictability of hydraulic variables on the morphology of the Nyaba River channel in southeastern Nigeria.
- The paper contributes to the understanding of river morphologies in the humid tropics and provides a systematic procedure for analyzing the relationship between channel morphology and hydraulic variables.

Disadvantages

- The findings may not apply to other rivers or regions.
- Other factors that may influence channel morphology, such as vegetation or human activities were not considered.

7. Conclusion and Recommendation

The sentence should be: The study found a significant relationship between the channel morphology and the hydraulic variables. Discharge alone accounted for 97.8% while Velocity accounted for 1.8%, and both provided a 99.6% explanation soft the difference in the channel morphology. Overall, the results indicate that discharge and velocity are significant predictors of the Nyaba River channel morphologic change, with discharge being the most influential factor.

There may be a need for future studies in this area as serious developmental projects such as intensive farming, industrial developments road constructions, etc are going on. Also, the effects of livestock farming cannot be neglected. Cattle movement along the river banks is causing the inordinate widening of the channels due incidence of induced land slumping, and increased surface runoffs. This will bring about ecological changes within the river corridors which will subsequently alter the river channel geometry. This will necessitate further studies in the area.

We recommend that appropriate measures be introduced to control overland flow and encourage infiltration. Employing appropriate conservation mechanisms to protect the river channel against erosion is highly advocated. The channels should be cleared of wood debris regularly as this may enhance over-flooding during the rainy season. 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 regularly.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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