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FLUVIAL PROCESSES AND CHANNEL MORPHOMETRY OF THE UPPER ORASHI BASIN IN SOUTHEASTERN NIGERIA

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ABSTRACT

This study is an attempt to document the hydraulic characteristics of the Orashi channel and to analyze its similarity or otherwise to other channels. Results show that the Orashi River has a general increase in width, depth and discharge downstream while velocity decreased downstream and that the exponents for the hydraulic geometry of the Orashi are; 1.08, 0.52, and -0.56 respectively for exponents b, f and m. These results are quite different from theoretically derived estimates. The relationship between the channel processes operating in the Orashi catchment and its morphology differs rather markedly from earlier studies and generalizations. While it attains some measure of channel equilibrium between morphology and hydrology, the Orashi channel is not well adjusted to the 'normal' flow of the hydrologic regimen. This may be explained by the presence of the Oguta Lake which acts as a local base level and the flow of the Orashi into the alluvial plains of the River Niger which affects considerably the morphologic and hydrologic character of the Orashi. Also, bed-load analysis of Orashi channel sediments indicated that 79% of material transported by the river is finer than the 300 micron and this highly cohesive nature of the Orashi channel perimeter sediments contributes significantly in influencing the (F) ratio of the Orashi channel.

KeyWords: Orashi, Drainage basins, watershed morphology, morphometric analysis, Nigeria

INTRODUCTION

The Orashi basin is generally ungauged and the recent calls for dredging activities and the establishment of an inland port at its catchment mouth at Oguta will likely make the Orashi River a 'disturbed' catchment. A river channel affected by changes that compromise the stream's ability to be self-maintaining is described as "disturbed" (Dudley, 2004). It is therefore expedient to study the channel process and basin morphology which is the hydraulic geometry of the Orashi river system.

Hydraulic geometry relations are of great practical value in prediction of channel deformation; layout of river training works; design of stable canals and intakes, river flow control works, irrigation schemes, and river improvement works; and so on.

Richards (1976) has reasoned that hydraulic geometry relations through their exponents can be employed to discriminate between different types of river sections. These relations can be used in planning for resource and impact assessment (Allen et al., 1994).

According to Dudley (2004), the dimensions of a river channel are a result of the ability of the water to erode the land surface opposed by the ability of land surface to resist that erosion. A river's ability to erode sediment is a function of the magnitude and frequency of stream-flow and suspended-sediment load in the system. Farming and forestry practices, residential and urban development can affect the amount, location, and timing of water movement through a watershed. Physical alteration of a watershed can introduce hydraulic instability in the system and cause the river to adjust its ability to transport water and sediment at the point of the activity; these changes can in turn, propagate upstream and (or) downstream. Such changes can include increased deposition (aggradation), increased erosion (degradation), bank slumping, over-widening, and the abandonment of existing channels for new ones (Dunne and Leopold, 1978; Rosgen, 1996).
Hydraulic geometry relationships, also known as regional curves relate stream channel dimensions to watershed drainage area, while established regional curves are important to channel assessment and stream restoration efforts as they can confirm identification of bank-full stage and channel dimension in un-gauged watersheds and help estimate the appropriate bank-full dimension and discharge for natural channel designs (Glickauf, et al., 2007).

This study is an attempt to document the hydraulic characteristics of the Orashi system and to analyze the Orashi systems similarity or otherwise to other channels.

Previous Works on Hydraulic Geometry:
Wohl and Wilcox (2005) stated that downstream hydraulic geometry, as developed by Leopold and Maddock (1953), proposed that downstream changes in channel geometry reflect primarily the influence of increasing discharge. This influence is expressed via consistent correlations between bankfull discharge and channel top width, flow depth, and mean velocity. This relationship can be expressed as:

$Q = w.\ d.\ v$ …………………………….. [1]

Where Q is bankfull discharge (m^3/s), w is channel top width (m), d is flow depth (m) and v is mean velocity. Any variation in discharge in the downstream direction will be accommodated by changes in these three variables. The downstream change in each variable can be estimated from discharge so that the following set of equations describes hydraulic geometry:

$w = aQ^b$ ……………………………… [2]

$d = cQ^f$ …………………………………[3]

$v = kQ^m$ ……………………………… [4]

The variables a, c, and k are coefficients or intercepts and b, f, and m exponents or slopes; b+m+f = 1 and ack =1.

A primary assumption of downstream hydraulic geometry is that these channel characteristics respond to changing discharge at a timescale of 1–2 year recurrence interval commonly postulated for bankfull flow and rivers have strong

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correlations between downstream increases in discharge and channel geometry (Wohl and Wilcox, 2005).

While, Leopold and Maddock (1953) used mean annual discharge to define their key results and arrived at exponent values for the downstream relations as 0.50, 0.40, and 0.10, for b, f and m, respectively, these values have been shown to be highly variable in other studies depending on regional climate and physiography (Eaton, 2010).

A common challenge faced by geomorphologists in hydraulic geometry investigations is the identification of the dominant process responsible for evolution of a particular form. When choosing between different, often equally plausible, process-based explanations, it is necessary either to reconstruct processes at the time of morphological change, or to observe processes as they happen, and on this basis, controversies over, for instance, which process or event is dominant is usually resolved (Lane and Richards, 1997). River form and fluvial process therefore evolve simultaneously and operate through mutual adjustments toward self-stabilization. The resulting physical appearance and character of the river is a product of adjustment of its boundaries to the current streamflow and sediment regime (Rosgen, 1994).

Stream pattern morphology is directly influenced by eight major variables including channel width, depth, velocity, discharge, channel slope, roughness of channel materials, sediment load, and sediment size (Leopold et al., 1964). A change in any one of these variables sets up a series of channel adjustments which lead to a change in the others, resulting in channel pattern alteration (Rosgen, 1994).

It should be noted that original works in hydraulic geometry were developed primarily using data from the western U.S. although considered to be universal in nature (Leopold and Maddock, 1953). According to Brockman (2010), studies since have shown that these postulates are only useful when they are used on streams that share similar physiographic characteristics such as hydrology, soils and extent of development (Rosgen, 1996; Keaton et al., 2005).

Stall and Fok (1968) and Stall and Yang (1970) also found that physiographic characteristics of a watershed influenced the coefficients of the power functions (Singh, 2003) and land use changes have also been known to influence stream morphology, causing a corresponding increase in channel width as discharge increased while larger critical stresses resulted in narrower streams (Lane and Foster, 1980; Singh, 2003).

We therefore set out in this study to establish the level of development of the Orashi hydraulic geometry and how it compares with previous studies. A well developed downstream hydraulic geometry is defined (Wohl and Wilcox, 2005) as where variation in discharge explains at least half of the variation in other response variables. We also explored correlations between response variables and potential control variables at the reach scale. Response variables including bankfull width, bankfull depth, stream power and grain size D50; D84: Potential control variables included bankfull discharge, denudation levels and drainage area (Wohl and Wilcox, 2004).

MATERIALS AND METHODS

Study Area

The Orashi (Ulasi) has its source from the Orlu-Dikenafai axis of the Awka-Orlu uplands in Nigeria and flows through Ihitte-Owerri [in Imo State] into the Okija areas of Anambra State. Flowing southwest, it links the Niger River valley system around Oguta (Fig.1). The catchment is characterized by the sediments of the Miocene-Oligocene Lignite Formation, the Coastal Plain Sands and the Recent sediment's of the Niger delta. The regional boundary of the study area is within latitudes 04° 45' and 06° 00' North and longitude 06° 40', and 06° 70' East, covering an area of over 1,200km^2.

Structurally, the area is characterized by a seaward regional dipping and a general absence of surface and sub-surface structures over the Coastal Plain Sands. Seen as a landform complex, the study area exhibits typical elevations of up to 350m in the upper quadrants but relief is as low as 25m in the southernmost tip at the Orashi-Oguta Lake confluence at Oguta.

The climate is Koppen‟s classification humid tropical type with the Am Af types, marked by a distinct wet and dry season.

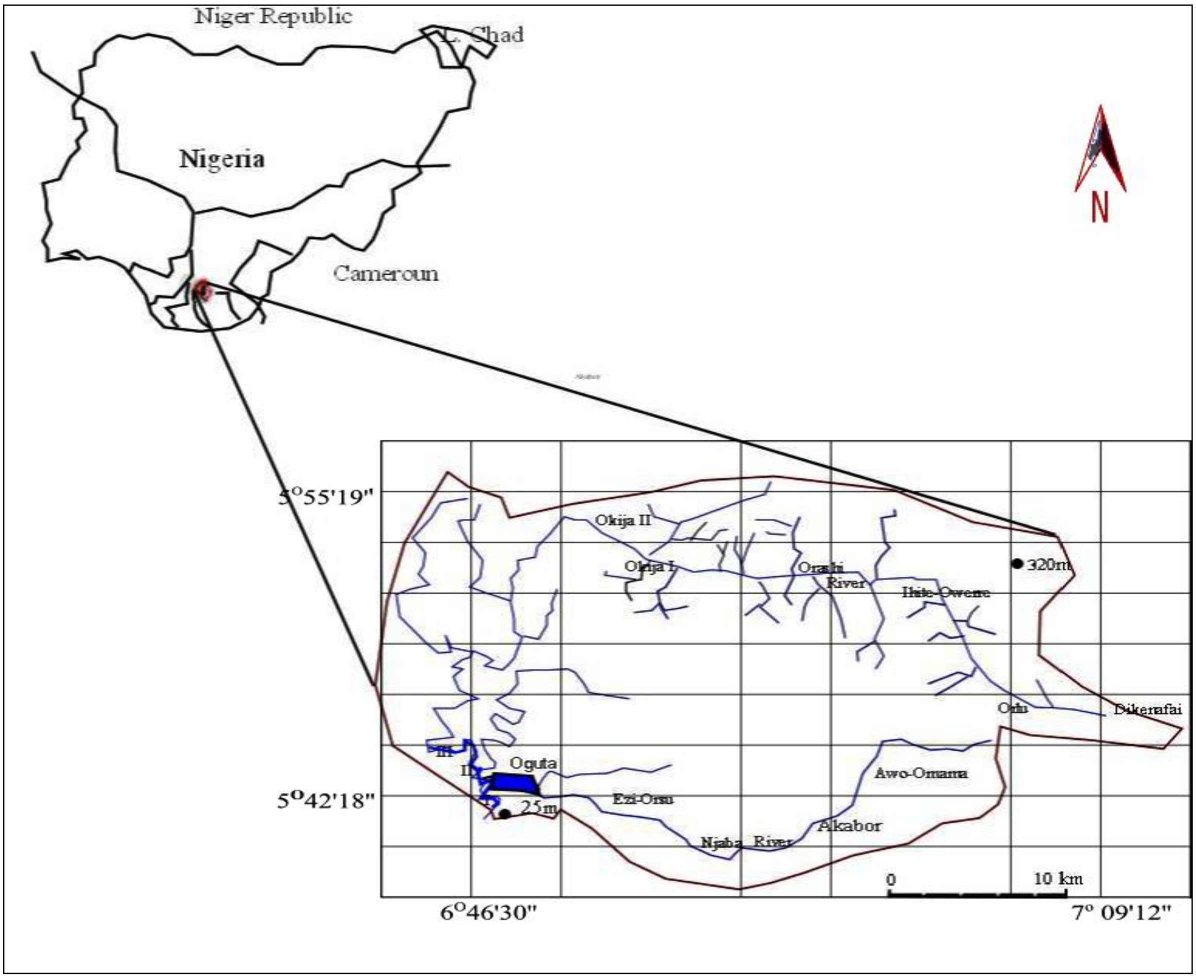

Fig 1. Study area in Nigeria

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The study area has three main soil types including the deep porous red soils of the coastal plains commonly called "acid sands', the deep porous brown soils derived from sandy deposits, and the pale brown loamy alluvial deposits derived from recently deposited materials.

The area falls within The Cross-Niger transition forests; the tropical moist broadleaf forest ecoregion of southeastern Nigeria, located between the Niger River to the west and the Cross River to the east. It was once mainly a tropical rain forest region but today supports one of the most densely-populated areas of Africa. As such the forest has been adversely affected and currently most of the vegetation in the northern parts of the study area is more of guinea savannah than rainforest (Werre, 2013).

Discharge

Fluvial processes considered in this study include river discharge, river bedload and solute load, and total sediment loads comprising suspended load and dissolved solids. Discharge (Q) which is the product of mean depth (d), width (w) and mean velocity (v), may be estimated from morphology measurements of a channel. Equation (1) represents the relationship between these variables. The dynamics of this relationship can be seen in the empirically derived equations (equations 2 - 4).

Stream discharge (Q) was estimated from morphology measurement of width (m), mean depth (m) and v = mean velocity (ms-1) using equation (1).

Stream velocity was measured using floats and calculated using an integrated survey of readings both at the surface and a point just above the riverbed. A minimum of four sample readings was taken at each sample point in order to compute the mean velocity for that cross-section. Appropriate correction factors as suggested by Morisawa (1976) and, Smith and Stopp (1979) were thereafter applied.

River width measurements taken from the bankfull stage (study was carried out in September when the river was at peak flow) were also taken.

Cross-sectional measurement of depths at each sample site involved a repeated sampling of water depth in at least four places across a channel section. From this, mean depths for such sections were computed. The product of the channel width and mean depth gives the channel cross-sectional area. If the river velocity (V) is multiplied by the cross- sectional area (A) of the active part of the river channel, the discharge (Q) is obtained. For each of the ten sample sites studied.

Sediment/Solute Analysis

River water samples were taken with simple dip bottles but in a depth-integrated sampling pattern (Goudie, 1981) and were analyzed for pH, conductivity, suspended solids and dissolved solids. Specific conductance or conductivity and pH were analyzed by a portable Benchman conductivity meter and total dissolved solids by evaporation to dryness in an oven (Goudie, 1981).

Channel perimeter sediments (including bed-load and riverbank sediments) were collected and analyzed for grain size distribution and results subjected to further calculations and statistical analysis. Bed-load sediment samples were taken with the aid of a metal scoop while river bank

sediments were sampled to a depth 0.8m using a one-meter long metal corer.
The sediment samples were oven dried for 24 hours thereafter weighed and sieved with an electro-mechanical shaker. Percentage retained weight results were plotted on the inclusive graphic measures of Folk and Ward (1957) in phi units.

Sediments were further analyzed for their mean, median, sorting, skewness, kurtosis and M (percent silt and clay) values. The M values for the catchment have been presented in Table 2 while the inclusive graphic measure of the bed load and river bank sediment are presented in Table 3.

RESULTS

Channel Parameters:

The different channel parameters for the catchment (mean depth, channel width, river velocities and discharge) are presented in Table 1. The interrelationships between these parameters are discussed below.

The results (as presented in Table 1) show that the Orashi River has a general increase in width, depth and discharge downstream while velocity decreased downstream.

Results from this study (Table 2) also revealed that the exponents for the hydraulic geometry of the Orashi are; 1.08, 0.52, and -0.56 respectively for exponents b, f and m. These results are quite different from Leopold and Maddock's (1953) exponent values for the downstream relations which are 0.50, 0.40, and 0.10, for b, f and m respectively.

Width/Depth/Discharge Relations:

Also in this study, the downstream relations for width and depth (w = Qb and v = Qf) are derived as W ∝ Q0.55 and D ∝Q0.36. Therefore, the relation for the width/depth ratio was as:

F ∝ Q0.19..... .. .. [5]

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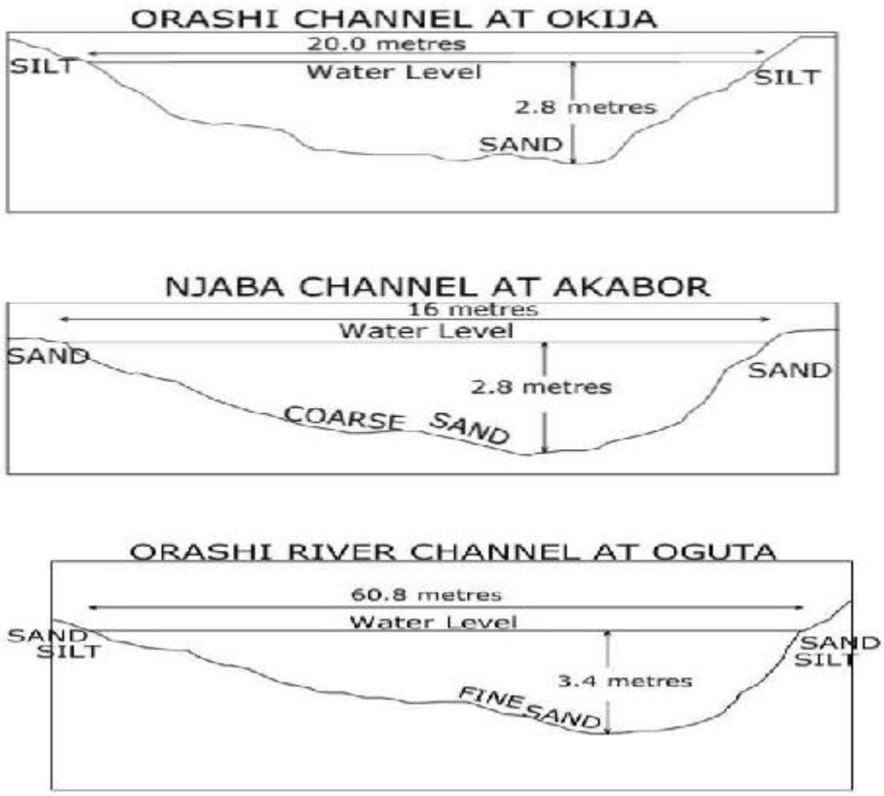
Table 1: Orashi River-channel Parameters

Location	Width	Mean Depth	Velocity m^{s}-1	Discharge (Cumecs)	Width/Depth Ratio
Okija arm					
Orlu	4.0	1.09	0.79	6.5	3.67
Ihitte-Owerri	10.0	1.45	0.68	9.85	6.9
Okija 1	20.0	2.45	0.62	30.4	8.16
Okija 11	29.5	2.69	0.57	35.6	10.96
Oguta 11	45.7	2.95	0.24	43.0	15.49
Oguta 111	42.6	2.75	0.32	38.2	15.49
Njaba arm					
Awo Omamma	20.9	2.09	0.44	24.2	10.0
Akabor	16.0	2.1	0.74	24.86	7.62
Izombe	21.4	2.39	0.58	28.8	8.95
Joined arm					
Oguta 1	60.8	3.1	0.24	45.0	19.6

Table 2: Exponents and Constants of Hydraulic Geometry

Orashi River	b	f	m	a	c	k	T otals b+f+m. axcxk	
	1.08	0.52	-0.56	0.68	0.42	2.45	1.04	0.70



Figs 2A, B and C: Orashi channel shape at Okija, Akabor and Oguta.

Also on the basis of the Lacey (1946) equations for width and depth relations as hinged on the median bed-sand size, the following width/depth ratio which includes the median grain size was derived:

$F = 6.36\ (Q.\ d_{50})^{1/6}$..... .. ..[6].

Equations (5 and 6) represent relations which suggest significant empirical relationships between width/depth ratio (F) and channel discharge (Q). Equation 5 represents the theoretically computed relation for the (F) ratio. The width/depth-discharge relation for the Orashi is therefore:

$F = 1.23\ Q^{0.33}$ . .. . [7]

Channel hydraulic geometry relations in the study area also showed similar results. The Orashi was observed to exhibit the following power function relations:

$w = 0.68\ Q^{1.08}$..... .. ..[8]

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$d = 0.42 Q^{0.52}$..... .. .. .. [9]

$v = 2.45 Q^{-0.56}$..... .. .. . [10]

The relationship of each of these factors to discharge is a straight line (Fig. 3). The empirical equation for width of water surface (W) with discharge (Q) (equation 8) indicates a rapid adjustment in width with increasing discharge. Depth also showed a similar adjustment in the downstream direction.

A relationship statistic calculated for the basin gave 'r' value of 0.89 with a coefficient of determination (r^2) as 79.2% and this value was found significantly related when tested with student's 't' test at the 0.01 confidence level. The high values of the coefficients of determination also indicate that much of the downstream variation in the (F) ratio can be accounted for by the changes in discharge.

Schumm (1960; 1977) tried to explain the relationship between channel shape, percentage silt and clay in channel perimeters (M) to be proportional to resistance to bank erosion. Using least squared calculations, we conclude that (M) does not exert any strong influence on channel morphologic changes (F) in the downstream direction. The following results were derived (see Table 3):

$F = 13.87 M^{-1.45}$ ($r = 0.34$; $r^2 = 11\%$).

Sediments and Solute Dynamics:

Table 3: Values of M (Percent Silt + Clay) in the Orashi River.

Location	M
Orlu	2.12
Ihitte-Owerri	2.74
Okija 1	1.8
Okija 11	2.04
Oguta 111	0.85
Oguta 11	0.76
Awo Omamma	3.92
Akabor	2.4
Izombe	4.5
Oguta 1	0.84

The student's 't' statistic was used to test the difference in the mean value of M in the catchment. This was in order to verify whether the noted differences in channel M values, was actually significant. With t calculated (0.23) being less than table t (2.552) at 18 degrees of freedom, the null was accepted suggesting that a relationship exist between the form of stream channels, the processes of water discharge and sediment characteristics in the catchment.

Water samples were also analyzed for the concentrations and transport of dissolved loads or solutes, since this is indicative of degree of chemical erosion in the

catchments. Results of conductivity and Total Dissolved Solids (TDS) in each of the sampling sites are given in Table 4. TDS [mg/L] was calculated using the method of Gregory and Walling (1973):
TDS = A.K... .. .. [11]

Where, K is conductivity in micro ohms, A = 0.65 (Conversion factor suggested by Walling and Webb (1978) and Lam (1978) based on dissolved solids characteristics of humid tropical rivers). The conductivity values of the Orashi River in sampled locations returned very minimal conductance ranging between 9.0 and 20.0 micro ohms, indicating relatively limited chemical activity or pollution. Solute concentrations are usually assumed to be uniformly distributed across a channel. The product of sample concentration and discharge provides the value of dissolved load discharge in (kg/sec) of the river as given by (Gregory and Walling, 1973; 169):

QS = QCs/1000. .. .. [12]

Table 4: Conductivity of Water Samples (in umhos)

Location	Cond. (uS/cm)	Computed TDS
Oguta 1	15.7	10.2
Oguta 11	15.0	9.75
Oguta 111	14.6	9.49
Okija 1	12.0	7.8
Okija 11	13.6	8.38
Orlu	12.6	8.84
Ihitte Owerri	12.9	6.17
Akabor	9.5	7.25
Izombe	11.2	5.98
Awo Omamma	9.2	6.17

Where QS is sediments discharge in kg/sec, Q is stream discharge in m^3/s, and Cs is sediment concentration in mg/1.

Results (Table 5) obtained are the concentrations and the sediment discharge rates computed using equation 12.

River bank sediments were observed to have rippled sedimentary structures a major feature of finer grained river deposition. Sediments were further subjected to grain size analysis. The M values for the catchments are presented in Table 3 while mean values for inclusive graphic measure of the bed load and river bank sediment are presented in Table 6.

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Table 5: Computed values of Sediment Discharge Rates

Location		Concentrations of Dissolved and Suspended Solids	Sediment Discharge rates
1.	Orashi at Orlu	0.2 gram/litre	0.0013 kg/sec
2.	Orashi at Ihite Owerri	0.6 gram/litre	0.0059 kg/sec
3.	Orashi at Okija	0.68 gram/litre	0.02 kg/sec
4.	Njaba at Awo Omamma	0.80 gram/litre	0.019 kg/sec
5.	Njaba at Izombe	0.85 gram/litre	0.245 kg/sec
6.	Orashi at Oguta	0.75 gram/litre	0.034 kg/sec

Table 6: Inclusive Graphic Measures in Phi (ø) Units.

	Mean	Median	Sorting	Skewness	Kurtosis
Orashi					
I. Bedload	1.08	1.13	0.67	-0.16	1.02
ii R. B. S.	2.12	2.13	1.29	-0.5	1.32

The mean and median particle size distribution of Orashi bed-load indicates that the river has a predominance of medium sand particles. Both values for mean and median are 1.08 and 1.13 respectively. The river bank sediment (R.B.S) values (2.12 and 2.13) however show that the streams's sub aerial perimeter is composed primarily of fine sand. On a comparative note therefore, the sorting values of Orashi (Table 6) indicate that the river has moderately sorted bedload, and poorly sorted river bank sediments. These results indicate the bimodal nature of these sediments. Indeed laboratory analysis revealed that these sediments exhibit modal values of both medium sand, fine sand and silt. The bedload sediments by contrast are primarily unimodal comprising fine sands only.

Application of the 't' test, on the sorting values, did not reveal any significant differences indicating that all the sediments bounding the channel perimeters may have a common origin.

Denudation Rates:

Mean annual denudation rates are usually estimated by the flow duration – sediment discharge method (Douglas, 1968; Anderson, 1972). Denudation rate in this study was determined following the method

outlined in Gregory and Walling (1973; 173):

Denudation in m3/km2/yr = total load (tones)/ area (km) 2 x specific gravity …….. [13]

Total sediment yield was computed from the suspended and dissolved values (Table 5) and was based on the methods of Cryer and Trudgill (1984). The denudation rate obtained for the basin based on bankfull discharge and mean concentrations of solute and suspended loads was 1.25 $m^3/km^2/yr$. Mechanical erosion is dominant in the

Orashi catchment at large, fostering a very turbid and murky discharge. Light vegetal cover and fine drainage have been found to enhance mechanical erosion in similar tropical catchments (Lam, 1978).

DISCUSSIONS

The above results show that the Orashi River has a general increase in width, depth and discharge downstream. Velocity however decreases downstream contrary to the views expressed by Smith and Stopp (1979) that "measurements of rivers in humid climates show that in general velocity is either fairly constant or increases downstream". A paradox thus emerges in the Orashi River system, because while the morphologic parameters of width and depth increase downstream, velocity which expectedly should be either constant or increase albeit slightly in a downstream direction, is observed to be decreasing downstream.

We however offer a somewhat different explanation for this anomaly in following sections. In fluvial geomorphology, significant relations have been shown to exist between discharge and many of the morphologic variables of streams (Leopold, Wolman and Miller, 1964; Edgar 1976).
Results from our study however (Table 2) show a great departure from the above derivations as values for exponents b, f and m give 1.08, 0.52, and -0.56 respectively, thereby resulting in a peculiar width-depth relationship as shown in equations 5 and 6. Klein (1981) states that, low b values normally occur for small basins (in lower flows) and for very big basins (in very high flows). Thus, the b = 0.5 value, being a good average, tends to smooth out deviations from the average. The value of b ranged from 0.2 to 0.89 in his study and it was argued that the simple power function for hydraulic geometry was valid for small basins and that did not hold over a wide range of discharges. The Orashi River therefore clearly defers from most other basins and could conversely be in the category of a small basin with an arrested high flow. The hydraulic power of the Orashi may be moderated by the presence of the Oguta Lake which acts as a local base level for the Njaba arm of the catchment.

Also of note is that the continuity principle requires the exponents of power functions to add up to 1.0. For the Orashi, exponents (b) channel width, (f) channel mean depth, and (m) channel mean velocity, sum up to 1.04. The coefficients a, c, k when multiplied yields a value of 0.70 indicating that the Orashi channel morphology is not well adjusted to flow variations. This is especially true around the designated catchment mouth at Oguta. It also confirms (Pickup and Rieger, 1979) that channel size and shape are not unique to a dominant discharge but tend to fluctuate about a mean condition as channel geometry is mostly affected by the history of recent flood events.

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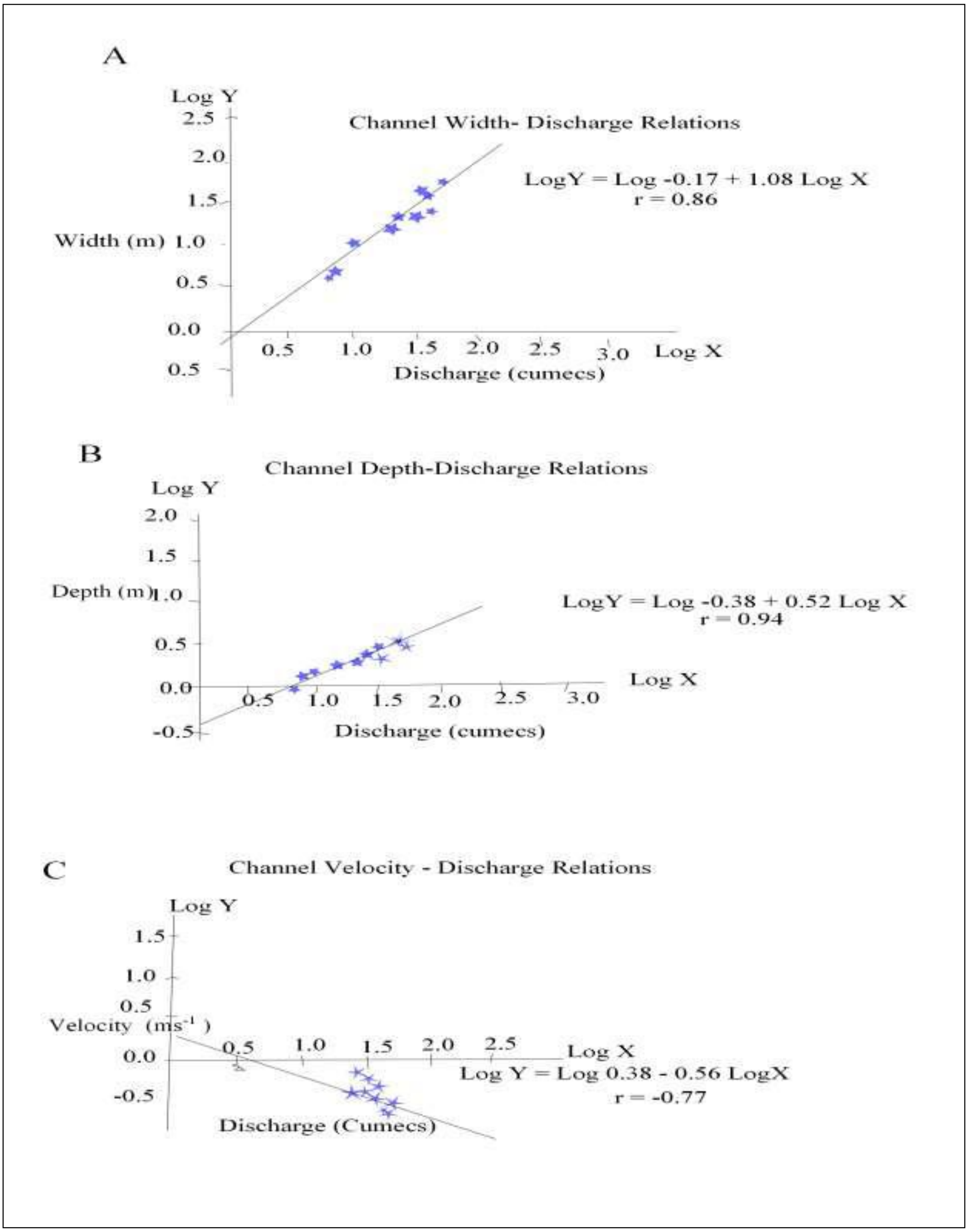

Fig. 3 A-Channel width-discharge Relations, 3B-Channel depth-discharge Relations, 3C Channel velocity-discharge Relations.

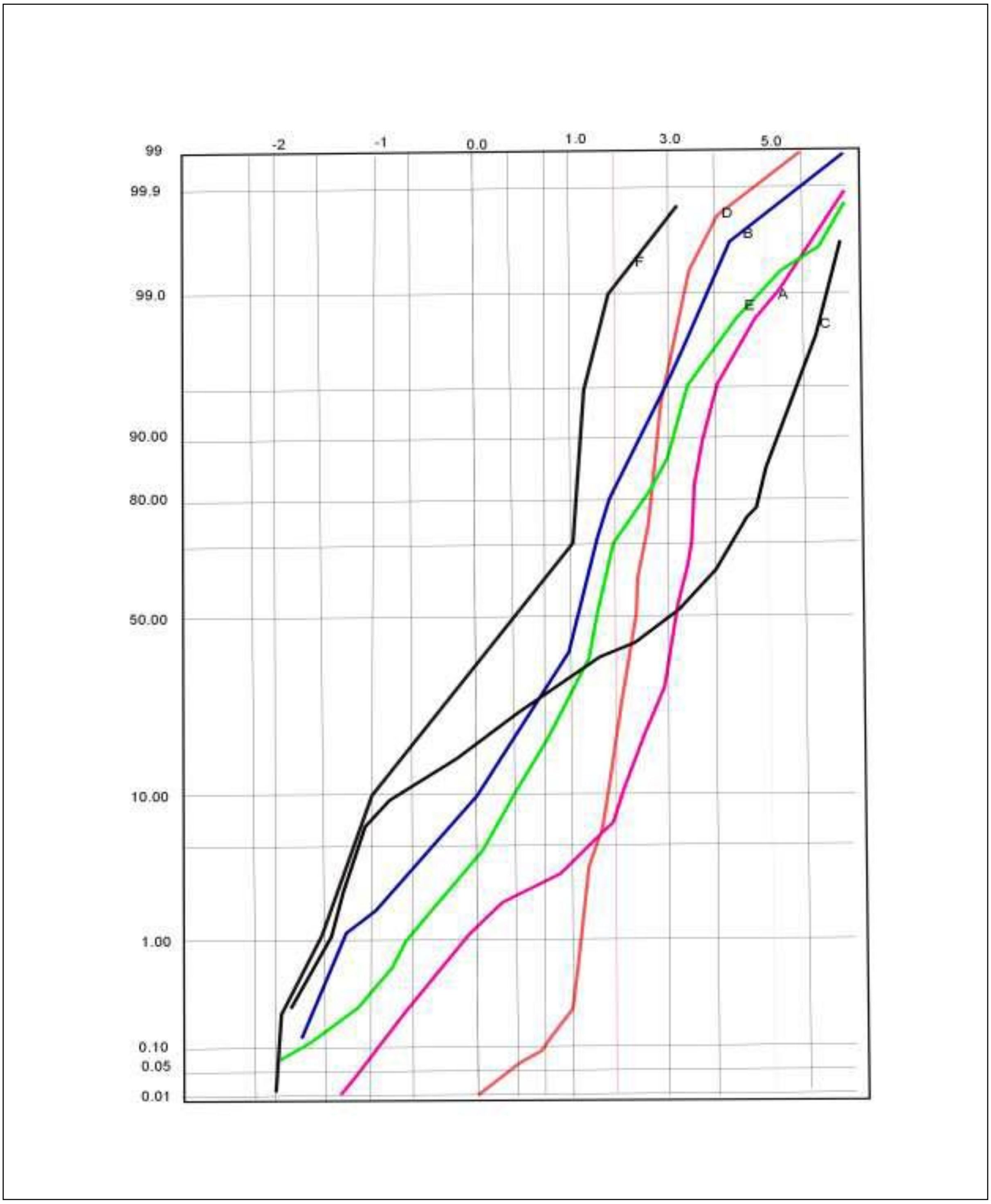

Fig 4: Grain size distribution Curve for the Orashi River (A-Riverbank sediment at Okija, B-Bedload at Okija C-Riverbank sediment at Oguta, D-Bedload at Oguta, E-Riverbank sediment at Akabor, F-Bedload sediment at Akabor).

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The works of Wolman (1955) and most especially the theoretically derived relationships of Leopold and Langbein (1962) form the basis of comparison with the results of this study. Their downstream relations for width and depth and velocity are as in equation (2) to (4) where the exponents b, f and m which describe changes in a channel cross-section in the downstream direction, as a result of change in stream discharge must sum up to 1.0, a requirement of the continuity principle and given as:
The theoretically derived values for the exponents in equation 5-9 are m = 0.09, f = 0.36, b = 0.55, z = -0.74 and y = -0.22.

This relation suggests that where grain size decreases systematically downstream, the effect of increasing discharge would be dampened so that width/depth ratio would not increase as rapidly as might be expected if discharge alone were considered. This was markedly observed in the Orashi catchment during the field work for this study, and it partially accounts for why velocities taper-off, instead of increasing in a downstream direction (see fig. 2).

However the empirical equation relating mean velocity with discharge (equation 10) shows a remarkable downstream decrease (Fig. 3). The observations of Morisawa (1968; 115) are pertinent here, to the effect that "sometimes velocities decrease downstream in some natural streams probably because the load of such a stream becomes significantly finer or less in proportion to the amount of discharge gained". This is strongly suggestive of what obtains in the Orashi River especially as bed-load sediment analysis downstream indicates a predominance of fine materials. Thus when the width/ depth (F) ratio is found poorly related to discharge, an additional term such as d.50 (the median grain size) or M, (the weighted percent silt + clay in the channel perimeter) often increases the amount of explanation provided for the variation in channel morphology (Schumm, 1977).

The results from sediments analysis suggest the catchment has homogenous sediments with respect to their morphogenesis and evolutionary development. Their bimodality and non-normal distribution, evidenced by the predominance of medium and fine sands, can be explained by prevailing environmental factors. The study area is underlain primarily by sedimentary structures, and being unconsolidated, provide ready material for bed load transport. In addition, the humid tropical environment has been noted for its extensive deep chemical weathering – a process which logically accounts for the near absence of coarse materials in all the materials analyzed. Figure 4 shows representative grain size distribution curves for the catchment on log-normal probability paper. All curves present gentle curvatures indicating the bimodality noted above. The pattern also suggests that no inherent differences exist in the character of the sediments; they are all homogeneous.

From Table 6, we conclude that the Orashi River has negatively skewed bed load and bank sediments. Three of the samples are nearly symmetrical, two are negatively skewed and two are positively skewed, suggesting that no real difference exits in these sediments. Also from the results obtained (Table 6), it may be seen that all the sediments have values that are either mesokurtic or leptokurtic; once more indicating the bimodal, non-normal distribution of sediment characteristic in the study area. The kurtosis values cluster around the point of symmetry, thus indicating a good measure of central tendency in these sediments. T-tests once again show no significant difference between the kurtosis values of these sediments at the 99% level.

Mechanical erosion is dominant in the Orashi catchment at large, fostering a very turbid and murky discharge. Light vegetal cover and fine drainage have been found to enhance mechanical erosion in similar tropical catchments (Lam, 1978). It may also be noted that although the catchment size is small, the values of 2.16, 1.99, and 0.33 m3/km2/yr derived by Jeje and Nabegu (1982) for Amafa, Hose and Onilare catchments in Ife area of south-western Nigeria are also comparable to the 1.25, for the catchment. Thus the erosion rates derived for the catchment is consistent with those derived for similar studies in other humid tropical environment.

Jeje and Nabegu (1982) used the value of 1.0 for the specific gravity in their study of sediment yield from small catchment in south-western Nigeria. This follows Walling"s (1971) observations that most of the sediment loads in channels are derived from the soil horizons which could have a specific gravity of less than 1.0. In this study, therefore, the same rational assumption was made for the value of specific gravity of the denuded material.

It may also be noted that although the catchment size is small, the values of 2.16, 1.99, and 0.33 m3/km2/yr derived by Jeje and Nabegu (1982) for Amafa, Hose and Onilare catchments in Ife area of south-western Nigeria are also comparable to the 1.25, for the catchment. Thus the erosion rates derived for the catchment is consistent with those derived for similar studies in other humid tropical environment.

The empirical findings of this study and in particular the arguments presented in previous sections have shown that study of form-process interrelationships in fluvial dominated landforms of south-eastern Nigeria, is best accomplished within the framework of contemporary fluvial processes. Evaluations of the hydrologic and sedimentologic processes operating in the studied catchment therefore indicate that variations exist, especially between empirical observation and theoretical postulations.

Field evidence indicates that the Orashi channel hydraulic geometry – in a downstream direction and adjustments in a downstream direction in width, mean depth and other morphologic parameters are not matched by an equitable adjustment in channel velocity. While the former increase downstream, velocity decreases – a variation noted by Morisawa (1968) for natural streams having an unusually high proportion of fine bed load material. This indeed may provide some explanation for the Orashi's aberration in channel hydraulic geometry.

Bedload analysis of Orashi channel sediments indicates that 79% of material transported by the river is fine material (finer than the 300 micron wire mesh, 0.3mm). Although this is the recorded figure at the Oguta sampling sites, similar high values of fine sediments are recorded for all other samples taken upstream.

The Njaba stream carries a bedload predominated by medium sand materials.

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However its possible influence in moderating the Orashi flow regime is arrested by the Oguta Lake into which it flows before joining the Orashi trunk stream.

The Oguta Lake itself provides another source of explanation for the Orashi's channel hydraulic geometry relations. The Oguta Lake acts as a local base level in this environment and therefore causes disequilibrium in the normal downstream adjustments of the Orashi channel.

In addition, the flow of the Orashi into the alluvial plains (an alluvial plain created by the Niger) southwest of Ozubulu changes considerably the morphologic and hydrologic character of the Orashi. Analyses of meander wavelength and amplitude of the Orashi channel around this area during the field work for this study suggest strongly that the river is expending much of its energy in traversing this wide zone.

Other parameters providing explanations for the characteristic variations in the hydraulic geometry of the Orashi River include width/depth (F) ratio, the percent silt + clay (M) and channel discharge (Q). Calculated M values confirm that the highly cohesive nature of the Orashi channel perimeter sediments contributes significantly in influencing the (F) ratio of the Orashi channel.

Therefore the relationship between the channel processes operating in the Orashi catchment and its morphology differs rather markedly from earlier studies and generalizations, while it attains some measure of channel equilibrium between morphology and hydrology, field evidence strongly suggests that the Orashi channel is not well adjusted to the 'normal' flow of the hydrologic regime (Morisawa, 1976; 132).

However sediment production and transportation in the Orashi are consistent with theoretical postulates. Field investigation shows that, on a comparative basis, the Orashi River is very active in the removal of sediments in particular suspended sediments from the catchment surface. Its waters are therefore constantly murky and turbid. Sediment concentrations of up to 0.75 gram/litre recorded at Oguta is consistent with the fine drainage network and porous sandy surface underlying much of the catchment surface.

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