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DOWNSTREAM HYDRAULIC GEOMETRY OF ENYONG CREEK S. E. NIGEIA: ITS IMPLICATIONS ON SURFACE WATER QUALITY

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ABSTRACT

This paper examines the channel morphology and dynamics of three sub-catchments in the lower Enyong Creek. Hydraulic geometryparameters were studied in relation to water quality parameters. High values of coefficients of determination between channel depth and discharge indicated that much of the downstream variation in channel width to depth ratio can be accounted for by processes of channel deepening. The physicochemical properties of threesub-catchments were also studied and results showed that the studied catchments adjust their geometry to changing discharges and these adjustments influenced water chemistry. Also, the result of factor analysis indicates thatadjustments in the hydraulic geometry accounted for 12.8% of variation in surface water quality.

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1. INTRODUCTION

Recent advances in understanding the linkages between geomorphological processesandevolution of landforms and assemblage of landforms in different morpho-climaticregions of the world have spurred interest in the relationships between evolution of streams and sediment yields surface water quality (Bridge, 2003, Charlston, 2008 and Ritter et al, 2011).It is true that stream channels have complex morphologies and a number of studies implicate several different controls on their development, including: tectonic and structural (VanLaningham et al. 2006), bedrock (Snyder et al. 2003), storm pulses (Gupta

1988), and non-fluvial processes such as landslides/debris flows (Brummer and Montgomery 2003, Stock and Dietrich 2006) and glaciers (Wohl et al. 2004). Other studies have demonstrated the characteristic morphology of streams (Morisawa, 1968, Gregory and Wallings,1973, Grant et al. 1990, Montgomery and Buffington 1997, Wohl and Merritt 2001, Udosen, 2015 and UdosenandEtok, 2016); their hydraulic geometry (Wohl 2004,Fashae and Faniran, 2015) and the complexity of sediment transport (Blizard andWohl 1998, Lenzi et al. 2004, Torizzo M, Pitlick J. 2004. Ausuebeogun and Ezekwe, 2012).

However, some tropical streams may have unique features that vary from their temperate counterparts. The absence of glaciation excludes glacial landforms, such as u-shaped valleys and coarse moraine deposits that are prevalent in some temperate montane basins. Relatively high rates of chemical and physical weathering often denude tropical landscapes and may affect rates of channel-sediment diminution and patterns of downstream fining (Brown et al. 1995, White et al. 1998, Rengers and Wohl 2007). Frequent landslides triggered by heavy rains introduce pulses of coarse sediment to the channels and strongly link fluvial and colluvial forces (Larsen et al. 1999). The relatively few studies that have addressed the underlying controls structuring the morphology of tropical streams demonstrate the influence of a variety of factors. Fashae and Faniran(2015), demonstrated the nature of interrelationships among channel morphologic variables along the alluvial section of River Ogun in Southwestern Nigeria. Lewis (1969) demonstrated that local lithologic factors, such as bed material cohesion and channel constriction, influenced at-station hydraulic geometry in the Río Manati of north-central Puerto Rico. In the streams of Jamaica and Puerto Rico, Gupta (1975) emphasized the role of high discharge relative to drainage area as a key hydraulic control shaping channel morphology. Similar characteristics were noted in the Río Chagres in Panama, where hydraulic controls due to notably high unit discharge are apparently sufficient to override lithologic controls and develop a basin with well-developed downstream hydraulic geometry (Wohl, 2005)

Downstream hydraulic geometry (DHG) characterizes systematic downstream changes in channel geometry as power-law relationships with discharge, and may be used to quantify the influence of fluvial controls on channel form (Leopold and Maddock 1953).The iconic research work by Leopold and Maddock (1953) was a watershed in hydraulic geometry. They used abundant flow records compiled at gauging stations throughout the western United States to establish statistically significant relationships between discharge and other variables of open channel in quasi-equilibrium condition. As it is today, these relationships are known as the hydraulic geometry of river channels. These relations are examined to understand how a stream channel adjusts and accommodates gains of water and sediment with increases in drainage area. These power functions as presented by Leopold and Maddock (1953) are illustrated as follows:

$w = aQb$......... (1)

$d = cQf$......... (2)

$v = kQm$......... (3)

The variables *w, d,* and *v* are wetted-channel top width, mean depth, and mean velocity of the cross section, respectively; *a, c, k, b, f,* and *m* are numerical constants, *b, f, m* are exponents while *a, c, k* are coefficients which must equal unity (Wohl et al. 2005).

DHG has successfully described river patterns worldwide in many physiographic environments ((Leopold and Maddock, 1953). The ubiquity of DHG in these self-forming rivers has been explained from a combination of basic hydraulic and sediment transport processes (e.g., Singh 2003, Parker et al. 2007). Although consistent power-law relations in downstream channel geometry have been observed in some rivers in the Niger Delta Region of Nigeria (Ausuegeogun and Ezekwe, 2014), it has been shown that rivers that are strongly controlled by geologic rather than hydraulic controls will often display poorly defined DHG (Wohl et al. 2004). The complicated hydraulics and sediment transport processes associated with the lower Enyong Creek characterized by heterogeneity in geology may confound these relationships.

It became quite evident from these studies that river basins in the humid tropics are among the most extreme fluvial environments in the world due to a combination of unplanned urbanization, high variability in annual rainfall and intense tropical storms which generate an energetic and powerful flow regime (Udosen, 2014]. The high rates of gully erosion and dramatically dissected landscapes prevalent in the humid tropical environments attest to the power of these rivers. Yet channel morphology that is sculpted by fluvial processes in humid tropical environments is relatively understudied, compared to the temperate regions of the world.This paper investigates controls on stream channel morphology in the Lower Enyong Creekin southeast of Nigeria, a tectonically inactive landscape with varying bedrocks and structural controls that is rapidly eroding due to extremely wet tropical conditions, frequent intense storms, and ahigh susceptibility to mass-wasting.

Study area- Location, geology and physiography

The study area is enclosed between latitudes 5°11′to 5°28′ N and longitudes 7°51′E to 8°00E (Fig. 1). Geologically, the area under study is underlain by a wide range of diverse geological formations ranging from Asu River Formations e.g the Abakiliki Anticlinorium to the recent alluvium in the south. The Asu River Group underlies most areas in the northern part of the study area e.g its intensely fractured outcrops at Uburu. The Asu River Group, which is Albian in age is sub-divided into three formations, comprising essentially of over 200m bluish- grey to olive brown shales and sandy shales, fine-grained micacceous and calcareous sandstones and some limestones (Offordile, 2002). The area is well represented by structurally controlled ridges, denudational hills e.g the 150m high Obotme conical hill, steep-sided valleys, saddle and col at Obot Ito Ikpo, extensive wetlands and alluvial plains forming soil covers of silty clay, sandy and heavily weathered loam and alluvium.

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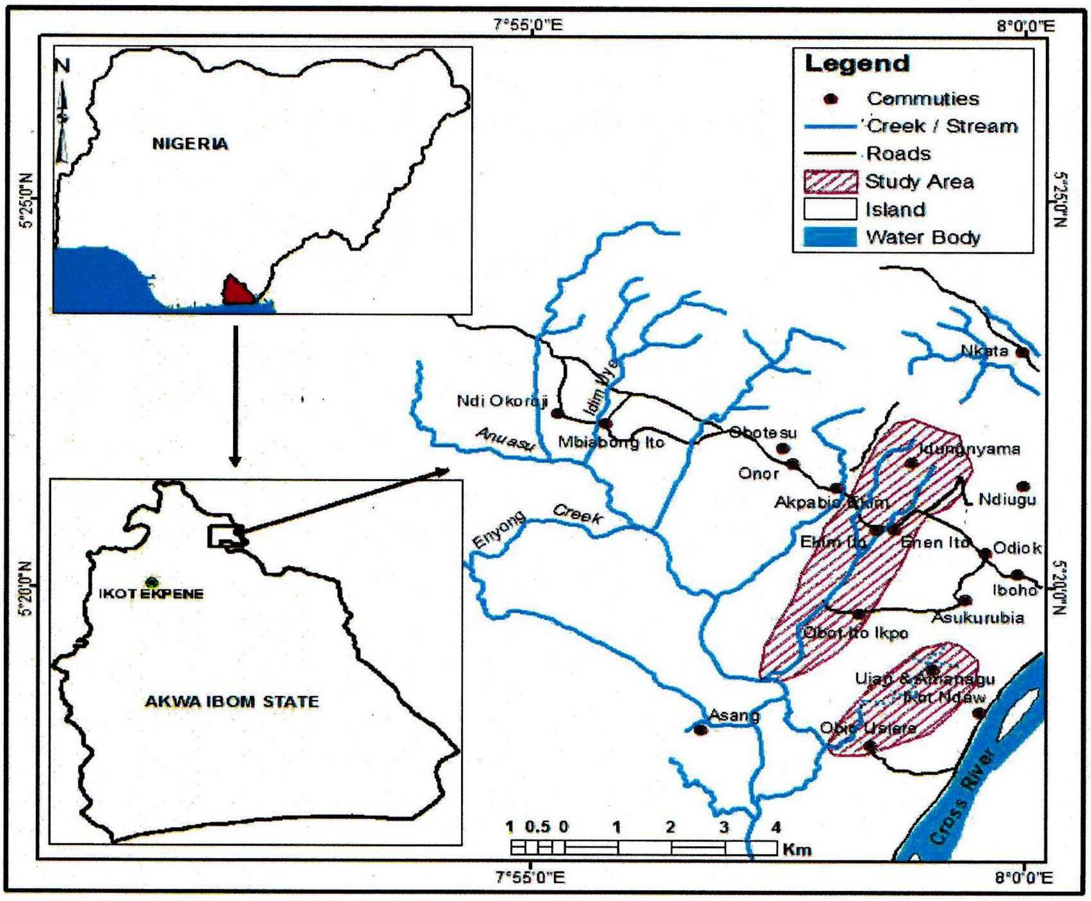

Figure 1: Location map of the study area

Climate, Soil and Vegetation

The details of annual and monthly rainfall for Umuahia (the closest station to the basin indicates that rainfall ranges from 1511mm in 1983 to 2572mm 1996 with a mean annual of2156mm, c.v.=44.4% recorded between 1972 and 2012 (Okutinyang, 2015). The monthly distribution of rainfall is shown in Table 1. Fig. 2 clearly shows eight wet months-March to October, the dry months are November to February. The rainfall pattern is uni-modal in most years. In the humid tropics rainfall is the main input into the river system and hence, Thornthwaites water balance was computed using rainfall and evaporation data (Udosen, 2000).

Table 1: Monthly Rainfall distribution at Umudike (1972-2012)

Month	Range	Mean	Raindays per month
Jan	0-78	15	1
Feb	0-132	38	3
Mar	4-266	113	7

Apr	70-357	176	12
May	102-445	270	16
Jun	101-576	288	18
Jul	166-450	292	21
Aug	103-535	306	21
Sep	206-670	341	21
Oct	75-499	257	16
Nov	0-212	53	5
Dec	0-35	7	1

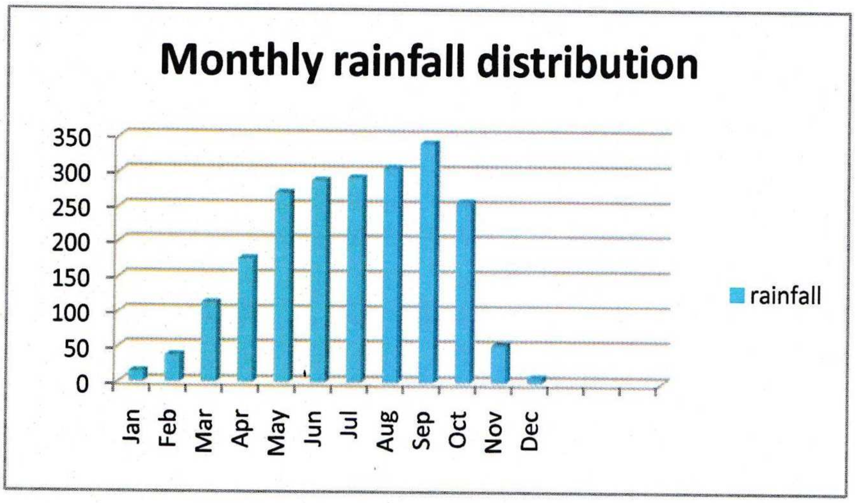

Fig 2: The mean monthly r5ainfall at Umuahia, (1972-2012)

The results indicate a runoff coefficient of 0.68 for Uyo, located barely 18kms south of the study area. The implication is that over 60 percent of rainfall is converted to surface runoff, depending on amount and type of vegetation, soil infiltration rates and slope aspects. Furthermore, the computed water balance indicates that ground water contributes significantly to channel flow from June to September .The demobilized rock minerals and metals may enter the river system from ground water between June and September.

As noted earlier, Enyong Creek enjoys tropical climate and the temperature ranges from 26 to 32° C. The fluctuations in temperature are fairly uniform in character, except during the dry months when the rise in temperature is higher than it is during the long wet period (eight months-March to October) and the level of humidity is high (84%) due to close proximity to the main Cross River Channel.

Materials and methods

The study involved map-based analyses of a topographic map sheet number 322 IkotEkpene NE at a scale of 1, 50,000. The different morphometric parameters were determined by using the standard methodologies while channel geometry, surface water quality as well as geographic co-ordinates were determined as shown in Table 2.

Table 2: Field Sampling in both wet and dry seasons

Parameters	Methods	Instruments
Velocity, cross sectional area and discharge	Discharge-Float method Velocity-distance/time Cross section-width x depthMorisawa (1976) and Smith and Stopp (1979). A correction factor of 0.85 was applied to results to correct for inadequacies (Morisawa 1976, Schumm 1977, Smith and Stopp 1979; Goudie 1981).	Linen tape, rope, float .
Physicochemical, heavy metals Water samples were collected approximately 15 – 20cm below the water surface with $125cm^3$ using pre-cleaned and chemically neutral 1 litre plastic vessels for laboratory analysis of other physicochemical parameters.	Schlosser, 1982; Hanson, 1973; Bartram and Balance, 1996). l, 1986; APHA – AWWA – WPCF, 2005; USEPA, 1979) quoted in Udosen and Etok, [2016]. Sampling was done at specific time intervals	In situ measurements and laboratory analysis AAS was employed for trace metals analysis.
Geographic co-ordinates	Field measurement in a boat	Hand Held GPS
Data analyses	Mean, range, standard deviation,Anova, logarithm transformation, Factor Analysis	Scientific calculator, SPSS package

SURCE :Field survey (2014)

Location of sample sites

This study was conducted on three locations along the Enyong Creek viz; Ito, ObioUsiere and Okopedi (Fig.1)The geographic co-ordinates are listed in Table 4.

Table 3: Sampling Villages/location.

Village	Location	
Ito	5°19.227'N	007°56.291'E
ObioUsiere	5° 15.693'N	007°56.970"E
Okopedi –Itu	5°12.144'N	007°58.913'E

Results and Discussion

Drainage Basin Morphometry

In the present study, the values of the morphometric variables computed/measured are summarized in Table 4. The relatively low bifurcation ratio indicates flatter hydrograph peak with least potential for flash flooding during storm events in the Lower Enyong Creek.

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Stream length of order-1in Ito sub-catchment is longer than those in ObioUsiere (Table 4]. The total area of Ito and ObioUsiere sub –catchments are 12.37km^2 and 4.44km^2 respectively. ObioUsiere sub-catchment is unique in that although, it has a small catchment, it has larger discharge figures and channel morphology parameters

Other aerial aspects such as indices of basin texture and shape viz; drainage density (Dd), stream frequency (Fs), texture ratio (Rt), elongation ratio (Re), circularity ratio (Rc) and form factor ratio (Rf) were calculated and results have been given in Table 4.

TABLE 4 :Morphometric properties of Order-2 streams draining Ito and Obio Usiere

Morphometric Parameters	ObioUsiere	Ito
Basin area	4.44 km^2	12.37km2
Basin length	3 km	8km
Length Area ratio	3.42	6.33
Relief Aspects		
Maximum basin relief	46m	137m
Minimum basin relief	3m	3m
Basin relief	43m	134m
Relief ratio	0.014	0.017
General channel slope	2^o	3^o
Ruggedness number	0.049	0.154
Basin perimeter	8.75km	19.75km
Drainage Texture		
Bifurcation ratio	2	3
Mean stream length order-1	1.93km	3. 04km
Drainage density	1.15km/km^2	1.15km/km^2
Stream frequency	0.68	0.32
Infiltration number	0.78	0.37
Indices of Drainage Basin shape		
Form factor	0.36	0.77
Elongation ratio	0.69	0.70
Circularity ratio	0.23	0.13
Lemniscate K factor	0.51	1.29
Length of overland flow	0.93km	0.49km
Constant of channel maintenance	0.87	0.87
Wandering ratio	1.06	1.10
Fitness ratio	0.34	0.41

SOURCE; Analyzed from topo. Sheet 322 IkotEkpene NE

The length of overland flow of Ito sub catchment is 0.49 kilometers, while that of ObioUsiere is close to a kilometer (0.93km), which shows gentler slopes and hence low surface runoff and longer flow paths (Fig. 4)

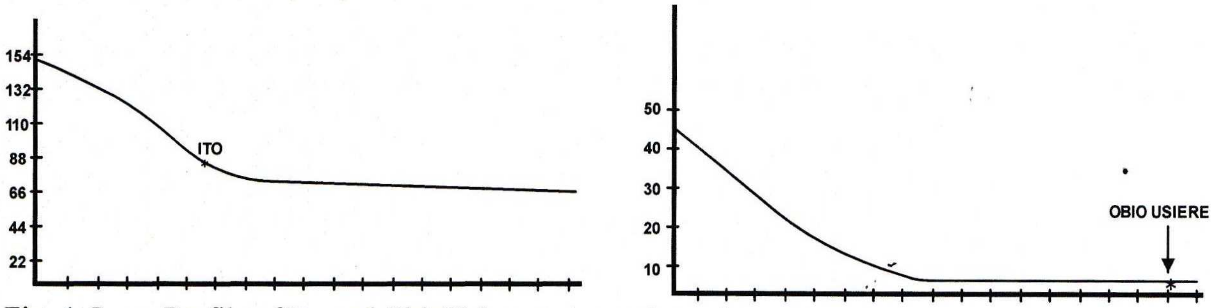

Fig. 4: Long Profile of Ito and ObioUsiere stream sub-catchments.

The headwaters of Enyong Creek are characterized by fairly steep ridges before cascading down the side of the ridge and leveling out along the floodplains (Fig. 4). The inflection point where the stream sharply steepens occurs at the edge of the intensely fractured outcrops around Uburu. Many alluvial rivers develop systematic changes in slope, channel geometry, and grain size from their headwaters downstream in response to changes in discharge and sediment yield (Paola and Seal 1995). These changes result in many well-known basin-scale patterns such as concave-upward longitudinal profiles and progressive downstream fining, whereby adherence or significant deviations from the theoretical patterns reflect the relative importance of lithologic and hydraulic controls.

A theoretical profile of a graded stream {as in the study area) has a smoothly concave-upward shape; steep in the headwaters and flat near the mouth (Hack 1957). A river of this form has achieved an assumed balance between the erosion from fluvial processes and the resistance from lithologic and tectonic forces. Deviations from this idealized grade, such as changes in concavity (Seidl et al. 1994) and the presence of segmentation/knickpoints (Crosby and Whipple 2006, Goldrick and Bishop 2007) can indicate the influence of non-fluvial forces. In the humid tropical environment,severe gully erosion and landslides/debris flows can locally constrain the channel gradient and concavity due to infrequent occurrence of high intensity rainstorms (Udosen, 2014).

Downstream Hydraulic Geometry ofEnyong Creek

In Table 5, the channel parameters of the lower Enyong Creek show a general downstream increase especially in depth and discharge characteristics. Channel width however shows a random pattern, although a general increase in the downstream direction is observable. This may be as a result of the river originating in the steep-sided sandstones ridges and cascading into the broad slopes of the floodplains underlain by recent deposits of fine-grained-sand from the main Cross River channel. The stream velocity increases from 0.162 to 0.257ms-^{3} with a mean of 0.19±0.05ms-3 at Ito to 0.21-0.42 ms-^{3}, with a mean of 0.28±0.08ms-^{3} at Okopedi downstream.

Table 5. Changes in Hydraulic Geometry at different locations in the lower Enyong Creek.

Parameters	**Min-Max-(MEAN) ITO**	**Min-Max(Mean) ObioUsiere**	**Min-Max(mean) Okopedi**
Transparency	69.5-95.5 (87.17±10.216)	35-125.5 (74.2±34.76)	29-75 (43±17.17)
Depth	3-5 (3.64±1.75)	4.29-5.29 (4.77±0.56)	7.3-8.9 (8.3 ± 0.58)
Width	25-34 (28 ± 25.29)	74-100.3 (75.92±17.82)	65-74 (69.5±3.27)
Velocity	0.162-0.257 (0.19±0.05)	0.117-0.35 (0.23±0.23)	0.21-0.42 (0.28±0.08)
Discharge	14.15-27.88 (19.91±5.64)	42.4-157.1 (107.28±47.48)	112.5-332.6 (215.6±88.3)
BOD	0.10-0.46 (0.3±0.16)	0.15-0.9 (1.40±1.98)	0.55-6.3 (1.98±2.17)
	W/D Ratio=7.69	**W/D Ratio=15.91**	**W/D Ratio=8.37**

Source: Field Measurements, 2014

Most geomorphologists are under the impression that the velocity of a stream is greater in the headwaters than in the lower reaches. The steepchannel gradient at head water of course, gives the impression of greater velocity than that observed in a large river downstream. The impression of greater velocity upstream stems in part from a consideration of river slopes which obviously are steeper in the upper than in the lower reaches. It will be recalled, however, that velocity depends on depth as well as on slope, as shown in the Manning equation

$$Q = \frac{1}{n} A R^{2/3} S^{1/2} \quad \ldots\ldots\ldots\ldots (4)$$

where
Q = discharge (m^3 s-1)
A = cross-sectional area (m^2)
R = hydraulic radius (m) and
S = slope or gradient of the stream

Depthis approximately equal to hydraulic radius for natural river sections. The fact that velocity increases downstream pre-supposes that the rate of increase of depth downstream tends to overcompensate for the decreasing slope and tends to provide a net increase of velocity at mean annual discharge in the downstream direction of a river.

Width-Discharge Relations. The relationship between channel width (m) and discharge is very weak (coefficient of determination is 0.25),which implies that channel width explains only 25% of variation in discharge in the lower Enyong Creek (Table 6). Fig. 5 indicates that the regression equation is given as ;
Y = 0.33x + 1.079................(5)

Its corresponding exponents and coefficients are 0.26 and 0.50±0.27 respectively. All these values were found significantly related when tested with the students' *t* test at the 0.01 confidence level.

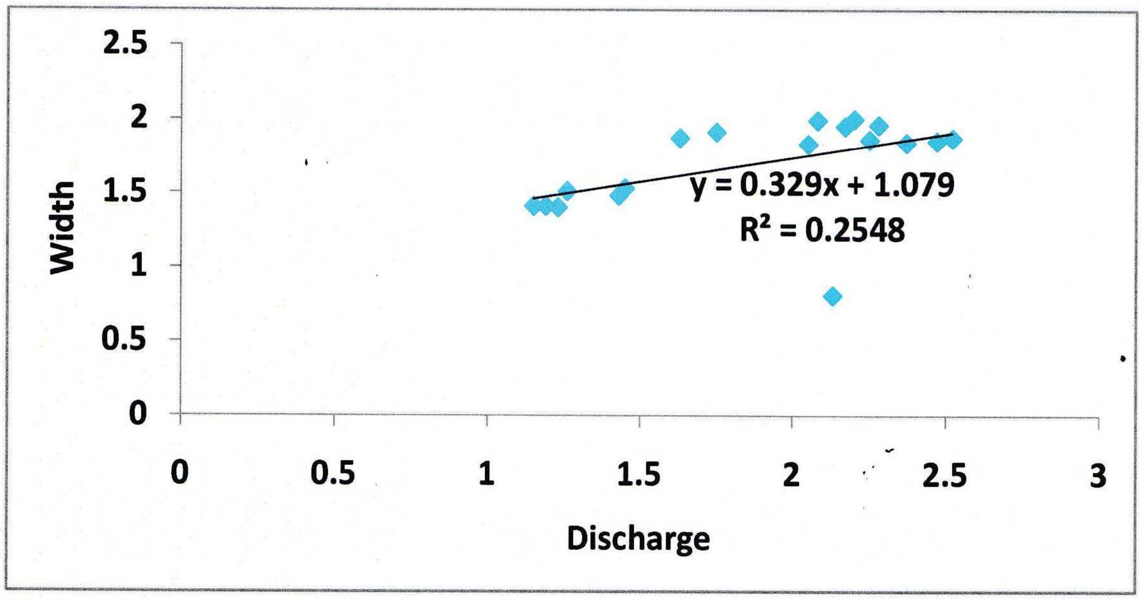

Fig.5: Relationship between channel width and discharge

Table 6: Exponents and coefficients of downstream hydraulic geometry of Enyong Creek

Parameter	Correlation Coefficient ±SE	Downstream Exponent	Regression Equation
Width	1.079±0.27	0.33	Y = 0.329x+1.079
Depth	0.186±0.089	0.29	Y = 0.285x +0.186
Velocity	-1.016±0.11	0.20	Y =0.198x -1.0168

***SE is used to represent the uncertainty in regression coefficient**

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Depth-Discharge Relations The relationship between channel depth (m) and discharge is very strong (coefficient of determination is 0.71),which implies that channel width explains only 71% of variation in discharge in the lower Enyong Creek (Table 6). Fig. 6 indicates that the regression equation is given as:

Y = 0.29x + 0.186................(6)

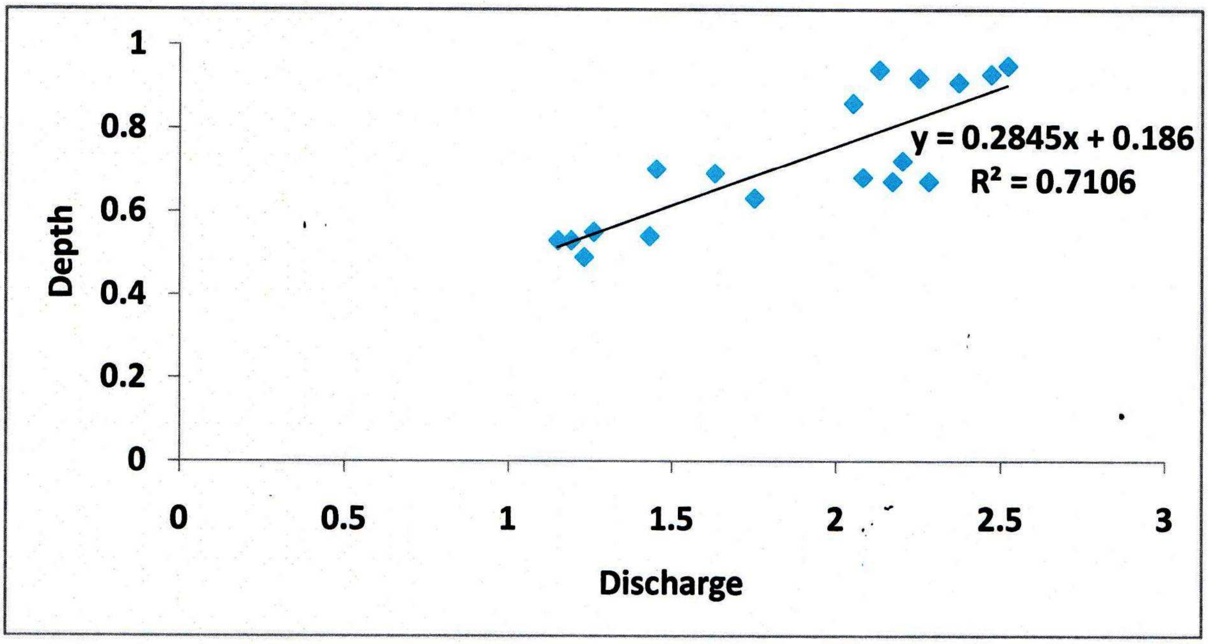

Fig 6: Relationship between channel depth and discharge

Velocity-Discharge Relations The relationship between current velocity (cm^{-3}) and discharge is moderately strong (coefficient of determination is 0.43), which implies that channel width explains only 43% of variation in discharge in the lower Enyong Creek. Fig. 7 indicates that the regression equation is given as:

Y = 0.20x - 1.0168................(7)

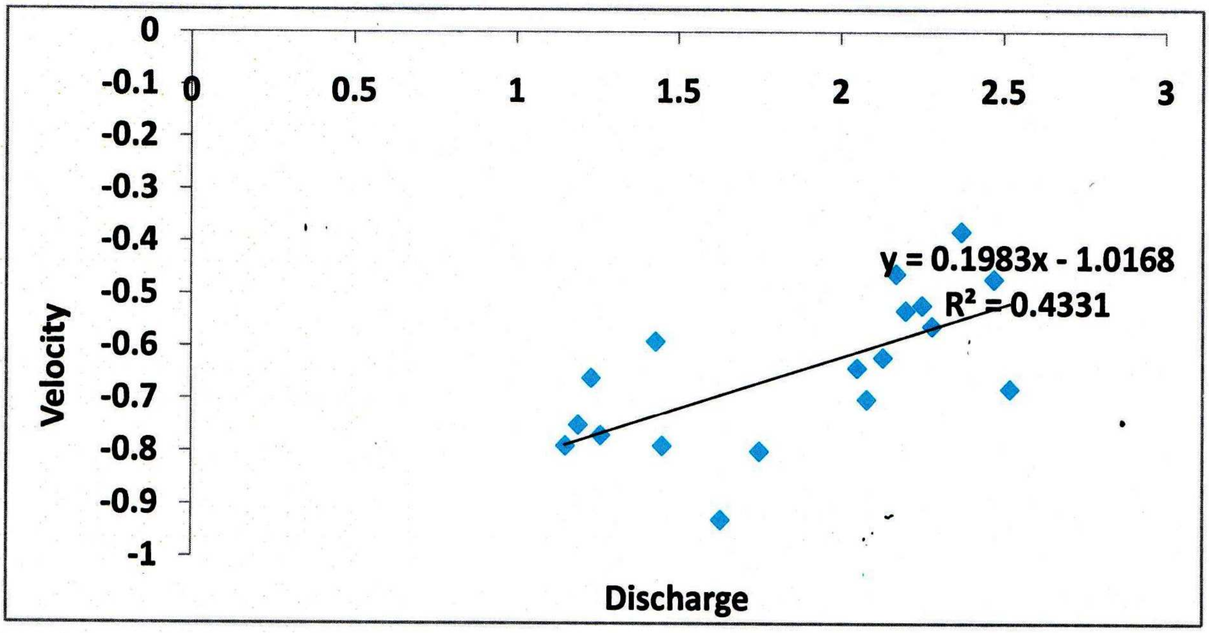

Fig. 7: Relationship between current velocity and discharge

The results indicate that the exponents of DHGare 0.33 for width, 0.29 for depth, and 0.20 for velocity. With increasing discharge, width increases at approximately 1.14 times the rate of depth. This implies that the width/depth ratio similarly increases in the downstream directionviz 7.69, 15.91, and 8.37 at Ito, ObioUsiereand Okopedi respectively. In a similar fashion, the channel form changes from a triangular 'v'-shape (low w/d ratio) in the headwaters(near the steep-sided sandstones ridge) to a more rectangular (high w/d ratio) form towards the mouth at Okopedi. Velocity increases at a much lower rate of change in the downstream direction resulting in a fairly higher mean cross-sectional velocity in the lower reaches than in the headwaters during a flood at active-channel discharge. In this study, the downstream relations for width, depth and velocity denoted as b = 0.33, f = 0.29 and m = 0.20. The sum of the exponents did not satisfy the requirements of the continuity principle. The values of *b, f, m did not* sum up to 1.0, i.e.: 0.33 + 0.29 + 0.20 = 0.82. The products of constants *a, c, k* also gives <1.0 (1.079 * 0.186 * -1.068 =< 1.0 (-0.86).

w = 1.079 Q0.33 (8)
d = 0.186 Q0.29 (9)
v = -1.068 Q0.20 (10)

The imperfect nature of these relationships suggests that Enyong Creek does not have a normal hydrologic regimen (Morisawa 1976) and is not well adjusted to the channel morphologic variables of width, depth and velocity, consequently, DHG is considered to be not well-developed in Enyong Creek. This study corroborates the observation by Udo (1971). Similarly, Abegunle et al (2001) noted that 'the oversized valley of the EnyongRivemay have resulted from the Imo Rive capturing its headwaters at a point near Umuahia'.It is also worth noting that fluvial instability may result from the nature of morphometric properties of contributing area and are scale-dependent [Parker, 1976].

Leopold and Langbein (1962) obtained their downstream relations for width, depth and velocity as $b = 0.55, f = 0.36$ and $m = 0.09$. Wolman (1955) obtained similar results from studies of the Brandywine Creek of Embreeville, Pennsylvania. These exponents when summed up add up to 1.0 a requirement of the continuity principle. The channel hydraulic geometry relations in the Niger Delta Region of Nigeria also showed similar results (Aisuebeogun and Ezekwe, 2014). The following morphology-discharge relations were established for River Sombriero in the Niger Delta Region of Nigeria.

$w = 3.88$ Q0.59 (11)
$d = 1.41$ Q0.22 (12)
$v = 0.18$ Q–0.19 (13)

The relationship of each of these factors or variables to discharge was linear and the sum of the exponents satisfies the requirements of the continuity principle. The values of *b, f, m* sum up to 1.0, i.e.: 0.59 + 0.22 + 0.19 = 1.0. The products of constants *a, c, k* also gives 1.0 (3.88 * 1.41 * 0.18 = 1.0. They also indicated that in the Sombreiro River the morphologic variables are highly interrelated..Hydraulic geometry has been used to determine the baseline geomorphic character in stream restoration designs and has been proposed as a preliminary method for determining in-stream flow requirements for habitat assessments (Jowett, 1998 and Shields et al, 2003). While such applications are typically reserved to describe changes along single river channels, it is possible that the downstream hydraulic geometry relations may extend throughout river networks where climatic and geologic controls are similar.

Implications on surface water quality

Some hydraulic characteristics of stream channels such as depth, width, velocity, are known to affect water quality in terms of suspended solutes, dissolved solids, P^H, cations, anions (Udosen, 2016b). In order to relate DHG to surface water quality, factor analysis was applied to 29 hydrologic, physicochemical, anions and trace metals variables measured for the selected sampling points in the Lower Enyong Creek. The eight factor model accounted for 88.2% of the variation in the original data. Factor 1 explained 14.5 % of the variation in data. It is obvious that factor 1 is predominantly related to trace metal loads viz; Cu, Ni and Cr, and is moderately related to salinity. This relationship is expected since the salinity of water bodies are indicative of heavily polluted water bodies.

Table 7: Results of Factor Analysis

Rotation Sums of Squared Loadings		
Total	% of Variance	Cumulative %

4.200	14.482	14.482
4.095	14.122	28.605
3.941	13.591	42.196
3.699	12.755	54.950
2.920	10.067	65.018
2.834	9.774	74.791
2.461	8.487	83.278
1.432	4.940	88.218

Extraction Method: Principal Component Analysis.

Factor 11 on the other hand, is essentially related to the variables that characterize water inflow from ground-water and cassava processing mills viz; and sulphate, ammonium and Zn [all are negatively related, except Zn]. . It also relates strongly with the water hardness. It is perhaps worth noting that nitrate, electrical conductivity, TDS and Pb (the only trace metals) load heavily on factor 111, while cross sectional characteristics viz; velocity, depth, transparency and discharge alone load heavily on factor 1V. Together, factors 1, 11, 111 and 1Vaccount for almost 55% of the variance in the data set. The other factors contribute progressively less, and they are related to Fe and temperature (factor V; TSS –factor V1 and P^H, Mg, BOD (factorV11) and hardness and channel width-factor V111.

Conclusion

The morphology of the stream channels in Enyong Creek are influencedby a combination of both local lithologic controls and moderate hydraulic forces Longitudinal profiles and concavity may beinfluenced strongly by lithologic boundaries. This study has shown that effective River planning and management is governed by an understanding of river morphology and channel processes.. Detailed morphological assessment also enhances the understanding of channel processes, its natural capability to adjust and depicts the inherent character of the river and possible response to human impact. It provides the basis to develop ecosystem based management for Enyong Creek.

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Factor Analys

Communalities

	Initial	Extraction
Cu	1.000	.977
Fe	1.000	.821
Zn	1.000	.933
Pb	1.000	.866
Cr	1.000	.961
Cd	1.000	.881

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Ni	1.000	.913
Salinity	1.000	.900
TDS	1.000	.868
Suspended_Solids	1.000	.829
Hardness	1.000	.943
Alkalinity	1.000	.928
Sulphate	1.000	.953
Dissolved_Oxygen	1.000	.710
Nitrate	1.000	.976
Calcium	1.000	.962
Magnesium	1.000	.813
Potassium	1.000	.815
Ammonium	1.000	.871
Sodium	1.000	.692
pH	1.000	.859
Temperature	1.000	.867
Conductivity	1.000	.867
Depth	1.000	.928
Width	1.000	.917
BOD	1.000	.877
Velocity	1.000	.922
Discharge	1.000	.899

Transparency	1.000	.837

Extraction Method: Principal Component Analysis.

Rotated Component Matrix[a]

	Component				
	1	2	3	4	5
Cu	.915	.252	-.174	.128	-.050
Fe	.203	.228	-.193	.160	.804
Zn	.149	.688	-.328	.201	.184
Pb	.022	-.113	.802	.116	-.176
Cr	.883	.244	-.154	.026	-.253
Cd	.361	.246	-.094	.224	-.551

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Ni	.916	-.111	-.010	-.080	.079
Salinity	.739	.106	-.368	-.081	.303
TDS	.195	-.569	-.671	-.180	-.106
Suspended_Solids	-.150	.011	.171	-.017	.282
Hardness	.320	-.242	-.008	.277	.093
Alkalinity	.060	-.517	-.239	-.038	.090
Sulphate	-.196	-.870	-.289	.017	-.192

Dissolved_Oxygen	-.363	.368	-.235	.415	.212
Nitrate	-.410	.007	.803	-.129	.129
Calcium	-.174	.073	.751	-.146	.112
Magnesium	.262	.441	.048	-.238	.280
Potassium	-.035	.685	-.056	-.320	.477
Ammonium	-.351	-.797	.215	-.171	-.015
Sodium	-.352	-.039	.489	.532	.034

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pH	.007	-.163	-.010	.186	-.206
Temperature	.148	-.161	-.040	-.068	-.895
Conductivity	-.050	-.077	.867	.110	-.155
Depth	.044	-.031	.056	.950	-.111
Width	-.102	.563	-.026	.214	-.354
BOD	-.282	.025	.064	.404	.063
Velocity	.145	.251	.000	.608	.355

Discharge	.109	.233	-.064	.791	-.071
Transparency	.039	.078	-.124	-.766	-.272

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.