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DOWNSTREAM MORPHOLOGIC CHARACTERISTICS OF THE ALLUVIAL SECTION OF LOWER RIVER OGUN, NIGERIA

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Abstract

Rivers constitute an important focus of attention in surface water studies because of their dynamic nature. Therefore, natural rivers develop a wide range of channel forms whose characteristics vary as a function of the position within the fluvial systems. This study examined the river channel morphologic parameters along the alluvial section of River Ogun in South western Nigeria. Data on the channel morphologic variables were collected through field measurement of the bankfull cross sectional characteristics of the river from where the longitudinal characteristics were defined. 48 cross sections were randomly established at bankfull stage along the river channel stretch of 90 km. Bankfull depth and width at each of the cross sections were determined using sonar (electronic sounding machine) that was mounted to a boat. Velocity was measured with the aid of a current meter, while other morphological parameters were estimated from the field data. Analysis of variance revealed that downstream morphological characteristics of the river varies distinctively at each cross section with bedslope as the most significantly varied among all other morphologic parameters (F=91.18; P=0.00). Pearson product moment correlation technique revealed that bankfull width had a correlation of 0.8 and 0.9 with wetted perimeter and cross sectional area respectively while bankfull depth (maximum) had correlations of 0.9, 0.8 and 0.78 with hydraulic radius, wetted perimeter and cross sectional area respectively. The research also revealed that gradient affects the discharge with a positive correlation of 0.9. The study ascertains the extent of variability in the morphologic characteristic of River Ogun which provides scientific basis for river maintenance and management.

Keywords: bankfull depth, bankfull width, alluvial section morphologic characteristics, river channel, Lower River Ogun

INTRODUCTION

The assessment of river condition relative to some ideal state is a concept receiving increasing attention in fluvial geomorphology. The morphology of any river shows a great variability and dynamic behaviour. Therefore, the river channel as a subsystem and an important component of the river basin system deserves studying in some details to enhance river-basin management which provides scientific grounding for river maintenance and management. Monitoring of channel morphology extends understanding of types and rates of responses to environmental changes. A proper understanding of this is essential for mined-land reclamation, channel modification for flood control and navigation, identification of areas of active tectonics and the litigation of boundaries etc. (Elliot, 1984). River channel morphology provide information on river characteristics and behaviour, infact, river morphology has been a subject of great challenge to scientists and engineers who recognized that any effort with regard to river engineering must be based on a proper understanding of the morphological features involved and the responses to the imposed changes (Chang, 2008). Examining river network behaviour enhances understanding of the way in which geomorphic processes behave across networks.

Several river condition assessment methods have been designed for countries worldwide; AusRivAS (Parsons et al., 2002), the Index of Stream Condition (Ladson and White, 1999; Ladson et al., 1999), the River Habitat Audit (Anderson, 1993) and River Styles (Brierley and Fryirs, 2005). River Styles for instance, provides a framework for assessing river condition using geomorphic criteria and achieves this largely by comparing the geomorphic character of reference reaches to test reaches of similar river types (Brierley and Fryirs, 2005). The investigation of river channel morphology and the attendant features is an interesting aspect of geomorphology which is of immense importance in understanding the processes affecting landforms. Therefore, geomorphic river condition assessments are valuable mechanisms for determining the present and future health of river systems (Maddock, 1999).

River morphology depicts the form of a river along its length and across its width and consequently its shape. River morphology is explained by channel patterns and channel forms, and is influenced by such factors as discharge, water surface slope, water velocity, depth and width of the channel, amount and size of the transported material, river bed materials, etc. These factors are not independent but inter-related to each other. Several studies had been carried out on the form and shape of river channels for instance, Soar et al., (2001 suggests that stream system adjusts in order to maintain a steady state, or dynamic equilibrium between the driving mechanisms of flow and sediment flow and the resisting forces of bed and bank stability and resistance to flow. Ward and D'Ambrosio (2008) in their study on stream classification identified factors that can influence channel morphology and concluded that channels with bedrock, have limited sediment supply whereas cobble and gravel bed channels are high energy channel with high sediment supply. Therefore, erosion instability, mass wasting and debris flow are more dominant processes as the bed material become finer and these affect channel morphology. They also emphasize slope as a major factor in channel morphology, as slope changes from upstream to downstream, an in relation the channel morphology also changes. Moreover, Montgomery and Buffington, (1997) emphasized that spatial variation is sediment supply may govern channel morphology in different segment of rivers. Channel response to increase sediment supply depends on the ratio of transport capacity to sediment supply. They linked the variables of channel morphology such as width, depth, bed slope grain size, bed forms and patterns to function of sediment supply, transport capacity and vegetation. Transport capacity in terms of frequency, magnitude, and duration of discharge and slope. Riparian vegetation also influences channel morphology in different ways. Vegetation protects banks from erosion and increases flow resistance by increasing roughness and reducing flow velocities so that channels with dense riparian forests tend to be narrower (Brookes et al., 2000). Moreover, vegetation on river banks and woody debris within the channel may act as sediment traps that create different channel morphologies and modify the channel type (Schumm, 2005). All these factors affect river channel morphology.

Over the last several decades, stream morphology researches has been undertaken by scientists in a wide variety of disciplines, yet our understanding of channel morphology, features and the factors influencing them is still incomplete. Most geomorphological investigations involving channel morphometry are concerned with the definition, measurement and analysis of quantitative indices describing the cross section, the bedform and long profile as well as the plan geometry of rivers (Goudie et al., 1990). According to Goudie (1990), morphology and particularly the cross section and plan-form properties of the channel has increasingly been linked to river flow characteristics which are also related to properties, quantities of bed materials and transported sediments.

Every river channel has its own characteristics that is unique in its own way and the dynamism involved in downstream river morphologic variables suggests the need for quantitative understanding of the behavior of river morphologic variables and this remains an important but yet elusive goal in fluvial geomorphology. Alluvial rivers are dynamic landforms subject to rapid change in channel shape and flow pattern. Examining alluvial river network behaviour enhances understanding of the way in which geomorphic processes behave across the channel. The variation in river channel morphology is a result of great range of hydrological conditions, sediment characteristics and geologic histories of the river. The nature of the materials through which a river flows initiates the three types of stream channels: bedrock, semi controlled and alluvial. Alluvial channel is composed of sediments transported by the river and it is susceptible to major morphologic change and to significant shifts in channel position as the alluvium is eroded, transported and deposited, and as the sediment load and water discharge changes. Since the alluvial section of any river is dynamic in nature in terms of its morphology, there is the need for a quantitative understanding of alluvial channel form and response to changes in governing conditions remains an important yet elusive goal in fluvial geomorphology (Fashae, 2011).

Analysis of river channel morphology appears to have been largely studied as many of the research efforts on river channels have focused almost exclusively on channel pattern (Ebisimiju, 1994; Holz and Baker, 1981; Beschta and Platts, 1986; Thorne, 1997; Friedman et al., 1996). Since, river channels show some common characteristics in areas of similar landform. The river channel as a subsystem and an important component of the river basin system deserves studying in some details to enhance river-basin management. This is the reason for examining some aspects of river channel morphology along the alluvial segment of River Ogun before empting into the Atlantic Ocean at the Lagos lagoon by analyzing the channel morphologic characteristics, interrelationship among the morphologic variables and the downstream variation for channel morphologic variables.

STUDY AREA

The Ogun River basin is located between latitudes $6^o33'$N and $8^o58'$N and longitudes $2^o40'$E and $4^o10'$E (Fig. 1). The catchment area is about 23,000km^2.

River Ogun takes its source from the Iganran hills at an elevation of about 530m above mean sea level and flows southwards over a distance about 480km, before it discharges into the Lagos lagoon. The lower River Ogun is defined for this study as the stretch from Mokoloki town to Isheri town downstream, especially areas underlain by sedimentary Abeokuta formation which consists mostly of sandstone of medium to coarse grain, poorly sorted and micaceous (Oyawoye, 1972). There are clay and mudstone intercalations; cross bedding is common and the rock is soft and friable, except where cemented locally by ferruginous materials. The main sedimentary rocks are the alluvial deposits, coastal plain sands both of Quaternary age. The choice of this portion of the Ogun River as the study site for this research work is based on the fact that most of the principal factors that control river geomorphology, namely: climate, geology, hydrogeology and relief, are relatively constant along the study segment of River Ogun coupled with the fact that the river is perennial in its flow.

The climate of the study area is controlled by the Inter Tropical Discontinuity (ITD). The ITD is an atmospheric zone between the maritime South West monsoon wind and the dry North East trade winds. This zone in West Africa moves with the location of the Sun in such a way that during the Southern summer, the ITD moves close to the coast and during the Northern summer, the ITD moves northwards to about latitude 14-15°N. As a result, the rainy and dry seasons are well marked. The rainy season begins earlier in the south where it lasts from March until the end of October or early November, giving at least seven months of rainfall. North of Oyo and Iseyin, the onset of the rains is delayed and generally begins late in April or early May and ends in mid-October (Ogun River Basin Development Authority, 1981). In late July and early August, dry days are prevalent and sufficiently regular to constitute what has been termed the "little dry season", with mean monthly figures below 100mm. The mean wet seasonal rainfall is about 1,015mm to 1,525mm in the Lower Ogun river and about 510mm to 1,525mm in the Upper (Ogun River Basin Development Authority, 1981). The actual number of rainy days ranges from 250-280 days. The mean annual rainfall of the study area ranges from 900mm to about 2000 mm (Ogun River Basin Development Authority, 1981). Temperatures are fairly uniform throughout the year with a mean annual of 26°C -27°C with an annual range of 5°C to 8°C while the relative humidity ranges between 60% and 80% (Ogun River Basin Development Authority, 1981). Annual evaporation rates are also high throughout the year, with monthly amounts varying from about 90mm in July to over

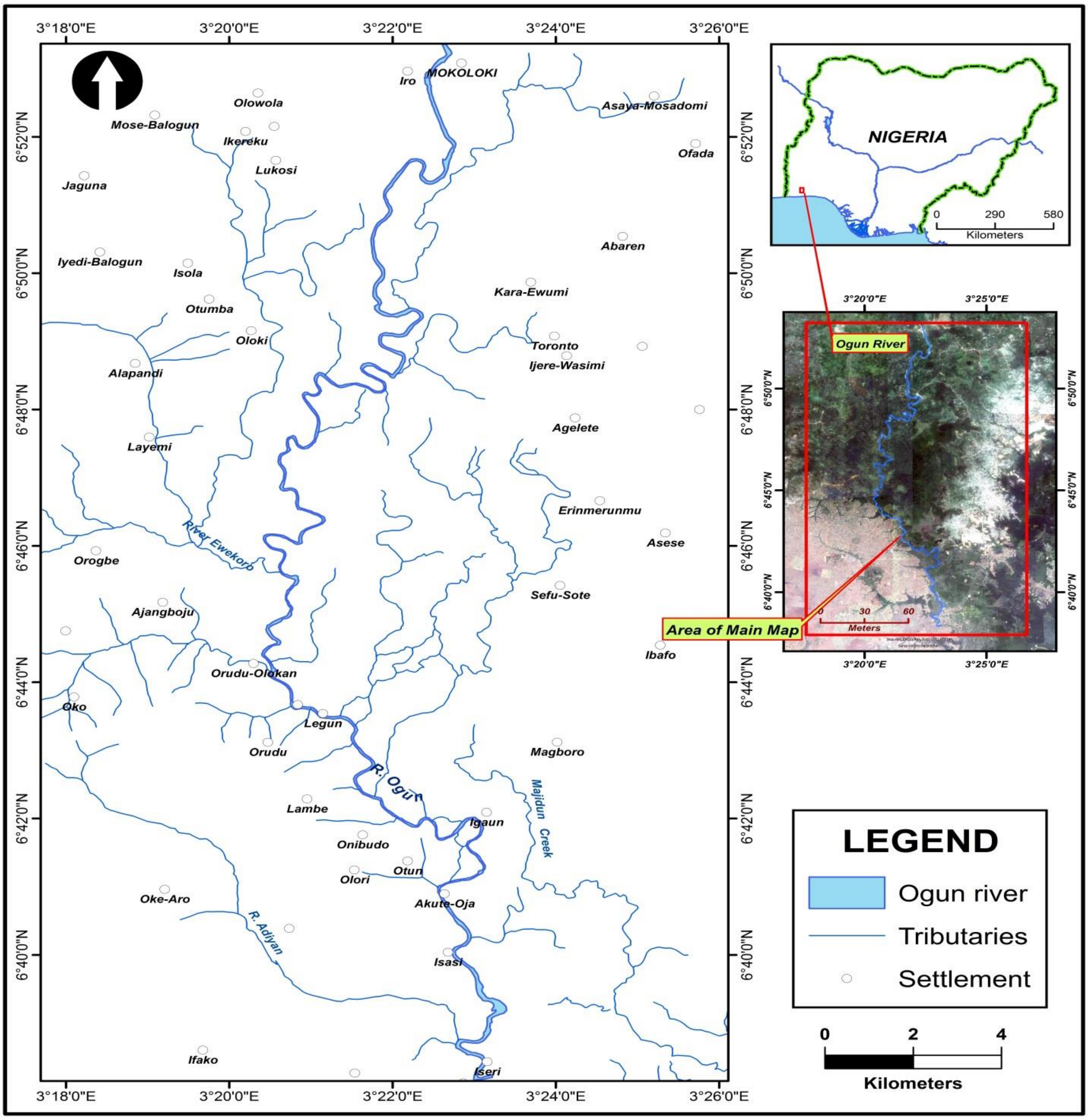

Fig. 1 Map of River Ogun showing the Alluvial River study Segment

130mm in January. The mean annual water surplus of the study area ranges from 254mm in the North to 508mm in the coastal belt. The total annual potential evapotranspiration is estimated at between 1600mm and 1900mm.

The Lower River Ogun is characterized by low slope angle and extensive floodplains with marshes and swamps. The total catchment of the lower Ogun is approximately 12,630km^2 while the length of the study stretch is approximately 90 km. The Lower Ogun Basin, where the study stretch lies has a mean slope of about than 3% and the landform consists of plains with straight and gently undulating topography. The general topography is characterized by a low, flat plain along the river, subject to frequent seasonal flooding and influenced by groundwater. For instance, at Mokoloki, the river bed sediments are coarser, making this section of the river channel relatively shallower and narrower, water being contained in less than 20% of the channel width while at the much lower section around Isheri, the channel is characterized with an average bankfull width of about 115.6m. Much as result of the downstream increase in the discharge and it subsequent production of alluvium that are mined for construction purposes. River Ogun basin comprises of two major rivers; Oyan and Ofiki at the upstream section, while other tributaries such as the Rivers Ewekoro and Adiyan are located at the lower extent of this study section (Fig. 1). Some of these tributaries are areic with no definite course. There is a lot of human influence on the river for instance, a number of portable water projects were mounted on the river for the provision of water to the rural populace. These include the mini water works at Akute (Fig. 2).

The drainage pattern of the river is dendritic in nature. Many of the subsequent and obsequent rivers and stream often dry up completely during the dry seasons while the consequent river (Ogun) often have reduced water level and discharge thereby leaving extensive floodplains and migratory bars at the sides. The lower River Ogun is characterized by a minimum discharge value of about 2.3m^3/s and a maximum values of 40 m^3/s at Akute . An increase in downstream discharge is indicative of the sudden change in the channel gradient due to the impoundment of water by barrage at Akute (Fig. 2). In addition, within downstream locations, further adjustments of the channel efficiency were achieved by the changing channel pattern of meanders and braids. This is evidenced with the occurrences of some fluvial forms such as ripples and pools sequences and formation of sand bars by the alluvium

MATERIAL AND METHODS

The morphological variables were evaluated for both the longitudinal and cross sectional profiles of the river to provide useful information on the state of the river channel at the time the study was carried out. The morphologic variables were collected through field survey where a total of forty-eight bankfull cross sections was unevenly surveyed at bankfull stage along the river channel stretch of 90 km. This is as a result of the occurrence of straight, meandering and braided channels along the river channel. The bankfull width and depth were also measured using automated SDE-28 ECHO depth sounder (sonar) whose visual interface was mounted in

Fig. 2 Barrage at Akute along River Ogun with the insert showing the width

the boat and the traducers was attached to the base of a moving boat, then suspended into the water to receive sound signal that translates into the depth values. The sonar machine has the capability of measuring the width perpendicular to the direction of the sounding from bank to bank. The depth values were collected at the centerline of the river. Bedload material was collected using the grab sampler technique by scooping the river bed to trap materials for its particle size at equidistant locations along the cross section. These materials were mixed together to obtain a composite representation of the cross section before taken to the laboratory for analysis using the hydrometer method. The coordinates of each cross section were recorded with the aid of an attached Garmin Global positing system (GPS). Beschta (1986) suggested that any attempt at characterizing channel morphology must recognize its three-dimensional aspects, therefore all the other channel morphologic variables, such as wetted perimeter, hydraulic radius and cross sectional area were calculated. Current meter was used to obtain measurements of the flow velocity from which the discharge of the river at each cross sectional point was estimated. Analysis of variance (ANOVA) that states that there is no significant variation in the downstream morphologic variables at 0.05 significant (α-) level was used to test for the variation of the downstream morphologic variables.

RESULTS

The longitudinal profile of Lower River Ogun

The alluvial section of the Lower River Ogun channel at bankfull stage suggests a concave-upward shape along its downstream gradient (Fig. 3), with an elevation of 29.7m above the mean sea level at Mokoloki located at a distance of about 10km downstream the studied segment of River Ogun while the elevation at Isheri is 8.1m above the mean sea level which is about 90 km downstream of Mokoloki, thus the river drops 21.6m along the studied reach. Hence, longitudinal zonation of channel forms may be recognized from the headwaters downstream to the river mouth.

It could be observed that there is a progressively lower gradient and an increase in the bankfull discharge as reflected the continuous addition of tributaries and increasing drainage area downstream. The profile is punctuated at knick points where the river cuts through valley floors as indicated at about 58km distance which is sharply defined due to human interference of the location of a barrage and sand mining activity respectively. The linear relationships that typically exists between gradient and downstream distance along the longitudinal profile of River Ogun reveals $R^2 = 0.49$, a value significant at 0.05 α-level with gradient accounting for 49% in the variation. The significance of the gradual lowering in the channel gradient provides explanation for the erosive and deposition work along the meanders and braided sections of the river and the plausible reason for the increase in fluvial landforms along the study stretch. Features such as ripples and pools sequence are evidenced at the concave and convex sections of these meanders which are interspersed by braids between the 10km to 40km downstream distance. These features are created by pattern scour and deposition at bankfull discharge where the riffles tend to occur at the inflection points and pools at bends. Also, oxbow lake, a lake with curved plan occupying cut-off channel reach that has been abandoned were encountered along the stretch while point bar deposits which are sediments laid down on the inside of meander bend largely by accretion are more pronounced.

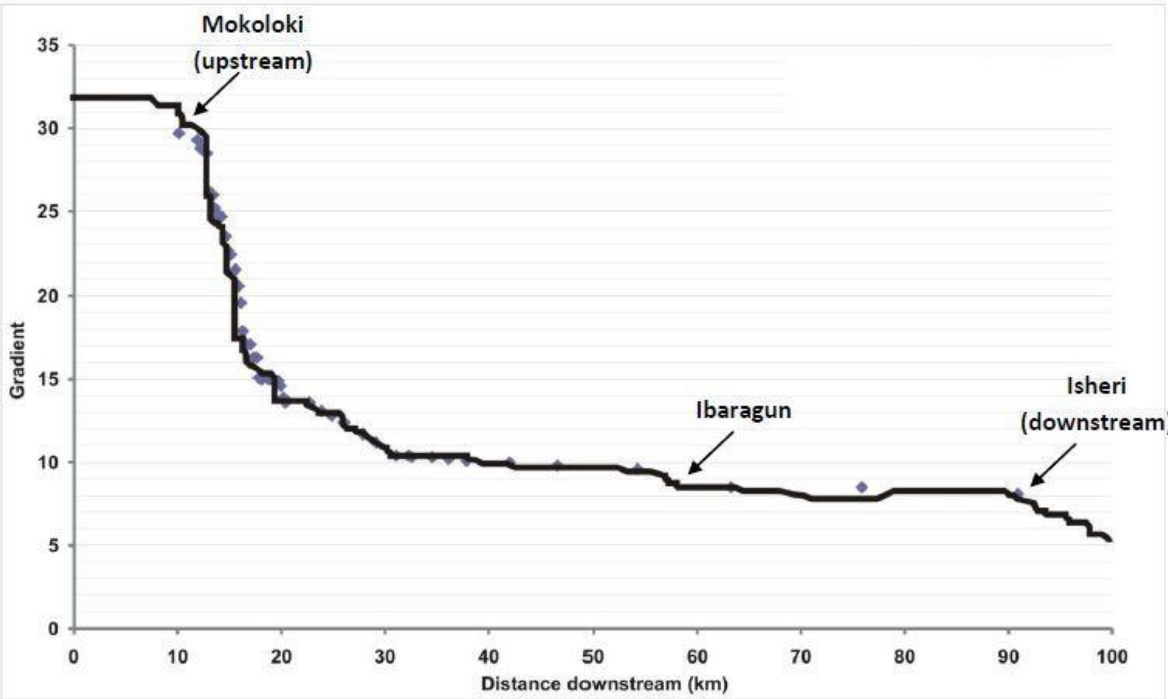

Fig. 3 Longitudinal Profile of Lower River Ogun

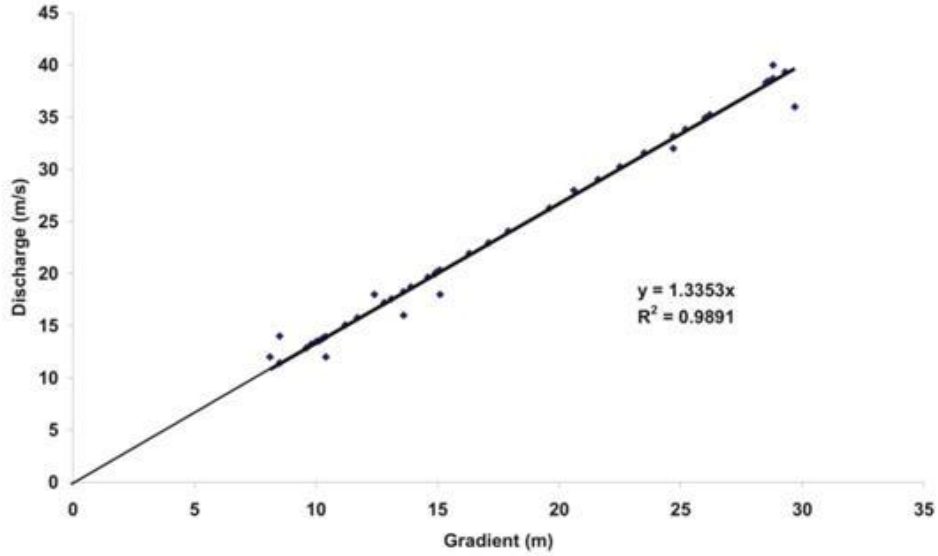

Fig. 4 Relationship between bankfull discharge and gradient along the Lower Ogun River Channel

number of factors are responsible for the concavity of river longitudinal profiles, notably the energy profiles best represented by the discharge pattern. This is evident from the linear relationships that typically exists between gradient and discharge along the longitudinal profile of rivers, which in this study reveals $R^2 = 0.98$, a value significant at 0.05 α-level (Fig. 4).

Variation of River Ogun Channel Morphologic Variables with Downstream Distance

River channel morphology of an alluvial channel reflects the movement of water and the particle size of the load flowing in it. The volume of water flowing within the channel together with the sediment load (dissolved and bedload) helps in shapening the channel morphology. A statistical description of each morphological variable along the channel is important as it provides a general summary illustration of the tendencies peculiar to the study (Table 1).

Depth and width are important variables of a river channel that suggests the morphology of any river. The maximum bankfull depth, which is indicative of the thalweg, or a line drawn to join the lowest points along the entire length of a riverbed shows that 4.3 m was the minimum point while the maximum was 9.6 m. The range of 5.3 m in the maximum bankfull depth indicated a wide gap between the deepest and the shallowest points along the thalweg from the centre line of the channel. However, the mean bankfull depths varied from a maximum of 7.4m to a minimum of 3.7 m. Figure 3 revealed that as the river tends towards reaching its mouth and with increasing distance downstream, there is an

Table 1 Morphological characteristics of the Lower River Ogun with the downstream analysis of variance (n =48)

Downstream variables	**Range (Min-Max)**	**Mean (standard deviation)**	**Downstream F-ratio**	**Variation (Significance value)**
Downstream distance from Mokoloki (km)	80.8 (10.1-90.9)	25.1(16.8)	-	-
Maximum depth (m)	5.3 (4.3-9.6)	7.7(1.2)	0.42	0.66
Mean depth (m)	3.7 (3.7-7.4)	6.0(0.8)	1.19	0.30
Bankfull width (m)	84.4(31.1-115.6)	59.8(15.3)	0.40	0.68
Width-depth ratio (-)	14.2(5.1-19.4)	10.2(3.2)	1.21	0.31
Crossectional area (m^2)	800.6(253.8-1054.4)	458.0(142.0)	0.08	0.93
Wetted perimeter (m)	86.3(47.6-133.9)	75.1(15.2)	0.30	0.74
Hydraulic radius	4.0(3.9-7.9)	6.0(0.8)	0.24	0.79
Discharge (m^3/s)	29.0(10.9-39.9)	2.3(9.1)	0.67	0.8
Particle size ratio	54.0(39.2-93.2)	71.3(14.4)	0.34	0.72
Bedslope (frictional slope)	0.4(-0.1-0.3)	-0.005(0.09)	91.18	0.0
Valley gradient	21.6(8.1-29.7)	17.0(6.7)	0.69	0.51
Velocity (m/s^1)	1.0(0.2-1.2)	0.5(0.2)	0.68	0.80

increase in depth which might be as result of the corresponding increase in downstream discharge except for the knick points that experience a huge increase in depth (Fig. 5). The knick points along the studied river section are indicative of accumulation of bedload at the barrage at Akute with an increase in gradient. Even though depth increases downstream, distance alone might not account for variation pattern observed (Fig. 6).

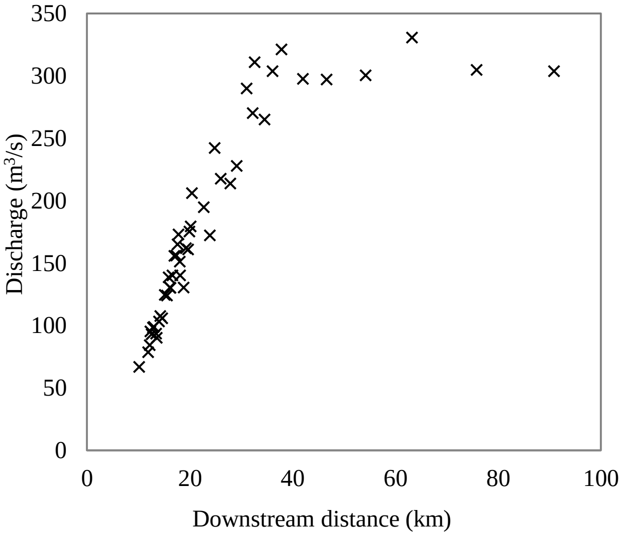

Fig.5 Relationship between discharge and downstream distance

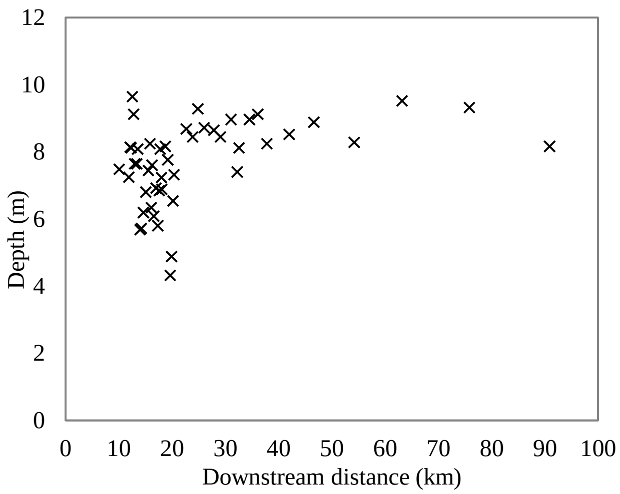

Fig. 6 Relationship between downstream distance and depth

The increase in depth suggests that there is a downstream increase in suspended sediment concentration which would invariably dampen turbulence (Merritt and Wohl, 2003). It was observed that there is a relationship between the particle size of the bed materials (mean=71.3) and the channel form with a decrease in size downstream. This accounts for wide, shallow and fine/smoother banks.

Theoretically, the bankfull width of a river is a function of its occurrence, magnitude of flow, type of transported sediment and composition of the bed and bank materials of the channel. The Lower River Ogun channel is characterized by a minimum bankfull width of 31.1 m, maximum bankfull width of 115.6 m and a mean of 59.76 m along the study stretch. Although river channel widths may generally increase downstream, a channel can still have a stable width even though the river is migrating laterally at a constant annual rate. As Clifton (1989) suggested, overall width, depth, and cross section area do not increase systematically downstream, while the spatial variability results from prevailing vegetation conditions. The width of a river can therefore remain relatively constant where erosion on one bank is compensated for by corresponding sediment deposition along the opposite bank. This is evident in some sections of the river where there are widths changes due to their response to the fluctuation in the rainfall amount and intensity that encourages the formation of migratory sand bars along this alluvial river (Fig. 7)

However, the downstream increase in width may be attributed to the composition of the bed and bank materials of the river channel. This could be linked to removal of the riparian vegetation for active farming activities (Fashae, 2011).

In summary, the morphologic characteristics of the river channel vary at different points along the river segment. This variation is indicated in the differences in values of the variables observed from the cross sections of the river. In order to provide an understanding of the variability of the channel morphologic factors in the study area, investigation of the spatial variations of the channel form variables along the downstream was carried out. The results revealed that variations occurred in virtually all the parameters downstream as reported in Table 2 where the analysis of variance for all the channel form variables indicated that there are variations. The F ratio which implies the extent of variation showed that the bed slope (F ratio 91.18 was the most variable downstream among the morphologic parameters considered followed by width depth ratio (1.21), while the cross-sectional area is the least variable with an F ratio of 0.08. The bed slope with F ratio as high as 91.18 is the most widely varied downstream, less variations occur in particle size ratio downstream with F ratio of 0.34. However, only the variation in bed slope reflected a statistical significant difference at 0.05 α-level while all other parameters varying downstream albeit with no statistical variations. This can be attributed to the fact that the study was carried out within a definable reach that is, along the alluvial segment (5^{th} order) of River Ogun. The significant variation in bed slope was however attributed to the rapid changes in the work of the river downstream, since the discharge increases systematically downstream, it is not unreasonable to expect the down cutting of the river channel bed changing as the flow, erosion and deposition actions changes, even within the same reach of the river. Furthermore, the finding that the bed slope and width depth ratio were the most variable morphological parameters along the 5^{th} order section of the River

Fig. 7 Migratory sand bars along the Lower River Ogun channel

Ogun channel was instructive because the two are about the best variables conceptually considered to describe the changes in channel shape. The increment in width depth ratio as the river flows towards its mouth is represented in Fig. 8.

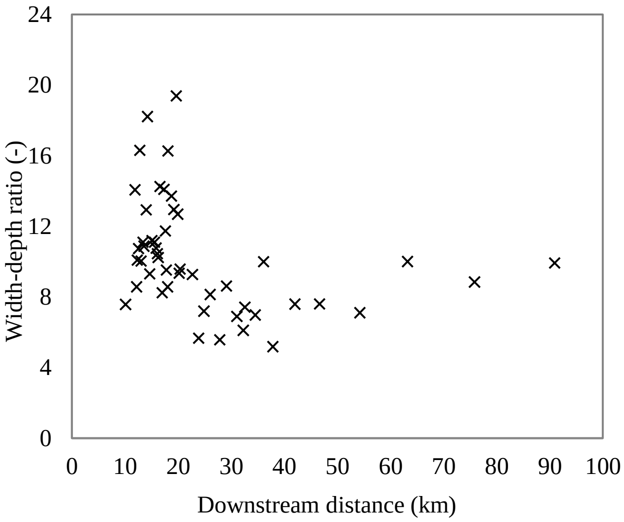

Fig. 8 Relationship between width depth ratio and downstream distance

Interrelationship among River Ogun channel morphologic variables

The interrelationship among channel morphologic variables along the alluvial section of the River Ogun was investigated using correlation analysis, to test the relationship occurring among the channel form variables. This technique deals with associations between two or more variables providing measures of the strength of association and statistical tests of its significance. The Pearson's product moment correlation method which considers parametric relationships was employed because the morphologic variables were measured at random intervals. This relationship was particularly considered with reference to the distance downstream, the result of which is reported in Table 2.

The width depth ratio at any point along the River Ogun channel was expectedly most influenced by the bankfull width with a correlation of 0.9 significant at 0.05 α-level while the wetted perimeter had a correlation of 0.8. The cross sectional area had a correlation of 0.9; the hydraulic radius dependent on the bankfull depth (maximum and mean) and the cross sectional area had correlations of 0.9 and 0.8 and 0.78 respectively.

In addition, as the river channel tends to near its mouth, the discharge, gradient and the flow velocity all reduces in magnitude. The width depth ratio, the bankfull width, wetted perimeter and the hydraulic radius also changes significantly as revealed from the multivariate graph in Figure 9. As the width depth ratio and the bankfull width increases towards the mouth of the river, the hydraulic radius decreases.

These were detected along the section investigated in this study to reveal negative correlation of -0.36 and -0.34 between downstream distance and bankfull width as well as width depth ratio respectively, significant at 0.05 α-level occurs, while a similarly positive correlation of 0.23 occurs between downstream distance and the hydraulic radius. This implies that the portion of the river distinctively describes the width, depth and hydraulic characteristics of River Ogun channel.

Downstream of River Ogun suggests that there is a reduction in the channel boundary resistance due to alluvium along the banks, while the channel-bed materials become slightly fine grained. The channel bed is composed of fine sand particles and the banks are mainly non-cohesive (Miller, 1956). The substantial changes observed in the correlation matrix has been reported in other studies including pattern changes

Table 2 Correlation matrix of downstream channel morphologic parameters

	Distance downstream	Maximum bankfull depth	Mean bankfull depth	Bankfull width	Width-depth ratio	Cross sectional area	Wetted perimeter	Hydraulic radius
Distance downstream	1							
Maximum bankfull depth	0.41	1						
Mean bankfull depth	0.08	0.82	1					
Bankfull width	-0.36*	-0.12	0.00	1				
Width depth ratio	-0.34*	-0.56	-0.55	0.90*	1			
Cross sectional area	-0.10	0.46	0.48	0.82*	0.39	1		
Wetted perimeter	-0.30	0.04	0.13	0.80*	0.73*	0.90*	1	
Hydraulic radius	0.23	0.90*	0.80*	0.30	-0.22	0.78*	0.45	1

*Correlation significant at 0.05 α-level

(Graf, 1988a), substantial widening (Burkham, 1972; Osterkamp and Costa, 1987; Kresan, 1988) and lateral migration (Graf, 1983b), entrenchment (Graf, 1983a) and floodplain erosion and deposition (Wells, 1990; Zawada and Smith, 1991).

DISCUSSION AND CONCLUSION

Rivers from source to mouth show a great variation in morphological characteristics such that the size and shape of the channel readily describes the section of the river. From the study, it can be inferred that among the eight morphological variables studied. The bankfull width and the depth of the channel indicate the most significant attribute of the channel form. The width depth ratio and bed slope were found to be the most variable morphological parameters along the studied channel. This is instructive because the two are the best variables conceptually considered to describe the changes in channel shape. The ratio of stream channel length to down-valley distance, which was measured on the long profile of the River Ogun, indicated the stream type (alluvial) and how the stream channel slope was adjusted to that of the valley slope. The interrelationship among channel morphologic variables along the alluvial section of River Ogun revealed that both the width depth ratio and the cross-sectional area at any point in the channel

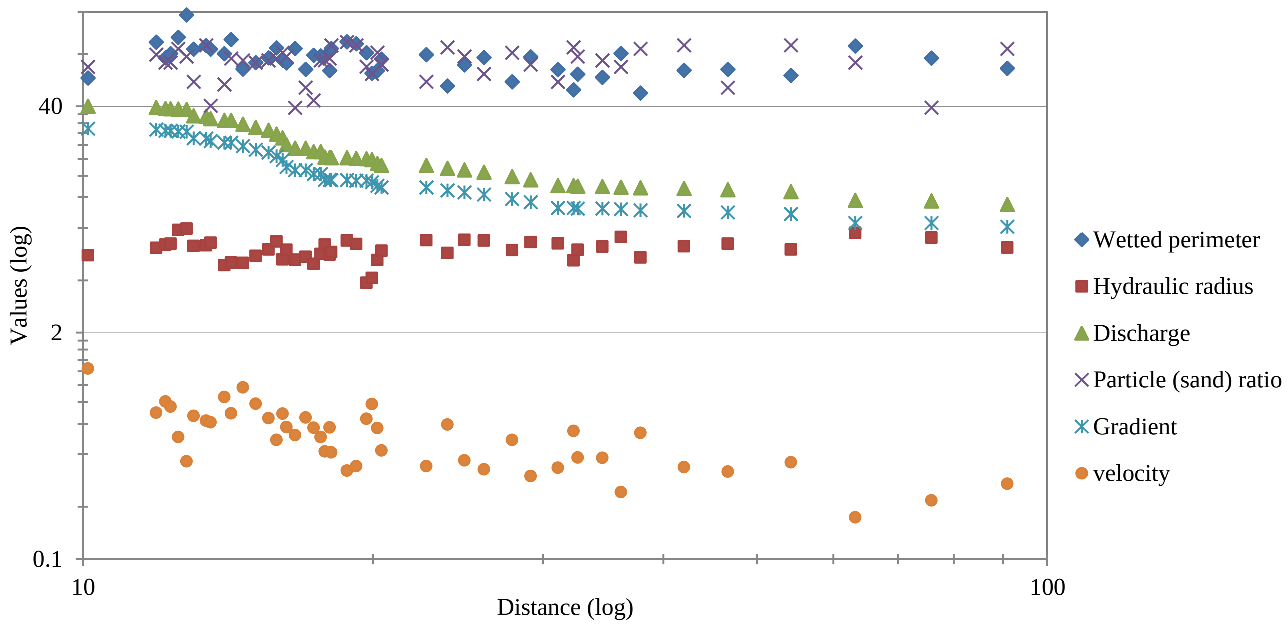

Fig. 9 Downstream pattern of the morphologic variables along the Lower River Ogun

were most influenced by the bankfull width with a correlation 0.82 significant at 0.05 α-level. Also, the wetted perimeter was equally related to the bankfull width with a correlation of 0.8 and the cross sectional area with a correlation of 0.8, the hydraulic radius was found to be dependent on the bankfull depth (maximum and mean) and the cross sectional area from a correlation of (0.9 and 0.8) and 0.78 respectively. The gradient of the channel most perfectly affects the discharge with a positive correlation of 0.9 significant at 0.05 α-level. The downstream increase in channel width might be due to the loose bank materials which reflect on the bank cohesion and roughness of the channel. The river discharge which is closely related to the flow velocity and the channel cross sectional area summarizes the processes occurring within the alluvial section of the River Ogun channel and resultant fluvial features, such as braids, incised meanders, point bars, riffles and pools.

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