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Geological Processes, Statistical Characterization and Downstream Fining of Alluvial Sediments of River Osun, Southwestern Nigeria

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Abstract

The geological processes, statistical characteristics and downstream fining of River Osun in southwestern Nigeria were studied. The objectives were to determine the variation in particles sizes, contributory effects from tributaries and, to determine the deposition characteristics of these sediments. A total of 10 samples were collected along the River Osun, from Osogbo to Omitutu, covering a total distance of 140 km. Sampling was done within the river bends, meanders and exposed bars adopting purposive sampling method. Each sample was washed, through 0.063mm sieve and mechanically sorted into a set of US mesh sieves of 2.360, 2.00, 1.00, 0.50,.250, .125 and 0.063 mm and a receiving Pan (Wentworth Classification) using a Ro-tap shaker in Soil Mechanics laboratory, at National Water Resources Institute, Kaduna. The various percentiles were calculated. The graphic mean of River Osun sediments range between -0.7 to 0.93ф with an average of 0.07ф. This indicates: a very coarse to coarse sand. It contains 40.79% fine gravel, 20.90% coarse sand, 21.29% medium sand and fine sand account for 16.90%. This showed that particles are carried as bed load and are either close to their source or there were mixing from tributaries. The sorting varied from 0.74 to 1.25 ф, with an average of 1.26 ф. It indicates a moderately to poorly sorted sand, which implies a rapid deposition or lateral addition of sands from other sources. The skewness values range from -0.06 to 0.42 ф (platykurtic to leptokurtic). This is a reflection of the flow characteristics of the deposition medium from low to high kinetic of energy of sediment transport causing deposition. The downstream fining showed a virtual departure from and exponential order; the effect could be attributed to the lateral addition/mixing, as well as anthropogenic factors like construction of dam, irrigation, and sand dredging along the channel. This study could be applied in the study of transportation and sizes of heavy minerals along the channel of River Osun.

Keywords: Sediments, Weathering, Mechanical shaker, Sorting, Fining

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INTRODUCTION

Earth's surface is in dynamic equilibrium, as a result of the balance between the internal geologic processes which create earthquakes, volcanic activity, mountain ranges and the external geologic processes that responsible for shaping and modifying the land relief, through weathering, erosion, transportation and deposition. The geologic agents of achieving these are the wind, water, living beings and gravity. Physical weathering produces mechanical breakdown of rocks into smaller fragments, whereas chemical weathering produces chemical decomposition of rock-forming minerals into different materials (Gurer, 2007). These terrigeneous sand-size particles consist of small rock fragments or crystals, silicates and quartz being the most common form. Feldspar follows silicates in abundance. Silicates are abundant crustal minerals and also the most solution-resistant, and remain intact after the surrounding rock matrix has eroded or dissolved away (Morris,*et al*.,1998). Bed sediment tends to decrease in size systematically with respect to distance downstream. Also, as the distance increases downstream, the channel size and discharges it carries increase; whereas the channel slope and bed material size decrease (Church, 1992).This reduction in particle sizes is known as downstream fining. It has been observed frequently in gravel-bed rivers (Kodama, 1994; Bluck, 1999; Gomez *et al*., 2001; Surian, 2002) and documented in large sand-bed rivers through modeling (Frings, 2008).It follows exponential decay order (but with no lateral sources of coarse sediments, (Shaw and Kellerhals,1982).The degree of downstream fining in sand-bed rivers is strongly influenced by the sediment distribution at upstream-located river bifurcations, tributaries, and other lateral sources. Some factors that determine whether a tributary will change the bed material characteristics are the size of the tributary as well as the differential size of the material carried within the tributary (Knighton, 1980), response to anthropogenic intervention in the fluvial system. Some researchers have attributed downstream fining to process of selective sorting (Ferguson and Ashworth1991; Paola *et al*,. 1992; Seal *et al;* 1997) and abrasion (Werrity 1992; Kodama 1994). Three mechanisms contribute to downstream fining are abrasion, hydraulic sorting or transport, and in-situ weathering (Knighton, 1998).

Breakdown and abrasion of sediment particles include both mechanical and chemical processes (Stralen, 1999). Breakdown involves both; whereby particles are reduced in size by wear either during transport or by in situ oscillation ("abrasion in place") (Hoey and Ferguson, 1994). Historically, downstream fining has been attributed to particle abrasion (Powell, 1998). According to (Murillo, 1998) abrasion processes include mechanical erosion mechanisms (splitting or breaking, crushing, chipping, cracking, grinding and sandblasting) and chemical processes (chemical attack). However, when a river bed contains a mixture of lithologies the more durable grains will act upon less durable grains until the less durable grains disintegrate (Abbott & Peterson, 1978). When such grain sizes are analysed, they could be used to determine the textural characteristics of sediments as all environments have their own signatures imprinted to depict different stages of denudational activities (Riyaz and Jeelani, 2015). It also provides important clues to the sediment provenance, transport history and depositional conditions (Friedman, 1979; Bui *et al*., 1990). The purpose of this study is to examine the geologic processes and downstream fining as well as sorting and grading characteristics of sediment of River Osun.

The objectives are to: determine the textures and variation of particle sizes along the river channel; examine the contributory effects of tributaries along the channel to sorting, grading, fining of particles; and to determine the deposition characteristics of these sediments.

The study Area

The study area is River Osun. It bears its origin form Igede Ekiti ($8^0$20'N $5^0$16'E) in Ekiti State flow through Ilesha forest before winding its way westwards through Osogbo and Ede, and then flow southwards through many agricultural plains and cities of about 273.5 km (NBS,2012) before discharging to Lekki lagoon (Olaniyan, *et al.,* 2018).Along its part, it has several tributaries in which their respective locations are shown in brackets: Asejire (Ikire), Osun (Ede), Gbodofon (Osogbo), Ahoyaya (Ikirun), Isin (Iree) , Oyi (Oke-Ila), Osin (Ila-Orangun), etc. (Olayiwola,*et al*.,2019),(Fig. 1).

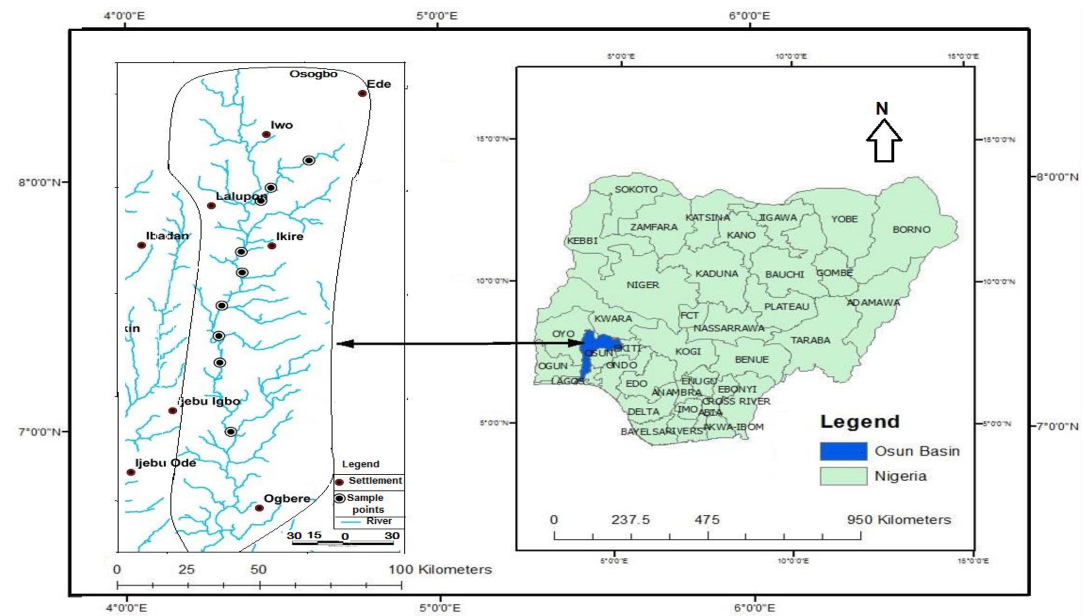

Fig. 1 Location map of study area showing sample points along the course of River Osun

Geology of the Study Area

Osun State is underlain by Pre-Cambrian-Cambrian rocks which comprises of migmatite, gneisses, schist and quartzite with pockets of granitic and, to a lesser extent, more basic materials (Rahaman,1981). The Basement Complex have been subjected to deformation during several orogeny cycles and it is difficult to differentiate between structures belonging to the separate periods of deformation (Fig.2).

Minor folds are very common in the gneiss and schists and from all available evidence (Rahaman, 1974), the basic geological structure of South-Western Nigeria is a complementary anticlinorium and synclinorium with northwards plunging axes. The quartzites did not escape the folding and refolding episodes which affected the entire region (Ajayi and Adegoke-Anthony, 1988). Foliated older granites have been found in places such as Iwo, with disordered arrangement of its feldspars are usually non-foliated. Rocks of Iwo area have magmatic, granitic, pegmatitic, and aplitic intrusions in the large Iwo-Ikire complex (Hubbard, 1975).

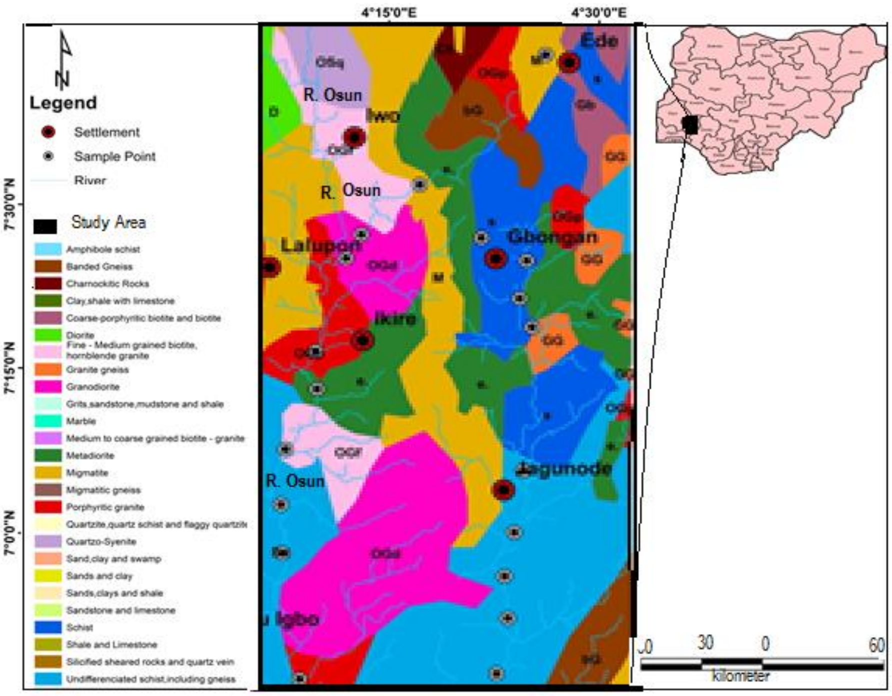

Fig. 2 Geological map of River Osun and its catchment area

Except for the hilly areas east of Ikirun,Oyan, Oke-Ila, the depth of weathering is considerable and probably extends to over 30m in places. The main effects of weathering are kaolinisation of the feldspars and leaching of the mobile constituents to form laterites at the top of the profile. The colour and composition of the laterite depend on the nature of the parent rocks.

MATERIALS AND METHODS

Sample collection

A total of 10 samples were collected along River Osun main channel between Osogbo to Omitutu area in south-western Nigeria in January 2024, (Fig.1).The purposive sampling method was adopted, in this case samples were collected from the exposed point bars or inside bends of a river meander or behind the boulders and in still water close to edge or border where water meets the land (within successive depths of 2.0-10.0cm; 10.0cm -20.0cm;20.0- 30.0cm) by scooping with a hand trowel covered with polythene to prevent washing away of fines. Other precautions and procedures adopted were as given in ASTM D75- a guiding principle in the sampling procedure.

About 5.0kg of wet sediment were collected in polythene bag from each location, these were then labeled with their code (e.g. OS 01 representing River Osun location 1), and coordinates recorded. The distances of sampling between one location and the other vary from 100m to 4000m, because of problem of accessibility and insecurity in some of the areas. These were later transported to Soil Laboratory of the National Water Resources Institute, Kaduna for analysis.

Laboratory Analysis

About 500 g of each sample was weighed and washed through sieve 0.063mm. After which the samples were dried in oven at 105^{o}C for 24hrs. Each sample was then split into quarters and 250g of sand was weighed in a meter balance (P20 model) with a precision 0.011g. Each sample was then mechanically sorted into a set of US mesh sieves of 2.360, 2.00, 1.00, 0.50,.250, .125 and 0.063 mm and a receiving Pan (Wentworth Classification) using a Ro-tap shaker. The fraction retained in each sieve and the pan was weighed in a balance and its weight recorded and tabulated.

The individual, as well as the cumulative weight percentage, was calculated and recorded. The phi values of the following percentile; 5%, 16%, 25%, 50%, 75%, 84% and 95% were read off from the curve (Fig.4, Tables 1,2,3). These were used to calculate the statistical parameters of standard deviation, skewness, kurtosis, mean and median as shown below. Equations 1-4 (Folk & Ward, 1957), are used to derive the various grain size parameters.

Graphical mean Mz= $\frac{\Phi(16+50+84)}{3}$……………………………………………………….……(1)

2) Inclusive graphic standard deviation (sorting)$\frac{\Phi(84-16)}{4}+\frac{\Phi(95-5)}{6.6}$……………….……..…(2)

3) Inclusive graphic skewness $S_k=\frac{\phi16+\phi84-2\phi50}{2(\phi84-\phi16)}+\frac{\phi5+\phi95-2\phi50}{2(\phi95-\phi5)}$……………………..……..….(3)

4) Graphic Kurtosis $K_G=\frac{\phi 95-\phi5}{2.44(\phi75-\phi25)}$…………………………………………………..(4)

Where Φ5, Φ16, Φ25, Φ50, Φ75, Φ84, and Φ95 repreents 5th, 16th, 25th, 50th, 75th, 84th, and 95th percentile respectively.

RESULTS AND DISCUSSION

The statistical parameters obtained from grain size analysis for 10 sediment samples were used for determining textural attributes-sorting, skewness, kurtosis and fineness ratio along the channel, using various percentile values. These are presented in Tables 1-4 below.

Table 1: Sampling interval and ratio of coarse to fine fractions along River Osun channel

S/N	Sample Code	Longitudes	Latitudes	Location Names/Nearby Locations	Sample Interval (Km)	Cum. Dist. (km)	% Coarse Sands	% Fine Sands	Coarse/ Fine
1	OS01	E04^0 24′ 51″	N07^{0}44′39″	Osogbo	0.0	0.00	15.27	49.38	0.31
2	OS02	E04^0 15′ 28″	N07^{0}34′24″	Ada Area	34.36	34.36	63.77	27.83	2.29
3	OS03	E04^0 11′ 07″	N07^{0}30′29″	North of Olode	14.04	48.40	46.09	42.02	1.09
4	OS04	E04^0 09′ 58″	N07^{0}28′37″	Lalupon	4.43	52.83	34.85	46.34	0.75
5	OS05	E04^0 07′ 42″	N07^{0}21′16″	Ikire	21.04	73.87	19.5	53.81	0.36
6	OS06	E04^0 07′ 48″	N07^{0}18′17″	Akinwande	7.68	81.55	37.91	30.55	1.24
7	OS07	E04^0 05′ 27″	N07^{0}13′32″	Olokuta	11.85	93.40	40.12	45.77	0.88
8	OS08	E04^0 05′ 06″	N07^{0}09′10″	Daramola	9.50	102.90	27.35	50.32	0.54
9	OS09	E04^0 52′ 08″	N07^{0}05′19″	Bolorunduro area	11.23	114.13	55.72	25.51	2.18
10	OS10	E04^0 06′ 27″	N06^{0}55′21″	Omitutu	26.60	140.73	40.32	37.3	1.08

Table 2: Particle size distribution of River Osun, southwestern Nigeria

Wentworth classification	Fine gravel	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	% Error
Phi scale	-1.239	-1.000	-0.239	0.234	1.235	1.737	3.989	
Particle size (mm)	2.360	2.000	1.000	0.500	0.250	0.125	0.063	
OS01	0.574	2.799	13.494	34.766	30.322	16.459	1.585	0.28
OS02	39.985	8.389	15.405	8.389	19.601	5.722	2.509	0.39
OS03	22.974	6.024	17.090	11.487	28.997	8.545	4.483	0.01
OS04	16.394	7.948	10.504	18.807	23.420	6.955	15.969	0.28
OS05	6.116	3.380	10.007	26.685	21.125	3.780	28.908	0.41
OS06	16.768	7.858	13.281	31.544	14.942	12.286	3.320	0.36
OS07	11.343	9.029	19.751	14.108	11.850	25.169	8.747	0.40
OS08	13.716	4.466	9.170	22.328	27.113	5.662	17.544	0.20
OS09	36.607	7.205	11.912	18.768	13.945	1.104	10.459	0.41
OS10	5.129	2.835	32.359	22.381	20.515	2.798	13.988	0.40

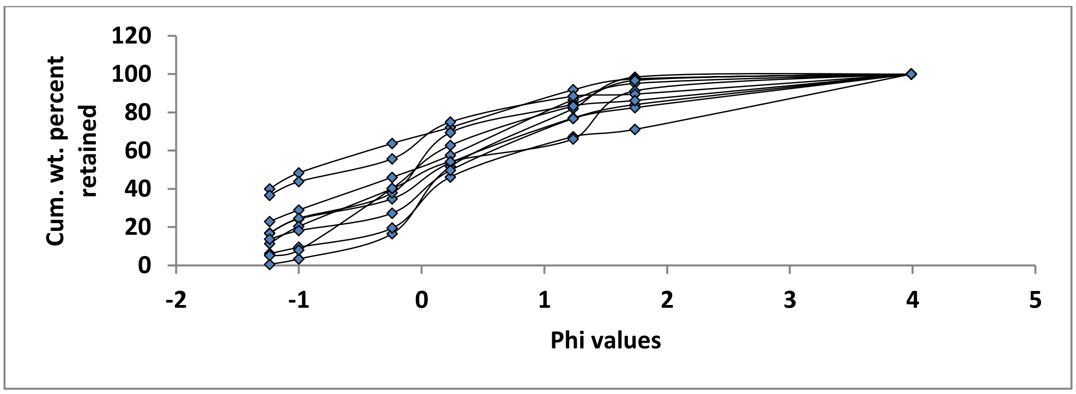

Fig. 3 Grain size distribution curves for all the Ten samples along River Osun channel

Table 3: Percentile values of sediment texture of River Osun

	LOCATION	5%	16%	25%	50%	75%	84%	95%
O	OS01	-0.8	-0.2	-0.1	0.23	1	1.3	1.6
S	OS02	-2.2	-2	-1.7	-1	0.4	0.8	1.5
U	OS03	-2	-1.4	-1.2	0	0.9	1.1	2
N	OS04	-1.6	-1.2	-0.9	0.1	1.2	1.7	3.2
	OS05	-1.2	-0.4	-0.1	0.4	2.1	2.8	3.6
R	OS06	-1.5	-1.3	-1	0	0.4	1.2	1.6
I	OS07	-1.4	-1.2	-0.9	0.1	1.3	1.4	2.4
V	OS08	-1.6	-1.2	-0.2	0.2	1.2	1.7	3.4
E	OS09	-2	-1.8	-1.6	-0.6	0.2	0.8	2.9
R	OS10	-1.3	-0.8	-0.6	0	0.8	1.3	3.2

Table 4: Summary of results of the statistical parameters for River Osun

LOCATION	MEAN	MEDIAN	SORTING	SKEW NESS	KURTOSIS	INTERPRETATION
OS01	0.44	0.23	0.74	0.28	0.89	Moderately sorted, coarse skewed, mesokurtic
OS02	-0.73	-1.0	1.26	0.32	0.72	Poorly sorted, very coarse skewed, platykurtic
OS03	-0.10	0.0	1.23	-0.06	0.78	Poorly sorted, nearly symmetrical, platykurtic
OS04	0.20	0.1	1.45	0.19	0.94	Poorly sorted, coarse skewed, mesokurtic
OS05	0.93	0.4	1.53	0.42	0.89	Poorly sorted, very coarse skewed, platykurtic
OS06	-0.033	0.0	1.09	-0.003	0.91	Poorly sorted, nearly symmetrical, mesokurtic
OS07	0.10	0.1	1.23	0.11	0.72	Poorly sorted, coarse skewed, platykurtic
OS08	0.23	0.2	1.48	0.16	1.46	Poorly sorted, coarse skewed, mesokurtic
OS09	-0.53	-0.6	1.39	0.25	1.12	Poorly sorted, coarse skewed, leptokurtic
OS10	0.17	0.0	1.21	0.33	1.32	Poorly sorted, very coarse skewed, leptokurtic

DISCUSSION

The mean value of the sediment

The breakdown (from Table 1) shows that 40.79% of the sediments are fine gravels, 20.90% coarse sands, 21.29% medium sands, while fine sands account for 16.97%. Averagely, it is essentially coarse sand. The mean values range between -0.7 to 0.93 ф with the average value of 0.07ф. This shows that these sand particles are transported as bed load. According to Visser (1996), sediment mean size which is lower than 3.5 ф will travel as bed load, while the sediment with mean size which is higher than 3.5 ф will travel as suspension loads. It is also an indication that the sediments are close to the provenance or the source rocks contains highly resistant minerals that can withstand long abrasion. Granite with large phenocrysts for instance weathers into larger mineral fragments compared to schist that compose of small mineral grains (Schaetzl & Anderson, 2005).The range of mean values also reduces along the channel, which is an indication that grain sizes reduces along the channel (Fig. 4).

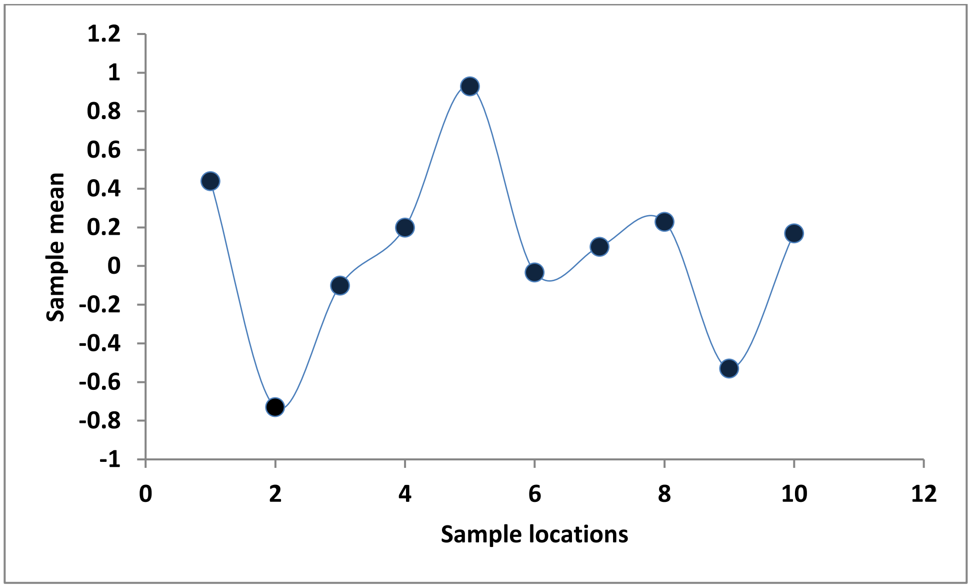

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Fig. 4 Variation of mean with locations

Sorting: Sorting varies from 0.74 to 1.25 Φ, with average value of 1.26 Φ .It indicates moderately sorted to poorly sorted. Poorly sorted sediments may indicate rapid rate deposition (Tijani and Nton 2009); as sorting gives hint to the energy conditions of the transporting medium from which the sediment was deposited (Atat *et al*.,2021). It could be an indication of short transportation from origin or a lateral addition from tributaries/ or absence of certain size ranges in the provenance (Weltje *et al*., 2007; Ajaegwu *et al*.,2015; Ahmed *et al.,* 2017).(Fig.5).

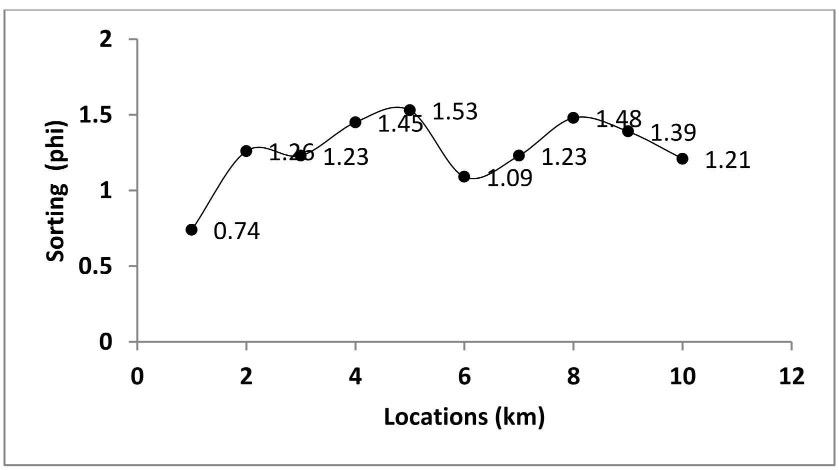

Fig. 5 Variation of sorting with locations

This indicate moderately well sorted to poorly sorted sediment. This variation in sorting values is likely due to continuous addition of fine or coarser materials in different proportion (Manivel *et al.,* 2016). The anthropogenic influence (sand mining activities and construction of dams) could also contribute to the scenario.

Table 5. Summary of Textural Factor of Sediment of River Osun

Grain parameters	Graphical Mean (Φ)	Median (Φ)	Standard deviation Sorting (Φ)	Graphical Skewness (Φ)	Kurtosis (Φ)
Min.	-0.73	-1.00	0.74	-0.06	0.72
Max	0.93	0.40	1.53	0.42	1.46
Average	0.07		1.26	0.19	0.98
Interpretation	Coarse sand		Moderately sorted to poorly sorted	Very coarse skewed to fine skewed	Platykurtic-Leptokurtic

Graphical Skewness

This is the percentage of coarse or fine fractions. It is a statistic for symmetrical distribution. A symmetrical curve indicates a zero value. The negative values denote coarser tail (coarse skewed) which is correlated with high energy and winnowing action (removal of fines); the positive values represent more fine material in the fine tail (that is fine skewed) and have to do with low energy levels (accumulation of fines) (Maity and Maiti, 2016).The skewness values range from -0.06 to 0.42 Φ, with an average of 0.19 Φ(Table 5). It indicates a very coarse skewed to fine skewed sand along the channel. It is an indication of fineness as movement progresses.

The graphic kurtosis

This measures the degree of flatness or peakedness of the grain size distribution curve. The Kurtosis values of the samples analyzed vary from 0.72 Φ to 1.46 Φ (platykurtic to mesokurtic), with an average of 0.98 Φ (Table 5). The leptokurtic nature of the curves indicates relatively better sorting at central portion of the distribution than at the extreme and peaks taller than that of normally distributed curve. This implies a varying (low to high) energy environment of deposition.

Downstream fining

The sampling of sediments covers a winding course of about 140km between Osogbo and Omitutu. The ratio of coarse sands to fine sands plotted against the distance is shown in Fig.6. These vary along the channel. It shows a complete departure from grain size fining discerned "Stenberg‟s law" whereby grain size decreases with increasing distance downstream. This effect could be due to lateral addition/mixing from more than 25 tributaries (Olayiwola *et al.,* 2019) discharging into River Osun. These rivers traverse different local geology of their sub-catchment areas. The lateral input could also be from outcrops of non-alluvial sediments (Werritty, 1992; Rice, 1999) and mass movements from slopes into the channel (Brierley and Hickin, 1985).

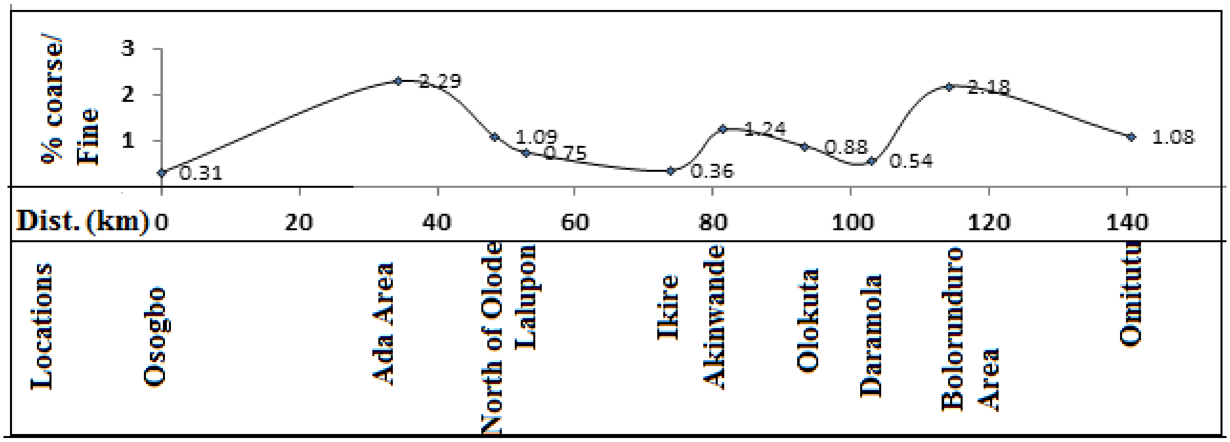

Fig. 6 Downstream fining along the channel of River Osun

CONCLUSION

Surface geological processes unlock mineral potentials of any environment. Sediments may be released to stream by weathering, erosion and transportation. The textural characteristics, mechanisms of deposition and depositional environment along River Osun channel studied through particle size analysis shows that the sediment are averagely coarse, poorly sorted and skewed from very coarse to fine skewed, with kurtosis varying from platykurtic to leptokurtic. The coarseness is from the weathering of the Crystalline Basement Complex rocks which underlain 93.32% of the Osun drainage basin. The energy of deposition varies from high to medium. This implies that after the storm, deposition still continuing. The percentage of coarse or fine fractions also showed a departure from exponential decay. This was attributed to lateral addition, mixing from about 25 tributaries, anthropogenic activities such as construction of dam, sand mining and other land use along the River Osun channel. This method of study can be adopted to study the dispersion of heavy minerals from their provenances; as heavy mineral grains are also susceptible to mechanical abrasion.

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