Engineering Properties of Textile Contamined Sediment: A Case Study of Oke-itoku River, Abeokuta Nigeria

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ABSTRACT: This work investigated the engineering impact of textile effluents contamination on sediments of the Oke-Itoku River. Sediment samples were collected from three segments along the River: River Source (RS), Non-Textile Polluted (NTP) and Textile Polluted (TP) segments. Sieve analysis of sediment samples was conducted. Direct shear strength at a constant displacement rate of 1.25 mm/min for three variations of normal stress (50 KN/m^2, 100 KN/m^{2}and 150 KN/m^2) was carried out. Compressive strength properties of sediments for the River sections were evaluated using their sediments as fine aggregates at consolidated-drained condition, 1:2:4 mix ratio and 60% water-cement ratio. The sieve analysis showed uniformity in the particle size distribution. Highest maximum shear stresses of 34.3 KN/m^2, 62.5 KN/m^2 and 91.5 KN/m^2 at normal stresses of 50 KN/m^2, 100 KN/m^2 and 150 KN/m^2 respectively were obtained for the sediment of the TP section. Also, average compressive strength of concrete made with sediments of the River sections as fine aggregates was highest for the TP section given as 25.45 N/mm^2. The textile effluent was responsible for the increase in the friction angle of the Oke Itoku river sediment and textile effluents can provide a means of increasing design strength of concrete.

Keywords: Sediment, particle size, shear strength, compressive strength, tie and dye pollution

INTRODUCTION

Engineering properties of soil such as cohesion, angle of internal friction, capillarity, permeability, elasticity and compressibility are usually considered when soil is used for construction. These properties of soil are frequently affected by world growing environmental pollution arising from strives from many countries of the world to raise their GDP through manufacturing. Textile manufacturing produces highly toxic effluents which directly affect the environmental soil and water bodies that continuously receive them.

The tie and dye industry is one of the high polluting industries and it is responsible for dyeing various kinds of textile cloths. Irrespective of the choice of dyes, all dyed cloths ends up being washed in baths in order to get rid of excess dyes that clots on the surface of dyed fabrics. This final process of textile dying produces highly toxic textile effluent that make up some industrial wastewater streams (Chequer *et al.*, 2013). About 50 percent of the dyes used in textile dyeing form part of textile effluents generated from bath process and about one million tonnes of these contaminants end up in the environment in various forms (Chequer*et al.*, 2013). The textile effluent flows into various water bodies when discharged without treatment and it accounts for the presence of heavy metals among other contaminants in world's water resources.

Contaminants from industrial waste discharge into rivers usually settle down, permeate the river bed and impair the sediment quality. River sediments exhibits magnetic properties thereby creating strong linear positive correlation of the mineral enrichment within river bodies (Wang *et al*, 2013). Such mineral enrichment arises from antropogenic activities along rivers and pollution can be classified as downstream polluted, upstream polluted or less affected segment polluted (Wang *et al*, 2013). Various laboratory experiments were carried out by researchers to determine the effect of industrial effluents and acid contamination on shear strength of sediments and soil (Gratchev and Towhata, 2013; Narasimha*et al*, 2012; Nawagamuwa *et al*, 2013). Further researches on the behaviour of such contaminated soil used as fine aggregates in concrete works have been investigated. (Narasimha *et al*, 2012; Kanitha *et al*, 2014; Vaddi*et al*, 2015; Murali *et al*, 2012)

The popular Itoku Batik market in Itoku, Abeokuta Nigeria contributes significantly in the textile effluent pollution of Oke-Itoku River which is a tributary of Ogun River, a major source of water supply in South western Nigeria (Oketola *et al*., 2013; Jaji *et al*., 2007). Sand mining activities at the downstream portion of Oke-Itoku River is a constant activity by construction workers. The tie and dye effluent contaminated sand is continuously hauled by locally-made 5 tonnes tippers mainly for construction purposes, there is need for environmental assessment of the sediment quality with respect to geotechnical properties of the soil and effect on concrete works. Structural failures are respite of types and characteristics of the materials used which have been issues of consideration in Nigeria lately. Sources of soil used for construction purposes are one of the so many structural considerations that should be inculcated in addressing structural failures problem in the country.

Contamination of soil or sediments can either lead to degradation or improvement of its engineering properties (Mittal and Srivastava, 2014; Bhattacharya *et al*, 2004; Reddy Babu *et al*, 2005)
This study is aimed at investigating the effects of tie and dye effluents contamination on the sediment quality of Oke-Itoku River.

MATERIALS AND METHODS

Description of the Study Area

Oke-Itoku river is a natural channel of water which derives its source from the Olumo rock waterfall. It collects storm water, commercial wastewater and domestic wastewater directly from the surrounding community and discharges downstream to Ogun river. Ogun River is a major hydrological component of Ogun-Oshun River Basin managed by Ogun-Oshun River Basin Development Authority (OORBDA); it is of great importance in the water supply of south western region of Nigeria. A section of the Itoku waterway from an upstream point with Latitude 7^{0}9’30”N, Longitude 3^{0}20’38” to downstream point with Latitude 7^{0}9’32”, Longitude 3^{0}20’29” is surrounded by local Adire-making colonies as shown in Figure 1. Within this section, the waterway constantly receives the by-products of the tie and dye processes either by direct discharge or flow from small network drainages around the settlement. This non-point source pollutant can be noticed along flow path from the constant dye discolouration of the water as it flows into Ogun river.

Sampling and Analysis

Sediment samples were collected from three different segments along Oke-Itoku River with five sampling points each. The three segments are the River Source (RS), Non-Textile Polluted (NTP) and Textile Polluted (TP) segments as shown in Figure 1. The samples were transferred to the laboratory in labeled polythene bags for analysis. Some portions of samples were oven-dried in preparation for laboratory sieve analysis. The direct shear test of the sediment samples was performed to determine the consolidated-drained shear strength of the three sections of the river sediment according to ASTM D 3080. The test set-up is as shown in Figure 2. A constant displacement rate of 1.25 mm/min for three variations of normal stress (50 KN/m^2, 100 $KN/m^2$and 150 KN/m^2) was equally applied for each of the sediment sample. Slump test, compacting factor test and compressive strength test were carried out on the concrete made with sediment sample as fine aggregates from each section of the river. After several trial mixes, a concrete mix ratio of 1:2:4 was used throughout and water-cement ratio of 60% was equally maintained. Concrete cubes of dimension 150 mm x 150mm x 150mm cured for 28 days according to BS 1881 were then analysed for compressive strength as shown in Figure 3.

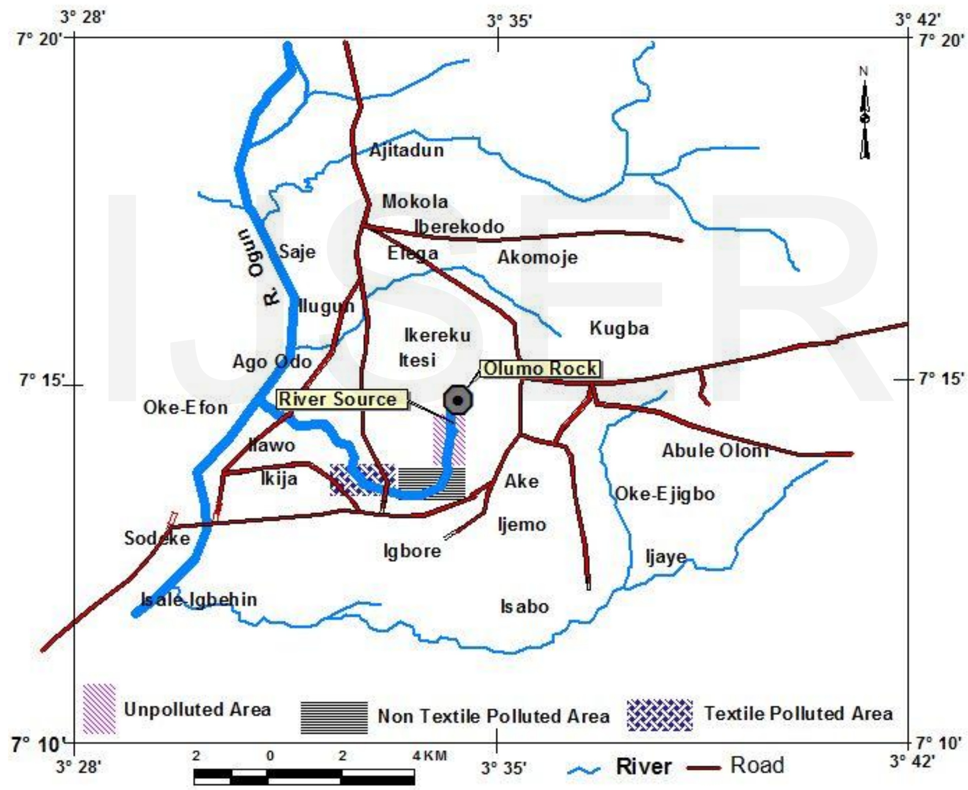

Figure 1: Map of the Study Area

RESULTS AND DISCUSSION

According to Unified Soil Classification System (USCS), all sediments from the Oke-Itoku River are fine sandy since average percent passing No. 4 sieve is greater than 50% and less than 50% passed through No. 200 sieve. Particle-size distribution curves of the average percent finer against particle size for the 3 segments of the River are shown in Figures 2, 3, and 4. The uniformity coefficients, C_u are 15.73, 11.13

and 15.73 respectively and coefficients of gradation, C_c are 0.127, 0.706 and 0.706 respectively. This shows there is uniformity in the particle size distribution of the entire Oke-Itoku river.

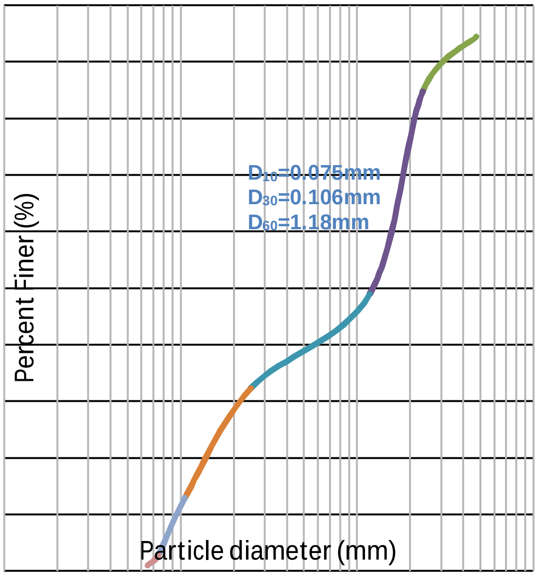

Fig. 2: Particle-size distribution curve of the sediment samples of RS section of Oke-Itoku River

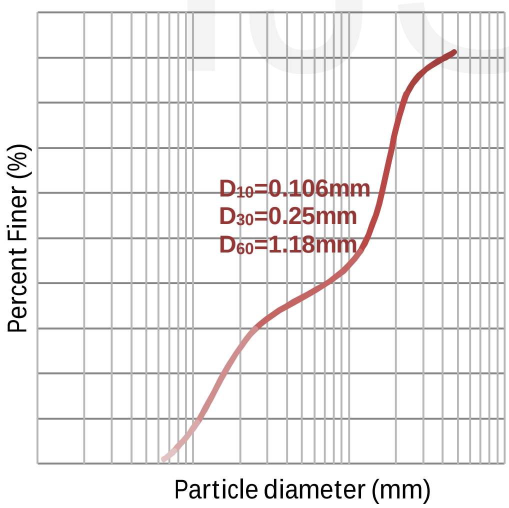

Fig. 3: Particle-size distribution curve of the sediment samples of NTP section of Oke-Itoku River

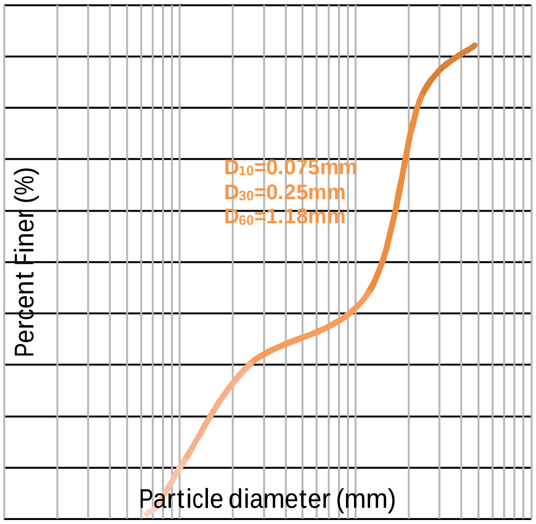

Fig. 4: Particle-size distribution curve of the sediment samples of TP Section of the Oke-Itoku River

Direct Shear Strength

The results of the direct shear test at a constant displacement rate of 1.25 mm/min for three variations of normal stress (50 KN/m^2, 100 KN/m^{2}and 150 KN/m^2) are presented in figures 5, 6 and 7 while the maximum shear stress for each test are reported in table 1. The Mohr-Coulomb failure plots on Figures 8, 9 and 10 shows the critical combinations of the shear stress and normal stress for each of the sediment type and Table 2 is the corresponding estimated angles of friction.

Mamo and Dey, (2014); Narasimha *et al*., (2012) all opined that shear strength properties of soil were affected by textile effluents and other industrial effluents treatment at various pore fluid content ratio. According to Oriola and Saminu, (2012) and Sarunas *et al*., (2013) this is one of the basis for the improvement and degradation of engineering properties of the environment's soil and issue to be considered in geotechnical designs. Narasimha *et al*. (2012) reported that irrespective of the pore fluid content ratios, the shear strength of soil samples treated with textile effluents increased with increasing percentage of textile effluent. This finding agreed with Oriola and Saminu, (2012). The change in chemical composition of clayey soils due to changes in environmental conditions was found to have effect on the geotechnical characteristics of clay (Wang and Siu, 2006). Modification of soil properties has been attributed to industrial wastes which cause foundation failures and structural damage in some cases (Narasimha *et al*., 2012).

The highest maximum shear strength obtained in the textile polluted sediment could be attributed to the capability of textile effluent to form chemical bonding with soil particles thereby increasing the resultant cohesion forces between the soil particles (Narasimha*et al*., 2012). The chemical bonding of soil particles was found to be affected by the changes in the pH of the pore fluids which was investigated by Gratchev and Towhata (2013). This study showed that textile effluents are alkaline and the pore fluids at the textile polluted area exhibited a mean pH of 6.42 which is higher than the mean pH of 5.72 at the River Source area. This resulted in stronger attractive forces among the particles of the sediment in the textile polluted area which agrees with the finding of Gratchev and Towhata (2013) that further drop in the pH below 5.5 leads to decrease in the maximum shear stress of the tested soil. It was also found that irrespective of the normal stress applied (50 KN/m^2, 100 KN/m^2 and 150 KN/m^2) the textile polluted sediment was consistent in demonstrating highest maximum shear stresses as shown on Table 1.

According to Nawagamuwa *et al*. (2013), the friction angle of loose sand was increased slightly above its typical value of 30 degrees by adding copper-slag waste. In this study, friction angles of the three categories of sediment were determined from the Mohr Coulomb failure envelopes in Figures 8, 9 and 10. Expectedly, the highest maximum shear stress of the textile polluted sediment translated into highest friction angle of 31.8 degrees which is similar to the effect of copper-slag mix on friction angle of loose sand reported by Nawagamuwa *et al.* (2013). It can be deduced that textile effluent is responsible for the increase in the friction angle of the River sediment since slight decrease was recorded at the non-textile polluted sediment.

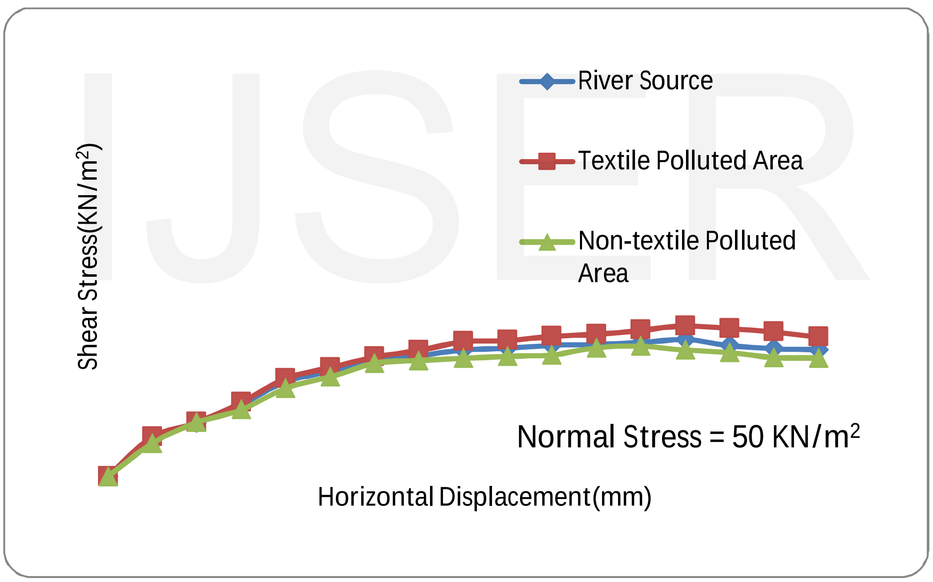

Fig 5: Direct shear test result on the sediments of the three river sections (σ=50KN/m^2)

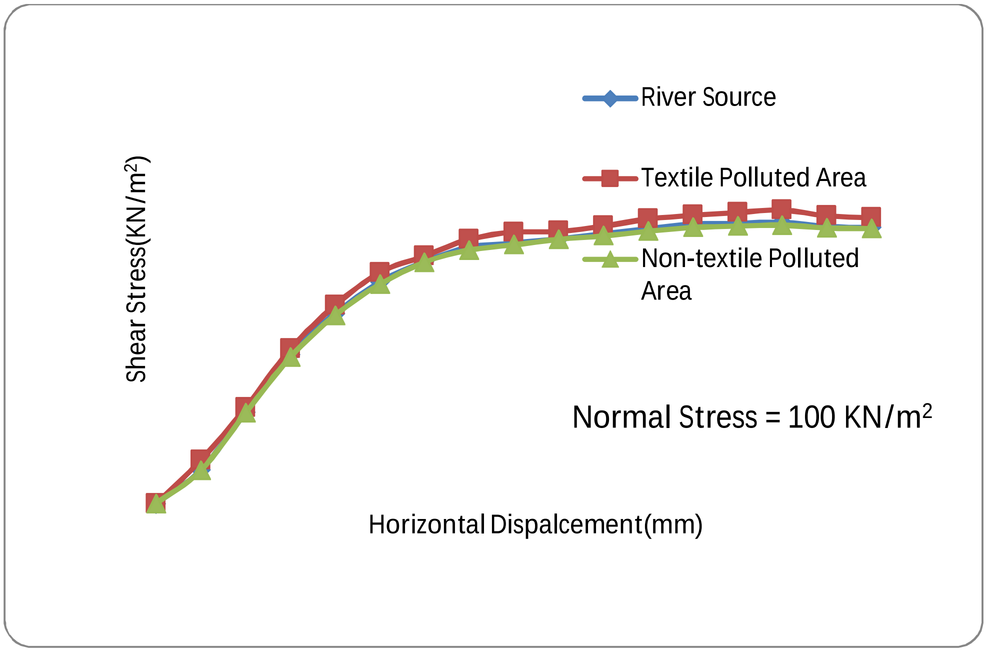

Fig.6: Direct shear test result on the sediments of the three river sections(σ=100KN/m^2)

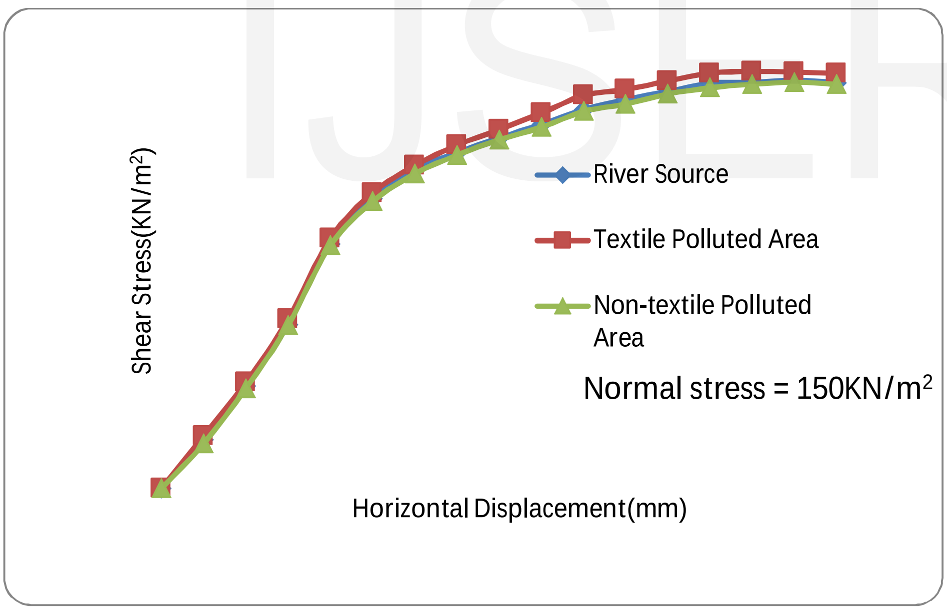

Fig.7: Direct shear test result on the sediments of the three river sections (σ=150KN/m^2)

Table 1: Maximum shear stress of corresponding normal stress

Normal Stress(KN/m^2)	Maximum Shear Stress(KN/m^2)		
	River Source	Non-Textile Polluted Area	Textile Polluted Area
50	31.2	29.7	34.3
100	59.9	59.3	62.5

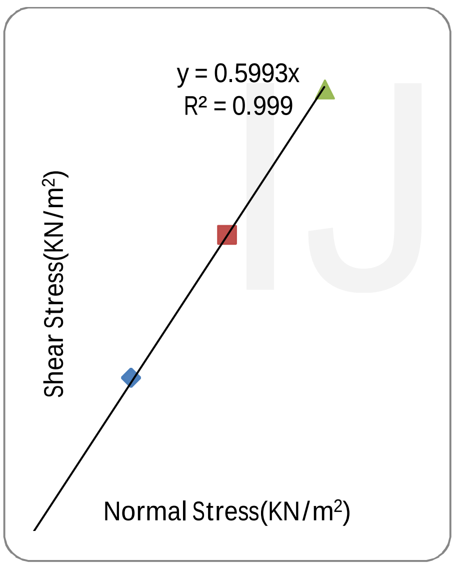

Fig. 8: Mohr-Coulomb failure envelope for sediment of the RS section.

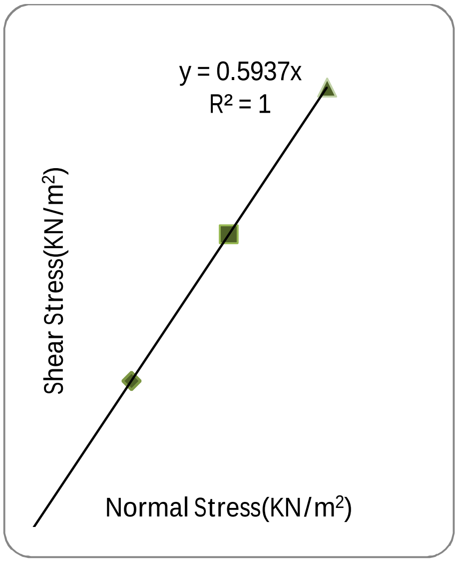

Fig. 9: Mohr-Coulomb failure envelope for sediment of the NTP section.

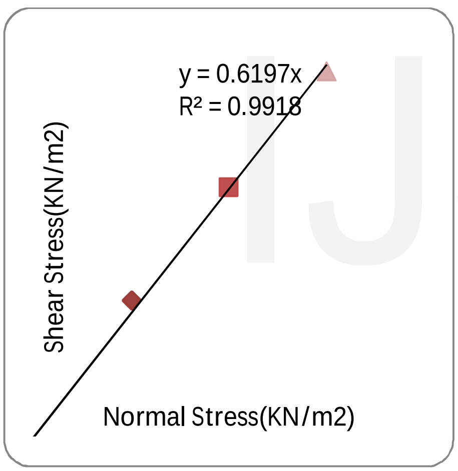

Fig. 10: Mohr-Coulomb failure envelope for sediment of the TP section.

Table 2: Friction angles of sediments in Oke-Itoku River

Sediment Sample Section	Friction Angle (degrees)
River Source	30.9
Non-textile Polluted Area	30.7
Textile Polluted Area	31.8

Workability and Compacting Factor

The results of the slump test and compacting factor test of concrete mix made with sediment samples of RS, NTP area and TP area are as shown in Table 3.

Compressive Strength

Table 5 presents the maximum loads applied and corresponding compressive strengths of the specimen cubes categorized by the sediment samples from the sections of the river. Figure 11 depicts the average compressive strength for each of the three sections of the river.

The degree of workability obtained for fresh concrete made from sediments of the three sections of the River as fine aggregate is medium which conforms to 50-100 mm slump recommended for "normal reinforced work without vibration and heavily reinforced sections with vibration" by Wilby (1991) as shown on Table 3 and Table 4. With water-cement ratio of 0.60 maintained for all the concrete mixtures and uniform mix design of 1:2:4; the degree of workability, slumps and compacting factors are similar for the three categories of fine aggregates. A similar result was obtained by Kanitha*et al*.(2014) using untreated and treated textile effluent wastewater for concrete mix.

In the comparative study by the researcher, mixing concrete with textile effluent wastewater compared favourably to that of portable water in terms of compressive strength and split tensile strength at medium degree of workability. The result of the compressive strength according to BS 1881 is depicted in Table 5 and Figure 10. According to Caltrans (2015), compressive strength is the most important factor of consideration in concrete design and concrete with 28-day compressive strength of $f_c' = 25$ N/mm^2 is the conventional minimum design strength target for reinforced concrete structures.

The concrete cubes made from fine aggregates of the textile polluted sediments of the River satisfied the minimum design strength target failing at average of 25.45 N/mm^2. On the contrast, specimen cubes made from sediments of the RS and NTP sections of the River produced compressible strengths which fall below the design strength target failing at 23.13 N/mm^2 and 22.63 N/mm^2 respectively. In general, the result agrees with the findings of Kanitha *et al*. (2014) and it is further affirmed that textile effluents can serve as catalyst for increasing design strength of concrete.

Table 3: Workability, slump and compacting factor of concrete made from sediment samples of the Oke-Itoku River

Sediment Samples	Slump (mm)	Compacting Factor	Degree of Workability
River Source	64	0.86	Medium
Non-Textile Polluted	63	0.89	Medium
Textile Polluted	66	0.87	Medium

Table 4: Interpretation of Compaction Factor Test Results as Described in British Road Note 4 (Wilby 1991)

Factor Workability	Slump, mm	Degree of Compaction		Applications
		Small Apparatus	Large Apparatus	
Very Low	0-25	0.78	0.80	Vibrated concrete in roads or other large sections.
Low	25-50	0.85	0.87	Mass concrete foundations without vibration. Simple reinforced sections with vibration.
Medium	50-100	0.92	0.935	Normal reinforced work without vibration and heavily reinforced sections with vibration.
High	100-80	0.95	0.96	Sections with congested reinforcement. Not normally suitable for vibration.

Table 5: Compressive strength of concrete made with sediments of Oke-Itoku River

Sediment Samples	Specimen Cubes	Force (KN)	Strength (N/mm2)
River Source	1	532.12	23.65
	2	541.44	24.06
	3	536.72	23.85
	4	461.94	20.53
	5	530.23	23.57
Non-Textile Polluted Area	6	517.43	23.00
	7	531.91	23.64
	8	459.88	20.44
	9	524.97	23.33
	10	511.72	22.74
Textile Polluted Area	11	583.32	25.93
	12	557.98	24.80
	13	567.49	25.22
	14	563.88	25.06
	15	590.41	26.24

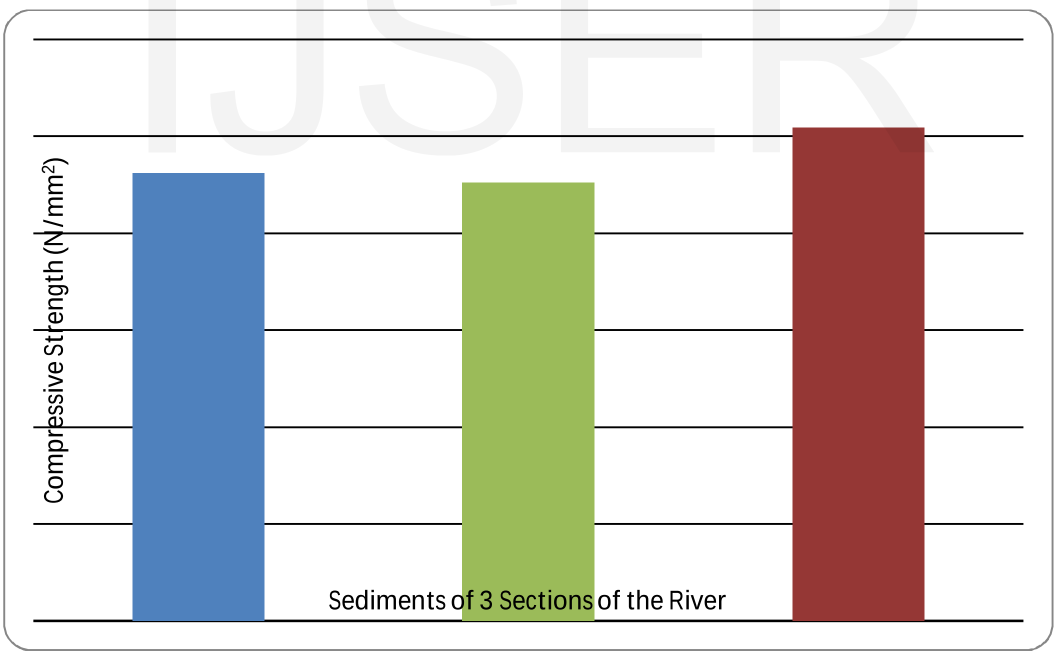

Figure 11: Average compressive strength of concrete made with sediments of the Oke-Itoku River

CONCLUSION

The shear strength properties of the tested sediments from the three sections of the River varied with the highest maximum shear strength recorded for the TP point source area. This translated into highest friction angle of 31.8^0 while the lowest maximum shear strength and friction angle of 30.7^0 were obtained in the NTP area.

The effect of textile effluent contamination on 28-days compressive strength properties of concretes made from TP sediment satisfied the conventional minimum design strength target of $f'c$ = 25N/mm^2 while concretes of the NTP sediments demonstrated mean compressive strength below the conventional strength target.

The study shows that textile effluents in soil as construction material has favourable effect on the immediate shear strength and compressive strength of its concrete cubes. However, further work should be carried out to determine the durability of the concretes in a long term.

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