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Standard sand for geotechnical engineering and geoenvironmental research in Nigeria: Igbokoda sand

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Abstract. This study entails establishing reference standard sand in Nigeria for engineering and geoenvironmental research work. Sands from four geographical locations in southwestern Nigeria were examined for baseline geotechnical and mineralogical properties. A total of sixteen sand samples were collected. The samples were air dried and subjected to tests in accordance with standard specifications. The tests carried out were: specific gravity, grain size analysis, moisture content, bulk density, porosity, void ratio, chemical analysis, X-ray diffraction and Differential Thermal Analysis. The properties of the samples were compared with a standard (Ottawa sand in Illinois of the United States) in order to find out which of the four samples selected from southwestern Nigeria could serve as standard baseline sand. The results show that Igbokoda sand has geotechnical and mineralogical characteristics closest to Ottawa sand. It was therefore concluded that Igbokoda sand could be used as a standard baseline sand for research work in southwestern Nigeria and other parts of Nigeria since it needs little processing to bring it to the same level as standard baseline sand, like the Ottawa sand.

Keywords: Igbokoda sand; baseline properties; laboratory experimental sand; geochemical characteristics; x-ray diffraction; Ottawa sand

1. Introduction

1.1 General overview

In Nigeria, sand is used as aggregates in the construction industry, test samples in geotechnical and soil science laboratories, experimental porous medium in hydrogeologic studies and for other uses. The use of sand for construction purposes grew significantly with the drive for increased paved road network and housing schemes. So far in Nigeria, very little has been done on standardizing the properties of sands. This research will assess the background parameters of four southwestern Nigeria sands in order to ascertain which of the sands can be used as a standard in Nigerian laboratory experiments.

Geotechnical and hydraulic testing of sand is required for various applications in a developing country like Nigeria. Some developed countries such as USA and Canada have standard sand for

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laboratory experiments, such as Ottawa silica sand in Illinois (USA) with fully characterized parameters. There is therefore need to characterize and assess the baseline properties for some southwestern Nigeria sands that could serve as a tool for investigations in soil mechanics and hydrogeologic applications.

The Ottawa standard sand is derived from the Middle Ordovician St. Peter Sandstone near Ottawa, Illinois and has been widely applied in experiments by geologists and engineers for several decades. Common tests include compressive strength, air content, tensile strength for hydraulic cement, and geochemical experiments. The sand also serves as a specification for graded sand, 20/30 sand, as well as masonry cement. Practical applications include building stone, abrasive, manufacturing of glass, and molding sand. Ottawa standard sand: consists of rounded grains of clear colourless quartz, which have diamond-like hardness, and are pure silica (Silicon Dioxide, SiO_2) uncontaminated by clay, loam, iron compounds, or other foreign substances. Ottawa sand is the general name for sands mined from numerous deposits found in the northern portion of the United States. “White and Northern sands” are other names used to identify Ottawa

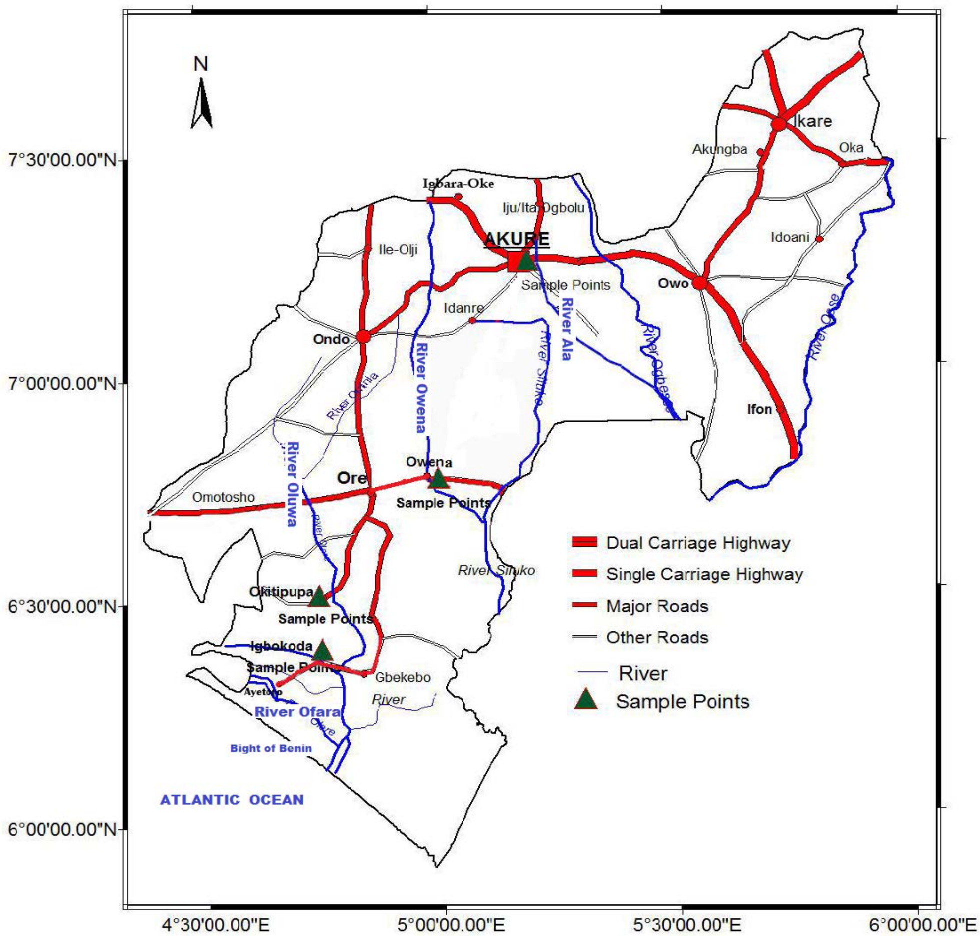

Fig. 1 Hydrological network within study area (Ondo State) showing where samples were taken (Adapted from Federal Surveys)

sand. These sands are considered by many to be the highest quality sands. They are characterized by high purity, whiteness (although some variations in colour do occur), high roundness, sphericity and lack of dust. The Ottawa sand was chosen by the American Society for Testing and Materials (ASTM) as the standard sand to be used in testing cement and the strength of concrete. Because the sand is typically regarded as a standard often detailed mineralogical analyses would not be required prior to experiments. (Ravia *et al*. 2008).

The major silica sand deposits in Nigeria are located at Ughelli in Delta State, Igbokoda in Ondo State, Baure in Katsina State, Badagry in Lagos State, and along the sandy shore line of the Atlantic Ocean (RMRDC 2010). Four alluvial sand samples were studied. Akure Sand Sample (AKRS) was collected along Ala River, Owena Sand Sample (OWNS) was collected from the Owena River, Okitipupa Sand Sample (OKPS) was collected along the bank of Oluwa River in a small town of Ebute-Ilu Abo in Okitipupa region, and Igbokoda Sand Sample (IGKS) was collected in Igbokoda town near Ofara River, a tributary of River Oluwa (Fig. 1). These major rivers are perennial and sands generally dominate the bed material and river banks of these rivers.

There are other high quality standard sands apart from the Ottawa sand in various parts of the world. CEN (Committee for European Norms) Standard sand is natural sand, which is siliceous and has silica content of at least 98% particularly its finest fractions. It is clean; the particles are generally isometric and rounded in shape. It is dried, screened and prepared in a modern workshop which offers every guarantee in terms of quality and consistency. The CEN sand is standard sand used for preparation of mortars in the testing of hydraulic cements by European standard. The sand is packaged in polyethylene bags each containing 1350 ± 5 g (BS EN 196-1:1995). Berhanu (2005) investigated the preparation of Ethiopian standard sand for the purpose of construction and testing. The sand samples for laboratory investigation and field test were collected from North Showa (Jema river valley) and Dire Dawa town, Ethiopia. Sand sample taken from North Showa was designated as sample NS and that of Dire Dawa is designated as sample DD. Laboratory and field tests conducted on both local sand samples showed that there is a high possibility that both local sand samples can replace the imported standard sand, especially the sand sample from North Showa. The specific gravity was 2.66 and 2.63 for sample NS and sample DD respectively. The specific gravity values somehow reflects the silica content of the sand i.e., the higher the silica content the higher the specific gravity. Mineralogical composition revealed 99.09% silicon dioxide SiO_2 content. The North Showa (Jema river valley) sand was recommended as the Ethiopian standard sand. Toyoura sand is Japanese sand extensively studied by several investigators (Shiratori *et al*. 2007, Chiaro *et al*. 2012). These researchers indicated that the mechanical properties of dry and saturated Toyoura sand are nearly identical. Toyoura sand is predominantly a uniform angular to subangular quartz fine sand with approximately 90% quartz and 4% chert. It has 89.78% SiO_2 content and 3.43% Al_2O_3 Content. Silica sand is available almost in all the states of India. Quartzanium is the Indian standard sand as per IS-650: 1991 of the Bureau of Indian Standards (BIS), to be used to various Cement Plants, Research Laboratories, and Civil Engineering Institutions to ensure the quality of Cement (BIS IS-650:1991). The Indian standard sand is whitish and has specific gravity Gs 2.65, SiO_2 Content (%): 99.38, Fe_2O_3 Content (%): 0.12 and Al_2O_3 Content (%): 0.25 (Pinal Corporation 2007).

2. Materials and methods

2.1 Location

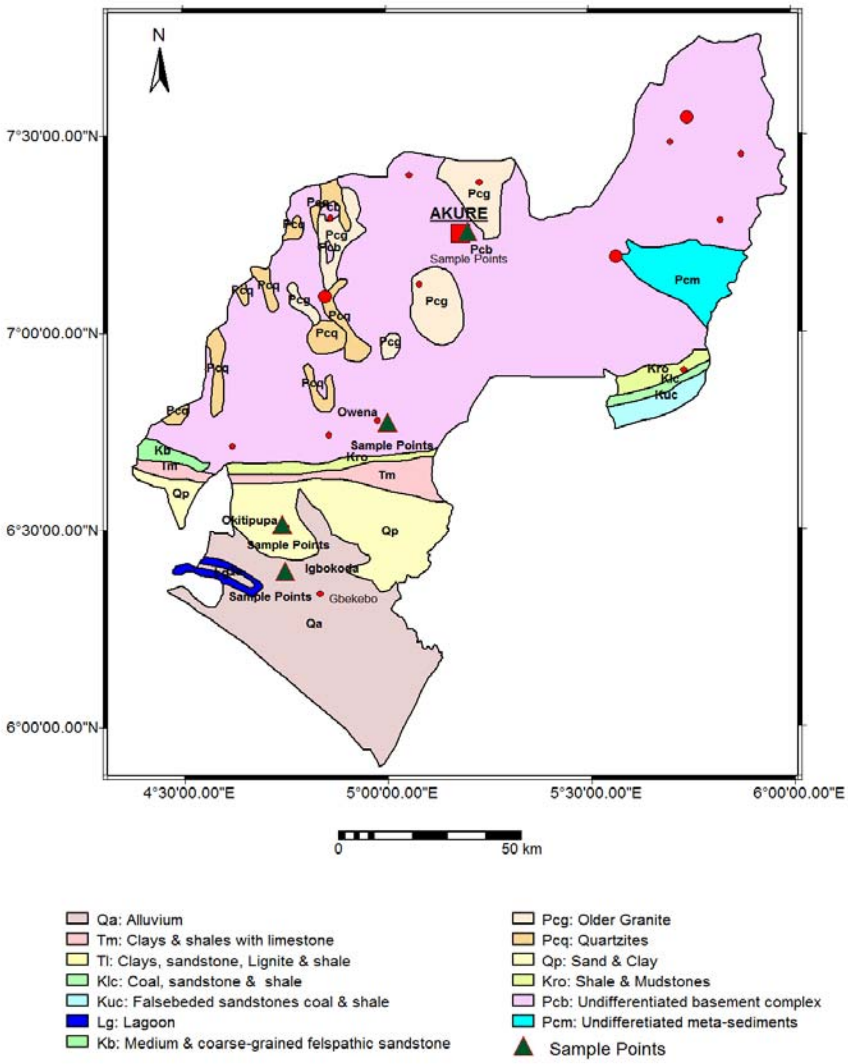

Fig. 2 Geological map of the study area (Modified after geology of Nigeria Akure sheet 62)

The study area is located in Ondo State in the South Western part of Nigeria (Latitudes 5º45 and 7º30 north of the equator and Longitudes 4°20 and 6º15 east of the Greenwich meridian). It is bounded to the north by Ekiti State and to the east by Edo and Delta States. It has a common boundary with Ekiti, Osun, and Ogun States along the north south line running along its western border and in the south. The area is readily accessible by road network. Fig. 1 shows the map of the study location. Soil samples were taken from four locations within the state; Akure, Owena, Okitipupa and Igbokoda.

Akure Sand Sample (AKRS) is located at Ayedun quarter along Ala River within Akure town, in Akure South Local Government area. The samples were collected at the proximity of Ala River. Owena Sand Sample (OWNS) was collected from Owena River, situated along Akure-Owena road, in Ifedore Local Government Area. Okitipupa Sand Sample (OKPS) is located along the bank of

Oluwa River in a small town of Ebute-Ilu Abo in Okitipupa Local Government Area. Igbokoda Sand Sample (IGKS) is located in Igbokoda town, along Igokoda-Ayetoro Road in Ilaje Local Government Area. The samples were collected at the proximity of Ofara River. The region is covered by three to eight meter over burden sand with dense clay underneath. All the locations are within Ondo State as shown in Fig. 1. Four samples were collected from the surrounding of each location and a total of sixteen bulk samples were taken from the four locations.

2.2 Regional geology of study area

Crystalline and sedimentary rocks dominate the geology of Ondo state. Ademeso (2009) recognized six major groups of rock in the basement complex of the southwestern Nigeria. The basement complex consists of crystalline rocks, which are largely Precambrian in age. The basement complex rocks are covered by the quaternary deposits, which tend to blanket all older deposits. The quaternary period is the youngest of the geological time scale as a result lies directly within the influence of a man (Okunade 2010).

The major soil differences within the study areas are directly related to differences in the parent materials of the underlying rock. Topographically, the basin can be divided into two distinct regions. The Northern region, where the basement complex outcrops gives rise to rugged undulating terrain. The migmatitic gneisses predominate in the central and southern part of the basement complex in this basin underlying such important town as Owena, Owo and part of Akure. The southern sedimentary outcrop areas are comparatively flat. The sediments are thinnest in the southern and eastern parts of the basin around the Okitipupa ridge west of Benin hinge line, the basement complex lies close to the surface and the sediments are therefore thinnest (see Fig. 2).

2.3 Sampling

The tools used for the collection of samples for the purpose of this project were shovel, hand auger, sample bag/sack and measuring tape. The soil samples were collected using shovel and kept in sample bags. Auger was also used to collect the sand samples and the measuring tape was used to measure the difference in distance between samples point A, B, C, and D of the sample location.

Sixteen bulk samples were taken altogether from 4 different geographical sample locations. Four different samples were taken from each location. In each location, first sample (A) was taken from the surface sample point, second sample (B) was taken from 300 mm below sample point A. (C) was obtained at the surface at a distance of one meter from sample point A and the fourth sample (D) was taken on the surface one meter before the sample point A. The same process was repeated in each geographical location.

The samples were labeled as follows

At **Igbokoda**:	IGKS A	first chosen sample location
(Location 1)	IGKS B	300 mm below first the sample location
	IGKS C	1 meter after the first sample location
	IGKS D	1 meter before the first sample location
At **Okitipupa**:	OKPS A	first chosen sample location
(Location 2)	OKPS B	300 mm below first the sample location
	OKPS C	1 meter after the first sample location
	OKPS D	1 meter before the first sample location

At **Owena**: (Location 3)	OWNS A	first chosen sample location
	OWNS B	300 mm below first the sample location
	OWNS C	1 meter after the first sample location
	OWNS D	1 meter before the first sample location
At **Akure**: (Location 4)	AKRS A	first chosen sample location
	AKRS B	300 mm below first the sample location
	AKRS C	1 meter after the first sample location
	AKRS D	1 meter before the first sample location

2.4 Laboratory analysis procedures

The laboratory tests that were carried out on these soil samples include both the index, mechanical and geochemical properties of soils. Soil tests were carried out in the following laboratories, Geotechnical Laboratory, Civil Engineering Department of the Federal University of Technology, Akure; Chemical Laboratory, Department of Soil and Crop Science, Federal University of Technology, Akure; and Geology Laboratory, University of Ibadan, X-Ray Unit, Rolab Research and Diagnostic Laboratory, Ibadan, Oyo State, Engineering Materials Department Institute, Akure. All the soil index and physical property tests were conducted according to the procedures in the Methods of Test for Soil for Civil Engineering Purposes BS 1377:1990 specifications as follows; moisture contents (BS1377:1990 Part 2:3), specific gravity (BS1377:1990 Part 4), density tests (BS1377:1990 Part 4:5), Particle Size Distribution (BS1377:1990 Part 2:9).

2.4.1 Geochemical analysis

Bulk sample of the experimental sands were taken to the Chemical Laboratory, Department of Soil and Crop Science, Federal University of Technology, Akure, Ondo state, Nigeria for Chemical Analysis. The samples were taken and kept in polythene bags upon transportation to the laboratory. The soil samples were air-dried and sieved with 2 mm mesh (Carter and Gregorich 2007), the sieved samples were used for the various mineral analysis.

Treatment of samples for metal analysis

Two grams of each of the samples was weighed into a boiling tube and digested using a digestion mixture containing concentrated hydrochloric acid and trioxonitrate V acid prepared as described by Dane and Topp (2002).

Fifteen mil of the digestion acid was added to the soil and heated with a funnel placed on the mouth of the tube. After heating at 120°C for 2 hrs, it was cooled, diluted to 50 ml with 8.8% $HN0_3$, which was then filtered. The filtrate was used for the various metal analyses.

Metal analysis

The metals were determined by using Atomic Absorption Spectrophotometer (AAS). Series of standard of each of the metals were prepared and run together with each sample at various wave lengths using a hollow cathode lamp of each metal (Lajunen and Perämäki 2004).

Determination of total phosphorus

Extraction of the total phosphorus from soil: The phosphorus was determined colorimetrically using the blue molybdate method. Series of standard phosphorus were prepared Harris (2007) and the absorption of the sample standard was read at 660 mm.

2.4.1 Mineralogy properties

X-Ray analysis

The powdered specimen was mounted on a small pedestal connected with a continuously rotating base. The x-rays were permitted to hit the specimen and be diffracted upon a film. Each line of the pattern represents a reflection from different atomic planes within the mineral (David *et al*. 2002). The sand minerals can be identified further by the temperatures required to extract structural water from their lattices.

Differential thermal analysis (DTA)

In differential thermal analysis, the temperature of the sample and a thermally inert reference material were measured as a function of temperature (usually sample temperature).

Table 1A Result of specific gravity tests of the studied sands

Location	Soil sample	Specific gravity
Standard	Ottawa	2.65
Igbokoda 1	IGKS A	2.63
	IGKS B	2.63
	IGKS C	2.63
	IGKS D	2.63
Okiti-Pupa 2	OKPS A	2.58
	OKPS B	2.64
	OKPS C	2.61
	OKPS D	2.62
Owena 3	OWNS A	2.67
	OWNS B	2.59
	OWNS C	2.63
	OWNS D	2.64
Akure 4	AKRS A	2.66
	AKRS B	2.69
	AKRS C	2.68
	AKRS D	2.67

Table 1B Result of average specific gravity tests of the studied sands

Soil Sample	Average specific gravity of soil sample	Comparison with Ottawa sand in percentage (%)	Percentage difference (%)
Ottawa	2.65	100	-
IGKS	2.63	99.2	0.8
OKPS	2.61	98.5	1.5
OWNS	2.63	99.2	0.8
AKRS	2.68	101.13	1.1

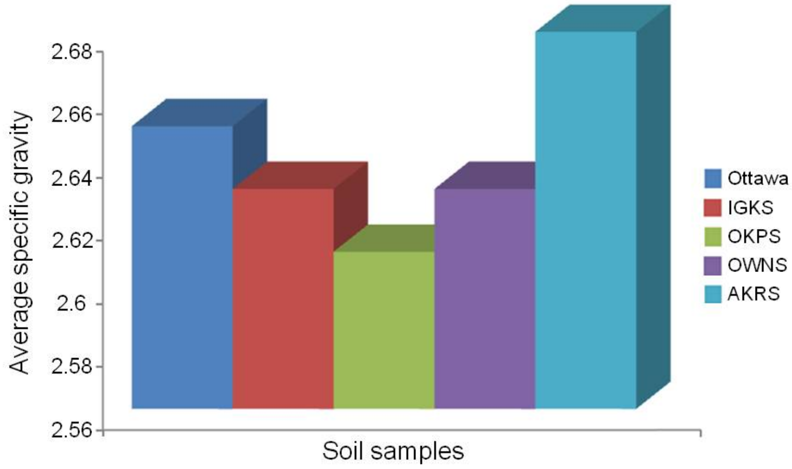

Fig. 3 Histogram of average specific gravity tests of the studied sands

Any transition which the sample undergoes will result in liberation or absorption of energy by the sample with a corresponding deviation of its temperature from that of reference (Ulery and Drees 2008). This differential temperature versus the programmed temperature at which the whole system is being changed indicates in the analysis the temperature at which the transition occurs and whether the transition is exothermic or endothermic.

The effect of high temperature on soil minerals was studied by this differential thermal analysis. The amount of water released by a mineral when heated to a high temperature is measured by using a special thermal balance.

In this analysis, a sample of the soil material and calcined alumina (heat treated and thus reduced to powdered aluminum oxide) were placed in cavities of a nickel block and heated to 110°C at the rate of about 2°/min (Ulery and Drees 2008). A curve of temperature different between the material under test and calcined alumina was drawn on an automatic recording drum; and each material yielded a characteristic curve.

3. Results and discussions

Comparative study of geotechnical parameters of each sand sample and standardized Ottawa silica sand was made. In this discussion, emphasis is laid on differences between the properties of sampled sands and standard Ottawa sand. Appropriate statistical methods were employed to obtain some relationships between properties of samples sands and standard sand.

3.1 Specific gravity

This is an important index property of sand that is closely linked with mineralogy/chemical composition. The specific gravity values of the sands are shown in Table 1A and Fig. 3. Both the table and the figure show that the specific gravity values of Akure sand to range from 2.66-2.69. Owena sand value is between 2.59 and 2.67. Okitipupa sand ranged between 2.58 to 2.64 while the value of the Igbokoda sand is 2.63. This result indicates that Ottawa Standard sand specific gravity value is within the range of the four sands with the Owena sand and Igbokoda sand giving a difference of less than one percent.

Table 1B and Fig. 3 show details of average Specific gravity of sand samples. From Table 3, comparisons were made in percentage in respect of Ottawa sand as 100%. The percentage difference for IGKS, OKTS, OWNS and AKRS are 0.8, 1.5, 0.8 and 1.1% respectively.

Table 2 The result of grain size distribution of the studied sands

Location	Sand sample	% Gravel	% Coarse sand	% Medium sand	% Fine sand
Standard	Ottawa	-	2	73	25
Igbokoda 1	IGKS A	-	9.56	85.46	4.98
	IGKS B	-	12.30	81.91	5.79
	IGKS C	-	10.73	83.89	5.38
	IGKS D	-	11.51	82.9	5.59
Okiti-Pupa 2	OKPS A	3.80	56.50	36.92	2.78
	OKPS B	3.16	59.44	35.02	2.38
	OKPS C	3.48	57.97	35.97	2.58
	OKPS D	3.32	58.70	35.50	2.48
Owena 3	OWNS A	6.52	46.00	39.20	8.28
	OWNS B	5.14	44.36	40.07	9.78
	OWNS C	5.83	45.18	39.96	9.03
	OWNS D	5.48	44.77	47.01	2.74
Akure 4	AKRS A	10.96	55.86	29.94	3.24
	AKRS B	12.68	50.08	33.98	3.26
	AKRS C	11.82	52.97	31.96	3.25
	AKRS D	12.25	51.52	32.97	3.26

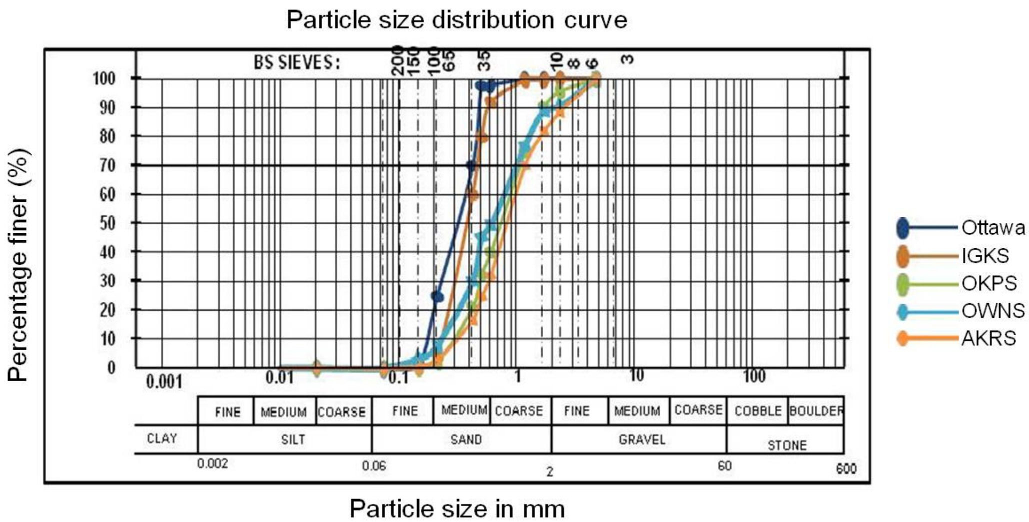

Fig. 4 Particle size distribution curves for the sand samples

Table 3 Result of bulk density test of the studied sands

Location	Sample	Point A	Point B	Point C	Point D	Average
		Bulk density (kg/m^3)	Bulk density (kg/m^3)	Bulk density (kg/m^3)	Bulk density (kg/m^3)	Bulk density (kg/m^3)
Standard	Ottawa	1650.0	1650.0	1650.0	1650.0	1650.0
1	IGKS	1571.59	1542.14	1556.86	1549.50	1555.02
2	OKPS	1486.93	1509.02	1497.99	1503.51	1499.36
3	OWNS	1509.02	1472.21	1490.62	1481.41	1488.32
4	AKRS	1553.18	1527.42	1540.30	1533.86	1538.69

3.2 Grain size distribution

The percentage grain size distributions of the studied sands are summarized in Table 2. The grading curves, the graph of grain size distribution and hydrometer analyses are shown in Fig. 4. From Table 2, it can be observed that the entire sand samples are uniformly graded. The percentage of medium sand is between 35.02 and 36.92 in Okitipupa while its coarse sand have the highest percentage range between 56.50% and 59.44%.

Sands from Igbokoda are of high percentage of medium sand and no gravel, while its fine sand ranges from 4.98% to 5.79% as shown in the Table 2. The percentage medium sand of the Owena sand is between 38.20% and 47.01% while its coarse percentage ranges from 44.36% to 46%. Akure sand have the highest percentage of gravel and lowest percentage of fine sand. Generally, it is clear from Fig. 4, that the grain size distribution of the Igbokoda sand is very closely related to that of the Ottawa sand.

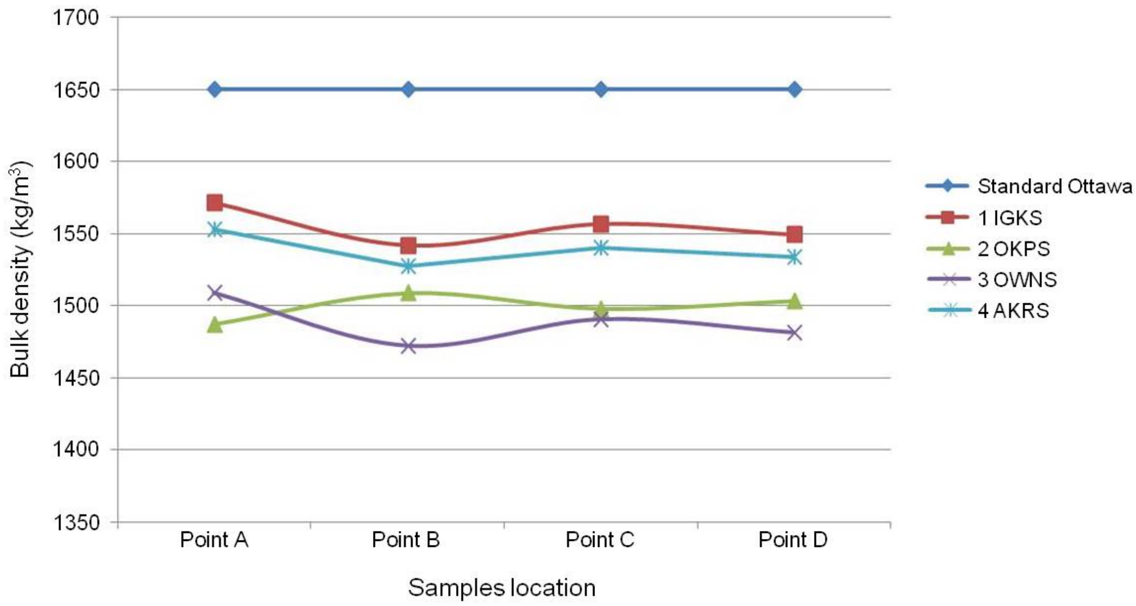

Fig. 5 Relating the bulk density of the samples with Ottawa sand

3.3 Bulk density (ρ_T)

This is an important factor in the selection of physical parameter of sand related to its texture. It is one of the main characteristics which describe the relative proportions of solid and void in a sand. Table 3 shows the summary of bulk density (ρ_T) of the sample sands. From Table 3, the bulk density at Location 1 (IGKS) ranges from 1542.14 kg/m^3 to 1571.59 kg/m^3 with an average of 1555.02 kg/m^3. This is the closest to Ottawa sand of 1650 kg/m^3. The results for Locations 2 (OKPS), 3(OWNS) and 4(AKRS) are 1499.36, 1488.32, 1538.69 kg/m^3 respectively. Fig. 5 shows that the bulk density of Igbokoda sand is the closest to that of Ottawa sand.

3.4 Porosity

It is an important parameter in the analysis of sand behavior. It is the ratio of the volume of voids to the total volume of the sand sample. Table 4 shows the in-situ porositi(ρ_T) the studied sands. Fig. 6 shows the graph comparing curves of the four sands with Ottawa sand. From Table 4, samples at Location 1(IGKS) porosity range from 31.8% to 35% with an average of 33%. This is the closest porosity to that of Ottawa sand of 33%. The results for locations 2(OKPS), 3(OWNS) and 4(AKRS) are 23.6, 31.0, 29.1 percent respectively. Sand bulk density (ρ_T) and in-situ porosity are vital index properties, since there are characteristic values of these properties for typical sand types. Generally from the bar chart (Fig. 6) Igbokoda sand has the closest porosity to Ottawa sand.

3.5 Geochemical analysis

The results of the geochemical analysis of the studied soils are presented in Table 5. From Table 5, the following observation can be made. The value of silica oxide (SiO_2) content is higher in Igbokoda sand than other studied sands. For Location 1 which is Igbokoda, the value ranges from 93.81% to 94.75% with an average of 94.24%, while the value varies from 87.42% to 89.57% in Location 2 which is Okitipupa with an average of 88.52%. For Location 3, the average value of silica in Owena sand is 85.26% and that of Akure is 77.15%. Igbokoda sand has the highest percentage of silica (94.24%) which is closer to that of Ottawa sand of 99.8%. The percentage of Iron oxide (Fe_2O_3) that was in the Igbokoda and Okiti-pupa sands were higher than Owena and Akure sands. Their values range from 0.755% to 0.997% in Igbokoda sand and 1.507% and 2.334% in Owena sand. The percentage of aluminium oxide (Al_2O_3) was only significant in Igbokoda sand with values ranging from 1.342% to 1.848% and 1.928% to 2.580% for Okiti-pupa sand.

Generally, the chemical analysis shows the Igbokoda sand to have chemical composition closest to that of Ottawa sand for SiO_2, Al_2O_3, CaO, K_2O, Na_2O and MgO but the most significant is the SiO_2 composition of 99.8% for Ottawa sand while the Igbokoda sand is 94.24% (Fig. 7).

3.6 Mineralogy

3.6.1 X-ray analysis of the studied sands

Bulk sample of the experimental sands were taken to the Engineering Material Development Institute, Akure, Ondo state, Nigeria for x-ray tests. The soil samples were ground into a powder

Table 4 Result of porosity test of the studied sands

Location	Sample	Porosity (%)				
		Point A	Point B	Point C	Point D	Average
Standard	Ottawa	33.0	33.0	33.0	33.0	33.0
1	IGKS	31.8	35.0	31.8	33.4	33.0
2	OKPS	28.6	28.6	28.6	28.6	28.6
3	OWNS	31.0	31.0	31.0	31.0	31.0
4	AKRS	29.1	29.1	29.1	29.1	29.1

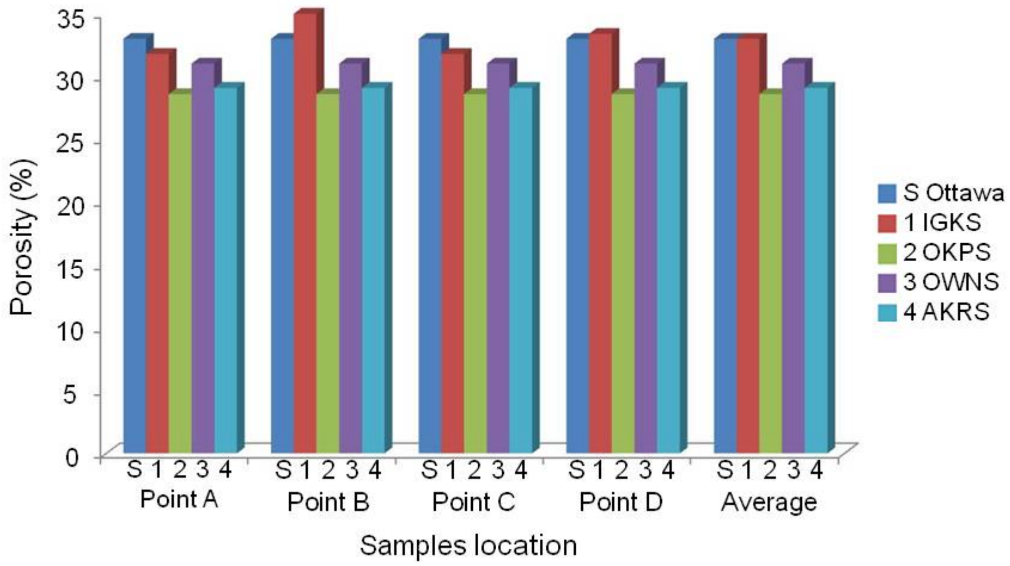

Fig. 6 Using bar chart to relate the porosity of the samples with Ottawa sand

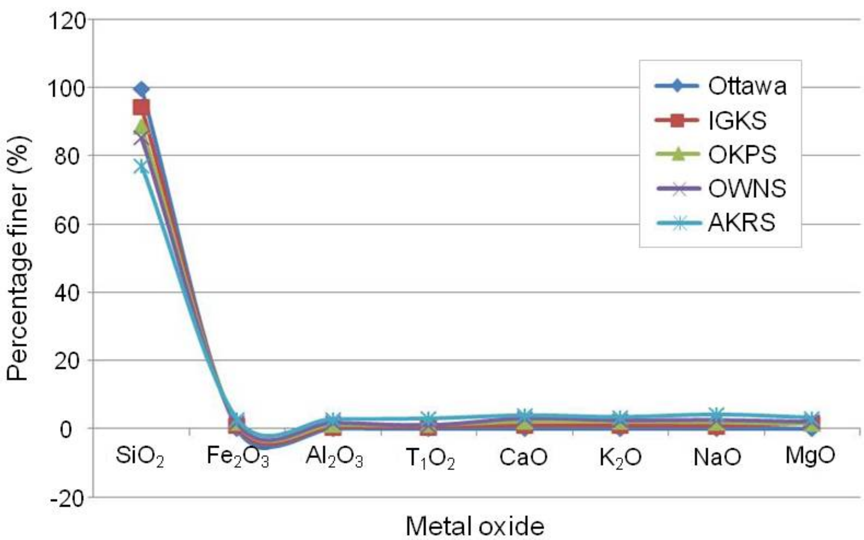

Fig. 7 Comparing the metal oxide of the samples with Ottawa sand

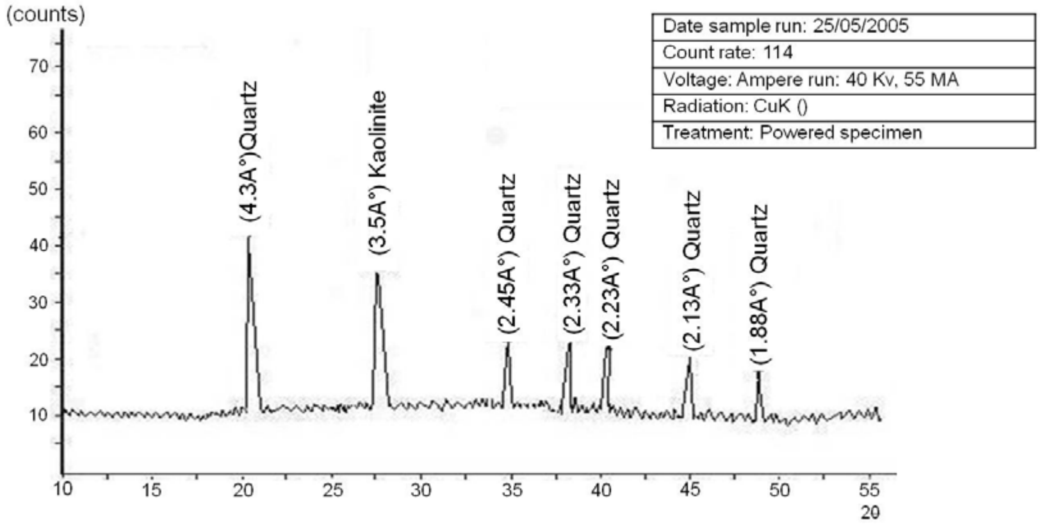

Fig. 8 X-ray diffraction of Igbokoda sand

Table 5 Result of geochemical analysis of the studied sands

Location	Soil sample	Metal oxide (%)							
		SiO_2	Fe_2O_3	Al_2O_3	T_iO_2	CaO	K_2O	Na_2O	MgO
Standard	Ottawa	99.8	0.02	0.06	0.01	0.01	0.01	0.01	0.01
Igbokoda 1	IGKS A	94.75	0.755	1.342	0.409	0.901	0.76	0.564	0.52
	IGKS B	94.58	0.759	1.848	0.192	0.902	0.763	0.763	0.193
	IGKS C	93.808	0.987	1.348	0.615	0.902	0.87	0.967	0.503
	IGKS D	93.813	0.997	1.348	0.515	0.904	0.88	0.725	0.618
	Average	94.24	0.87	1.47	0.48	0.90	0.82	0.75	0.47
Okiti-Pupa 2	OKPS A	87.42	1.595	1.96	1.525	1.418	1.835	2.45	1.797
	OKPS B	89.37	1.704	1.928	1.005	1.518	1.734	1.631	1.11
	OKPS C	89.57	0.473	1.98	0.78	0.555	1.982	2.225	1.435
	OKPS D	87.777	1.974	2.58	1.27	1.10	2.622	1.265	1.412
	Average	88.52	1.69	2.11	1.14	1.15	2.04	1.92	1.43
Owena 3	OWNS A	85.79	1.806	1.573	-	2.803	2.978	3.113	1.937
	OWNS B	85.89	1.507	1.443	1.292	3.704	1.978	2.423	1.763
	OWNS C	85.184	1.598	1.908	1.510	2.84	2.987	2.321	1.652
	OWNS D	84.166	2.334	2.205	1.353	2.844	1.97	2.421	2.707
	Average	85.26	1.81	1.78	1.04	3.05	2.48	2.57	2.01
Akure 4	AKRS A	78.53	2.785	3.972	2.404	3.449	3.787	2.204	2.869
	AKRS B	75.53	3.686	3.874	2.771	4.48	3.183	3.644	2.832
	AKRS C	79.39	2.322	3.873	2.198	3.245	2.189	2.823	3.960
	AKRS D	75.142	2.153	4.63	4.214	4.245	4.293	2.373	1.950
	Average	77.15	2.74	4.09	2.90	3.85	3.36	2.76	3.15

Table 6 Relative percentage of quantities of minerals in the studies sands

Sample location	Minerals (%)					
	Quartz	Kaolinite	Illite	Halloysite	Feldspar	Chlorite
Ottawa	99.8	0.01	0.01	0.01	0.01	-
IGKS	81.40	18.60	-	-	-	-
OKTS	71.59	28.41	-	-	-	-
OWNS	74.49	-	25.5	-	-	-
AKRS	60.28	18.46	-	-	21.51	-

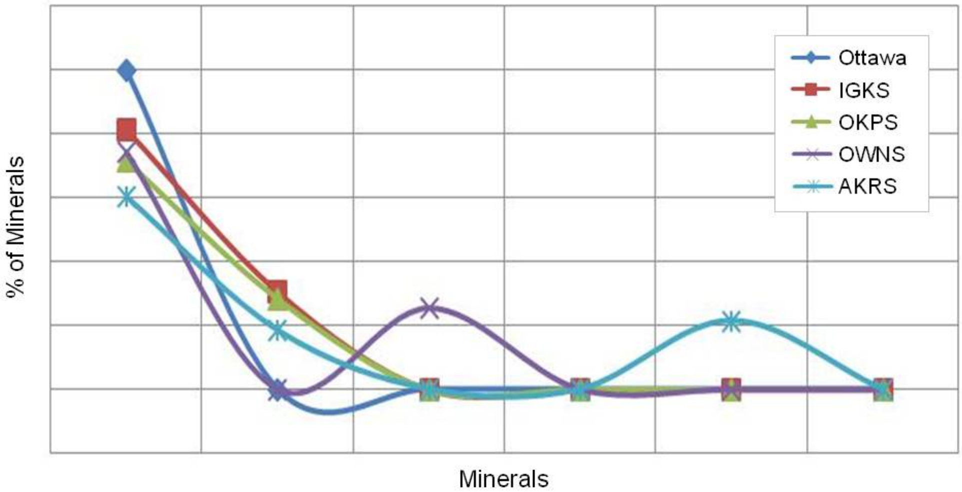

Fig. 9 Relating percentage of quantities of minerals in the studies sands with Ottawa sand

form (2-4 μm). Minerals in the sand fractions were identified from the oriented and random powder diffraction pattern following the procedures given by David *et al*. (2002). Identification of the minerals present in the soil samples was based on x-ray powder data for minerals David *et al*. (2002).

From the results of x-ray diffraction analysis, the following conclusions were arrived at regarding the mineralogy of the soil samples. It can be noted that quartz is prominent in the studied sands: Igbokoda, Akure, Owena and Okiti-pupa sands. In Fig. 8, the presence of quartz in Igbokoda sand was confirmed by the following reflections; 4.3A^0, 2.45A^0, 2.33A^0, 2.23A^0, 2.13A^0 and 1.88A^0. The presence of kaolinite was confirmed by the following characteristic peaks; 3.5A^0.

In Okitipupa sand quartz was prominent and the presence of quartz was confirmed by the following characteristic peaks; 3.58A^0, 2.48A^0, 2.45A^0, 2.28A^0 and 1.81A^0. The presence of kaolinite was confirmed by a reflection at 3.58A^0. In Owena sand, the presence of quartz was also confirmed by the following reflections 3.22A^0, 2.4A^0, 2.24A^0, and 1.54A^0. The presence of Illite was confirmed by a reflection at 3.22A^0. In Akure sand, quartz was prominent. The presence of quartz was confirmed by the following characteristic peaks; 3.51A^0, 3.46A^0, 2.46A^0, 2.28A^0, 1.86A^0, and 1.4A^0. The presence of kaolinite was confirmed by a characteristic peak at 2.28A^0.

Feldspar presence was confirmed by peaks at $4.04A^0$ and kaolinite by peak at $3.51A^0$. Table 6 and Fig. 9 show that quartz mineral was prominent in the studied sands. The quantities of quartz in Igbokoda, Okitipupa, Owena and Akure sands are 81.40, 71.59, 74.49 and 60.28% respectively. Also, quantities of kaolinite in Igbokoda, Okitipupa and Akure sands are 18.60, 28.41 and 18.46% respectively. Owena shows 25.51% of illite While Akure shows 21.25% of feldspar. Therefore the Igbokoda sand quartz quantity of 81.40% is the closest to Ottawa sand quartz quantity of 99.8%.

3.6.2 Differential thermal analysis (DTA)

Bulk sample of the experimental sands were taken to the Geology Department, University of Ibadan, Ibadan, Oyo state, Nigeria for Differential Thermal Analysis. The sand minerals can be identified by the temperatures required to extract structural water from their lattices or transformation of one sandy mineral into another. The amount of water released by a mineral when heated to a high temperature was measured by using thermal balance. The characteristic (*differential thermal or DTA*) curves for the types of clay minerals identified in the sand samples are shown in Fig. 10. It shows that Igbokoda sand gives examples of such curves for some major types of sand minerals. In the case of quartz, the structural water starts to be released at temperatures of about 550°C and 600°C respectively which correspond to the breaking point of the endothermic curve. On the other hand, for Owena sand sample and Akure sand sample the structural water starts to be released at temperatures of about 600°C and 700°C respectively. Further heating causes recrystallization in the Okitipupa sand sample which starts at the temperature of about 800°C, 1000°C for Owena sand, and 900°C for Akure sand. Recrystallization starts at 800°C for Igbokoda sand, corresponding to the starting point of the exothermic curve. This is comparable with 700°C for Ottawa sand. In the process of recrystallization, both alumina and silica were formed.

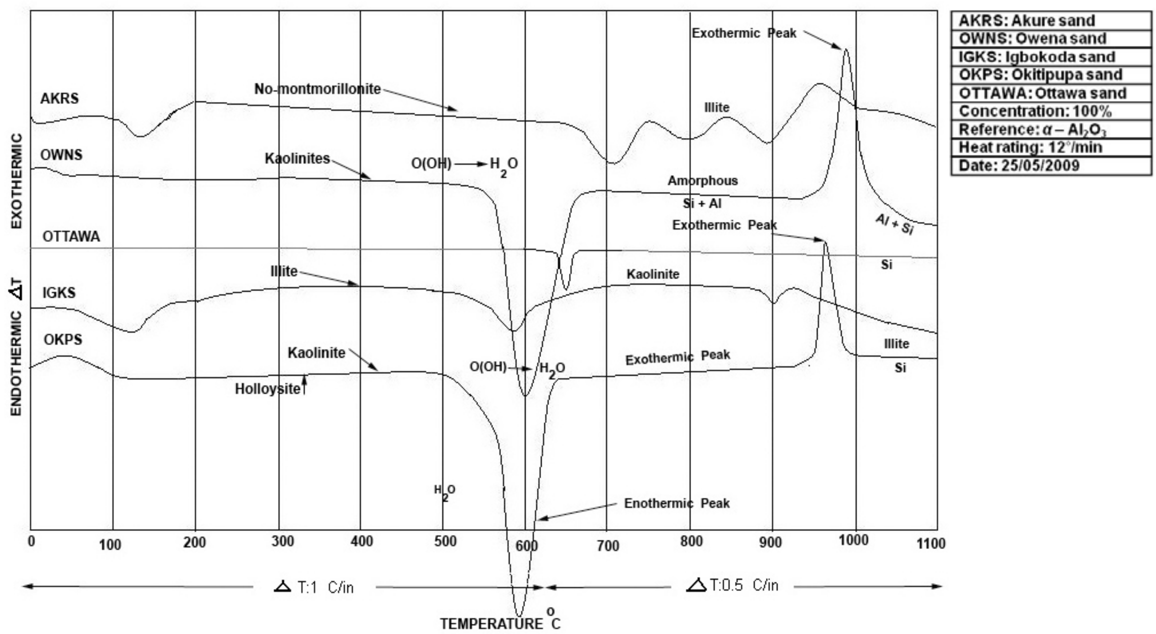

Fig. 10 Differential thermal analysis (DTA) of the four studied sand samples

4. Conclusions

Igbokoda sand is the only sand out of the studied sands with grain size distribution closest to the Ottawa sand. There is less than 1% difference in specific gravity values for the Ottawa sand and the Igbokoda sand. The bulk density of Igbokoda sand is also significantly closer to Ottawa sand than the other studied sands. The results of the in-situ porosity and bulk density of the studied sands showed that Igbokoda sand has values almost the same as the Ottawa sand.

The results of chemical analysis also showed that all the studied sands have variation in percentages of silica, iron, aluminum, magnesium, potassium, titanium, calcium and sodium oxide in all the sample locations. However, the percentages of silicon oxide (94.2%) and quartz in Igbokoda sand are closest to that of Ottawa sand. Olasupo and Omotoyinbo (2009) obtained silicon oxide content of 95.8% for the Igbokoda Silica sand. A report on the Non-metallic Mineral Endowments in Nigeria by the Raw Materials Research and Development Council, Abuja (RMRDC 2010) has an average value of 99.8% SiO_2 for the Igbokoda silica sand. It can therefore be concluded from all the parameters studied that Igbokoda sand is the closest to Ottawa sand. With the results obtained from this research work, it is recommended that Igbokoda sand should be established as standard baseline sand for all subsequent engineering work in the West African sub-region. The properties are similar to those of the Indian standard sand, Toyoura sand (Japan), CEN (Committee for European Norms) standard sand and the Ethiopian standard sand. Little processing of the Igbokoda sand may be required to bring it to the same level as a standard baseline sand as has been achieved by the Ottawa sand.

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