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GEOTECHNICAL CHARACTERIZATION AND EROSION RISK ASSESSMENT OF SOILS: A CASE STUDY OF GOMWALK BRIDGE, FEDERAL UNIVERSITY OF TECHNOLOGY, OWERRI, SOUTHEASTERN NIGERIA.

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ABSTRACT

Background: *The engineering properties of soils are fundamental in civil engineering construction projects, especially in road constructions, foundations, embankments, and dams. Geotechnics, or engineering geology, is a vital field applied in engineering contexts (Glossop, 1968; Roberts, 1981). Key geotechnical parameters influencing erosion initiation, progression, monitoring, and material selection for soil erosion control include grain size distribution, density, void ratio, porosity, shear strength, Atterberg limits, and compaction (dry density, moisture content relation) (Okeke and Enwelu, 2010). Understanding soil mechanics and earth materials is crucial for predicting, preventing, or mitigating damage caused by natural or human-induced hazards such as erosion, floods, subsidence, and landslides. It is also vital for designing engineering structures, predicting foundations' performance, and ensuring the stability of bridges, buildings, and other man-made structures based on underlying soil properties.*

Aim: *This study aims to assess the contribution of local geology and specific geotechnical properties of sediments at the Gomwalk Bridge gully erosion site, Federal University of Technology, Owerri, Southeastern Nigeria. The objective is to correlate these properties with erosion susceptibility.*

Methods: *The research employed a reconnaissance survey and sample collection methods, integrating laboratory analysis with geotechnical studies.*

Conclusion: *The research findings offer crucial insights into the geotechnical characteristics of the soils surrounding the Gomwalk Bridge gully erosion site at FUTO in Southeastern Nigeria. These insights are pivotal for devising effective strategies to combat gully erosion, ensuring sustainable infrastructure, and maintaining environmental stability in the region. Continued research and ongoing monitoring are imperative for implementing long-lasting solutions and mitigating the adverse impacts of gully erosion.*

Keywords: *Gomwalk Bridge, gully erosion, geotechnical investigation, soil properties, stability.*

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INTRODUCTION

In the geotechnical realm, comprehending the intricate interplay of soil composition, topographical features, and human activities holds heightened significance, especially within the context of Southeastern Nigeria. This region is characterized by undulating landscapes and erratic climatic patterns, a geographical setting that intensifies the challenge of gully erosion. Numerous studies (Nwachukwu et al., 2017; Egboka & Okpoko, 2015) underscore the severity of gully erosion and its adverse impacts on infrastructure and communities in this area. The Gomwalk Bridge, situated within the Federal University of Technology Owerri (FUTO), serves as a pertinent case study that encapsulates the prevalent geotechnical challenges and erosion risks unique to this region (Akpan et al., 2020). Through rigorous soil characterization and erosion risk assessment, this research aims to unravel the intrinsic properties of the soil, identify key contributing factors to erosion, and propose tailored engineering interventions, aligning with the urgent need for sustainable land management in Southeastern Nigeria.

This study represents a vital endeavor toward sustainable geotechnical engineering practices by scrutinizing the soil and terrain complexities specific to gully-prone regions in Southeastern Nigeria. The Gomwalk Bridge area, situated in the academic enclave of FUTO, stands at the convergence of academic, infrastructural, and environmental dynamics, making it an ideal case study. The erosion threat not only jeopardizes the integrity of critical infrastructure but also raises significant environmental and societal concerns (Nwilo & Badejo, 2006). Understanding the geotechnical properties of the soils, the role of local topography, soil-water interactions, and human influence on the erosion process is fundamental to devising effective countermeasures tailored to the unique challenges of Southeastern Nigeria.

This research aims to provide comprehensive insights into the soil composition, mechanical properties, and erosion vulnerability, considering the intricacies of the Gomwalk Bridge site and similar gully-prone areas within Southeastern Nigeria. The findings derived from this case study will significantly contribute to the broader body of geotechnical knowledge, offering a nuanced perspective on erosion risk assessment in regions with comparable geological and climatic characteristics. Ultimately, the results and recommendations derived from this study aspire to inform sound engineering practices and policy decisions, fostering sustainable land management and infrastructure development in Southeastern Nigeria.

LITERATURE REVIEW

Erosion is a natural process, but human activities have significantly accelerated its global occurrence. Various factors contribute to erosion, including climatic aspects such as wind, storms, temperature, and precipitation. Geological factors like sediment rock type, porosity, and permeability also play a significant role. Excessive erosion leads to problems such as desertification, decline in agricultural productivity due to land degradation, and sedimentation of waterways. Factors influencing erosion rates encompass the quantity and intensity of precipitation, average temperature, temperature fluctuations, seasonality, wind speed, and storm frequency. Blanco (2010) illustrated that rainfall and wind contribute to over 80% of natural erosion causes, while human activities like industrial agriculture, deforestation, road construction, anthropogenic climate change, and urban sprawl are significant contributors to erosion, as studied by Julien (2010).

Ahnert (1970), Montgomery et al. (2002), and Palumbo et al. (2010) have established the interrelation between topography and erosion rate by demonstrating that hillslope gradient and topographic relief increase with erosion rates. However, studies have shown that this relationship breaks down at high erosion rates, as hillslope angles reach a limiting gradient, as evidenced by Schmidt (33), Burbank (2011), Montgomery (2002), Binnie (2007), and DiBiase (2010). This suggests that geological factors are vital in understanding the geomorphology of an area, emphasizing the importance of utilizing geophysical methods to unravel geological processes.

Geomorphology delves into the study of the physical features or landscape of the Earth's surface and their connection to geological structures. Billi et al. (2003) and Di Biase (2011) have demonstrated that the topographic configuration of landscapes reflects the interplay between geology and climate-driven surface processes, dictating erosion rates and controlling topography. Generally, geological factors determine slope, while climate influences the efficiency of erosional processes. Understanding the relationship between erosion rates and landscape morphology is fundamental in geomorphic studies, as highlighted by Yoo et al. (2008a) and Tucker et al. (2010). Furthermore, identifying critical correlations between topographic form and erosion rates offers the potential to interpret geological or climatic conditions based solely on topography, a point underscored by Ahnert (1970), Burbank (2011), and Wobus et al. (2006).

In similar vegetation and ecosystems, regions experiencing frequent and high-intensity precipitation, strong winds, and storms are anticipated to undergo more erosion. Nichols (2001) also revealed that soil composition, moisture, and compaction are crucial determinants of rainfall erosivity. Sediments with a clayey composition tend to resist erosion more effectively than sandy or silty sediments due to the binding of soil particles by clay particles. Moreover, soils rich in organic matter tend to be more erosion-resistant since organic materials facilitate soil colloid coagulation, resulting in a stable and robust soil structure, as affirmed by Glennie (1970).

LOCATION AND GEOLOGY OF THE STUDY AREA

The study site is situated within the Niger Delta Basin of Nigeria, precisely between latitudes 5° 23.35' and 5° 23.43' North and longitudes 7° 59.23' and 7° 59.31' East (refer to Figure 1). This specific area is found at an elevation of approximately 43 meters above mean sea level within Owerri West, a local government area in Owerri, Imo State, located in Southeastern Nigeria. The region is easily accessible through a well-established road network.

Geographically, the study area falls within Nigeria's equatorial rainforest belt. The average monthly temperature ranges from 25 to 28.5°C, while the mean annual rainfall measures around 2500 mm, with the majority occurring between May and October (National Root Crop Research Institute, 2011). The rainy season, typically from May to October, is characterized by moderate temperatures and high relative humidity. Rainfall distribution exhibits two troughs in November-December and August (associated with the August break), while it peaks sharply in June, July, and September, tapering off in November and December (NIMET, 2012). The area's geomorphology features a sub-horizontal landscape with a gentle slope. The prevailing wind directions in Owerri and its surroundings, including the study area, are primarily South-West, North-West, and West, with South-West being the dominant direction (Anyanwu and Iwuagwu, 1994). Wind patterns significantly influence the dispersion of gaseous emissions in and around the landfill.

Geologically, the study area is underlain by the Benin Formation, dating from Miocene to recent times, a significant stratigraphic unit within the Niger Delta Basin (refer to Figure 2). Initially referred to as the Coastal Plain Sands (Simpson, 1956), the Benin sands and sandstones primarily represent deposits from a continental upper deltaic plain environment. As documented by various researchers (Etu–Efeotor, 1981; Etu-Efeotor and Akpokodje, 1990; Offodile, 2002; Udom et al., 2002; Olobaniyi and Owoyemi, 2006), the Benin Formation is highly permeable and productive, predominantly composed of sand (70-100 percent), occasionally intercalated with clay, sandstone, conglomerates, and isolated gravel units. The sand is typically coarse-grained, pebbly, and poorly sorted, with occasional lenses of fine-grained sands (Short and Stauble, 1967; Onyeagocha, 1980). Alluvial deposits overlie the formation, while the Ogwashi-Asaba Formation, consisting of lignite, sandstones, clays, and shale, underlies it. The Benin Formation is a crucial aquifer for groundwater storage, characterized by high porosity and permeability, making some parts of the area susceptible to groundwater pollution. In terms of hydrology, the study area is drained by the Otamiri River (refer to Figure 1). The river flows southwards from Egbu, passing through Owerri and various towns in Imo State, eventually reaching Ozuzu in Etche, Rivers State, before reaching the Atlantic Ocean. The Otamiri River watershed, covering an area of about 10,000 km2, is characterized by depleted rainforest vegetation. The river serves various purposes, including domestic and commercial water supply, fishing, recreation, and sand mining activities. Moreover, it also functions as a tourist attraction and a hub for research activities.

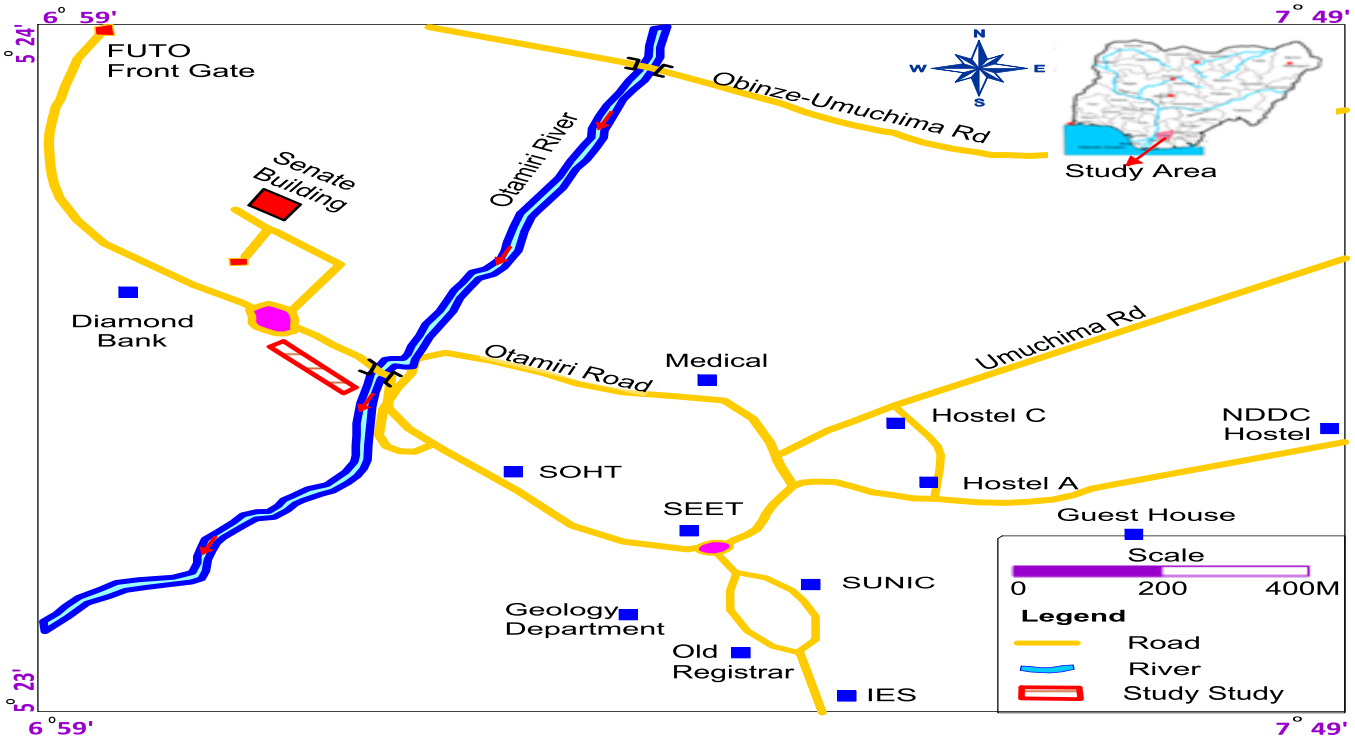

Figure 1: Topographic Map showing study area and environs.

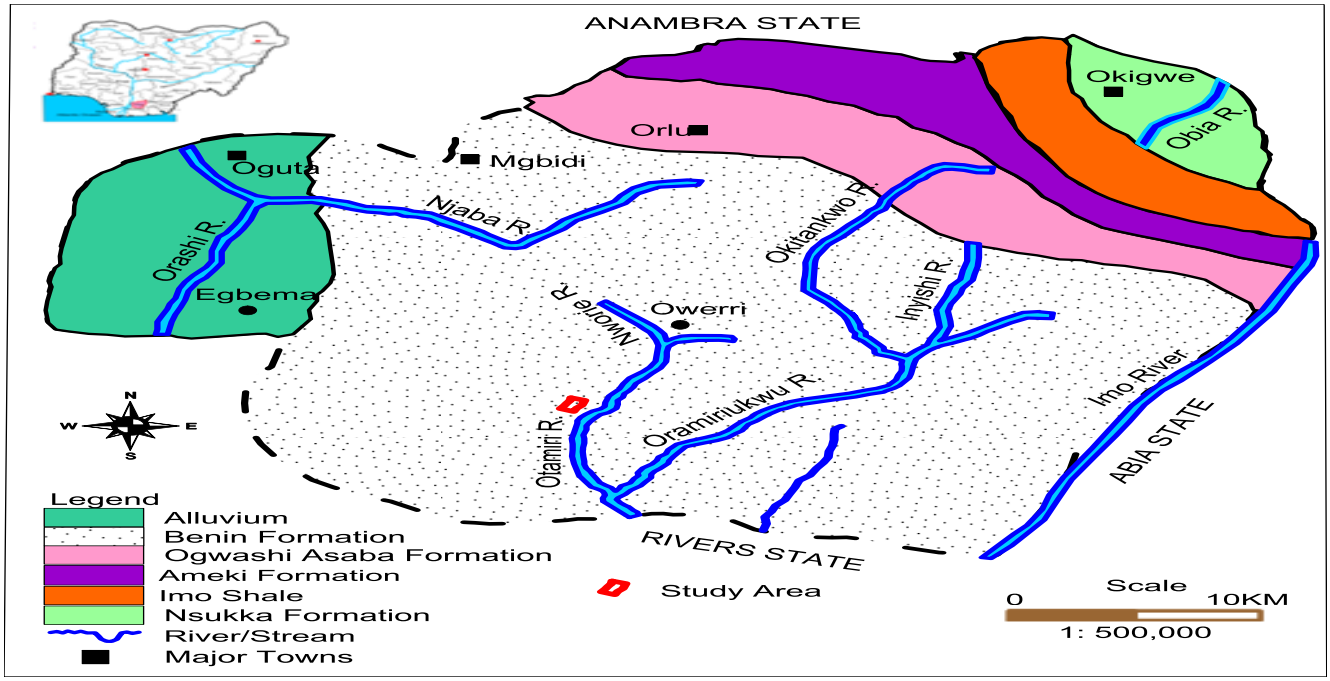

Figure 2: Geological Map of Imo state showing the Study Area

METHODOLOGY

A reconnaissance mapping was carried out to identify strategic points for sediment sampling; and to identify gully activities. The research also utilized personal observation methods and snapping of pictures of the site condition (plates 1 and 2).The soil samples were collected along the gully length. The length and width of the gully area were measured to be 120 m by 4 m in dimension (Figure 3).

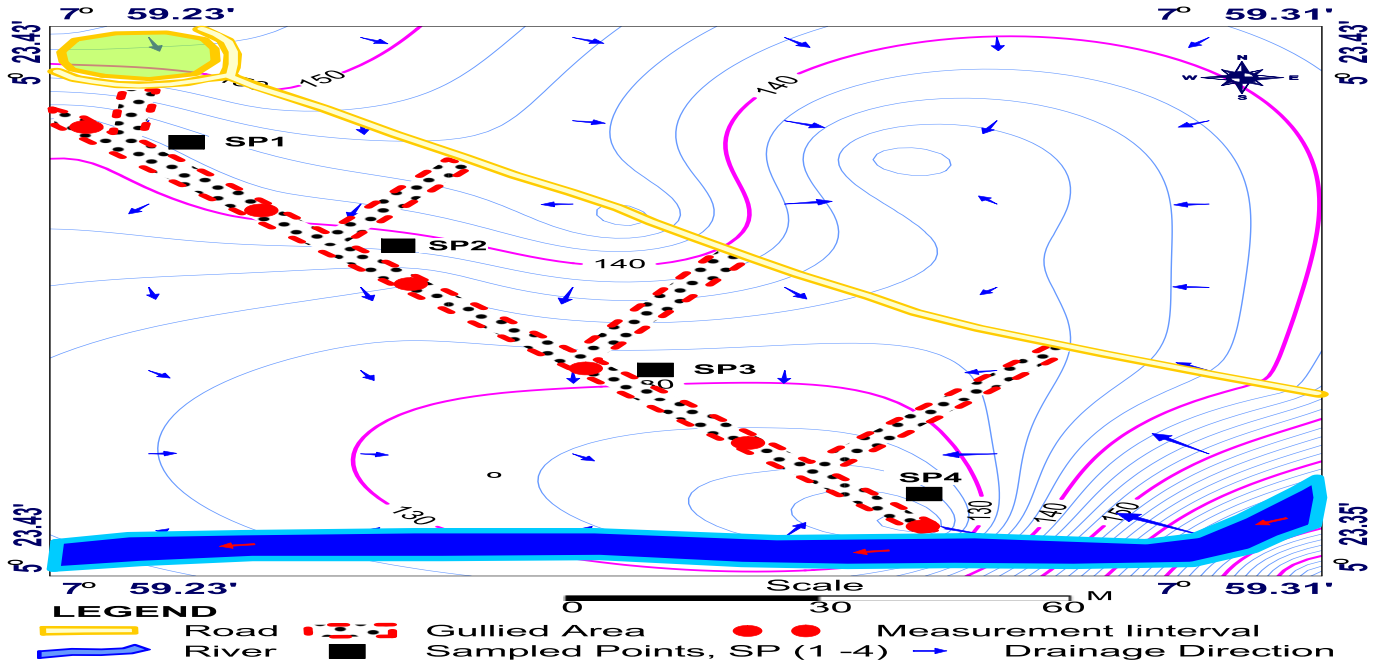

Figure 3. Sampled Points around the Gullied Area

Soil samples were collected with the aid of a hand auger at a depth of 1m from the ground surface. Four sampling points were taken along the gully length at an interval of 30m.The soil samples were taken to the laboratory for both index and performance tests. The index properties analyzed were the moisture content, Atterberg limit, bulk density, and sieve analysis. The results of index properties guided the selection of performance tests which include compaction and hydraulic conductivity. The laboratory tests were conducted at the Institute of Erosion Studies of the Federal University of Technology, Owerri, and were all performed following the specified standard procedures (BS, 1975; ASTM 1979).

- **Grain Size Distribution**

Sieve analysis was used to determine the particle size distribution of grains in a soil mass. The apparatus used for this test included B.S. test sieves, a mechanical shaker, a weighing balance, and a sieve brush. A known weight of samples was placed on carefully selected sieves. The sieves were placed on the mechanical shaker. Sieving was done using the internal and vertical movement of the sieve accompanied by a jarring action. The cumulative percentage retained and cumulative percentage passing were calculated using the equations below.

$$\%\ soil\ retained = \frac{Weight\ of\ soil\ retained}{total\ \ soil\ weig\ ht} \times 100\%$$

% passing = Total % retained (100) - % passing on each sieve

A known weight of prepared samples was sieve-washed and dried. The sample was sieved and the amount retained on each sieve was collected and weighed to determine the percentage of material passing each sieve size.

Table 1. Sieve Analysis for Sample A and B

Sieve size (mm)	SAMPLE A			SAMPLE B		
	RET	% RET	% PASSING	RET	% RET	% PASSING
4	0.00	0.00	100	0.00	0.00	100
2.36	0.00	0.00	100	0.00	0.00	100
2	4.40	1.53	98.47	3.25	2.02	97.98
1.18	26.75	9.29	89.18	16.75	10.40	87.58
0.85	39.90	13.86	75.32	23.85	14.80	72.78
0.6	56.00	19.46	55.86	30.80	19.12	53.66
0.425	46.80	16.26	39.6	23.70	14.71	38.95
0.3	51.90	18.03	21.57	29.25	18.16	20.79
0.15	42.65	14.82	6.75	23.50	14.59	6.2
0.125	14.30	4.97	1.78	6.10	3.79	2.41
0.075	2.40	0.83	0.95	2.25	1.39	1.02
0.063	0.60	0.21	0.74	0.20	0.12	0.9
Pan	2.05	0.71	0.03	1.20	0.74	0.16

Table 2. Sieve Analysis for Sample C and D

Sieve size (mm)	SAMPLE C			SAMPLE D		
	MASS RET	% RET	% PASSING	MASS RET	% RET	% PASSING
4	0.00	0.00	100	13.65	5.69	94.31
2.36	0.00	0.00	100	11.20	4.67	89.64
2	1.55	0.49	99.51	9.30	3.88	85.76
1.18	6.50	2.04	97.47	36.80	15.35	70.41
0.85	20.15	6.33	91.14	23.00	9.60	60.81
0.6	48.50	15.23	75.91	29.00	12.10	48.71
0.425	55.30	17.36	58.55	11.85	4.94	43.77
0.3	84.00	26.37	32.18	50.90	21.23	22.54
0.15	89.45	28.08	4.1	40.40	16.85	9.69
0.125	7.05	2.21	1.89	8.90	3.71	1.98
0.075	2.95	0.93	0.96	1.60	0.67	1.31
0.063	0.85	0.27	0.69	0.70	0.29	1.02
PAN	2.15	0.68	0.01	1.80	0.15	0.27

The coefficient of uniformity (C_u) and coefficient of curvature (C_c) were calculated to determine the grading of soil. The key particle sizes used in the calculation include D_{10}, D_{30}, and D_{60} which represent grain size values at 10 %, 30 %, and 60 % passing respectively. The following formulae were used to calculate C_u and C_c respectively.

Uniform coefficient, $C_u = \frac{D_{60}}{D_{10}}$

Coefficient of concavity, $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$

For a material to be well graded it must fulfill one or all of the following: that C_c is between 1.0 and 3.0; and or C_u must be greater than 4.0 for gravels and greater than 6.0 for sands. Otherwise, it is poorly graded (SP). The main outcome of this test was the grain size distribution curve, which provided percent gravel, percent sand, and percent fines (silt + clay).

- **Liquid Limit Test**

Table 3. Liquid Limit Determination for Sample A and B

SAMPLE	Sample A			Sample B		
CAN ID	A	B	C	A	B	C
WT of can + wet soil	44.7	38	38.3	39.2	36.5	37.6
Wt. of can + dry soil (g)	42.1	36.3	35.4	31.2	30.8	31.5
Wt. of can (g)	16.9	17.5	18.5	19.5	17.2	19.6
Wt. of dry soil	25.2	18.8	16.9	11.7	13.6	11.9
Wt. of moisture (g)	2.6	1.7	2.9	8.0	5.7	6.1
WATER CONTENT%	10.3	9	17.2	68.36	41.91	51.26
NO OF BLOW	16	23	35	11	29	49

TABLE 4. Liquid Limit Determination for Samples C and D

SAMPLE	Sample C			Sample D		
CAN ID	A	B	C	A	B	C
WT of can + wet soil	56.8	41.2	45.1	37.5	32.7	40.2
Wt. of can + dry soil (g)	40.2	31.7	34	30.7	28.3	29.6
Wt. of can (g)	16.9	17.5	18.5	19.5	17.2	19.6
Wt. of dry soil	22.4	19.7	14.3	9.6	12.0	8.5
Wt. of moisture (g)	3.2	1.9	3.1	9.3	6.3	4.9
WATER CONTENT%	10.3	9	17.2	68.38	41.91	51.26
NO OF BLOW	16	23	35	11	29	49

- **Plastic Limit, (PL)**

It is the moisture content at which the soil begins to behave like plastic. A representative sample of air-dried soil passing the 425 µm BS test Sieve was thoroughly mixed with water on a glass plate until it was sufficiently plastic to be molded into a ball.

A piece of soil was taken and rolled into a ball between the hands until it developed a hairline crack on the surface. The sample was then divided into two and each of these two was divided into four and tested as follows:

The soil is rolled into a 6mm diameter thread between the thumb and index finger. This was further rolled into 3mm with some pressure between the fingertips and a cleaned flat glass plate. The sample was remolded into a 6mm diameter thread and again rolled into 3mm. This procedure was repeated until longitudinal and transverse cracks appeared at a rolled diameter of 3mm. The moisture content was determined after these cracks appeared. This procedure was carried out two times for each sample.

Table 5. Plastic Limit Determination for Samples A and B

SAMPLE		Sample A		Sample B	
Determination No		A	B	A	B
Wt. of can (g)	M_1	22.5	19	19	21.5
Wt. of can + wet soil (g)	M_2	33.8	33.6	29.7	35.6
Wt. of can + dry soil (g)	M_3	31.2	30.8	27.1	31.8
Calculation					
Wt. of water (g)	$W_w = M_2$	2.6	2.8	2.6	1.1
Wt. of dry soil	$W_s = M_3$	8.7	11.8	8.1	10.3
Moisture content	$W = \frac{W_w}{W_s}$	29.89	23.73	32.1	10.87
Average PL (%) = $\frac{WP_1+W}{2}$		26.81		21.49	

TABLE 6. Plastic Limit Determinationfor Samples C and D

SAMPLE		Sample C		Sample D	
Determination No		A	B	A	B
Wt. of can (g)	M_1	22.5	19	19	21.5
Wt. of can + wet soil (g)	M_2	33.8	33.6	29.7	35.6
Wt. of can + dry soil (g)	M_3	31.2	30.8	27.1	31.8
Wt. of water (g)	$W_w = M_2$	2.6	2.8	2.6	1.1
Wt. of dry soil	$W_s = M_3$	8.7	11.8	8.1	10.3
Moisture content	$W = \frac{W_w}{W_s}$	29.89	23.73	32.1	10.87
Average PL (%) = $\frac{WP_1+WP_2}{2}$		26.81		21.49	

- **Plasticity Index, (PI)**

It is the difference between liquid limit, LL, and plastic limit, PL (PI = LL - PL). It represents the range of soil moisture content over which soil is plastic.

- **Liquidity Index, (LI)**

It is the ratio of the differences between the natural moisture content and plastic limit, W_n, - PL, to the plasticity index, PI. Mathematically:

$$\text{Liquidity Index, LI} = \frac{Wn - \text{PL}}{\text{PI}}$$

- **Moisture Content Test**

This test was used to determine the water content of the soil. It is expressed as a percentage of the weight of water to the dry weight of the soil. A known weight of samples was taken out of the preserved samples from the field and weighed. The sample was oven-dried at a temperature of about 110^0C for about 24 hours. The weight of the sample was taken again and was used to calculate the moisture content with the following formula:

$$\text{Moisture content}, w = \frac{M_2 - M_3}{M_3 - M_1} \times 100\left(\text{Mg}/\text{m}^3\right)$$

M_1 = mass of container, M_2 = mass of wet soil + container, M_3 = mass of dry soil + container. It is expressed in percentages. This procedure was carried out for each sample three times.

TABLE 7. Natural Moisture Content for Samples A, B, C, and D

SAMPLE		A	B	C	D
Wet soil + container (g)	M_2	92.30	95.70	98.50	95.70
Dry soil + Container (g)	M_3	82.10	82.45	90.10	86.45
Container (g)	M_1	23.40	18.85	21.50	23.40
Dry soil (g)	$M_3 - M_1$	58.70	63.60	68.60	63.05
Moisture loss (g)	$M_2 - M_3$	10.20	13.25	8.40	9.25
Moisture content %	W	17.38	20.83	12.24	14.67
Where $W = \frac{m_2 - m_3}{m_3 - m_1} \times 100\%$					

- **Bulk Density Test**

This test was carried out to determine the weight per unit volume of loose dry material such as powder and sand. The unit of measurement is kg/m^3. The values of bulk density of soil are typically between 1 – 2kg/m^3 (Grossman and Reinsch, 2002). It is inversely proportional to porosity and directly proportional to compaction and runoff. The apparatus used included a cylinder of known weight and volume, flat–bladed knife, a 1kg metal rod (18 inches) and a weighing balance were the apparatus used for this test. The cylinder was filled with sand leveled with flat–bladed knife and weighed without compaction. The cylinder was emptied after the weighing. Five layered compactions with 1kg metal rammer were carried out on the sample in the cylinder. The sample was weighed and was used to calculate the bulk density. These procedures were repeated three times for each sample and the following formula was used to determine the bulk density for each sample:

$$\text{Bulk density}, \rho = \frac{W_2 - W_1}{V}$$

W_1 = weight of cylinder, W_2 = weight of cylinder and sample, V = volume of cylinder.

- **Compaction Test**

Compaction is the process by which the moisture content change in the soil is controlled, increasing unit weight, and shear strength, and reducing permeability. This makes the soil less susceptible to settlement under load, especially repeated loading. This is usually done by mechanical means (Brian, 1978). A 2.5kg method of compaction was used for this test. The apparatus consists of a 2.5kg rammer, a known volume of the mold with a removable base, and a detachable collar. Three kilograms of air-dried soil was used for the test and the test was repeated five times for each sample. The moisture content used was between 4% - 20% of the weight of the sample, and samples were mixed thoroughly before compaction. Three layers of compaction were done for each trial and 27 blows were used to compact each layer. Graphs of dry density, ρ_d against moisture content were plotted using rock work software to determine the optimum moisture content. Bulk density and dry density were calculated using the following formula:

$$\text{Bulk density} = \frac{M_1 - M_2}{1000}\left(\text{Mg}/\text{m}^3\right)$$

$$\text{Dry density}, \rho_d = \frac{M_2 - M_1}{1000(1+m)}$$

M_1 = mass of mold (g), M_2 = mass of mold and compacted sample (g), 1000 = volume of mold (cm^3), m = moisture content used.

Table 8. Bulk Density for Sample A and B

SAMPLE		A			B		
MEASUREMENT NO		1	2	3	1	2	3
Weight of mold + compacted Soil	(A)	248.2	286.6	294.4	248.6	278.9	281.4
Weight of mold (g)	(B)	103.5	103.5	103.5	103.5	103.5	103.5
Weight of compacted soil (g)	(A – B)	144.7	182.5	190.7	145.1	175.4	177.9
Volume of mould(cm^3)	98.2	98.2	98.2	98.2	98.2	98.2	98.2
Bulk Density, (τ)	$\frac{Wt.\ of\ soil}{volume\ of\ soil}$	1.47	1.86	1.94	1.48	1.79	1.81
Average bulk density(mg/m^3)		1.76			1.69		

Table 9. Moisture Content/ Dry Density Determination for Sample A and B

SAMPLE		A			B		
Can Identification		1	2	3	1	2	3
Mass of mold + Wet Soil	(M_2)	88.50	66.00	63.40	65.35	74.00	58.90
Mass of mould + Dry Soil	(M_3)	77.40	57.50	52.50	58.20	62.50	49.30
Mass of mould	(M_1)	18.90	19.40	19.40	17.60	18.90	19.20
	Calculation						
Weight of Water	($M_2 – M_3$)	11.10	8.50	10.90	7.15	11.50	9.60
Weight of Dry Soil	($M_3 – M_1$)	58.50	38.10	33.10	40.60	43.60	30.10
Moisture Content (W %)	$\frac{M_2 - M_3}{M_3 - M_1} \times 100$	18.97	22.31	32.93	17.40	26.30	32.00
Dry Density(τd) (mg/m^3)	$\frac{Bulkdensity}{(1 + w)}$	1.24	1.52	1.46	1.26	1.42	1.37

Table 10. Bulk Density for Sample C and D

SAMPLE		C			D		
MEASUREMENT NO		1	2	3	1	2	3
Weight of mold + compacted Soil	(A)	256.0	278.9	265.0	231.5	280.1	278.3
Weight of mold (g)	(B)	103.5	103.5	103.5	103.5	103.5	103.5
Weight of compacted soil (g)	(A – B)	152.5	175.4	161.5	128.0	176.6	174.8
Volume of mould(cm^3)	98.2	98.2	98.2	98.2	98.2	98.2	98.2
Bulk Density, (τ)	$\frac{Wt.\ of\ soil}{volume\ of\ soil}$	1.55	1.79	1.64	1.46	1.83	1.80
Average Bulk Density(mg/m^3)		1.66			1.70		

Table 11. Moisture Content/ Dry Density Determinationfor Sample C and D

SAMPLE		C			D		
Can Identification		1	2	3	1	2	3
Mass of mold + Wet Soil	(M_2)	46.20	62.50	54.70	91.50	72.50	63.40
Mass of mould + Dry Soil	(M_3)	41.70	53.40	45.40	85.26	62.90	52.50
Mass of mould	(M_1)	18.90	19.30	17.60	18.90	22.20	19.40
	Calculation						
Weight of Water	($M_2 – M_3$)	4.50	9.10	9.30	9.91	9.60	10.90
Weight of Dry Soil	($M_3 – M_1$)	22.80	34.10	27.80	66.36	40.70	33.10
Moisture Content (W %)	$\frac{M_2 - M_3}{M_3 - M_1} \times 100$	19.70	26.80	33.40	18.87	23.70	33.20
Dry Density(τd) (mg/m3)	$\frac{Bulkdensity}{(1 + w)}$	1.29	1.41	1.24	1.23	1.48	1.35

DISCUSSION

- **FIELD ASSESSMENT**

The protection of the slope of the embankment of materials from the erosive force of water at the reclaimed site close to Otamiri River has failed either due to poor engineering practice or the rearing of cattle by the Fulani. Also, improper and failed drainage channels thatconvey flood water on sloped terrain, especially in loose soil structure areas are responsible for the development of gully at the site drainage channel (Plate 1, 2, 3).



Plate 1: Failed Embankment



Plate 2. Failed Drainage Channel

Part of the artificial bank of earth material raised above the immediate surroundings to carry a roadway is now being eroded. This was as a result of deforestation and cattle rearing. Moreover, apart from deforestation, overgrazing was also responsible for the removal of the grasses that once protected the soils from the direct impacts of rainfall. Consequently, erosion has started wreaking havoc by eroding the embankment raised to carry the only roadway that links the Federal University of Technology Owerri from the front gate (plate 3).



Plate 3. Bare Land Due Deforestation

- **RESULT OF GRAIN SIZE ANALYSIS AND DISTRIBUTION**

The non-uniform soil particles/well-graded (W) designation of the soil is based on the coefficient of concavity C_c and uniformity coefficient; C_u which are computed from data obtained from the grain-size distribution curve (Figures 4 and 5).

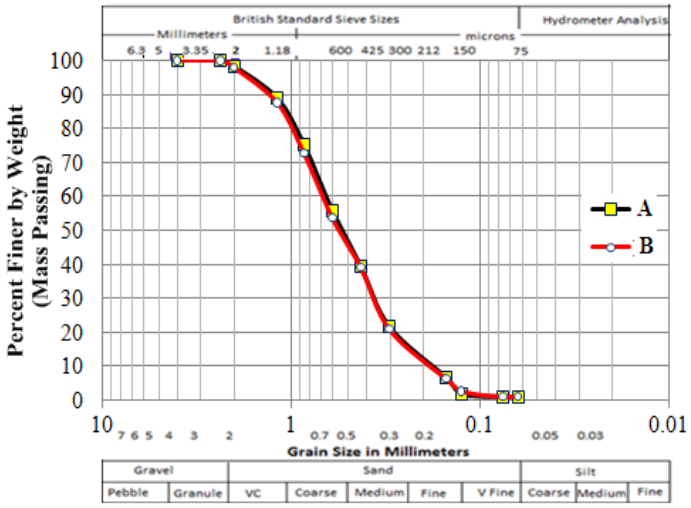

Figure 4: Particle Size Distribution Curve for samples A and B

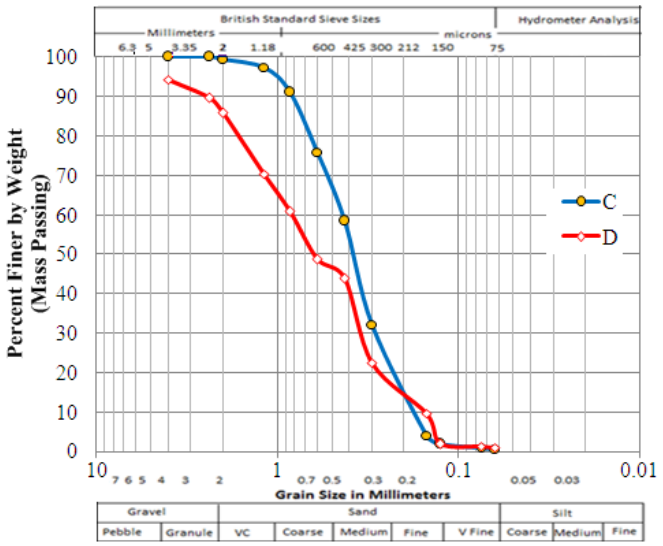

Figure 5: Particle Size Distribution Curve for samples C and D

Analysis of grain size distribution of the surficial sediment sloping from A to D as shown on the semi-logarithm graph indicates a relatively high percentage of sand 98.47, 97. 98, 99.51, and 85.76 % respectively. The results are consistent with the findings of many authors (Reyment, 1965; (Avbovbo, 1978; Onyeagocha, 1980; (Uma and Egboka, 1985) regarding the geology and hydrogeology of the area.

The summary of grain size analysis (Table 12) shows that the coefficient of curvature (C_c) of samples A to C ranges from 1.06 to 1.10 and lies between ($1.0 \leq C_c \leq 3$) and hence are classified as well-graded sand (SW). It implies that these lithologic units show a good representation of all particle sizes. Alternatively, sample D shows poorly graded (GP) with a coefficient of curvature (C_c) of 0.90 (i.e. $C_c < 1$) and hence indicates excess or absence of intermediate particle sizes.

Table 12. Summary of Results on Grain Size Analysis

Location	Gravel%	Sand%	D_{10}	D_{30}	D_{60}	D_{50}	C_u	C_c
1	1.53	98.47	0.18	0.37	0.69	0.55	3.83	1.10
2	2.02	97. 98	0.19	0.38	0.70	0.56	3.68	1.09
3	0.49	99.51	0.18	0.29	0.44	0.39	2.44	1.06
4	14.24	85.76	0.16	0.35	0.85	0.63	5.31	0.90
Uniform coefficient, $C_u = \frac{D_{60}}{D_{10}}$; Coefficient of concavity, $C_c = \frac{D_{30} \times D_{30}}{D_{10} \times D_{60}}$								

D_{10} Denotes grain size value at 10% passing.

A large value of C_u indicates that D_{60} and D_{10} sizes differ appreciably.

Soil particle grains ranging from 0.5 to 0.25 mm in diameter are medium-grained sand whereas grains that range from 1 to 0.5 mm in diameter are coarse sand (Wentworth Grade Scale). So, the grain size value (mm) at 50 % passing indicates that samples A - D are medium-grained sand (Table 12). These sediments are porous, and permeable and do not

offer natural protection against groundwater pollution. The coarse-grained nature of the sediments could mean a rapid infiltration rate for runoff and its constituents and could serve as a migration pathway for contaminant transport. Though, textural characteristics of the sediments can ultimately influence the rate of infiltration.

In the event of gully development, the cohesionless whitish and gravelly sediments are highly susceptible to gully erosion. Obiefuna *et al.*, (1999) were of the view that a high percentage of sand and a low percentage of silty/clay content in the soil contribute to gully development.

The sands are therefore highly permeable on account of their loose, coarse grains. The cohesionless and coarse-grained nature of the sediments makes the control of gully erosion difficult after the red lateritic sediments at the surface have been eroded.

1. **Hydraulic Conductivity (K)**

Hydraulic conductivity values (K) were calculated from grain size data in the laboratory (Carter 1983) and were used to obtain estimates of the regional groundwater velocities. According to Allen Hazen (1930), the hydraulic conductivity (K) of the soil was derived from the relationship:

$$K = A\,(d_{10})^2$$

Where A is a dimensionless coefficient which is equal to 1 and d_{10} is the grain size value (in mm) at 10% passing.

Location	D_{10} (mm)	$(D_{30})^2$	$K = A(d_{10})^2$ (cm/sec)
1	0.18	0.0324	0.0324
2	0.19	0.0361	0.0361
3	0.18	0.0324	0.0324
4	0.16	0.0256	0.0256

2. **Activity of Clay**

This is the measure of the contribution of clay minerals to the plasticity of the lateritic soil given as

$$A_c = \frac{P.I}{Percentage\ \ of\ Clay}$$

Hence, $A_c = \frac{24.49\%}{32.29\%} = 0.76.$

The activity of clay is between 0.75 and 1.25 and is said to be normal. The value of the activity of clay is directly proportional to the potential volume change of the laterite.

- **Water Content**

The average percentage of the water content of 1, 2, 3, and 4 are 17.38, 20.83, 12.24 and 14.67 % respectively (Table 7). The water content values of the study area are relatively low. The water retention capacity of the sediment increases from location 1 to 2 decreases to 3 and

eventually increases to 4. Unconsolidated sands lose moisture very quickly on exposure to heat or atmosphere as a result of little or no clay mineral

1. **Collapsibility of Sediments**

Collapsible sediments exhibit low strength at moisture content approaching saturation, resulting in a collapse of the soil skeleton and large decreases in soil volume. Priklonski's (1952) criterion employed the liquidity index to estimate the degree of collapsibility. The natural moisture content is less than the plastic limit (equation 16) and hence, the liquidity index of the sediment samples is less than zero. So, the sediments are likely to suffer collapse because they are in a very dry state.

$$K_D = \frac{\text{Natural Moisture Content} - \text{Plastic Limit}}{\text{Plasticity Index}}$$

where:

$K_D < 0$: Highly Collapsible Soil

$K_D > 0.5$: Noncollapsible Soil

- **LIQUID AND PLASTIC LIMIT RESULTS**

The result of the liquid and plastic limit determination is shown in Table 13 (Figures 6 and 7). This indicates that the soil has a low amount of water retention capacity and hence capable of providing a migration pathway for contaminants.

Table 13. Natural Moisture Content and Liquidity Index for Samples 1, 2, 3 and 4

SAMPLE	Wn (%)	LL (%)	PL(%)	PI(%)	LI	Term
1	17.38	10.40	26.81	-16.41	0.57	Non-collapsible
2	20.83	48	21.49	26.51	- 0.025	Highly collapsible
3	12.24	10.40	26.81	-16.41	0.888	Non-collapsible
4	14.67	48	21.49	26.51	- 0.26	Highly collapsible:

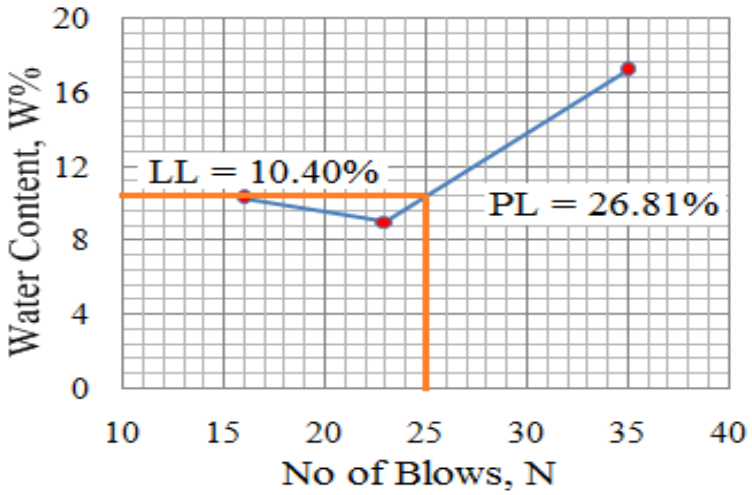

Figure 6: Liquid Limit for Sample 1

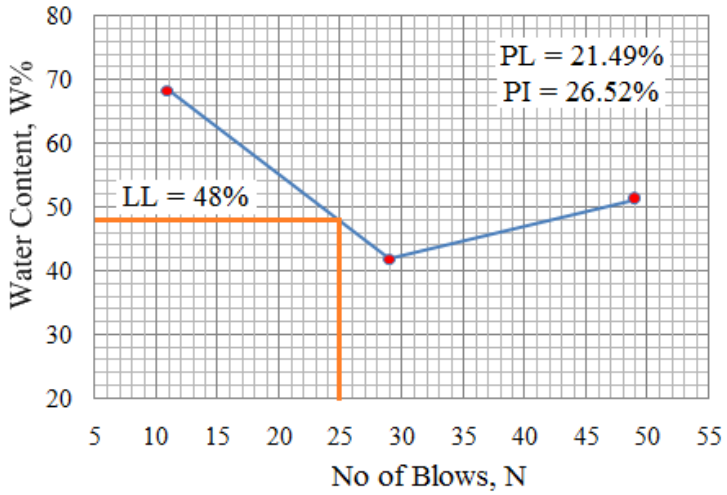

Figure 7: Liquid Limit for Sample 2

Table 14: Liquid Limits and Compressibility (Venkatramaiah 2006)

Sample	LL (%)	Range of LL (%)	Compressibility
1	10.40	< 30	Low
2	48	30 – 50	Medium
3	10.40	30 – 50	Low
4	48	> 50	Medium

Table 14 shows that the liquid limit of the soil is indicative of medium compressibility. The greater the liquid limit, the greater the compressibility of the sediment. Based on their Atterberg limits, the sediment with little or no cohesion will crumble easily when dry, highly dispersive upon the action of the river current, and also when fully saturated and collapsible. Generally, sediments with low liquid limits have high hydraulic conductivity (Kabir and Taha, 2004). All the samples show that the sediments have a liquid limit below 50% and as such have low swelling potential (Pitts, 1984; Kalantari, 1991).

1. **Plastic Limit**

The plastic limit of the samples ranges from 21.49 to 26.81%.

Also, Dudley (1970) reported that most of the collapsing sediments have a liquid limit of below 45 % and a plastic limit of below 25 %.

Thus, the liquid and plastic limit results indicate that the sediments are collapsible

2. **Plasticity Index**

According to Kabir and Taha (2004), it is the key property in achieving low hydraulic conductivity. The samples have plasticity indexes ranging from 16.41 to 26.51 % respectively. At locations 1 and 4, the plasticity index of the samples falls within the range of 25 – 35 %, so the sediments have medium swelling potential whereas at locations 2 and 4, the plasticity index is below 25 % implying low swelling potential (Pitts, 1984; Kalantari, 1991). At locations 1 and 4, the surficial sediments have reasonable organic matter, and clay minerals such as Kaolin whereas in locations 2 and 3 the organic matter of the sediments

might have been washed off by erosion. The sediments with a plasticity index not exceeding 25 % are not expected to suffer shrinkage at all. Therefore, they cannot minimize hydraulic conductivity.

- **COMPACTION TEST**

Plots of dry density versus water content are presented below (Figures 8, 9, 10, and 11). The compaction curves show that the dry density increases with increasing water content up to a maximum and later decreases. The result of the compaction tests indicates that the range of OMC from 22.31 to 26.80 % is required to achieve MDD of the samples ranging from 1.41 to 1.52 mg/m^3.

Table 15. Proctor Compaction Test for Samples A - D

SAMPLE	MDD(Mg/m^3)	OMC (%)
A	1.52	22.31
B	1.42	26.30
C	1.41	26.80
D	1.48	23.70

The order of MDD of the samples is as follows: A > D > B > C whereas the order of the OMC is C > B > D > A. Sample 1 has the highest MDD at OMC of 22.31% whereas; sample 3 has the lowest MDD at 26.80%. It is important to compact the sediments to improve the load-bearing capacity, reduce soil settlement, and stabilize the slope. However, the addition of water above optimum moisture content can result in slope failure or instability. Therefore, OMC is used as a guide to know the amount of water to add during construction work.

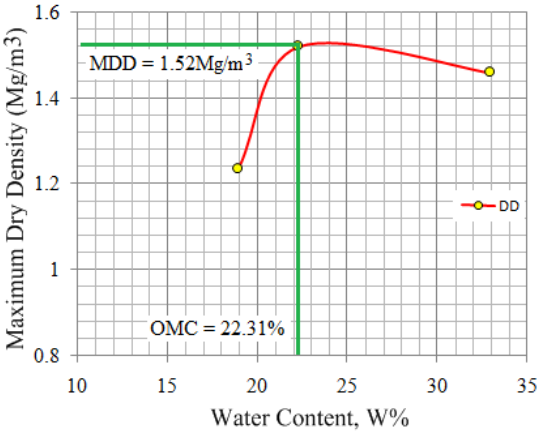

Figure 8. Maximum Dry Density vs. Moisture Content for Sample A

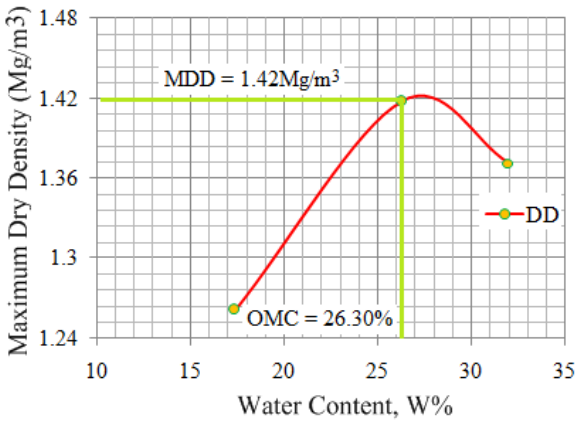

Figure 9. Maximum Dry Density vs. Moisture Content for Sample B

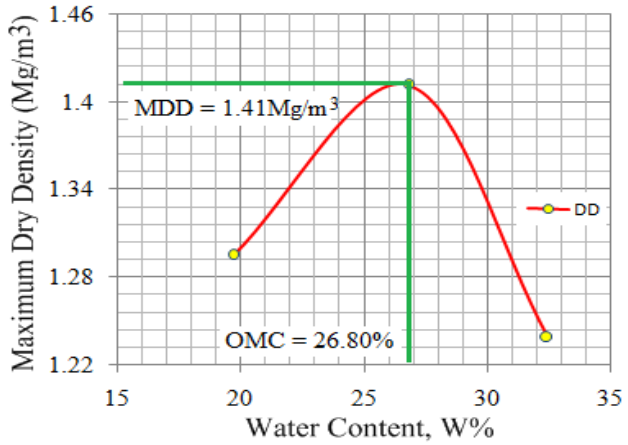

Figure 10: Dry Density-Water Content Relationship Curve for C

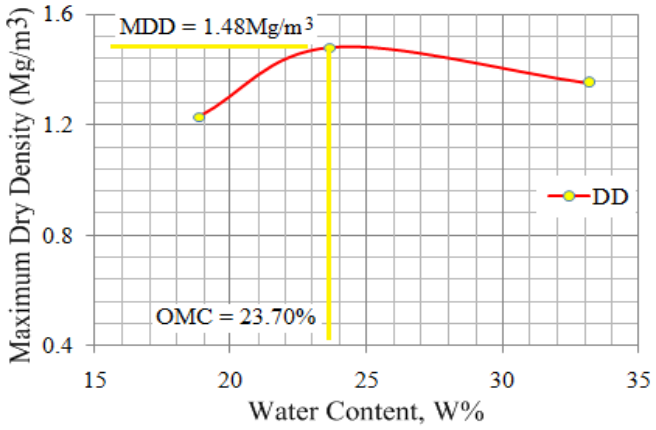

Figure 11: Dry Density-Water Content Relationship Curve for D

Okunade (2007a), working on the geotechnical properties of sediments including around the study area, reported MDD between 1.7- 2.1 g/m^3 and OMC between 9 - 24 %. Okunade's works justify our findings concerning OMC and MDD.

CONCLUSION

The geotechnical properties of the bank sediments and bank stability analysis along the FUTO road by Otamiri Bridge have provided valuable information in land resource evaluation.

Texturally dominant Sandy (95.43%) with subordinate Clay-Loam (24%), ranging hydraulic conductivity from 2.56 x 10-2 to 3.61 x 10-2 cm/sec has characterized the bank sediments with poor stability susceptible to liquefaction.

The geotechnical properties of samples A, B, and C collected at the upper reaches well graded sand (SW) while sample D collected at lower reaches close to the river shows poorly graded (GP). Such types of sediments under similar conditions of compressibility may experience a greater degree of variability in failure under similar load conditions.

The geotechnical properties of soils that influence the development of gully at the erosion site include loose soil (low density), high hydraulic conductivity, and high percentage composition of sand with little or no binding material.

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