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Assessment of the Gully Erosion Problems in Idemili Drainage Basin, Southeastern Nigeria, Using Geotechnical Tools

Anaekwe, Michael Uchechukwu[1], Okoyeh, Elizabeth Ifenyinwa[2], Ben-Owope, Ogechukwu Anastasia[3] and Udegbunem, Innocent Ejike[4]

[2,4]Department of Geology, Nnamdi Azikiwe University, Awka, Anambra State, Nigeria

[1,3]Anambra State Materials Testing Laboratory, 1-5, Ministry of Works, Awka, Anambra State, Nigeria

Corresponding Author: Anaekwe, Michael Uchechukwu

Address: Anambra State Materials Testing Laboratory, No. 1-5, Ministry of Works, Awka, Anambra State, Nigeria

Email: itembamichael@gmail.com, **Phone No:** 07032403437

ABSTRACT

An assessment of the geotechnical parameters in the formation of gully erosion in high risk erosion areas such as Idemili drainage areas of Anambra State is presented. The soil around these gully erosion sites were investigated by collecting samples from the gully walls at depths 2m and 5m for laboratory analysis. Fourteen samples were collected in different locations of the study area and analyzed. Sieve analysis, Atterberg limits, triaxial tests and Compaction tests were carried out on the selected soil samples. The soils generally have similar geotechnical properties. The sieve analysis indicated that the percentage of sand ranges from 73.60% to 91.34% while that of fines range from 8.66% to 26.44%. The hydraulic conductivity ranges from 274.48 m/day to 410.78 m/day. Liquid limit ranges from 25.50% to 29.80%. The Plastic Limit ranges from 22.40% to 27.50%. The Plasticity Index ranges from 1.20% to 4.40%. The Maximum Dry Density (MDD) ranges from 1.81kg/m³ to 2.04kg/m³. The Optimum Moisture Content (OMC) ranges from 8.09% to 11.47%. Result of geotechnical investigation and laboratory analysis showed that the soil in the study area is majorly loose sand. They contain very small amount of clay which serves as a binding material. The maximum dry density values are generally low which indicates that the soils are unconsolidated and friable. Enlightenment and awareness of erosion control should include land use habits of the people in their agricultural practices. Concrete terracing of gully affected areas is recommended to reduce the impact or the force of rain-drop. This will restrict the widening of incipient gullies.

Keywords: *Geotechnical properties, Gully erosion, Sieve analysis, Compaction test*

1. Introduction

Erosion is a worldwide phenomenon that involves several geological processes tending to reduce land surface to equilibrium by loosening and removing soil and rock [1]. Through erosion the earth surface is being sculptured into new landforms. The tendency is to reduce all land surfaces to the global base level, the sea level [2]. Following the definition of gully, the gullies in Anambra State in particular and Southeast Nigeria would modestly be described as catastrophic. With many of them having depth and width exceeding tens of meters. Several authors have attributed the development of gullies in Anambra State to the influence of human activities on natural and geologic processes, while others suggested that gullies are linked with concentrated runoff processes. Erosion is very important for sediment formation, soil rejuvenation and for concentrating some economic heavy mineral deposits such as placers that are loosened, removed, transported and concentrated. Erosion also helps to expose deposits which have been hitherto buried in the subsurface [3].

This research work gives an understanding of gully initiation and development using geotechnical tools. Data gathered from the field will guide in the determination of gully erodibility potential, while the laboratory work will help in the calculation of hydraulic conductivity/permeability, porosity, bulk density and specific gravity and understanding the causes, effects and control measures of gully erosion in Idemili drainage areas, Anambra State, Nigeria where the menace has continued to pose an enormous challenge to geologists and other earth and environmental scientists.

The work is aimed at the assessment of the geotechnical characteristics of gully erosion in Idemili drainage areas.

The study area lies between latitudes 6°00N and 6°12^{1}N and longitude 6°45^{1}E and 7°06^{1}E and falls within the Anambra Basin of Nigeria, with an area extent of approximately 652.56km^2. The major towns in the study area include Nnobi, Oraukwu, Abatete, Ogidi, Alor, Umuoji, Uke and Ojoto. It is accessible via Awka - Nnewi and Onitsha-Nnewi asphalt roads. The study area is located in southeast, Nigeria as shown in Fig. 1.

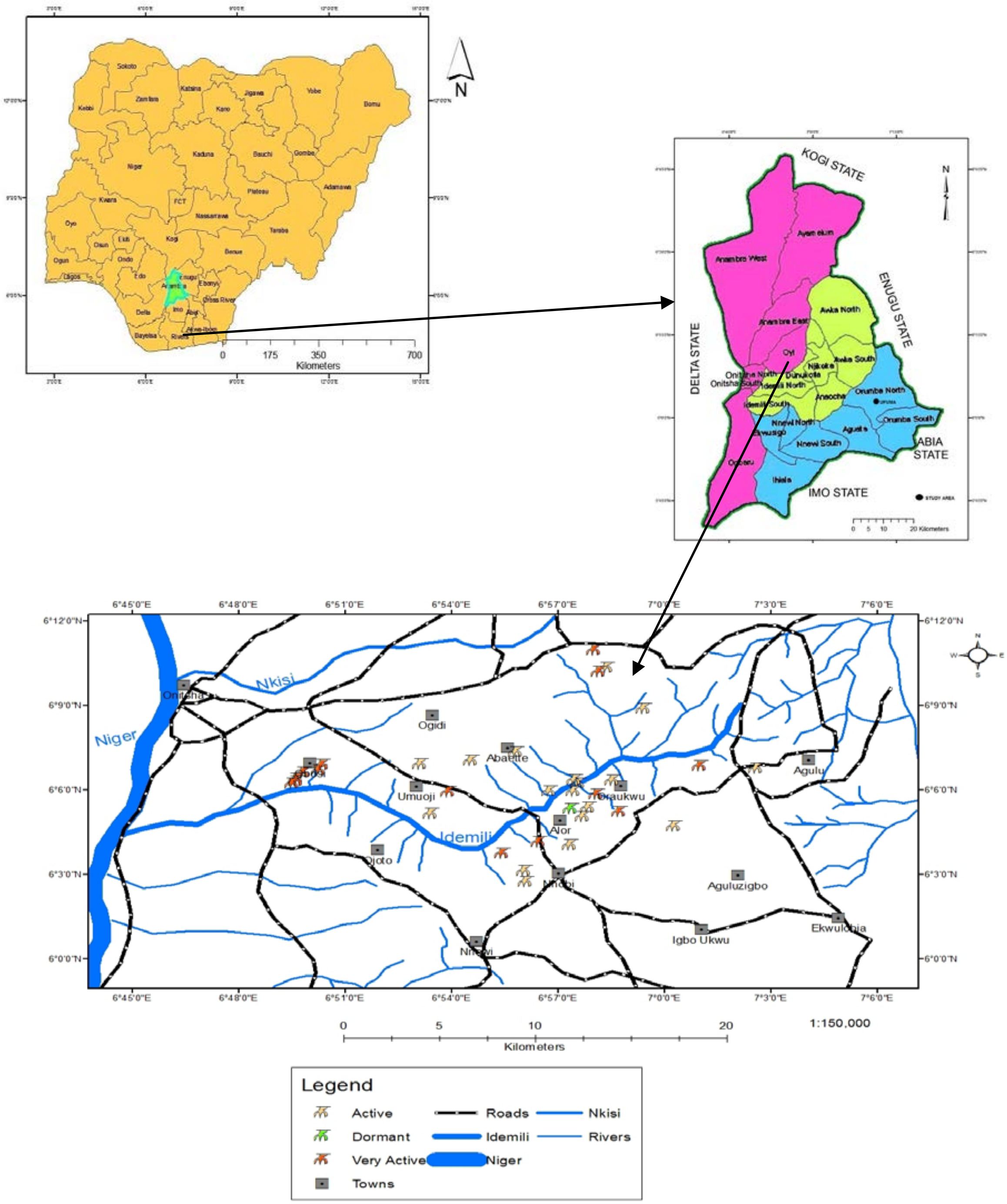

Fig. 1: Accessibility map of the study area

1.1 Geology of the Study Area

The main geological formation in the study area is the Nanka Sand which is underlain by the dark grey Imo Shale and overlain by the lignite-clay bearing Ogwashi-Asaba Formation. The Nanka Formation is predominantly sandy, with thin claystone and siltstone bands/laminations. The sand is poorly sorted, and medium to coarse grained. These units, separated by shale-siltstone-fine sand layers, may be as thick as 30m in some places. The deposits also exhibit well developed patterns of alternating cross-bedded sands and layers of dark-grey shales [4]. The shale units generally occur in beds 40-50cm thick alternating with fine sand and siltstone. The units generally have a low dip ranging between 7^0 and 9^0west [5]. The sands are generally loose, friable and poorly cemented with thin shaley layers. The sands are also very permeable. Depth to the water table varies spatially and seasonally. During the rainy season, the area receives enormous amount of downpour and the water table rises. The water table falls during the dry season as a result of hydraulic head decay. This results in decreased flow rates and an increase in the depth of the saturate zone. During the dry season, gully activities are therefore at a minimum. The expansion and growth of gully complex is enhanced by the high pore pressure, particularly during the peak recharge times of the rainy season, this high pore pressure reduces the effective strength of the unconsolidated sands.[5] The sands are gradually loosened and eroded by runoff. The behavior of the interbedded shales and clay which undergo large changes in volume as a result of alternating wetting and drying contribute to the growth of gully erosion. The shale increases in volume, becoming plastic and sticky when wet during the rains. During the dry season, they form a caked dry mass. Drying causes contraction of the clay and shale, resulting in the formation of extensive tension cracks.[2] These cracks widen with time, and during the rains, they serve as channels for vertical flow of water to the underlying sand/shale boundaries. The shales and clays become thoroughly saturated after many days of rainfall, swells and develop tendency to slide. Large masses of sand underlain by these shale and clay slide down dip into the gully, with the shale acting as lubricant. Embankments, catch pits and trees originally planted to control the menace as well as properties of people in the locality have been carried away by the sliding mass into the gullies [6].

In the project area, once a flood path has been defined, the upstream part of it begins to deepen backwards (headwards) while the behavior of the downstream part is determined by the base level [7]. Deepening of the downstream part ceases once the base level has been reached unless the base level itself deepens. The said headward recession takes place by corrasion, rockfall and undermining[3]. While this process determines the linear progression of a gully, the sidewalls undergo another series of mass movements that widen the gully and determine its lateral dimension or width. The mass movements include debris fall, slides, slumps and debris. flow (Figs. 2.1 and 2.2). In areas where the bedrock is exposed, fractures facilitate mass movements. [7] attributed the causes of gullies to the combination of physical, biotic and anthropogenic factors. [8] are of the opinion that gullies are caused by hydrogeological, hydrogeochemical and geotechnical properties of the rocks in the affected area. [9] are in agreement with Nwajide and Hogue on the causes of gullies in Southeastern Nigeria. One of the first major studies of gully erosion in the area was by Geological Survey of Nigeria (GSN), published in GSN Bulletin 21. Other studies on this issue include those of [10][7][11][12][3] and [13] among others.

Fig. 2.1: Debris Slides at Ndam, Nnobi

Fig. 2.2: Slump at Ezigbo, Oraukwu

2. MATERIALS AND METHODS

Field work was carried out in the study area, accompanied with sample collection at a depth of 5m using hand auger at seven different gully locations (Oraukwu, Abatete, Alor, Ogidi, Nnobi, Umuoji and Obosi) for laboratory analysis.. The collected samples were then taken to the laboratory for geotechnical analysis.

Geotechnical and geophysical studies were carried out in the laboratory. Three samples were taken at different locations from each town for laboratory analysis but the average of their results was used. The laboratory procedure includes both index and performance test. Three properties (moisture content, Atterberg limit, and sieve analysis) were determined. The results of the index properties guided the selection of the samples for performance test such as compaction and triaxial tests. The laboratory tests were conducted at the Anambra State Materials Testing Laboratory, Awka, Anambra State, with strict adherence to the specified standard procedures.

2.1 Sieve analysis:

200g of prepared samples were sieve washed and dried. A known weight of samples was placed on the top sieve of a known size. The sieves were placed on the mechanical shaker. Sieving was done by means of internal and vertical movement of the sieve accompanied by a jarring action. 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. The cumulative percentage retained and cumulative percentage passing were calculated.

Table 1: Soil Grain Size Classification (mm)[14]

Soil Type	USCS Symbol	USCS Range	AASHTO Range	USDA Range	MIT Range
Gravel	G	76.2 to 4.75	76.2 to 2	> 2	> 2
Sand	S	4.75 to 0.075	2 to 0.075	2 to 0.05	2 to 0.06
Silt	M	< 0.075	0.075 to 0.002	0.05 to 0.002	0.06 to 0.002
Clay	C	< 0.075	< 0.002	< 0.002	< 0.002

2.2 Atterberg limit test

This is used to determine the plasticity of soil. Soils within the high plastic range have the tendency to resist soil erodibility while soils within the low plastic are susceptible to erosion. Liquid limit, plastic limit, plasticity index, liquidity index and relative consistency are some parameters determined through Atterberg limit test. The results of the Atterberg limit test were plotted using appropriate software for soil classification.

While Liquid Limit (LL) test is the moisture content at which the soil begins to behave like fluid under the influence of a standard blows using Casagrande device, Plastic Limit (PL) test is the moisture content at which the soil begins to behave like plastic. The Plasticity Index is the difference between liquid limit (LL) and plastic limit (PL), The plasticity index represents the range of soil moisture content over which soil is plastic. The presence of high or low intergranular cohesive force in a soil determines how the soil reacts to erodibilty. The high clay content of a soil minimizes the devastation caused by gully [6].

Table 2: Standard range of plastic limits of soil [15]

PLASTIC LIMIT OF SOIL (%)	PLASTICITY
Below 35%	Low Plasticity *
Between 35 – 50%	Intermediate Plasticity
Above 50%	High Plasticity

Table 3: Plasticity indices and corresponding states of plasticity [16]

S/N	PLASTICITY INDEX (%)	STATE OF PLASTICITY
1	0	Non Plastic
2	1 – 5	Slight *
3	5 – 10	Low
4	10 – 20	Medium
5	20 – 40	High
6	> 40	Very High

2.3 Moisture content test

It is expressed as a percentage of the weight of water to the dry weight of the soil and it is calculated as

$$\text{Moisture content}, w = \frac{M_2 - M_3}{M_3 - M_1} \times 100 \quad (1)$$

2.4 Hydraulic Conductivity and Porosity Determination

The hydraulic conductivity (K) is defined as; $K = k\rho g/\mu$ (2)

Where, k = intrinsic permeability of porous medium and ρ and μ are density and dynamic viscosity of fluid respectively, g = the gravitational acceleration.Hydraulic conductivity is a direct function of average grain size distribution of granular porous media. Several formulae have been established by many researchers and scientists based on experimental work using the hydraulic conductivity and grain size relationship, such as

[17][18][19][20]. The applicability of these formulae depends on the type of soil in which hydraulic conductivity is to be estimated.

2.5 Alyamani and Sen Formula:

$$K = 1300 \times [I_o + 0.025\,(d_{50} - d_{10})]^2 \qquad (3)$$

Where K is the hydraulic conductivity (m/day), I_o is the intercept in (mm) of the line formed by d_{50} and d_{10} with the grain-size axis, d_{10} is the effective grain diameter (mm), and d_{50} is the median grain diameter (mm). For the purpose of this work, this formula is best applicable to calculate the hydraulic conductivity since the properties of the flow medium can only be determined either in the lab or field.

Porosity is a measure of the void spaces in a material, and is a fraction of the volume of voids over the total volume between 0 and 1, or as a percentage between 0% and 100%. Porosity has great influence on gully development, if the porosity is high; flow of water through the soil tends to be high leading to the leaching of surface soil during long duration of rainfall, this in turn leads to the development of gully erosion [21].
Hazen gave the formula of calculating porosity from the empirical formula which depends on the method used in grain size analysis. Porosity (n) is derived from the empirical relationship;

$$\text{Porosity, } n^* = 0.255\,(1 + 0.83^{Cu}) \qquad (4)$$

Where Cu = coefficient of grain uniformity given as D_{60}/D_{10}
D_{60} represents the grain diameter (mm) in which 60 percent of the sample is finer and D_{10} represents the grain diameter (mm) for which 10 percent of the sample is finer. This generally is the basis for different empirical formulas.

2.6 Compaction Test:
Compaction test is carried out with the aim of determining the moisture density relationships of the soil. Soils that are well compacted have low permeability and low water absorption and undergo minimal settlement or form high resistance to gully erosion [7][11][22][23]. The Compaction test was carried out using a cylindrical

metal mould with effective weight of 4560g and volume 2304.82cm^3, 4.5kg metal rammer, cylinder for measuring water, metal tray for mixing, tray for collecting weighted samples, electronic weighing machine, grease for oiling and cleaning rammer, hand towels for mixing, two iron slab red-like scrappers for cutting surface of when compacted into mould, chisel, scoop, hammer, and a container for collecting samples to oven dry. One point method was used for the present work. Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were read off in the graph at the peak point of the curve obtained from the laboratory data.

Bulk density and dry density were calculated using the following formulae:

$$\text{Bulk (wet) Density, } \rho_w = \frac{M2 - M1}{2304.82} \quad (kg/m^3) \quad (5)$$

$$\text{Dry Density, } \rho_d = \frac{100 \text{ x wet density}}{100 + \text{moisture content}} \quad (kg/m^3) \quad (6)$$

M_1 = mass of mould (g), M_2 = mass of mould and compacted sample (g), 2304.82 = volume of mould (cm^3), m = moisture content (%) used.

Table 4: Compaction Classification [22]

Maximum Dry Density (kg/m^3)	**Optimum Moisture content (%)**	**Classification**
1.44 – 1.685	20 – 30	Clay
1.60 – 1.845	15 – 25	Silty clay
1.75 – 2.165	8 – 15	Sandy clay

2.7 Triaxial shear test

Consolidated undrained test was conducted to determine the shear strength properties of soil samples. Each sample was subjected to a normal stress by compression of the fluid in the chamber. Rock work software and suffer 8 software were used to plot the graph of normal stress to determined angle of internal frictional and cohesion.

Table 5: Standard range of values for Triaxial: Underwood [24]

Laboratory test Observation	Average range of values	
Cohesion (KN/m^2)	Unfavourable 35 – 700	Favourable 700 – 10,500
Angle of Internal Friction φ(°)	10 – 20	20 – 65

3. Results and Discussion

The sieve analysis result shows that the study area is predominantly sandy (table 6 and Fig 3). From table 6, the percentage of the sand ranged from 76.09% in Abatete to 89.30% in Oraukwu, while the percentage of fines ranged from 10.70% in Oraukwu to 23.91% in Abatete. Using Fig.3 from Oraukwu as an example to illustrate the grading of the soil, it showed the gradation of the soil with smooth curve which is of high sand with little fines. Based on the grain size analysis results, removal and transportation of the soil grains by runoff water is easier because the soil samples contain smaller contents of fines, smaller particles are easily carried away by water since the transporting medium requires relatively small amount of energy. This is why erodibility potential of the soil units is high. These materials are highly susceptible to gully erosion. These results agree with [25] who concluded that high sand and low silty/clay content in the soil contribute to gully growth.

Table 6: Summary of Sieve Analysis of Samples

Location	Gully Depth (m)	Sand (%)	Fines (%)
Oraukwu	2.0	90.01	9.99
	5.0	86.33	13.67
Abatete	2.0	77.74	22.26
	5.0	76.09	23.91

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Alor	2.0	78.31	21.69
	5.0	76.45	23.55
Nnobi	2.0	84.41	15.59
	5.0	81.92	18.08
Obosi	2.0	84.42	15.58
	5.0	84.60	15.40
Ojoto	2.0	88.30	11.70
	5.0	84.50	15.50
Ogidi	2.0	88.50	11.50
	5.0	86.70	13.30

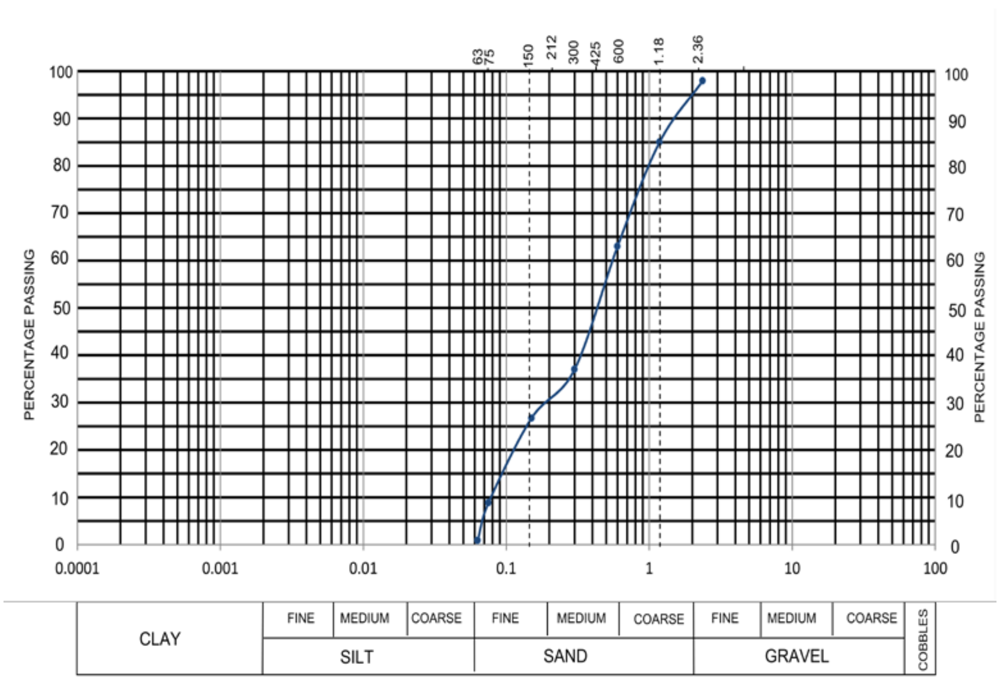

Fig. 3 Sieve graph of Oraukwu at 2m

The hydraulic conductivity and porosity of the area are high (table 7). The hydraulic conductivity ranges from 274.48 m/day in Alor to 410.78 m/day in Ogidi. This is why the movement or flow of water within the soil is very high as suggested by [26] that soils with high hydraulic conductivity allows high flow of water through the soil, thereby contributing to the dislodgement of the soils during the peak of rainy season which in turn gave rise to gully formation in the area.

Table 7: Summary of grain size values from empirical formula

S/N	Location	Gully depth (m)	Hydraulic Conductivity (K) (m/day)	Porosity (n*) (%)	C_c	C_u	D_{60} (mm)	D_{50} (mm)	D_{30} (mm)	D_{10} (mm)	I_o (mm)
1	Oraukwu	2 5	395.58 410.38	30.57 30.94	1.32 1.31	8.67 8.29	0.65 0.63	0.54 0.55	0.25 0.25	0.075 0.076	0.54 0.55
2	Abatete	2 5	425.53 410.60	30.24 29.57	3.56 3.85	8.40 9.85	0.63 0.64	0.56 0.55	0.41 0.40	0.075 0.070	0.56 0.55
3	Alor	2 5	274.63 274.48	30.92 31.56	1.26 1.40	8.31 7.71	0.53 0.54	0.45 0.45	0.22 0.23	0.065 0.070	0.45 0.45
4	Nnobi	2 5	312.45 286.71	31.56 32.17	3.06 2.74	7.71 7.20	0.54 0.54	0.48 0.46	0.34 0.37	0.070 0.075	0.48 0.46
5	Obosi	2 5	274.63 299.52	30.77 31.56	3.43 2.98	8.46 7.71	0.55 0.54	0.45 0.47	0.35 0.33	0.065 0.070	0.45 0.47
6	Ojoto	2 5	395.76 381.08	30.01 30.35	3.33 3.54	9.29 8.91	0.63 0.65	0.54 0.53	0.38 0.41	0.070 0.073	0.54 0.53
7	Ogidi	2 5	395.76 410.78	30.53 29.94	3.38 3.45	8.71 9.38	0.63 0.61	0.54 0.55	0.39 0.37	0.070 0.065	0.54 0.55

The liquid and plastic limits were used to obtain the plasticity index which is a measure of the plasticity of the soils (table 8). The liquid limit ranges from 25.50% in Ojoto at 5m to 29.80% in Oraukwu at 2m, the plastic limit ranges from 22.50% at 5m in Nnobi to 26.80% at 2m in Abatete, the plasticity index is from 2.00% at 5m in Obosi to 4.40% at 5m in Abatete. These results from the plastic limits of the soil samples fall below 35% and could be classified as having low plasticity [15] while the values of plasticity index fall within the range of 1 and 5 which could be said to be slightly plastic [16]. All the soil samples from the various gully sites are within the low plastic range, the plasticity index revealed that the soils are non-cohesive. The non-cohesive nature of the soil in the area account for the gully erosion problems because water flows through the soil with ease and move the soil particles down slope with increase in velocity of motion of the water.

Table 8: Summary of Atterberg limits of samples

Location	Gully Depth (m)	L.L (%)	P.L (%)	P.I (%)
Oraukwu	2.0	29.80	26.80	3.00
	5.0	26.90	23.00	3.90
Abatete	2.0	27.50	25.30	2.20
	5.0	28.90	24.50	4.40
Alor	2.0	27.50	23.75	3.75
	5.0	25.90	22.55	3.35
Nnobi	2.0	27.55	23.75	3.70
	5.0	26.00	22.50	3.50
Obosi	2.0	28.50	24.30	4.20
	5.0	27.00	25.00	2.00
Ojoto	2.0	27.60	23.50	4.10
	5.0	25.50	22.50	3.00
Ogidi	2.0	28.50	26.20	2.30
	5.0	28.70	25.80	2.90

The compaction result (Table 9) shows that the moisture content ranges from 4.85% at 2m to 14.58% at 2m in Obosi, while the bulk density (wet density) ranges from 1.78kg/m^3 in Abatete at 2m to 2.04kg/m^3 in Oraukwu at 2m. Fig.4 from Oraukwu was used as an example on how to read off the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) from the graph. From (table 10), the optimum moisture content (OMC) values range from 8.09% in Ogidi at 2m to 10.32% in Alor at 2m, while maximum dry density (MDD) ranges from 1.83kg/m^3 in Abatete at 2m to 2.04kg/m^3 in Oraukwu at 2m. The bulk density values are high which indicates that the soil is not compact but loose. It is generally desirable to have soil with a low bulk density (wet density) <1.5 kg/m^3 for optimum movement of air and water through the soil, Soil structural degradation increases if the bulk densities get higher [27]. The values of OMC and MDD falls within the range classified as sandy clay by [22]. Also, similar values gotten by [28] was classified as low and that such soils are considered loose with little amount of clay that serves as binders which in turn aids gully formation.

Table 9: Summary of Compaction results of Oraukwu

	Depth	2.0m		5.0m	
S/N	**Location**	**M.C (%)**	**D.D (kg/m^3)**	**M.C (%)**	**D.D (kg/m^3)**
1.	Oraukwu	6.49	1.92	6.50	1.93
2.		7.97	1.98	7.82	1.97
3.		9.79	2.04	8.81	2.02
4.		11.20	2.01	9.35	2.00
5.		12.45	1.96	13.10	1.90
1.	Abatete	4.86	1.78	6.81	1.93
2.		6.87	1.80	7.72	1.99
3.		8.44	1.83	9.92	2.03
4.		10.81	1.81	11.36	2.01
5.		14.56	1.79	13.55	1.93
1.	Alor	6.50	1.94	6.35	1.95
2.		6.86	2.00	7.75	1.98
3.		10.32	2.03	9.26	2.00
4.		11.34	1.99	11.92	1.96
5.		12.23	1.95	13.04	1.94
1	Nnobi	5.50	1.87	5.72	1.85
2		7.80	1.90	7.79	1.88
3		8.76	1.93	10.10	1.91
4		10.10	1.88	12.80	1.88
5		12.08	1.86	13.69	1.87
1	Obosi	4.85	1.88	6.80	1.85
2		6.86	1.90	7.32	1.88
3		8.44	1.93	9.18	1.93
4		10.80	1.90	10.84	1.88
5		14.58	1.88	11.97	1.80
1	Ojoto	6.27	1.89	6.50	1.89
2		7.41	1.91	7.76	1.91
3		9.25	1.95	9.76	1.92
4		11.00	1.90	11.72	1.88
5		12.41	1.85	13.42	1.86
1	Ogidi	6.31	1.92	6.34	1.80
2		6.90	1.94	7.72	1.88
3		8.09	1.97	9.26	1.91
4		9.96	1.93	11.84	1.87
5		12.82	1.88	12.88	1.85

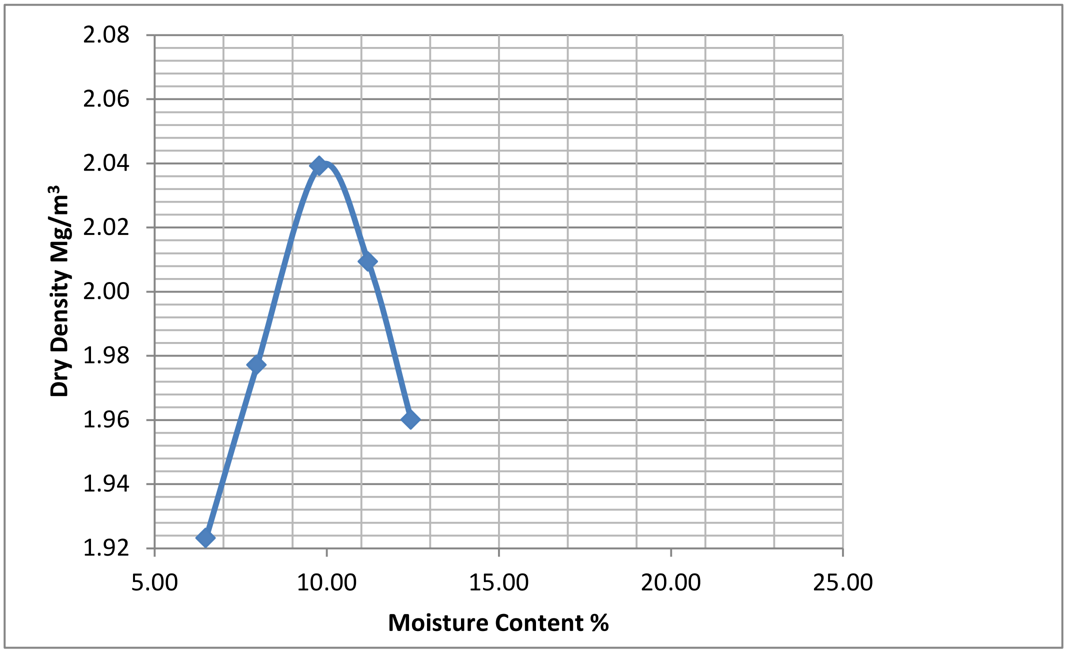

Fig. 4 Compaction graph of Oraukwu at 2m

Table 10: Summary of optimum moisture content and maximum dry density of the samples

S/N	Location	Gully depth (m)	OMC (%)	MDD (kg/m^3)
1	Oraukwu	2 5	9.79 8.81	2.04 2.02
2	Abatete	2 5	8.44 9.92	1.83 2.03
3	Alor	2 5	10.32 9.26	2.03 2.00
4	Nnobi	2 5	8.76 10.10	1.93 1.91
5	Obosi	2 5	8.44 9.18	1.93 1.93
6	Ojoto	2 5	9.25 9.76	1.95 1.92
7	Ogidi	2 5	8.09 9.26	1.97 1.91

The triaxial shear test result (table 11) shows that the angle of friction is between 15^0 in Oraukwu to 19^0 in Alor, Ojoto and Ogidi, while the cohesion, C is between $35KN/m^2$ in Abatete to $56KN/m^2$ in Nnobi. These values are low when compared with 65Kpa cohesion and 26° angle of friction classified as average by [29] and unfavorable as classified by [24] thus, can only offer little resistance to the effect of both surface water and subsurface flow.

Table 11: Summary of triaxial results

S/N	Location	Gully depth (m)	Cohesion (KN/m^3)	Angle of Internal Friction φ(°)
1	Oraukwu	5	42	15
2	Abatete	5	35	16
3	Alor	5	42	19
4	Nnobi	5	56	17
5	Obosi	5	42	18
6	Ojoto	5	36	19
7	Ogidi	5	53	19

4. Summary and Conclusion

Idemili drainage area is underlain by the Eocene Nanka sands and the Oligocene Ogwashi-Asaba formation. Nanka Formation hosts the major gully erosion sites in the area. The results from this research shows that properties of the soil in the area greatly influence gully development. The integration of geotechnical analysis helped to determine the percentage of sands to fines and depth to water table. Quartz or silica which is a constituent of sand is the predominant mineral. Interestingly, there was no significant difference in the results of the gully areas. Results from particle size analysis, plastic limit, liquid limit and plasticity index, triaxial test showed that the area is predominantly sandy, have low plasticity and not compact, non cohesive and less ability to resist shear deformation stresses.

5. Recommendation

Integration of geochemical and geophysical methods in future studies of soil susceptibility to gully erosion development is strongly recommended.

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