IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 10, Issue 4 Ser. I (Jul. – Aug. 2022), PP 26-37
www.iosrjournals.org

Geotechnical and Environmental Impact Studies of the Umuago Urualla Gully Erosion Site Southeastern Nigeria

Nnadozie,K. C.,Ibeh, J.C.Esomonu, I., Fagorite, V. I.and Okeke, O.C
Department of Geology, Federal University of Technology, P.M.B 1526, Owerri, Nigeria.
ziemann4ken85@gmail.com

Abstract
This work was aimed at finding out the causes and proffering solutions to the devastating menace of erosion in UmuagoUruallaIdeato North LGA Imo State. Samples were collected and analyzed in the laboratory for geotechnicaland environmental impact studies. Such tests include: grain size analysis, Atterberg limit tests (liquid, and plastic and plasticity index);moisture content, compaction test, direct shear strength, Specific gravity, and porosity were also analyzed. The results revealed that, sieve analysis indicate that the soil from the gully site range from medium to coarse grain with low percentage of silt /Clay, and of a fluvial depositional environment. The liquid and plastic limits range from 20.15 to 30.00%, and 14.00. 18.8% respectively. Moisture contents are of low value of range 6.4 to 7.04%. The compaction test was of a low value of range 1.8 to 1.86g/cm^3 which indicates that soil is not compacted but loose. Direct shear strength the apparent cohesion ranges from 18 to 170 with an average of 55 while the angle of internal friction ranges from 16 to 43 with an average of 32^0. Specific gravity ranges from 2.71to8.41, and the high porosity value of 35% shows that the soil is prone to erosion. Remedial measures such as detachments measures, slope measures, the use of structural control measures such as check dams and non-structural control measures such as the use of vegetative cover should be applied. A maximum consideration should be given to concrete terracing of gully affected areas. Hence one the major problems of gully erosion in UmuagoUrualla southeastern Nigeria has to do with type of formation it belongs to (Ameki Formation) because its friability nature contributed to gully erosion problems.

Keywords: *Erosion, Liquid limit, Plastic limit, Porosity and Urualla.*

Date of Submission: 05-07-2022 Date of Acceptance: 19-07-2022

I. Introduction

Soil can be defined as a natural body consisting of layers (horizons) of mineral constituency of a variable thickness, which differ from the parent materials in their morphological, chemical, physical and mineralogical characteristics (Mitchell & Soga, 2005; Morgan, 2009; White, 2018).In engineering it is referred to as loose, unconsolidated earth materials or rock (regolith) which is produced from the disintegration of rock while in soil science it is the layer of weathered, unconsolidated material that contains organic matter and is capable of supporting plant growth. While soil erosion can be defined as the geomorphological process whereby the surface layer of weathering rock is loosened and carried away by wind or running water and a lower horizon in the soil (Ofomata, 1988; Zachar, 2011).

Gully erosion is clearly the result of water action attributed to a condition that either lowers the resistance of the surface soil in a given locality or increase the size or velocity of the following water (Morgan, 2009; Poesen et al., 2011). Gully erosion in this part of the country has beenattributed to engineering works, agricultural practices associated with economic development and population pressure other human activities such as road activities etc (Ofomata 1988, Okoye, 1980; Morgan, 2009).

The intensive exploitation of soil for agricultural production and capital infrastructure almost has affected every aspect of Nigeria’s economy.In the Southeastern states of Nigeria especially Imo state, the problem of soil erosion has reached a disturbing level. Human activities and engineering practices have aided the gradual removal and exposure of the soil surface to big problem of erosion which has resulted intovillagers fleeing their ancestral land, encroachment of the hazard into residential areas, abandonment of properties and structures, social disequilibrium between the people, land vegetation, water resources and rapid decrease in agricultural activities as a result of soil erosion. The application of geology in the assessment and evaluation of the causes and remedies of the gully erosion sites cannot be overemphasized because it helps us to know the type of lithology most susceptible to erosion and those that are least susceptible. Soft rocks are most susceptible than hard rocks to soil erosion, it is for this reason that most of the devastation caused by soil erosion lies within the sedimentary basin of south eastern Nigeria.

Although, several studies on the problems concerning soil erosion, its causes and remedies have been presented at various levels, yet the problem still persist. For instance, Nwachukwu and Owette (2015) carried out an assessment on the surface processes and subsurface characteristics that contribute to the formation and expansion of gully erosion in Akpulu - Ideato North County, Imo state indicating that the gully is advancing aggressively, threatening life, property, food production, and security of ecosystem in Akpulu and environs. While, Ekwueme et al. (2021) assessed gully erosion in parts of Enugu north, Southeastern Nigeria using some geotechnical parameters with results indicating presence of coarse sand, fine sand, low amount of clay and silt in small proportion, loosed soil with low binding materials, instability of soil structure, low moisture content and other bio-activities that has contributed to the rate of increase of gully erosion in the study area. Other worker such as; Igwe (2012), Abdulfatai et al. (2014), Okengwo et al. (2015), Okorafor et al. (2017) and Egboka et al. (2019) have conducted similar studies within the region.

Generally, the geotechnical properties of the soil which is an integral and important part of evaluation in soil erosion brings into view certain parameter which must be taken into consideration when investigating the causes and remedies of erosion. The impact of such environmental hazard needs to be evaluated for the benefit of the local populace. Hence, the geologic evaluation of causes, remedies and environmental impacts of the UmuagoUrualla gully erosion site was carried out in order to determine the causes and proffer control measures to the problem of erosion in the study area. The objectives of the study are: (1) to analyze the gully erosion problem in Imo State Southeastern part of Nigeria using Umuago Urualla as a case study (2) to delineate the environmental effects of erosion, (3) to determine the efficiency of the erosion control measures already in place in the areas and; (4) to recommend more effective measures to improve on the existing control measure.

II. Study Area Description and Geology

The study area is located within the town of Urualla in Ideato North Local Government Area of Imo State and lies between latitude $7^0$5N to $7^0$54N and longitude $9^0$11E to $9^0$14E (Figure 1). The area is underlain by Benin Formation which is the major stratigraphic unit in the Niger Delta Basin of Nigeria, comprises of sands, silts, gravel and clayey intercalations. Stratigraphically, the formation consist mainly of sandstone and sands, with clays and sandy clays occurring as lenses (Reyment, 1965).The sands are pebbly and mostly unconsolidated. The pebbles are essentially made up of quartz mineral. The colour of the sandstones is white or yellowish brown; while some places the colour is pinkish to light grey.

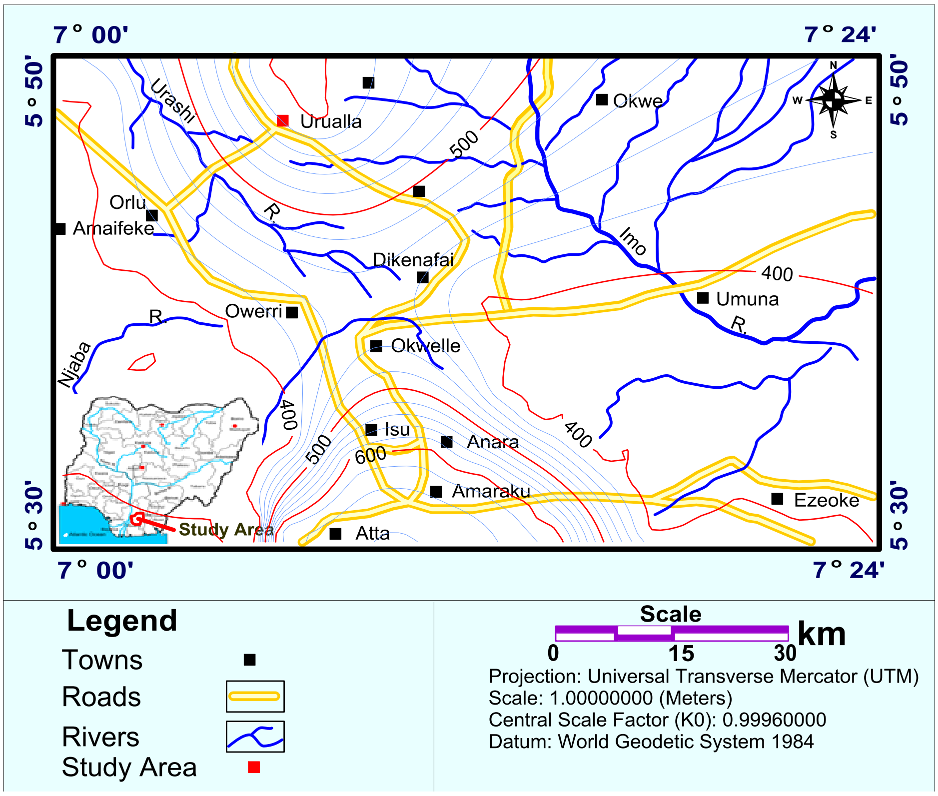

Figure 1: Topographic Map Showing the Study Area (Source: Google earth map, 2020)

III. Materials and Methods

3.1Field Studies and Sample Collection

The methods adopted in the evaluation involved integration of geotechnical analyses to determine the properties of the sediments. The geotechnical parameters include the grain size analysis, atterberg limits, moisture content, specific gravity and compaction and shear strength. It is the use of these approaches that aid in the effective and meaningful evaluation of the cause and remedies of gully erosion site in UmuagoUrualla Imo state.Soil samples were collected from four locations at the gully site with the aid of a hand auger. The samples collected were immediately put in polythene bag, tied and labeled for easy identification and to avoid loss moisture. Finally, the samples were taken to the laboratory for various geotechnical test analyses.

3.2 Laboratory Test

3.2.1 Grain size Analysis

The sieve analysis is used to determine the percent by weight of the sizes of the particles. The sizes of the particles provide information about the environment of deposition. Larger heavy particles are deposited in high energy environments and small light particles are deposited in low energy environments. The particles size is used to determine whether the materials are classified as a clay, silt, sand or gravel.
Percentage of the soil retained of any sieve is given in Equation 1 as:

$$\frac{\text{Weight of soil retained}}{Total\ soil\ weight} x\ 100 \qquad (1)$$

The values (% finer] obtained from calculation were plotted against the logarithm of the sieve diameter. Care was taken to minimize or avoid less of soil sample during sieving as any loss can greatly affect the accuracy of the result obtained.

3.2.2 Atterberg Limit Test

Atterberg limit are used to describe the changes in the moisture content of a soil as it moves from solid state to semi-solid state to plastic state and finally to liquid state. Also it is used to denote the firmness of a soil. Atterberg limits test is applicable to fine grained soils that have their particles sizes below 0.065mm.A soil in a liquid state will flow under its own weight.
A soil in a plastic state exhibits plastic characteristics (mouldable into any shape). Moisture content can affect these four states existence as the diagram below illustrates. Hence the results of this test can be used to help predict other engineering properties.
Liquid Limit (W_L):The liquid limit of a soil is the moisture content of the soil at which the soil stops acting as liquid and starts acting as a plastic and it is denoted by W_L. Under the plastic condition, it can exhibit plastic characteristics. Also it can be defined as the boundary between the liquid and plastic state of soil.
Plastic Limit:The plastic limit of a soil; is its moisture content as the soil changes from plastic to non-plastic or semi-solid state and it is denoted by Wp. It can be describe as the limit between the plastic and the semi-solid of a soil.

3.2.3 Specific Gravity

This can be describe as the ratio between the mass of dry solids and the mass of distilled water displaced by the dry soil particles at 4^0C.

$$Gs = \frac{GL\ (m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_2)} \qquad (2)$$

Where
GS = specific gravity of the soil
GL = specific gravity of the liquid used at constant temperature
M_1 = mass of density bottle (g)
M_2 = mass of bottle + dry soil (g)
M_3 = mass of bottle + stopper + liquid (g)
M_4 = mass of bottle + stopper + soil + liquid (g)
Hence, the specific gravity is a dimensionless quantity

3.2.4 Moisture Content

This is known as the ratio of the mass of water to the mass of dry soil grains in the soil mass usually expressed as percentage.
However the water or moisture content is one of the easiest properties of a soil obtained it is also the most useful.

$$\text{Moisture content} = \frac{m_2 m_3}{m_3 - m_1} \text{ x } 100 \qquad (3)$$

Where
M_1 = weight of the container
M_2 = weight of the container + soil
M_3 = weight of the dry soil

3.2.5 Compaction Test

Compaction test means compacting/pressing the soil particles close to each other by mechanical methods in order to stabilize the soil. Soil compaction can be a very economical method of soil improvement and it is often used to make ground suitable for the foundations of roads and buildings. It is also used in the placing of soil fills and in the construction of earth dams to ensure suitable soil properties.

The Standard Method of Compaction Test(Proctor) was employed in the analysis, with three(3) layers, 25 number of blows per layer and with a hammer of mass 2.5g, at a height of 305 mm

Results obtained from these test were presented as a moisture-density curve with y axis coordinated representing the dry density which is plotted against the moisture content (w %) along the x axis. The peak of the curve is designated maximum dry density (MDD) or 100% compaction while the x – axis peace is designed the optimum moisture content (OMC).

3.2.6 Direct Shear Stress

The shear strength of a soil is defined as its maximum resistance to shearing. The shear strength of a soil depends on the following, internal friction between the grains and cohesions of the grains in a soil

$$\text{Shear Strength} = \frac{Shear\ Force}{\text{Area of the soil sample}} \qquad (4)$$

3.2.7 Porosity

This is the fraction of the total volume of a sample that is occupied by pore spaces. It is usually expressed as a percentage. Total porosity is the total pore space including the interstices and voids whether connected or not. Whereas effective porosity is the measurement of the porosity which is interconnection and can be used for strong fluids the total porosity is greater than the effective porosity. These pore spaces constitute the passage or channel way for the fluids.

Aim: To know the total volume of sample/soil occupied by pore space.

$$Volume\ of solid\ insample(V_S) = \frac{Dryunitweig\ ht}{Specificgravity} \qquad (5)$$

$$Volume\ of avoid(Vv) = 1 - Dryunitweighed \qquad (6)$$

$$The\ void\ ratio(e) isgiven\ as\ e = \frac{V_v}{V_s} \qquad (7)$$

Where V_V = volume of void
V_S = volume of solid
e = Void ration

$$Porosity.(n) asgivenasn = \frac{V_V}{V} x \frac{100}{1} \qquad (8)$$

Where V = total volume
n = porosity

Note: v = Vs + Vv

The relationship between void ratio and porosity is given as

$$n = \frac{e}{1+e} \qquad (9)$$

But if porosity (n) is given void ratio (e) can be determine by

$$e = \frac{n}{1-n} \qquad (10)$$

IV. Results and Discussion

4.1 Results of the Geotechnical Studies

The results of the various analyses carried out on the entire sample are shown below.

4.1.1Sieve Results

The sieve analyses indicate that the soil from the gully erosion sites are within the medium to coarse grain range with low percentages of silt / clay (Table1 and Figure 2).Therefore the soil is non plastic. The coefficient of uniformly Cu ranges from 2.2 to 2.7 and the coefficient of curvature (Cc) ranges from 0.8 to 2.8 which indicates that the soil samples are poorly graded. Environment of deposition is said to be fluvial (deltaic) depositional environment.The coefficient uniformity (Cu) from the graph is less than 6. Therefore it revealed that the soil underlying the study area is poorly graded. The soils in the study area are classified as poorly graded gravel (GP). This implied that all the soil particle sizes were well represented.

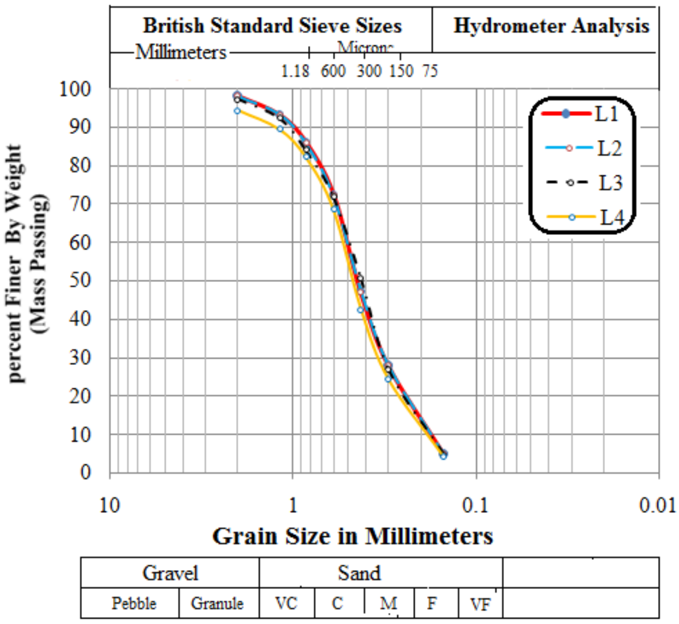

Figure 2: Sieve Analysis Curve Sample A -D

Table1: Summary of Sieve Analysis Result

Location	D10	D30	D50	D60	$Cu = \frac{D60}{D10}$	Cc = $\frac{(D30)^2}{D60\,xD10}$
1	**0.2**	**0.3**		0.5	$Cu = 2.5$	0.9
2	**0.11**	**0.3**		**0.41**	$Cu = 3.727$	1.995
3	**0.21**	**0.3**	0.4	**0.48**	$Cu = 2.286$	0.893
4	**0.21**	0.31	0.45	**0.51**	$Cu = 2.429$	**Cc = 2.895**
					Cu is less than 6 Therefore it is poorly graded	**Cc = 1 < 3 (Well graded)**

4.1.2 Natural Moisture Content Test

The result of the natural moisture content of the samples (A, B, C and D) ranged from 6.8 to 9. 99% (Table 2). This indicates that, the soil readily loses water on exposure to heat.

Table 2: Showing Result of Natural Moisture Content

Sample	A		B		C		**D**	
Moisture Content Trial No	1	2	1	2	1	2	1	2
Can Identification	**H**	**4**	**33Y**	**22Y**	**20B**	**41**	**13Y**	**50Y**
Mass of can + Wet Soil (M_2)	53.3	45.7	49.6	49.8	54.2	51.3	52.8	54.0
Mass of can + Dry Soil (M_3)	51.1	43.9	47.6	47.9	52.0	47.4	50.4	52.0
Mass of can (M_1)	19.0	17.5	19.2	20.6	20.1	17.6	17.5	20.3
Calculation								
Weight of Water , $M_2 - M_3$	2.2	1.8	2	1.9	2.2	3.9	2.4	2.0
Weight of Dry Soil, $M_3 - M_1$	32.1	26.4	28.4	27.3	31.9	29.8	32.9	31.7
W = $\frac{M_2 - M_3}{M_3 - M_1} \times 100\%$	6.85	6.82	7.04	6.96	6.90	13.09	7.29	6.31
Average	6.84%		6.99%		9.99%		6.80%	

4.1.3 Liquid Limits

The result of liquid and plastic limit determination is shown in Figure 3. This indicates that the soil has low amount of water retention capacity and hence unsuitable for use as liner materials. The liquid limit, plastic limit and plasticity index ranged from 20.2 to 29.20%, 14.40 to 19.10% and 5.8 to 12.25% respectively.Thus the liquid limits are generally low and indicates that the soil underlying the area is non-plastic.

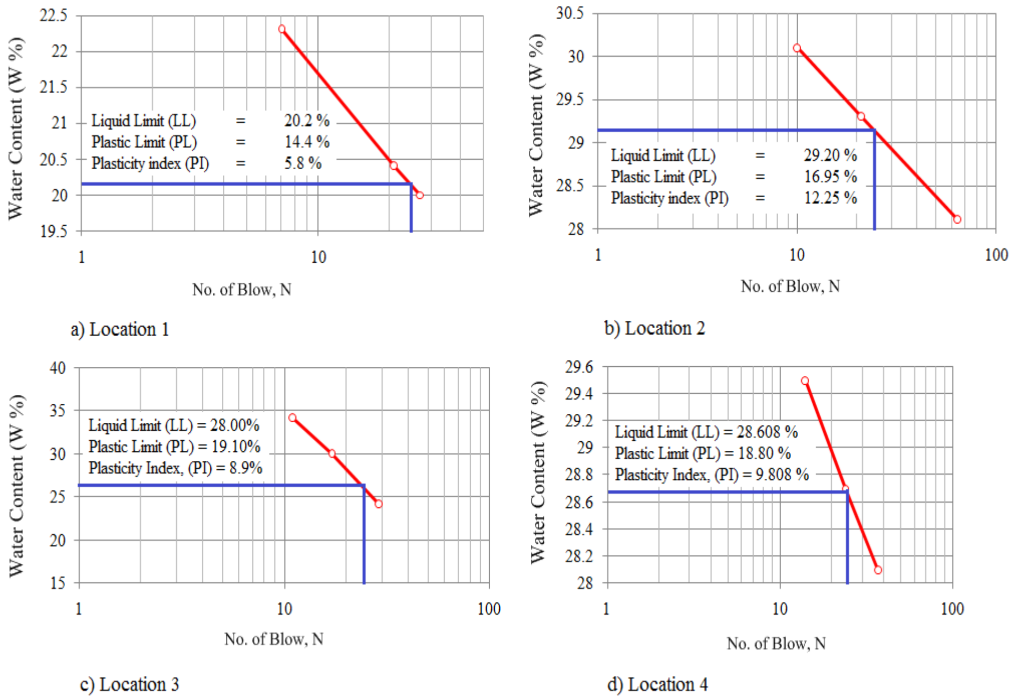

Figure 3: A Graph of Liquid Limit for Sample A- D

Table 3: Specific Gravity Determination by Density Bottle Method

Sample	A	B	C	D
Bottle + stopper (g)m_1	153.0	153.0	152.8	152.5
Bottle + soil (g),m_2	162.5	162.3	158.9	158.5
Bottle + stopper + soil + liquid (g), m_3	655.0	655.1	654.9	654.9
Bottle + stopper + liquid (g), m_4	649.0	649.1	649.7	649.7
Specific gravity of the liquid used, G_1	1.000	1.000	1.000	1.000
Specific gravity of the soil G_2	2.71	3.30	6.78	8.43

Computing the specific gravity of the soil

$$Gs = \frac{G_1(m_2 - m_1)}{(m_4 - m_1) - (m_3 - m_2)}$$

The specific gravity test values ranges from 2.71 to 8.41 which indicates that the relative density of the soil is low which makes the soil incapable to resist erosion

4.1.4 Compaction Test

The results of the compaction test are shown in Figure 4. The maximum dry density values (MDD) of the soil samples ranged from 1.82 to 1.86(g/cm3 while optimum moisture content values (OMC) of the soilsamples ranged from 10.40 to 14.20%.Hence the maximum dry density values are generally low which indicates that the soil is not compacted but loose.

Sediments in its natural state are not densely compacted. So, compaction is required to improve the load bearing capacity, reduce soil settlement and stabilize the slope.So, the lateritic sand can achieve more stability at lower compactive energy than the brownish sand. However, addition of water above the optimum moisture content can result into slope failure or instability.

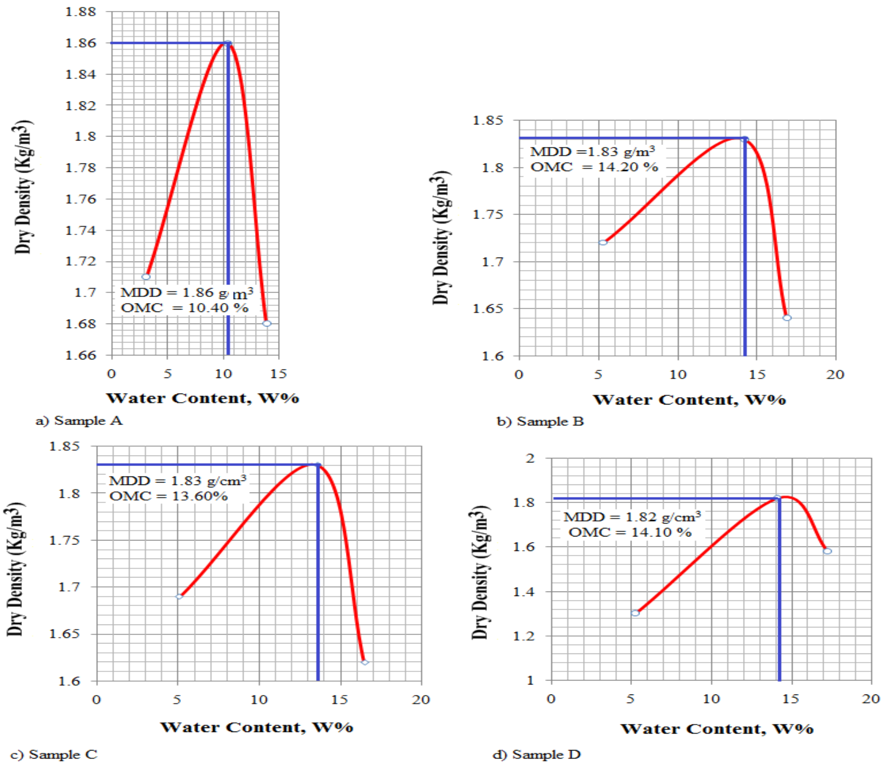

Figure 4: A graph of compaction test sample A -B

4.1.5 Direct Shear Stress

From direct shear stress graph (Figure 5a -d) the apparent cohesion (C) ranges from 18 to 170 with an average of 56, while the angle of internal friction ranges from 16 to 43 with an average of 32^0.

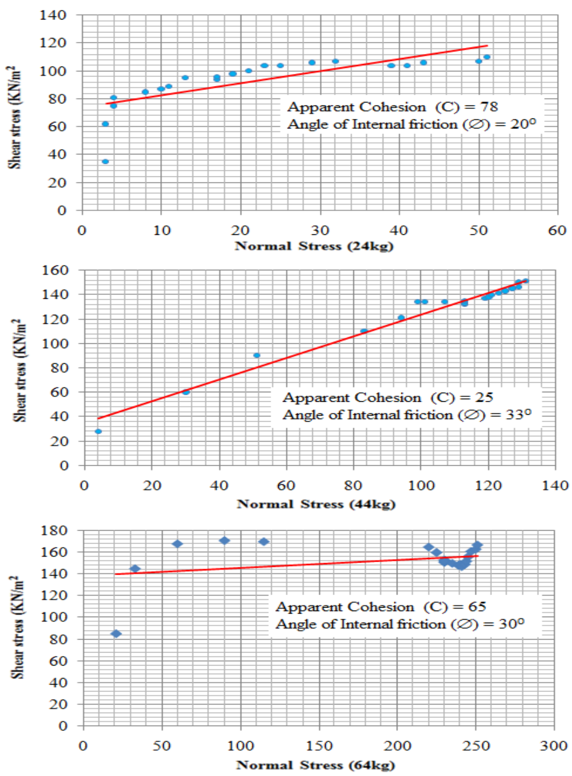

Figure 5a: A graph of Direct shear test sample A 3 location 1

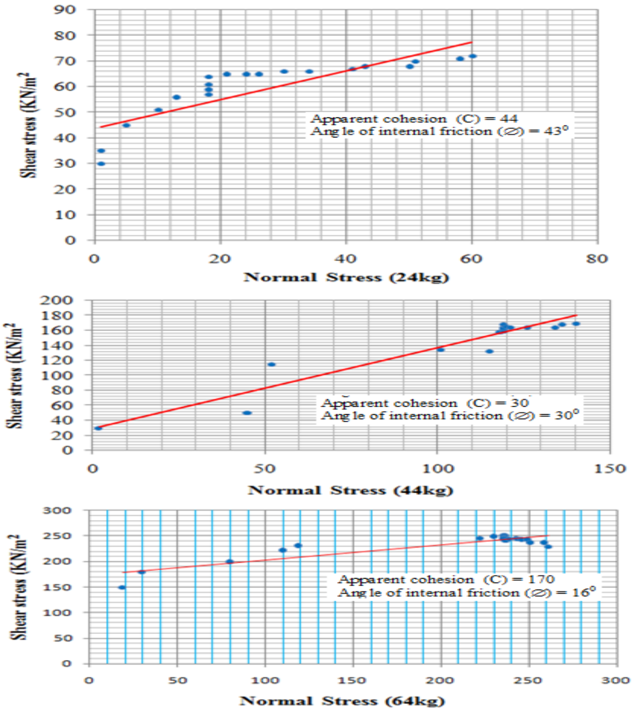

Figure 5b: A Graph of Direct Shear Test Sample B1 Location 2

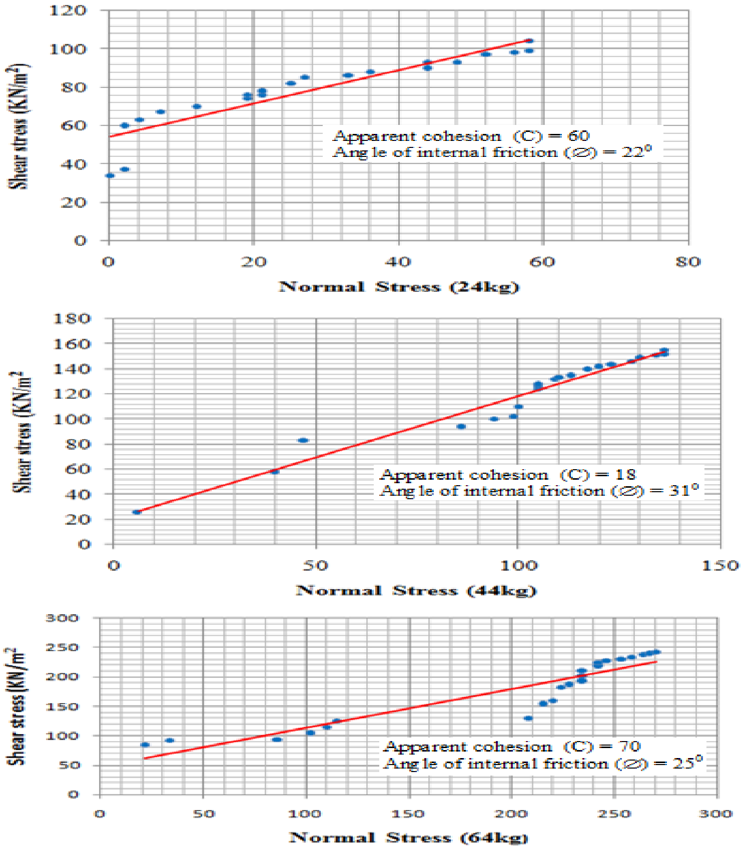

Figure 5c: A Graph of Direct Shear Test Sample C1 location 3

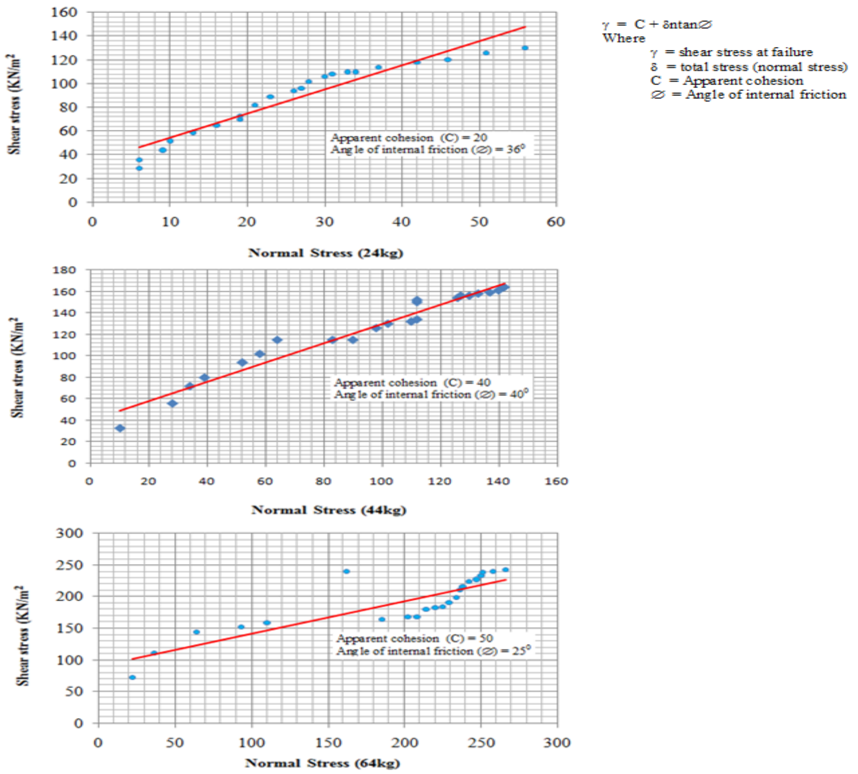

Figure 5d: A graph of Direct shear test sample D3 location 4

The summary of the apparent cohesion (C) and the angle of internal friction is presented in Table 4.

Table 4: Summary of C and ∅

Samples	C	∅
A1	78	20^0
A2	25	33^0
A3	65	30^0
B1	44	43^0
B2	30	30^0
B3	170	16^0
C1	60	22^0
C2	18	31^0
C3	70	25^0
D1	20	36^0
D2	40	40^0
D3	50	25^0
Total	670	378

$$Average\ for\ C = \frac{670}{12} = 56$$

$$Average\ for\ \varnothing = \frac{378}{12} = 32^0$$

The result of the porosity test is shown in Table 5.

Table 5: Porosity Determination

Weight of ring + sample (g)	302.5
Weight of ring (g)	106.5
Weight of sample	196.0
Volume of sample (cm^3)	98.2
Bulk unit weight (mg/m^3)	2.0
Moisture content of sample (%) from the moisture content test	6.85
Dry unit weight (mg/m^3)	1.77

4.1.6 Computation of Porosity

$$volume\ of\ solids\ in\ sample\ (Vs) = \frac{Dry\ unit\ wt}{specific\ gravity}$$

$$Vs = \frac{1.77}{2.71} = 0.65cm^3$$

Volume of voids (Vv) = 1 – V_3
= 1 – 0.65 = 0.35cm^3

$$The\ void\ ratio\ (e) = \frac{Vv}{Vs} = \frac{0.35}{0.65} = 0.54$$

$$\therefore\ Porosity\ (n) = \frac{e}{1+e} = \frac{0.54}{1+0.54} = 0.35$$

$$n = 35\%$$

The hydrological test (porosity and permeability) indicates a high porosity of 35%. Thus, the study area is prone to develop high pore water pressure.

4.2 Discussion

The control of gully could be achieved geologically**,** structurally or use of Vegetation**.** The first step towards effective control of UmuagoUrualla gully erosion is to declare the entire gully area and its environ a disaster area. This will ensure that all types of farming and construction activities are brought to immediate stop.

The next step is to integrate the geological, geotechnical and hydrogeological data (Egboka & Nwankwo, 1985; Nwajide, 1977; Egboka & Orajaka, 1987; Emenike, 2001). The purpose is to select a suitable site for construction of channel and other civic engineering work. Also there will be need for extensive excavation to remove at least the top large of the soil and refilling it with concrete material particularly in areas worst affected by erosion (Egboka & Orajaka, 1987).

The policy of constructing a single Channel to lead the Major drainage has proved ineffective because of the ability of the flood water to easily move off course using its own path rather than follow the Channel path. To arrest this situation, several Channel will be constructed so that whatever the origin and location of the flood water it will be caught by one of the channels (Ebgoka & Orajaka, 1987).

Structural Control Measures

There are different structures that can be used to control gully erosion such as Brush Jill's, earth plugs, woven – wire check dams, brush wood check dams, log check dams, loose stone check dams, boulder check dams, Gabion check dams etc. Due to the nature of the soil, topography and the degree of gulling, Gabion check dams seem to be the best structural method of controlling the gully erosion.

Settling basins should be constructed to silt the sand, fill the basin with sand and to slow down the speed of run-off to zero. A percentage slope of 1.5% slopes relative to each other should be considered adequate in the construction of the settling basins.A settling basin has three components namely the inlet, the closed basin and the outlet. The inlet as the first opening of the basin receives the flood into the settling basins and transfers the water to the closed basins. The closed basin is where the speed of the flood is reduced drastically before the flood move into the outlet basin that pushes it out with very low speed close to zero. The sand particles that the flood carried into the settling basin are deposited in the closed basin.

Use of Vegetation

All structural measures used in gully control must be accompanied with vegetative measures to obtain a sound result.

The general principles of vegetation control includes

i. All structural measured should be completed in the dry season and the accompanying vegetation measures undertaken during the following rainy season.
ii. Suitable tree seedlings and cuttings must be planted just behind the structural measures
iii. Shrub and grass cutting must be planted between the structural measures.
iv. Gentle slopes which do not need any structured measures should be planted with tree. Seedlings, grass and shrub cuttings.

V. Conclusion and Recommendations

The results obtained in this geotechnical and environmental impact investigation show that the soils in the study area are cohesionless, not compacted, non – plastic, poorly graded and of a fluvial (deltaic) depositional environment. The low moisture content of the soil analyzed implies that the soil sample readily gives out water on exposure to heat, this increase the shear strength of the soil while an adverse effect is felt during the raining season

The gully erosion soil is very prone to developed high pore water pressure, this is due to the high porosity, low permeability and low infiltration rate of the sample.

Exaggerated emphasis on only engineering control measures involving construction of check – dams, backfilling with soils and construction of drainage seem not to be enough in tackling the menace of gully erosion. However, the use of an integrated approach involving geotechnical, environmental, engineering practices and afforestation will provide better result in protecting the soil and reducing run – off.

Thus in tackling the problem of erosion, characterization of the inherent geotechnical properties of the sediments present in the study area is paramount.

Hence, gully erosion problem facing the area can be controlled if the following measures should be taken into consideration;

1. Adequate enlightenment through organizing of seminars and workshop for the people of UmuagoUrualla is required to mobilize support from the populace.
2. Gully control measures such as terracing and intercepting drains should be constructed outside the gully to control inflow of run – off into the gully.
3. Human activities and farming practices that expose and accelerate the breakdown of the soil should be avoided.
4. Environmental laws that encourage afforestation and discourage deforestation should be implemented. Tree planting (such as bamboo trees, cashew trees, and palm trees) campaigns aimed at slope stabilization should be intensified.
5. Careful integration of water resources management, soil conservation and vegetation on the scale of a drainage basin. In particular, the technologies of water harvesting and spreading are essentials to the control of surface runoff.
6. Measures like structural run-off central should be put in place. These structural control includes:

- Sediments traps to stop run-off carrying sediments and trap the sediments.
- Riprap (rock lining) to protect channel banks from the erosive water flow.
- Diversion like or perimeter like to divers' excess water to places where it can be disposed of properly.

7. Finally,further investigation should be embarked upon.

Acknowledgements

I am grateful to my mentor, Mr. Oluwayomi Ariyo for his academic support and advice. I am highly grateful to my family, Mr. and, Mrs Cosmas Nnadozie, Tony Nnadozie, Mr. Nduka Ozurigbo and my nieces and nephews for their support, prayers, encouragement, love and support.

References

[1]. Abdulfatai, I. A., Okunlola, I. A., Akande, W. G., Momoh, L. O., & Ibrahim, K. O. (2014). Review of gully erosion in Nigeria: causes, impacts and possible solutions. *Journal of Geosciences and Geomatics*, *2*(3), 125-129.

[2]. Egboka, B. C. E., & Nwankwor, G. I. (1985). The hydrogeological and geotechnical parameters as agents for gully-type erosion in the rain-forest belt of Nigeria. *Journal of African earth sciences (1983)*, *3*(4), 417-425.

[3]. Egboka, B. C. E., & Orajaka, I. P. (1987). Soil and gully erosion models for effective control programmes. *Geoforum*, *18*(3), 333-341.

[4]. Egboka, B. C., Orji, A. E., & Nwankwoala, H. O. (2019). Gully Erosion and landslides in southeastern Nigeria: causes, consequences and control measures. *Global Journal of Engineering Sciences*, *2*(4), 1-11.

[5]. Ekwueme, O. U., Obiora, D. N., Okeke, F. N., & Ibuot, C. (2021). Environmental assessment of gully erosion in parts of Enugu north, Southeastern Nigeria. *Indian Journal of Science and Technology*, *14*(29), 2400-2409.

[6]. Emenike, E. A. (2001). Geophysical exploration for groundwater in the sedimentary environment: a case study. *Global Journal of pure and applied sciences*, *7*(1), 97-102.

[7]. Igwe, C. A. (2012). Gully erosion in southeastern Nigeria: role of soil properties and environmental factors. *InTech Open Science*, 157-171.

[8]. Mitchell, J. K., & Soga, K. (2005). *Fundamentals of soil behavior* (Vol. 3). New York: John Wiley & Sons.

[9]. Morgan, R. P. C. (2009). *Soil erosion and conservation*. John Wiley & Sons.

[10]. Nwachukwu, M. A., & Owette, I. (2015). Environmental and geotechnical assessment of an aggressive gully erosion site in Nigeria. *International Journal of Forest, Soil and Erosion (IJFSE)*, *5*(1), 8-16.

[11]. Nwajide, C.S. (1977). *Sedimentology and Stratigraphy of the Nanka Sand*. University of Nigeria Research Publications.

[12]. Ofomata, G. E. K. (1988, April). The Management of Soil Erosion Problems in South-eastern Nigeria. In *International Symposium on Erosion in South-eastern Nigeria, Federal University of Technology, Owerri, April* (Vol. 12, p. 14).

[13]. Okengwo, O. N., Okeke, O. C., Okereke, C. N., & Paschal, A. C. (2015). Geological and geotechnical studies of gully erosion at ekwulobia, oko and nanka towns, southeastern nigeria. *Electronic Journal of Geotechnical Engineering*, *20*, 113-122.

[14]. Okorafor, O. O., Akinbile, C. O., & Adeyemo, A. J. (2017). Soil erosion in South eastern Nigeria: a review. *Scientific Research Journal (Scirj)*, *5*(9), 30-37.

[15]. Okoye, P.I. (1980). A Study of the factors which Control Gully Erosion. *B. Science Dissertation, University of Nigeria*, Nsukka.

[16]. Poesen, J., Torri, D. B., & Vanwalleghem, T. (2011). Gully erosion: procedures to adopt when modelling soil erosion in landscapes affected by gullying. *Handbook of erosion modelling*, 360-386.

[17]. Reyment, R. A. (1965). *Aspects of the geology of Nigeria: the stratigraphy of the Cretaceous and Cenozoic deposits*. Ibadan university press.

[18]. White, A. F. (2018). Chemical weathering rates of silicate minerals in soils. *Chemical weathering rates of silicate minerals*, 407-462.
[19]. Zachar, D. (2011). *Soil erosion*. Elsevier.