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RESEARCH ARTICLE

GEOTECHNICAL INVESTIGATION OF GULLY EROSION SITES IN UMUALO VILLAGE, UDI LGA, ENUGU STATE SOUTHEASTERN NIGERIA

Nwobodo N. Anthonia[a], Ohakwere-Eze C. Michael[b*], Chukwu N. Osondu[a]

[a]Department of Industrial Physics, Enugu State University of Science and Technology, Enugu.
[b]Geophysics & Environmental Research Group, Department of Physics, Federal University of Kashere, Gombe.
[*]Corresponding author email: michael.ohakwereze@gmail.com

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ABSTRACT

Geophysical and geotechnical conditions of soils at the study area were investigated and accessed. Conseinfluencestwo true representative soil samples from different locations within gully sites have been analyzed to evaluate geologic conditions and geotechnical parameters that influence the gullies problems. This study tends to evaluate geotechnical properties of the soil within the gully site. The assessment was mainly to provide insight on the geologic conditions and geotechnical parameters that contribute immensely to gully development in the study area. The findings from this research should be useful in controlling gully erosion in the study area. From the geotechnical analysis, textural characteristics were predominantly sandy, loamy and clay and silt in small proportion. Liquid limit (LL) ranged from 20.40 to 22.26 %, Plastic limit (PL) of 14.82 to 17.48 % were observed, with plasticity index (PI) of 5.58 and 4.78 % respectively. Bulk density ranged from 1.45 to 1.54 g/cm^3, the total porosity ranged from 42.075 to 45.208 %. The Aggregate stability ranged from 33.67 to 40.24% and water holding capacity ranged from 29.507 to 30.482%. The results obtained show that factors responsible for the menace of gully erosion in the study area include; loose soil materials and dominant coarse sand. Other field observation factors include; topography, deforestation, bush burning that distort the texture of the soil contribute to the menace of gully erosion in the area. Hence to prevent these catastrophes caused by this erosion, necessary enlightenment campaigns on best agricultural practices that can reduce surface runoff in soil and water conservation is important. Also, strong culvert should be constructed at different locations in that area.

KEYWORDS

Aggregate Stability, Geotechnical investigation, Gully sites, Plasticity Index, Soil erosion.

1. INTRODUCTION

Soil erosion is a geo-morphological process which results in the gradual or quick removal of the surface layer of weathered rock or sediments by agents of denudation and the subsequent transportation to another depositional environment (Egboka, 2000). Gully erosion has been considered as one of the most fatal hazard that poses a serious threat to human existence, agricultural land, infrastructure and socio-economic activities (Amah et al., 2008). It is a clear form of soil degradation and destruction, which occurs where surface water flow become trapped in a small concentrated stream, and begins to erode channels in the ground surface, making it wider and deeper (Chikwelu and Ogbuagu, 2014).

Gully is the worst stage of all types of soil erosion and it is a highly visible form of erosion, which greatly impacts on the soil's quality and a number of soil functions (including the production of food and other biomass, water storage, filtering, and transformation, habitat and gene pool, physical and cultural environment for mankind, and source of raw materials) (Abdulfatai et al., 2014). The effect can be seen in accidents on the road, flooding, poor drainages and destroying road networks, washing away our fertile soils surfaces, and increase in water treatment coats, destroying buildings, fences and silting of reservoirs among others. This has not only cause a setback to the economy of the area but it has caused loss of lives and properties in millions of Naira annually. In order to mitigate these gullies, there is increased need for soil investigations to obtain information and adequate understanding of the geotechnical properties of the sandy soil.

Over 2,800 active erosion sites comprising of over 1000 in Anambra, 300 in Imo, 500 in Abia, 500 in Enugu, and 500 in Ebonyi states were relayed by World Igbo Environmental Foundation (WIFE) (Ojukwu, 2018). In Southeastern Nigeria, soil geological studies have revealed that gully erosion has remained active over many years, ravaging the physical ecology of the landscape. These have sparked interest in geotechnical and engineering geological issues because of how they affect foundations, natural resources, and building structures.

Studies by recent researchers have attributed the formation and growth of gullies to the influence of human activities on geomorphologic processes. But previous researchers who had worked on these soils have shown that the primary causes of the gully erosion lie in the hydrogeological and geotechnical properties of the soils in the area. Researchers carried out research work on the sandy soils in South eastern Nigeria (Ofomata, 2016; Floyd, 1965; Nwajide and Hoque, 1979; Okagbue and Uma, 1987; Akpokodje, 2001; Okagbue and Aghamelu, 2010; Teme, 2001; Okeke and Enwelu, 2010; Okagbue and Ezechi, 1988).

The aim of this study was to carry out environmental assessment of erosion sites. The specific objectives were to assess the geotechnical properties of the soil, determine the factors responsible for the erosion formation and recommend possible solutions to the hazard. The assessment was mainly to provide insight on the geologic conditions and geotechnical parameters that contribute immensely to gully development and to study the influence of the fines content on the mechanical/geotechnical behavior of the sandy soil in the study area.

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2. Geology and Location of the Study Area

The study area Umualo village in Nsude, Udi LGA of Enugu State, Southeastern Nigeria is geographically bounded by coordinates of 6° 24' North, 7° 24' East (Figure 1). The geology of Udi falls under Anambra Basin which consists of six major rock formations; Enugu shale, Agwu shale, Mamu formation, Ajali formation, Nsukka and Imo shale formation. These rocks are grouped into four formations namely: Mamu formation, Ajali Sandstone, Nsukka Formation, and Imo Shale Formation as inferred (Adetona and Abu, 2013). Sediments deposited during this time period occur in four distinct physiographic provinces, namely the Cross River plains, the Escarpment, the Plateau and the Anambra Plains. Some of these sediments are of considerable economic importance and contain reserves of coal, natural gas, glass sands and considerable prospects for liquid hydrocarbon according (Obiora et al., 2015). The topography is aptly defined by the Nsukka-Okigwe cuesta which stretches from Eha Alumona to Obollo Afor as its higher limit and Eha-Amufu as the lower limit. Two thirds of the land area is made up of a loose sandy ferrallitic soil, and the other third is made up of a loamy clay soil. The kind of vegetation is derived guinea woodland savannah with sparse grass tufts serving as soil cover. Agronomy is the predominant land use in the region. A group researchers remarked that subsistence agriculture is the predominant occupation in this vegetation zone (John et al., 2015). Buildings and road construction are other land-use.

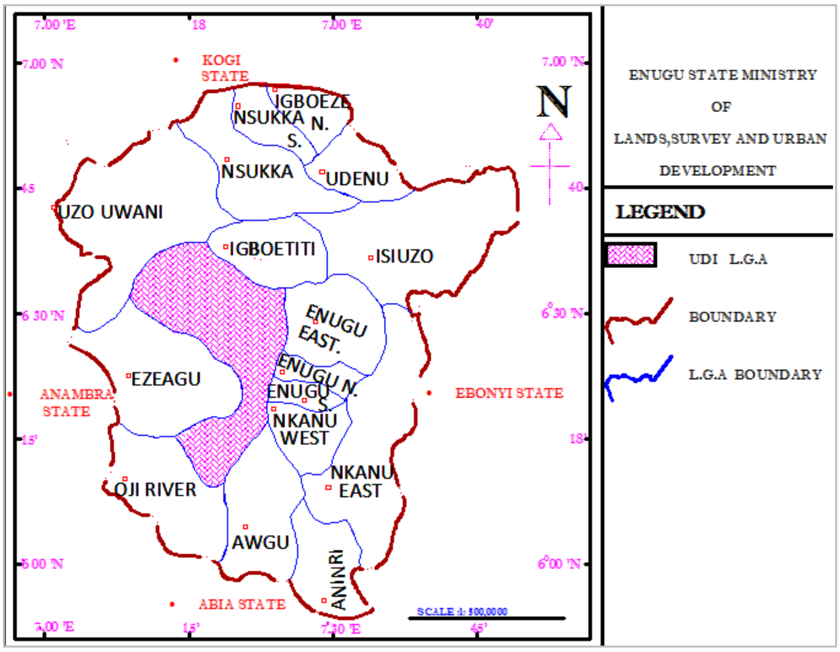

Figure 1: Map of Enugu State with Udi L.G.A (Okwu- Delunzu et al., 2018).

3. Materials and Methods

The materials that were used for this study include: soil sample, soil auger, core samplers, hammer, polythene bags and masking tape, laboratory equipment (measuring cylinder, sieves, beaker etc), Global positioning system (GPS).

The soil evaluation which comprised field work and laboratory analyses were carried out. These procedures were adapted:

(i) Field work which involves collection of soil samples along the selected erosion site using core sampler, polythene bags; mapping out the geological coordinates using GPS.

(ii) Laboratory analysis of the samples.

Hence, in this study, an attempt has been made to employ applicable laboratory tests to evaluate and assess geotechnical parameters of the soil within the gully site intended to give a clear view on the cause of gully on the site and how to control it. Soil samples designated as sample A and sample B were randomly collected from active erosion sites for laboratory analysis.

3.1 Laboratory Analysis

Soil particle distribution, chemical properties (organic matter, soil PH, exchangeable cations), hydraulic conductivity, total porosity, bulk density and aggregate stability were tested using different measuring instruments in the laboratory and results were obtained. The results were analyzed as follows;

3.1.1 Bulk Density

The soil samples collected at the erosion site were weighed to determine the wet weight. The sample was then dried at 105^0C until a constant weight was reached and it was recorded as m.

Now, the bulk density = $\frac{oven\ dry\ mass\ of\ sample}{volume\ of\ cylinder\ (v)} = \frac{m}{v}$ (1)

But sample volume, $v = \pi r^2$h = volume of the cylinder containing the sample

3.1.2 Particle Size Distribution

In determination of the percentage clay, silt and coarse sand, the following procedures were taken:

(i) 50 g of the soil sample were weighed into a 50 ml shaking bottle and 0.1 mole of sodium hydroxide solution was added into the weighed sample followed by 200 ml of distilled water. This solution was stirred rigorously for 40 minutes.

(ii) The suspension was decanted until the suspension was clear and the sediment was transferred into a 250 ml beaker and was dried at 105^0C. It was sieved with 0.25 mm sieve and the coarse sand on the sieve was weighed.

The following deductions were made to arrive at the particle size distribution result:

(i) Percentage clay

Percentage clay enables us to determine the fraction of clay in the soil sample. Knowing the percentage clay in the area helps to analyze the susceptibility of the soil in area to erosion. It was calculated using the equation below;

% Clay = $\frac{2\ hours\ readng\ of\ hydometer}{weight\ of\ sand\ used} \times 100 = \frac{T_2}{w} \times 100$ (2)

(ii) Percentage silt

This tells us the quantity of silt that is contained in the soil sample. It is defined as the hydrometer reading when the soil sample is mixed for 40 seconds (T_1) minus the hydrometer reading when it's mixed for 2 hours (T_2) divided by the weight of the soil sample used.

$\%\ silt = \frac{T_1 - T_2}{w} \times 100,$ (3)

Where T_2 = second hydrometer reading, T_1 = first hydrometer reading

(iii) Percentage Coarse sand

The fraction of coarse sand contained in the soil was calculated using the equation below;

% Coarse sand = weight of dried sediment (W) multiplied by two.

=> % Coarse = 2× W (4)

(iv) Percentage Fine sand

% Fine = 100 – (% $silt$ + % $clay$ + % $coarse$) (5)

3.1.3 Determination Of Water Holding Capacity of The Soil

In determination of the water holding capacity of the soil, the following procedures were taken:

(i) The wet weight of the sample and the core was weighed and was recorded as m_{wet}. The sample was then dried in oven at 105^{0}C and the oven dry weight too was recorded as m_{dry}.

The water retention capacity was then calculated as follows:

$$\%\ water\ holding\ capacity = \frac{mass\ of\ water}{oven\ dry\ soil} \times 100, \quad (6)$$

Where mass of water = water retained by the soil = $m_{wet} - m_{dry}$

Oven dry soil = oven dry weight of core containing soil sample – weight of empty core.

3.1.4 Calculation Of Total Porosity

Total porosity (T.P) can be calculated as:

$$T.P = 100\left(1 - \frac{B.D}{Pd}\right), \quad (7)$$

Where Pd is constant known as the particle density = 2.65g/cm^3

3.1.5 Aggregate Stability

Soil aggregate stability is a measure of the ability of soil to resist degradation when exposed to external forces such as water erosion and wind erosion, shrinking and swelling processes, and tillage (USDA, 2008; Papadopoulos *et al.,* 2009).

$$Aggregate\ Stability = \frac{mass\ of\ WSA - mass\ of\ sand}{mass\ of\ sample - mass\ of\ sand} \times 100\% \quad (8)$$

where WSA is the water stable aggregates

3.1.6 Atterberg Limits

The Atterberg limit test is used in determining the following parameters: liquid limit, plastic limit, plasticity index. Plastic Index (PI) is the difference between liquid limit (LL) and plastic limit (PL).

$$PI = LL - PL \quad (9)$$

4. Results

The results of the research work were presented and discussed as follow:

4.1 Soil Physical and Geophysical Properties

The soil's physical and geophysical properties are those related to the size and arrangement of the solid particles, and how the movement of liquids through the soils is affected by the particles. The geophysical properties of the soil are:

(a) Bulk density

The bulk densities of the soil samples were calculated as;

$$\text{Bulk density} = \frac{oven\ dry\ mass\ of\ sample}{sample\ volume\ (v)} = \frac{m}{v} \quad (10)$$

For sample A

For the soil sample A, the oven dry mass of the soil sample m = 182.4 g. The volume of the core sampler, v =118.81cm^3.

=> Bulk density (B.D) = $\frac{182.4}{118.81}$ = 1.535 g/cm^3

For sample B

For the soil sample B, the oven dry mass of the soil sample, m = 172.5 g, since v (volume) is the same as in A, then;

=> Bulk density (B.D) = $\frac{172.5}{118.81}$ = 1.452 g/cm^3

(B) Particle size distribution or textural classes.

(i) Percentage clay

This was calculated using equation 2

For sample A

$\% clay = \frac{9.8}{50} \times 100$ =19.6 %

For sample B

$\% clay = \frac{10.14}{50} \times 100$ =20.28 %;

(ii) Percentage silt

The fraction of silt contained in the soil was determined using equation 3.

For sample A

$\% silt = \frac{13.44-9.8}{50} \times 100 = 7.28$ %

For sample B

$\% silt = \frac{13.16-10.14}{50} \times 100 = 6.04$ %

(iii) Percentage Coarse sand

Also, the fraction of coarse sand contained in the soil was calculated using the equation 4 as,

For sample A

$\% coarse = \frac{29.5}{50} \times 100 = 59\%$

For sample B

$\% coarse = \frac{30.5}{50} \times 100 = 61\%$

(iv) Percentage Total Sand

For sample A

Hence, total sand =100 – (% $silt$ + % $clay$)

=100 – (19.6 + 7.28)

= 100 – 26.88 = 73.12%

% Fine = 100 – (% $silt$ + % $clay$ + % $coarse$)

=> % Fine = 100 – (7.28+19.6+59) = 14.12 %

For sample B

Total sand =100 – (% $silt$ + % $clay$)

=> Total sand = 100 – (6.04+20.28) = 100 – 26.32 = 73.68 %

The percentage fine sand was calculated by subtracting the sum of the percentage clay, silt and coarse sand from 100. This was done using equation 5 as;

% Fine = 100 – (20.28 + 6.04 + 61) = 12.68 %

(C) Water holding capacity of the soil

For sample A

For soil sample, A, the extent at which the soil retains water was calculated using the equation 6.

=> $\%\ water\ holding\ capacity = \frac{55.6}{182.4} \times 100$ = 30.482 %

For sample B

Also the extent at which the soil sample, B retains water was calculated using equation 6 as in the soil sample, A

=> $\%\ water\ holding\ capacity = \frac{50.9}{172.5} \times 100$ = 29.507 %

(D) TOTAL POROSITY

Total porosity (T.P) was calculated using equation 7 as:

T.P = $100\left(1-\frac{B.D}{Pd}\right)$, where *pd* is constant = 2.65g/cm³

For sample A

T.P = $100\times\left(1-\frac{1.535}{2.65}\right) = 42.075$ %

For sample B

T.P = $100\times\left(1-\frac{1.452}{2.65}\right) = 45.208$ %

The results are summarized in the Tables 1, 2 and 3

Table 1: Soil Physical Properties (Where SL = sandy loam)

Sample	Particle Size Distribution					Water holding capacity %	Atterberg Limit		
	Textual class	Clay (%)	Silt (%)	Fine sand (%)	Coarse sand (%)		%Liquid Limit (LL)	%Plastic Limit (PL)	% Plasticity Index (PI)
A	SL	20	7	14	59	30.482	20.40	14.82	5.58
B	SL	20	6	13	61	29.507	22.26	17.48	4.78

Table 2: Soil Geophysical Properties

S/N	Bulk Density g/cm³	% Total porosity	Hydraulic conductivity cm³/hr	Water holding capacity %	Aggregate Stability	
					Mean-Weight Diameter (mm)	% Aggregate Stability
Sample A	1.54	42.075	101.01	30.482	1.952	40.24
Sample B	1.45	45.208	101.01	29.507	1.785	33.67

Table 3: Soil Chemical Properties (Where: TC=Test Class, OM=Organic matter)

Sample	pH value	Organic Matter (%)	Exch. Bases (me/100g)			
			Na^+	K^+	Ca^{2+}	Mg^{2+}
A	5.1	0.38	0.02	0.04	1.60	0.80
B	5.2	0.32	0.02	0.03	1.40	0.60

5. Discussion

Tables 1-3 present the summary results of the geotechnical evaluation of the study area. It shows that the area is predominantly sandy, with loamy, clay and silt in small proportion; 73% total sand for sample A and 74% for sample B. This result is one of the evidences that the area is susceptible to gully erosion because according to area with predominantly sandy soil is susceptible to gully erosion (Silas, 2012; Ocheli et al., 2021). Also, from the percentage aggregate stability, percentage total porosity, and bulk density test of the soil, it shows that the study area is prone to gully erosion. The percentage aggregate stability of the study area is 40.24% and 33.67% for sample A and B respectively, which shows that the soil has low aggregate stability. The authors, had shown that soils with low aggregate stability are prone to erosion (Chude, 2018; Ocheli et al., 2021). The Bulk density ranged from 1.45 to 1.54 g/cm³, which according to these results are comparatively lower than the mean density of 2670 kgm⁻³ (ie 2.7 g/cm³) for materials in the upper continental crust (Robert et al., 2011; Okoyeh et al., 2014). Thus the soils are dominated by lighter materials, raindrop impact can easily detach the soil particles from their original materials.

The water holding capacity of the gully site was discovered to be low. It was discovered that the water holding capacity of sample A is 30.482 % and 29.507 % for sample B. This is clear evidence that the area does not have the ability to retain water very well. The implication of this result is that any small run-off will tend to pass through the soils thereby moving them to other positions, hence causing erosion. The effect can be more for heavy rain or run-off. The liquid limit (LL) ranges from 20.40 to 22.26 %, plastic limit (PL) ranges from 14.82 to 17.48 % with a mean value of 24.94 %. The discrepancy between the liquid limit and the plastic limit gives the value of the plasticity index (PI), which measures the plasticity of the soil, and the value ranges from 5.58 and 4.78 % with a mean value of 5.29 %. However, the gully samples were observed to have low value of plastic limit which are in accordance with, who pointed out that PL $<$ 35 % should be considered low plasticity indicating low content of fine materials and also shows that the soil in the area is loose and prone to erosion (Emeh and Igwe, 2017).

Similarly, Table 3 presents results of soil chemical properties. These are some of the important chemical properties of the soil required when assessing gully erosion. The pH reveals the soil's alkalinity or acidity. The pH value for the two samples, A and B in the study area were 5.1 and 5.2 respectively. This implies that the soil in the study area is moderately acidic. The implication is that the soil may not be affected by micro-organisms that work on organic matter which might enhance the binding of soils to resist the erosivity of rainfall and run-off impact. Also, there are low values of organic matter content (OMC) of the soil of the study area. This shows that the soils in the area are porous and cannot support the growth of some plants that are supposed to protect the soils from erosion, which according to with observed that area with low OMC and water holding capacity is prone to erosion (Okoyeh, 2014; Ofomata, 2016).

6. Conclusion

The textural characteristics were predominantly sandy with loamy, clay and silt in small proportion. Liquid limit (LL) ranged from 20.40 to 22.26 %, Plastic limit (PL) of 14.82 to 17.48 % were observed, with plasticity index (PI) of 5.58 and 4.78 % respectively. Bulk density ranged from 1.45 to 1.54 g/cm³, the total porosity ranged from 42.075 to 45.208 %. The Aggregate stability ranged from 33.67 to 40.24 % and water holding capacity ranged from 29.507 to 30.482 %. The results obtained show that factors responsible for the menace of gully erosion in the study area include; loose soil materials and dominant coarse sand. Other field observation factors include; topography, deforestation, bush burning that distort the texture of the soil contribute to the menace of gully erosion in the area. Hence to prevent these catastrophe caused by this erosion, necessary enlightenment campaigns on best agricultural practices that can reduce surface runoff in soil and water conservation is important. Also, strong culvert should be constructed at different locations in that area.

Recommendations

It is recommended that government should construct underground convert on the gully site of the study area to divert the runoff water to area less susceptible to erosion. Also, farmers should have a change of attitude in order to avoid the possible causes of erosion on their farmland. This may be achieved by planting more trees, avoiding deforestation, and overgrazing as well as encouraging the use of those sustainable agricultural practices.

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