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Understanding the Factors and Processes of the Umuagwo –Urualla Gully Erosionin Ideato North LGA of Imo State, Nigeria

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Abstract This paper describes a gully erosion study undertaken at Umuagwo – Urualla in the Ideato North Local Government Area of Imo State, Nigeria. The study involved the morphometric measurement of the gully, collection of soil samples for geotechnical analysis, geophysical investigation (using Vertical Electric Sounding) to determine the subsurface complexities of the gully area, peizometric measurement to determine response to hydraulic pressure as well as landuse/landcover of the study area. VES result indicate that the subsurface complexity of the gully is underlain by shale and siltstone while its overburden is constituted of sandy or loose soil materials which is permeable to a depth of about 32.5m where shale formation begins to predominate forming a semi-impermeable layer to the infiltrating water. The geotechnical characteristics of soil are predominantly sands whose fines (silt/clay) are very negligible. The sands are loose and highly permeable, and are non-plastic, cohesion is small (3kN/m^2), Angle of internal friction 24° Shear strength 177.8 kpa. The study found out that the area has fast lost its thick vegetation to light vegetation and has resulted in surface runoff. The poor soil quality, upward seepage and out flowing of groundwater weakened the cohesive force of the soil thereby encouraging the sliding of overburden materials resulting in the formation and growth of the gully.

Keywords Urualla, Gully Erosion, VES, pore-pressure, Shear strength, Soil Consistency

Introduction

Natural or geologic erosion of the land is one of the processes of nature that help bring about the formation of soil. However when the processes becomes accelerated forming gullies, it constitutes a serious problem. Ideato North and South Local Government Areas of Imo State, Nigeria has several gully erosions; one of the well-known and perhaps the biggest and pervasive gully erosion in the area is the Umuagwo-Urualla gully erosion. Several efforts have been initiated to resolve the continued growth of this gully to no avail. It is speculated that the gully is formed on a "disappeared river channel". To arrest (predict and control) the continued growth of this gully will require sufficient understanding of the mechanisms – causes and processes of this gully erosion. The aim of this research therefore was to determine the likely influence of geotechnical property of the soil and groundwater pore pressures on the formation and continued growth of the Urualla gully in order to ascertain the right remedial measure to solve the gully problem

Materials and Method

Study Area

Urualla is in Ideato North Local Government Area of Imo State (figure 1). The area is generally characterized by a rugged topography with anelevation of about 351m above mean sea level (MSL). The relief is gentle on the North-west facing flank while it is rugged and almost steep escarpment on the South-East Flank (Figure 2 & 3).

Geologically, this highland region appears to be a low asymmetrical ridge/cuesta of the Awka – Orlu-Okigwe Uplands, which trend roughly North West to North East, in line with the geological formations that underlie it which is believed to be part of the Lower Benue trough. The dominant geological formation is the Eocene Ameki Sands which is a sequence of unconsolidated or poorly consolidated sand, 305m thick, underlain by the thick Imo Shale formation of Palaeocene age, and overlain by the lignite-clay seams of the Oligocène Ogwashi-Asaba formation. The Ameki Sands are predominantly sandy with thin claystone and siltstone bands, lenses and laminations. The sand is poorly-sorted, cross-bedded 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. The unconsolidated sands are loose, friable and poorly cemented with thin shale layers. The sands are very permeable while the shales are not. Below the water table, these sands and shales are saturated with water which affects their strength.

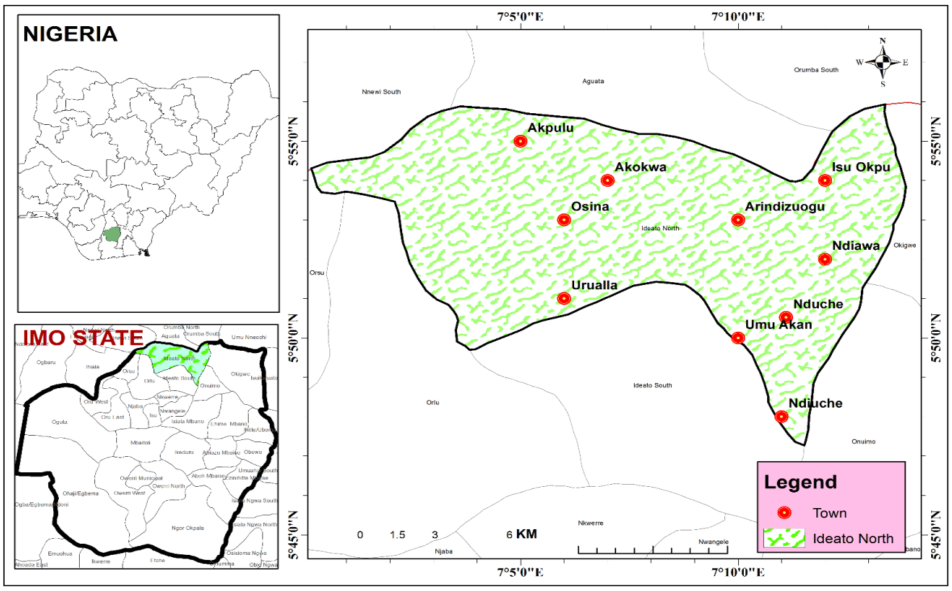

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Figure 1: Map of Ideato North LGA showing Urualla (the Study Area)

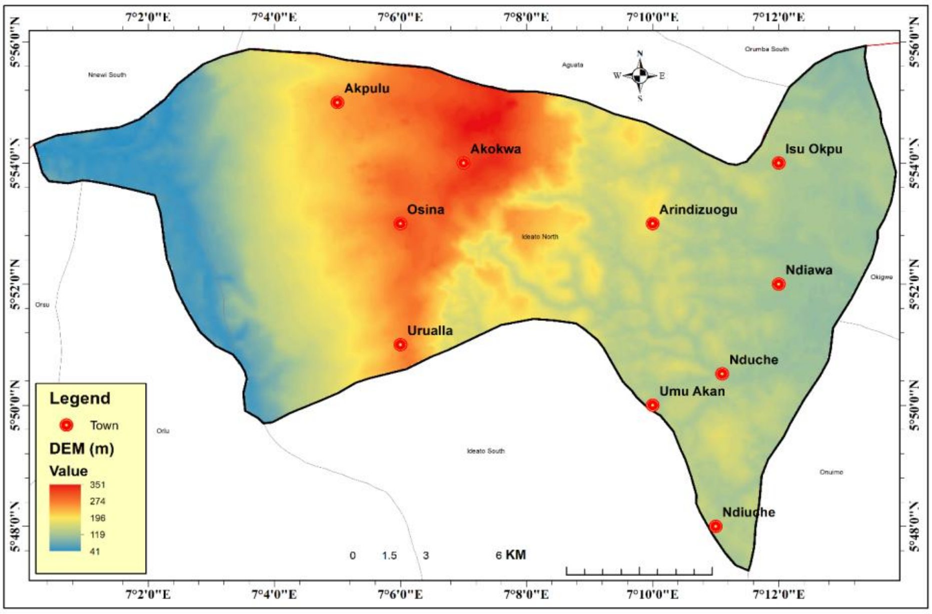

Figure 2: Digital Elevation (showing Relief) of Ideato North

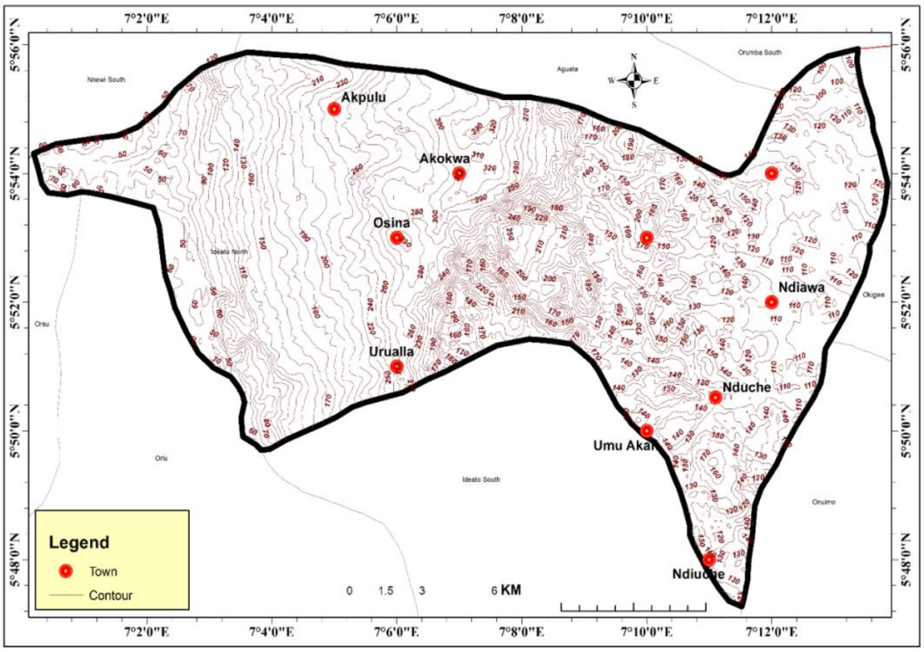

Figure 3: Contours of Ideato North

The study area falls under the climatic classification of humid, semi-hot equatorial type. Annual rainfall varies from 1,990mm to 2,200mm however, variations occur in rainfall amount from year to year, rainfall distribution is bimodal, with peaks in July and September. The rainy season begins in March and lasts till October or early November. From March to May, there are violent storms. Rainfall is often at its maximum at night and during the early morning hours. The higher annual rainfall depths and rainfall days encourage the production of large volumes of runoff that move over the land surface.

The study gully (The Umuagwo, Urualla gully) has an average length of about 1,998m; average width at the top of 16m and depth of 27.5m Slope is between 2° to 7°. It can be accessed from the Queen of Apostolic Parish Catholic Church Road Junction between Obioha and Obodoukwu road. At the mouth of the gullyis a major crustal depression which may have been caused either by ancient tectonic activity or erosion processes (figure 4)

Figure 4: Google earth view of Urualla gully

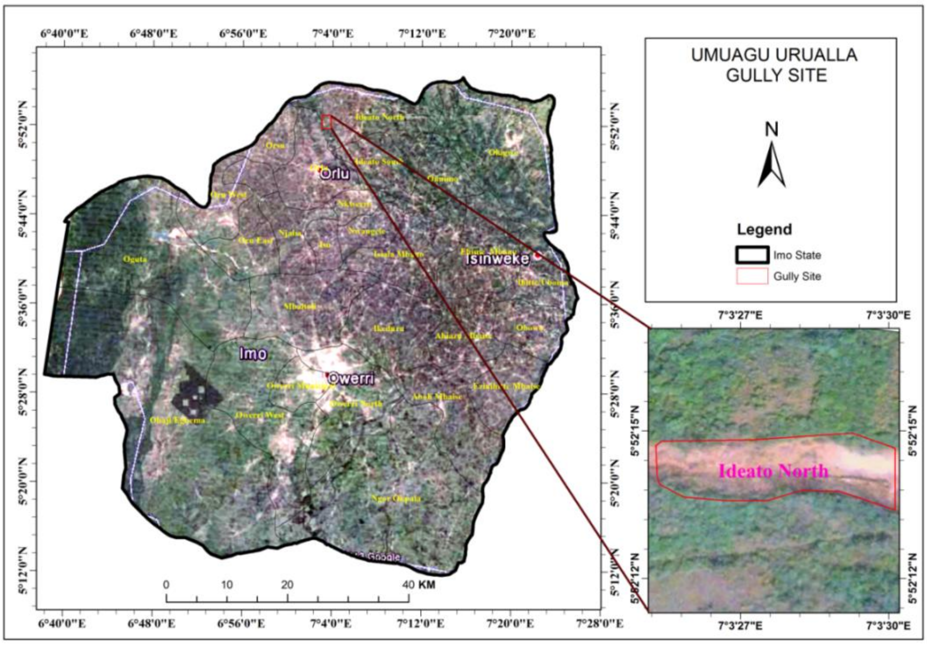

Figure 5: Location of Urualla gully the map of Imo State

Methodology

Determination of the Subsurface Complexity of Gully Area

This involves the geophysical survey and study of the subsurface geology and depth of erosive material across the project area in respect of lithology, and identification of the water table-saturated zone. OHMEGA-500 Electrical Resistivity Equipment was used to conduct a Vertical Electric Sounding (VES). Schlumberger configuration was used for a total spread (L) of 320 m. VES station was located close to the gully, with the traverse running normal. A distance of 160 m ($^L/_2$) was covered on the right of traverse towards Obiohia, and another 160 m ($^L/_2$) was run on the left towards Umunwanado, in each traverse all necessary precautions required in geo-electric measurement were duly considered. The survey lasted approximately 1hr 30 min in each location under favorable weather condition.

Field Techniques

Transmitter electrodes (A, B) are used to inject current into the ground. The current flow between A and B is measured with the potential electrodes (M, N) (Figure 6).

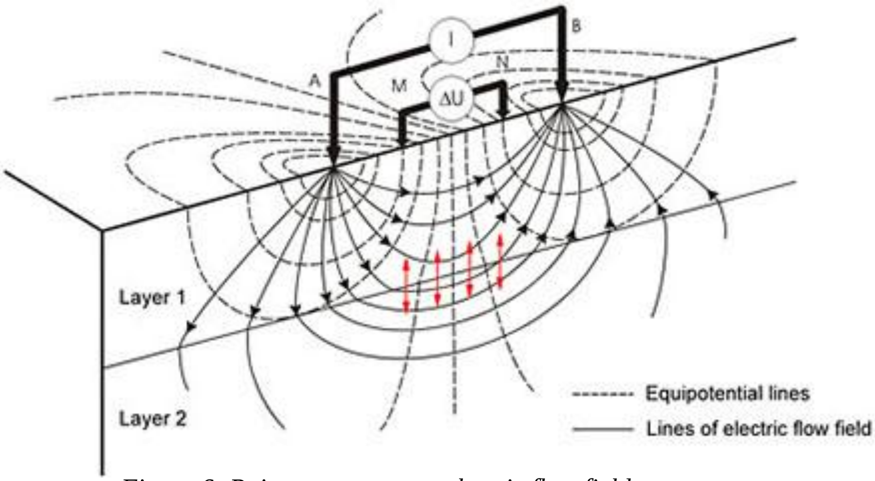

Figure 6: Point-measurement electric flow field

Several 4-point-measurements are taken where the receiver electrodes M, N remain in place and the transmitter electrodes are symmetrically extended outwards. Thus the current penetrates successively deeper into the ground. When the current flow sinks to a layer with different electrical conductivity the current flow field is deformed, this can be measured at the receiver electrodes M, N. From this data a layer model based on the electrical conductivity of the different subsurface materials is calculated.

Data Processing

Data generated in the field were subjected to full computer processing techniques, applying the Schlumberger computer automatic analysis package, and the Advanced Geophysics Incorporation (AGI) 1D resistivity analytical software.

$$\text{Apparent Resistivity } (\rho a) = \frac{\pi (AB/2)^2 - (\mathbf{MN}/2)^2 * R}{\mathbf{MN}} \ (Ohm\text{-}m)$$

AB/2 = Current Electrode spread, MN/2 = Potential Electrode spread

Thus Apparent Resistivity Equation can be expressed as follows:

$$\rho a = K \times R \ (\Omega\text{-m}), \quad (1)$$

Where: K = geometric factor; $\frac{\pi (AB/2)^2 - (\mathbf{MN}/2)^2}{\mathbf{MN}} (m)$

R = field resistance = I/V (Ohms).

I = current passed to the earth through electrodes, and V = voltage

Geotechnical Assessment of Gully Soil/Morphological Characteristics

The length of the gully was measured with the aid of a measuring wheel and tape. The length was compared with that generated by on-screen measurement on the GIS interface. The length was divided into 4 segments and on each segment depth and width was determined to get average Cross Sectional Area (CSA). For Slope, the clinometer was used to measure the slope/gradient, reading was done when the bulb in the plume line becomes stationary in the centre. The relief/geology of the area was determined from the geologic map of Imo State. GPS coordinates, terrain altitude were determined with hand held Garmin 75 GPS equipment.

On each segment of the gully wall, soil samples were collected at three distinct positions including the top, midway and gully bottom (to make a compost) for the determination of moisture content (Atterberg limits), soil texture, soil structure and bulk density (high bulk density. The samples were placed in black cellophane bags designed for the purpose, tied and labeled accordingly and transported to the Soil Laboratory of the Erosion Research Centre of the Federal University of Technology, Owerri.

Infiltration tests at various locations were performed using the Double Ring Infiltrometer method (DRI). Tensiometers and piezometers were also used to measure the responses of the area to hydraulic pressure before and after a storm event, groundwater pressures heads were measured at various locations along the slopes. The piezometers were made out of 5cm diameter PVC pipes, the lower end of the pipes were perforated to allow the passage of water but covered with fine mesh screen to prevent blockage by soil particles. Several readings were taken during the dry and wet months.

Results and Discussion

Subsurface complexity Results of the Gully Area

Vertical Electric Sounding Results (VES)

Figure 7 below is the gully area map showing the VES lines, the study gully and the direction of the flow of groundwater while Figure 8 is Result of Vertical Electric Sounding (VES) of the Umuagwo gully erosion site at Urualla showing the subsurface geology and depth of erosive material as well as the lithology and the water table saturated zone where tables 1 and 2 are derived below

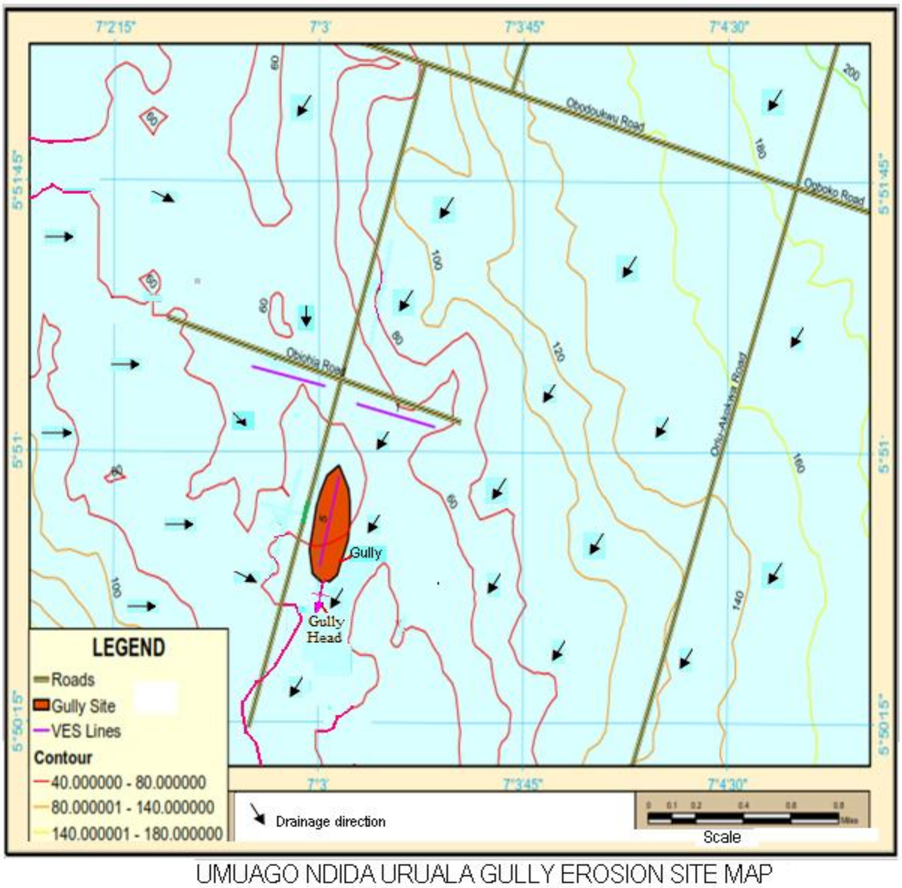

Figure 7: VES Lines & Contour of Umuago Gully Erosion Site

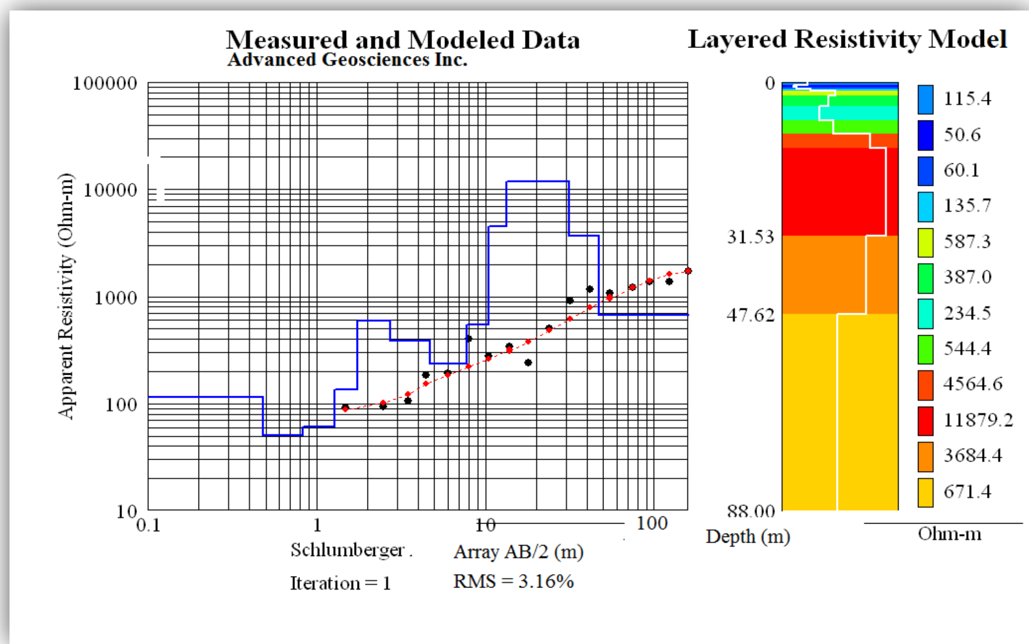

Figure 8: Umuagwo – Urualla Erosion VES

The analytical result presented by the AGI 1D Software and the Schlumberger Automatic analysis package (Fig 7) revealed twelve geo-electric layers (Table 1) which were constrained to 8 sub-layers (Table 2).

Table 1: Geo-electric Layers of Umuagwo-Urualla Gully

Layer	ohm-m	Thickness (m)	Bottom depth (m)
1	115.41	0.484	0.484
2	50.6	0.347	0.831
3	60.1	0.448	1.279
4	135.7	0.479	1.758
5	587.34	0.986	2.745
6	387.01	1.988	4.733
7	234.45	3.026	7.759
8	544.37	2.716	10.475
9	4564.57	3.013	13.488
10	11879.2	18.045	31.533
11	3684.44	10.088	47.621
12	671.43		

Table 2: Geo-electric layers (Constrained)

Layer	Depth (m)	Resistivity (ohm-m)	Lithology	Colour
1	0.83	115	Topsoil	Mixed blue
2	2.7	587	Silty sand	Green
3	7.7	234	Sandy clay	Blue
4	10.4	544	Silty sand	Green
5	13.4	4564	Sandstone	Red
6	31.5	118.79	Shale sandstone	Red
7	47.6	36.84	Siltstone	Off red
8	>88	671	Shale	Yellow

From the VES result, the subsurface complexity indicates that the gully is underlain by shale and siltstone while its overburden is constituted of sandy or loose soil materials. The implication is that the top sandy formation is very permeable to a depth of about 32.5m where shale formation begins to predominate forming a semi-impermeable layer to the infiltrating water.

Soil Characteristics of the Gully Erosion Site

Soil Consistency (Atterberg Limit) of gully Erosion Site

Soil consistency test generally describes the physical condition of the soil at the various moisture contents as evidenced by their behaviour towards mechanical stress, the soil consistency test conducted for this project is the Atterberg limits test. These, are widely used as a means of estimating the plastic properties of soil in other to determine their structure

The result of soil consistency (Atterberg limit and their interpretation guide is presented in the following tables below;

Table 3: Laboratory result of soil consistency (Atterberg limit)

Gully segment	LL	PL	PI	Permeability
1	NP	NP	0	$2.3X10^2$
2	NP	NP	0	√√
3	NP	NP	0	√√

Table 4: Guide to interpretation of Plastic Limits

Plastic limit of soil	Plasticity
< 35%	Low
35% - 50%	Intermediate
< 50%	High

Table 3 shows that the liquid limit and the plastic limit for all samples is NP (Non plastic) while the permeability is $2.3x10^2$. The corresponding table (4) indicates that the plastic limit and Liquid limit is non plastic. The plasticity index therefore is zero %. The implication is that the gully erosion soils are loose, unconsolidated and friable. Comparing this result with the result of VES table 2 the soil can be described as either sandy clay or sandy silt.

Soil Shear Strength

Shear strength is a term used in soil mechanics to describe the magnitude of the shear stress that a soil can sustain. The shear resistance of soil is a result of friction and interlocking of particles, and possibly cementation or bonding at particle contacts. The laboratory results are presented below

Shear strength (τ) = C + tan Φ σn

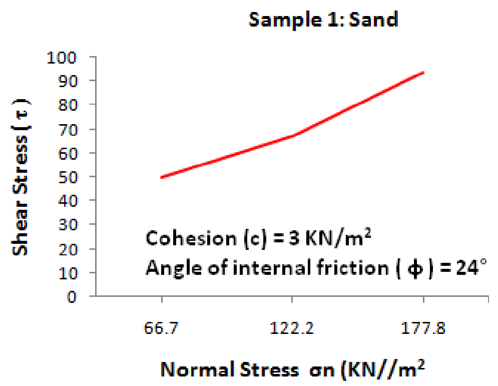

Figure 9: Shear Stress vs Normal Stress for Sample 1

Table 5: Soil Shear Strength

Sample	Cohesion (KN/m^2)	Angle (Φ) of Int. friction (Degrees)	Max normal Stress (σ n) (KN/m^2)	Shear strength (τ) C+ σ n tan Φ (KN/m^2)
Lateritic	3	24	177.8	

C = Cohesion

Φ = Angle of internal friction

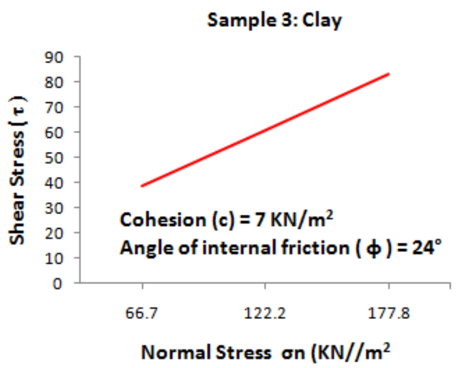

Figure 10: Shear Stress vs Normal Stress for Sample 3

Table 6: Shear strength

Gully segment	Shear strength (kpa)	Cohesion (kpa)	Int. friction (°)
1	177.8	3	24
2	177.8	10	20
3	177.8	7	24

Usually, the angle of internal friction (angle of repose) is considered weak and subject to failure when it is between 20-35 °, Table 6 can be interpreted to mean that the soil shear strength is weak and can easily be dislodged and transported away by force of erosivity.

Grain Size Distribution

Table 7: Grain Size Distribution

Gully Segments	Grain Size Distribution D_{10}	D_{30}	D_{60}	D_{80}	CU	CC	Grade
1	0.15	0.25	0.52	0.60	3.46	0.8	Poor
2	0.14	0.24	0.50	0.57	3.57	0.82	Poor
3	0.13	0.22	0.47	0.55	3.62	0.079	poor

Table 7 shows that all the soil samples collected in the Urualla gully are about 80% coarse grained (medium grained sand) and 20% fine (Silt). Their Cu is on the average 3.3 while their Cc ranged between 0.079 – 0.80 indicating that they are poorly graded and susceptible to erosion. Usually a well graded soil will have a Cc>5 provided its Cu is between 1 and 3, in this case, the result is not showing so, this is an indication that the grain size is coarse and makes a poorly graded soil. Furthermore, the values of Cc greatly differ from 1.0 indicating grain sizes missing between D_{60} and D_{10} and with large Cu values, it clearly show that the soil is more of coarse grained than fine. The conclusion drawn from this table is that these soils are coarse grain with very little fine. Placing them with permeability values and the Atterberg limits, there is a strong positive correlation, indicating its strong susceptibility to detachment and erosion

Moisture Content

Table 8: Moisture Content Determination

Can identification no.	Sand 24	Laterite 31	Clay 17
Wt of wet soil + can (g)	30.9	30	34.1
Wt. of dry soil + can (g)	29.7	28.2	32
Wt. of can (g)	19.1	17.1	21.2
Wt. of dry soil (g)	10.6	11.1	10.8
Wt. of water (g)	1.2	1.8	2.1
Water content, w (%)	11.3	16.2	19.5

Water content for sand 11.3%, laterite 16.2% and clay 19.5%.

Table 9: Piezometric measurement

Distance from Stream	Elevation	Piezometric Reading	Groundwater Pressure
0 – 50 m	332	330	0.5
300 – 350 m	345	340	4.5

Table 9 show that there is a relationship between piezometer readings to vertical elevation and horizontal distance at each of the measurement where piezometer readings coincide with land surface elevation such coincidence results in continuous wetting of the soil, sliding of the overburden materials and consequent production of quicksand conditions at the bottom of the valley because effective or intergranular pressure are reduced, interlocking of particle is disturbed and attraction between particles are reduced and a confirmation that water table is closer to the surface as one moves down slope towards the stream.

Landuse Landcover in the Gully Area

The landuse/land cover classification of the study area (figure 11) show that Built-up area is 25.3% of all the available land in Ideato North LGA while light vegetation (farms and sparse vegetation) is 39.6% (75.6km^2) The result further showed about 22.2 km^2 (11.6 %) is occupied by either open space and or gully erosion and this occur in and around light vegetation an indication that anthropogenic activities such as farming is a major contributor to the formation of gully erosion.

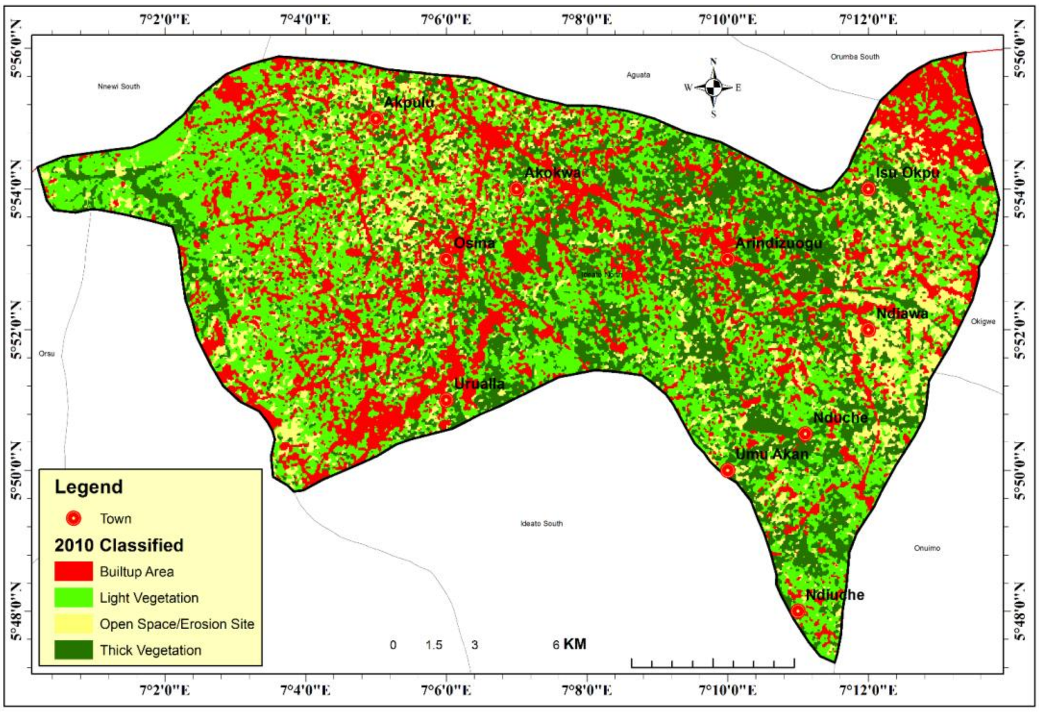

Figure 11: Landuse/Landcover of Ideato North LGA

Class	Area(Km²)	Percent (%)
Built-up Area	47.8	25.3
Light Vegetation	75.6	39.6
Thick Vegetation	45	23.5
Open Space/Erosion Site	22.2	11.6
Total	190.6	100
Overall Accuracy	76.5%	
Kappa Coefficient	0.6698	

Discussion

Gully Erosion Mechanism (Processes and Factors of Urualla Gully erosion)

Success at controlling the occurrence of gully erosion largely depends on the process governing their formation. From the field survey and laboratory investigation, it was observed that the Urualla gully might have been developed and continues to grow by at least two dominant processes which can occur in isolation or in combination with one another. The processes include:

Gullies formed as a result of Nick Point Formation/Slumping

Most gullies in high elevation area with gently sloping, start out as shallow overland flow paths that carry flows during periods of rainfall At some point in the sheet flow (typically, where the gradient dips), a nick point is formed along the drainage path. This nick point may develop into a bell-shaped scour hole (especially if there is a difference in lithology of the underlying soil structure), which is usually deeper than the immediate downstream gully bed. The nick point occurs at the downstream end of the gully and usually at significant change in grade along the flow path, such as the point where the overland flow spills into watercourses (rill formation). Head cut begins and causes the head of the gully to migrate up the valley forming the gully. This action of runoff is aided by the soil type. The underlying geology of the study area which outcrop as gravely, poorly sorted sandy loam soil makes it easy for water to flow through and continue the erosion. Consequently, the further the gully migrate up the valley, the higher and less stable the gully banks become and with continuous rainfall the gully banks get saturated and slumps, a process referred to as gravity erosion. The Urualla is on a geologic formation that is porous, non-sorted, sandy and gravelly; aided by high topography with gentle sloping and adequate rainfall.

Gullies formed from Dry & cracking/Slumping (Gravity Erosion)

Prior to the initial formation of the gully, it is believed that because of the little cohesive/binding materials in the Urualla gully soil, the top soils have a tendency to swell during the raining season and dry during the Dry season leading to alternate drying and cracking of the soil. Extreme drying of the top soil results in the extensive cracking that allows lines to cut through on the surface and provide channel for water flow. In areas where sand and shales are the dominant geologic formation the sands are unconsolidated, loose, friable and poorly cemented with thin shale layers as can be seen from the laboratory result. The sands are very permeable while the shales are not, such that during the wet season, the high permeable sandy formation receives sufficient water from surface runoff which causes the water table to rise resulting in high groundwater flow rates saturating the sands and shales formation below the water table affecting their strength. Then during the dry season, the water table falls as a result of hydraulic head decay (Table 9) this produces decreased flow rates, and an increase in the depth of the unsaturated zone.

According to Akpokodje *et al.,* 1986 and Hudec *et al.,* 2006 in areas where there are overlying lateritized soils the less permeable clay layers are lubricated and saturated with water [1-2]. The clays subsequently expand and lose their shear strength. The piezometer readings show that there is a continuous wetting of the soil, as a result of the shales being thoroughly saturated after many days of rainfall, the clay minerals swell and develop a tendency to slide. Large masses of sand underlain by the plastic shale slide down dip into the gully, with the shale acting as a lubricant (figure 12)

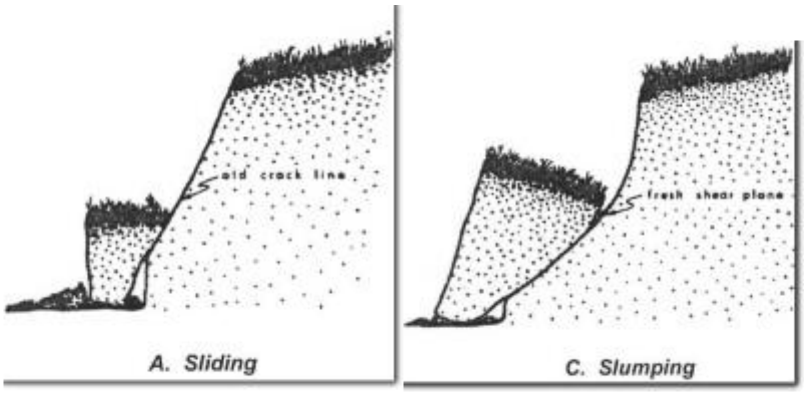

Figure 12: Gravity Erosion resulting from saturated soil forming gullies

One fact is clear from literature and from a close field investigation of Urualla gully; the development of the gullies usually do not follow strictly the generalized stages of sheet, rill, and gully erosion. Sheet erosion may occur but is generally not spectacular before a gully erosion forms. In agreement with Okagbue and Uma [3], this research finds that Urualla gully erosion is rather progressive through the following stages:

(a) Formation of rills,
(b) Development into incipient gully,
(c) Shallow gully<15 m deep), and
(d) Deep gullies (>15 m deep).

The main erosional activity at the first three stages involves the surficial removal of soil grains and small chunks of earth by rain splash, concentrated flood run-off along the rills and existing gully and minor undercutting at the toe of the channels.

Summary and Conclusion

From field observation, the factor of Urualla gully is a combination of factors which may include the soil, geology, erosivity, slope & elevation etc. The findings on the soil physical properties gave credence to the assumption that the nature of the soil as a result of the underlying geology is the principal factor responsible for the massive gully erosion in the study area. The principal variable of soil erodibility factor is the soil structure which is reflected in the Consistency (Moisture content/Atterberg limits), shear strength, and bulk density. For example, soil consistency (moisture content/Atterberg limits) shows that they are none plastic, meaning they have no binding materials in the soil and as such they are less cohesive. These findings as expected reflected in the Plasticity Index (P.I). The P.I values are low indicating that cohesion (binding of grain particles) is low. Poor binding or poor cohesion in soil tend to disaggregate when in contact with moving water under the force of gravity, this finding agrees with the works of Ofomata and Nwajide & Hogue [4-5].

Bulk density of soil show that the average bulk density of the area is 1.8g/m^3 and this finding is in agreement with the works of Obasi and Ijeoma (1991); Hudec *et al.*, (2006) and Onu, 2011 that have found similar result for the area [2, 6-7]. The standard measurement for bulk density is 1.6g/m^3 when soil bulk density is above this limit it tends to hardened up the soil. There are two possible scenarios that can result from this: first, the compaction will lead to cracks on the soil surface during the Dry season and during the raining season, these cracks will form the channels for water to flow and since most of the underlying geology is gravely and poorly sorted, erosion will begin to occur by the formation of rills, incipient gullies. Secondly, when the underlying formation is shale or lateritic, as a result of the leaching of silica in the sand alongside sodium, potassium and calcium by percolating water; iron, aluminum oxides and hydroxides stay behind, the clay mineral will swell, increase in volume, become plastic and cover the pore spaces preventing percolation and infiltration resulting in excessive surface overland flow and cause the soil to slide because it is saturated and weakened [8-9]. Bulk Density, Atterberg limits and Permeability are factors that influence the Shear Strength of any soils. The way and manner grains are packed is important as it governs the angle of repose or internal friction of the soil.

Soil Texture is a very important variable that influence erosion in the area. From the preceding discussion, the dominant soil type is sandy soil which is poorly sorted and in some cases gravely. Coarse grain soils have little to no binding materials and as such allow quick passage of water which ultimately enhances sediment transportation. The sandstone units are porous and permeable and have less “fines’ than the clay/shale units. Water infiltrates/percolates and flow through the top soil and sand units readily but get trapped in the sand/shale interface. The clay/shale units’ serves as barriers to downward water flow and therefore confine water to certain sand units which creates two undesirable conditions, namely: excess overland flow (runoffs) and high pore-water pressure build-up in the sands.

This excess overland flow subject the thin soil horizon to stress and sooner or later breaks the thin and fragile soil horizon thereby initiating soil erosion. The entrapped water in the porous and permeable loose sands (low in “fines” which ordinarily serves as cementing materials) leads to high pore-water pressure build-up. This is in turn leads to low shear strength of the interface and reduce the shear resistance at this boundary and cause the surface to be slippery and finally results in the sliding and slumping of the sand units.

In conclusion, accelerated erosion is activated by both nature and human activities. The human components in soil erosion are connected with poor engineering and agricultural practices and other land use activities. Only the most severe rainfall and large hailstorm events will lead to overland flow in a forest. The landuse/landcover of the area show how greatly thick vegetation have given way to light vegetation thereby triggering the surface runoff and erosion. The soil type and the groundwater/pore pressure are the major cause of the development and growth of this gully.

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