GEOPHYSICAL AND GEOTECHNICAL EVALUATION OF AN EROSION SITE IN EBEM-OHAFIA AREA OF ABIA STATE, SOUTHERN NIGERIA.

ABSTRACT

This work is an integrated evaluation of the external and internal structures of an erosion site in Ebem-Ohafia area of Abia state, Nigeria. The study is aimed at evaluating the erosive nature of the sediments using the geophysical and geotechnical methods of investigation. The geophysical method used was the electrical method which employed the Schlumberger electrode configuration with maximum half current electrode spacing of AB/2 = 165m, and 4 vertical electrical sounding (VES) data were acquired. Results show that the top soil resistivity values vary from 58.8 Ωm – 886.6 Ωm, that of the weathered layer vary from 100 Ωm - 3586.6 Ωm; and the maximum depth of each sounding location varies from 33.4 m - 59.6 m. In the geotechnical approach, four soil samples from each of the sounding locations were used for the study. The geotechnical results show that the soil has relatively high clay content with plasticity index ranging from 6.0% -12.0%. The consistency limits of the soils generally indicate low to medium plasticity. The natural moisture content varies from 5.3% to 9.4%; while the liquid limit ranges from 27.4% - 41.1%. It was however concluded that geomorphologic and anthropogenic factors are the major causes of the erosion menace.

Keywords: *Geo-electrical data; plasticity index; geomorphology, erosion menace.*

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.

It is a natural process, but human (anthropogenic) activities significantly contribute to activities stimulating erosion.

Soil erosion is caused by climatic factors such as wind, storm, temperature and precipitation. Water (rainfall) and wind are responsible for over 80% of the natural causes of erosion (Blanco and Lal, 2010), therefore given similar vegetation and ecosystems, areas with high-intensity precipitation, more frequent rainfall, more wind, or more storms are expected to have more erosion.

It can also be caused by geological factors such as sediment rock type and its porosity and permeability. The composition, moisture, and compaction of soil are all major factors in determining the erosivity of rainfall. Sediments containing more clay tend to be more resistant to erosion than those with sand or silt, because the clay helps bind soil particles together (Nichols, 2009). The topography of the land also determines the velocity at which surface runoff will flow, which in turn determines the erosivity of the runoff.

There are four types of erosion resulting from rainfall: splash, sheet, rill, and gully erosion. Splash erosion which is generally seen as the first but least severe stage in the soil erosion process is followed by sheet erosion, then rill erosion and finally gully erosion being the most severe of the four (Zachar, 1982; Toy. et al, 2002).

Erosion rates dictate the morphology of landscapes, and therefore quantifying them is a critical part of many geomorphic studies. Geomorphology pertains to the study of the physical features (landscape) of the surface of the earth in relation to their geological structures. Since the topographic form of landscapes reflects interplay between geology and climate-driven surface processes; therefore these interactions dictate erosion rates and control topography.

Geologic factors generally determine topography while climatic factors modify the efficiency of the erosional processes. Therefore, an understanding of relationships between erosion rates and landscape morphology becomes essential to geomorphic studies (Yoo and Mudd, 2008a; Tucker and Hancock, 2010). Thus areas susceptible to extreme gully erosion processes owe their vulnerablity to a combination of distinct geological, geo-morphological, and pedological characteristics (Ogbonna et. al 2011, John et.al, 2015).

Methods to directly measure erosion rates are expensive and time consuming (Hurst et.al, 2012), therefore causes of erosion are better studied and erosion-prone areas highlighted for precautionary and remediation actions. Since it is established that geologic factors play crucial role in geomorphology of an area; then the use of geophysical and geotechnical methods in the evaluation of geologic processes of an area therefore comes to play.

The study area is located within Ohafia Local Government Area of Abia State which lies between latitude 5°30´ N to 5°45´ N, and longitude 7°45´ E to 7°55´ E. It is part of the tropical rainforest characterized by dry and rainy season with a total annual rainfall of over 1400 mm and an annual temperature range of 23°C to 32°C (Fig. 1). This study is necessary because gully erosion is considered a major cause of geo-environmental degradation in the Southeastern part of Nigeria whereby a greater percentage of lands are devastated annually during the rainy season.

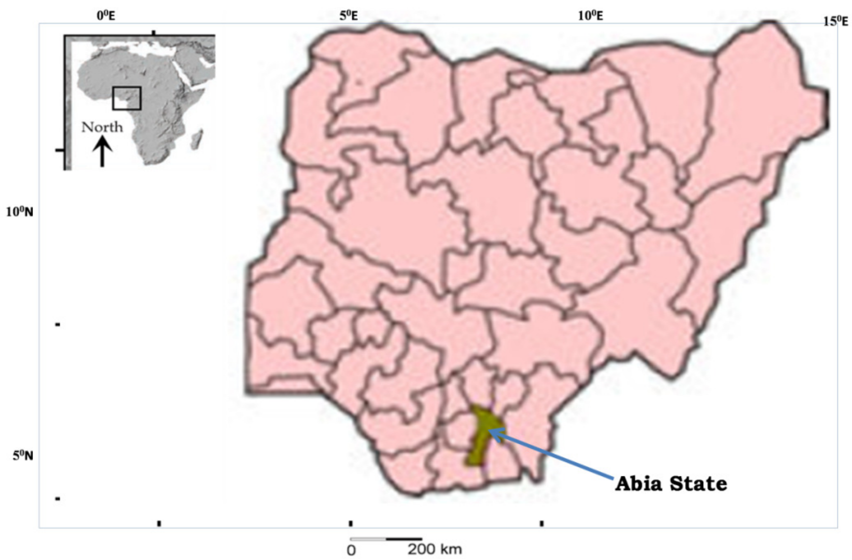

Fig. 1: Location map of Nigeria showing Abia State the study area.

The geology of Ohafia local government area falls within the Deltaic marine sediment of Cretaceous to Recent age. There are three major geologic formations in the area: the Nkporo formation, Mamu formation (Lower Coal Measures) and the Ajalli (false-bedded sandstones) formation (Fig. 2).

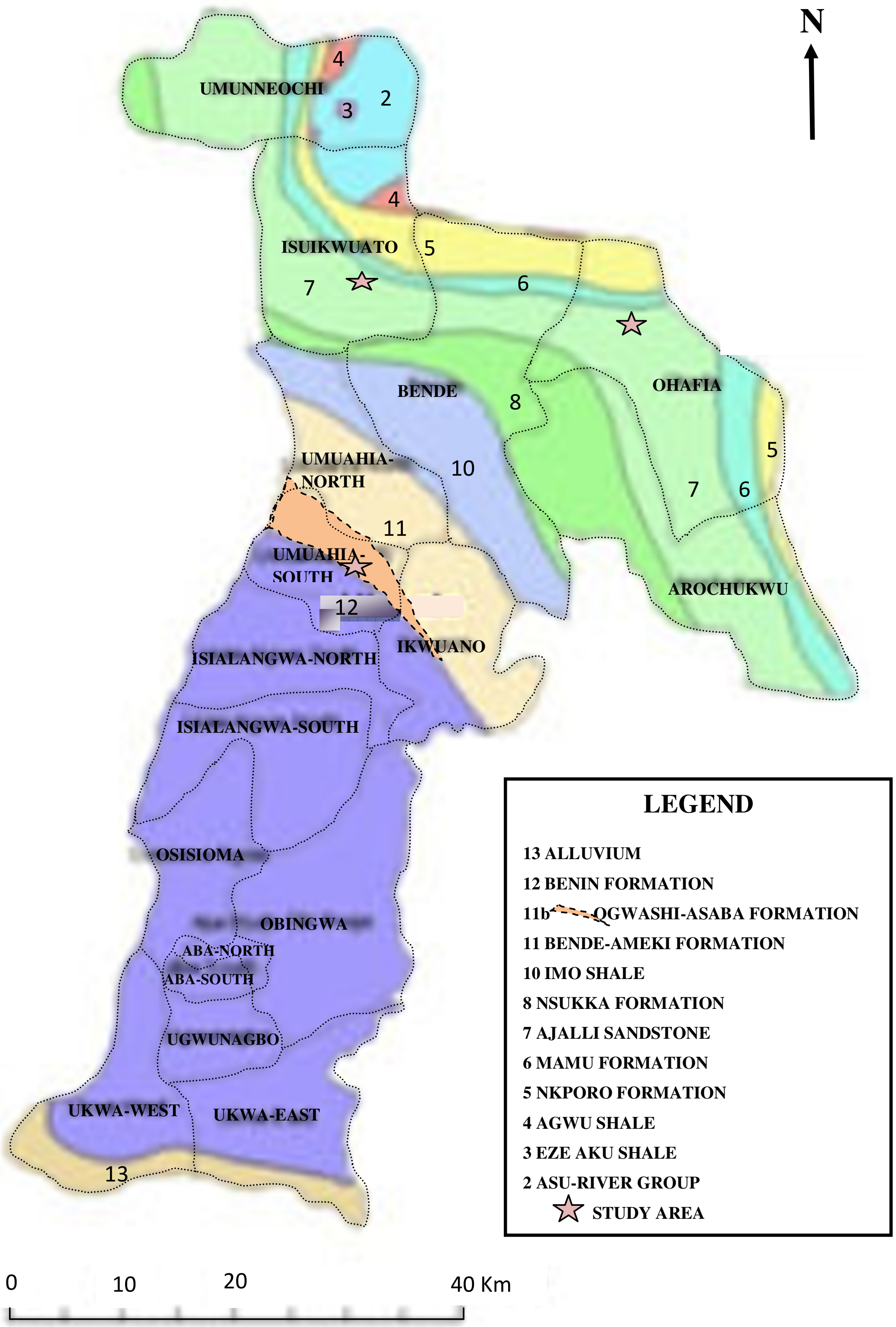

Fig. 2: Geologic map of Abia State showing the Local Government Areas and the study area (Modified after GSN, 1985).

MATERIALS AND METHODS

Four (4) Vertical Electrical Sounding (VES) stations were carried out in proximity to the chosen erosion sites using the Schlumberger configuration (Fig. 3). The Garmin GPS 72 was used in determining the coordinates in longitude, latitude and elevation above mean sea level of each of the sounding point.

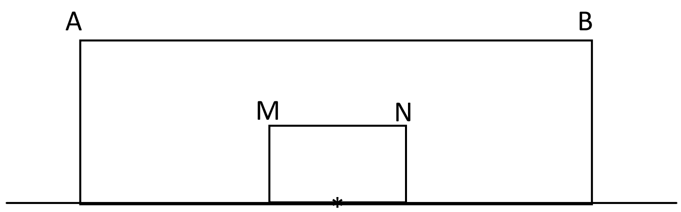

Fig. 3: Schematic diagram of the Schlumberger electrode configuration used in the study.

Then the ABEM Terrameter which was used in the data acquisition was deployed to the position where direct current (DC) from the Terrameter was passed into the ground using two metal stakes (current electrodes 'AB/2') linked by insulated cables. The current developed a ground potential difference whose voltage was determined using two other electrodes 'MN/2', which were kept in line with the pair of current electrodes. For each VES profile, the distance between the potential electrodes (MN/2) was varied gradually from 0.5 m to 14 m to obtain a measurable potential difference. The half current electrode separation (AB/2) was also correspondingly varied from 1.5 m to 165 m.

The observed field data which is the ratio of the resulting voltage to the imposed current is only a measure of resistance of the subsurface (ground resistance). This is read off directly from the Terrameter and is used to compute the corresponding apparent resistivity in Ohm-meters by multiplying with the geometric factor (values as functions of electrode spacing), which then gives the required apparent resistivity results as functions of depths of individual layers as shown below:

$$\rho a = \pi R\left(\frac{L^2 - a^2}{2a}\right) \quad \text{... (1)}$$

Where ρ_a = Apparent resistivity, L = 'AB/2' = Half current electrode spacing (m).
a = MN/2 = Half potential electrode spacing (m), R = Resistance in ohms.
$\pi\left(\frac{L^2 - a^2}{2a}\right)$ = Geometric factor (K).

The sounding curves for each point was obtained by plotting the computed apparent resistivity against the half current electrode spacing (AB/2) on a log-log graph scaled paper and initial estimates of the resistivities and thicknesses of the various geoelectric layers were obtained and used for computer iteration using RESIST software package.

The final interpreted results were used for the preparation of geoelectric sections and histograms.

Soil samples at each erosion study site were collected from the surface to a depth of 1 m and preserved in airtight polythene bags upon collection, then thereafter transported to the laboratory for some geotechnical and soil physical analyses in accordance with British Standard 1377.

The determination of some of the parameters was done after air drying of the samples by spreading them out on trays in a fairly warm room for four days, while that of natural moisture content was done immediately upon reaching the laboratory.

The parameters determined include natural moisture content, void ratio, grain-size analysis, liquid limit, plastic limit and plasticity index.

RESULTS AND DISCUSSIONS

GEOPHYSICAL CHARACTERISTICS OF THE SOIL SAMPLES

Geophysical Results

Five curve types were identified within the study area. These include AAK, KQAK, HQK, KQQ and KQH type with the AAK as the predominant curve type (Table 1). The typical curve types are as shown (Fig. 4 and Fig. 5). The summary of the VES interpretation shows that the number of the geoelectric layers varies between five and six layers (Table 1).

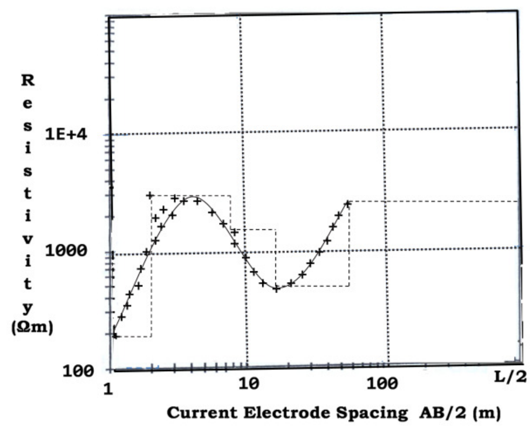

Fig. 4: Typical curve of VES 3

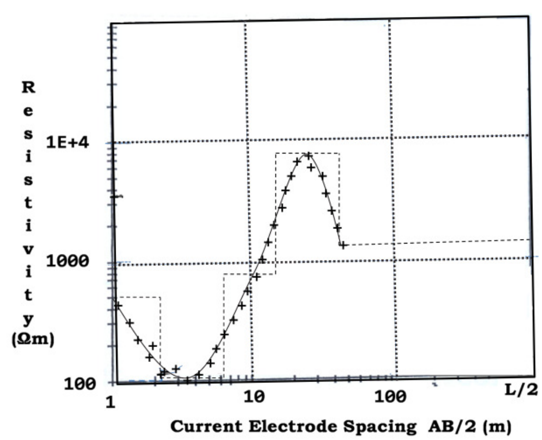

Fig. 5: Typical curve of VES 4

Geoelectric Parameters

The VES interpretation results were used to prepare a geoelectric cross-section (Fig. 6). The geoelectric cross-sections delineated a maximum of five geoelectric layers comprising the top soil, coarse-grained sands, medium-grained sands, flne-grained sands, silts, clays and sandstone. The top soil is composed of fine-grained sands, silts and clays with resistivity values varying from 58.8 Ωm – 886.6 Ωm and thickness of between 0.5 – 2.2 m. The weathered layer ranges in composition from coarse-grained sands to clays and silts with resistivity values that vary between 100 Ωm and 3586.6 Ωm.

Table 1: A summary of the VES interpretation results

VES Station	Location	GPS Reading		Type curve	Number of layers	Resistivity of layers (Ωm)	Thickness of layers (m)	Total thickness (m)	Fitting error (%)
		Elevation (m) m.s.l	Co-ordinates						
1	Ebem Ohafia 1	164.7	$5^{0}38.214^{'}$ N $7^{0}49.409^{'}$ E	AAK	5	ρ_1=888.6 ρ_2 =3586.6 ρ_3 =4240.0 ρ_4= 4820.2 ρ_5= 2290.0	t_1 = 0.6 t_2 = 2.2 t_3 = 10.0 t_4 = 40.9 t_5 = ?	53.7	2.0
2	Ebem Ohafia 2	164.3	$5^{0}37.888^{'}$ N $7^{0}49.709^{'}$ E	KQH	5	ρ_1=188.2 ρ_2 =3002.5 ρ_3 =1640.0 ρ_4= 480.2 ρ_5= 2890.0	t_1 =1.0 t_2 = 5.6 t_3 = 10.0 t_4 = 43.0 t_5 = ?	59.6	2.3
3	Ebem Ohafia 3	153.6	$5^{0}37.862^{'}$ N $7^{0}49.696^{'}$ E	HQK	5	ρ_1=481.8 ρ_2 =100.0 ρ_3 = 812.0 ρ_4= 8050.0 ρ_5= 1430.0	t_1 = 2.2 t_2 = 3.8 t_3 = 5.9 t_4 = 37.0 t_5 = ?	48.9	2.5
4	Ebem Ohafia 4	149.9	$5^{0}37.428^{'}$ N $7^{0}49.527^{'}$ E	KQQ	5	ρ_1=58.8 ρ_2 =294.6 ρ_3 = 46.1 ρ_4= 45.6 ρ_5= 39.6	t_1 = 0.5 t_2 = 4.0 t_3 = 13.9 t_4 = 15.0 t_5 = ?	33.4	2.7

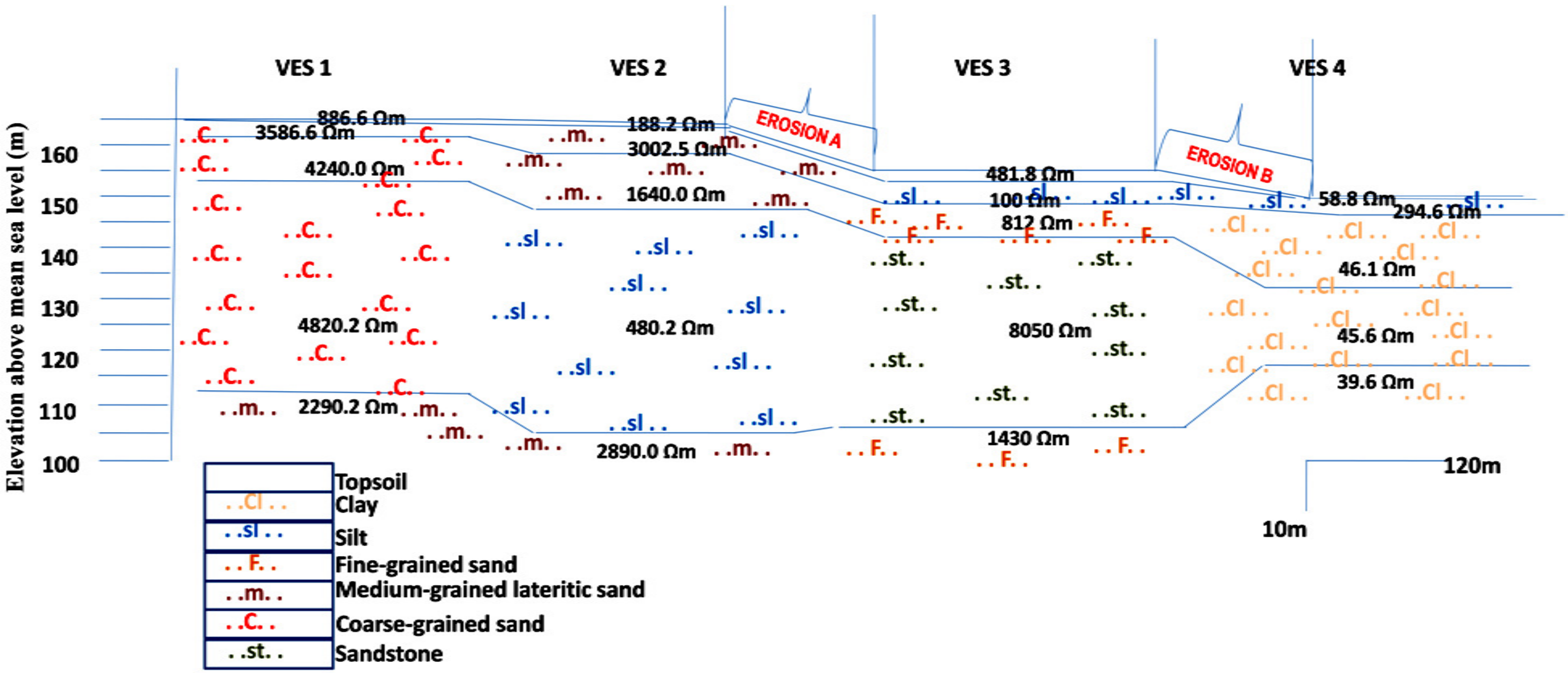

Fig. 6: The geo-electric cross-section of the study area.

4.2 GEOTECHNICAL / PHYSICAL CHARACTERISTICS OF THE SOIL SAMPLES

Physical characteristics of soils determine their structures which relates to the physical state of the soil complex. The parameters that make up the soil structure include properties such as soil texture and grain-size distribution, bulk density and moisture content, porosity and permeability etc. These parameters in turn aid in determining the stability of soils, thus influencing the resultant arrangement/re-arrangement of soil structures.

4.2.1 Soil texture and Mechanical sieve analysis

Soils that are largely made up of fine particle are likely to have more chemical reactions and exchangeable cations, but a reduction in the silt and clay fractions tends to lower the reaction thus leading to the loss of top soil. Based on particles size, finer particles are defined as particles less than 0.075 mm in diameter (Fig. 7).

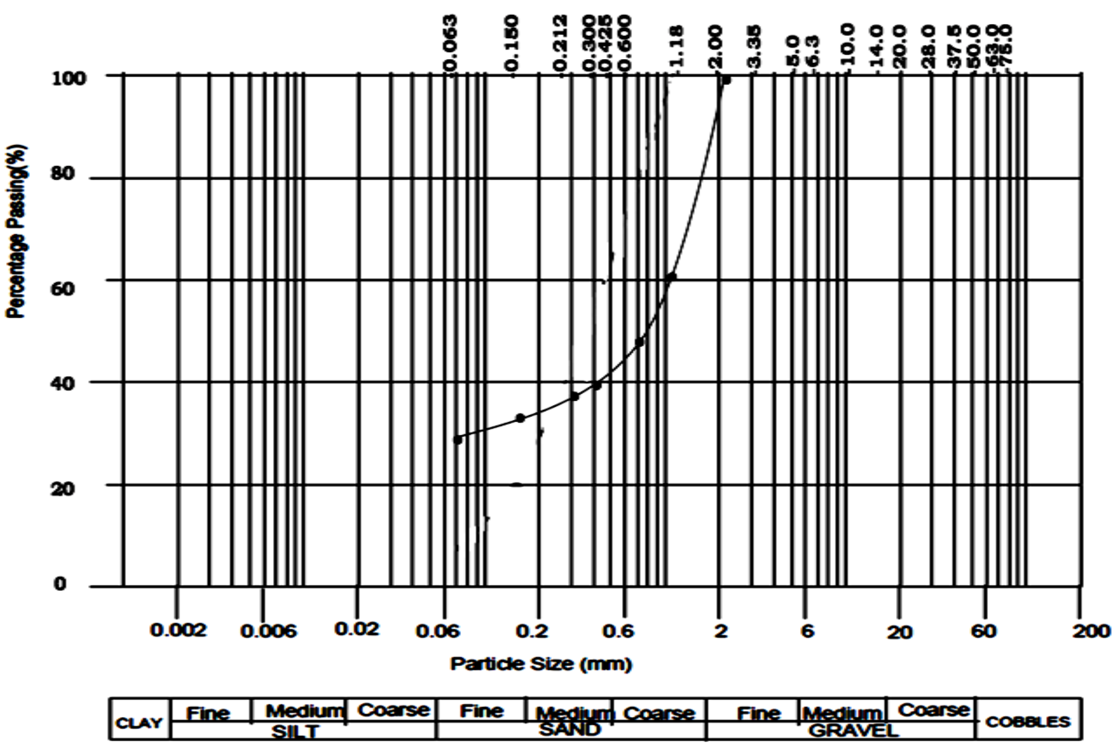

Fig. 7: The grain size distribution curve of OHAFIA 1 soil sample

Grain size distribution analyses show that the tested soils range from 30 - 35% passing the 0.075 mm sieve (Table 2). The finer particles that passed through the 0.075mm sieve were subjected to Atterberg limit tests.

Table 2: Soil textural analysis of the top soils of the erosion sites in the study area

Sample Location	Textural characteristics	Percentage passing the sieve diameter (%)			Remarks
		0.075mm sieve	0.6mm sieve	2.00mm sieve	
VES 1	Loose gritty medium to fine grained sands	30.0	48.4	100.0	Brownish-red silty-sand
VES 2	Loose gritty fine grained sands	32.0	49.0	100.0	Brownish-red silty-clay sand
VES 3	Sticky medium to fine grained silty sands	33.0	49.0	100.0	Brownish-red silty-clay sand
VES 4	Malleable fine grained clayey sands	35.0	46.1	100.0	Brownish-red clayey sand

4.2.2 Water content and void ratio

The natural moisture content of the tested soil samples ranges from 5.3% - 9.4% (Table 3). Sandy soils fall within the range of 5 to 15% (Terzaghi et al. (1996). Therefore tested soil samples are adjudged to be sandy deposits.

4.2.3 Atterberg limits

The result of the finer soil samples subjected to Atterberg limit tests shows that the lowest value for Liquid limit is that of Ohafia 3 which is 27.4%; while the highest value is that of Ohafia 4 which 41.1%.

On the other hand, Ohafia 3 also recorded the lowest Plastic limit which is 19.2%, while Ohafia 4 of 29.1% has the highest (Table 3).

Table 3: A summary of the results of the soil physical characteristics

	Natural Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity index (%)
VES 1	5.3	32.0	26.0	6.0
VES 2	7.8	30.3	20.1	10.2
VES 3	7.0	27.4	19.2	8.2
VES 4	9.4	41.1	29.1	12.0

But since soil consistency is a measure of the degree and kind of cohesion and adhesion between the soil particles in relation to its resistance to deformation; and varies with moisture content, and soil minerals. Therefore, the difference between the liquid limit and the plastic limit (plasticity index) is of utmost concern (Table 4).

Table 4: Plastic indices and their corresponding state of plasticity (Modified after Burmister, 1997)

Plasticity Index	State of plasticity
0	Non-plastic
<5	Slightly plastic
5-10	Low plastic
10 - 20	Medium plastic
20 - 40	Highly plastic
>40	Very high plastic

Soils with high plasticity index (PI) tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 (non-plastic) tend to have little or no silt or clay.

Plasticity index is reported as NP (non-plastic) when either the liquid limit or plastic limit cannot be determined especially when the soil sample is extremely sandy, or when the plastic limit is equal to or greater than the liquid limit.

The plasticity index gives an indication of, among other things, an increase in moisture content required to convert a soil from a semisolid to a liquid state. It is the range in moisture at which a soil is in a plastic state, and therefore may be considered as a measure of the cohesion possessed by a soil.

From the result of the laboratory analysis, Ohafia 1 has the lowest value of plasticity which is 6.0%, while Ohafia 4 has the highest plasticity index of 12.0%.

The plasticity index of soil samples from Ohafia 1 and Ohafia 3 fall between 5.0% and 10.0%, and are therefore of low plasticity, while Ohafia 2 and Ohafia 4 are of medium plasticity (Burmister, 1997).

4.3 GEOMORPHOLOGICAL AND ANTHROPOGENIC CONTRIBUTIONS TO EROSION MENANCE IN THE STUDY AREA

Lithology influences the rate at which erosion occurs. Friability, transportability, infiltration, permeability of different horizons, aggregate stability, surface scaling, top soil depth and water holding capacity are inherent depositional parameters of sediments. Areas overlain with sands are prone to erosion menace than areas overlain with clay; this is because clays are stiff and sticky.

Due to the fact that the electrical resistivity of sediments depends on lithology, water content, clay content and salinity (Choudhury and Saha, 2004, Amos-Uhegbu, 2014); it is therefore imperative to correlate the VES data with the lithological information obtained from adjacent erosion sites (John et. al, 2015).
From the lithologs derived from the erosion sites and geoelectric sections generated from the VES survey; including other lithologs and geoelectric sections sourced from previous studies, a better subsurface understanding of the lithological sequence of the area was obtained.

Amos-Uhegbu et.al (2012) lithologically deduced from drill-hole and geoelectric data that Cretaceous sediments within the study area having resistivity < 100Ωm are clays, 100Ωm - 500Ωm are silts, 500Ωm - 1500Ωm are fine-grained sands, 1500Ωm - 3000Ωm are medium-grained sands, 3000Ωm - 5500Ωm are coarse-grained sands, and > 5500Ωm as sandstone.

From the above indication and also from in-situ observations, the topsoils of VES 1, VES 2, VES 3 and VES 4 are sands, silts, silts and clays respectively. The primary cause of erosion A (between VES 2 and VES 3) is probably anthropogenic thus leading to the loss of soil cover (topsoil) of silty origin, and subsequently exposing the sandy weathered layer. This triggered the gully erosion A and the rate of the menace was checkmated by the silty topsoil of VES 3, after the loss of sediment thickness of about 10.7 m along a distance of about 140 m (Table 1, Fig. 6).

Structural stability of the vicinity of VES 3 for about 200 m is observed, but between VES 3 and VES 4, there was loss of sediment thickness (erosion B) of about 3.7 m along a distance of 100 m. The primary cause of erosion B (between VES 3 and VES 4) is likely geo-morphological due to facies change (silty to clayey topsoil).

For the fact that the slope of VES 1 is towards VES 2, the structural and slope stability of the vicinity of VES 1 is due to the presence of the silty topsoil of VES 2 which is about 1m thick. Any anthropogenic interference on this 1m thick silty topsoil could trigger devastating gully erosion that is likely to erode sediment (sandy) thickness of about 15.6 m of VES 1 and VES 2.

On the other hand, the vicinity of VES 4 is totally stable because of the clayey nature of the sediment layers from the topsoil to the depth of the 5th layer which is the limit of the probe.

CONCLUSION AND RECOMMENDATION

Gully erosion may also start as a shallow steep-sided and V-shaped cut which migrates and expands into massive gully with flatter gentle slope downwards. Since erosion menace is always experienced during the rainy season and unfortunately agricultural practices involving the use of land for cropping is during the rainy season; this involves the removal of vegetative cover and also tillage of lands in the study area.
Therefore, regular monitoring of erosion sites in the area should be made to ascertain whether the gully is still active or dormant. If the gully is still active, the main source (factor) should be determined. A situation whereby the source is surface runoff, a diversion should be made from

the gully by earthworks. Also, re-vegetation should be done to reduce the process such as the planting of deep-rooted perennial grasses and trees in and on the sides of gullies and ephemeral waterways that have the potential to become gullies.

Finally, it is therefore established from this study that integrated geophysical and geotechnical methods are effective tools in the evaluation of erosion menace.

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