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Geophysical and Geotechnical Evaluation of Erosion Sites in Ebem-Ohafia Area of Abia State, Southern Nigeria

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Authors' contributions

This work was carried out in collaboration of both authors. Author CAU designed the study and wrote the protocol together with the first draft of the manuscript. Author UJJ led in the field survey and managed other laboratory analyses. Author CAU managed the literature searches. Both authors read and approved the final manuscript.

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Short Research Article

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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 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 = 165 m, 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

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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%. By using the resistivity values together with plasticity index in the evaluation, it is established that the higher the value of layer resistivity, the lower the plasticity index of the layer. This indicates that the vicinity of VES 1 is the most erosion-prone locality in the study area, while the vicinity of VES 4 remains stable. The plastic index of the soils within the area is adjudged to be of low to medium plasticity (,20%); hence, the soils are expected not to exhibit high cohesion potential. It was however concluded that geomorphologic and anthropogenic factors are the major causes of the erosion menace in the area. Subsequently, good agricultural practices and regulars monitoring of the area is recommended.

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

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 [1].

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 [2], 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. While on the other hand, incessant cultivation of land on steep slopes, mechanized agriculture, deforestation, roads, anthropogenic climate change and urban sprawl are amongst the most significant human activities stimulating erosion [3]. Also, the tillage of agricultural lands which breaks up soil into finer particles increases wind erosion rates because the smaller particles are easily picked up by the wind. For the fact that most of the trees are mainly removed from agricultural fields, winds travel at higher speeds in such an open area [4].

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 [5]. 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 [6,7].

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 [8,9]. Thus areas susceptible to extreme gully erosion processes owe their vulnerability to a combination of distinct geological, geo-morphological, and pedological characteristics [10,11].

Methods to directly measure erosion rates are expensive and time consuming [12], 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.

For the fact that soil comes from a complex interaction between earth materials, climate, and organisms acting over time, soil characterization by sampling and in-situ testing will always face perturbation effects.

Alternatively, near surface site characterization using geophysical methods yields important information related to the soil characteristics, and can also provide insight into the processes that control the geomorphic evolution of landscapes [13,11].

In soil stratification, bulk density, texture (clay content), and water content have been identified as parameters of interest for developing indicators dealing with compaction, decrease in organic matter, erosion and shallow landslides [14].

Bulk density can be determined from S-wave velocity, electrical conductivity and, to a lesser extent by magnetic susceptibility and viscosity.

Clay content can be determined from electrical conductivity, reflectance and, to a lesser extent by S-wave velocity.

Water content can be determined from dielectric permittivity, and, to a lesser extent from electrical conductivity and reflectance.

From the above indications, soil electrical conductivity integrates several factors, this allows for a more detailed characterization of the soil properties with repeated measurements at the same site, as well as by combining data with other sources of information [11].

In addition to that, Vertical electrical conductivity profiles have lesser soil perturbation effects, and are able to retrieve corresponding variations of soil characteristics with depth by performing measurements with different sensor configurations. Hence, the choice of using vertical electrical sounding (VES) technique of Electrical resistivity method in this study.

Vertical electrical sounding (VES) have also been used in the evaluation of erosion sites [15], [11].

Despite the highlighted points and indications leading to the choice of VES technique, John et.al, (2015) realized that for a thorough evaluation of an erosion site; geophysical technique alone may give a limited evaluation. Integrated approach have been used in some geo-environmental studies [16,17]. Thus, this study is an integration of geotechnical technique and the already chosen geophysical technique (VES) in the evaluation of the erosion sites.

2. MATERIALS AND METHODS

2.1 Location and Physiography of the Study Area

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).

Abia state is characterized by a great variety of landscapes ranging from rolling hills to dissected escarpments, and has major geomorphologic regions (plains and lowlands) such as the Niger River Basin and the Delta; the Coastal plain and the Cross River basin; and the plateau and the escarpment [11].

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. This also necessitated the study during the rainy season when all major agricultural activities are taking place.

Ohafia local government area falls within the south-eastern part of the Anambra basin. The south-eastern part of the Anambra basin is a part of the scarplands of south Nigeria. The north-south trending of Enugu escarpment forms the major watershed between the lower Niger drainage system to the west, and the Cross-River and Imo drainage systems to the east [10].

2.2 Geological Settings of 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 which is the study locality (Fig. 2).

The Ajalli Formation of Cretaceous age consists of red earth sands which form the false sandstones. These in turn consist of great thickness of friable but poorly sorted sandstones. It is overlain by Nsukka Formation.

2.3 Geophysical Investigation of the Site

The 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.

Then the ABEM Terrameter SAS 4000 which was used in the data acquisition was deployed to the position where a direct current (DC) from a 12V battery linked to 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:

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

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).

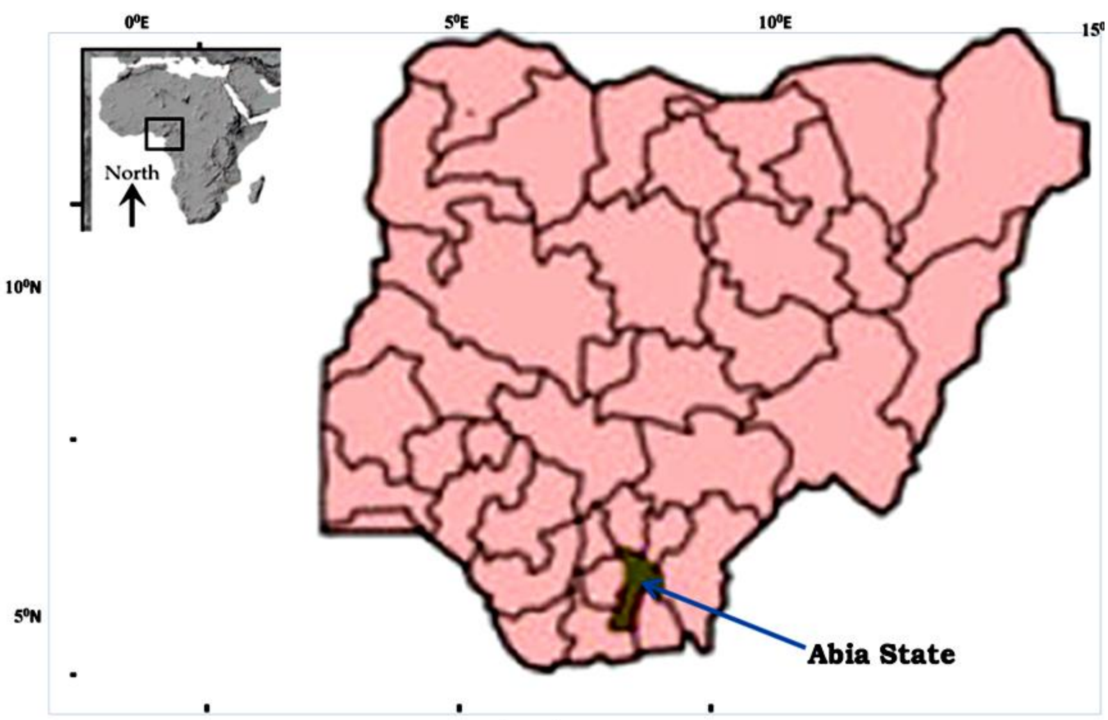

Fig. 1. Location map of Nigeria showing Abia State the study area

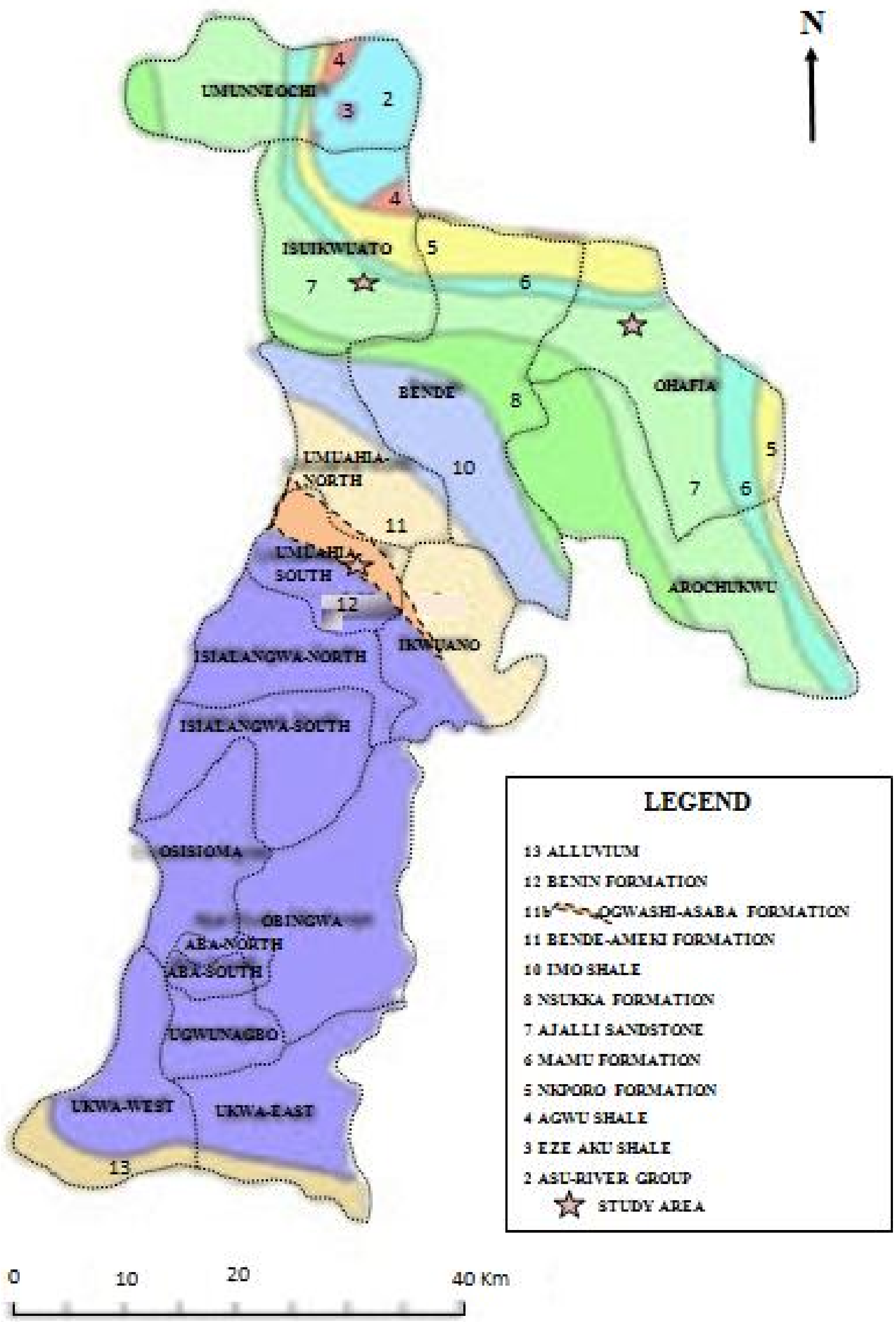

Fig. 2. Geologic map of Abia State showing the local government areas and the study area (Modified after geological survey of Nigeria (GSN), 1985)

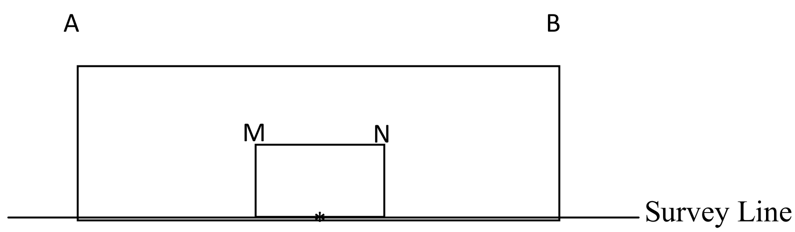

Fig. 3. Schematic diagram of the schlumberger electrode configuration used in the study

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.

2.4 Geotechnical Investigation of the Site

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 specification [18].

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.

The natural moisture content of the samples collected from the field was determined in the laboratory within a period of 24 hours after collection.

The field soil samples that were collected and preserved in airtight polythene bags were labelled 'm_{wet}'.

The wet samples 'm_{wet}' were put in an oven pan and weighed on a scale. The weighed wet samples 'm_{wet}' were heated in an electric oven at a uniform temperature of 110°C for about 100 minutes, and then allowed to cool.

Upon cooling, the samples are re-weighed on the scale and labelled 'm_{dry}'.

The moisture content especially in geotechnics is expressed as a percentage of the sample's dry weight: (% moisture content = u * 100)

where $$u = \frac{m_{wet} - m_{dry}}{m_{dry}} \quad (2)$$

While, porosity is expressed as a percentage of the sample's wet weight: (% moisture content = u * 100)

where $$u = \frac{m_{wet} - m_{dry}}{m_{wet}} \quad (3)$$

Porosity is the ratio of the volume of voids (containing air, water, or other fluids) in a soil to the total volume of the soil expressed as void fraction usually between 0 and 1, or as a percentage between 0 and 100.

In order to conduct the sieve analysis, the soil samples were first oven-dried and then all lumps broken into smaller particles. The soil is then shaken through a stack of sieves ranging from BS 2.00 mm to BS 0.075 mm with a pan below the stack.

After sieving, the mass of soil retained on each sieve is determined and expressed in percentage:

Mass of soil retained=

$$\left(\frac{total\ weight - mass\ of\ weight\ retained}{total\ weight}\right) * 100 \quad (4)$$

The soil particles that passed through the 0.075 mm sieve were subjected to Atterberg limits tests inorder to determine the consistency of the soils.

3. RESULTS AND DISCUSSION

3.1 Geophysical Results

3.1.1 Analysis of sounding curves

Sounding curves obtained over a horizontally stratified medium is a function of the resistivities and thicknesses of the layers as well as the electrode configuration [19]. The calculated apparent resistivity is plotted against the corresponding half current electrode separation (AB/2) to construct the VES curves, and the letters Q,A,K and H are used in combination to indicate the variation of resistivity with depth (Fig. 4).

Four type curves were identified within the study area. They are AAK of VES 1, KQH of VES 2, HQK of VES 3, and KQQ of VES 4 type (Figs. 5, 6, 7 and 8).

3.1.2 Geoelectric sections

Due to the fact that the electrical resistivity of subsurface materials are at times dependent on the physical conditions of interest such as lithology, porosity, water content, clay content and salinity [20,17] and [20]. Therefore; electrical resistivity measurements determine subsurface resistivity distributions by differentiating layers based on resistivity values, thus geoelectric sections are presented in connection with the resistivity and thickness of the individual layers (Fig. 9).

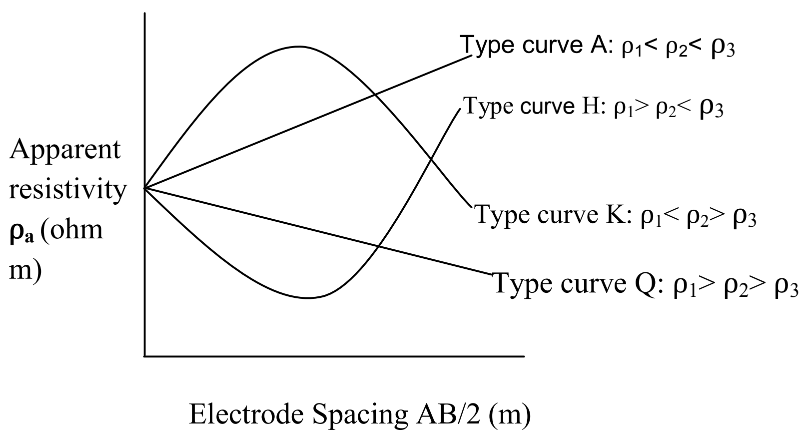

Fig. 4. Schematic diagram of resistivity type curves for layered structures

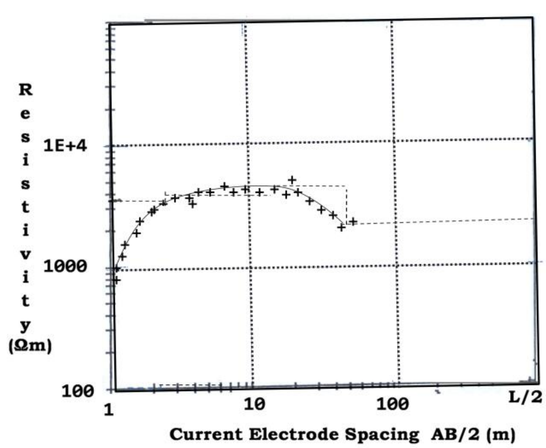

Fig. 5. Typical curve of VES 1

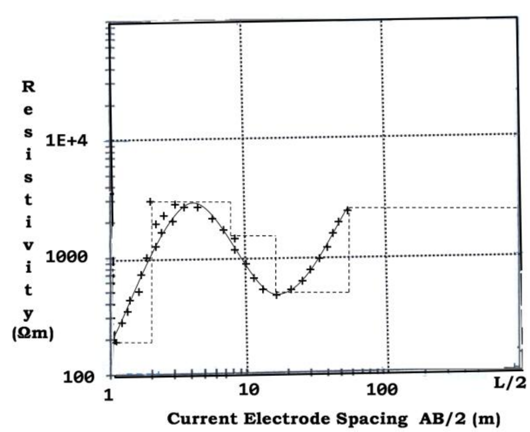

Fig. 6. Typical curve of VES 2

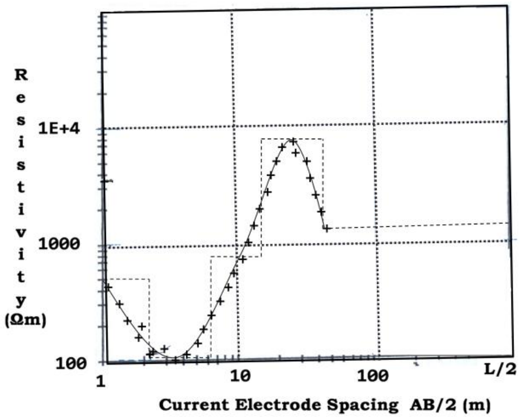

Fig. 7. Typical curve of VES 3

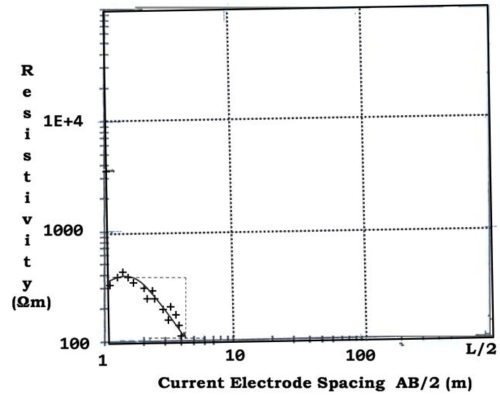

Fig. 8. Typical curve of VES 4

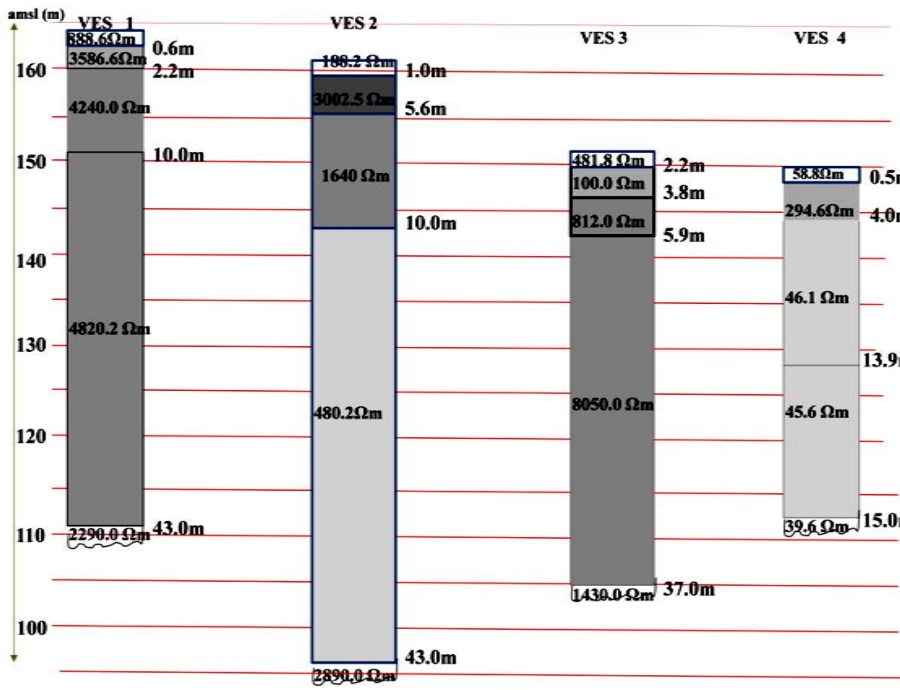

Fig. 9. Geoelectric sections of VES 1, 2, 3 and 4

3.1.3 Geoelectric parameters

The summary of the VES interpretation shows that there are five geoelectric layers (Table 1). The top soil is composed of resistivity values ranging from 58.8 Ωm – 886.6 Ώm and thicknesses between 0.5 m – 2.2 m. While the weathered layer resistivity values ranges from 100 Ωm - 3586.6 Ωm with their corresponding thicknesses of ranging from 2.2 m – 5.6 m.

Also total thickness of each VES station ranged from 33.4 m – 59.6 m.

3.2 Geotechnical Results

Geotechnical 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.

Table 1. A summary of the VES interpretation results

VES station	Location	GPS Reading of Co-ordinates / Elevation (m) m.s.l	Type curve	Number of layers	Resistivity of layers (Ωm)	Thickness of layers (m)	Total thickness (m)	Fitting error (%)	Source of data
1	Ebem Ohafia 1	5°38.214' N 7°49.409' E 164.7	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	Present study
2	Ebem Ohafia 2	5°37.888' N 7°49.709' E 164.3	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	[11]
3	Ebem Ohafia 3	5°37.862' N 7°49.696' E 153.6	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	[11]
4	Ebem Ohafia 4	5°37.428' N 7°49.527' E 149.9	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	Present study

3.2.1 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. 10).

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 0.075 mm sieve were subjected to Atterberg limit tests.

3.2.2 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% [21]. Therefore tested soil samples are adjudged to be sandy deposits.

3.2.3 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).

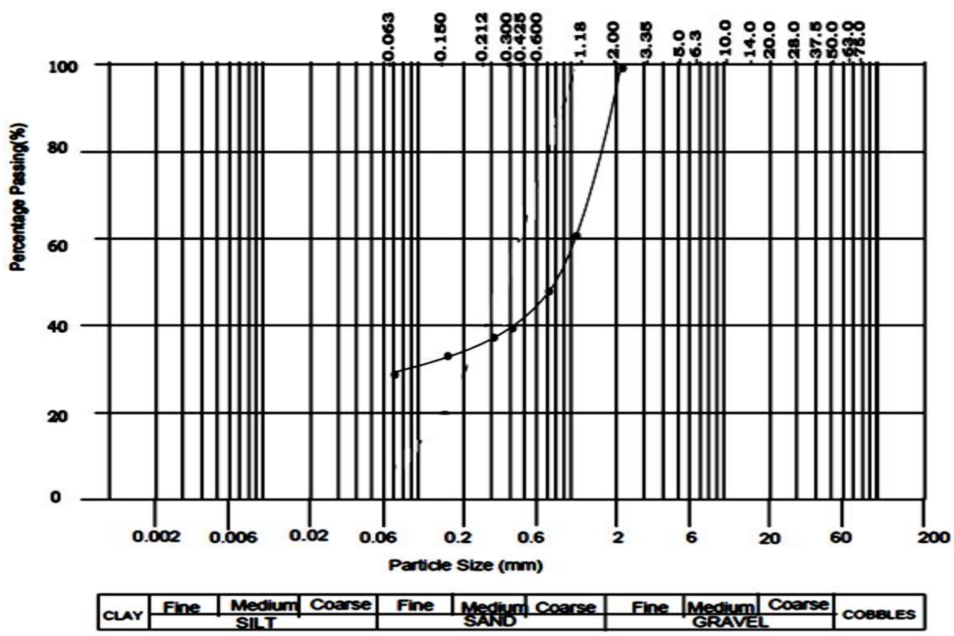

Fig. 10. The grain size distribution curve of OHAFIA 1 soil sample

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
		0.075 mm sieve	0.6 mm sieve	2.00 mm 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

Table 3. A summary of the results of the soil geotechnical 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 [22].

3.3 Integrated Evaluation of the Erosion Sites

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.

Since the electrical resistivity of sediments depends on lithology, water content, clay content and salinity; a correlation of VES data with the lithological information of same erosion site is imperative [11].

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. [20] lithologically deduced from drill-hole and geoelectric data that Cretaceous sediments within the study area having resistivity < 100 Ωm are clays, 100 Ωm - 500Ωm are silts, 500 Ωm – 1500 Ωm are fine-grained sands, 1500 Ωm – 3000 Ωm are medium-grained sands, 3000 Ωm – 5500 Ωm are coarse-grained sands, and > 5500 Ωm as sandstone. Thus, the higher the resistivity of under-compacted / unconsolidated sediment, the lesser clay (fines) it contains; and also less cohesive (sticky) it is in behaviour.

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.

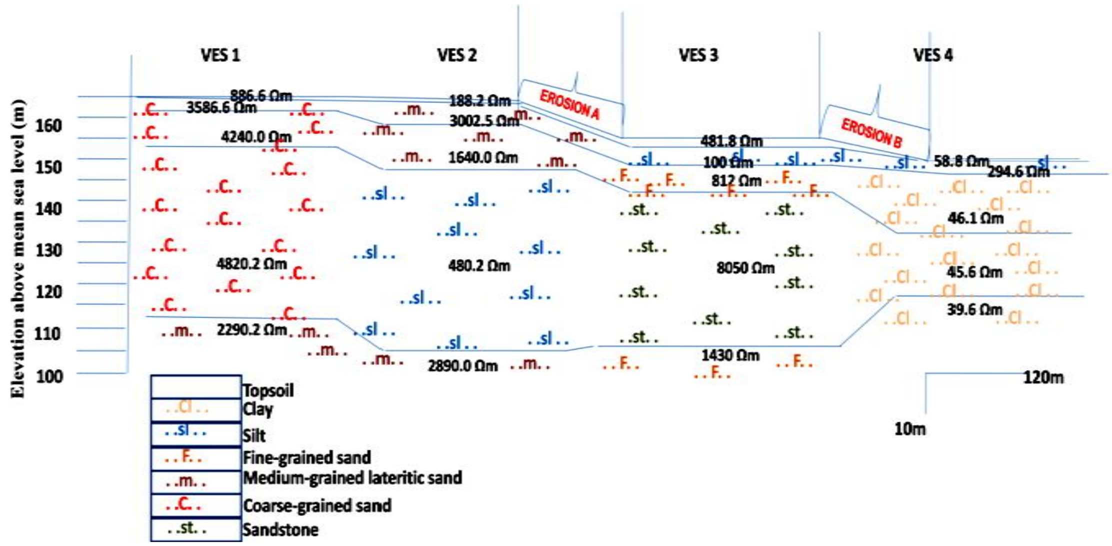

Fig. 11. The geo-electric cross-section of the study area

The interpreted results were used to prepare a geoelectric cross-section (Fig. 11). The geoelectric cross-sections delineated a maximum of five geoelectric layers comprising the top soil, coarse-grained sands, medium-grained sands, fine-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.

The primary cause of erosion A (between VES 2 and VES 3) is probably anthropogenic (land cultivation) 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 (Fig. 11).

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 / terrain change (a change from silty to clayey topsoil along a slope); but could also have been facilitated by anthropogenic activities (land cultivation).

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 1 m thick. Any anthropogenic interference on this 1 m 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.

Thus corroborating that the higher the plasticity index of soils, the more cohesive they are; hence the more resistant they are to erosion menace.

4. CONCLUSION AND RECOMMENDATION

This study 'Geophysical and geotechnical evaluation of an erosion site in Ebem-Ohafia area of Abia State, Southern Nigeria' which was carried out using geoelectrical surveying method of geophysics, and laboratory geotechnical methods has provided information on the likely causes of erosion menace in the area.

The geophysical results revealed five geoelectric layers within the study area with the resistivity of the topsoils ranging from 58.8 Ωm – 886.6 Ωm; and their thicknesses ranging from about 0.5 m to about 2.2 m.

By using the resistivity values together with plasticity index in the evaluation, it is established that the higher the layer resistivity value, the lower the plasticity index of the layer. Therefore, this indicates that the vicinity of VES 1 is the most erosion-prone locality in the study area; while the vicinity of VES 4 remains stable.

The geotechnical laboratory results show that the natural moisture content ranges from 5.3% to 9.4%.; while the plastic index ranges from 6.0% to 12%. This indicates that the plastic index of the soils within the area is less than 20%; therefore can be generally adjudged to be of low to medium plasticity; hence, the soils are expected not to exhibit high cohesion potential.

The vicinity of VES 2 owes its stability to the 1 m-thick silty topsoil layer; therefore any form of interference leading to the removal of the topsoil could trigger another set of devastating erosion menace in the area. Therefore, good agricultural practices should be adopted in the area.

Since erosion menace in the study area 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, re-vegetation should be done to reduce the erosion 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.

Continuous monitoring of the area and extended investigations to other areas is also recommended.

Finally, the study have shown that by putting into consideration other factors (land use, topography, and lithology); this integrated approach (geoelectrical method of geophysics and geotechnical methods) can aid in identifying areas that are susceptible to gully erosion menace.

It is therefore established that geophysical and geotechnical methods are effective tools in the evaluation of erosion menace.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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