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Geophysical Evaluation of Erosion Sites in some Parts of Abia State, Southeastern Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author MUI designed the study, author UJJ wrote the protocol and led in the field investigation. Author CAU wrote the first draft of the manuscript and determine the correction factor. Authors UJJ and CAU managed the literature searches. Authors MUI and CAU carried out the geophysical data analysis. All authors read and approved the final manuscript.

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ABSTRACT

This work evaluates the external and internal structures of erosion sites in parts of Abia state, Nigeria and determines the gully erosion sensitivity of the sediments. Attributes such as lithology, land use, geomorphology, and climate were factored-in as gully erosion predisposing factors. The geophysical method used was the electrical method which employed the Schlumberger electrode configuration with maximum half current electrode spacing of AB/2 = 150 m, and 8 vertical electrical sounding (VES) data were acquired. The computer-aided resist software method was used for further processing and interpretation of the VES data. Thereafter some geo-electrical sections were drawn and hence the geologic units of the area obtained. Results show that the resistivity of the erosive materials range between 812.0 Ωm-3,738 Ωm, while the depth ranges from 16.6 m (VES 3) to 90.7 m (VES 6). A correction factor was used in determining the true thickness of sediments where surface resistivity sounding data were acquired. The method depicts a valuable tool for assessing depth, thickness and nature of erosive material.

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1. INTRODUCTION

Egboka [1]; Igboekwe [2]; and Ogbonna [3] defined soil erosion as a gradual or quick geomorphological process of separating the surface layer of weathered rock or sediments by agents of denudation and the consequent transport and deposition of the materials to other locations; thus leaving an exposure of a lower soil horizon.

Erosion is a natural process, but human (anthropogenic) activities have significantly increased the rate at which erosion is occurring globally.

It can be caused by a number of factors some of which include climatic factors such as wind, storm, temperature and precipitation. It can also be caused by geological factors such as sediment rock type and its porosity and permeability.

Excessive erosion causes problems such as desertification, decline in agricultural productivity as a result of land degradation and waterways sedimentation. Factors affecting erosion rates include the amount and intensity of precipitation, the average temperature, as well as the typical temperature range, seasonality, wind speed, and storm frequency. Blanco [4] showed that water (rainfall) and wind are responsible for over 80% of the natural causes of erosion, while Industrial agriculture, deforestation, roads, anthropogenic climate change and urban sprawl are amongst the most significant human activities stimulating erosion as studied by Julien [5].

In similar vegetation and ecosystems, areas with frequent and high-intensity precipitation, more wind and storms are expected to have more erosion.

Nichols [6] also showed that soil composition, moisture and compaction are also major factors in determining the erosivity of rainfall. Clayey sediments tend to be more resistant to erosion than sandy or silty sediments, because clay particles bind soil particles together. Since organic materials coagulate soil colloids, therefore soils with high levels of organic materials are often more resistant to erosion because they create a more stable and stronger, soil structure as indicated by Glennie [7].

Vegetation acts as an interface between the atmosphere and the soil. It increases the permeability of the soil to rainwater, thus decreasing runoff. It shelters the soil from winds, which results in decreased wind erosion. The roots of plants interweave and bind the soil together thus forming a more solid mass that is less susceptible to both water and wind erosion. The removal of vegetation increases the rate of surface erosion as studied by Styczen [8].

The topography of the land determines the velocity at which surface runoff will flow, which in turn determines the erosivity of the runoff.

Longer, steeper slopes (especially those without adequate vegetative cover) are more susceptible to very high rates of erosion during heavy rains than shorter, less steep slopes. Steeper terrain is also more prone to landslides and other forms of gravitational erosion processes as indicated by Whisenant [9]; Blanco [4], and Wainwright [10].

Blanco [4] and Lobb [11] have shown that human activities that increase erosion rates include unsustainable agricultural practices such as mono-cropping, farming on steep slopes, the slash and burn treatment of tropical forests together with the use of pesticide and chemical fertilizer which in turn kill organisms that bind soil together.

The tillage of agricultural lands which breaks up soil into finer particles increases wind erosion rates by dehydrating the soil, thus making it possible to break into smaller particles that are easily picked up by the wind. Since most of the trees are mainly removed from agricultural fields, winds travel at higher speeds in such an open area as studied by Whitford [12]. Imeson [13] shows that heavy grazing reduces vegetative cover and causes severe soil compaction, both of which increase erosion rates Also, Deforestation removes the humus and litter layers from the soil surface, including the vegetative cover that binds soil together thus causing increased erosion rates.

Nîr [14] indicated that urbanization affects erosion processes by removing vegetative cover, and also makes land impervious with layer of asphalt or concrete, thus altering drainage patterns, and increasing the amount of surface runoff and surface wind speeds. This increased runoff disrupts surrounding watersheds by changing the volume and rate of water flowing through them as reported by James [15].

Four primary types of erosion resulting from rainfall occur. They are splash erosion, sheet erosion, rill erosion and gully erosion. Splash erosion is the first and least severe stage in the soil erosion process, this is followed by sheet erosion, then rill erosion and finally gully erosion which is the most severe as indicated by Zachar [16]; and Toy [17].

Obreschkow [18] shows that in splash erosion, a small crater is created in the soil by the impact of a falling raindrop by ejecting soil particles. It occurs when raindrops hit bare soil; and the explosive impact breaks up soil aggregates so that individual soil particles are 'splashed' onto the soil surface. The splashed particles can rise as high 60 cm (vertically) above the ground and move up to 1.5 metres (horizontally) from the point of impact on level ground. The particles block the spaces between soil aggregates, so that the soil forms a crust that reduces infiltration and increases runoff.

Sheet erosion is the removal of soil in thin layers by impacts of raindrop and shallow surface flow. This occurs when the rate of rainfall is faster than the rate of soil infiltration and surface runoff occurs; subsequently the loosened soil particles are carried by overland flow down the slope as highlighted by FAO [19]. In sheet erosion, soil loss is so gradual that the erosion usually goes unnoticed, but the cumulative impact accounts for large soil losses. Early signs of sheet erosion include bare areas, water puddles as soon as rain falls, visible grass roots, exposed tree roots, and exposed subsoil or stony soils.

Rill erosion refers to shallow drainage lines that mainly develop when surface water concentrates in depressions or through low points and erodes the soil. It occurs on hilly slopes of disturbed upland with the development of small non-lasting concentrated flow paths that function as both sediment source and delivery systems for erosion. The flow depths are typically of the order of a few centimeters usually less than 30 cm and the slopes may be quite steep. Rills are usually active where water erosion rates are highest.

Poeson [20,21], indicated that gully erosion occurs when surface water runoff accumulates and flows rapidly in narrow channels during or immediately after heavy rains, thus removing soil to form incised channels of considerable depth greater than 30 cm.

Erosion rates dictate the morphology of landscapes, and therefore quantifying them is a critical part of many geomorphic studies. Methods to directly measure erosion rates are expensive and time consuming as studied by Hurst [22], therefore causes of erosion are better studied and erosion-prone areas highlighted for precautionary and remediation actions.

All these aforementioned natural and human factors that influence the rate of erosion are observed everywhere in Abia state Fig. 1. The question now is why are there problems of gully erosion in some localities in Abia state while others are free? The answer lies in the geomorphological process inherent in the deposition of the sediments being eroded.

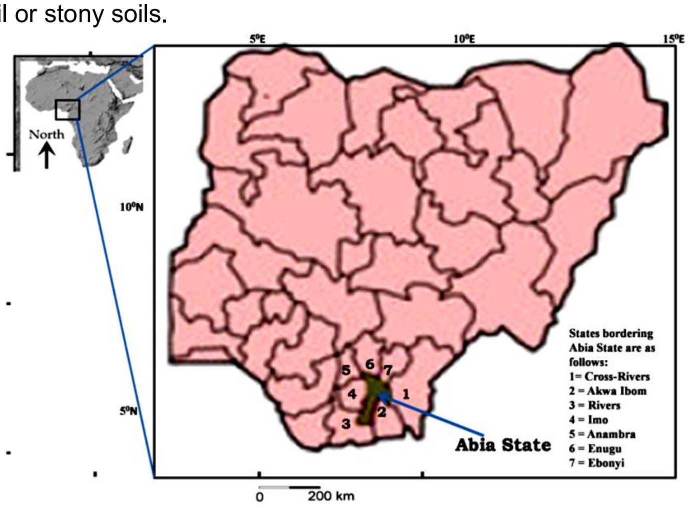

Fig. 1. Location map of Nigeria showing Abia State the study area

Geomorphology is the study of the physical features (landscape) of the surface of the earth and their relation to its geological structures.

Billi [23] and Di Biase [24] have shown that the topographic form of landscapes reflects interplay between geology and climate-driven surface processes. These interactions dictate erosion rates and control topography.

Since geologic factors generally determine slope, while climate modifies the efficiency of erosional processes. An understanding of relationships between erosion rates and landscape morphology is essential to geomorphic studies as shown by Yoo [25]; and Tucker [26]. Moreover, if critical relationships between topographic form and erosion rates can be identified, there is potential to interpret geologic or climatic conditions based on topography alone as studied by Ahnert [27]; Burbank [28] and Wobus [29].

Gilbert [30]; Ahnert [27]; Montgomery [31]; and Palumbo [32] have shown that the interdependency of topography and erosion rate has been established through the demonstration that hillslope gradient and topographic relief increase with erosion rates. However, several studies have identified that any such relationship breaks down at high erosion rates, as hillslope angles reach a limiting gradient as studied by Schmidt [33]; Burbank [28]; Montgomery [34]; Binnie [35]; Ouimet [36]; DiBiase [37]; Matsushi [38]. Thus, indicating that geologic factors play a crucial role in the geomorphology of an area, hence the use of geophysical methods in unraveling the geologic processes comes to play.

1.1 Regional Geology and Physiography of the Study Area

Abia state the study area is located within the tropical rainforest belt. Climate of the area is characterized by two main seasons: the rainy season and the dry season. The dry season originates from the dry northeasterly air mass of Sahara desert (Harmattan), while the rainy season originates from humid maritime air mass of Atlantic Ocean.

The rainy season spans from Mid-April to Mid-November while the dry season spans from Mid-November to Mid-April. The rainy season is characterised by double maxima rainfall peaks in July and September, with a short dry season of about three weeks between the peaks known as the August break.

The mean monthly rainfall in the rainy season in the area ranges from about 320 mm to 335 mm while that of the dry season is about 65mm, thus the annual average rainfall ranges from about 2000 mm to 2400 mm with high relative humidity values over 70% as indicated by Leong [39].

Abia state is characterized by a great variety of landscapes ranging from dissected escarpments to rolling hills and has principal 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.

Petters [40] reported that geologically present Nigeria was probably broad regional basement uplift (upwarp), with no major basin subsidence and sediment accumulation during the Paleozoic to Early Mesozoic, simply because older Phanerozoic deposits were not preserved, but around this region Paleozoic deposits accumulated northwards in the Northern Iullemeden Basin in Niger, westwards in Coastal Ghana, and Southward in Brazil, South America

A triple-R junction (rift system) developed during the break-up of Gondwana leading to the separation of the continents of South America and Africa in the Late Jurassic. The third arm of the rift after extending to about 1000 km northeast from the Gulf of Guinea to Lake Chad failed (aulacogen), thus forming the Benue Trough. A rapid subsidence of the trough ensued (aulacogen - failed continental margins) as a result of the cooling of the newly created oceanic lithosphere. Subsequently sediments from weathering of the basement uplift were deposited into the trough through rivers and lakes by Early Cretaceous.

By Mid-Cretaceous onwards marine sedimentation took place in the Benue Trough; thus making it possible in conjunction with other geologic events for Nigeria to be presently underlain by sedimentary basins as shown in Fig. 2.

The Benue Trough is arbitrarily divided into Lower, Middle and Upper Benue Trough; and by Santonian times the area underwent intense folding and compression whereby over 100 anticlines and synclines were formed.

After the Santonian-Campanian tectonism which formed the Abakiliki anticlinorium, the western margin of the Lower Benue Trough subsided, and the corresponding synclinorium became the Anambra basin where over 2500 m of deltaic complexes accumulated. However by Eocene, the inception of Tertiary Niger Delta basin commenced. Thus, the Late Cretaceous deltaic sedimentation in the Anambra basin was followed by the shift in deltaic deposition southward and consequently the construction or outbuilding of the Niger Delta took place.

Fig. 3 shows that there are about 11 different geologic Formations in Abia State of Nigeria; and cases of erosion menace have been frequently reported especially in the northern and central parts of the state than in the southern parts. The localities being studied are in Umuahia-south Local Government Area (central), Isuikwuato Local Government Area (northern) and Ohafia Local Government Area (northern).

Isuikwuato and Ohafia local government areas fall 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-eastern 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. It is an asymmetrical ridge stretching in a sigmoid curve for over 500 km from Idah on the River Niger to Arochukwu on the Cross-River.

Crystalline basement rocks and other younger intrusives occur along, Ishiagu area of Ebonyi State and Uturu, Lokpa and Lekwesi areas of Isuikwuato in Abia State. These rocks are the anticlines and synclines on which the sediments of the area are sitting. They are intensely fractured and highly weathered and are often affected by landslides.

The sediments of the area are Deltaic marine sediments of Cretaceous to Recent in age. The geological formations in the area are the Nkporo shale formation, Mamu formation (Lower Coal Measures) and the Ajalli (false-bedded sandstones) formation which is the study locality as shown in Fig. 3.

The Ajalli formation of Cretaceous age consists of red earth sands which form the false-bedded sandstones. These in turn consist of great thickness of friable but poorly sorted sandstones. In Abia state, Ajalli formation spans from Isuochi (Umunneochi Local Government Area) through Uturu, Eluama and Ovim (Isuikwuato Local Government Area) and Alayi (Bende Local Government Area) into Ohafia Local government Area where it narrows down to south of Nguzu (Afikpo area of Ebonyi state) before running south into Arochukwu Local Government Area. It is overlain by Nsukka formation.

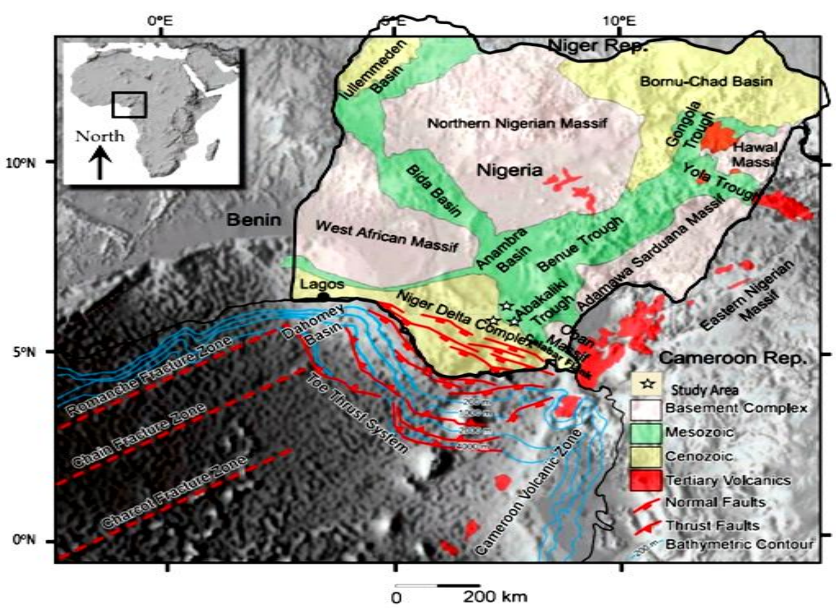

Fig. 2. Geological outline map of Nigeria showing basement outcrops, major sedimentary basins, tectonic features and locations of the erosion sites

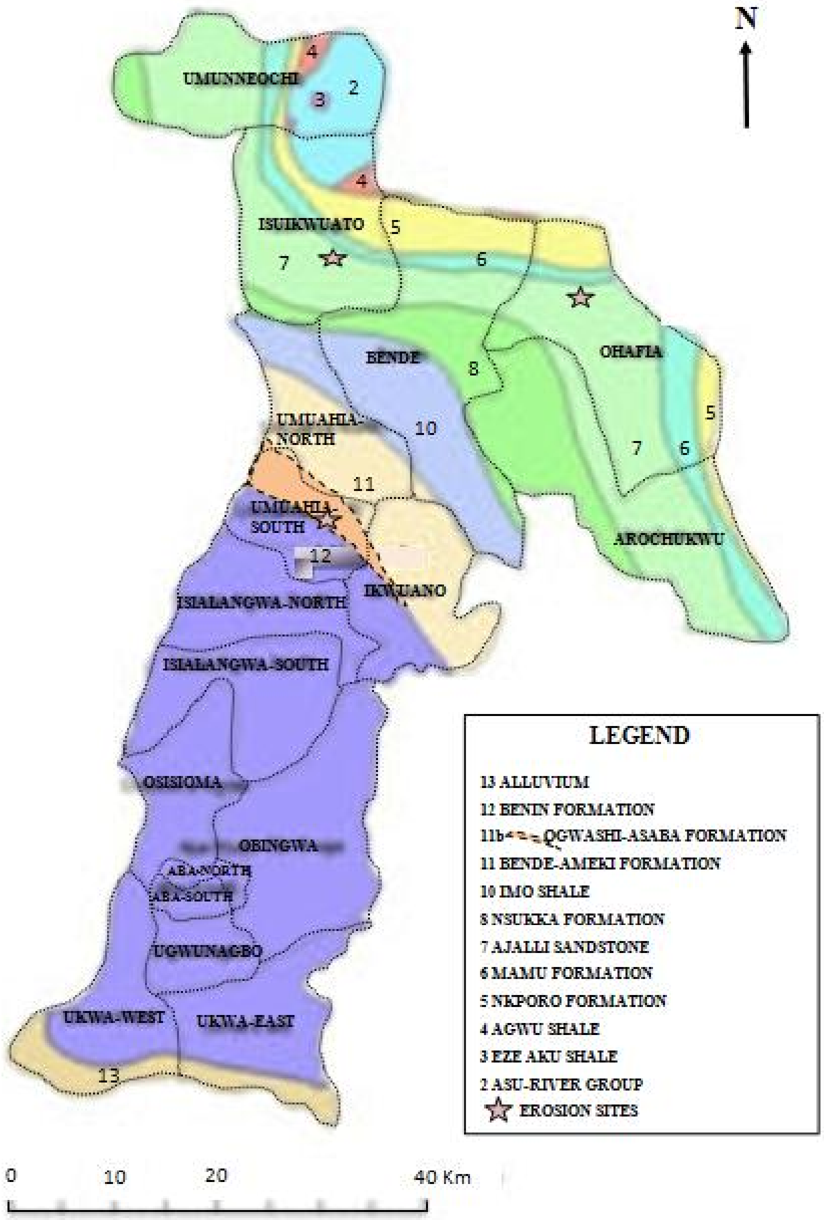

Fig. 3. Geologic map of Abia State showing the Local Government Areas and the study areas (Modified after GSN, 1985)

2. MATERIALS AND METHODS

Soil comes from a complex interaction between earth materials, climate and organisms acting over time. Soil characterization by sampling and in-situ testing faces unavoidable perturbation effects. On the other hand, geophysical techniques provide an effective alternative for site assessment. Shallow-subsurface exploration can provide insight into the processes that control the geomorphic evolution of landscapes. Sensitive systems requiring broad spatial information demand innovative methods for delineating subsurface structure and weathered profile development. Shallow applied geophysical techniques fulfill these requirements while also determining specific properties of the subsurface. Santamaria [41] have shown that near surface site characterization using geophysical methods yields important information related to the soil characteristics. In turn, geophysical measurements can be associated with soil parameters relevant to geotechnical or pedological engineering analysis.

In soil stratification, these characteristics 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 as presented by Grandjean [42].

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, 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.

Vertical electrical conductivity profiles and corresponding variations of soil characteristics with depth could potentially be retrieved by performing measurements with different sensor configurations.

Thus the use of vertical electrical sounding (VES) as a geophysical tool for subsurface delineation cannot be over-emphasized. It is a very sensitive and non-destructive method.

It is been used in groundwater exploration, landfill and solute transfer delineation, it is also been used in-depth geotechnical studies to determine the suitability of building sites for heavy structures and thus could be used in the evaluation of erosion menace when the major cause is geological as reported by Wobus [43]; Grandjean [42]; Skácelová [44]; Igboekwe [2].

A total of eight Vertical Electrical Soundings (VES) were obtained using ABEM SAS 4000 Terrametter with the Schlumberger configuration. In the Schlumberger configuration, all the four electrodes were arranged collinearly and symmetrically placed with respect to the centre with a maximum current electrode spacing of AB/2 = 165 m; and maximum potential electrode spacing of MN/2 = 14 m.

The Garmin 12 Geographic Positioning System (GPS) was used in determining the site elevation and co-ordinates in longitude and latitudes. Upon choosing a sounding point, the ABEM Terrameter was deployed to the position where a 12V direct current (DC) fed to the terrameter was passed into the subsurface using two current electrodes ‘AB/2’. Kept in line with the pair of current electrodes are two potential electrodes ‘MN/2’ which were used in determining the ground potential difference in voltage.

For each sounding station, in order to a measurable potential difference, the distance of the potential electrodes from the centre (MN/2) was gradually increased in steps starting from 0.5 m to 14 m; while the half current electrode separation (AB/2) was also increased starting from 1.5 m to 165 m.

The measured field data (subsurface resistance) is the ratio of the voltage (ground potential difference) to the imposed current. This measured subsurface resistance is multiplied with the geometric factor (values as functions of electrode spacing), which then gives the corresponding apparent resistivity (Ωm) as functions of depths of individual layers:

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

where, ρ_a = Apparent resistivity, R = Subsurface resistance in ohms, $\pi\left(\frac{L^2 - l^2}{2l}\right)$ = Geometric factor (K), L = ‘AB/2’ = Half current electrode spacing(m), *l* = MN/2 = Half potential electrode spacing(m).

The apparent resistivity was plotted against the half current electrode spacing (AB/2) on a log-log graph scale paper; and preliminary values of the resistivity and thickness of the different geoelectric layers were acquired and used for computer iteration using RESIT software package. Table 1 shows a profile of VES data and location points in the study area.

Table 1. A profile of VES data and location points in the study area

VES stations, locations, cordinates and elevations above mean sea level	Number of layers	Resistivity of layers (Ωm)	Thickness of layers (m)	Total thickness (m)
1 Ubakala Umuahia N (130.6 m) 5°29.490'N 7°26.657'	3	ρ_1 =1320.0 ρ_2 =821.0 ρ_3 =480.0	**t_1 =2.8** **t_2 = 16.0** **t_3 = ?**	18.8
2 Ubakala Umuahia M (151.9 m) 5°28.324'N 7°25.160'E	3	ρ_1 =3738 ρ_2 =1695 ρ_3 =478	**t_1 =2.2** **t_2 = 18.4** **t_3 = ?**	20.6
3 Ebem Ohafia (164.3 m) 5°37.888'N 7°49.709'E	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
4 Ebem Ohafia (153.6 m) 5º37.862'N 7º49.696'E	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
5 ABSU P1 (198.4 m) 5°49.543' N 7°23.771'E	3	ρ_1 =7900.0 ρ_2 =2327.3 ρ_3 =230.0	**t_1 =1.4** **t_2 =85.8** **t_3 = ?**	87.2
6 ABSU P1 (179.5 m) 5°49.242' N 7°23.418'E	6	ρ_1 =1445.0 ρ_2 =3170.0 ρ_3 =1875.0 ρ_4 = 2250.0 ρ_5= 260.0 ρ_6= 5070.4	**t_1 =2.3** **t_2 = 5.0** **t_3 = 9.0** **t_4 = 16.4** **t_5 = 58.0** **t_6 = ?**	90.7
7 Ugwelle junction (174.6 m) 5°49.714' N 7°23.896'E	5	ρ_1= 107.7 ρ_2 =222.0 ρ_3 =498.0 ρ_4 = 2466.0 ρ_5=23290.0	**t_1 =2.8** **t_2 = 3.0** **t_3 = 3.0** **t_4 = 8.0** **t_5 = ?**	16.8
8 Mbalano Isuikwuato (124.1 m) 5°46.772' N **7**°23.151'E	5	ρ_1 = 7901.0 ρ_2 = 405.0 ρ_3 = 192.5 ρ_4 = 28.1 ρ_5 = 16.3	**t_1 = 1.8** **t_2 = 2.0** **t_3 = 17.7** **t_4 = 58.6** **t_5 =?**	80.1

3. RESULTS AND DISCUSSION

3.1 Geophysical Characteristics

3.1.1 Analysis of sounding curves

Zohdy [45] highlighted that sounding curves acquired on a horizontally stratified medium is a function of the electrode configuration, together with resistivities and thicknesses of the layers.

Fig. 4 shows that VES curves are constructed when the calculated apparent resistivity is plotted against the corresponding half current electrode separation (AB/2), and a combination of the letters Q,A,K and H are used in indicating the variation of resistivity with depth. Resistivity curves of some sounding locations in the area are as shown in Figs. 4a, b and c.

Table 2 shows five curve types were identified within the areas studied. These include Q, KQH, HQK, AAA, QQQ and KHKH type with the Q as the predominant curve type. The number of layers varies between 3 and 6 layers.

3.2 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 as outlined by Zohdy [46];

Choudhury [47]; and Amos-Uhegbu [48]. 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, see Figs. 5a and b.

3.3 Geophysical Evaluation of the Erosion Sites

The determined range of resistivity is between 16.3 Ωm-23,290 Ωm while the maximum depth varies from 16.8 m and 90.7 m.

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 menance than areas overlain with clay, this is because clays are stiff and sticky.

Amos-Uhegbu [48] lithologically deduced from drill-hole and geoelectric data that sediments with resistivity < 100 Ωm are clays, 100 Ωm – 500 Ωm 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.

Also, Ward [49]; Telford [50]; and Lowrie [51] deduced range of resistivity for the following: 1,000 Ωm – 10,000 Ωm as quartzite, 50 Ωm – 100,000 Ωm as basalt, 150 Ωm – 45,000 Ωm as fresh granite, 10 Ωm – 10,000 Ωm as limestone, 10 Ωm – 1,000 Ωm as argillite, 1000 Ωm – 10,000 Ωm as gravel.

From the above indication, the surface and second layer resistivity of VES 1 and VES 2 coincides with the lithological samples obtained at the site as sands. Since the area was subjected to other factors inducing the rate of erosion, the area remains prone to erosion menace. There is a likelihood of VES Station 1 eroding to 18.8 m, while VES Station 2 eroding to 20.6 m, see Fig. 5a.

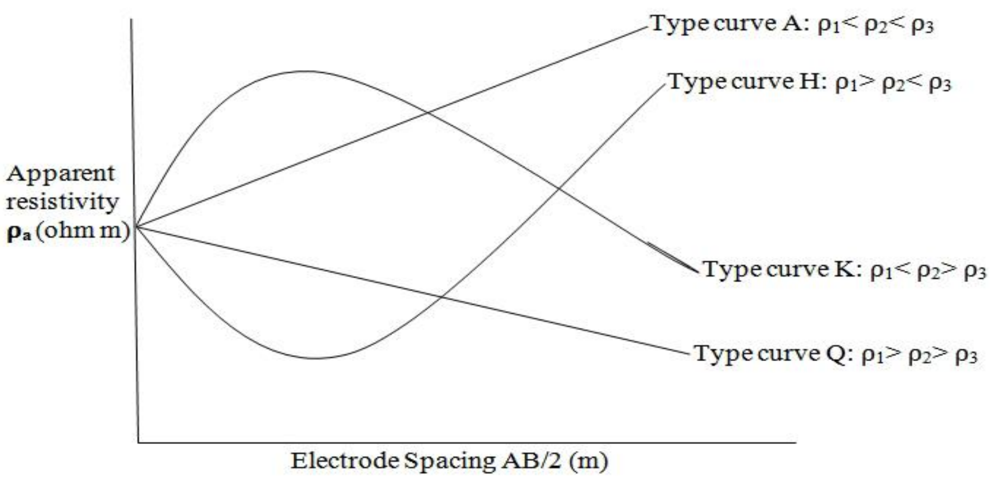

Fig. 4. An illustration of resistivity type curves for 3-layered structures

Table 2. Resistivity type curves of VES locations

Type curve	Q	KQH	HQK	AAA	QQQ	KHKH
Number of layers	3	5	5	5	5	6
Sounding location	VES 1,2,5	VES 3	VES 4	VES 7	VES 8	VES 6

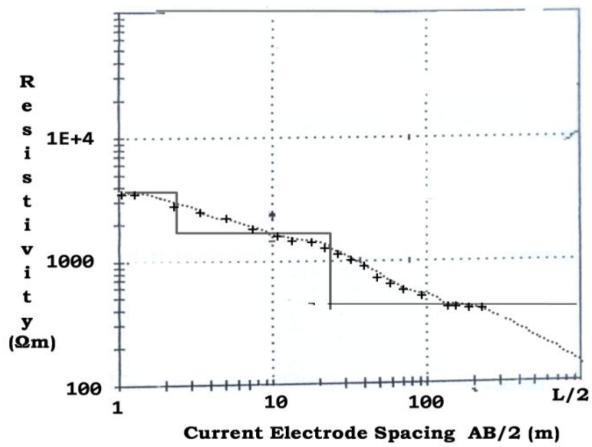

Fig. 4a. A computer modelled curve of VES 2 at Ubakala Umuahia

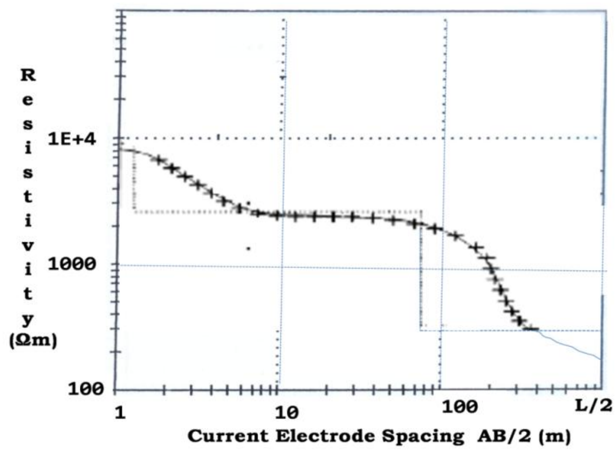

Fig. 4b. A computer modelled curve of VES 5 at Abia State University Uturu

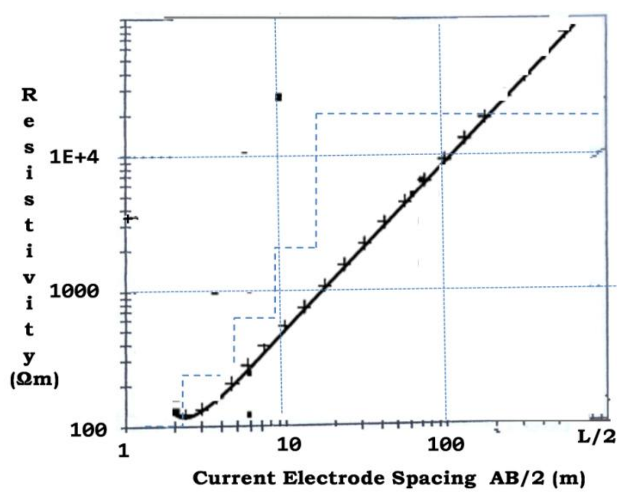

Fig. 4c. A computer modelled curve of VES 7 at Mbalano Isuikwuato

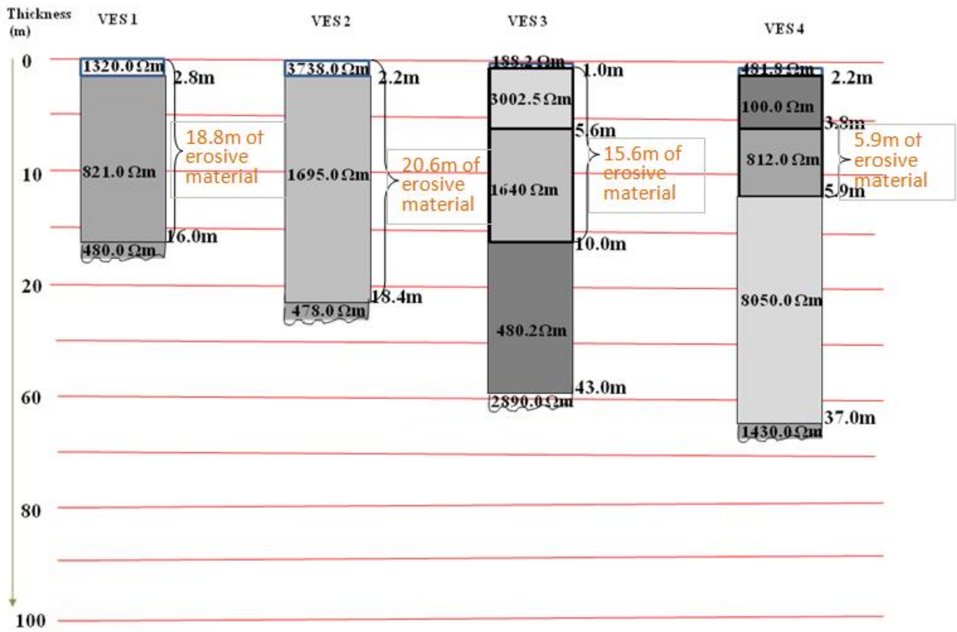

Fig. 5a. Geoelectric sections of VES 1, 2, 3 and 4

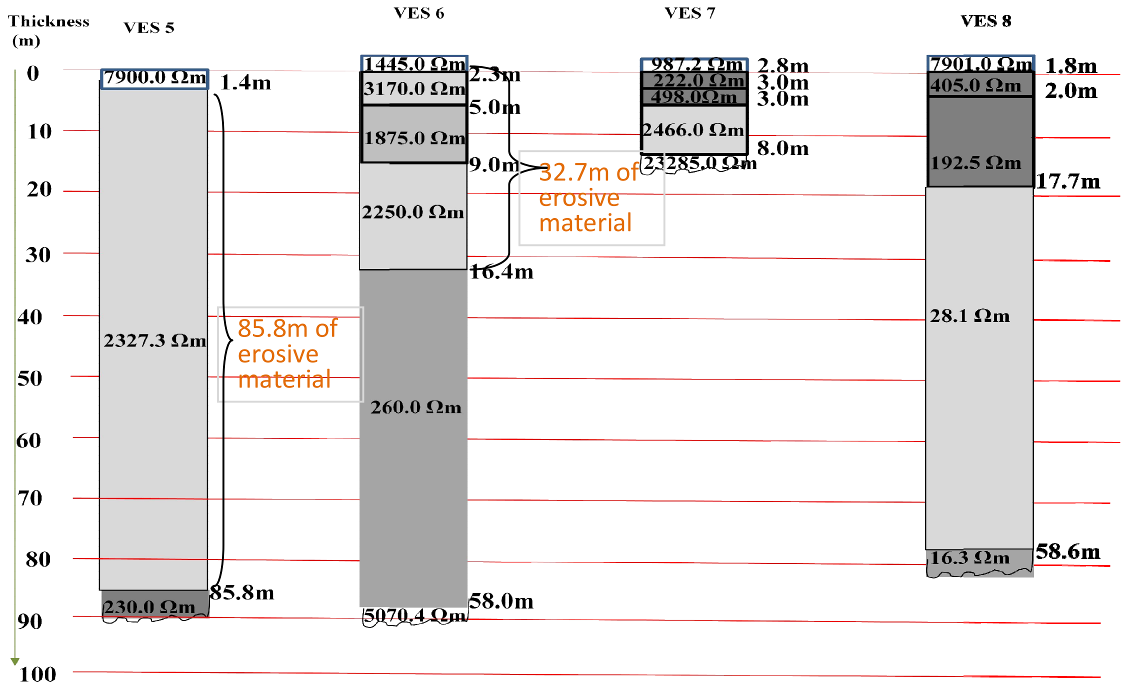

Fig. 5b. Geoelectric sections of VES 5, 6, 7 and 8

The data of VES Station 3 was acquired at the uphill plane of the erosion site at Ebem, while the data of VES Station 4 was acquired at the down-hill plane. As shown in Fig. 6 below, to get to the clay layer (480.2 Ωm) of VES 3, about 16.6m of sediments have been eroded which gives the top layer of VES 4 (481.8 Ωm).

Surface layer of VES 5 is gravel while the second layer which is sand has about 85.8 m of it that is prone to erosion menace while 32.7 m of sediments of VES Station 6 is prone to erosion menace.

The base of VES Station 7 with resistivity of 23,285Ωm is the basement complex, the vicinity of VES 7 and 8 (low resistivity layers) are not experiencing gully erosion but landslide (caving in) of roads, mud cracks, springing up of streams in the rainy season and subsequent caving and sliding.

3.4 Geophysical Prediction of the Thickness of Erosion-prone Sediments

The data of VES Station 3 was acquired at the uphill plane of the erosion site at Ebem, while that of VES Station 4 was acquired at the down-hill plane.

Also from geoelectric section, about 16.6m of sediments have been eroded to give the first layer of VES Station 4, see Fig. 6.

From Table 1, surface elevation of VES Station 3 is 164.3 m above sea level while that of VES Station 4 (down slope plane) is 153.6 m. Therefore, the thickness of sediments eroded is 164.3 -153.6 m = 10.7 m.

This shows that geophysical methods provide us with information related to the geophysical anomaly (layers, horizon, faults etc) but the exact depth of such anomalies are at times spurious, thus giving rise to the use of more than one geophysical method or by confirming through drilling or by rock exposure as it is the case here, see Fig. 7.

Therefore, a correction factor is introduced to give the actual thickness (depth) of sediments that are prone to erosion menace.

Thus from the geoelectric section, 16.6m was calculated as the actual thickness of the sediments while measurements using lithological/surface elevation gave a value of 10.7 m. The correction factor is therefore calculated as $\frac{16.6m}{10.7m}$ = 1.55.

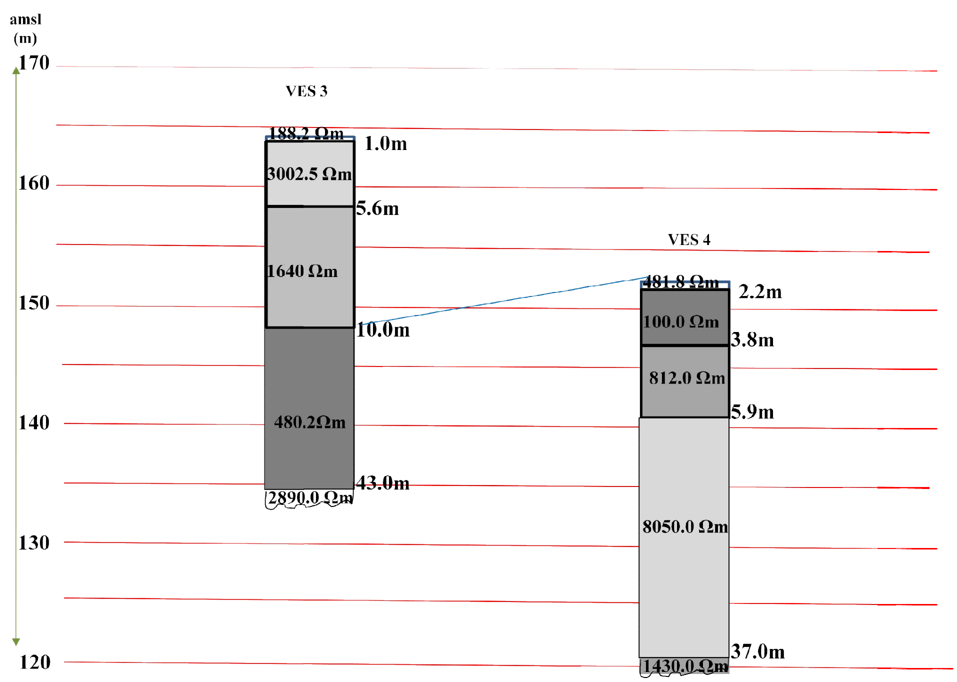

Fig. 6. Geoelectric sections of up-hill and down-slope planes of Ebem erosion site

Fig. 7. Gully erosion site at Ebem Ohafia area of Abia State, Nigeria showing the depth of eroded soil

This correction factor (1.55) is now used in dividing the thickness of erosion-prone sediments acquired through surface resistivity measurement which gives the actual thickness of erosion-prone sediments.

For example, from VES Station 1, 18.8 m of sediments are considered prone to erosion based on surface resistivity sounding; but to get the actual thickness, we divide by the correction factor.

$$\text{So, } \frac{18.8m}{1.55} = 12.1 \text{ m.}$$

This correction factor can now be used in determining the actual thickness of sediments where surface resistivity sounding have been acquired.

4. CONCLUSION

It is therefore established from this study that geophysical methods are effective tools in the evaluation of erosion menace. The study have shown that the application of predisposing factors (land use, topography and lithology) together with geoelectrical method of geophysics as an evaluation tool can aid in identifying areas that are susceptible to gully erosion menace.

Determined is that areas with unstable geomorphological factors and are overlain with resistivity ranging from 500 Ωm to 5500 Ωm are prone to erosion menace. This study has also shown that thickness of sediments determined from surface resistivity soundings together with measurements of the thickness of exposed rock layers can lead to estimation of actual thickness of sediments using a correction factor.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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