GEOPHYSICAL DETERMINATION OF THE CAUSES OF EROSION IN SOME PARTS OF ABIA STATE, SOUTHEASTERN NIGERIA.

ABSTRACT

This work evaluates the external and internal structures of erosion sites in parts of Abia state, Nigeria and further goes ahead in determining the gully erosion sensitivity of the sediments. Site attributes such as lithology, land use, slope, and slope-length 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 = 150m, 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 are drawn and hence the geologic units of the area obtained. Results show that the resistivity range is between 16.3Ωm-23,290Ωm with maximum depth of 16.8m and 90.7m, while surface resistivity varies from 107.7Ωm -7901.0Ωm. A correction factor was determined and used in determining the true thickness of sediments where surface resistivity sounding data were acquired. The method represents a useful tool for sustainable planning, conservation and prediction of future impacts on land. The application of this methodology is recommended to assess gully erosion sensitivity and impacts in other areas with similar conditions.

Keywords: Geo-electrical data; correction factor; erosion menace.

INTRODUCTION

Soil erosion is a geomorphological process whereby the surface layer of weathered rock is separated and carried away by agents of denudation thus leaving an exposure of a lower soil horizon. Egboka (2000) further defines it as the gradual or quick removal of sediments (soil, clays and sand pieces of blocks of minerals) by agents of denudation such as running water (streams, rivers, floods,) wind, man, animals, and the consequent transport or removal of weathered sedimentary materials along varied distances to various and distant location and eventual deposition elsewhere.

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.

Water (rainfall) and wind are responsible for over 80% of the natural causes of erosion (Blanco and Lal, 2010), while Industrial agriculture, deforestation, roads, anthropogenic climate change and urban sprawl are amongst the most significant human activities stimulating erosion (Julien, 2010).

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

Also, 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). Soil containing high levels of organic materials are often more resistant to erosion, because the organic materials coagulate soil colloids and create a stronger, more stable soil structure (Glennie, 1970).

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 (Styczen and Morgan 1995).

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 (Whisenant, 2008); (Blanco and Lal, 2010); (Wainwright and Brazier, 2011).

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 (Blanco and Lal, 2010); (Lobb, 2009).

The tillage of agricultural lands which breaks up soil into finer particles is one of the primary factors. It increases wind erosion rates by dehydrating the soil and breaking it up into smaller particles that can be picked up by the wind, moreover most of the trees are generally removed from agricultural fields thus , allowing winds to have long open runs to travel over at higher speeds (Whitford, 2002). Heavy grazing reduces vegetative cover and causes severe soil compaction, both of which increase erosion rates (Imeson, 2012). 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.

Urbanization has major effects on erosion processes, it denudes the land of vegetative cover, alters drainage patterns, and also covers the land with impermeable layer of asphalt or concrete that increases the amount of surface runoff and increases surface wind speeds (Nîr, 1983). This increased runoff, in addition to eroding and degrading the land that it flows over, also causes major disruption to surrounding watersheds by altering the volume and rate of water that flows through them, this also causes a large increase in the rate of bank erosion (James, 1995).

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

In splash erosion, the impact of a falling raindrop creates a small crater in the soil, ejecting soil particles (Obreschkow, 2011). The distance these soil particles travel can be as much as 0.6 m vertically; and five 1.5 m horizontally on level ground.

Once the rate of rainfall is faster than the rate of infiltration into the soil, surface runoff occurs and carries the loosened soil particles down the slope, this is referred to as Sheet erosion. Sheet erosion is the transport of loosened soil particles by overland flow (FAO, 1965).

Rill erosion refers to the development of small, ephemeral concentrated flow paths which function as both sediment source and sediment delivery systems for erosion on hillslopes. Generally, where water erosion rates on disturbed upland areas are greatest, rills are active. Flow depths in rills are typically of the order of a few centimeters and slopes may be quite steep.

Gully erosion occurs when runoff water accumulates and rapidly flows in narrow channels during or immediately after heavy rains or melting snow, removing soil to a considerable depth.

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 (Hurst et.al, 2012), 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.

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 (Yoo and Mudd, 2008a; Tucker and Hancock, 2010). 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 (Ahnert, 1970; Burbank et al., 1996; Wobus et al., 2006a).

The interdependency of topography and erosion rate has been established through the demonstration that hillslope gradient and topographic relief increase with erosion rates (Gilbert, 1877; Ahnert, 1970; Montgomery and Brandon, 2002; Palumbo et al., 2010). However, several studies have identified that any such relationship breaks down at high erosion rates, as hillslope angles reach a limiting gradient (Schmidt and Montgomery, 1995; Burbank et al., 1996; Montgomery, 2001; Binnie et al., 2007; Ouimet et al., 2009; DiBiase et al., 2010; Matsushi and Matsuzaki, 2010). 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.

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.

Near surface site characterization using geophysical methods yields important information related to the soil characteristics (Santamaria et al., 2005). 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 (Grandjean et. al, 2007).

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 (Grandjean, 2007; Skácelová et. al, 2010., Igboekwe et.al, 2012).

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 = 165m; and maximum potential electrode spacing of MN/2 = 14m.

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 gradually increased in steps starting from 0.5m to 14m to obtain a measurable potential difference. The half current electrode separation (AB/2) was usually increased in steps starting from 1.5m to 165m.

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).

The measured resistance of the subsurface is used to compute the corresponding apparent resistivity in Ωm 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:

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

where, ρ_a = Apparent resistivity, R = 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 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 scale paper; and initial estimates of the resistivities and thicknesses of the various geoelectric layers were obtained and used for computer iteration using RESIT software package (Table 1).

Due to the fact that the electrical resistivity of sediments depends on lithology, water content, clay content and salinity (Mc-Neill, 2003; Choudhury and Saha, 2004) it became imperative to correlate the VES data with the lithological information obtained from adjacent erosion sites.

Table 1: A profile of VES data and location points.

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 UmuahiaN (130.6m) $5^{0}29.490^{!}$N $7^{0}26.657^{!}$	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 UmuahiaM (151.9m) $5^{0}28.324^{!}$N $7^{0}25.160^{!}$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 (164.3m) $5^{0}37.888^{!}$N $7^{0}49.709^{!}$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
3 Ebem Ohafia (153.6m) $5^{0}37.862^{!}$N $7^{0}49.696^{!}$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 (198.4m) $5^{0}49.543^{!}$ N $7^{0}23.771^{!}$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 (179.5m) $5^{0}49.242^{!}$ N $7^{0}23.418^{!}$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 (174.6m) $5^{0}49.714^{!}$ N $7^{0}23.896^{!}$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 (124.1m) $5^{0}46.772^{!}$ N $\mathbf{7^{0}}23.151^{!}$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

RESULTS AND DISCUSSION

GEOPHYSICAL CHARACTERISTICS

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 (Zohdy 1976). The calculated apparent resistivity is plotted against the corresponding half current electrode separation (AB/2) to construct the VES curves (Fig. 1), and the letters Q,A,K and H are used in combination to indicate the variation of resistivity with depth (Table 2). Computer modelled resistivity curves of some sounding locations in the area are as shown in Figure 2a, b and c.

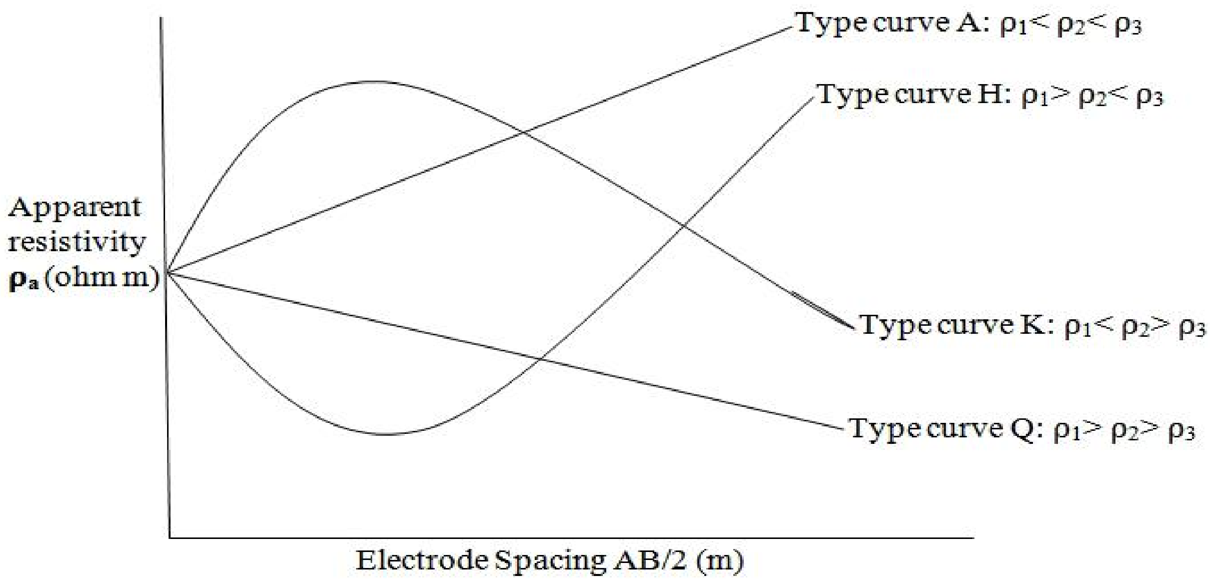

Fig. 1: Schematic diagram of resistivity type curves for 3-layered structures.

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

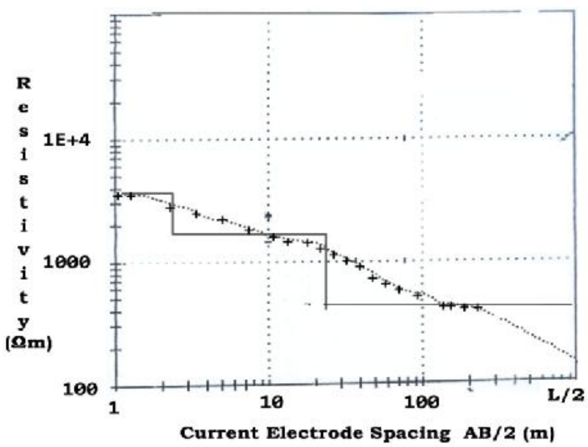

Fig. 2a: A computer modelled curve of VES 2 at Ubakala Umuahia.

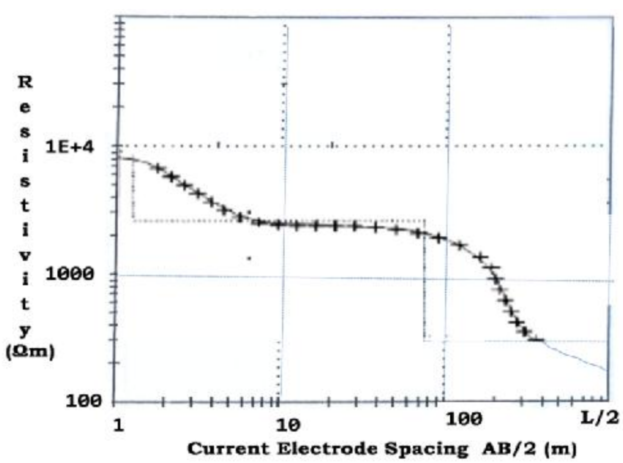

Fig. 2b: A computer modelled curve of VES 5 at Abia State University Uturu.

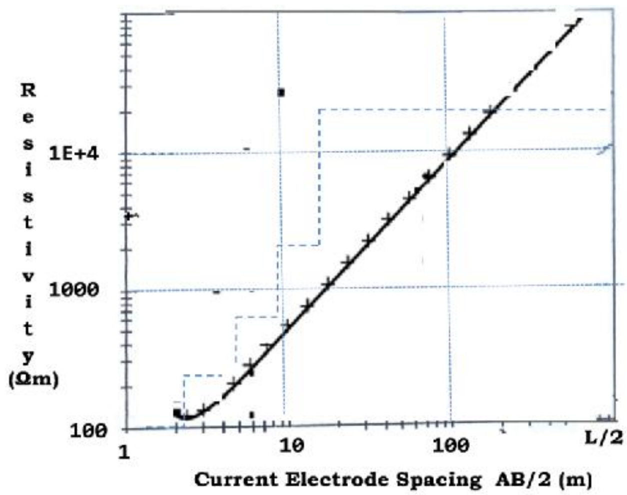

Fig. 2c: A computer modelled curve of VES 7 at Mbalano Isuikwuato.

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 (Table. 2). The number of layers varies between 3and 6 layers.

Geoelectric sections

Since electrical resistivity of subsurface materials are at times related to the physical conditions of interest such as lithology, porosity, degree of water saturation and presence or absence of voids in the rocks, therefore electrical resistivity measurements determine subsurface resistivity distributions thus differentiating layers based on resistivity values.
So, geoelectric sections are displayed in terms of the relationship between the resistivity of the layers and their thicknesses (Fig. 3).

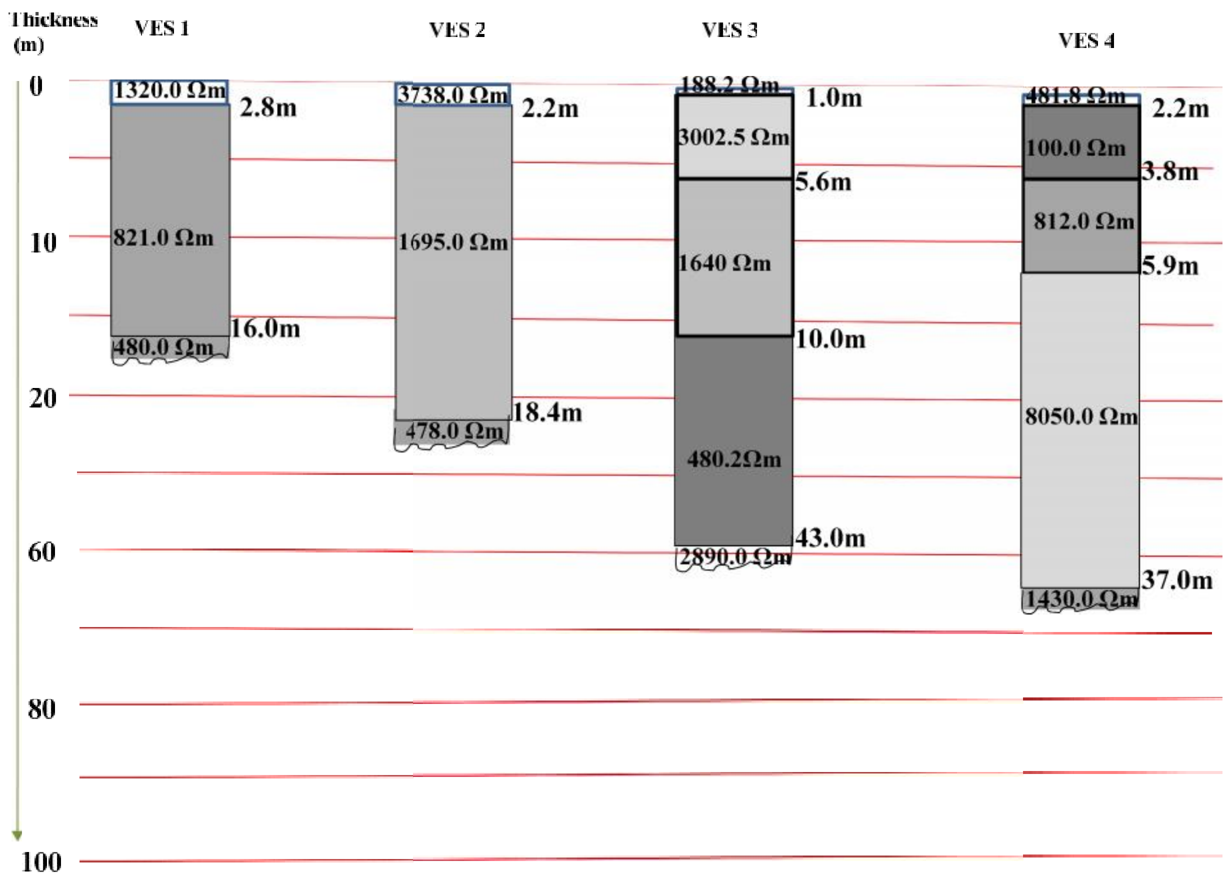

Fig. 3a: Geoelectric sections

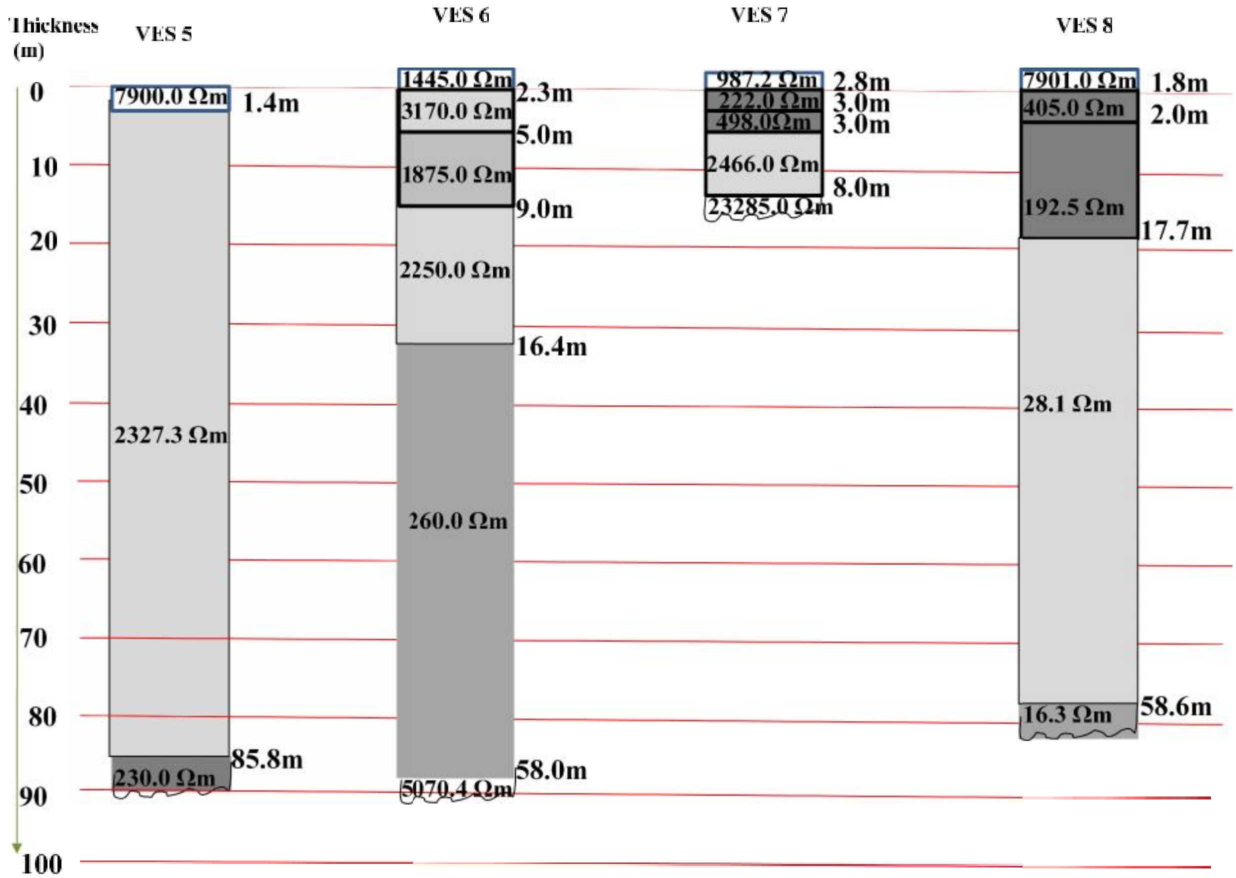

Fig. 3b: Geoelectric sections

Geophysical Evaluation of the Erosion Sites

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

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 et.al (2012) lithologically deduced from drill-hole and geoelectric data that sediments with 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.

Also, (Ward, 1990), Telford et.al (1990), and Lowrie, (2007) deduced range of resistivity for the following: 1,000Ωm – 10,000Ωm as quartzite, 50Ωm – 100,000Ωm as basalt, 150Ωm – 45,000Ωm as fresh granite, 10Ωm – 10,000Ωm as limestone, 10Ωm – 1,000Ωm as argillite, 1000Ωm – 10,000Ωm as gravel.

From the above indication, the surface and second layer resistivity of VES 1 and VES 2 coincided with the lithological samples gotten 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's a likelihood of VES Station 1 eroding to 18.8m, while VES Station 2 eroding to 20.6m.
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 Figure 4 below, to get to the clay layer (480.2Ωm) of VES 3, about 16.6m of sediments have been eroded which gives the top layer of VES 4 (481.8Ωm).

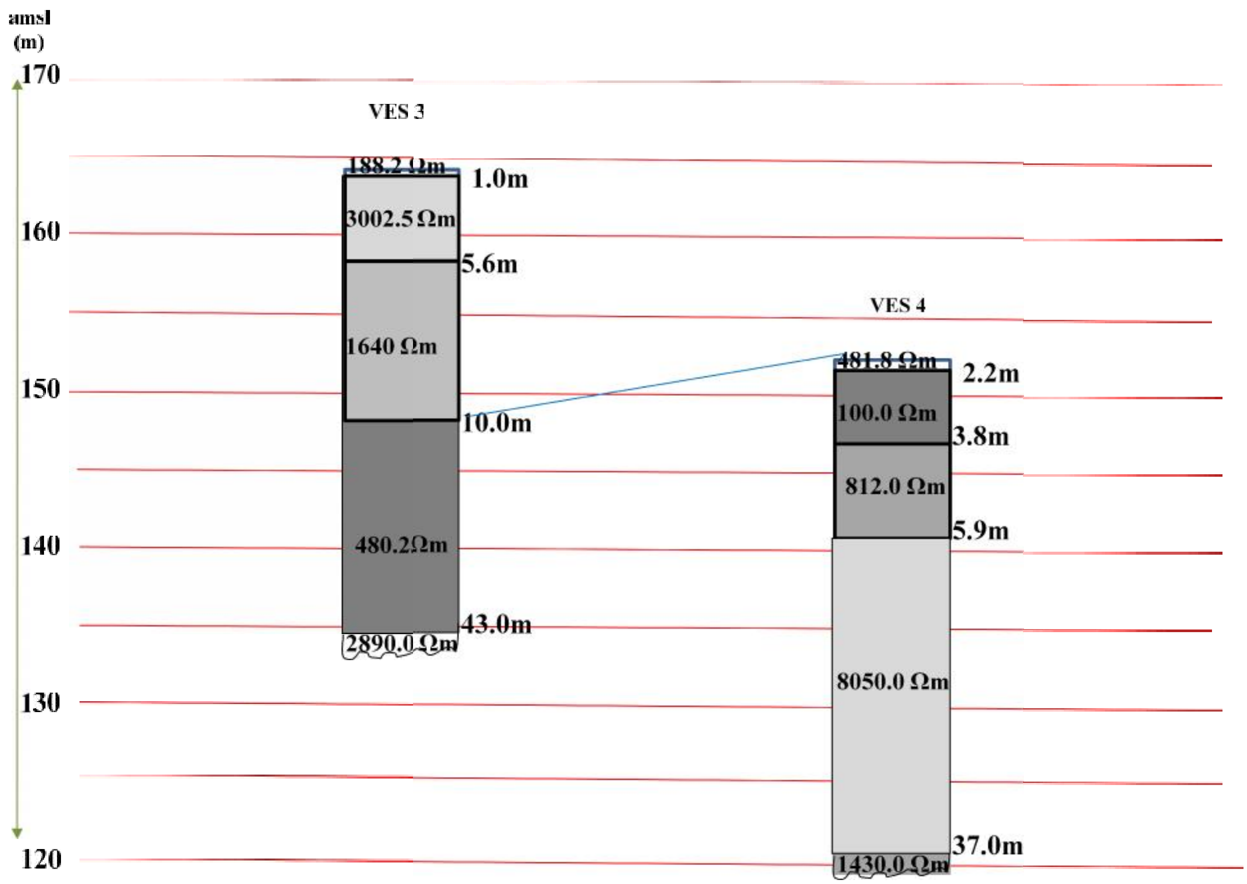

Fig. 4: Geoelectric sections of up-hill and down-slope planes of Ebem erosion site

Surface layer of VES 5 is gravel while the second layer which is sand have about 85.8m of it that is prone to erosion menace while 16.4m 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.

Geophysical prediction of the thickness of erosion-prone sediments

Recall that 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.
Recall also from geoelectric section that about 16.6m of sediments have been eroded to give the first layer of VES Station 4 (Fig. 4).
Now from Table 1, surface elevation of VES Station 3 is 164.3m above sea level while that of VES Station 4 (down slope plane) is 153.6m. Therefore, the thickness of sediments eroded is: 164.3 -153.6m = 10.7m
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.
Therefore, a correction factor is introduced to give the actual thickness (depth) of sediments that are prone to erosion menace.
Thus from geoelectric section, we have 16.6m while from lithological/surface elevation measurements, we have 10.7m, therefore correction factor = $\frac{16.6m}{10.7m}$ = 1.55

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, 18.8m of sediments are considered prone to erosion based on surface resistivity sounding; but to get the actual thickness, we divide by the correction factor.
So, $\frac{18.8m}{1.55}$ = 12.1m.
This correction factor can now be used in determining the actual thickness of sediments where surface resistivity sounding have been acquired.

CONCLUSION

It is therefore established from this study that geophysical methods are effective tools in the evaluation of erosion menace. Determined is that areas overlain with resistivity ranging from 500Ωm to 5500Ωm are prone to erosion menace and are sediments mainly of sands. Also established is that thickness of sediments can be estimated using a correction factor.

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