THE EDITOR,
I HAVE AGAIN READ THROUGH THIS PAPER AND EFFECTED SOME CORRECTIONS. THE PAPER IS NOW RECOMMENDED FOR PUBLICATION AFTER THESE CORRECTIONS ARE DULY EFFECTED. UNFORTUNATELY I COULD NOT CHECK THE REFERENCES.

GEOPHYSICAL EVALUATION OF EROSION SITES ~~AND THE ESTIMATION OF EROSION-PRONE SEDIMENTS~~ ? Not necessary. 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 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 = 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 were drawn and hence the geologic units of the area obtained. Results show that the resistivity of the erosive material 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.~~ What again is surface resistivity? A correction factor was ~~determined and~~ used in determining the true thickness of sediments where surface resistivity sounding data were acquired. The method depicts a valuable tool for assessment, depth, thickness and nature of erosive material. ~~sustainable planning, management and prediction of future effects on land. The methodology is recommended for application in assessing gully erosion sensitivity and effects in areas of similar conditions.~~

Comment [u1]: Maximum depth cannot be 16.8 m and at same time time 90.7 m?

Comment [u2]: Assessing

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

INTRODUCTION

Soil erosion is 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 (Egboka, 2000; Igboekwe, 2012; Ogbonna et.al, 2011).
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 similar vegetation and ecosystems, areas with frequent and high-intensity precipitation, more wind and storms are expected to have more erosion.

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 (Nichols, 2009). Since organic materials coagulate soil colloids, therefore soils with high levels of organic materials are often more resistant to erosion because they 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 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 (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 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 (Nîr, 1983). This increased runoff disrupts surrounding watersheds by changing the volume and rate of water flowing through them (James, 1995).

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 (Zachar, 1982; Toy. et al, 2002).
In splash erosion, a small crater is created in the soil by the impact of a falling raindrop by ejecting soil particles (Obreschkow, 2011). 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 60cm (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 (FAO, 1965). 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 30cm, and the slopes may be quite steep. Rills are usually active where water erosion rates are highest.
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 30cm (Poeson. et al, 2002); (Poeson. et al, 2007), and Borah et.al (2008).

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.

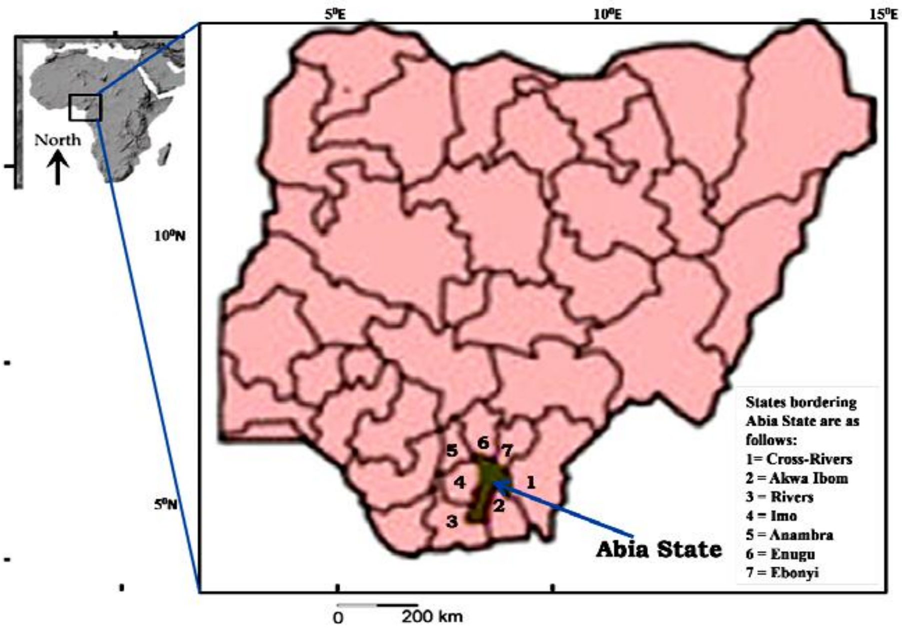

Fig. 1: Location map of Nigeria showing Abia State the study area.

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 (Billi and Dramis, 2003; DiBiase and Whipple, 2011).

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.

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 320mm to 335mm while that of the dry season is about 65mm, thus the annual average rainfall ranges from about 2000mm to 2400mm with high relative humidity values over 70% (Leong, 1978).

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.

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 **(Petters, 1991).**

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 1000km 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 (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 2500m 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.

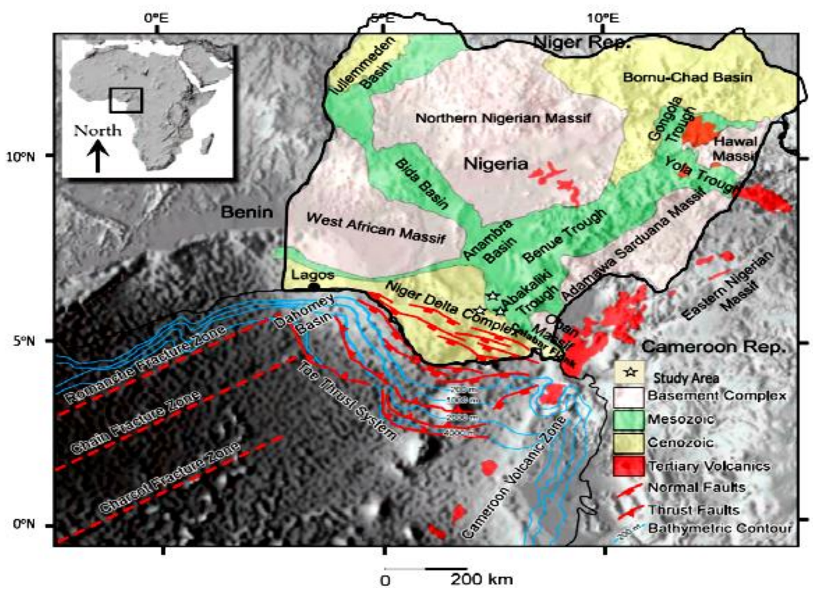

Fig. 2: Geological outline map of Nigeria showing basement outcrops, major sedimentary basins and tectonic features (Modified after Onuoha, 1999).

LOCATION OF STUDY AREA IS NECESSARY ON THIS TECTONIC MAP SHOW SIGNIFICANCE OF THE MAP

There are about 11 different geologic formations in Abia State of Nigeria (Fig. 3); 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 (Ibe et al., 1998). 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 (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.

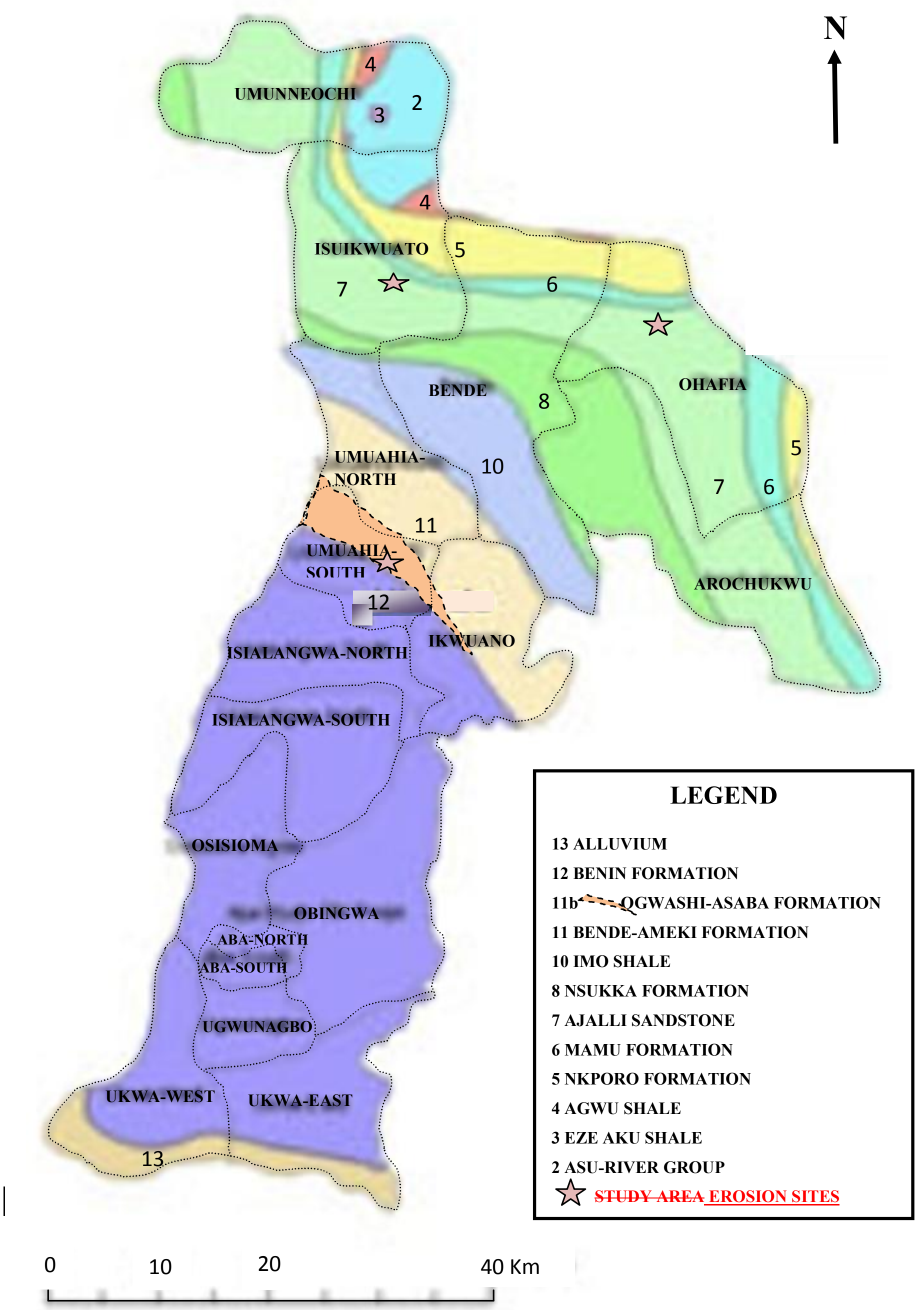

Fig. 3: Geologic map of Abia State showing the Local Government Areas and the study areas (Modified after GSN, 1985).

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 (Wobus et al., 2006b; 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.

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 0.5m to 14m; while the half current electrode separation (AB/2) was also increased starting from 1.5m to 165m.

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:

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

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).

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 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	**t_1 =1.0** **t_2 = 5.6** **t_3 = 10.0**	59.6

		ρ_4= 480.2 ρ_5= 2890.0	**t_4 = 43.0** **t_5 =**	
3 Ebem Ohafia (153.6m) $5^{0}37.862^{!}$N $7^{\mathbf{0}}49.696^{!}$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 acquired on a horizontally stratified medium is a function of the electrode configuration, together with resistivities and thicknesses of the layers (Zohdy, 1989). The 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 (Fig. 4). Resistivity curves of some sounding locations in the area are as shown in Figure 4a, b and c.

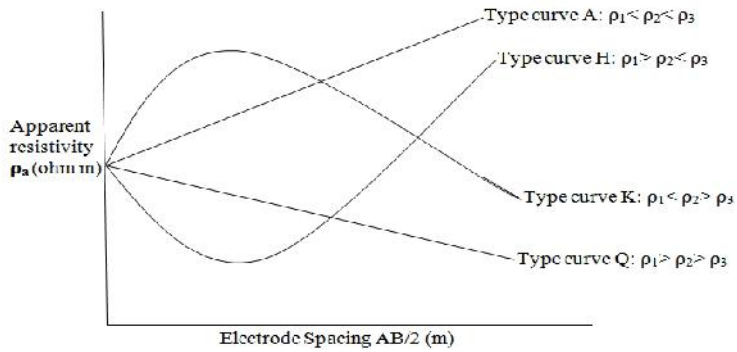

Fig. 4:An illustration of resistivity type curves for 3-layered structures.

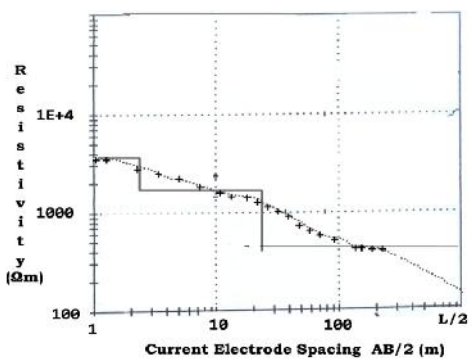

Fig. 4a: A computer modelled curve of VES 2 at Ubakala Umuahia.

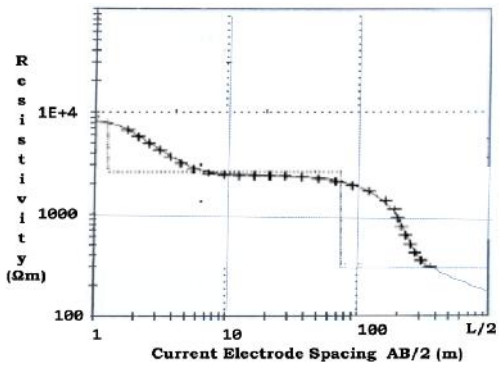

Fig. 4b: A computer modelled curve of VES 5 at Abia State University Uturu.

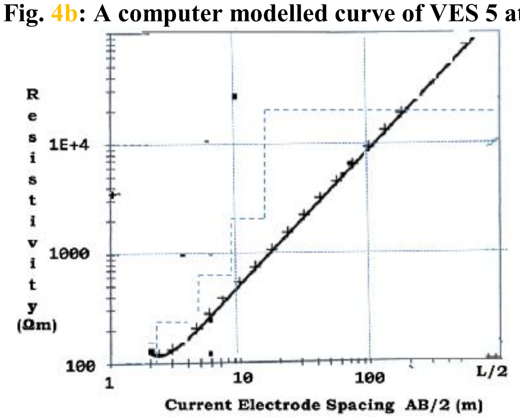

Fig. 4c: A computer modelled curve of VES 7 at Mbalano Isuikwuato.

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.

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	VES 1,2,5	VES 3	VES 4	VES 7	VES 8	VES 6

Location						

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 (Zohdy, 1965; Choudhury and Saha, 2004; Amos-Uhegbu et al., 2012). 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. 5).

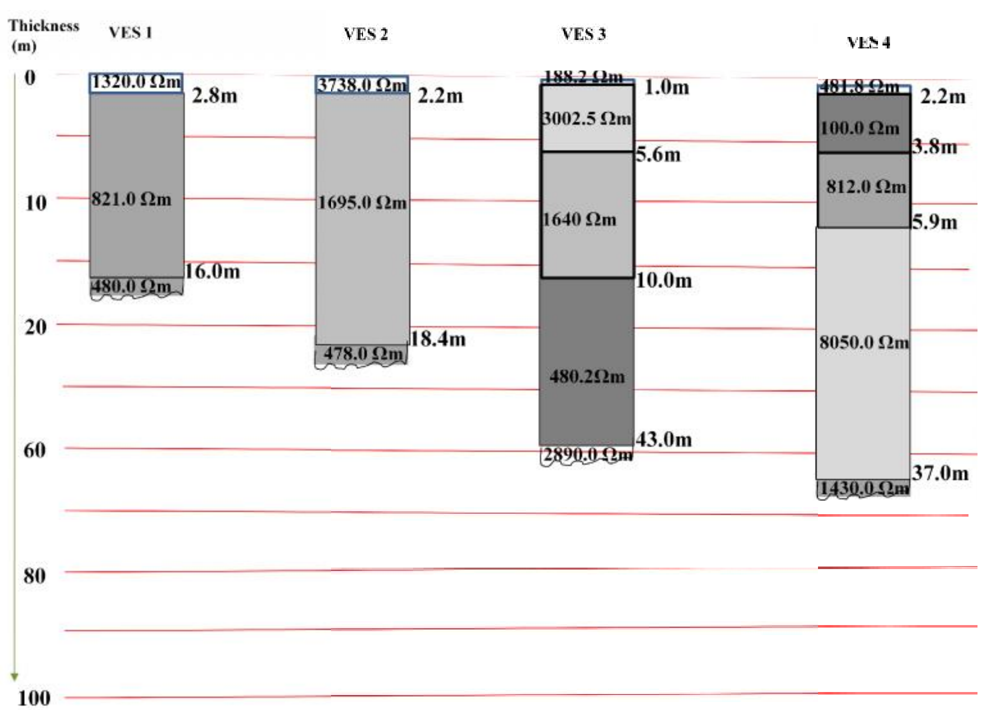

Fig. 5a: Geoelectric sections of VES 1, 2, 3 and 4.

YOUR GEO-ELECTRIC SECTIONS MUST INDICATE DEPTH, THICKNESS AND NATURE OF THE EROSIVE MATERIAL AND CORRELATED FROM VES STATION TO ANOTHER TO JUSTIFY THE TITLE OF YOUR WORK

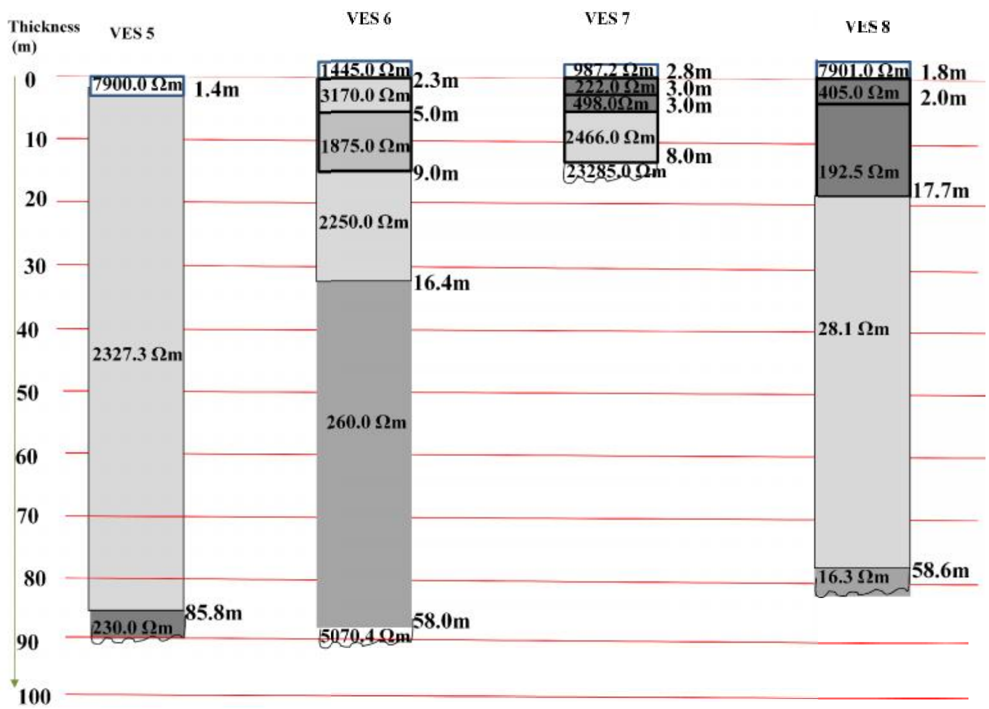

Fig. 5b: Geoelectric sections of VES 5, 6, 7 and 8

SEE COMMENTS ON FIG 5a

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 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 18.8m, 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 6 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).

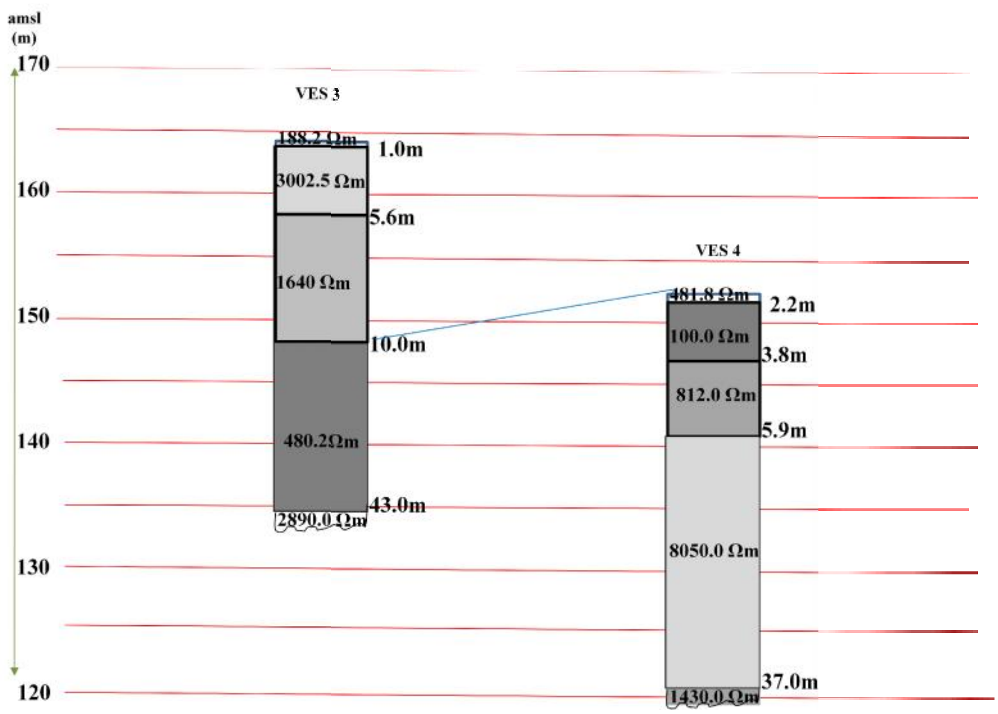

Fig. 6: Geoelectric sections of up-hill and down-slope planes of Ebem erosion site

ON THIS FIGURE ALSO SHOW DEPTH OF EROSIVE MATERIAL. SHOW LINES OF CORRELATION

Surface layer of VES 5 is gravel while the second layer which is sand has 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

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 that about 16.6m of sediments have been eroded to give the first layer of VES Station 4 (Fig. 6).

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 (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[illegible]m was calculated as the actual thickness of the sediments while measurements using litholo[illegible]surface elevation gave a value of 10.7m. The correction factor is therefore calculated as [illegible] = 1.55

This correction factor (1.55) is n[illegible]d in dividing the thickness of erosion-prone sediments acquired through surface resistivity measurement which gives the actual thickness of erosion-prone sediments.

For e[illegible]e. from VES Station 1, 18.8m of sediments are considered prone to erosion based on surfa[illegible]vity sounding; but to get the actual thickness, we divide by the correction factor.

So, [illegible]12.1m.

This c[illegible]n factor can now be used in determining the actual thickness of sediments where surface resistivity sounding have been acquired.

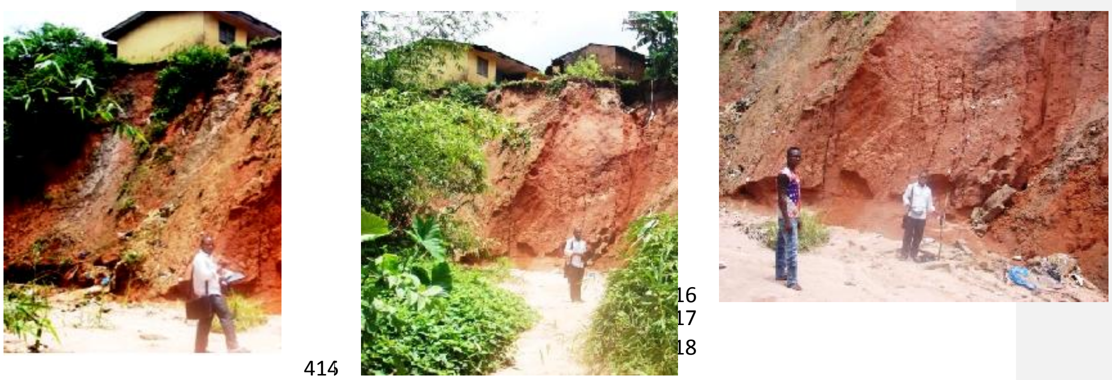

Fig. 7: Gully erosion site at Ebem Ohafia area of Abia State, Nigeria.

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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 500Ωm to 5500Ωm 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.

REFERENCES

Ahnert, F. (1970), Functional relationships between denudation, relief, and uplift in large mid latitude drainage basins, Am. J. Sci., 268(3), 243–263, doi:10.2475/ajs.268.3.243.

Amos-Uhegbu, C., Igboekwe, M.U., Chukwu, G.U., Okengwu, K.O., and Eke, K.T. (2012). Hydrogeophysical Delineation and Hydrogeochemical Characterization of the Aquifer Systems in Umuahia-South Area, Southern Nigeria. British Journal of Applied Science & Technology, 2(4): 406-432.

Billi, P and Dramis, F. (2003). Geomorphological investigation on gully erosion in the Rift Valley and the northern highlands of Ethiopia. Catena 50:353–368.

Binnie, S. A., Phillips, W. M., Summerfield, M. A., and Fifield, L. K. (2007). Tectonic uplift, threshold hillslopes, and denudation rates in a developing mountain range, Geology, 35(8), 743–746, doi:10.1130/G23641A.1.

Blanco, H and Lal, R (2010). Principles of Soil Conservation and Management. Springer.;641pages. ISBN 978-90-481-8529-0.

Burbank, D. W. and Anderson, R. S. (2011). "Tectonic and surface uplift rates". Tectonic Geomorphology. John Wiley & Sons. pp. 270–271.

Choudhury, K. and Saha, D.K. (2004). Integrated Geophysical and Chemical Study of Saline Water Intrusion. Groundwater, 42(5) 671-677.

DiBiase, R. A., and Whipple, K. X. (2011). The influence of erosion thresholds and runoff variability on the relationships among topography, climate, and erosion rate, J. Geophys. Res., 116, F04036, doi:10.1029/2011JF002095.

DiBiase, R. A., Whipple, K. X., Heimsath, A. M. and Ouimet, W. B. (2010). Landscape form and millennial erosion rates in the San Gabriel Mountains, CA, Earth Planet. Sci. Lett., 289(1–2), 134–144, doi:10.1016/j.epsl.2009.10.036.

Egboka, B.C.E.(2000). “Erosion, Its Causes and Remedies”. A key note address on Erosion Control and Sustainable Environment. University of Nigeria, Nsukka, Nigeria.

Food and Agriculture Organization (1965). "Types of erosion damage". Soil Erosion by Water: Some Measures for Its Control on Cultivated Lands. United Nations. pp. 23–25. ISBN 978-92-5-100474-6.

Gilbert, G. K. (1877), Report on the Geology of the Henry Mountains, 160 pages, U.S. Gov. Print. Off., Washington, D. C.

Glennie, K.W. (1970). "Desert erosion and deflation". Desert Sedimentary Environments, Volume 14. Elsevier. ISBN 978-0-444-40850-1.

Goudie, A. (2000). "The human impact on the soil". The Human Impact on the Natural Environment. MIT Press. 188pages. ISBN 978-0-262-57138-8.

Grandjean, G., Malet, J.P., Bitri, A., and Meric O., 2007. Geophysical data fusion by fuzzy logic or imaging mechanical behaviour of mudslides. Bull. Soc. Geol. France, 177, 2, 133-143.

Hurst, M. D., Mudd, S. M. , Walcott, R. ,. Attal, M., and Yoo, K. (2012), Using hilltop curvature to derive the spatial distribution of erosion rates, J. Geophys. Res., 117, F02017, doi:10.1029/2011JF002057.

Igboekwe, M.U., Eke, A.B., Adama, J.C. and Ihekweab, G.. 2012. “The Use of Vertical Electrical Sounding (VES) in the Evaluation of Erosion in Abia State University, Uturu and Environs”. *Pacific Journal of Science and Technology*. 13(2):509-520.

Imeson, A. (2012). "Human impact on degradation processes". Desertification, Land Degradation and Sustainability. John Wiley & Sons. 165pages.

James, W. (1995). "Channel and habitat change downstream of urbanization". In Herricks, Edwin E. & Jenkins, Jackie R. Stormwater Runoff and Receiving Systems: Impact, Monitoring, and Assessment. CRC Press. 105pages.

Julien, Pierre Y. (2010). Erosion and Sedimentation. Cambridge University Press. p. 1.

Leong, G. C (1978). Certificate physical and Human Geography. Oxford University Press.. 198pages.

Lobb, D.A. (2009)."Soil movement by tillage and other agricultural activities". In Jorgenson, Sven E. Applications in Ecological Engineering. Academic Press.

Lowrie, W. (2007). Fundamentals of Geophysics, 2nd Edition. Cambridge University Press 381pages.

Matsushi, Y., and. Matsuzaki, H. (2010), Denudation rates and threshold slope in a granitic watershed, central Japan, Nucl. Instrum. Methods Phys.Res., Sect. B, 268(7–8), 1201–1204, doi:10.1016/j.nimb.2009.10.133.

Montgomery, D. R. (2001), Slope distributions, threshold hillslopes, and steady-state topography, Am. J. Sci., 301(4–5), 432–454, doi:10.2475/ajs.301.4-5.432.

Montgomery, D. R., and M. T. Brandon (2002), Topographic controls on erosion rates in tectonically active mountain ranges, Earth Planet. Sci. Lett., 201(3–4), 481–489, doi:S0012821X02007252.

Nichols, Gary (2009). Sedimentology and Stratigraphy. John Wiley & Sons. 93pages.

Nîr, Dov (1983). Man, a Geomorphological Agent: An Introduction to Anthropic Geomorphology. Springer. pp. 121–122.

Obreschkow (2011). "Confined Shocks inside Isolated Liquid Volumes - A New Path of Erosion?". Physics of Fluids.

Ogbonna, J.U., Alozie, M., Nkemdirim, V and Eze M. U. (2011). GIS Analysis for Mapping Gully Erosion impacts on the Geo-formation of the Old Imo State, Nigeria. *ABSU Journal of Environment, Science and Technology, Volume 1;* 48-61

Ouimet, W. B., Whipple, K. X. and Granger, D. E. (2009). Beyond threshold hillslopes: Channel adjustment to base-level fall in tectonically active mountain ranges, Geology, 37(7), 579–582, doi:10.1130/G30013A.1.

Palumbo, L., Hetzel, R., Tao, M. and Li, X. (2010). Topographic and lithologic control on catchment-wide denudation rates derived from cosmogenic 10Be in two mountain ranges at the margin of NE Tibet, Geomorphology, 117(1–2), 130–142, doi:10.1016/j.geomorph.2009.11.019.

Petters , S . W . 1991 . Regional geology of Africa . *Lecture Notes in Earth Sciences* **40 ,** 722 pp. (Springer-Verlag , Berlin) .

Poeson, J., Vandererckhove, L., Nachtergaele, J., Wijdenes, D.O., Verstraeten, G., and Wesemael, B.V. (2002). "Gully erosion in dryland environments". In Bull, Louise J. and Kirby, M.J. Dryland Rivers: Hydrology and Geomorphology of Semi-Arid Channels. John Wiley and Sons. ISBN 978-0-471-49123-1. pp229-

Poeson, J. (2007). "Gully erosion in Europe". In Boardman, John and Poeson, Jean. Soil Erosion in Europe. John Wiley & Sons. pp. 516–519. ISBN 978-0-470-85911-7.

Santamarina J.C, Rinaldi V.A., Fratta D., Klein K.A., Wang Y.H., Cho G..C., Cascante G. A. (2005). Survey of Elastic and electromagnetic properties of near surface soils. In Near Surface Geophysics. Investigation in geophysics No 13.

Schmidt, K. M., and. Montgomery, D. R (1995). Limits to relief, Science, 270(5236), 617–620, doi:10.1126/science.270.5236.617

Skácelová, Z., Rapprich, V., Valenta, J., Hartvich, F., Šrámek, J., Radoň, M., Gaždová, R., Nováková, L., Kolínský, P., Pécskay, Z. (2010). Geophysical research on structure of partly eroded maar volcanoes: Miocene Hnojnice and Oligocene Rychnov volcanoes (northern Czech Republic) Journal of Geosciences, 55 (2010), 333–345 DOI: 10.3190/jgeosci.072

Styczen, M.E. and Morgan, R.P.C. (1995). "Engineering properties of vegetation". In Morgan, R.P.C. and Rickson, R. J. Slope Stabilization and Erosion Control: A Bioengineering Approach. Taylor and Francis. ISBN 978-0-419-15630-7.

Telford, N.W., Geldart, L. P., Sheriff, R. S. and Keys, D. A. (1990). *Applied Geophysics*. *2nd Edition.* Cambridge University Press, Cambridge. 744pages.

Toy, T. J., Forster, G.R., and Renard, K.G. (2002). Soil Erosion: Processes, Predicition, Measurement, and Control. John Wiley and Sons. 338pages.1. ISBN 978-0-471-38369-7.

Tucker, G. E., and Hancock, G.R. (2010), Modelling landscape evolution, Earth Surf. Processes Landforms, 35, 28–50, doi:10.1002/esp.1952.

Wainwright, J. and Brazier, R. E. (2011). "Slope systems". In Thomas, David S.G. Arid Zone Geomorphology: Process, Form and Change in Drylands. John Wiley & Sons. ISBN 978-0-470-71076-0.

Ward, S. H. (1990). Resistivity and induced polarization methods. In *Geotechnical and Environmental Geophysics*, vol. 1, ed. S.H. Ward, Tulsa, OK: Society of Exploration Geophysicists, p. 147–190.

Whisenant, S. G. (2008). "Terrestrial systems". In Perrow Michael R. and Davy, Anthony J. Handbook of Ecological Restoration: Principles of Restoration. Cambridge University Press. 89pages. ISBN 978-0-521-04983-2.

Whitford, W.G. (2002). "Wind and water processes". Ecology of Desert Systems. Academic Press. 65pages. ISBN 978-0-12-747261-4.

Wobus, C., Whipple, K. X., Kirby, E., Snyder, N., Johnson, J., Spyropolou, K., Crosby, B. and Sheehan, D. (2006a), Tectonics from topography: Procedures, promise, and pitfalls, Spec. Pap. Geol. Soc. Am., 398, 55–74,doi:10.1130/2006.2398(04).

Wobus, C. W., Crosby, B. T. and Whipple, K. X. (2006b), Hanging valleys in fluvial systems: Controls on occurrence and implications for landscape evolution, J. Geophys. Res., 111, F02017, doi:10.1029/2005JF000406.

Yoo, K., and Mudd, S. M. (2008a), Discrepancy between mineral residence time and soil age: Implications for the interpretation of chemical weathering rates, Geology, 36(1), 35–38, doi:10.1130/G24285A.1.

Yoo, K., and Mudd, S. M. (2008b), Toward process-based modeling of geochemical soil formation across diverse landforms: A new mathematical framework, Geoderma, 146(1–2), 248–260, doi:10.1016/j.geoderma.2008.05.029.

Zachar, D. (1982). "Classification of soil erosion". Soil Erosion. Vol. 10. Elsevier. p. 48.

Zohdy, A. A. R. (1965). The auxiliary point method of electrical sounding interpretation and its relationship to the Dar-Zarrouk parameters. *Geophysics,* 30, 644-660.
Sands, Roger (2005). "The environmental value of forests". Forestry in a Global Context. CABI. pp. 74–75. ISBN 978-0-85199-089-7.

Zohdy, A. A. R**.** (1989). A New Method for the Automatic Interpretation of Schlumberger and Wenner Sounding Curves.*Geophysics,* 54(2): 245-253.