Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2024, 11(1):190-202**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Comparative study of geophysical and geotechnical assessment of selected gully erosion in Nsukka zone, Southeastern Nigeria

Oliver U. Ekwueme

Ph.D, Department of Physics, Federal University of Technology, Akure
Email: ouekwueme@futa.edu.ng
Telephone no: +2347067490871

Abstract The textural classification of soil was preponderantly loamy, sandy and clayey, with percentage clay ranged from 8% to 18%, percentage silt ranged from 3% to 9%, percentage fine sand ranged from 20% to 38% and percentage coarse sand ranged from 29% to 69%. The moisture content ranged from 7.07% to 31.73% respectively. The percentage of total porosity value was ranged from 41.13% to 47.55%. Hydraulic conductivity value ranged from 8.89m/day to 22.73m/day. The first layer resistivity value ranged from 16.8Ωm to 2144.6Ωm with thickness ranged from 0.3m to 5.6m and depth of 0.3 to 5.6m. The high values of hydraulic conductivity ranged from 18.7 to 27.7m/day. The low values of hydraulic conductivity ranged from 0.303 to 6.39m/day. The high values of porosity ranged from 31.5 to 40.4, while low porosity values ranged from 20.1 to 26.9%. The intermediate porosity value ranged from 27 to 31.4%.

Keywords Nsukka zone, geotechnical survey, vertical electrical sounding

1. Introduction

Investigation of environmental hazards such as gully erosion requires geophysical and geotechnical understanding of the soil and rock properties which give important information on the nature and the rise of such disastrous effects on the formation of gullies in the area. Research has shown that subjecting soil samples to some levels of physical tests with the aim of identifying those parameters which induces soil erodibility can be achieved with method of geotechnical survey. This survey as opined by Chikwelu and Ogbuagu (2014), Uhegbu and John (2017), Amagu et al. (2018), Obiefuna and Adamu (2012), Okengwo et al. (2015), Umoru et al. (2015), Okunlola et al. (2014), Imasuen et al. (2011), Akpokodje et al. (1986), Ezechukwu and Madubuike (2015), investigate soil properties based on the basic measurement of the nature of a fine-grained soil, its consistency properties, the capacity of water to flow through the soil and classify the soil based on the textual classes, measure the capacity of the soil to resist degradation when exposed to external forces, measure the degree of soil looseness or compaction etc. Similarly, electrical resistivity method plays important roles in identifying the properties and constituents of the soil particles. It studies the horizontal and vertical discontinuities in the electrical properties of the subsurface (Adegbola, et al., 2010; Igboekwe, et al., 2012; Kearey and Brooks, 1991; Keller and Frischknecht, 1966; Niwas and de Lima, 2003; Uhegbu and John, 2017; Zeyad, 2017; Hassan, et al., 2017; Heigold, et al., 1979; Jatau, et al., 2013; John, et al., 2015; Loke, 2009; Meindinyo, 2017; Olawuyi and Abolarin, 2013). This geophysical method is an active method with the application of electrical potential and subsurface electrical current generated by a direct current source and the resulting resistances are measured at the surface. Igboekwe et al. (2012) noted that the electrical method is a geophysical tool for the determination of the subsurface geology of a place. This agrees with the work of Amangabara and Otumchere (2016) who investigated the problem of gully erosion in Ideato North LGA of Imo

State, using VES and showed that the classification of subsurface structure were mainly sandy and other loose soil materials. Other researchers including; Obi and Okekeogbu (2017), Okoyeh et al. (2014), Meindinyo et al. (2017), Abdullahi et al. (2015), Uhegbu and John (2017), opined that VES method has contributed in determining subsurface geology and in evaluating the gully erosion of an area. Therefore, in this present work, an effort was made in identifying the factors that influences the effect of gully erosion in parts of Nsukka zone by applying geotechnical and vertical electrical sounding methods of which the results of the two methods were correlated to have evidential support on the factors of gully formation in the area.

Location and Geology of Nsukka zone

Udenu, Igbo-eze north, Nsukka and Igbo-eze south were all found in Nsukka zone which is located in Anambra basin Enugu State of Nigeria. The study area is situated within the Latitude of 6° 40′0′′N to 7° 10′0′′N and Longitude of 7° 15′0′′E to 7° 45′0′′E with approximately 30 square kilometer. Nsukka zone is located within the tropical rainforest belt and its climate is classified by the rainy season and the dry season. The areas fall within derived savanna belt and characterized by the growth of tall, thick and undergrowth trees. Figure 1 is the map showing Nsukka zone. While Figure 2 indicate parts of survey line area.

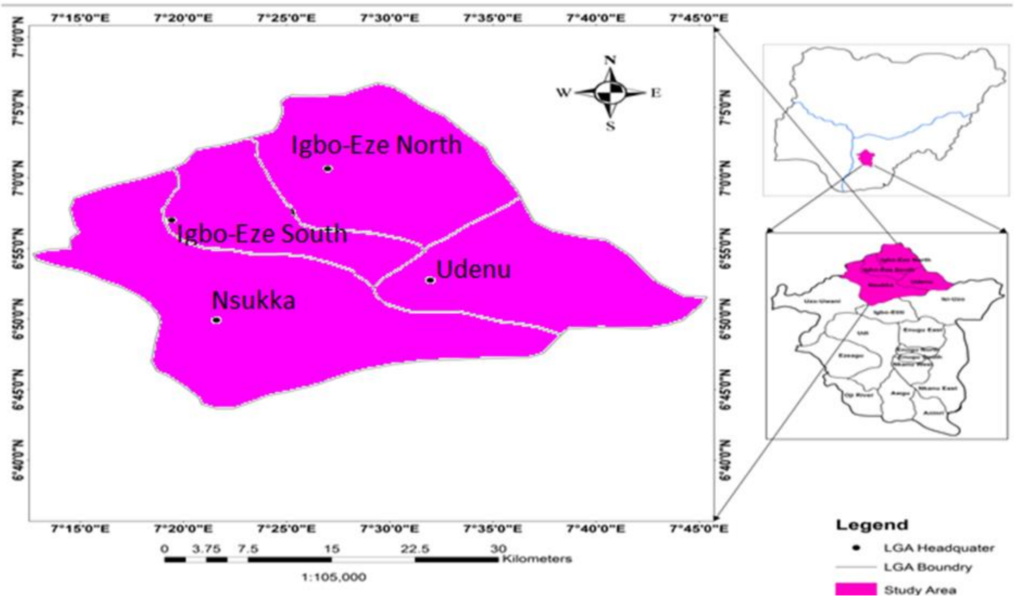

Figure 1: Map showing Nsukka zone

Figure 2: Parts of survey line within Nsukka zone

Nsukka zone is one of the major and widely known geology in Anambra basin (Figure 3). The topography of Nsukka zone is undulating making the flow of water to be irregular in nature. There are dispersed mountains and hills within the zone, and these contributes approximately to the land slopes as well as unstable elevated geological formation in the area, which may also be attributed to either ancient tectonic activity or erosion processes. The major land use in this area include; subsistence farming, road and house construction.

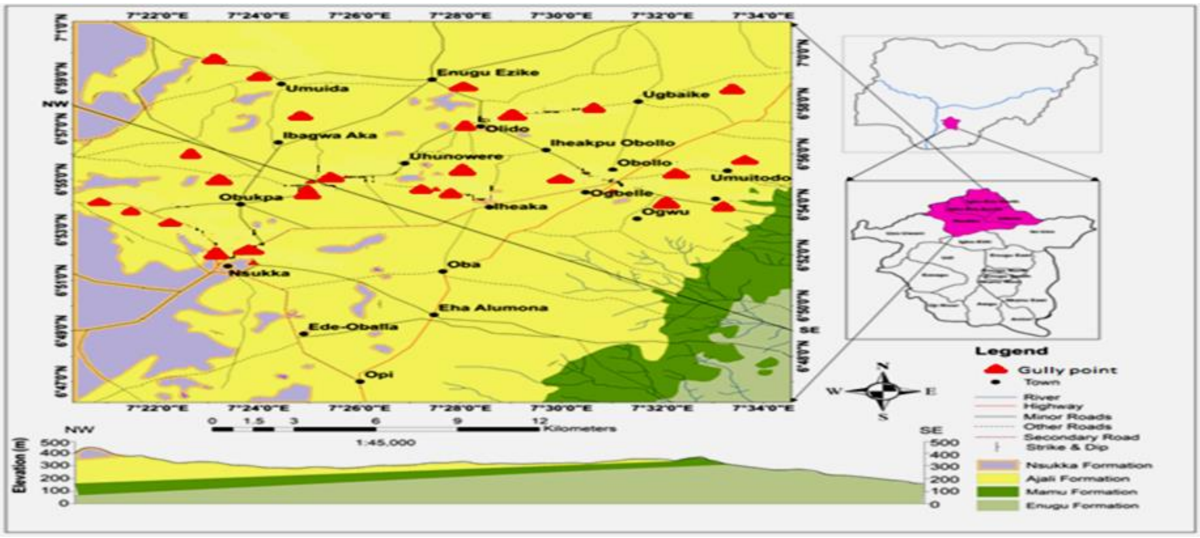

Figure 3: Geology map showing gully site in the study area

Geophysical investigation techniques of the erosion site

The VES data were obtained during the field work using Resistivity Meter (Model SSR-MP-ATS), IGIS, Electrodes, Hammers, Garmin GPS, 24 volts battery, two current cable reels, two potential cable reels, and two measuring tapes. Schlumberger electrode configuration was used in this geophysical investigation with a maximum current electrode spread of 400m. The Vertical Electrical Sounding (VES) stations were carried out along the gully erosion site and a total of thirty-five VES were obtained. The GPS was employed to estimate the coordinates and elevation within each gully point in Nsukka zone. The Resistivity meter was employed for the acquisition of data. This was done by connecting direct current from a 24V battery to the resistivity meter which was passed into the ground by the help of current electrodes. The two other electrodes connected in the middle were used to determine the voltage when current developed ground potential difference. The total of thirty-five VES point was obtained during the field work. Figure 4 is the survey materials employed in this research.

Figure 4: Survey materials

During the field work, Schlumberger electrode configuration was applied for VES data collections. In this Schlumberger electrode array, both the pairs of potential electrodes and current electrode have a common mid-point, but there are differences between distances of their neighboring electrodes. This configuration array helped to determine the depth from top to bottom and the layers thickness, as well as resistivity values (Evans, 2006). Data obtained in the field were subjected to computer processing software called WIN RESIST, which apply the Schlumberger computer automatic analysis package. The apparent resistivities were estimated by equation given thus;

$$\rho_a = \pi \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] \quad (1)$$

where AB = distance between the two current electrodes, MN = distance between the potential electrodes, and R_a = apparent electrical resistance measured in the field and ρ_a = apparent resistivity which can also be written as;

$$\rho_\alpha = K.R\alpha \quad (2)$$

Where K = geometric factor given by

$$K = \pi \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] \quad (3)$$

The apparent field resistance is given by;

$$Ra = \frac{V}{I} \quad (4)$$

The equation 4 is the resistance (R) of a resistor connected in a series with the current (I), and the change in potential (Δ V) as described by George Simon Ohm. Thus;

$$\Delta V = I\,R \quad (5)$$

Using this Ohm's Law, the value of resistance (R) can easily be calculated by plugging values of voltage (ΔV) and current (I). Therefore, electrical resistivity concept applied in this work is based on this relationship (Equation 5), with the assumption that the resistor in the circuit (Figure 5) is the Earth.

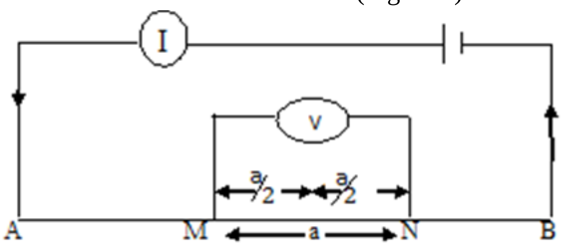

Figure 5: Sketch of Schlumberger electrode configuration (Lowrie, 1997)

Geotechnical survey of gully soil

Geotechnical survey was conducted by collecting soil samples from each point of the gully site. Soil samples were collected. The samples were collected within the depth range of 0.5 to 1.0m employing soil auger, core samplers and hammer, and packaged and labeled in polythene bags for laboratory analysis. The geotechnical parameters applied include; Atterberg limit (liquid limit, plastic limit and plasticity index), particle size distribution and porosity test, permeability or hydraulic conductivity test, were determined. The laboratory analyses were conducted at the Soil Science Department Laboratory of the University of Nigeria, Nsukka.

The Atterberg limits test were carried out using 100g of the stiff paste of soil sample thoroughly mixed with distilled water. 10g of soil was removed which flowed together and weighed to 0.01g and dried in an oven at 110˚C. Liquid limit, plastic limit and plasticity index were parameters of Atterberg limit determined. These parameters helped to estimate the plasticity and clay content of the soil sample. Plasticity index (PI) was evaluated by the estimation of difference between liquid limit (LL) and plastic limit (PL). PI was achieved by applying the expression (Ekwueme et al., 2021);

$$PI = LL - PL \quad (1)$$

Hydraulic conductivity for different samples was obtained by applying a simplified and widely used mathematical relation of the form;

$$q = -k \frac{\Delta H}{L} \quad (2)$$

where q = flux, k = hydraulic conductivity, and $\frac{\Delta H}{L}$ = hydraulic head gradient (Ekwueme et al., 2021).

Particle size distribution was obtained with 50g of the sieved sample in the dispersion cup filled with distilled water and 25cm^3 of 10% sodium hexametaphosphate solution. The following deductions were estimated according to Ekwueme et al. (2021):

40 seconds reading (for derivation of % sand)

$$\left(\frac{\text{40 seconds hydrometer reading}}{\text{mass of sample}} \times 100\right)\% = \%(\text{Silt} + \text{Clay}) \quad (3a)$$

$$100\% - (\%\,Silt + Clay) = \%\,Sand \quad (3b)$$

2 hours reading (for derivation of % clay)

$$\left(\frac{2\ hours\ reading}{mass\ of\ sample} \times 100\right)\% = \%Clay \quad (3c)$$

$$100\% - (\%Sand + \%Clay) = \%Silt \quad (3d)$$

$$\text{Percentage of each fraction} = \frac{mass\ of\ each\ fraction}{mass\ of\ H_2O_2 - treated\ sample} \times 100\% \quad (3e)$$

2. Results and Discussion

Vertical Electrical Sounding

The VES data were analyzed using automated computer software known as WINRESIST. Figure 6 indicate parts of VES curves, layers, depth and thickness obtained when the calculated apparent resistivity (ρ_a) was plotted against half current electrode distance (AB/2). Table 1 shows the summarized result of VES survey and indicates the variation of electrical resistivity of subsurface materials which basically depends on those physical characteristics of the material such as porosity, permeability, water content and clay content as opined by Zohdy (1965). The table identifies the geoelectrical section including; resistivity variation with the corresponding depth and thickness of the layer resistivity. The layer model number varies from 2 to 5 layers and are predominantly KHA, KH, A, H, AA, AK, and HA curve types. The curve names were made possible using the curve matching process shown in the Table 3.

Table 2 shows the resistivity values for first layer extracted from Table 1, hydraulic conductivity and percentage porosity values obtained using first layer resistivity results. The first resistivity layer was taken for the fact that the gully erosion occurs when its depth is accurately above 30cm. The depths obtained for the first resistivity layer approximately agrees with the notion stated. Therefore, throughout this work, first layer resistivity result was used to obtain other parameters or considered to be the reference point. The variations of first layer resistivity were observed to range from 16.8Ωm to 2144.6Ωm with thickness ranged from 0.3m to 5.6m and depth of 0.3 to 5.6m. According to Loke, (2009), such spatial variation indicates that the area is more of low resistive materials constituting top sandy formation which are permeable and susceptible to erosion. The contour map plotted with the help of arcGIS computer software for the first layer resistivity as shown in Figure 7 captured the VES point and its community name with the variations of the resistivity in the study area. First layer contour map shows very low resistivity values ranged from 17.6 – 254 Ωm as indicated by the resistivity legend bar for VES 1, 2, 20, 23-26, 29, 30-33 and 35. This result agrees with the observation made by Amangabara and Otumchere (2016) that the implication of such results indicates that the area is more of weak protective capacity with lose surface compatibility and easily eroded by surface runoff. Areas like VES 4-8, 13-19, 21, 22, 27, 28 and 34 has resistivity values that ranged from 255 – 962 Ωm has intermediate resistivity variations which implies that the areas are dominated with medium resistive materials like fine sand to sandy clay across the study area which have some levels of protective materials which can sustain some levels of runoff and detachability of soil particles. Within VES 3, 9, 11 and 12 has high resistive materials and indicate according to Telford et al. (1990) that the area consists mainly of siltstone, clay soil, loamy sand or compacted clay materials.

Figure 8 shows the contour map indicating the spatial distribution of hydraulic conductivity results obtained from the first layer resistivity values. The high values of hydraulic conductivity are predominantly found at the VES 29, 33 and 35 with hydraulic conductivity values ranging from 18.7 to 27.7 m/day. This region with high values of hydraulic conductivity correspond to the southeastern area (Figure 8) where resistivity value is also the lowest (Figure 7) indicating more of loosed materials such as sandy soil. The high value result indicates that the rate in which the water permeates through the soil is high (Heigold et al. 1979), and therefore, the area is susceptible to erosion. The low values of hydraulic conductivity ranged from 0.303 to 6.39 m/day was observed to have spatially distributed within northern, eastern, southern and scarcely in the western region (Figure 8), situated at the VES 3-19, 22-23, 27 and 34. The implication of such low value of hydraulic conductivity within these regions is an indication that the soil constituent's area made up of some protective capacity that prevent to some extent the water permeability to the soil. The soil compatibility prevents water percolation in the area and the soil structure is suspected to include; silt soil, clay soil and loam clay (Heigold et al. 1979).

The porosity contour map of first resistivity layer in Figure 9 shows the percentage variartion of porosity values in the study area. The highest values of porosity ranged from 31.5 to 40.4%, located at the VES 1, 24, 30, 32, 33 and 35. These areas shows layers of the soil with greater open space that cannot not resist any form of degradation and therefore, vulnerable to erosion. This region corresponds to the area where we have low resistivity value as in Figure 7, and high hydraulic conductivity as in Figure 8 that indicates area with weak protective capacity and susceptible to erosion. However, areas like VES 3-19, 21, 22 and 27 have low porosity values ranged from 20.1 to 26.9%, indicating soil particles with adequate protective capacity and compatibility of soil constituents. The intermediate porosity value is located at the VES 2, 20, 23, 25, 26 and 29-31, with porosity value of 27 to 31.4%.

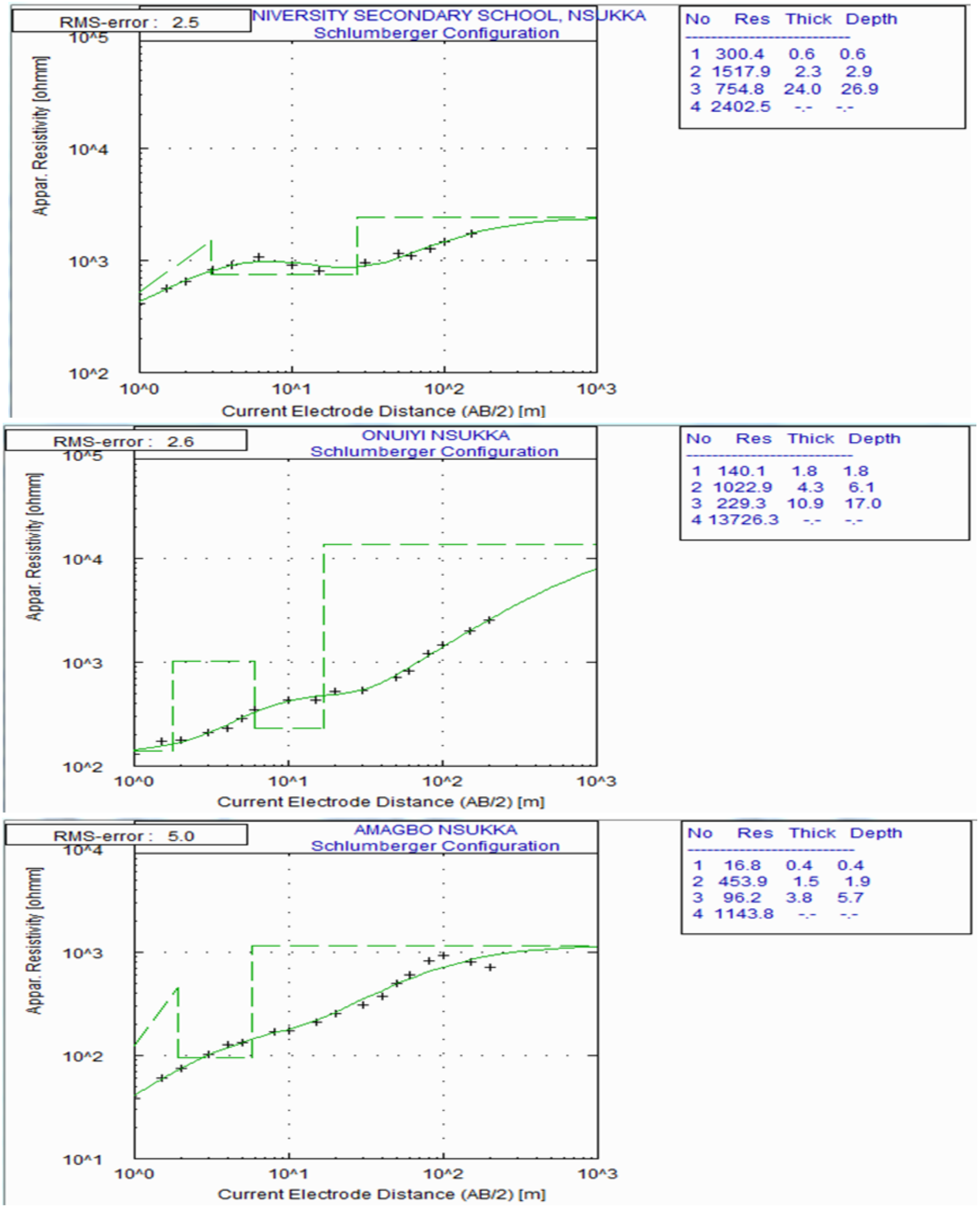

Figure 6: Parts of computer model curve

Table 1: Summary of the results obtained from interpreted VES data

VES	Location	Latitude (°N)	Longitude (°E)	Layer resistivity (Ωm)					Thickness (m)				Depth (m)				Curve type
				ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	d_1	d_2	d_3	d_4	
1	Obollo-afor central	6.9144	7.5209	72.7	382.9	330.6	1898.4	6308.2	1.1	4.0	4.9	22.2	1.1	5.0	9.9	32.1	KHA
2	Ogwu Road	6.9066	6.5273	144.1	7633.1	1383.8	23969.9	-	0.5	5.9	19.1	-	0.5	6.3	25.5	-	KH
3	Umuitodo	6.9219	7.5366	957.9	4682.5	13461.1	-	-	2.3	6.6	-	-	2.3	8.8	-	-	A
4	Obollo-Etiti	6.8997	7.5525	353.3	1867.8	44540.2	-	-	2.5	2.7	-	-	2.5	5.2	-	-	A
5	Ogbelle Road	6.9120	7.5200	388.8	223.7	4220.1	-	-	5.0	4.2	-	-	5.0	9.3	-	-	H
6	Iheakpu Obollo 1	6.9161	7.5070	291.8	409.5	31183.6	-	-	3.9	2.4	-	-	3.9	6.3	-	-	A
7	Iheakpu Obollo 2	6.9160	7.5021	391.9	2188.5	8290.2	32650.0	-	0.7	18.2	25.2	-	0.7	18.9	44.1	-	AA
8	Iheakpu Ol	6.9171	7.4982	627.6	2028.4	3680.6	31111.1	-	3.0	4.5	7.6	-	3.0	7.5	15.1	-	AA
9	Ugbaike 1	6.9571	7.5018	2144.6	4166.8	3492.3	14192.4	-	1.9	3.8	6.4	-	1.9	5.7	12.1	-	KH
10	Ugbaike 2	6.9609	7.4977	1269.9	1371.5	3054.3	29058.8	-	2.6	9.8	22.5	-	2.6	12.4	34.9	-	AA
11	Amufie 1	6.9587	7.4887	1717.9	2832.6	3650.5	28189.8	-	0.6	15.9	24.2	-	0.6	16.5	40.8	-	AA
12	Amufie 2	6.9568	7.4808	1392.7	2650.6	11930.8	5686.6	-	1.1	6.1	38.7	-	1.1	7.3	46.0	-	AK
13	Olido	6.9507	7.4671	351.6	1279.8	1855.0	33627.1	-	0.5	8.4	10.4	-	0.5	8.9	19.2	-	AA
14	Umuida 1	6.9859	7.4140	359.5	190.0	21978.4	-	-	4.5	5.6	-	-	4.5	10.1	-	-	H
15	Umuida 2	6.9854	7.4018	339.4	1481.3	1639.7	5246.8	-	1.6	5.3	12.3	-	1.6	7.0	19.3	-	AA
16	Eya-Umui	6.9928	7.3916	751.6	1622.8	1384.1	21792.2	-	1.8	4.3	10.8	-	1.8	6.1	16.9	-	KH
17	Eya-Umui	6.9937	7.3876	685.5	1403.1	1632.5	6860.4	-	1.2	4.3	5.0	-	1.2	5.5	10.5	-	AA
18	Orie Igbo-I	6.9050	7.4683	247.2	1857.9	1184.2	15226.4	-	0.6	3.1	9.7	-	0.6	3.7	13.4	-	KH
19	Amagu-Ihe	6.9068	7.4646	436.5	2639.8	841.4	13403.2	-	1.6	4.8	10.8	-	1.6	6.4	17.2	-	KH
20	Ugo-Iheak	6.9091	7.4603	86.2	1633.2	456.3	29223.9	-	0.5	2.6	8.4	-	0.5	3.1	11.5	-	KH
21	Ekoyi-Ihea	6.9102	7.4555	382.9	949.0	997.7	3059.0	-	1.9	6.1	16.8	-	1.9	8.0	24.8	-	AA
22	Iheakpu Av	6.9149	7.4172	463.9	1366.0	614.7	16901.0	-	1.1	4.6	12.8	-	1.1	5.7	18.5	-	KH
23	Oruku Ihea	6.9172	7.4214	192.9	438.6	1175.5	4172.8	-	1.9	5.9	16.0	-	1.9	7.7	23.7	-	AA
24	Uhunower	6.9182	7.4254	134.5	665.4	837.7	7095.8	-	1.1	9.0	21.5	-	1.1	10.1	31.6	-	AA
25	Achara Uh	6.9194	7.4308	205.1	306.7	605.8	11242.9	-	3.0	1.9	3.4	-	3.0	4.9	8.4	-	AA
26	Isi-Uzo Uh	6.9204	7.4280	76.6	405.5	245.5	1949.0	-	0.8	3.4	11.3	-	0.8	4.2	15.4	-	KH
27	University Sec.Sch.Ul	6.8618	7.3979	300.4	1517.9	754.8	2402.5	-	0.6	2.3	24.0	-	0.6	2.9	26.9	-	KH
28	Onuiyi Roa	6.8700	7.3960	140.1	1022.9	229.3	13726.3	-	1.8	4.3	10.9	-	1.8	6.1	17.0	-	KH
29	Ugbene Al	6.8677	7.3839	172.4	989.0	485.8	4768.0	-	0.7	2.3	8.6	-	0.7	3.0	11.6	-	KH
30	Ekoyi Alor	6.8771	7.3811	320.3	548.8	547.5	2797.5	-	5.6	4.6	18.1	-	5.6	10.3	28.3	-	KH
31	Obukpa Ns	6.8880	7.3708	174.1	339.7	590.4	17281.0	-	0.5	8.2	5.8	-	0.5	8.7	14.5	-	AA
32	Ibagwa An	6.8949	7.3587	114.2	2.7	13.1	824.9	-	1.0	1.9	1.6	-	1.0	2.9	4.5	-	HA
33	Ebugwu Ib	6.9005	7.3323	28.0	968.9	3079.2	2374.3	-	0.3	25.7	38.2	-	0.3	26.0	64.2	-	AK
34	Isi-Uja Nsu	6.8645	7.4092	367.0	2118.8	930.6	16971.0	-	1.4	4.4	51.4	-	1.4	5.8	57.2	-	KH
35	Amagbo N	6.8762	7.3874	16.8	453.9	96.2	1143.8	-	0.4	1.5	3.8	-	0.4	1.9	5.7	-	KH

Table 2: First layer resistivity values for hydrogeophysical parameters

Ves	Location	Latitude (°N)	Longitude (°E)	Resistivity layer1(ρ_1)	Hydraulic cond; K1(m/day)	Porosity $Ø_1$(%)
1	Obollo-Afor Central	6.9144	7.5209	72.7	7.088298	34.313
2	Ogwu Road	6.9066	6.5273	144.1	3.7443	31.44106
3	Umuitodo	6.9219	7.5366	957.9	0.639694	23.48956
4	Obollo-Etiti	6.8997	7.5525	353.3	1.622005	77.67648
5	Ogbelle Road	6.9120	7.5200	388.8	1.483415	27.27456
6	Iheakpu Obollo 1	6.9161	7.5070	291.8	1.938794	28.4793
7	Iheakpu Obollo 2	6.9160	7.5021	391.9	1.472467	27.24123
8	Iheakpu Obollo 3	6.9171	7.4982	627.6	0.949018	25.26453
9	Ugbaike 1	6.9571	7.5018	2144.6	0.301618	20.10633
10	Ugbaike 2	6.9609	7.4977	1269.9	0.491754	22.306
11	Amufie	6.9587	7.4887	1717.9	0.370966	21.0376
12	Amufie 2	6.9568	7.4808	1392.7	0.451183	21.91853
13	Olido	6.9507	7.4671	351.6	1.62932	27.69673
14	Umuida 1	6.9859	7.4140	359.5	1.595896	27.60346
15	Umuida 2	6.9854	7.4018	339.4	1.683888	27.84497

16	Eya-Umuida 1	6.9928	7.3916	751.6	0.802103	24.50767
17	Eya-Umuida 2	6.9937	7.3876	685.5	0.874026	24.8941
18	Orie Igbo-Eze	6.9050	7.4683	247.2	2.263235	29.17558
19	Amagu-Iheaka	6.9068	7.4646	436.5	1.331621	26.78879
20	Ugo-Iheaka	6.9091	7.4603	86.2	6.046971	33.59801
21	Ekoyi-Iheaka	6.9102	7.4555	382.9	1.504727	27.33875
22	Iheakpu Awka 1	6.9149	7.4172	463.9	1.258104	26.53323
23	Oruku Iheakpu Awka	6.9172	7.4214	192.9	2.852401	30.21673
24	Uhunowere Central	6.9182	7.4254	134.5	3.993017	31.73046
25	Achara Uhunowere	6.9194	7.4308	205.1	2.693805	29.9593
26	Isi-Uzo Uhunowere	6.9204	7.4280	76.6	6.75106	34.09365
27	University Sec. UNN	6.8618	7.3979	300.4	1.886967	28.35737
28	Onuiyi Road	6.8700	7.3960	140.1	3.843928	31.55923
29	Ugbene Alor Uno	6.8677	7.3839	172.4	3.167583	30.68836
30	Ekoyi Alor Uno	6.8771	7.3811	320.3	1.777372	28.08811
31	Obukpa Nsukka	6.8880	7.3708	174.1	3.138722	30.64717
32	Ibagwa Ani 1	6.8949	7.3587	114.2	4.651408	32.41726
33	Ebugwu Ibagwa Ani	6.9005	7.3323	28.0	17.26174	38.31822
34	Isi-Uja Nsukka	6.8645	7.4092	367.0	1.565452	27.51678
35	Amagbo Nsukka	6.8762	7.3874	16.8	27.79917	40.46253

Table 3: Classification of VES curve types

VES Curve Type	VES Curve characteristics	Remarks
H-Type or Bowl Curve	$\rho_1 > \rho_2 < \rho_3$	It occurs where the intermediate resistivity layer is lower
K-curve or Bell Curve	$\rho_1 < \rho_2 > \rho_3$	Occurs where the intermediate resistivity layer is higher
A-curve or Ascending Curve	$\rho_1 < \rho_2 < \rho_3$	Occur where resistivities successively increase
Q-Type or Descending Curve	$\rho_1 > \rho_2 > \rho_3$	Occur where resistivities successively decrease

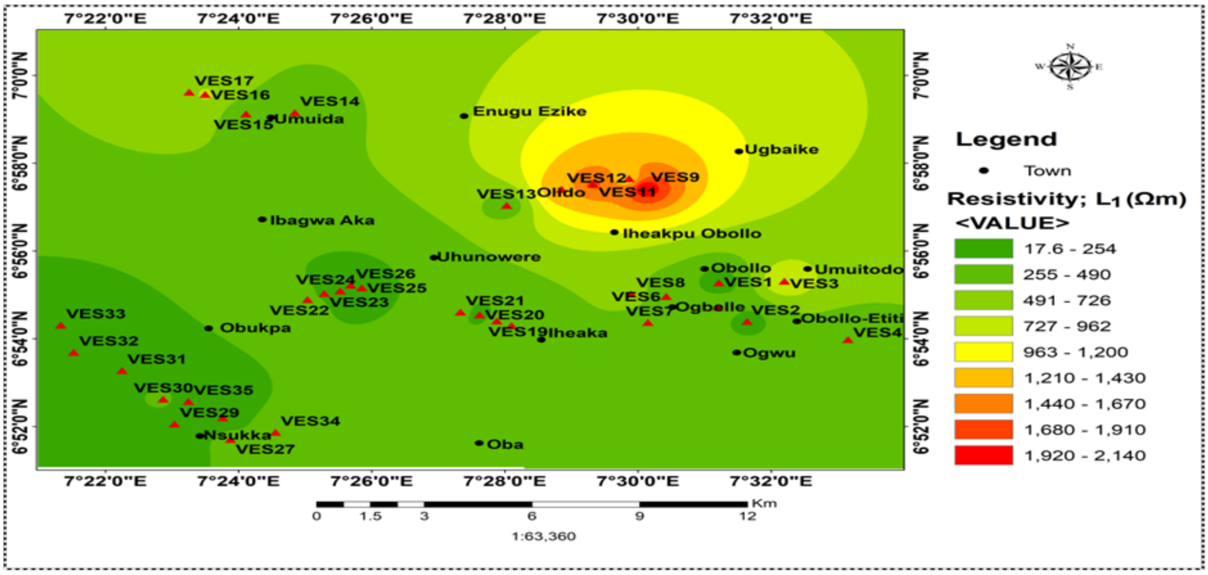

Figure 7: First layer resistivity contour map

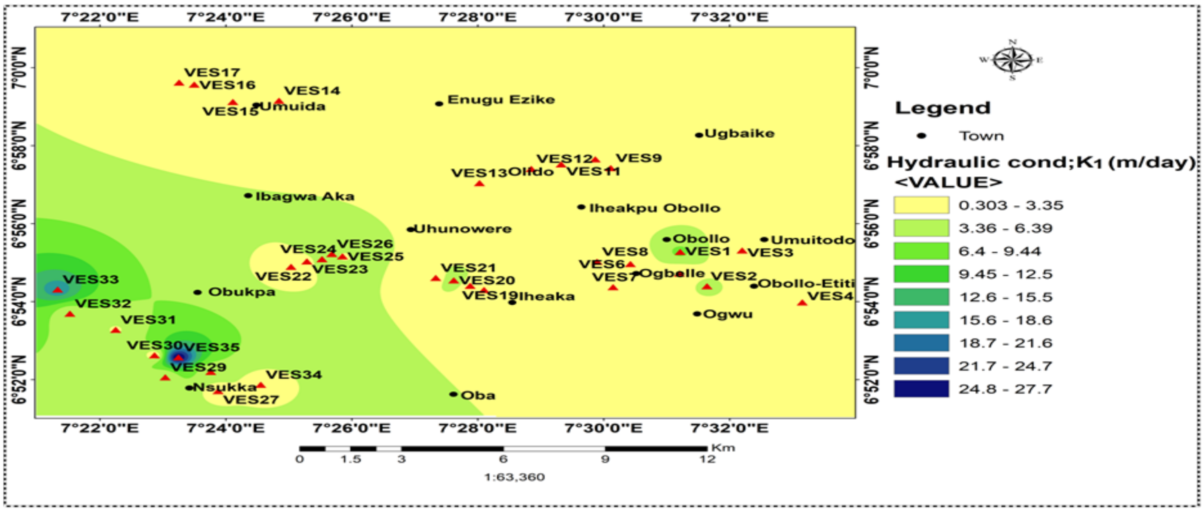

Figure 8: Hydraulic conductivity (1 layer)

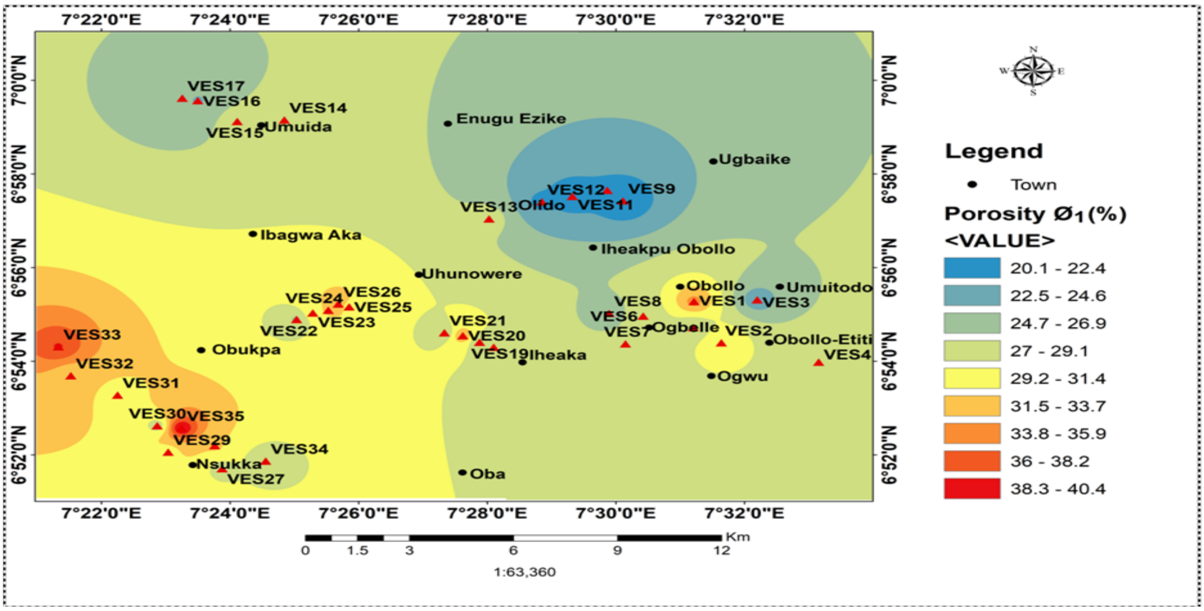

Figure 9: Porosity contour map (1 layer)

Result of Geotechnical Survey

The soil samples obtained from Igbo-eze south, Igbo-eze north, Nsukka and Udenu local government areas were analyzed in the Soil Science Department Laboratory of University of Nigeria, Nsukka, in view to obtain the information on the soil, based on particle size distribution, porosity test, hydraulic conductivity test and water holding capacity that form parts of the geotechnical parameters. The Table 4 is the summary results for the geotechnical analysis applied in this work.

The textural classification of soil was mainly loamy, sandy and clayey, with percentage clay ranged from 8% to 18%, percentage silt ranged from 3% to 9%, percentage fine sand ranged from 20% to 38% and percentage coarse sand ranged from 29% to 69%. The particle size distribution results indicate that the study areas were majorly dominated with fine and coarse sandy soil with low layers of clay and silt in such small proportion. The implication is that the presence of this sandy soil contributes immensely to the gully erosion menace in the area, as its porosity and permeability nature were weak to erosion protective capacity. The moisture content ranged from 7.07% to 31.73% respectively. The low moisture content value shows that the soils are loose and hence cannot hold much water. According to Okagbue and Ezechi (1988), such low moisture contents cause breakdown on the soil structure. The value percentage of total porosity ranged from 41.13% to 47.55%. The results shows that the gully sample within Igbo-Eze South anf Nsukka have relatively medium porosity, which indicates sandy soil with larger macro-pores. Within Igbo-Eze North and Udenu, indicates decrease in porosity values showing fine textures with micro porosity. Hydraulic conductivity value ranges from 8.89m/day to 22.73m/day. These results indicates that area with low value of conductivity were majorly dominated with silt, clay soil or the compatibility of soil is high, whereas area with relatively increase in hydraulic conductivity value shows that the textural class is more of loose materials such as sandy soil or the area has more of bio activities like decays of roots crop and activities of other insect. According to Freeze and Cherry (1979) states that the hydraulic conductivity is evaluated based on grain size for common geological media. Therefore, the relatively high range of value of hydraulic conductivity shows that the area has low protective capacity and hence increases erosion in the area.

Table 4: Section of geotechnical survey results

S/No	Sample Description	Hydraulic Conductivity (Permeability) (cm^3/hr)	% Total Porosity	Particle Size Distribution					%Moisture Content
				Textual Class	%Clay	% Silt+	%Fine Sand (F.S)	%Coarse Sand (C.S)	
1	IGBO-EZE SOUTH L.G.A	8.89	47.55	Sandy Loam	14	3	38	45	24.38
2	IGBO-EZE NORTH L.G.A	16.16	41.13	Loam Sand	8	3	22	67	7.07
3	NSUKKA L. G. A	14.14	45.28	Sandy Loam	18	9	44	29	31.73
4	UDENU L. G. A	22.73	41.51	Loam Sand	8	3	20	69	8.34

Result Comparison

The results obtained using VES data and geotechnical data is comparatively related as shown on the Table 5. The textural classes for both vertical electrical sounding and geotechnical analysis results identified similar dominance of sandy soil in large proportion in the study area. Other classes identified include clay, loamy and scarcely silt. The porosity values obtained from the methods employed differs little with each other. The differences observed may be attributed to the processes involved in the research method. The maximum porosity values obtained from VES data ranged from 27.85 to 40.46%. The geotechnical values for porosity ranged from 41.13 to 45.28%. The porosity values obtained from VES data were the values gotten from the calculated apparent resistance measured from the field using resistivity meter, whereas the porosity results obtained from geotechnical analysis were purely laboratory analysis. This laboratory analysis involved direct measurements and readings from the soil sample. Therefore, the differences noticed in the range of values of those methods may be attributed to the approach adopted for each of the methods employed. Consequently, the calculated maximum hydraulic conductivity values for VES data ranged from 1.68 to 27.79 m/day, and that for geotechnical values ranged from 8.89 to 22.73 cm^3/hr. The variations in the values may be attributed to the fact that the parameters employed for the analysis differs. But, all the parameters compared have the same directional effect on the soil vulnerability to erosion in the study area.

Table 5: Summary of comparison of methods employed

Nsukka zone	K-values for VES	K-values for Geotech	%Porosity for VES	%Porosity for Geotech	Textual classesof soil (VES)	Textual classes of soil (GEOTECH)
Igbo-Eze-North LGA	1.68	16.16	27.85	41.13	Sandy layer, dry clay and silt	Sandy loam, silt in small proportion, clay, more of fine and coarse sand
Udenu LGA	7.09	22.73	34.313	41.51	Coarse & loose sandy soil, silt & clay	Sandy loam, small silt and clay, more of fine and coarse sand
Igbo-Eze South LGA	6.75	8.89	34.09	47.55	silt, sandy layers and presence of clay	Presence of sandy loam, silt, clay, fine and coarse sand
Nsukka LGA	27.79	14.14	40.46	45.28	Sandy layers, silt, clay and bedrock	fine & coarse sand, sandy loam & silt in small proportion

Conclusion

The VES results obtained in parts of Nsukka zone, Southeastern Nigeria show that there are factors responsible for the menace of gully erosion in the study area. Low resistivity layers show dominance of motley topsoil which constitutes mainly sandy or loose soil materials which is very permeable and therefore vulnerable to erosion. Indication from high resistivity values shows that soil structure in some parts of the study areas has compacted soil layers with layers of silt, clay soil and bedrock. The hydraulic conductivity shows that the measure of the ability of water to flow through the soil is very high. The porosity result indicates that the amounts of pores or open space between the soil particles is high and therefore, contribute majorly to the factor influencing the gully erosion in Nsukka zone. The geotechnical analyses which identify coarse sand, fine sand, clay and silt in small percentage greatly influences the gully erosion in the area. These soil particles are loosed, friable and low binding materials with less cohesive. Unstability of soil structure and low moisture content as observed also influences the rate of erosion in the area. Bio-activities such as termites, earthworm and decaying plant root increases the porosity of the soil and permittivity. Other field observation factors include; climate change, topography, deforestation, bush burning that distort the texture of the soil and other anthropogenic factors contribute to the menace of gully erosion in Nsukka zone.

Recommendations

Engineering soil control such as check-dams, construction of ditches, maintenance of roads and drainage system should be employed to control erosion in these areas. Afforestation and other agro programs should be introduced to protect the soil from direct impact of raindrops and runoff. Government should set up committee to checkmate human activities such as faming, bush burning, digging of sand, indiscriminate dumping of waste at erosion site. Constant geotechnical estimation should be carried on the soil to assess changes in the soil properties and the environment.

References

[1]. Abdullahi MG, Toriman ME, Gasim MB (2015) The Application of Vertical Electrical Sounding (VES) for Groundwater Exploration in Tudun Wada Kano State, Nigeria. J Geol Geosci 4: 186. doi: 10.4172/2329-6755.1000186

[2]. Adegbola, R. B., Oseni S. O., Sovi, S. T Oyedele, K. F. and Adeoti, L. (2010). Subsurface Characterization and its Environmental Implications using the Electrical Resistivity Survey: Case with LASU Foun dation Programme Campus Badagry, Lagos State, Nigeria. Nature and Science. 8(8) pp. 146-151.

[3]. Akpokodje, E. G., Olorunfemi, B. N., and Etu-Efeotor, J. O. (1986). Geotechnical Properties of Soils Susceptible to Erosion in Southeastern Nigeria. Nigeria Journal App. Sci. 3 (1): 81-95.

[4]. Amagu, A. C., Eze, S. N., Jun-ichi, K. and Nweke, M. O. (2018). Geological and Geotechnical Evaluation of Gully Erosion at Nguzu Edda, Afikpo Sub-Basin, Southeastern Nigeria. Journal of Environment and Earth Science, 8(12): 148-158.

[5]. Amangabara, G. T. and Otumchere, V. N. (2016). Understanding the Factors and Processes of the Umuagwo –Urualla Gully Erosionin Ideato North LGA of Imo State, Nigeria. Journal of Scientific and Engineering Research, 3(1):55-67.

[6]. Chikwelu, E. E. and Ogbuagu, F. U. (2014). Geotechnical Investigation of Soil around Mbaukwu Gully Erosion Sites, South-Eastern Part of Nigeria. Journal of Applied Geology and Geophysics, 2: 06-17.

[7]. Ekwueme, O. U., Obiora, D. N., Okeke, F. N., Ibuot, J. C. (2021). Environmental assessment of gully erosion in parts of Enugu north, Southeastern Nigeria. Indian Journal of Science and Technology 14(29): 2400-2409. https://doi.org/ 10.17485/IJST/v14i29.933

[8]. Evans, U. F. (2006). A Study of Superficial Sediments and Aquifers in Parts of Uyo L.G.A., Akwa Ibom State using Electrical Method. Unpublished Masters Thesis, Department of Physics, University of Calabar, Calabar, Nigeria.

[9]. Ezechukwu, I.A. and Madubuike, C.N. (2015). Environmental Impact Assessment of Gully Erosion in Umuoji, Idemili North L.G.A in Anambra State. International Journal of Engineering and Science,4 :44-53

[10]. Freeze, R. A. and Cherry, J. A. (1979). Groundwater. Prentice-Hall Inc., Englewood cliffs, New Jersey, 7632:604.

[11]. Hassan E, Rai JK and Anekwe UO (2017) Geoelectrical Survey of Ground Water in Some Parts of Kebbi State Nigeria, a Case Study of Federal Polytechnic Bye-Pass Birnin Kebbi and Magoro Primary Health Center Fakai Local Government. Scientific & Academic Publishing, 7(5): 141-149.

[12]. Heigold PC, Gilkeson RH, Cartwright K and Reed PV (1979) Aquifer transmissivity from surficial electrical method, Groundwater, 17(14): 338-345.

[13]. Igboekwe, M. U., Eke, A. B., Adama, J. C. and Ihekeaba, G. (2012). The use of vertical electrical sounding (VES) in the evaluation of erosion in Abia state University, Uturu and its environs. The Pacific Journal of Science and Technology, 13(2):509-520.

[14]. Imasuen, O. I., Omali, A. O. and Ibrahim, I. (2011). Assessment of environmental impacts and remedies for gully erosion in Ankpa Metropolis and environs, Kogi State, Nigeria. Advances in Applied Science Research, 2 (5): 372-384.

[15]. Jatau BS, Patrick NO, Baba A and Fadele SI (2013) The use of Vertical Electrical Sounding (VES) for Subsurface Geophysical Investigation around Bomo Area, Kaduna State, Nigeria. Journal of Engineering, 1 (3): 10-15.

[16]. John UJ, Igboekwe MU and Uhegbu CA (2015) Geophysical Evaluation of Erosion Sites in some Parts of Abia State, Southeastern Nigeria. Physical Science International Journal, 6(2): 66-81.

[17]. Kearey, P. and Brooks, M. (1991). An Introduction to Geophysical Exploration. London: Blackwell Scientific Publication.

[18]. Keller, G. V. and Frischknecht, F. C. (1966). Electrical methods in geophysical prospecting. Pergamon Press Inc., Oxford.

[19]. Loke MH (2009) Electrical Imaging Surveys for Environmental and Engineering Studies, A Guide to 2D and 3D Surveys. Workshop held in USM.

[20]. Meindinyo ROK, Utuedeye O and Adedokun IO (2017) Vertical Electrical Sounding (Ves) for the determination of underground resistivity in part of Nigeria Wilberforce Island, Amassoma, Bayelsa State. Journal of Research & Method in Education, 3(7): 53-61.
[21]. Niwas, S., and de Lima, O. A. (2003). Aquifer parameter estimation from suface resistivity data. Ground Water, 41(1), 94-99.
[22]. Obiefuna, G. I. and Adamu, J. (2012). Geological and Geotechnical Assessment of Selected Gully Sites in Wuro Bayare Area NE Nigeria. Research Journal of Environmental and Earth Sciences, 4(3): 282-302.
[23]. Obi, N. I. and Okekeogbu, C. J. (2017). Erosion Problems and their Impacts in Anambra State of Nigeria: (A case of Nanka community). International Journal of Environment and Pollution Research, 1 (5): 24-37.
[24]. Okagbue CO, and Ezechi JO. (1988). Geotechnical Characteristics of Soils Susceptible to Severe Gullying in Eastern Nigeria. Bulletin of the International Association of Engineering Geology; 38: 111.
[25]. Okengwo, O. N., Okeke, O. C., Okereke, C. N. and Paschal, A. C. (2015). Geological and Geotechnical Studies Of Gully Erosion at Ekwulobia, Oko and Nanka Towns, Southeastern Nigeria. Electronic Journal of Geotechnical Engineering, 20: 114-122.
[26]. Okoyeh, E. I., Akpan, A. E., Egboka, B. C. E. and Okeke, H. I.(2014). An Assessment of the Influences of Surface and Subsurface Water Level Dynamics in the Development of Gullies in Anambra State, Southeastern Nigeria. Earth Interactions, 4(18):1-24.
[27]. Okunlola, I. A., Abdulfatai, I. A., Kolawole, L. L. and Amadi, A. N. (2014). Geological and Geotechnical Investigation of Gully Erosion along River Bosso, Minna, North Central Nigeria. Journal of Geosciences and Geomatics, 2(2): 50-56.
[28]. Olawuyi AK and Abolarin SB (2013) Evaluation of Vertical Electrical Sounding Method for Groundwater Development in Basement Complex Terrain of West-Central Nigeria. Nigerian Journal of Technological Development, 2(10): 22-28.
[29]. Telford, W. M., Geldart, L. P. and Sheriff, R. E. (1990). Applied Geophysics, 2nd edition. Cambridge University Press.
[30]. Uhegbu, C. A. and John, U. J. (2017). Geophysical and Geotechnical Evaluation of Erosion Sites in Ebem-Ohafia Area of Abia State, Southern Nigeria. Advances in Research, 10(3):1-14.
[31]. Umoru, C. I., Shuaibu, A. M., Abdullahi, I. N. and Umar, M. U. (2015). Geotechnical Assessment of Gully Erosion at Ankpa Area, North Central Nigeria. Journal of Applied Chemistry, 8: 36-48.
[32]. Zeyad, H. A. H. (2017). Use of Electrical Resistivity Methods (2-D and VES) in Proposed Landfill Site Investigation – A Case Study of Al Fukhari Landfill, Southeastern Gaza Strip, Palestine. Journal of Environment and Earth Science, 7(3):119-127
[33]. Zohdy, A. A. R. (1965). The auxiliary point method of electrical sounding interpretation and its relationship to the Dar-Zarrouk parameters. Geophysics, 30(4): 644-660.