STM JOURNALS
Research & Reviews: Journal of Physics
ISSN: 2278-2265(online), ISSN: 2347-9973(print)
Volume 4, Issue 3
www.stmjournals.com

Geophysical Determination of Water Bearing Formation Using 2-Dimensional Geo-Electrical Resistivity Imaging in Ologbo Area of Edo State

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Abstract

2-Dimensional Geoelectrical Resistivity Imaging Survey was carried out to locate water bearing formation at Ozolua road (line 12) and Lonestar area (line 19) in Ologbo, Ikpoba-Okha Local Government area of Edo State, Nigeria. Wenner – Schlumberger Array was carried out to map the electrical properties as an aid to characterizing the subsurface conditions using Petrozenith Earth Resistivity Meter. A total of seventy-eight soundings were obtained in each of the areas and the field data was processed and inverted using zondres2d software to obtain 2-dimensional true resistivity of the subsurface. In the first profile, the resistivity range lies between 350 to about 10000 Ωm, indicating variation in soil matrix, grain size distribution and water saturation. The decrease in resistivity at a depth below the top soil along the bottom right of the profile indicates the presence of saturated soil. In the second profile, the study reveals the range of spatial distribution of sand deposits with large quantity of gravel indicated by high resistivity of about 10000 Ωm. The resistivity of the study areas suggest that the near surface materials comprises of coarse sand and gravel while the underlying deeper materials also has high resistivity values. The resistivity values of the models probably indicates presence of water bearing formation in the survey area at greater depth of penetration. It is suggested that more research should be carried out so as to probe deeper into the formation in other to get to the aquifer table.

Keywords: *2D resistivity imaging, pseudosection, water, Ologbo*

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INTRODUCTION

About 75% of the earth's surface is covered by water yet qualitatively 97% of this vast natural resource falls unfit for human use [1]. Though groundwater contributes only 1% of the earth's total water resources, it has strategically remained valuable as the major and preferred source of drinking water because of its naturally high quality and availability in the face of surface water reservoir maintenance, culture deficiency and regular supply inconsistencies [2].

Intermittent clean water supply shortages are major problems of the inhabitants of the Ologbo area, Edo state, Nigeria. The role of surface geophysical tools for evaluating groundwater resources is documented in the literature [3–5]. As aquifers become more exploited and the number of contaminated land areas is increasing, special attention is paid to 2D geoelectrical resistivity Imaging techniques, which present useful advantages in a cost-effective way on a different scale over most common methods centred on point investigations and trace tests [6]. Electrical resistivity method can be used to obtain, quickly and economically, details about the location, depth and resistivity of subsurface formations, [7].

RESISTIVITY THEORY

The purpose of electrical surveys is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, the true resistivity of the subsurface can be estimated.

Consider a current flowing through a homogenous cylindrical wire of length (L), cross sectional area (A) and resistance R shown in Figure 1.

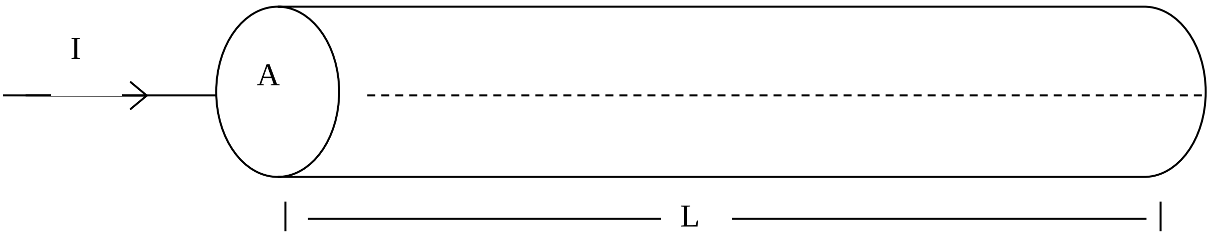


Fig 1: *Current Flowing Through a Homogenous Cylindrical Wire.*

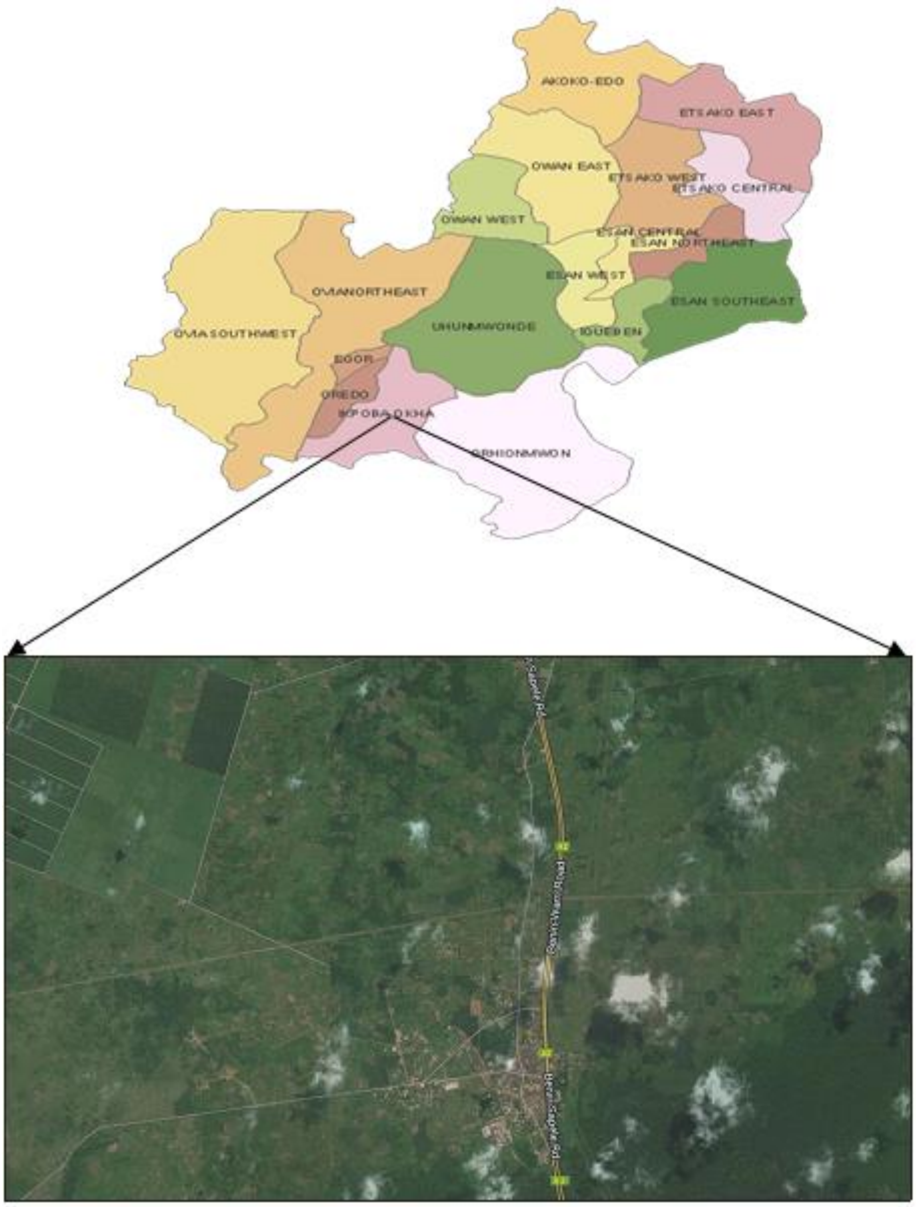


Fig 2: *Satellite Image of Ologbo Area (Source: Google Earth).*

The resistance (R) of the wire to current flow can be expressed as:

$$R \propto \frac{L}{A} \qquad (2.1)$$

$$R = \rho \frac{L}{A} \qquad (2.2)$$

Where

ρ is the resistivity (in ohm – metre), a proportionality constant indicating the ability of the conductor to oppose a flow of charge.

L is the length of wire (in meter)

A is the cross sectional area of the wire (meter square)

R is the resistance (in ohm)

I is the current (ampere)
From ohm's law

$$R = \frac{\Delta V}{I} \quad (2.3)$$

$$\frac{\Delta V}{I} = \rho L/A \quad (2.4)$$

The fundamental equation governing direct-current electrical prospecting is

$$\rho = K\frac{\Delta V}{I} \quad (2.5)$$

Where:

$$K = \frac{2\pi}{\left\{\left(\frac{1}{r_1} - \frac{1}{r_2}\right) - \left(\frac{1}{r_3} - \frac{1}{r_4}\right)\right\}} \quad (2.6)$$

K is known as the geometric factor. Thus, by evaluating the value of K using equation (2.6), and measuring resistance, we obtain resistivity, ρ.This measured quantity is known as the *apparent resistivity*, ρ_a for an inhomogeneous earth.

THE STUDY AREA

Ologbo is located within the Benin Formation in the Niger Delta Basin. The whole area of Ologbo is underlain by sedimentary rocks. These rocks are of ages between Paleocene to recent. The sedimentary rocks are made up of 90% sandstone with shales intercalations. The sedimentary rock is a coarse grain, gravelly, locally fined, poorly sorted, sub angular to well round and bears lignite streaks and wood fragment [8]. The Benin formation has high underground water potential due to low percentage of clay layers. The formation is about 180m thick. It is the youngest formation. [9].The overburden is made up of mainly unconsolidated sediments: clay and sand (Figure 2).

METHODOLOGY

The data was acquired using the Petrozenith earth resistivity meter. The Wenner-Schlumberger hybrid array was adopted. This enabled the build-up of a pseudosection. With the geometric factor K for the array used, the resistance value readings were converted to apparent resistivity. Two locations were investigated in Ologbo Area of Edo State. A total of seventy-eight Wenner-Schlumberger soundings were done in each of the areas (Figure 3).

The K factor is given by

$$K = \pi an(n+1) \quad (4.1)$$

$$K = \pi \times 5 \times 1(1+1) = 31.42 \quad (n=1) \qquad K = \pi \times 5 \times 2(2+1) = 94.26 \quad (n=2)$$

$$K = \pi \times 5 \times 3(3+1) = 188.52 \quad (n=3) \qquad K = \pi \times 5 \times 4(4+1) = 314.2 \quad (n=4)$$

$$K = \pi \times 5 \times 5(5+1) = 471.3 \quad (n=5) \qquad K = \pi \times 5 \times 6(6+1) = 659.82 \quad (n=6)$$

The Petrozenith meter gives the value V/I *which is our* R(*resistance*). *We multiply this value with the geometric factor* K *for each level to get our* ρ_a (*apparent resistivity*)

Table 1 & 2 *displays the various readings*

Maximum depth of penetration is given by

$$d = 0.217 \times L$$

$$d = 0.217(2an + a)$$

$$d = 0.217(2 \times 5 \times 6 + 5) = 14.11m$$

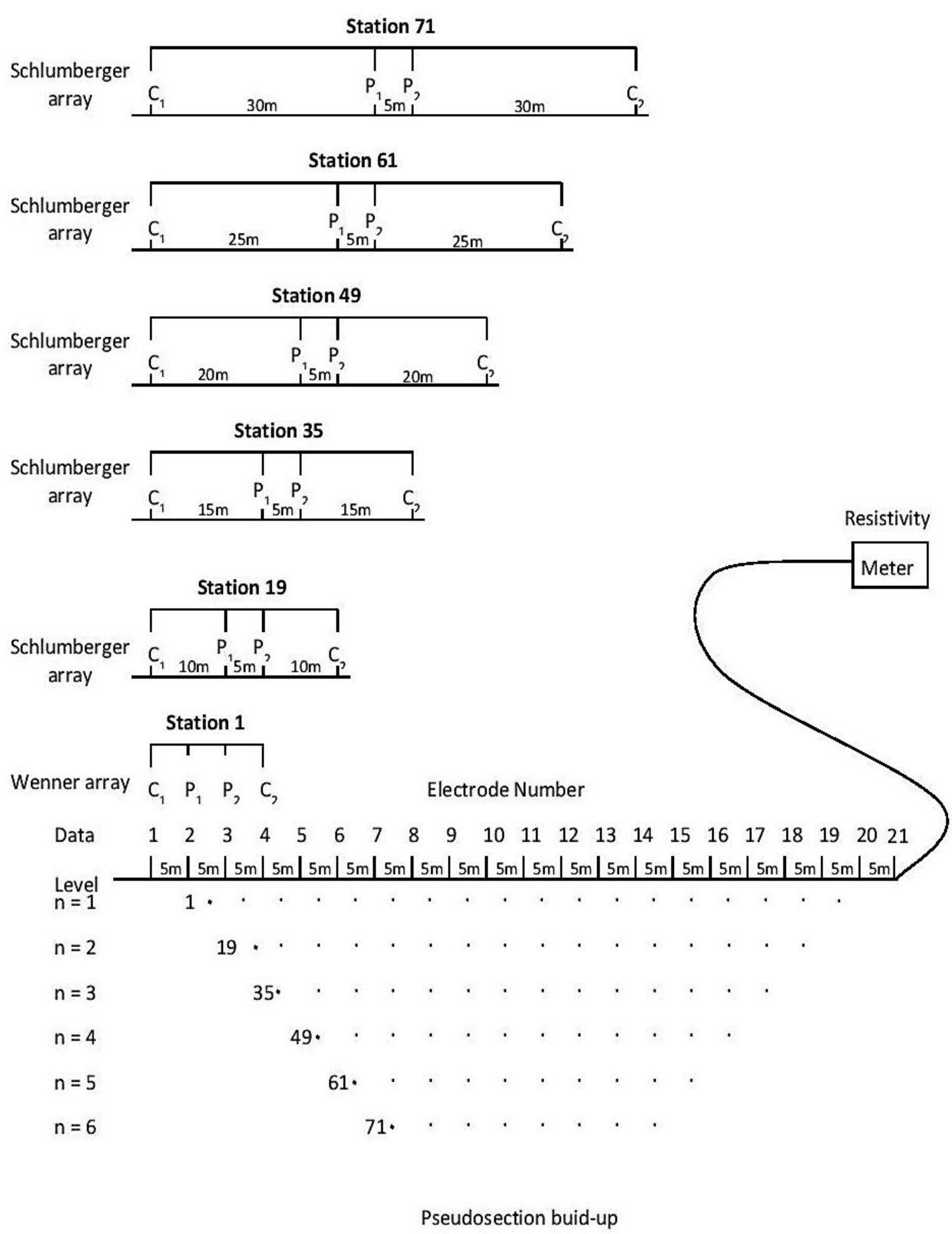


Fig. 3: *Wenner-Schlumberger Array Used In Acquiring The Data.*

RESULTS, ANALYSIS AND DISCUSSION

2D dimensional electrical resistivity imaging provides both vertical and lateral image of the subsurface thus enhancing continuity. The true resistivity model of the subsurface was obtained by inverting the data obtained using the ZONDRES2D software. The resistivity Table 1 and Table 2 for the two lines are shown below:

Research & Reviews: Journal of Physics
Volume 4, Issue 3
ISSN: 2278-2265(online), ISSN: 2347-9973(print)

Table 1: *Line 12 Data Sheet.*

		2D Electrical Resistivity Imaging Field Data Report Sheet				
	Array type	Wenner-Schlumberger	DATE	4-04-2014		
	Instrument used	Petrozenith Earth Resistivity Meter	STATE	Edo		
	Location	Ozolua Road	LGA	Ikpoba Okha		
	Line number	L12	Town	Ologbo		
	Observer	-				
	Begin coordinate/altitude	N6^{o} 04.411' , E005^{0} 39.327' / 25.1m				
	End coordinate/altitude	N6^{o} 04.409' , E005^{0} 39.380' / 25.1m				
	GEOMETRICAL FACTOR: 31.42	ELECTRODES SPACING : 5m				
S/No	C1	P1	P2	C2	R (Ω)	ℓa (Ωm)
1	0	5	10	15	142.8	4486.776
2	5	10	15	20	99.79	3135.402
3	10	15	20	25	117.42	3689.336
4	15	20	25	30	94.02	2954.108
5	20	25	30	35	118.72	3730.182
6	25	30	35	40	114.17	3587.221
7	30	35	40	45	112.58	3537.264
8	35	40	45	50	116.76	3668.599
9	40	45	50	55	99.1	3113.722
10	45	50	55	60	99.43	3124.091
11	50	55	60	65	89.09	2799.208
12	55	60	65	70	80.88	2541.25
13	60	65	70	75	84.81	2664.73
14	65	70	75	80	73.94	2323.195
15	70	75	80	85	73.32	2303.714
16	75	80	85	90	89.76	2820.259
17	80	85	90	95	108.09	3396.188
18	85	90	95	100	105.31	3308.84
	GEOMETRICAL FACTOR: 94.26	ELECTRODES SPACING : 10m				
1	0	10	15	25	38.28	3608.273
2	5	15	20	30	42.57	4012.648
3	10	20	25	35	27.97	2636.452
4	15	25	30	40	60.46	5698.96
5	20	30	35	45	41.69	3929.699
6	25	35	40	50	39.5	3723.27
7	30	40	45	55	42.87	4040.926
8	35	45	50	60	36.64	3453.686
9	40	50	55	65	33.15	3124.719
10	45	55	60	70	34.22	3225.577
11	50	60	65	75	32.86	3097.384
12	55	65	70	80	33.89	3194.471
13	60	70	75	85	38.83	3660.116
14	65	75	80	90	29.54	2784.44
15	70	80	85	95	36.23	3415.04
16	75	85	90	100	57.09	5381.303

	GEOMETRICAL FACTOR: 188.52	ELECTRODES SPACING: 15m				
1	0	15	20	35	21.08	3974.002
2	5	20	25	40	19.6	3694.992
3	10	25	30	45	21.29	4013.591
4	15	30	35	50	19.54	3683.681
5	20	35	40	55	18.43	3474.424
6	25	40	45	60	20.12	3793.022
7	30	45	50	65	18.46	3480.079
8	35	50	55	70	18.04	3400.901
9	40	55	60	75	19.1	3600.732
10	45	60	65	80	18.02	3397.13
11	50	65	70	85	16.38	3087.958
12	55	70	75	90	17.85	3365.082
13	60	75	80	95	16.57	3123.776
14	65	80	85	100	18.33	3455.572
	GEOMETRICAL FACTOR: 314.2	ELECTRODES SPACING: 20m				
1	0	20	25	45	11.12	3493.904
2	5	25	30	50	14.25	4477.35
3	10	30	35	55	13.13	4125.446
4	15	35	40	60	13.74	4317.108
5	20	40	45	65	11.71	3679.282
6	25	45	50	70	10.26	3223.692
7	30	50	55	75	10.5	3299.1
8	35	55	60	80	11.16	3506.472
9	40	60	65	85	10.3	3236.26
10	45	65	70	90	9.59	3013.178
11	50	70	75	95	11.91	3742.122
12	55	75	80	100	9.48	2978.616
	GEOMETRICAL FACTOR: 471.3	ELECTRODES SPACING 25m				
1	0	25	30	55	6.22	2931.486
2	5	30	35	60	5.98	2818.374
3	10	35	40	65	5.81	2738.253
4	15	40	45	70	9.74	4590.462
5	20	45	50	75	6.52	3072.876
6	25	50	55	80	5.83	2747.679
7	30	55	60	85	5.02	2365.926
8	35	60	65	90	4.88	2299.944
9	40	65	70	95	6.42	3025.746
10	45	70	75	100	7.3	3440.49
	GEOMETRICAL FACTO : 659.82	ELECTRODES SPACING : 30m				
1	0	30	35	65	3.83	2527.111
2	5	35	40	70	3.72	2454.53
3	10	40	45	75	5.97	3939.125
4	15	45	50	80	4.35	2870.217
5	20	50	55	85	4.17	2751.449
6	25	55	60	90	4.42	2916.404
7	30	60	65	95	4.48	2955.994
8	35	65	70	100	4.6	3035.172

Table 2: *Line 19 Data Sheet.*

		2d Electrical Resistivity Imaging Field Data Report Sheet				
	Array type	Wenner-Schlumberger	DATE	7-04-2014		
	Instrument used	Petrozenith Earth Resistivity Meter	STATE	Edo		
	Location	Lonestar Area	LGA	Ikpoba Okha		
	Line number	L19	Town	Ologbo		
	Observer	-				
	Begin coordinate/altitude	N6^{o} 03.933’ , E005^{0} 38.784’ / 16.0m				
	End coordinate/altitude	N6^{o} 03.986’ , E005^{0} 38.797’ / 18.2m				
	Geometrical factor : 31.42	ELECTRODES SPACING : 5m				
S/No	C1	P1	P2	C2	R (Ω)	ℓa (Ωm)
1	0	5	10	15	71.44	2244.645
2	5	10	15	20	91.63	2879.015
3	10	15	20	25	88.28	2773.758
4	15	20	25	30	79.02	2482.808
5	20	25	30	35	93.21	2928.658
6	25	30	35	40	1670	52471.4
7	30	35	40	45	82.59	2594.978
8	35	40	45	50	84.74	2662.531
9	40	45	50	55	88.22	2771.872
10	45	50	55	60	81.46	2559.473
11	50	55	60	65	98.24	3086.701
12	55	60	65	70	83.33	2618.229
13	60	65	70	75	99.94	3140.115
14	65	70	75	80	76.29	2397.032
15	70	75	80	85	91.29	2868.332
16	75	80	85	90	90.45	2841.939
17	80	85	90	95	90.98	2858.592
18	85	90	95	100	97.27	3056.223
	GEOMETRICAL FACTOR : 94.26	ELECTRODES SPACING : 10m				
1	0	10	15	25	29.34	2765.588
2	5	15	20	30	30.66	2890.012
3	10	20	25	35	28.82	2716.573
4	15	25	30	40	33.35	3143.571
5	20	30	35	45	31.47	2966.362
6	25	35	40	50	35.63	3358.484
7	30	40	45	55	33.54	3161.48
8	35	45	50	60	40.85	3850.521
9	40	50	55	65	30.49	2873.987
10	45	55	60	70	34.16	3219.922
11	50	60	65	75	37.07	3494.218
12	55	65	70	80	38.42	3621.469
13	60	70	75	85	29.8	2808.948
14	65	75	80	90	35.67	3362.254
15	70	80	85	95	34.41	3243.487
16	75	85	90	100	33.63	3169.964

	GEOMETRICAL FACTOR : 188.52	ELECTRODES SPACING: 15m				
1	0	15	20	35	16.19	3052.139
2	5	20	25	40	17.56	3310.411
3	10	25	30	45	18.68	3521.554
4	15	30	35	50	16.18	3050.254
5	20	35	40	55	18.66	3517.783
6	25	40	45	60	19.13	3606.388
7	30	45	50	65	20.91	3941.953
8	35	50	55	70	15.73	2965.42
9	40	55	60	75	21.08	3974.002
10	45	60	65	80	18.79	3542.291
11	50	65	70	85	20.87	3934.412
12	55	70	75	90	15.83	2984.272
13	60	75	80	95	20.61	3885.397
14	65	80	85	100	19.03	3587.536
	GEOMETRICAL FACTOR : 314.2	ELECTRODES SPACING: 20m				
1	0	20	25	45	10.27	3226.834
2	5	25	30	50	10.37	3258.254
3	10	30	35	55	10.24	3217.408
4	15	35	40	60	11.96	3757.832
5	20	40	45	65	10.87	3415.354
6	25	45	50	70	2910	914322
7	30	50	55	75	10.23	3214.266
8	35	55	60	80	12.61	3962.062
9	40	60	65	85	12.53	3936.926
10	45	65	70	90	14.07	4420.794
11	50	70	75	95	9.68	3041.456
12	55	75	80	100	13.87	4357.954
	GEOMETRICAL FACTOR : 471.3	ELECTRODES SPACING 25m				
1	0	25	30	55	7.16	3374.508
2	5	30	35	60	6.98	3289.674
3	10	35	40	65	8.03	3784.539
4	15	40	45	70	7.08	3336.804
5	20	45	50	75	9.24	4354.812
6	25	50	55	80	6.71	3162.423
7	30	55	60	85	8.66	4081.458
8	35	60	65	90	8.59	4048.467
9	40	65	70	95	8.93	4208.709
10	45	70	75	100	6.66	3138.858
	GEOMETRICAL FACTOR : 659.82	ELECTRODES SPACING : 30m				
1	0	30	35	65	4.23	2791.039
2	5	35	40	70	5.16	3404.671
3	10	40	45	75	4.73	3120.949
4	15	45	50	80	6.14	4051.295
5	20	50	55	85	4.22	2784.44
6	25	55	60	90	5.74	3787.367
7	30	60	65	95	6.23	4110.679
8	35	65	70	100	6.67	4400.999

The geo-electric images were interpreted geologically using knowledge of geology of the survey area, borehole log around the survey area, resistivities of sediments, rocks and minerals available in literatures (Figures 4–6). Table 3 below shows resistivities of some earth materials from *geophysics.ou.edu/enviro/electric/index.html* [10].

Table 3: *Resistivity of some Earth Materials [10].*

Material	Resistivity Ω-m
Wet to moist clayey soil and wet clay	1s to 10s
Wet to moist silty soil and silty clay	Low 10s
Wet to moist silty and sandy soils	10s to 100s
Sand and gravel with layers of silt	Low 1000s
Coarse dry sand and gravel deposits	High 1000s
Well-fractured to slightly fractured rock with moist-soil-filled cracks	100s
Slightly fractured rock with dry, soil-filled cracks	Low 1000s
Massively bedded rock	High 1000s

Material Electric Resistivities (room temperature)		**Geological Material Resistivities**	
Material	**Resistivity Ω-m**	**Material**	**Resistivity (ohm-cm)**
Silver	1.6x10^{-8}	Seawater (18^{0}C)	21
Copper	1.7x10^{-8}	Uncontaminated surface water	2x10^4
Aluminum	2.7x10^{-8}	Distilled water	0.2-1x10^6
Carbon (graphite)	1.4x10^{-5}	Water (4^{0}C)	9x10^6
Germanium*	4.7x10^{-1}	Ice	3x10^8
Silicon*	2x10^3	**Rocks (in situ)**	
Carbon (diamond)	5x10^{12}	**Sedimentary**	
Polyethylene	1x10^{17}	Clay, soft shale	100 - 5x10^3
Fused quartz	>1x10^{19}	Hard shale	7 - 50x10^3
*Values very sensitive to purity.		Sand	5 - 40x10^3
		Sandstone	10^4 - 10^5
Minerals		Glacial moraine	1 – 500x10^3
Copper (18^{0}C)	1.7x10^{-6}	Porous limestone	1 – 30x10^4
Graphite	5 – 500x10^{-4}	Dense limestone	>10^6
Pyrrhotite	0.1 – 0.6	Rock salt	10^8 - 10^9
Magnetite crystals	0.6 – 0.8	**Igneous**	5x10^4 - 10^8
Pyrite ore	1 - 10^5	**Metamorphic**	5x10^4 – 5x10^9
Magnetite ore	10^2 – 5x10^5	**Rocks (laboratory)**	
Chromite ore	>10^6	Dry granite	10^{12}
Quartz (180^{0}C)	10^{14} - 10^{16}		

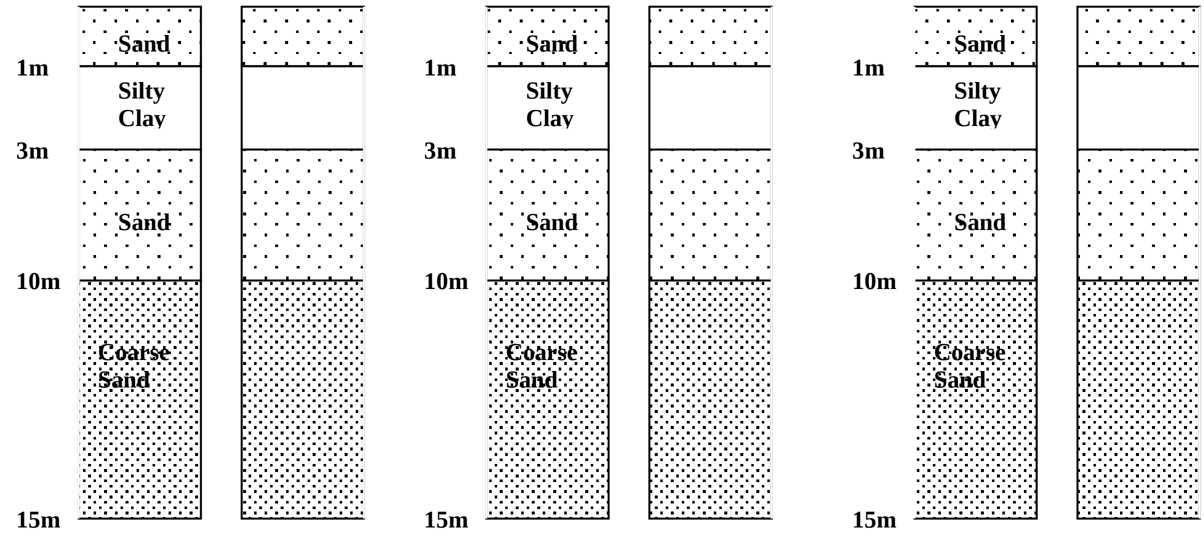
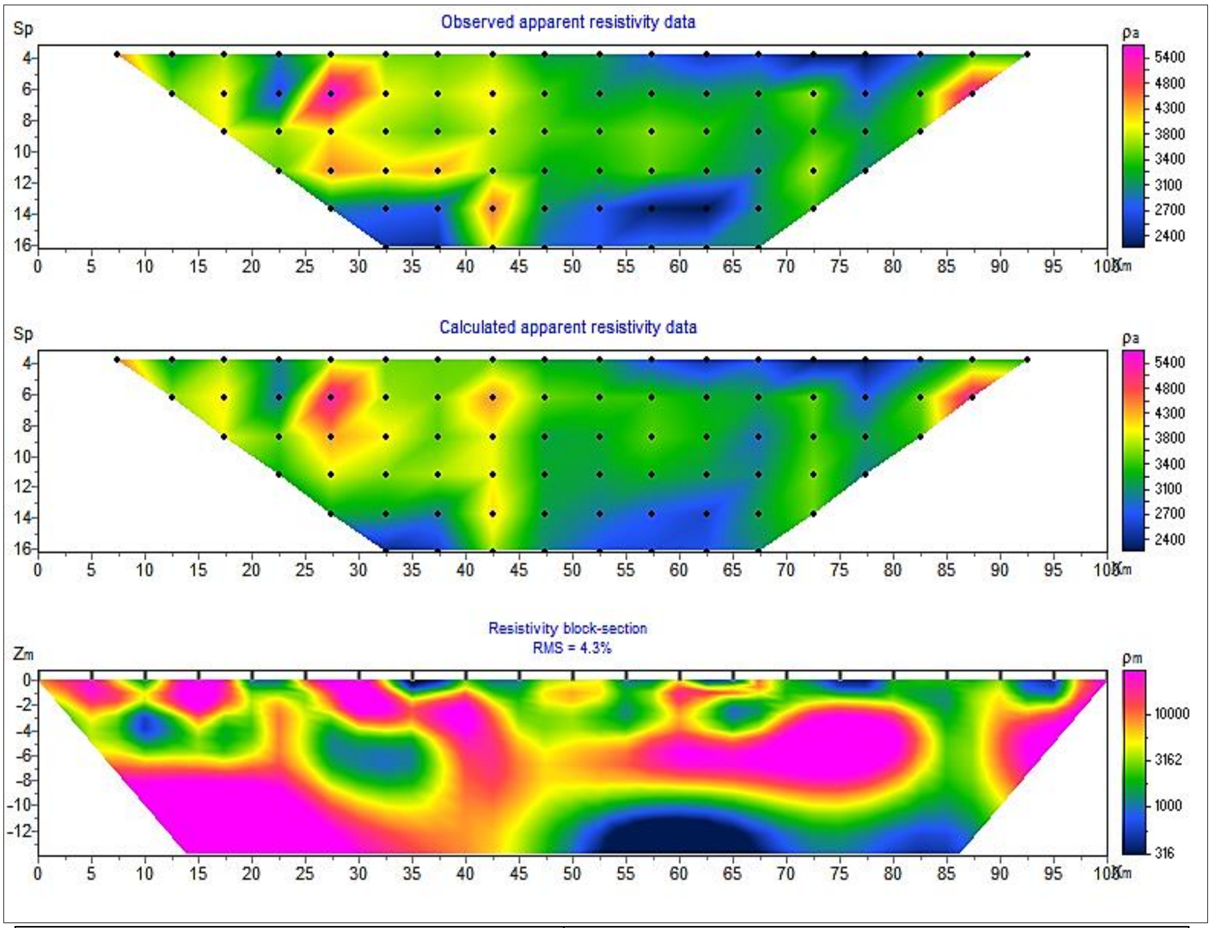
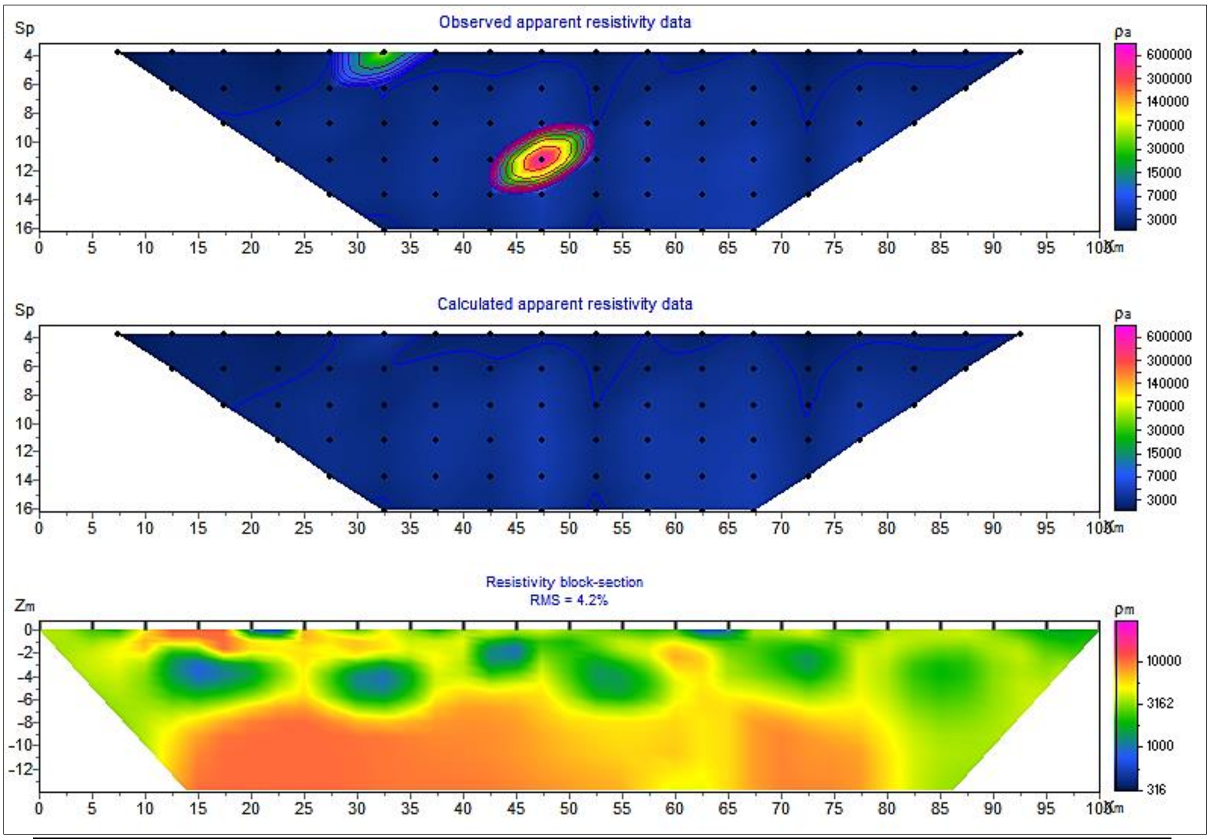


Fig. 4: *Borehole log Around Project Area*
Source: *Environmental and Social Impact Assessment for the Greenfields Petrochemical Company Project. https://www3.opic.gov/environment/eia/greenfields/eia_greenfields.html. Chapter 5, Pg. 15.*



Survey Aim:	**Survey Date**: 4/04/2014
Survey Line No./ Length/Direction: L12/100m/E-W	**Equipment Used:** Petrozenith Earth Resistivity Meter
Site Description: Ozolua Road	**Array/Software Used:** Wenner-Schlumberger/Zondres2d
State/Town/ LGA: Edo/Ologbo/Ikpoba Okha	**Begin /End Coordinates:**N 6.074°,E5.655°/N6.073°,E 5.656°

Fig.5: *Line 12 Geological Picture.*



Survey Aim:	**Survey Date**: 7/04/2014
Survey Line No./ Length/Direction:	**Equipment Used:** Petrozenith Earth Resistivity Meter
Site Description: Lonestar Area	**Array/Software Used:** Wenner-Schlumberger/Zondres2d
State/Town/ LGA: Edo/Ologbo/Ikpoba Okha	**Begin /End Coordinates:** N 6.066°,E5.646°/N6.664°,E 5.647°

***Fig.6**: Line 19 Geological Picture.*

In the first Profile, 2-D Resistivity distributions of subsurface soil in the area show similar variation of resistivity of subsurface soil at different depths characterized by very high resistivity materials in the profile line. The resistivity range lies between 350 Ωm to about 10000 Ωm, indicating variation in soil matrix, grain size distribution and water saturation. At near surface (from the depth of about 0.5 m, which is the top soil, to the depth of about 8 m) relatively high resistivity values obtained in some of the profiles reveal that of coarse sand as shown by the borehole log around the area. The decrease in resistivity at a depth below the top soil along the bottom right of the profile indicates the presence of saturated soil.

In the second profile, the study reveals the range of spatial distribution of sand deposits with large quantity of gravel indicated by high resistivity of about 10000 Ωm

CONCLUSION

2D electrical resistivity imaging techniques have been successfully used to investigate the subsurface structures at the proposed site for Ologbo area in Edo state. This was with a view to detecting water bearing formations. The acquired apparent resistivity data were interpreted using the Zondres 2D software.

The resistivity of the study areas suggest that the near surface materials comprises of coarse sand and gravel while the underlying deeper materials also has high resistivity values. The resistivity values of the models probably indicates presence of water bearing formation in the survey area at greater depth of penetration.

It is suggested that more research should be carried out so as to probe deeper into the formation in other to get to the aquifer table.

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Cite this Article

Esangbedo J, Adagbon JE. Geophysical determination of water bearing formation using 2-dimensional geo-electrical resistivity imaging in ologbo area of edo state. *Research & Reviews: Journal of Physics*. 2015, 4(3): 11–22p.