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Determination of Groundwater Status and Characteristics of the Subsurface Layers Using Electrical Vertical Sounding (VES) and Dipole-Dipole Configuration at Osasogie Road and Environs Southern, Nigeria

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INFORMATION

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ABSTRACT

The study area is situated between latitudes 5.605188°N to 5.622456°N and longitudes 6.377649°E to 6.389605°E and the aim of this study is to determine the groundwater status and characterise the subsurface layers using Electrical Vertical Sounding (VES) and Dipole- Dipole configuration at OSASOGIE Road and Environs Southern, Nigeria. ABEM SAS-300C Terrameter along with necessary accessories equipment were used to carried out eleven (11) VES and one (1) Dipole-Dipole data acquisition. From the results interpretation of VES 1-11, it reveals five (5) to six (6) geo-electric layer and the aquifer apparent resistivity ranges from 646.45Ωm to 3852.6Ωm with an average of 2249.62Ωm. The presence clay materials in the study have depth range of 7m to 14m deep which has a negative impact on the roads constructed in the area. When rain falls, the roads are flooded causing the clay materials to expand and contrast leading to cracks on the road, because the Engineering geologist and Civil engineers fails to identify characteristics of the subsurface soil. From the result of Dipole-Dipole, it is revealed that the profile point from 60m to 150m at a depth of 0.0m to 20.0m has very low resistivity and very high conductivity because the surface soil has a high porosity and high permeability which allow surface water to flow into the soil. The Longitudinal conductance values range from 0.00416 to 0.06025Ω-1 with an average of 0.032205Ω-1 and Transmissivity values range from 452.869248 to 504.481402 m2/day with an average of 478.675325m2/day. The presence of clay materials in the subsurface soil of the study must be excavated first during construction of road to avoid failure and crack in the road. This research will help engineering geologist and civil engineer to suggest the best foundation design for a building and reduce cost of maintenance of failed if the clay material is put into consideration first before construction.

1. Introduction

Flooding, Failed Road and contaminated water bodies is a major in developing countries like Nigeria. Flood and Failed Roads are major problems in Benin city especially the Osasogie road and environs in Egor local Government Area of Edo State (ELGA, 2021). This problem is a serious issue, because it has caused many house owners to relocate from their homes. When rain falls the road is flooded which causes the road to fail because the water does not infiltrate easily into soil and also there is bad drainage system in that area leading to the contamination of the groundwater in that area. The aim of this research is to determine and identify the lithological characteristics of the subsurface soil using VES and dipole-dipole survey of electrical resistivity method. This research work will enable Civil Engineers and Engineering Geologist to have proper knowledge of the subsurface layer characteristics and to safe money in reconstruction of the failed roads. This research will help people living around the study area to know whether the groundwater is contaminated or not.

The VES method is used to investigate the electrical properties of subsurface layers and it has been used for wide variety of environmental and engineering problems (Zohdy, 1975). This geophysical method is used because it is one of the simplest and less costly methods and can be used to identify geological structures (Al-Sayed et al., 2007). The VES had been used to delineate the different subsurface layers and also been used in delineating the aquifer units, subsurface structure and their characteristics (Okonkwo et al., 2013).

The study is carried out in Egor Local Government Area (ELGA, 2021), Benin City, Edo State. It is situated between latitudes 5.605188°N to 5.622456°N and longitudes 6.377649°E to 6.389605°E. Egor Local Government Area falls under the Tropical Savannah Climate while the LGA covers a total area of 93 km^2 (Giuseppe et al., 2019; ELGA, 2021). It has an area of 93 km^2 and a population of 444171 (National Bureau of Statistic, 2020).

There are different tribal groups that made up the local government namely: the Esan, Bini, and the Owan. The area experiences two major seasons which are the rainy and the dry seasons while the average temperature of the area is at 28 °C. The estimated humidity level of the Egor Local Government Area (ELGA, 2021) is estimated at 68 percent. The people are predominantly farmers.

Benin City's climate is hot and humid. The rainy season is from April to November while the dry season is from December to March. Temperature in Benin City is very high with an average daily temperature of about 28 °C in the dry season and about 24 °C in the wet season. The study area has a low temperature range. Benin City and its environs experience intense rainfall especially in the rainy or wet season. Rainfall is present all year, with an annual total of 2000–2300 mm, and monthly average of about 180 mm (Ministry of Environment, Benin Report, 2009). This intense rainfall is induced by excessive evapotranspiration in the urban area due to prevalent high temperature. Relative humidity in the study area is also high, reaching about 80% in the wet season and 70% in the dry season (Manpower Nigeria, 2020).

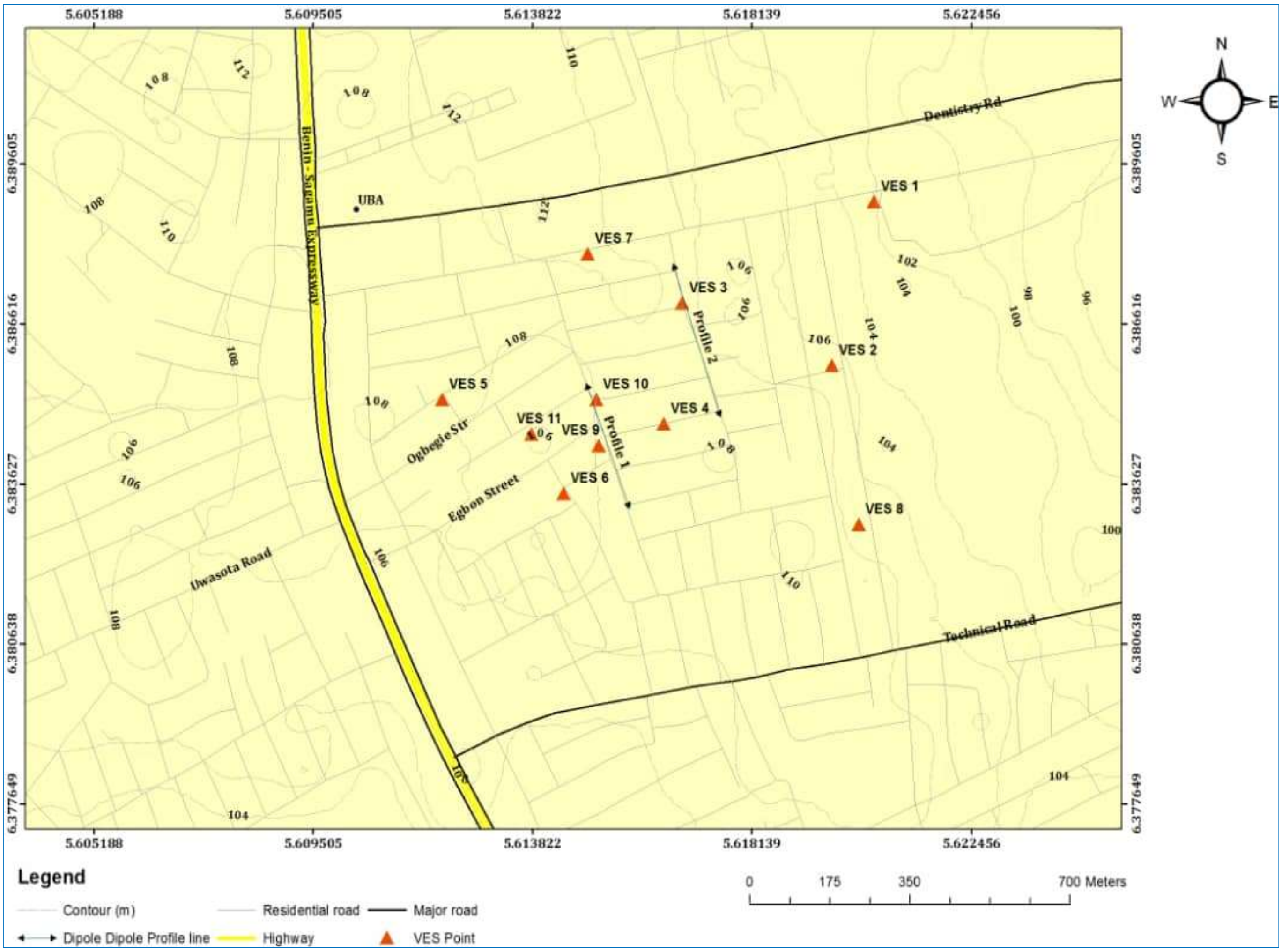

Fig. 1. Base map of the study area

2.1. Geology of the Study Area

The Delta Region is underlain by Sedimentary Formation of the South Sedimentary Basin (Short and Stauble, 1967). The South Sedimentary Basin is made up of Sedimentary Formation which the Benin Region is lying on. The geology is marked by top reddish earth, composed of ferruginous or lateralized clay sand. The term Benin sand was first used to describe the reddish earth underlain by sands, sandy clays and ferruginous sandstone that marked the Paleo-coastal Environment of Paleocene-Pleistocene Age. Delta Region comprises of Benin Formation, alluvium, drift/top soil and Azagba-Ogwashi (Asaba-Ogwashi) Formation (Short and Stauble, 1967). The geology of the study area is marked by lateralized Clay, Sand and Sandstone. The Sandstone marks the Paleo-Coastal Environment of Palaeocene-Pleistocene Age (Reyment, 1965). These sediments spread across the southern fringes of the Anambra Basin and marking the upper facies off-flaps of the Niger Delta Basin (Catherine, 2016). The name Coastal Plain Sands is use to describe the Formation of red earth underlain by Sands and Clays that mark an ancient Coastal Plain Environment now exposed in Calabar, Owerri, Onitsha (Catherine, 2016). The Delta Region is Oligocene-Pleistocene in age. The dip direction of the Benin Formation southward.

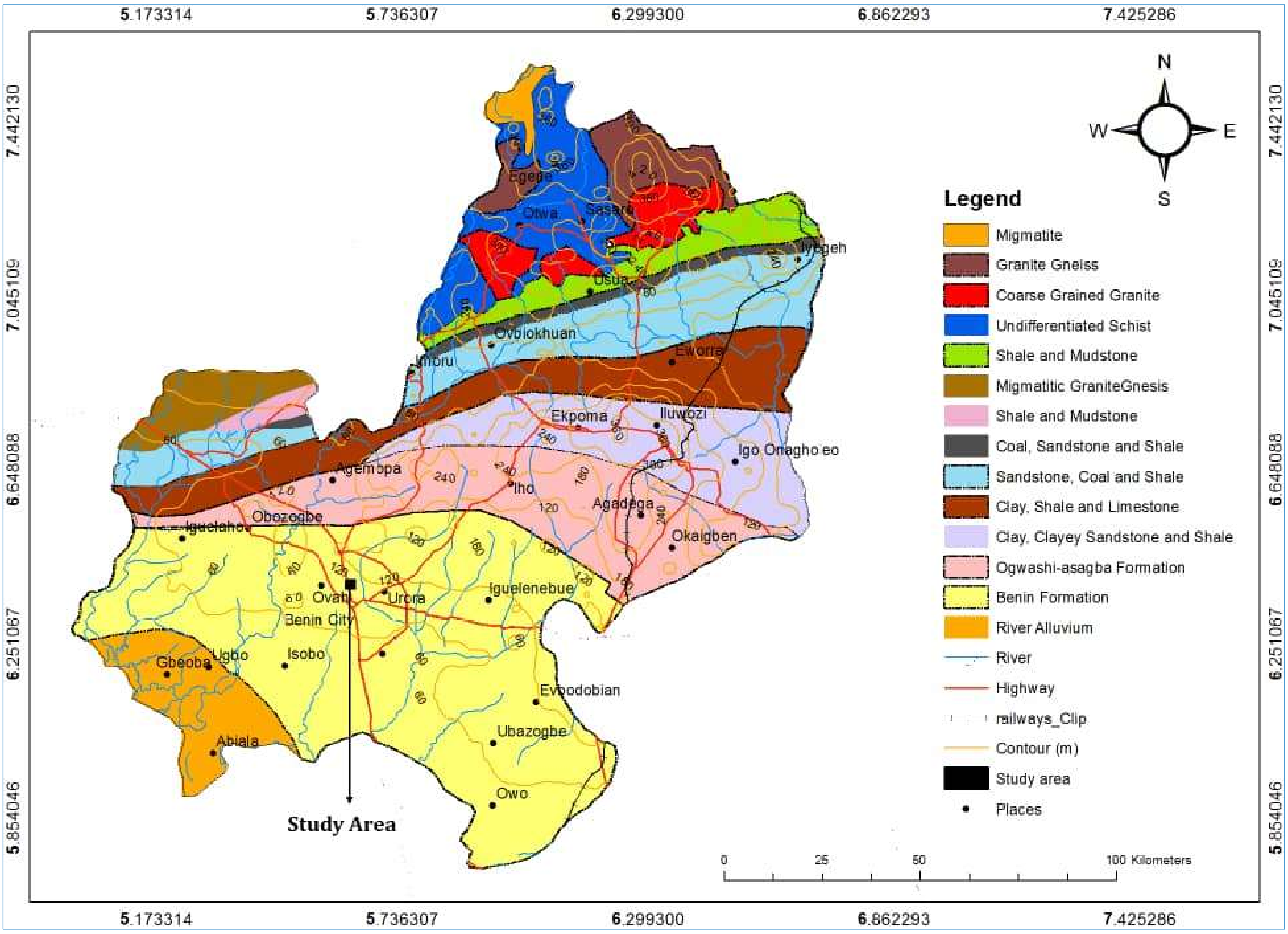

Fig. 2. Geological map of Delta State, Nigeria

The study area is underlain by the Benin Formation which is an important groundwater reservoir. This basin is characterized by top reddish to reddish brown lateritic massive fairly indurated clay and sand, capping thick sequences of poorly bedded friable-loose sand gravelly- pebbly sand and pinkish-white clay stringers (Oomkens, 1974).

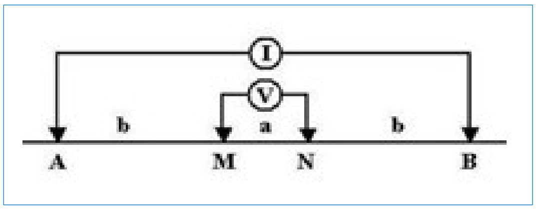

Fig. 3. Schlumberger array

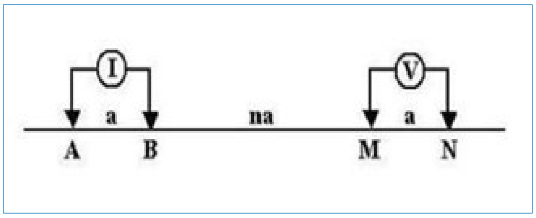

Fig. 4. Dipole-dipole array

The hydraulic conductivity and transmissivity have an average value of 20.662 m/day and 893.57 m^2/day, respectively. Four groundwater potential zones were delineated including medium grain sandstones, sand, clayey-sand and shaly-sand (Kwami et al., 2019).

In 'Characterization of Aquifers Using Geo-electrical Methods in Parts of Abia State, South-eastern Nigeria', the highly productive aquifers in Abia State are confined to the alluvial deposits and the coastal plain sands lithologies, which consist of fine, medium and coarse-grained and often siliceous sands with some intercalation of clays. The alluvium occurs mainly in the Ukwa West and East local government areas. Drilling depths in this aquifer range from 30 m to 140 m (Abija et al., 2018).

Table 1. A summary of the VES interpretation and resistivity model parameter and lithology

S/N	Coordinate point	Geo-electric layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology	Curve Type
VES 1	6.38888°N, 5.62056°E Elevation: 102 m	1	64.777	0.72979	0.72979	Top soil	AKQ
		2	233.48	7.0064	7.72064	Lateritic Clay	
		3	1351.5	5.0315	12.768	Medium-Coarse Sand	
		4	1272.4	30.463	43.231	Medium-Coarse Sand (aquifer zone)	
		5	286.92	Infinity	Infinity		
VES 2	6.38583°N, 5.61972°E Elevation: 106 m	1	133.97	0.8395	0.8395	Top soil	AKA
		2	308.58	0.74536	1.5849	Lateritic Clay	
		3	959.3	23.873	25.457	Medium Sand	
		4	2543.4	10.624	36.081	Medium-Coarse Sand (Aquifer zone)	
		5	3636.7	Infinity	Infinity		
VES 3	6.38700°N, 5.61678°E Elevation: 106 m	1	84.223	0.69649	0.69649	Top soil	AHK
		2	205.75	7.7159	8.4124	Lateritic Clay	
		3	114.38	6.2064	14.619	Silt	
		4	1267.4	27.441	42.059	Medium-Coarse Sand	
		5	20.821	Infinity	Infinity		
VES 4	6.38475°N, 5.61642°E Elevation: 108 m	1	178.14	0.8279	0.8279	Top soil	KHK
		2	410.61	4.0902	4.9181	Clay	
		3	191.5	7.3309	12.332	Silt	
		4	1915.8	32.691	44.94	Medium-Coarse Sand	
		5	761.6	Infinity	Infinity		
VES 5	6.38698°N, 5.61344°E Elevation: 108 m	1	95.839	1.0826	1.0826	Top soil	AAK
		2	407.33	5.9593	7.0418	Clay	
		3	643.06	35.009	42.051	Fine Sand	
		4	879.21	52.979	95.03	Medium Sand (Aquifer zone)	
		5	210.89	Infinity	Infinity		
VES 6	6.38344°N, 5.61444°E Elevation: 108 m	1	38.928	0.55197	0.55197	Top soil	KHK
		2	405	1.0373	1.5892	Clay	
		3	276.25	4.9671	6.5564	Clay	
		4	255.31	6.4387	12.995	Clay	
		5	2681.6	37.677	50.672	Medium-Coarse Sand (Aquifer zone)	
		6	137.71	Infinity	Infinity		
VES 7	6.38791°N, 5.614917°E Elevation: 112 m	1	110.28	1.0922	1.0922	Top soil	AKH
		2	207.2	2.6522	3.7443	Clay	
		3	352.46	10.545	14.289	Clay	
		4	86.143	18.664	32.953	Silt	
		5	2106.5	25.129	58.082	Medium-Coarse Sand (Aquifer zone)	
		6	2672.1	Infinity	Infinity		
VES 8	6.38287°N, 5.620262°E Elevation: 110 m	1	62.198	0.32082	0.3978	Top soil	AKA
		2	266.83	6.4922	6.813	Clay	
		3	2149.4	2.9061	9.7191	Medium-Coarse Sand	
		4	3852.6	37.522	47.242	Medium-Coarse Sand (Aquifer zone)	
		5	3216.3	Infinity	Infinity		
VES 9	6.39340°N, 5.615137°E Elevation: 108 m	1	31.187	0.59836	0.59836	Top soil	AAK
		2	221.64	8.6452	9.2436	Clay	
		3	3083.3	9.6362	18.88	Medium-Coarse Sand	
		4	646.45	21.076	39.956	Fine Sand	
		5	235.6	Infinity	Infinity		
VES 10	6.38344°N, 5.61508°E Elevation: 108 m	1	50.884	1.0666	1.0666	Top soil	HAA
		2	1147.6	1.3438	2.4104	Lateritic Sandy-Clay	
		3	123.41	1.2575	3.6679	Silt	
		4	5263.5	19.25	22.918	Medium-Coarse Sand	
		5	924.35	34.78	57.698	Medium Sand (aquifer zone)	
		6	557.32	Infinity	Infinity		
VES 11	6.38583°N, 5.619725°E Elevation: 106 m	1	8.5807	0.35327	0.35327	Top soil	AKA
		2	1879.5	2.4528	2.8061	Lateritic Sandy-Clay	
		3	87.042	5.0626	7.8687	Silt	
		4	190.28	4.6882	12.557	Silt	
		5	1123.3	31.9	44.457	Medium-Coarse Sand (Aquifer zone)	
		6	739.39	Infinity	Infinity		

Also, in 'Geoelectric Evaluation of Aquifer Vulnerability in Igbanke, Orhionmwon Local Government Area of Edo State, Nigeria. The results of the geoelectric investigation revealed six geoelectric layers namely the topsoil, laterite clayey sand, fine to medium sand, medium sand, medium to coarse Sand and coarse sand which are in agreement with the driller's log obtained from the borehole. The overburden protective capacity in the area was evaluated using the total longitudinal unit conductance values. The values obtained show poor and weak protective capacity rating in almost all parts of the study area. The aquifer of the study area is not protected since the protective capacity rating is poor (< 0.1) (Egbai et al., 2015).

According to Ojeogal et al. (2022), Geotechnical Investigations of Road Failures along Benin Technical School Road, Benin City, Edo State was carried out. The results of the test showed that the soil samples were mainly silty /clay with little amount of fine sand and the CBR result reveals none of the soil samples met the criteria for road sub-grade as CBR values for all the soil samples were above the required 10%.

Findings indicates that failure along the study area were due to the unsuitability of the soils as sub grade material and effect of ground water intrusion and unstable geotechnical properties of soils in the study area, wrong drainage designs and improper application and usage of constructional materials.

Table 2. A Summary of electrical properties of aquifer for all VES stations

S/N	Resistivity (ρ, Ωm)	Thickness (m)	Conductivity (δ, Ωm^{-1})	Longitudinal conductance (S, Ω^{-1})	Transverse Resistance (TR, Ωm^2)	Hydraulic conductivity (K)	Transmissivity (Tr, m^2/day)
VES 1	1272.4	30.463	0.00078	0.02394	38761.12	15.95620	486.073721
VES 2	2543.4	10.624	0.00039	0.00416	27021.08	42.62700	452.869248
VES 3	1267.4	27.441	0.00079	0.02165	34778.72	17.89541	491.067946
VES 4	1915.8	32.691	0.00052	0.01706	62629.42	14.93940	488.383925
VES 5	879.21	52.979	0.00114	0.06025	46579.67	9.522290	504.481402
VES 6	2681.6	37.677	0.00037	0.01405	101034.64	13.08657	493.062697
VES 7	2106.5	25.129	0.00047	0.01193	52934.24	19.09465	479.829460
VES 8	3852.6	37.522	0.00026	0.00974	144549.55	13.13699	492.926139
VES 9	646.45	21.076	0.00155	0.03260	13624.580	22.49924	474.193982
VES 10	924.35	34.780	0.00108	0.03763	32148.893	14.10063	490.419911
VES 11	1123.3	31.900	0.00089	0.02840	35833.270	15.28467	487.580973

3. Materials and Methods

In this research work, the Dipole-Dipole and Schlumberger array of Electrical Resistivity Survey method was adopted. ABEM Terrameter SAS 300C was used to carry out this survey which is powered by a 12.5v D.C power source. Other accessories attached to the Terrameter includes the booster, four metal electrodes, cables for current and potential electrodes, hammers (3), measuring tapes, mobile phones for a long-distance spread. Dipole-Dipole array is also called 2D resistivity surveying and its electrode spacing configuration is 10 m.

The Schlumberger configuration was adopted for the vertical electrical sounding with a maximum current electrode separation AB of 430 m, which was deemed sufficient in allowing a depth penetration of 215 m (AB/2) while the Potential electrode separation was increased several times during the sounding at MN/2 equals 0.2 m to 10 m. A Global Positioning Satellite (Germin model) instrument was used to determine well coordinates and elevation. Different electrode spacing is used when sending electric current into the ground depending on which part of the earth the anomaly is to be investigated.

3.1. Field Methods

The Schlumberger array is more complex when spacing between the current electrodes is not equal to the spacing between the potential electrodes. The vertical electrical sounding with Schlumberger array as a low-cost technique and veritable tool in groundwater exploration is more suitable for hydrological survey of sedimentary basin. The method is regularly used to solve a wide variety of groundwater problems. Formula for geometric factor (G) and Apparent Resistivity (ρa) for Schlumberger array is given as:

$$G = \pi \frac{b(b+a)}{a}, \rho a = \frac{\mathrm{V}}{\mathrm{I}} \pi \frac{b(b+a)}{a} \quad (1)$$

Dipole-Dipole array uses apparent resistivity to generate 2D imaging which represent the various layers in subsurface soil. The spacing between the current electrode pair, C2-C1, is given as 'a' (Ria, 2017) which is the same as the distance between the potential electrodes pair P1-P2. The array has another factor marked as 'n' which is the ratio between the C1 and P1 electrodes to C2-C1 (or P1-P2) dipole separation 'a'. For surveys with this array, the 'a' spacing is initially kept fixed and the 'n' factor is increased from 1 to 2 to 3 until up to about 6 in order to increase the depth of investigation (Loke, 2000).

The array is most sensitive to resistivity changes between the electrodes in each dipole pair. Note that the sensitivity contour pattern is almost vertical. Thus, the dipole array is very sensitive to horizontal changes in resistivity. That means it is good in mapping vertical structures, such as dykes and cavities, but relatively poor in mapping horizontal structures such as sills or sedimentary layers (Loke, 2004).

The median depth of investigation of this array also depends on the 'n' factor, as well as 'a' factor. The formular for Geometric factor (*G*) and Apparent resistivity (ρ_a) for Dipole-Dipole arrey is given as:

$$G = \pi an(n+1)(n+), \rho a = \frac{\mathrm{V}}{\mathrm{I}} \pi an(n+1)(n+2) \quad (2)$$

3.2. Data Processing

The data collected were pre-processed by ensuring data quality, and calculating the resistivity of the various reading by multiplying it with the necessary constant. Also, field graphs were plotted using manual graphs. The IX1Dv3 and Dipro software application was used to determine the thickness and resistivity values. The Schlumberger values was first match curve manually before inputting it into the computer software program to obtained the resistivity model parameters and the values is now run by the program as a routine which in turn displayed an automatically plotted graph with an error tolerance limit set forth eprogram iteration and when this is done, the model parameters become the interpreted geoelectric layer as shown in the Table 1.

The data obtained, both from Schlumberger and Dipole-Dipole array were analyzed using the geophysical software IX1Dv3 and Dipro. The geoelectric layers, depth was generated, as well as the resistivity spread. The analyzed data was interpreted to determine the aquifer potential and delineate the lithology of the investigated area.

The resistivity values and depths obtained after iteration were used to interpret the lithology of the study area which showed five (5) to six (6) layers from the eleven (11) VES location and five layers from the Dipole-Dipole location respectively as shown in (Table 1 and 5, Figs. 4 and 5).

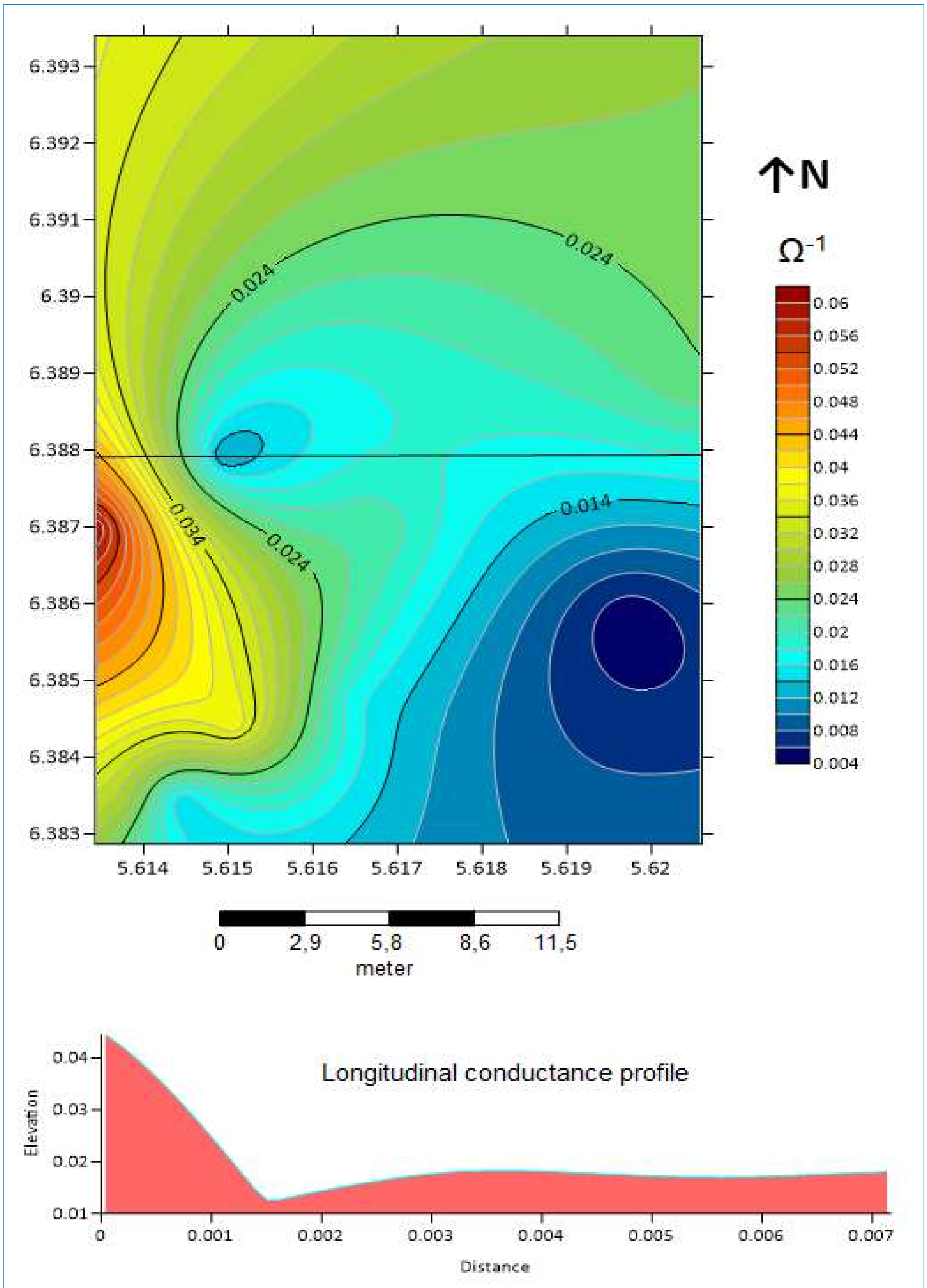

Fig. 5. Map of study area showing the variation in Longitudinal Conductance

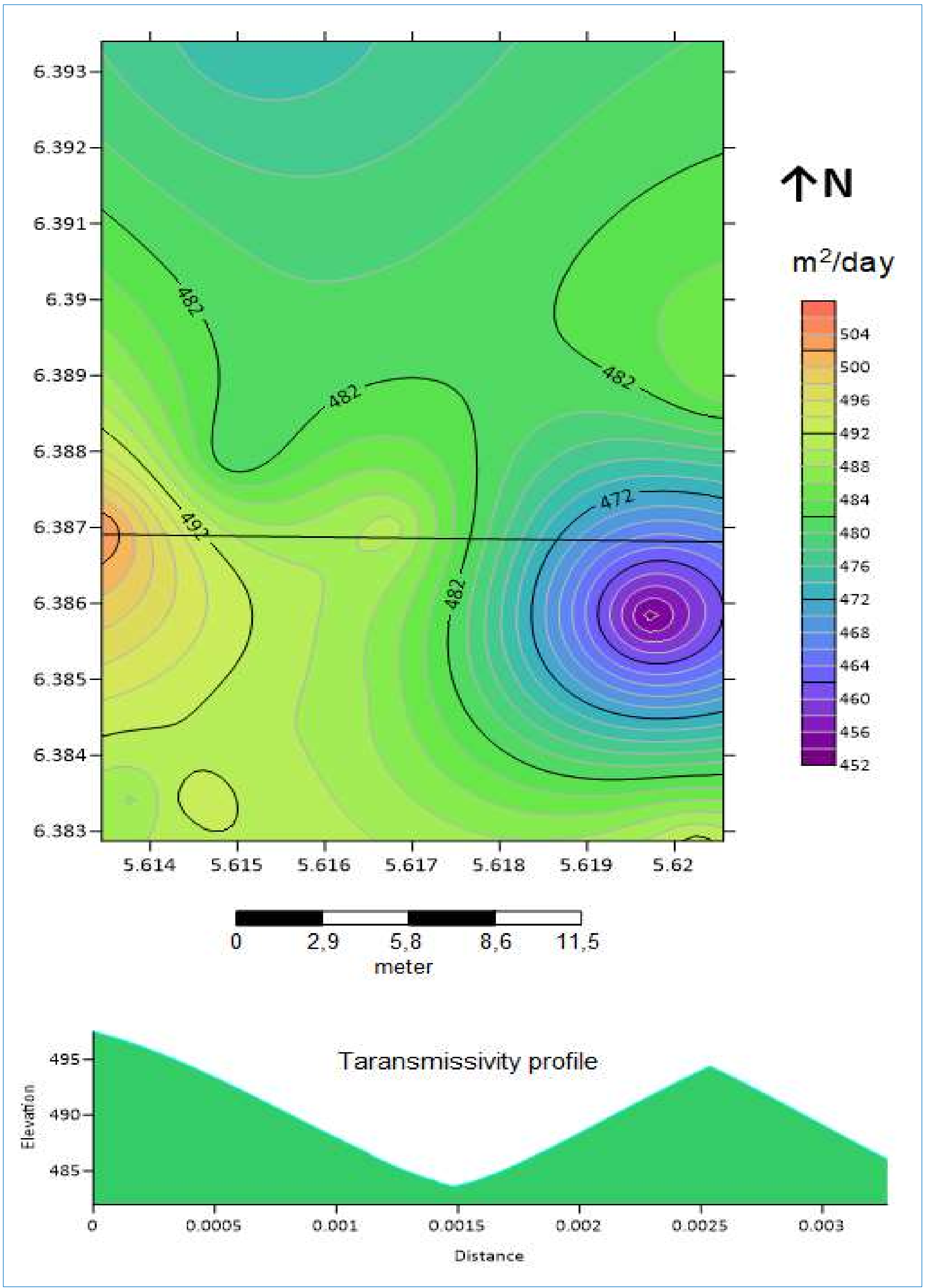

Fig. 6. Map of study area showing the variation in Transmissivity

3.3. Hydraulic Parameters

Longitudinal conductance (S) is a measure of the impermeability of a rock layer (Billing, 1972). The formulas for longitudinal conductance and Transverse Resistance is given as;

$$Si = \frac{h1}{\rho 1} \quad (3)$$

$$Ti = \rho 1 \times h1 \quad (4)$$

For a sequence of horizontal, homogeneous and isotropic layers of resistivity ρ1 and thickness h1. Eqs. 3 and 4 defined the Dar Zarrouk parameters (Maillet, 1947), (Longitudinal conductance (S) and Transverse resistance (TR) as follows:

$$S = \frac{h1}{\rho 1} + \frac{h2}{\rho 2} + \frac{h3}{\rho 3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \sum_{i=o}^{n} \left(\frac{hi}{\rho i}\right) \quad (5)$$

For Transverse Resistance (TR)

$$TR = h1\rho 1 + h2\rho 2 + h3\rho 3 \ldots\ldots\ldots . \sum_{i=o}^{n} (\mathrm{hi\rho i}) \quad (6)$$

It shows the relationship between aquifer transmissivity, and longitudinal conductance as proposed by Todd (1980).

$$Tr = K\delta TR = Kh \quad (7)$$

where *Tr:* aquifer transmissivity, *K:* hydraulic conductivity, *σ:* electrical conductivity (reciprocal of resistivity), *TR:* traverse resistance, *S:* longitudinal conductance and *h:* aquifer thickness. The tydraulic conductivity *(K)* was determined using the equation given by Heigold et al. (1979).

$$K = 386.40Rrw^{-0.93283} \quad (8)$$

4. Interpretation of Results

4.1 Interpretation for Schlumberger Array

The apparent resistivity of VES 1–11 obtained from the field for aquifer yield potential ranges 646.45 to 3852.6 Ωm with thickness range of 10.624 to 52.979 m, the drill depth to groundwater for VES 1 ranges from 33 m (108) to 44m(144ft); VES 2 ranges from 36 m (118ft) to 46 m (150 ft); VES 3 ranges from 56 m (184 ft) to 66 m (216 ft); VES 4 ranges from 36 m (118 ft); VES 5 ranges from 44 m (144 ft) to 54 m (177 ft); VES 6 ranges from 48 m (157 ft) to 58 m (190 ft); VES 7 ranges from 33 m (108 ft) to 59 m (193 ft); VES 8 ranges from 46 m (151 ft) to 56 m (184 ft); VES 9 ranges from 43 m (143 ft) to 53 m (174 ft); VES 10 ranges from 43 m (141 ft) to 61 m (200 ft); and VES 11 ranges from 33 m (108 ft) to 43 m (141 ft). The curve types for VES 1-11 are: AKQ, AKA, AHK, KHK, AAK, KHK, AKH, AKA, AAK, HAA, and AKA.

The electrical properties of the aquifer are conductivity, longitudinal conductance, transverse resistance, hydraulic conductivity and transmissivity. The conductivity ranges from 0.00026 to 0.00155 Ωm^{-1}, longitudinal conductance ranges from 0.00416 to 0.06025 Ω^{-1}**,** transverse resistance ranges from 13624.580 to 144549.55Ωm^2.

Table 3. A Summary of longitudinal conductance(S) and transmissivity (Tr) of aquifer with its indication according to (Oladapo and Akintorinwa 2007; Offodile, 1983)

S/N	Location coordinate points	Longitudinal conductance (S, Ω^{-1})	Protective capacity rating	Transmissivity (Tr, m^2/day)	Classification of well
VES 1	6.38888°N, 5.62056°E Elevation: 102 m	0.02394	Poor	486.073721	Moderate potential
VES 2	6.38583°N, 5.61972°E Elevation: 10 6m	0.00416	Poor	452.869248	Moderate potential
VES 3	6.38700°N, 5.61678°E Elevation: 106 m	0.02165	Poor	491.067946	Moderate potential
VES 4	6.38475°N, 5.61642°E Elevation: 108 m	0.01706	Poor	488.383925	Moderate potential
VES 5	6.38698°N, 5.61344°E Elevation: 108 m	0.06025	Poor	504.481402	Excellent potential
VES 6	6.38344°N, 5.61444°E Elevation: 108 m	0.01405	Poor	493.062697	Moderate potential
VES 7	6.38791°N, 5.614917°E Elevation: 112 m	0.01193	Poor	479.829460	Moderate potential
VES 8	6.38287°N, 5.620262°E Elevation: 110 m	0.00974	Poor	492.926139	Moderate potential
VES 9	6.39340°N, 5.615137°E Elevation: 108 m	0.03260	Poor	474.193982	Moderate potential
VES 10	6.38344°N, 5.61508°E Elevation: 108 m	0.03763	Poor	490.419911	Moderate potential
VES 11	6.38583°N, 5.619725°E Elevation: 106 m	0.02840	Poor	487.580973	Moderate potential

Table 4. Aquifer protective capacity of longitudinal conductance (according to Oladapo and Akintorinwa (2007)) and aquifer classification based on transmissivity values (Offodile, 1983)

S/N	Longitudinal Conductance (Ω-1)	Protective Capacity Rating	Transmissivity (m2/day)	Classification of well
1	>10	Excellent	>500	High potential
2	5–10	Very good	50–500	Moderate potential
3	0.7–4.9	Good	5–50	Low potential
4	0.2–0.69	Moderate	0.5–5	Very low potential
5	0.1–0.19	Weak	<0.5	Negligible potential
6	<0.1	Poor		

Table 5. Summary of 2D resistivity structure of Dipole-Dipole array

Layers	Colour Indication	Resistivity Ranges	Lithology
1	Blue	20.8 – 52.5 Ωm	Leachate
2	Green	52.5 – 472 Ωm	Clay
3	Yellow	544 – 929 Ωm	Fine – Medium Sand
4	Light Brown	1111 - 3498 Ωm	Medium – Coarse Sand
5	Deep Brown	4114 - 13374 Ωm	Coarse – very Coarse Sand, Sandstone

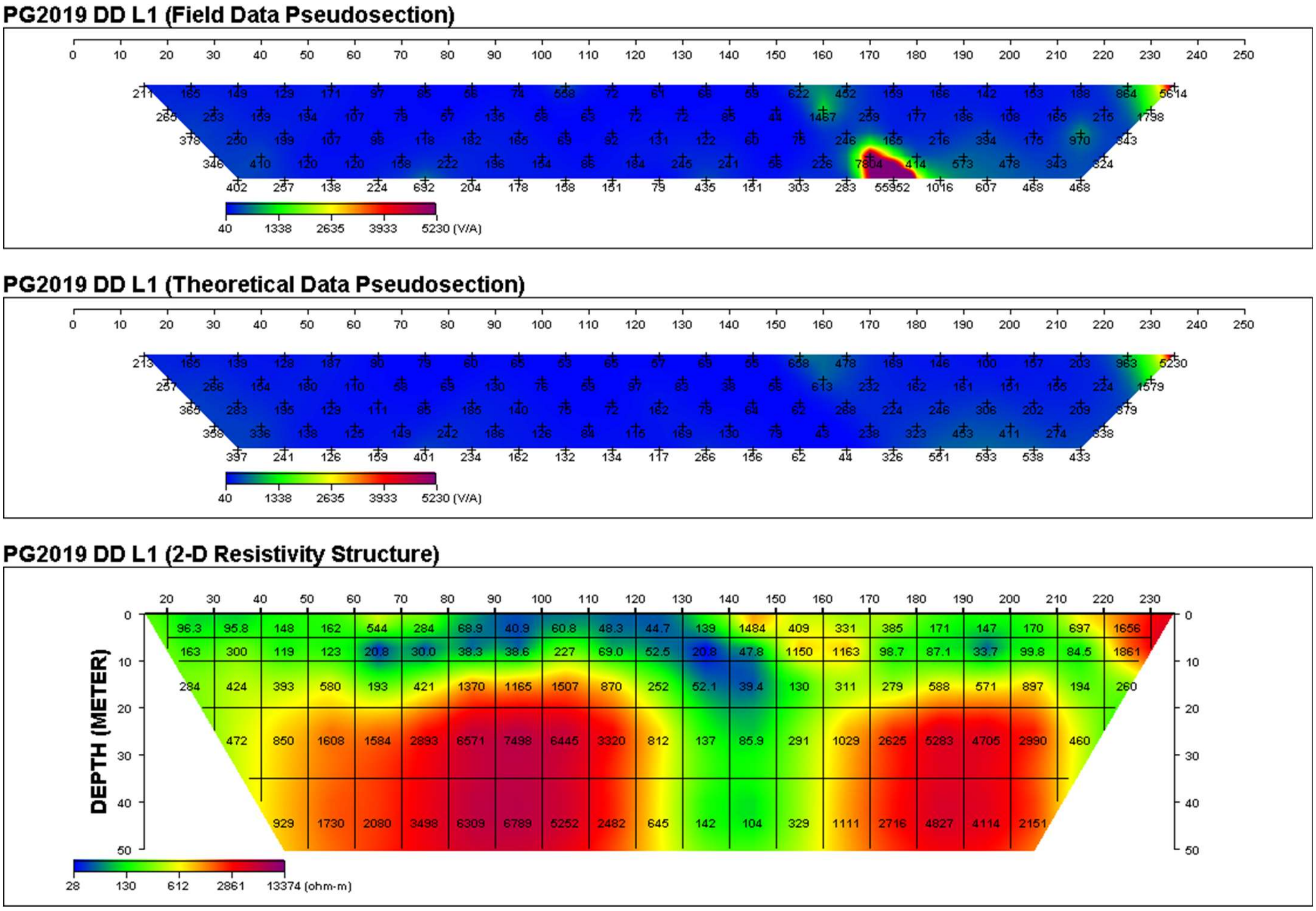

Fig. 7. Dipro Inversion based on FEM modeling of Dipole-Dipole array

Hydraulic conductivity ranges from 9.522290 to 42.62700 and the transmissivity ranges from 452.869248 to 504.481402 m^2/day as in Figs. 6 and 7. The aquifer has a poor protective capacity because the overburden lithology is highly porous according to Oladapo and Akintorinwa (2007) and the transmissivity classification of the wells is moderate to excellent Offodile (1983) as shown in Table 2, 3 and 4.

4.2. Interpretation for Dipole-Dipole Array

From Table 5, Figs. 7 and 8), it reveals that the blue colouration represent leachate which has apparent resistivity range of 20.8 Ωm to 52.5 Ωm, the green colouration represents the topsoil (surface) of the study area which has apparent resistivity range of 52.5 Ωm to 472 Ωm which is mainly made-up clay materials of low resistivity. While the yellow colouration represents immediate layer which has apparent resistivity range of 544 Ωm to 929 Ωm which is mainly fine to medium sand then the light brown colouration represents the weathered rock which has apparent resistivity range of 1111 Ωm to 3498 Ωm which is medium to coarse sand and the red colouration represent bedrock which has apparent resistivity range of 4114 Ωm to 13374 Ωm which is mainly coarse to very coarse sand with little present of sandstones.

It is revealed that the leachate has migrated from 60 m to 130 m along the horizontal profiling with a depth range of 0 m to 10 m deep and 130 m to 140 m along the horizontal profiling with depth 0m to 20m deep, the leachate has infiltrated deep into the soil to contaminated the groundwater at 20 m deep because the surface soil has a high porosity and high permeability which allow surface water to flow into the soil.

5. Discussion

From Table 1, VES 3, 4, 6, 7 and 11 with 6.38700°N, 5.61678°E with an elevation of 106m and 6.38475°N, 5.61642°E with an elevation of 108m, 6.38344°N, 5.61444°E with an elevation of 108m, 6.38791°N, 5.614917°E with an elevation of 112 m and 6.38583°N, 5.619725°E with an elevation of 106 m respectively. The result reveal that both locations has more of clay-materials and Silt in the subsurface soil up to a depth of 14m, the presence of the clay-material and silt has caused the road constructed in those location to fail because when the clay materials come in contact with water its expanse and contrasts which cause the road to crack or fail and full of pot-holes. When rain falls the water does not easily infiltrate into the soil, the water stays in the location for a long time, which causes the road in that area to fail. This fail roads costs the Edo State government a lot of money to maintain but with this research the engineering geologist and civil engineers will be able to provide measure to avoid failure of road in that area.

From Tables 2 and 3, the aquifer protective capacity is poor because the sediment/lithology overlying the aquifer is porous and the aquifer transmissivity classification is moderate to excellent.

From Tables 1 and 5, the apparent resistivity values from the VES 1-11 and Dipole-Dipole array ranges from 646.45 Ωm to 3852.6 Ωm and 1111 Ωm to 3498 Ωm respectively. The lithology of the aquifer zone is medium to coarse Sand.

From Figs. 7 and 8, the survey reveals the presence of leachate plume which has infiltrate into subsurface soil to a depth of 20 m and can contaminate the groundwater because the aquifer protecting capacity is poor.

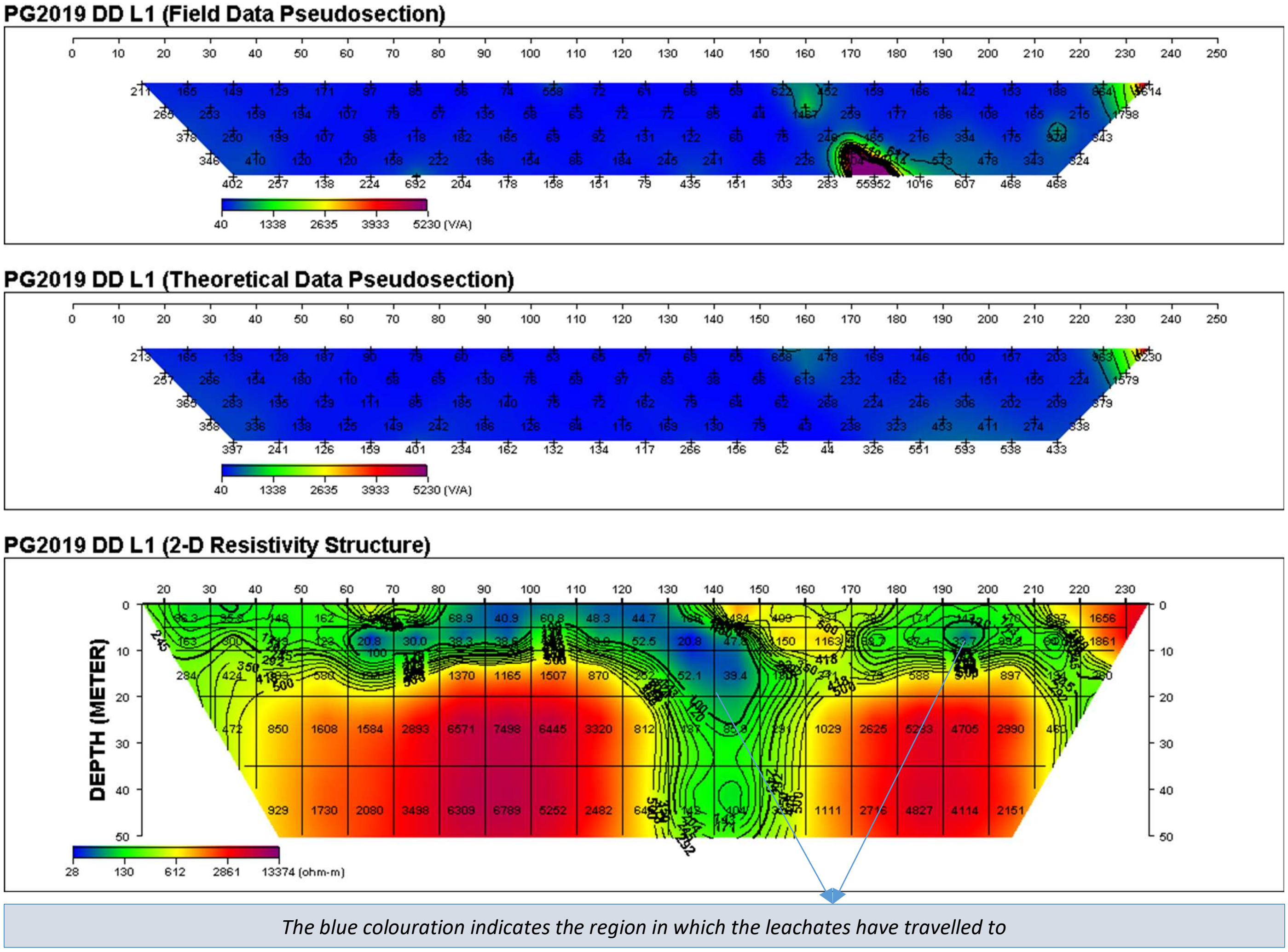

Fig. 8: Dipro Inversion based on FEM modeling with contour of Dipole-Dipole array

6. Conclusion and Recommendation

6.1. Conclusion

The aquifer transmissivity classification is moderate and the water yield of boreholes in the study will be also moderate. The curve types are: AKQ, AKA, AHK, KHK, AAK, KHK, AKH, AKA, AAK, HAA, and AKA. The software used to analysis the data are IX1Dv3 and Dipro respectively. This research has been to discover the cause of the failed roads and suggest solution to the failed road in the study.

The presence of clay materials in the subsurface soil of the study must be excavated first during construction of road to avoid failure and crack in the road. This research will help engineering geologist and civil engineer to suggest the best foundation design for a building and reduce cost of maintenance of failed if the clay material is put into consideration first before construction.

6.2. Recommendation

The recommended drill depth to groundwater for VES 1 is an average range of 38 m (126 ft); for VES 2 is an average range of 41 m (134 ft); for VES 3 is an average range of 60 m (200 ft); for VES 4 is an average range 41 m(134 ft); VES 5 is an average range of 49 m (160 ft); VES 6 is an average range 43 m (141 ft); VES 7 is an average range of 46 m (151ft); VES 8 is an average range of 51 m (167 ft); VES 9 is an average range of 48 m (158 ft); VES 10 is an average range of 52 m(170 ft); VES 11 is an average range of 38 m (125 ft). From (Figs. 5 and 6). I recommend deep borehole for the study area to avoid contamination from leachate plume. Soil test must be carried out before starting any project. Before construction of road is been carry out in the study, the clay materials must be excavated to a reasonable depth to avoid failure and loss of tax payer money on a failed project. Proper drainage system must be done to avoid infiltration of bad or wasted water into soil which will contaminate the groundwater in that area.

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