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GROUNDWATER POTENTIAL AND AQUIFER VULNERABILITY STUDIES IN OMADINO IN DELTA STATE, NIGERIA USING SURFACE GEOELECTRIC MEASUREMENT

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Eight vertical electrical soundings employing the Schlumberger array were carried out with maximum current electrode spacing of 300 m to ascertain the groundwater potential in the area. The apparent resistivity data obtained were iterated using IP2WIN software. The results indicate that the aquifer resistivity and thicknesses ranged from 182 – 1206 Ωm and 5.96 – 20.9 m, respectively. The average thickness of aquifer established in the study is 12.47 m at an average depth of 6.25 m. The longitudinal conductance revealed that the protective capacity is weak in most part of the area and is best protected in the southeast portion of the study area. The transmissivity obtained for the aquifer in the study area is of moderate potential with values: $T_{mean} = 149.9\ m^2day^{-1}$, $T_{min} = 30.2\ m^2day^{-1}$, and $T_{max} = 498\ m^2day^{-1}$. The hydraulic conductivity estimated has a mean value of 11.3139 m/day. The study showed that the south east to northwest portion is best suited for siting of borehole as a result of its thicker aquifer, higher transmissivity and protective capacity.

Key words: Aquifer, hydraulic conductivity, transmissivity, protective capacity, Omadino.

INTRODUCTION

The natural resource of greatest importance to man is water which occurs either as surface water or groundwater. Sustainable development in any region is greatly dependent on the provision of clean water for its inhabitants. The access to clean water is however becoming very challenging due to rapid population growth, industrialization and social- economic development. Surface water abounds in the vicinity of the study area and it is the major source of water for the people of Omadino. It is however prone to contamination as a result of the increased activities of oil companies in nearby towns of Warri and environs and uncontrolled domestic waste disposal (Aweto and Akpoborie, 2015). This makes groundwater the best alternatives for domestic and industrial use.

Groundwater is stored in aquifer which is a body of rock that has enough porosity to hold and store water and many residents access it through hand dug wells and boreholes. The depth to groundwater varies and can be as deep as 50 m or greater in the Niger Delta region and requires proper planning and technique to explore it (Orji and Egboka, 2015). For high productive and long term yield, surface geophysical data should be acquired to determine aquifer characteristics such as depth to groundwater, thickness, and the water quality in order to suggest suitable borehole site for potable water. The surface methods include geophysical, hydrogeological, geological, geomorphological and geochemical methods (Anomohanran, 2013). Characterizing soils using resistivity measurements has been very successful because of the high contrast of resistivity values between clayey soils and carbonate rocks. These electrical properties of the subsurface formation provide useful information for groundwater resources which has been translated into important hydrogeological and geophysical information by various researchers (Mbonu, et al., 1991, Okolie, 2009, Niwas, et al., 2011, Anomohanran, 2011, Iserhien-Emekeme, 2014a, Ofomola, 2014, Jegede, et al., 2012, Iserhien-Emekeme, 2014b). However, concerning groundwater in Omadino, Mode et al., 2010, using hydrochemistry, stated in their research that groundwater in the areas based on chemical quality in comparison with World Health Organisation (WHO) standards is unsuitable for drinking because heavy metals of interest exceed permissible limits. This is why an attempt is made in this study to delineate the subsurface to ascertain the groundwater potential and aquifer vulnerability in the area using geoelectric measurement.

LOCATION AND GEOLOGY

The study area (Omadino) is located in the Southern part of Nigeria. It lies within latitudes 5° 37' 47" N and longitudes 5° 44' 58" E (Figure. 1) within the oil rich Niger Delta Basin. It is about 433 km from the country's capital, Abuja and at a distance of about 19 km east from the Warri airport. It has a flat topography and an elevation of 17 m above sea level. The vegetation is the tropical rain forest characterized by tress and grasses and a mean annual rainfall of about 3000 mm (NIMA, 2003). The mean annual temperature is between 28°C. The area is drained into the Warri and Forcados River with major tributaries that are dendritic in pattern (Mode et al., 2010). The study area falls within the Niger Delta Basin which consists of three formations, namely, the Akata Formation, Agbada Formation and the Benin Formation. The Benin Formation is the youngest (Miocene to Recent) and underlies most of the Niger Delta basin. However, from the South of Asaba through Abraka and Sapele to the coast, is characterized by the younger Holocene deposits of the Sombreiro-Warri Deltaic Plain and merges with the Mangrove Swamp and Freshwater Swamp wetlands to the west and south west (Akpoborie and Aweto, 2012, Mode et al., 2010, Orji et al., 2015). Detailed literature on the Niger Delta formation is well documented (Short and Stauble, 1967, Asseez, 1989, Murat, 1970, Akpoborie, 2011).

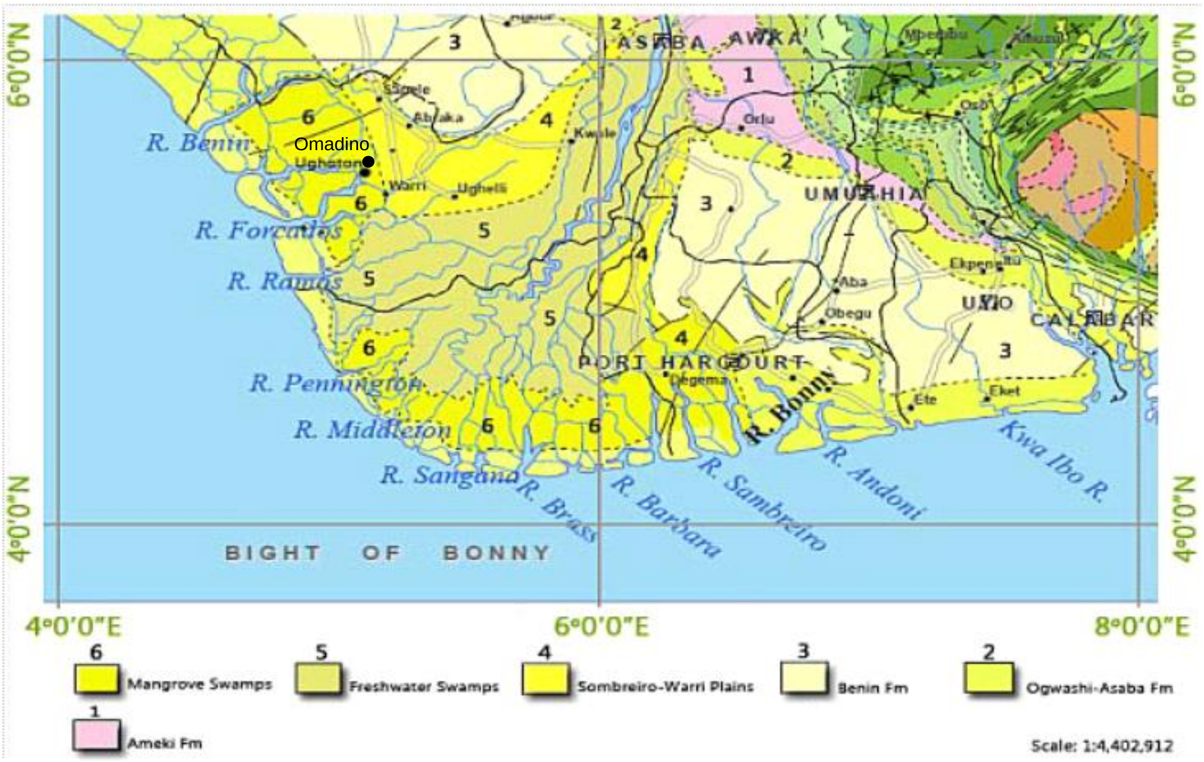


Figure 1. Geological map of the Niger Delta region showing the study area (Adapted from NGSA, 2004).

MATERIALS AND METHODS

Eight vertical electrical soundings (VES) were carried out employing the Schlumberger electrode configuration (Figure 2). The choice for the Schlumberger array was its high degree of penetration, reliability, ease of use and accuracy.

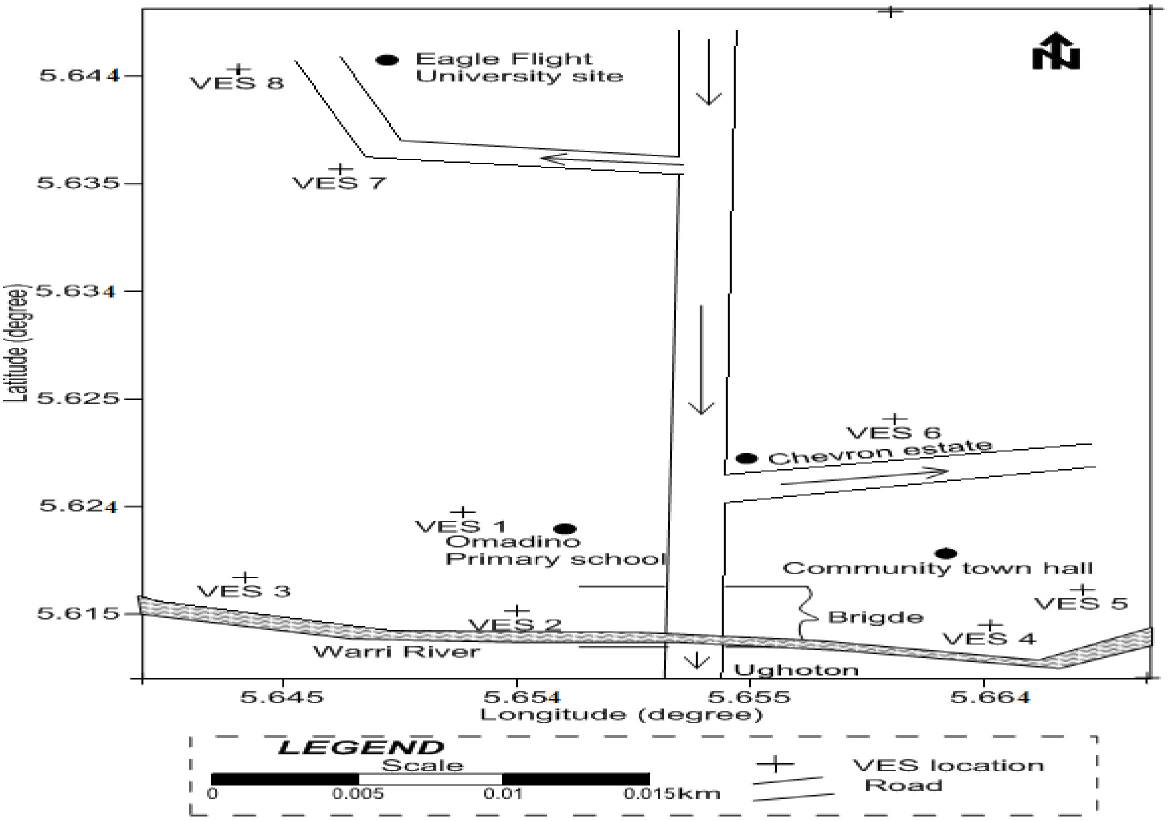


Figure 2. Location map showing VES points.

The Schlumberger configuration involves the ejection of current into the earth through a pair of electrode AB and measuring the resulting potential difference through two different pair of electrodes MN. The Allied Omega (Ohmega) Terrameter was used for the survey and the maximum spacing for current (AB/2) and potential (MN) electrodes was 150 m and 10 m respectively. The apparent resistivity (ρ_a) was computed using Equation1,

$$\rho_a = G\frac{\nabla V}{I} \tag{1}$$

where G is the geometric factor given as;

$$G = \pi\left(\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right) \tag{2}$$

and

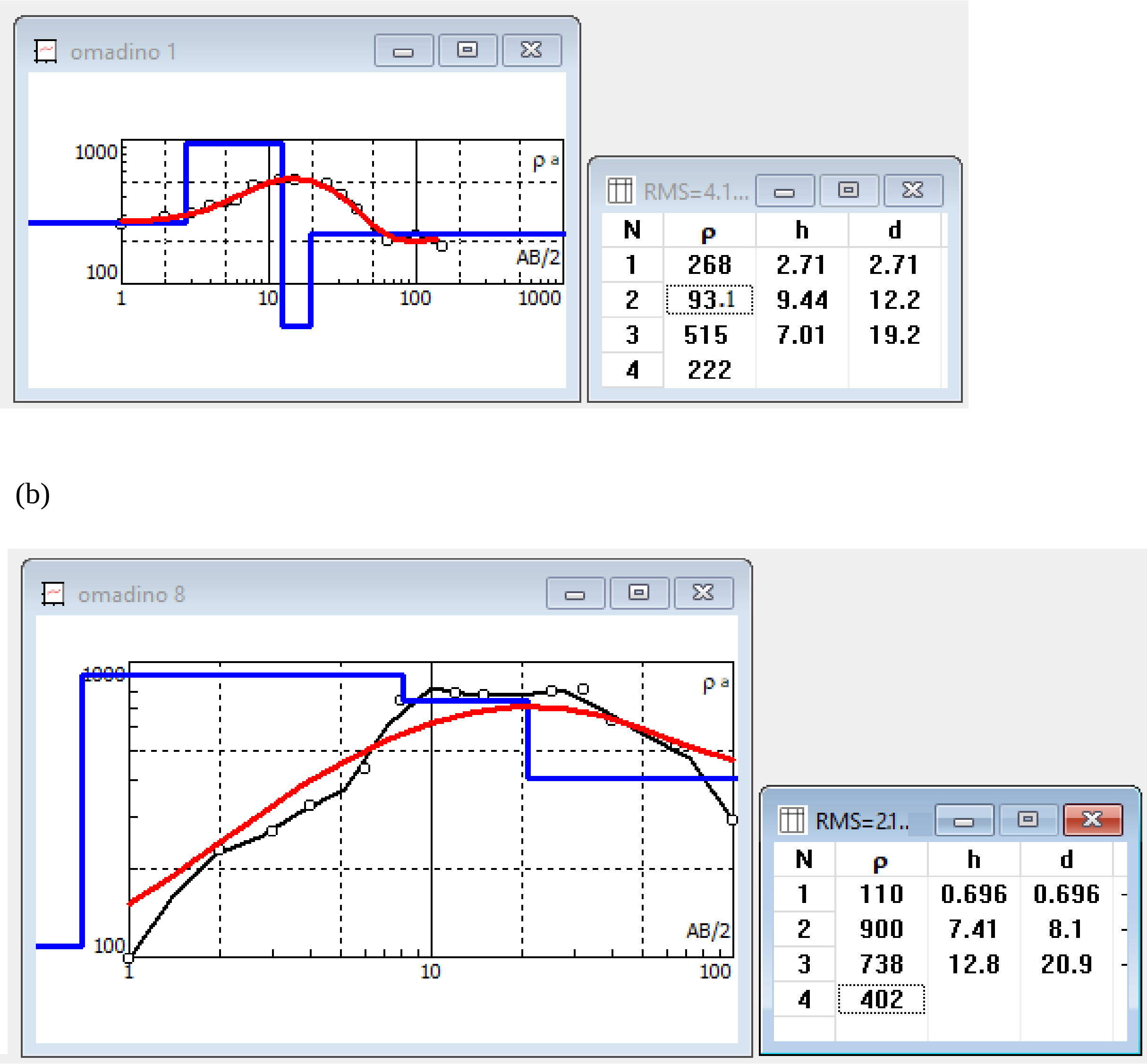
$$\frac{\Delta V}{I} = R \tag{3}$$

Also, ΔV is the potential difference measured in volts, and I is the current in Ampere. The VES data were interpreted using the IP2WIN software, an iterative inversion- modelling program to obtain the layer thickness (h) and resistivity (ρ) in all the sounding location. The first order geoelectric parameters were used to derive the Dar-Zarrouk parameters, that is, longitudinal conductance (S) = h/ρ and transverse resistance (R) = ρh. The hydraulic conductivity (K) was estimated using K = $0.058/\rho$ (Okiongbo and Soronnadi-Ononiwu, 2015) while the transmissivity (T) was calculated using T = Kh.

RESULTS AND DISCUSSION

The computer-modeled interpretation of resistivity results reveals the resistivity and thickness of the various layers in the surveyed area. The geoelectric layers are made up of topsoil, clay and sand. Two samples of the modeled curve are shown in Figure 3 and the estimated geoelectric parameters and curve types are presented in Table 1.

(a)



N	ρ	h	d
1	268	2.71	2.71
2	93.1	9.44	12.2
3	515	7.01	19.2
4	222		

N	ρ	h	d
1	110	0.696	0.696
2	900	7.41	8.1
3	738	12.8	20.9
4	402		

Figure 3. Resistivity curves and model parameters for (a) VES 1 (Omadino Primary School) and (b) VES 8 (around Eagle Flight University site).

Geoelectric sections

The geoelectrical sections along SW – SE direction (Figure 4) revealed 4 geoelectric layers within the study area. The topsoil resistivity and thickness range from 28.3- 213 Ωm and 0.5- 0.69 m respectively. Underlying the topsoil is clay with low resistivity range of 22.7- 97.6 Ωm and thickness ranging from 2.19- 4.71 m. The third layer is composed of fine to coarse grain sand and indicates the aquiferous zone in the area with thickness range of 5.96 -17.5 m and resistivity range of 182 -988 Ωm. The fourth layer is fine to medium sand except in VES 4 that reveals clay with a resistivity of 42.6 Ωm. Four geoelectric layers are also revealed in the geoelectric section of VES along the SE – NW direction (Figure 5). The topsoil resistivity ranges from 40.2 -446 Ωm with thickness ranging from 0.5- 2.71 m. The second layer is clay in the southeast with resistivity of 22.7 and 93.1 Ωm in VES 4 and VES 1 respectively; an increase of resistivity towards the northwest direction is observed in VES 7 and 8 around the Eagle Flight University area with values of 957 Ωm and 900 Ωm, respectively, possibly indicating fine sand. The third layer is the aquifer zone and consists of medium grain to medium-coarse grain sand with

Table 1. Geoelectric parameters and lithological delineation of study area.

VES	Layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Curve type	Inferred lithology
1	1	268	2.71	2.71	HK	Topsoil
	2	93.1	9.44	12.2		Clay
	3	515	7.01	19.2		Medium grain sand
	4	222				Fine grain sand
2	1	213	0.5	0.5	HK	Topsoil
	2	97.6	3.08	3.58		Clay
	3	988	5.96	9.54		Medium-coarse grain sand
	4	117				Fine grain sand
3	1	36.9	0.671	0.671	AA	Topsoil
	2	78.4	4.71	5.38		Clay
	3	232	12.03	9.54		Fine grain sand
	4	556				Medium grain sand
4	1	40.2	0.696	0.696	HK	Topsoil
	2	22.7	2.19	2.89		Clay
	3	458	8.87	11.8		Medium grain sand
	4	42.6				Clay
5	1	28.3	0.5	0.5	AK	Topsoil
	2	36.6	4.34	4.84		Clay
	3	182	17.5	22.3		Fine grain sand
	4	146				Fine graine sand
6	1	689	0.5	0.5	HAA	Topsoil
	2	84.9	0.214	0.714		Clay
	3	398	5.32	6.04		Fine-medium grain sand
	4	1206	10.5	16.5		Medium grain sand
	5	1220				Medium grain sand
7	1	446	0.5	0.5	AK	Topsoil
	2	957	6.45	6.95		Clay lateritic sand
	3	1069	4.02	11		Medium grain sand
	4	227				Fine grain sand
8	1	110	0.696	0.696	KQ	Topsoil
	2	900	7.41	8.1		Clay lateritic sand
	3	738	12.8	20.9		Fine-medium grain sand
	4	402				Fine grain sand

resistivity range of 458- 1069 Ωm and thickness range of 4.02-12.8 m. The fourth layer is clayey sand with resistivity range of 42.6 - 402 Ωm and undefined thickness and may not be good for drilling productive boreholes.

Hydrogeologic Maps

The first order geoelectric parameters from the resistivity data were also used to obtain the Dar-Zarrouk parameters (Table 2) and generate hydrogeological maps (aquifer resistivity, longitudinal conductance, aquifer thickness and transmissivity) using Surfer 8 software (Golden Software, Inc., 2002). The aquifer has resistivity which varies from 182-1206 Ωm. The map of variation of resistivity values is shown in Figure 6 and reveals that the southwest and southeast parts of the area consist of low resistive materials. Higher resistive materials with likely high

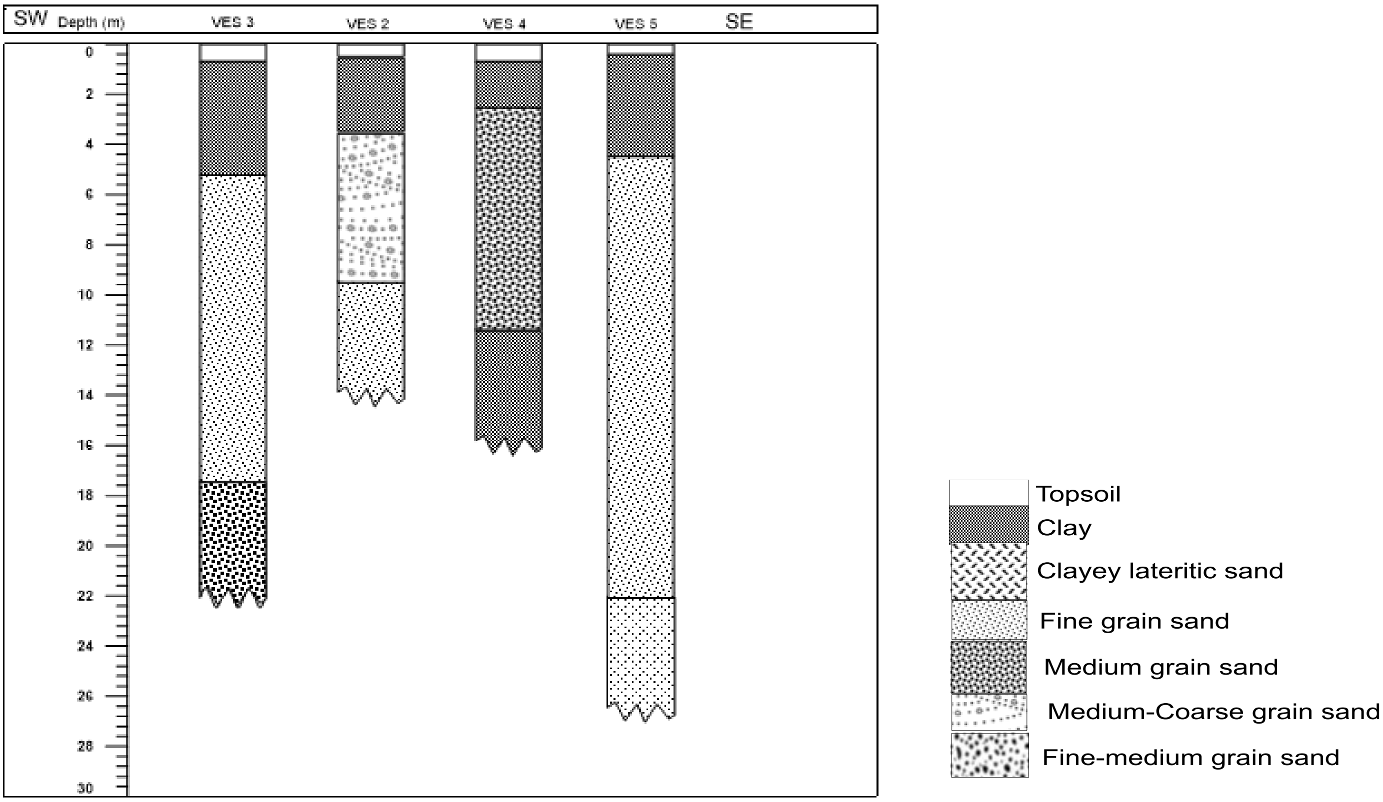


Figure 4. Geoelectric section along SW – SE direction.

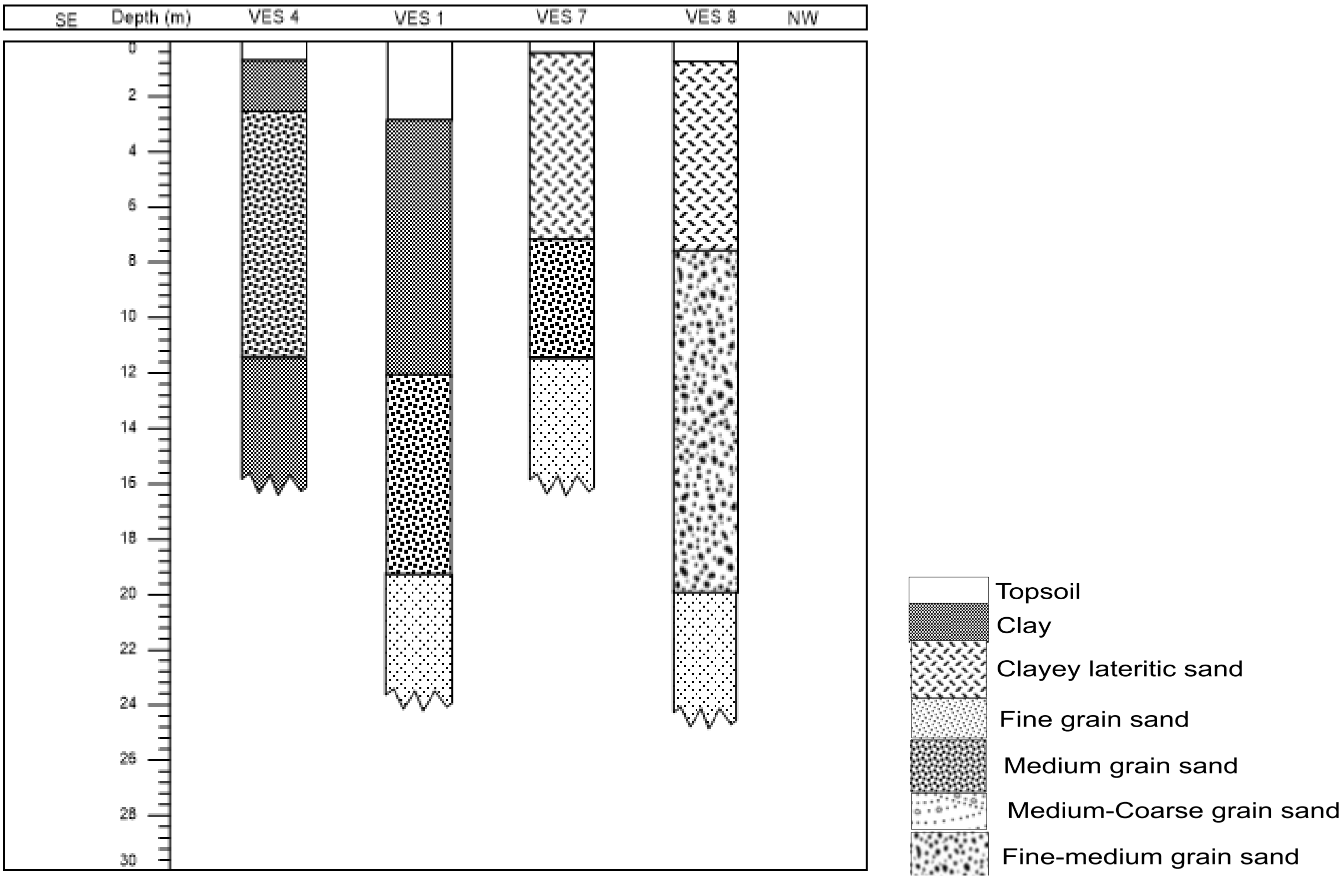


Figure 5. Geoelectric section along SE – NW direction.

Table 2. Dar Zarrouk parameters at Omadino.

VES	Aquifer Resistivity ρ (Ωm)	Aquifer Thickness (h)m	Longitudinal Conductance S = σh	Transverse Resistance R=h ρ	Hydraulic conductivity K=0.058/ ρ	Transmissivity T = kh	Protective Capacity Rating
1	515	7.01	0.01361165	3610.15	9.73048544	68.2107029	Weak
2	988	5.96	0.00603239	5888.48	5.07206478	30.2295061	Poor
3	232	12.03	0.05185345	2790.96	21.6	259.848	Weak
4	458	8.87	0.01936681	4062.46	10.9414847	97.0509694	Weak
5	182	17.5	0.09615385	3185.00	27.5340659	481.846154	Moderate
6	1206	16.5	0.01368159	19899.00	4.15522388	68.561194	Weak
7	1069	11	0.01028999	11759.00	4.68774556	51.5652011	Weak
8	738	20.9	0.02831978	15424.20	6.7902439	141.916098	Weak
K= 11.3139 m/day							

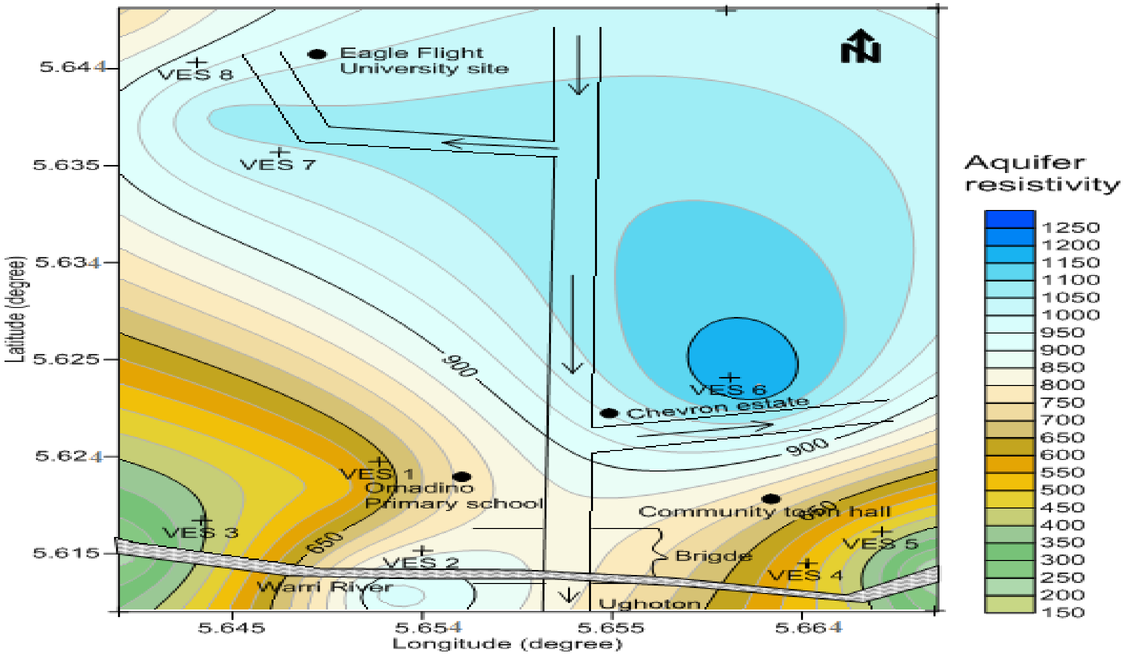


Figure 6. Map of aquifer resistivity.

groundwater potential are observed in the east central and northwestern area. The aquifer thickness variation of 5.96- 20.9 m is shown in Figure 7. It can be deduced from the map (Figure 7) that the aquifer thickness increases from the far end of the southeast (around VES 5) towards northwest (around VES 8) and infers zones of high groundwater potential. The result of the survey indicates that the average thickness of aquifer in the study area is 12.47 m at an average depth of 6.25 m. The longitudinal conductance value rating of Oladapo et al., (2004) and modified by Ofomola, (2014) given as < 0.01 (poor), 0.01 – 0.05 (weak), 0.06 – 0.09 (moderate), 0.1 – 0.49 (good), 0.5 – 1(very good) and > 1 (excellent) was used to determine the protective capacity of the aquifer as presented in Table 2 and longitudinal conductance map (Figure 8). It reveals that most of the area surveyed has aquifer with weak protective capacity except around VES 5 that reveals moderate protection of the aquifer. The weak protective capacity is likely due to the thin clay layer of thickness (2.19 - 4.71 m) overlying the aquifer.

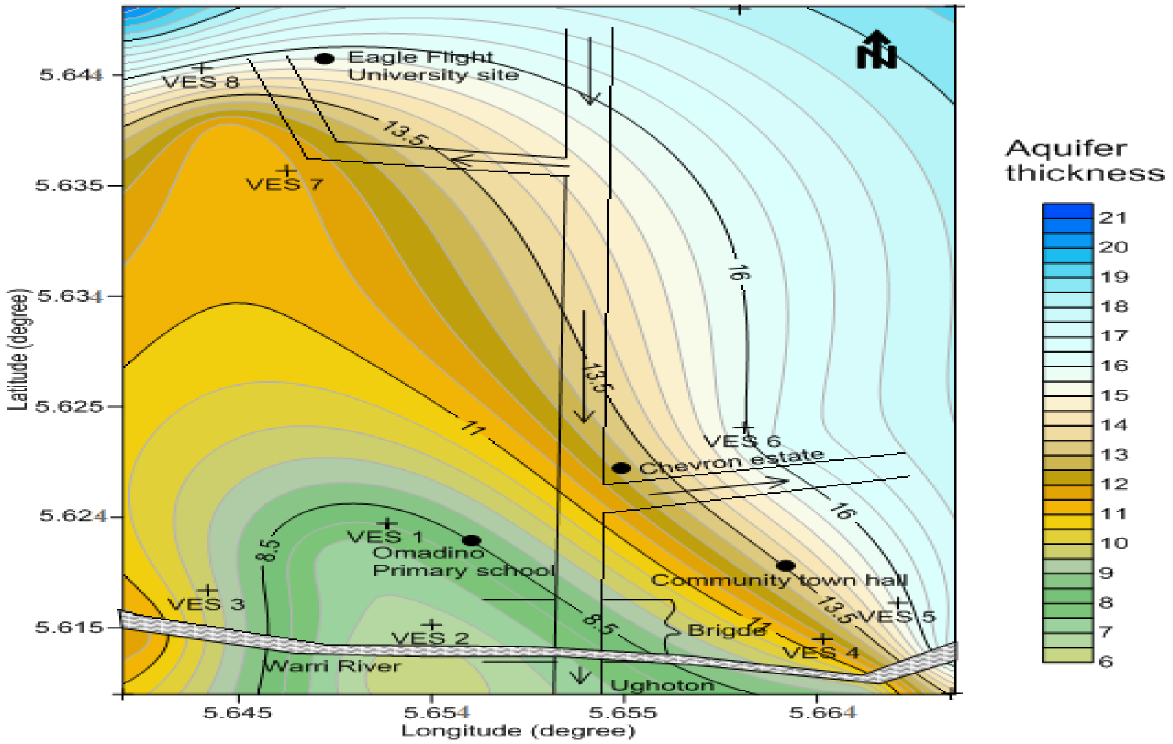


Figure 7. Map of aquifer thickness.

The hydraulic conductivity of shallow Quaternary alluvial aquifer was given by Okiongbo and Soronnadi-Ononiwu, (2015), as K= 0.058/ ρ. This relation was used to estimate the hydraulic conductivity for the area and a mean value of 11.3139 m/day was obtained (Table 2). The transmissivity values obtained for the aquifers in the study area are T_{mean} = 149.9 m^2day^{-1}, T_{min} = 30.2 m^2day^{-1}, T_{max} = 498 m^2day^{-1} and shows that the area is of moderate potential (Gheorghe, 1978). The highest value of T = 481.8 m^2day^{-1} is obtained at VES 5 as observed in Figure 9.

Conclusion

Vertical electrical soundings were used to delineate the subsurface and ascertain the groundwater potential in the area. The geophysical survey reveals that the area consists of topsoil, clay, fine to medium grained sand of various resistivities and thicknesses. The average thickness of aquifer established in the study is 12.47 m at an average depth of 6.25 m. The longitudinal conductance map reveals that the protective capacity of the groundwater is weak in most part of the area and can easily be subjected

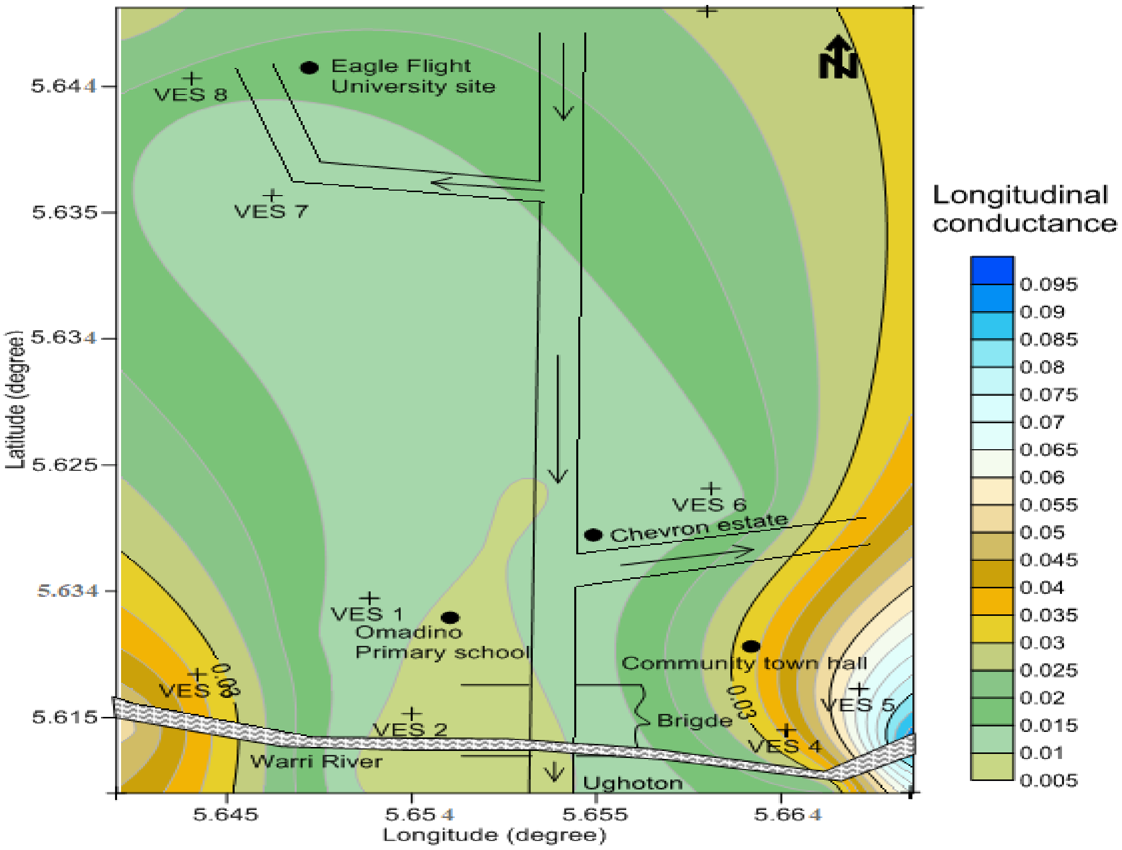


Figure 8. Map of longitudinal conductance.

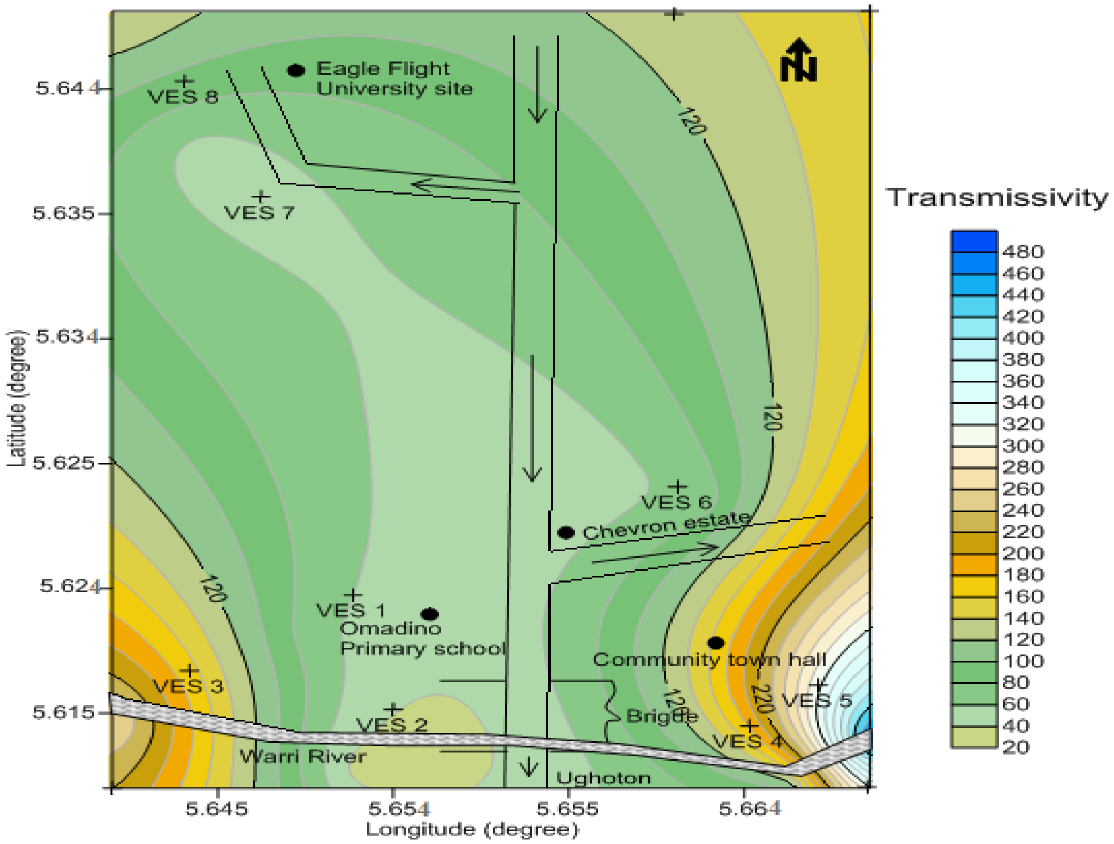


Figure 9. Map of aquifer transmissivity.

to infiltration of leachate and oil spills. This is probably a reason for Mode, et al., (2010)'s findings. The transmissivity obtained for the aquifers in the study area is of moderate potential with values, T_{mean} = 149.9 m^2day^{-1}, T_{min} = 30.2 m^2day^{-1}, and T_{max} = 498 m^2day^{-1}. The hydraulic conductivity estimated has a mean value of 11.3139 m/day. The study shows that the south east to northwest part of the area is best for siting of borehole as a result of its thicker aquifer, higher transmissivity and protective capacity.

CONFLICT OF INTERESTS

The author has not declared any conflict of interests.

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