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Geo-electric Groundwater Vulnerability Assessment of Overburden Aquifers at Awka in Anambra State, South-Eastern Nigeria

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Abstract
The subject of investigation in this study is the use of electrical resistivity method to assess the vulnerability of aquifers using resistivity parameters of the upper most geo-electric materials' layer overlying the aquifer. Thirteen (13) vertical electrical sounding (VES) points were conducted at various locations within the study area. The result of the study shows that the longitudinal unit conductance values obtained from the study area ranges from 0.020142 to 7.111671 mhos. The areas that are classified weak and poor are most susceptible to contamination, while the good, very good and excellent classification indicates high protective geological formation to contamination. Vulnerability map of the study area produced from the longitudinal unit conductance indicates that the Northern area has good to very good protective capacity rating while the Eastern zone indicates poor to weak protective capacity. Shale layer seems to provide higher longitudinal conductance generally in the study area and hence better protective capacity. It can be inferred from this study that a minimum shale thickness of 10m is required to provide good protective capacity for groundwater. The results of this study have provided reliable information about the protective capacity of the materials overlying the aquiferous unit which should be considered for planning, development and siting of prospective water resource projects in the study area

Keywords: Vertical electrical sounding, vulnerability assessment, longitudinal conductance, protective capacity, South East Nigeria.

1. Introduction

Underground water pollution is progressively emerging as a serious challenge in different countries in Europe, Asia and Africa. It gained international scientific interest during the last decades and has been studied using several approaches and techniques. The vulnerability of ground water qualitatively reflects the natural ability of the aquifer to be reached and affected by pollution from surfaces (landfill, industrial wastewater discharge, chemical fertilizers, pesticides, herbicides etc) (Sadkaoui *et al*. 2013). Electrical resistivity surveys have been used for many decades in hydro-geological, mining and geotechnical investigations. More recently, it has been used for environmental surveys. A number of geophysical exploration techniques are available which enables an insight to be obtained rapidly in the nature of water bearing layers and include geo-electric, electromagnetic, seismic and geophysical borehole logging (Alile, *et al*. 2008) [1]. These methods measure properties of formation materials, which determine whether such formation may be sufficiently porous and permeable to serve as an aquifer. The electrical resistivity method and seismic refraction method are the surface geophysical methods commonly used for groundwater exploration (Asawa, 2009) [4]. The protection of groundwater reservoir is given by the covering layers, also called protective layers. An effective groundwater protection is given by protective layers with sufficient thickness and low hydraulic conductivity (Aweto, 2011) [5]. It depends on the aquifer characteristics as well as the geological and hydrological environment.

Specific vulnerability is determined by the aquifer intrinsic vulnerability and the contaminant loading that is applied to the specific point of the hydro-geological basin. The present study involves the use of electrical resistivity method to assess the vulnerability of aquifers using geo-electric parameters of the near-surface materials overlying the aquifer. This method is much easier, it is a well-established method, the equipment is inexpensive, mobile, easy to operate, provides relatively rapid areal coverage with the depth of penetration limited only by the ability to extend electrode spacing (U.S. Environmental Protection Agency, 2006)[13]. From the time the study area became the seat of government power (i.e the state capital) for the state, there has been enormous migration of people to the town. The increase in population and urbanization in the study area puts the groundwater resources at risk. Since potable surface water is not readily available in the study area, the alternative is to depend on groundwater source. Hence the major source of water in the study area is groundwater resource. There is need for constant monitoring and evaluation of the water resources in the region to prevent occurrence of epidemics and to adopt appropriate water management strategies. Hence this study aims at assessing with the use of electrical resistivity method the vulnerability of aquifer in the region to contamination.

Location and Geology

The study area (Awka in Anambra State of Nigeria) has a topography that slopes gently towards Mamu River with major cuestas lying in the North-South direction. The first ridge peaks at 300 m above sea level at Agulu (outside Awka) while the minor cuesta peaks at 150m at Ifite-Awka. A major part of Awka is underlain by a thick sequence of shale and sandstone formed in the Paleolene age. Major soil types which exist within this region are loamy, clay and fine white sands, and lateritic soils. The study area is located between Latitude 6º12'- 6º16' N and Longitude 7º04' - 7º07' E and lies within the tropical wet climate zone having two distinct seasons: wet season (April- October) and dry season (November – March). The mean temperature which prevails over this region varies between 27 ºC – 28 ºC which most times peak to 35 ºC between January and April. This region also witnesses a mean annual rainfall of about 2000 mm with maximum monthly rainfall during the peaks ranging from 270 mm – 360 mm (Odumodu and Ekenta, 2012) [11].

The map of the area is shown in the figure below:

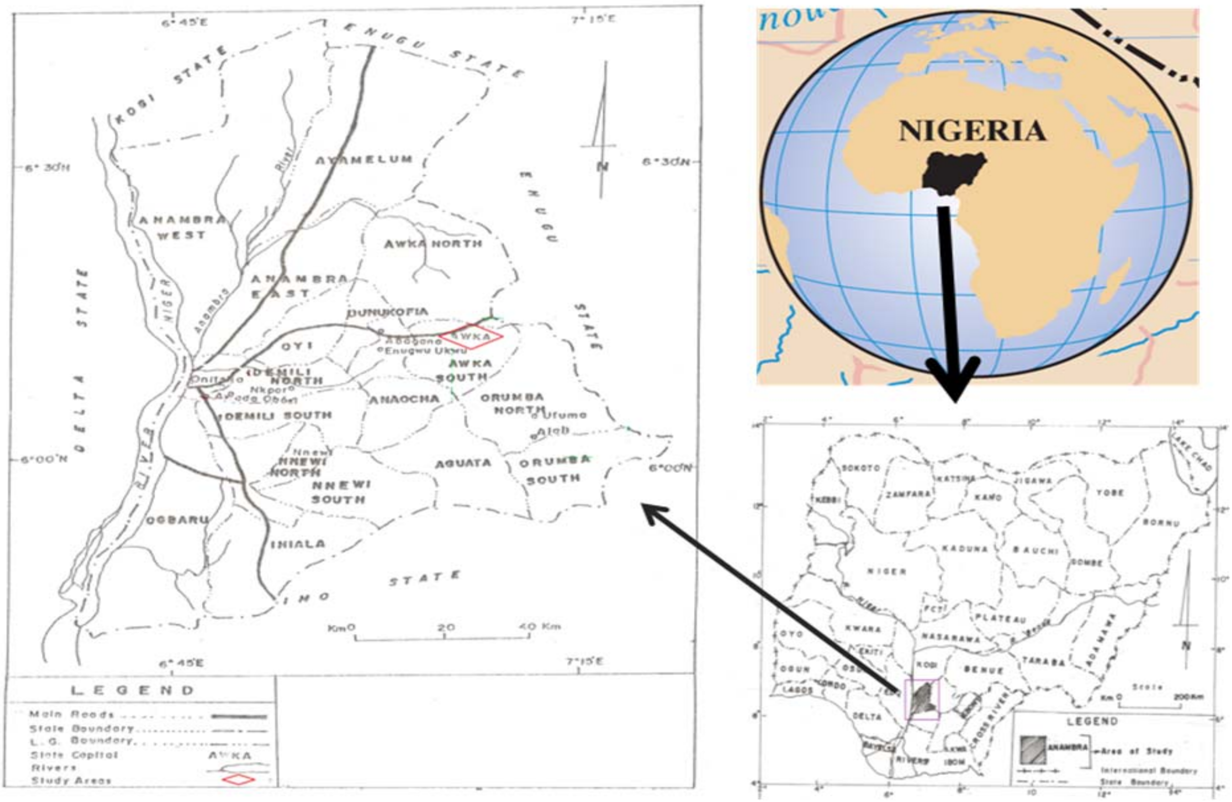


Figure 1: Map showing the study area in Anambra state of Nigeria

Materials and Methods

Geoelectric sounding (VES) surveys in the area were conducted using ABEM Terrameter Self Averaging System (SAS) 1000C which displays apparent resistivity values digitally as computed from Ohm's law. The ABEM Terrameter SAS 1000C performs automatic recording of both voltage and current, stacks the results, computes the resistance in real time and digitally displays it (Dobrin and King, 1976)[6]. From the field data, the apparent resistivity, which is a function of AB/2 (half the current electrode spacing) was calculated and interpreted with computer software (One dimentional Interpex Version 3). An electrode made of stainless steel was driven into the soil at each end of the spread A and B. Both electrodes were then connected to the current sender of the Terrameter. The electrodes M and N were also driven into the soil and connected to the voltage receiver. At each position of A and B, the current was sent, and the potential difference between M and N was measured. Also, the distances AB and MN were measured. Following the placing and connection of all electrodes, resistance measurements were made beginning with the smallest

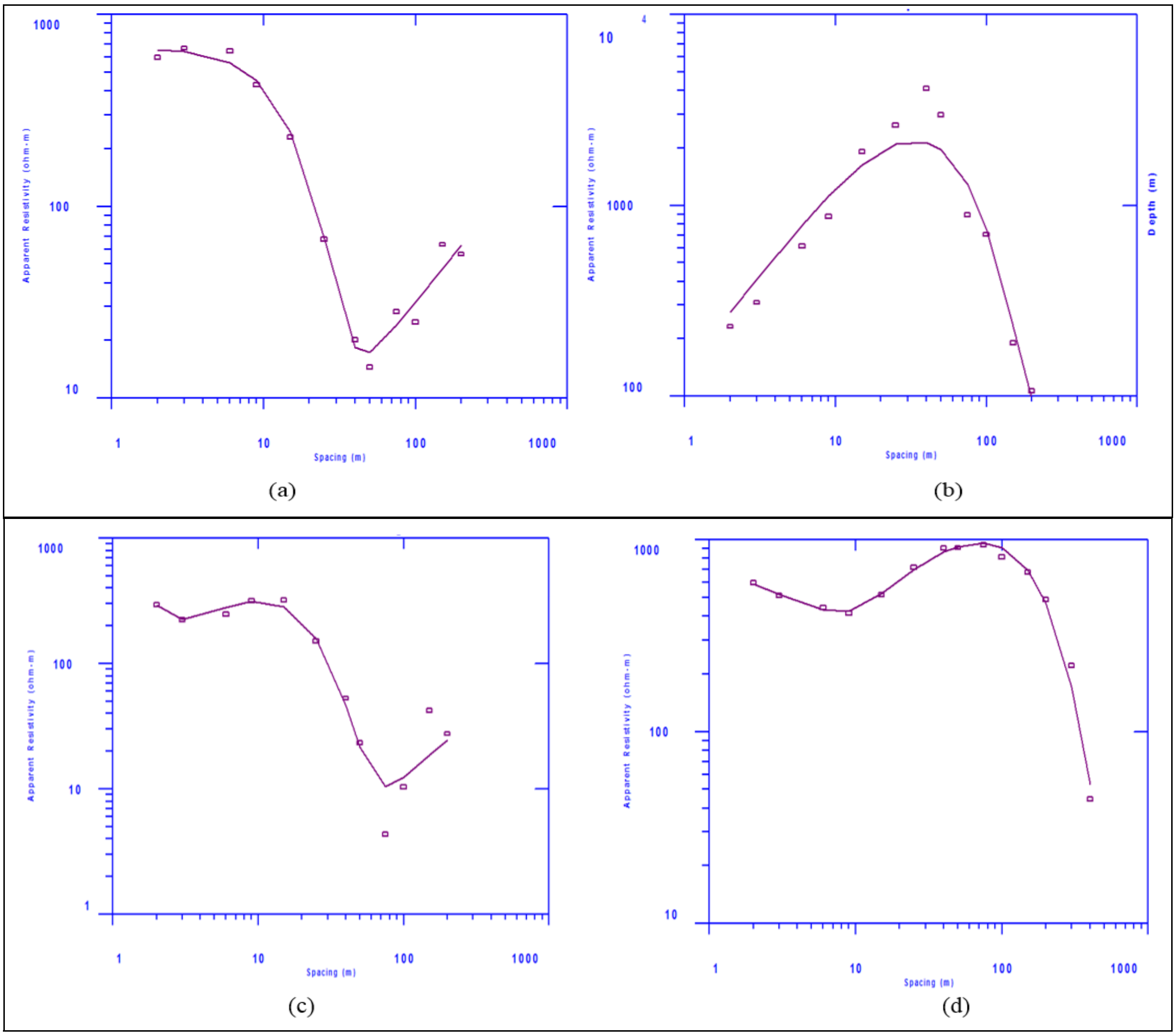
spacing and progressing outward. When the ratio of the distance between the current electrodes to that between the potential electrodes becomes too large, the potential electrodes must also be displaced outwards otherwise the potential difference becomes too small to be measured with sufficient accuracy (Koefoed, 1979) [8]. The Root Mean Square error was less than 10%. The apparent resistivity values obtained in the field was plotted against half current electrode spacing in a bi-logarithmic graph. The curves of best fit were traced and the data obtained from the smooth curve was noted. Qualitative and quantitative interpretations of the field curves were carried out by inspection to obtain the type of curves. The Golden SURFER 8.2 was used to produce the aquifer vulnerability map of the study area.
Thirteen (13) vertical electrical sounding (VES) points were conducted at various locations within the study area in order to study the variations in the resistivity distribution of the soil with depth. GPS device was used for measuring the spatial location (latitude and longitude) for the VES points (Table 2).

Aquifer Parameter Estimation
The resistivity parameters of the upper most geoelectric layer in the study area have been used to assess the vulnerability of the underlying aquifer. The combination of the resistivity and thickness in the Dar Zarrouk parameter (longitudinal conductance) have been used by various researchers in groundwater potential and aquifer vulnerability studies (Golam *et al.* 2014; Oborie and Udom, 2014) [7, 10]. High longitudinal conductance values usually indicate relatively high protective capacity and should be accorded the highest priority in terms of groundwater vulnerability assessment. The total longitudinal conductance (S) for each of geoelectric sounding (VES) stations was computed from the relation:

$$S = \Sigma (hi / \rho i) = h1 / \rho 1 + h2 / \rho 2 + ...+ hn / \rho n \qquad (1)$$

Where S is the total longitudinal conductance, Σ is summation sign, hi is the thickness of the ith
Layer and ρi is the resistivity of the ith layer.
The total longitudinal conductance (S) values computed were plotted and contoured to produce the aquifer vulnerability map.

Results and Discussions
3.1 Geo-electric Sections
The most important parameter in quantitative interpretation is the depth of the aquiferous units. Depth to water information is contained in the interpretation of the geo-electric curves. In VES 1 the sounding encountered five geo-electric units: top soil, sand, shale, water saturated sand and sand. Furthermore, Fig. 2 is a typical interpretation results of geo-electric sounding data acquired in the area (VES 1, 2, 6, 7, 9 and 10).



(a) (b) (c) (d)

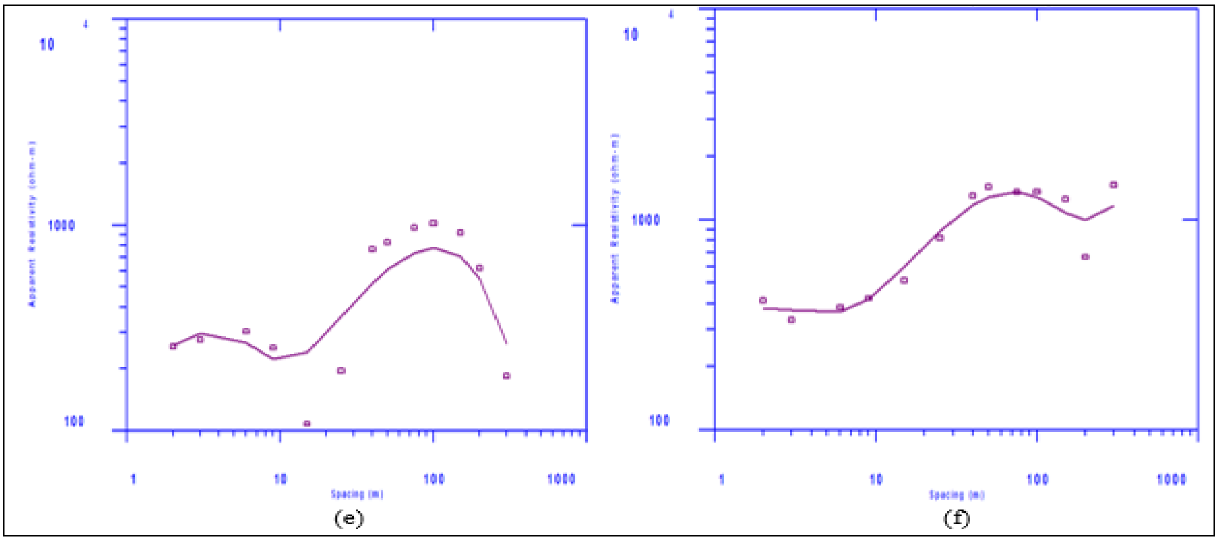


Fig 2: Typical interpretation results of geo-electric sounding data acquired in the study area (a) VES 1 (b) VES 2 (c) 6 (d) VES 7 (e) VES 9 (f) VES 10.

3.2 Assessment of Aquifer Vulnerability

The earth medium acts as a natural filter to percolating fluid, the ability of the earth to filter fluid is dependent on the aquifer thickness, the covering materials and the protective capacity of the overlying overburden of the aquifer. Silts and clays are suitable aquitards which often constitute protective geologic barriers and when they are found above an aquifer they constitute a protective cover (Lenkey *et al.* 2005)[9], they thus protect the aquifer from surface and near-surface contamination, because their low hydraulic conductivity leads to high residence time of percolating water. Table 1 presents longitudinal conductance/protective capacity ratings. The table enables the classification of the study area into various grades. The areas that are classified weak and poor are most susceptible to contamination, while the good, very good and excellent classification indicates high protective geological formation to contamination.

Table 1: Longitudinal Conductance/Protective Capacity Rating (Ogungbemi *et al.* 2013)

Longitudinal Conductance (mhos)	Protective Capacity Rating
>10	Excellent
5-10	Very good
0.7-4.9	Good
0.2-0.69	Moderate
0.1-0.19	Weak
<0.1	Poor

Clayey overburden has been reported by several authors to be characterized by relatively high longitudinal conductance, which offers protection to the underlying aquifer (Golam *et al.* 2014; Anomohanran, 2013; Rădulescu, *et al.* 2006) [7, 2, 13]. Table 2 shows the soil layers, geo-electrical resistivity, aquifer thickness, lithology. Longitudinal conductance, and the protective capacity of the VES points. The study area lithology is characterised with sand, shaly-sand and shale. Shale layer in this study seems to offer higher longitudinal conductance in the absence of clay. The longitudinal unit conductance (S) values obtained from the study area, ranges from 0.020142 to 7.111671 mhos. The results of assessment of the aquifer vulnerability (Table 2) shows that the protective capacity at VES 2, 4, 5, 7, 10, 11, 12, 13, are poor, these regions are characterised by thin or no shale layers, it therefore implies that the aquifer in these locations are vulnerable to contamination. VES 9 indicates weak protective covering; here shale layer has a thickness of 9.5m. VES 1 and 12 has a good protective capacity, with shale layers of 10.3m and 29.7m thickness. VES 3 and 6 has a very good protective capacity; this is probably as a result of the increase in the number of layers (4 layers) before the water table as against two to three in other VES station, also the presence of high values of shale layer aquifer thick could contribute to its higher protective capacity. VES 3 has shale and shaly-sand thickness of 23.6 and 24.6 respectively, while VES 6 has shale and shaly-sand thickness of 57.9m and 2.3m respectively. Shale layer generally in the study area tend to provide higher longitudinal conductance and hence better protective capacity. Consequent upon these observations it can be inferred from this study that a minimum shale thickness of 10m is required to provide good protective capacity for groundwater using the longitudinal conductance aquifer assessment criteria.

Table 2: VES Coordinates points, Geoelectric parameters, lithological delineation and protective capacity of the study area

VES No. and Coordinates point	Layers	Resistivity (Ωm)	Thickness (m)	Lithology	Longitudinal conductance	Protective capacity
VES 1 6º12.534'N 7º03.459'E =	Layer 1	597.02	2.2	Top soil	0.003685	2.917093 (Good)
	Layer 2	858.21	6.3	Sand	0.007341	
	Layer 3	10.22	29.7	Shale	2.906067	
	Layer 4	139.14	66.8	Water saturated sand		
VES 2 6º14.380'N 7 º05.963'E	Layer 1	232.92	2.7	Top soil	0.011592	0.028266 (Poor)
	Layer 2	875.54	6.7	Shaly-sand	0.007652	
	Layer 3	4090.2	36.9	Sand	0.009022	
	Layer 4	1004	59.5	Water saturated sand		
VES 3 6º12.635'N 7 º03.677'E	Layer 1	425.23	2.2	Top soil	0.005174	7.03078 (Very Good)
	Layer 2	3.41	23.6	Shale	6.920821	
	Layer 3	38.14	24.6	Shaly-sand	0.644992	
	Layer 4	532.52	55.8	Sand	0.104785	
	Layer 5	183.21	79.5	Water saturated sand	0.433928	
VES 4 6º13.629'N 7 º05.458'E	Layer 1	3103.1	3.5	Top soil	0.001128	0.025714 (Poor)
	Layer 2	1220.2	6.2	Shaly-sand	0.005081	
	Layer 3	4650.2	90.7	Sand	0.019505	
	Layer 4	3813.2	49.6	Water saturated sand	0.013007	
VES 5 6º12.635'N 7 º03.677'E	Layer 1	640.41	2.3	Top soil	0.003591	0.020142 (Poor)
	Layer 2	2320.2	38.4	Sand	0.016551	
	Layer 3	1894	65.2	Water saturated sand	0.034424	
VES 6 6º12.391'N 7 º03.256'E	Layer 1	389.18	2.3	Top soil	0.00591	7.111671 (Very Good)
	Layer 2	151.05	2.3	Shaly sand	0.015227	
	Layer 3	635.23	13.3	Sand	0.020937	
	Layer 4	8.19	57.9	Shale	7.069597	
	Layer 5	687.03		Water saturated sand	0	
VES 7 6º14.432'N 7 º05.621'E	Layer 1	720.91	2.2	Top soil	0.003052	0.044251 (Poor)
	Layer 2	329.05	7.4	Shaly sand	0.022489	
	Layer 3	1528.6	28.6	Sand	0.01871	
	Layer 4	893.21	151.9	Water saturated sand	0.170061	
VES 8 6º12.895'N 7 º04.274'E	Layer 1	92.08	2.8	Top soil	0.030408	0.510408 (Moderate)
	Layer 2	687.01	3.6	Sand	0.00524	
	Layer 3	46.11	20.9	Shale	0.453264	
	Layer 4	893.21	19.2	Sand	0.021496	
	Layer 5	217.18	140.6	Water saturated sand	0.647389	
VES 9 6º13.639'N 7 º05.861'E	Layer 1	300.22	2.1	Top soil	0.006995	0.177559 (Weak)
	Layer 2	504.03	4.1	Sand	0.008134	
	Layer 3	78.11	9.5	Shale	0.121623	
	Layer 4	970.41	39.6	Sand	0.040807	
	Layer 5	619.08	142.8	Water saturated sand	0.230665	
VES 10 6º13.738'N 7 º05.395'E	Layer 1	411.09	2.6	Top soil	0.006325	0.075195 (Poor)
	Layer 2	83.24	3.9	Shale	0.046852	
	Layer 3	1439.8	31.7	Sand	0.022018	
	Layer 4	947.05	158.9	Water saturated sand	0.167784	
VES 11 6º14.536'N 7 º05.832'E	Layer 1	393.01	2.4	Top soil	0.006107	0.044156 (Poor)
	Layer 2	144.16	2.3	Shale	0.015954	
	Layer 3	2050.2	45.3	Sand	0.022095	
	Layer 4	1235.4	106.1	Water saturated sand	0.085885	
VES 12 6º15.572'N 7 º06.572'E	Layer 1	125.7	2.5	Top soil	0.019889	1.225978 (Good)
	Layer 2	8.54	10.3	Shale	1.206089	
	Layer 3	82.01	8.9	Shallow saturated shale	0.108523	
VES 13 6º14.224'N 7 º05.478'E	Layer 1	182.7	2.7	Top soil	0.014778	0.03167 (Poor)
	Layer 2	219	3.7	Sand	0.016895	
	Layer 3	158	5.1	shallow saturated shale	0.032278	

By using the resistivity values measured from the geo-electric survey, longitudinal unit conductance of the overlying overburden was evaluated. Vulnerability map of the study area was produced from the longitudinal unit conductance (Figure 3), which gives detailed information on the pattern of the protective capacity of the natural overburden over the aquifer in the study area. The map indicates that the Northern area has good to very good protective capacity rating because of the thick shale formation overburdening the region. The Eastern zone indicates poor to weak protective capacity, and is characterised by thin or lack of shale layer formation and consequently is susceptible to contamination.

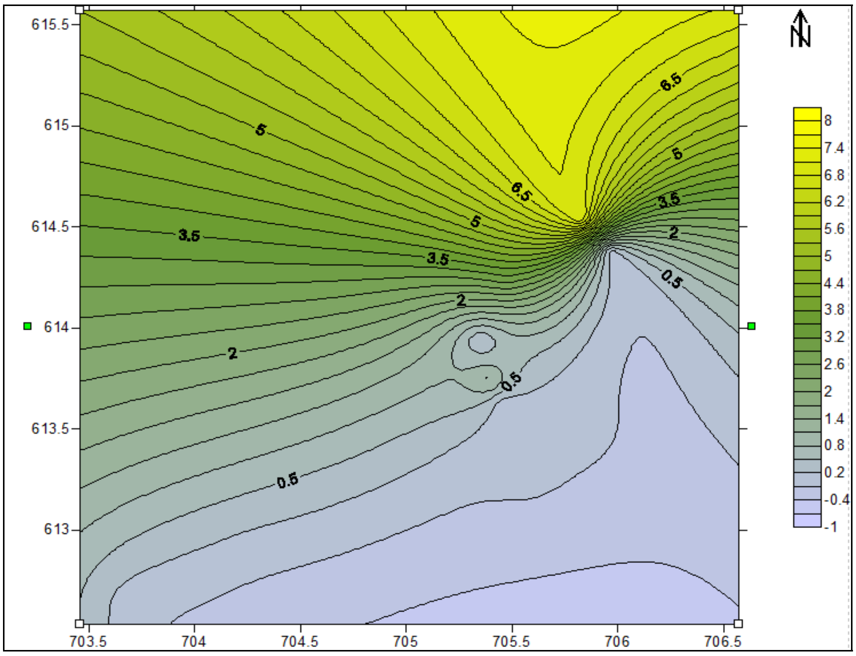


Fig 3: Aquifer Vulnerability Map

Conclusion

About 53.8% of the study area has poor protective capacity, 7.69% weak protective capacity, 7.69% moderate protective capacity, 15.4% good protective capacity and 15.4% very good protective capacity. This indicates that overlaying soil layers in the area though thick enough, but the absence of clayey or shale layer formation could make the groundwater vulnerable to contaminant. The results of the assessment of aquifer vulnerability shows that the protective capacity at VES 2, 4, 5, 7, 10, 11, 12, 13, are poor, these regions were characterised by thin or no shale layers. VES 9 indicated weak protective covering with a shale layer thickness of 9.5m. VES 1 and 12 are of good protective capacity, with shale layers thickness of 10.3m and 29.7m. VES 3 and 6 had a very good protective capacity, and this is probably as a result of increase in the shale layer thickness. Vulnerability map of the study area produced from the longitudinal unit conductance indicates that the Northern area has good to very good protective capacity rating, while Eastern zone indicates poor to weak protective capacity. Shale layer generally in the study area seems to provide higher longitudinal conductance and hence better protective capacity. It can be inferred from this study that a minimum shale thickness of 10m is required to provide good protective capacity for groundwater.

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