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AQUIFER PROTECTIVE CAPACITY EVALUATION USING VERTICAL ELECTRICAL RESISTIVITY METHOD AT KAFIN HAUSA METROPOLIS, JIGAWA STATE, NIGERIA.

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ABSTRACT

Thirty two (32) vertical electrical sounding points where sounded within Kafin Hausa metropolitan using Schlumberger configuration. The VES data acquired from the field were analysed and interpreted using IPI2Win and Surfer (Version 15). The results of the VES points obtained were compared with the borehole log and geology of the study area which revealed five to six layered formations. Clayey sand as top layer, mixed medium sand with coarse sand as the second layer, mixed fine sand with medium to coarse sand as the third layer, medium to coarse sand with siltstone as the fourth layer, medium to coarse sand as the fifth layer and coarse sand as the six layer. Longitudinal unit conductance of the study area ranges from 0.02 Ωm^{-1} to 11.87 Ωm^{-1}**.** About 63% of the aquifer of the whole study area (more than half) are poorly and weakly protected, as such these areas are vulnerable to contamination. The transverse resistance of the study area ranges from 2206.5 Ωm^{2} to 14228.89 Ωm^{2}**.** All the VES points within the study area have higher value of transverse resistance. Therefore, there are better chances of abundance of ground water within the study area which need to be safeguard from contaminations.

Keywords: *Schlumberger, VES, Transverse resistance, geological structures*

INTRODUCTION

Sufficient, good and quality of ground water has extensively increased nowadays due to consciousness, need and technology. Thus, many people rely on the exploration and exploitation of groundwater. Exploration for groundwater, which is one of the most valuable natural and available resources and is important for the sustenance of life on earth, requires a number of techniques(Bashir, Izham, & Main, 2014; T. Journal & June, 2013; Study, Ado, Author, & Oladimeji, 2012).The availability of water has played a key role in the development of all civilizations. Indeed, especially in the ancient times, water scarcity prevented the development of settlements (Utom, Odoh, & Okoro, 2012). Social welfare and economic development may also be hampered in the absence of reliable water supplies. This is particularly true of sub-Sahara and Sahara countries, such as Nigeria, where water resources are extremely limited and highly valued as a social and economic good.

Vertical electrical sounding (VES) is commonly used in electrical resistivity surveys to determine the vertical variation between the electrical resistivity below the earth's surface and the potential field generated by the current (Anomohanran, 2015). The technique involves inducing an electric current into the ground by means of two implanted electrodes and measuring the difference in potential between two other electrodes, referred to as the potential electrodes. The electric current used is the direct current provided by a dry cell. Therefore, analysis and interpretation of the geo-electric data are on the basis of direct current. The resistivity computed from the measurement of induced current and the potential difference is referred to as the "apparent resistivity". This measurement is based on the assumption that the ground is uniform. However, in reality, the resistivity of the earth is determined by inhomogeneous lithology and geological structures. Therefore, a graph of apparent resistivity against current electrode spacing is used to determine vertical variation in formation resistivity. Interpretation of this graph gives the true resistivity and depth of the geo-electric layers and is also used to ascertain the presence or otherwise of groundwater aquifers in the area. The parameters that are known to affect the estimation of groundwater resources include aquifer thickness and the size and degree of inter connection of pore spaces within the aquifer material (Abiola, Enikanselu, & Oladapo, 2009; Rabenau, 1985).These properties affect the ability of an aquifer to store and transmit groundwater (Engineering, Tizro, Voudouris, & Kamali, 2014).

Vertical electrical sounding (VES) is commonly used in electrical resistivity surveys to determine the vertical variation between the electrical resistivity below the earth's surface and the potential field generated by the current (Anomohanran, 2015; I. Journal & Geosciences, 2016; Longpia, 2017). The technique involves inducing an electric current into the ground by means of two implanted electrodes and measuring the difference in potential between two other electrodes, referred to as the potential electrodes. The electric current used is the direct current provided by a dry cell. Therefore, analysis and interpretation of the geo-electric data are on the basis of direct current. The resistivity computed from the measurement of induced current and the potential difference is referred to as the "apparent resistivity". This measurement is based on the assumption that the ground is uniform. However, in reality, the resistivity of the earth is determined by inhomogeneous lithology and geological structures. Therefore, a graph of apparent resistivity against current electrode spacing is used to determine vertical variation in formation resistivity. Interpretation of this graph gives the true resistivity and depth of the geo-electric layers and is also used to ascertain the presence or otherwise of groundwater aquifers in the area. The parameters that are known to affect the estimation of groundwater resources include aquifer thickness and the size and degree of inter-connection of pore spaces within the aquifer material. These properties affect the ability of an aquifer to store and transmit groundwater (I. Journal & Geosciences, 2016; Utom et al., 2012).

The electrical resistivity method can be used in a wide range of geophysical investigations, such as exploration for minerals, engineering investigation, geothermal studies, archaeological surveys and geological mapping (A.E., L.C., F.E., & F.D., 2016; Anizoba, Chukwuma, Chukwuma, & Chinwuko, 2015; Chinwuko, Anakwuba, Nwokeabia, & Onyekwelu, 2014; Chukwuma E.C et al., 2015).The method has been used extensively in Nigeria and other parts of the world to investigate the subsurface. Patel & Dasgupta, (2007)used it to estimate the aquifer properties of Sagar Island Region in India, where they observed that the results correlated significantly with borehole data from the area. Patel & Dasgupta, (2007) used the method to map electrical resistivity distribution in the Al-Avovb Basin in Palestine, showing the existence of a continuous moderate formation accompanied by an upper clayey layer and a strong correlation with existing wells located in the study area. In Nigeria, the geo-electrical resistivity method has been used to search for potable water and to evaluate formation strata by many researchers. In this study, we investigate the aquifer protective capacity of Sule Lamido university Kafin Hausa jigawa State using vertical electrical sounding (VES).

LOCATION OF THE STUDY AREA

Kafin- Hausa is located within the coordinates 12°14'26" N and 9°54'47" E in DMS (Degrees Minutes Seconds) or 12.2406 and 9.91306 (in decimal degrees). Kafin Hausa is among the twenty seven local governments that constitute Jigawa State (north eastern part of the state) as shown in figure (1) below.It borders with Bauchi state to the south and east, with Auyo local government to the north. To the west Kafin Hausa shares border with Miga, Jahun and Kiyawa local governments. Kafin Hausa (Kafin Hausa) is a populated place in Jigawa, Nigeria (Africa) with a population of 271,058 at the 2006 census and it has an area of 1,380 km².

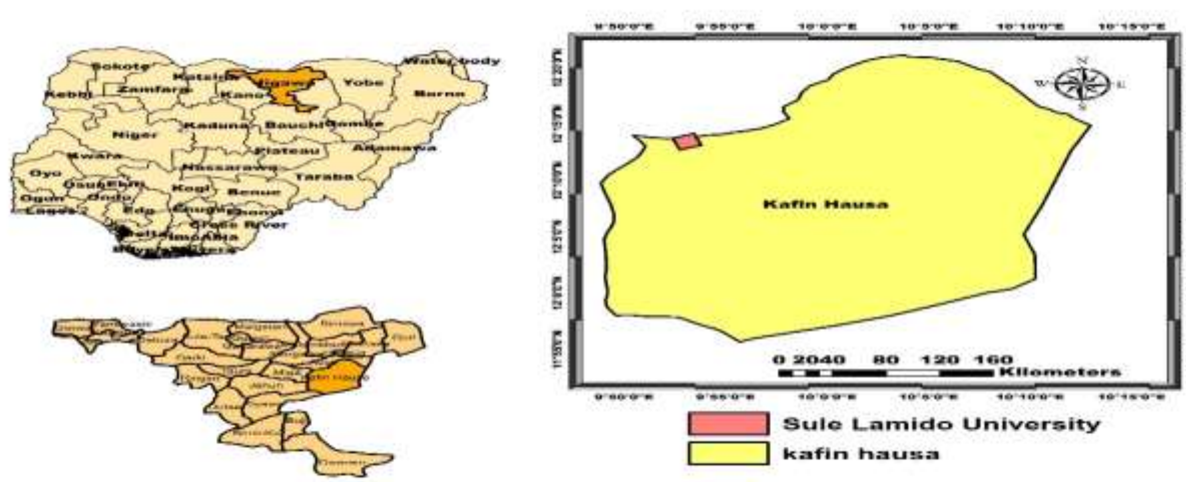

Fig. 1: Location of the Study Area.

TOPOGRAPHY, GEOLOGY AND HYDROLOGY OF THE STUDY AREA.

The southern part of Jigawa comprises the Basement Complex while the northeast is made up of sedimentary rocks of the Chad Formation. The northwest and southern parts of the state are underlain by granites, schist and gneisses of the basement complex. The ancient Pre Cambrian-rocks of the basement complex are separated from the younger sediment of the Chad Formation by a hydrological divide, which runs through Kiyawa, Dutse and Yankwashi. Kafin Hausa is located closed to the hydrological divide within chad formation as shown in figure (2). The Chad formation occupies the north eastern parts of the state (where Kafin- Hausa lies). However, the basement complex rocks have undergone weathering to give rise to fairly deep soils which are often covered by a sheet of laterite which has been exposed by denudation in some places. (Wekipedia Retrieved 2017 10-20).

The main rivers are Hadejia, Kafin Hausa and Iggi Rivers with a number of tributaries feeding extensive marshlands in north-eastern part of the state. Hadejia – Kafin Hausa River traverses the State from west to east through the Hadejia- Nguru wetlands and empties into the Lake Chad Basin. The climate of Jigawa State is semi- arid, characterized by a long dry season and a short arid wet season. The climatic variables vary considerably over the year and are erratic. The temperature out regime is warm to hot. The mean annual temperature is about 25°C but the mean monthly values its range between 21°C in the coolest month and 31 °C in the hottest month. (Wekipedia, Retrieved 2017 10-20).

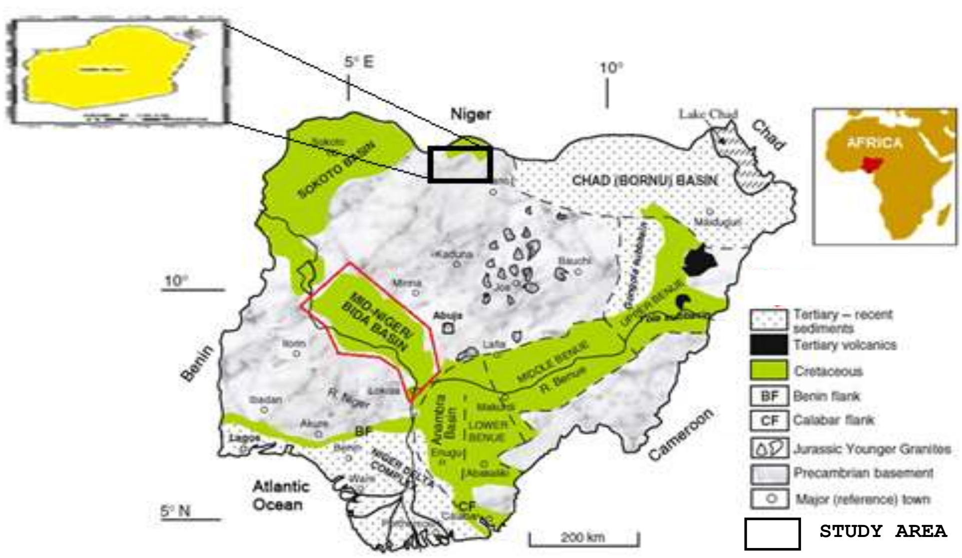

Fig. 2: Geology and Hydrology of the Study Area. (Wekipedia Retrieved 2017 10-20)

TOPOGRAPHY AND VEGETATION OF THE STUDY AREA

The state has a total land area of approximately 22,410 square kilometres. Its topography is characterized by undulating land, with sand dunes of various sizes spanning several kilometres in parts of the State. Most parts of Jigawa lie within the Sudan Savannah with elements of Guinea Savannah in the southern part. Total forest cover in the State is very much below national average of 14.8%. Due to both natural and human factors, forest cover is being depleted, making northern part of the State highly vulnerable to desert encroachment. The State enjoys vast fertile arable land to which almost all tropical crops could adapt, thus constituting one of its highly prized natural resources. The Sudan Savannah vegetation zone is also made up of vast grazing lands suitable for livestock production.

MATERIALS AND METHOD

Materials

In carrying out the research work, a number of instrument/ materials were used in conducting and acquiring data. These instruments or materials are: Alied Ohmega Terrameter, Cable on wheels, a laptop computer, software (IPI2win and Suffer version 11), metal electrodes, hammers, connecting wires, measuring tape and geographical positioning system (GPS).

Method

The geophysical prospecting method adopted for this study is the Vertical Electrical Sounding (VES) techniques of the electrical resistivity method. The Alied Ohmega terrameter was employed as the primary instrument. For adequate depth penetration, the Schlumberger electrode configuration was used with half maximum current and potential electrode separation of 100 m and 15m respectively. A total of twenty (32) VES soundings were carried out. Results from the field data were subjected to interpretation using the IPI2Win iterative software in order to model the data and to deduce the true resistivity, true thicknesses of each geo-electric layers as well as the lithology of the area under investigation. The thicknesses of the aquifer (h) and the apparent resistivity (ρa) of the aquiferous layer were obtained from the interpreted data and were employed in the determination of the transverse resistance (T_r) and the longitudinal conductance (L_c). The L_c and T_r are employed to deduce the aquifer protective capacity of the study area.

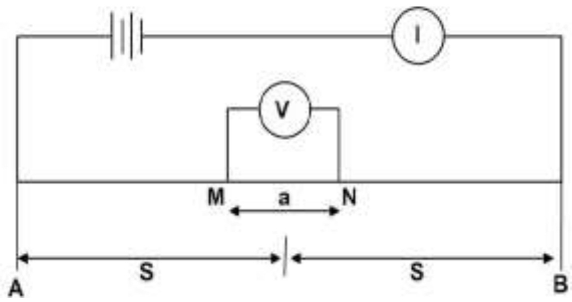

Fig. 3: Sketch showing Schlumberger electrode configuration.

Theory

The quantitative treatment of field data started with the conversion of measured resistance (R_a) to apparent resistivity (ρ_a) using a standard equation given as:

$$\rho_a = \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN} \right] \times \frac{\nabla V}{I} \qquad (1)$$

where AB is the current electrode spacing and MN is the potential electrode spacing, thus, eq. (1) can now be written as:

$$\rho_a = RK \qquad (2)$$

where R is the resistance and K is the geometrical factor.

The combination of subsurface resistivity and thickness into single parameter gives rise to the Dar Zarrouk parameters deployed for the study.A geoelectric layer is described by two fundamental parameters: its resistivity *ρi* and its thickness, *hi*, where the subscript *i* indicates the position of the layer in the section (*i* = 1 for the uppermost layer). Dar Zarrouk parameters; Total Transverse unit Resistance, *T* (Ωm^2) and Total Longitudinal Unit Conductance, *S* (Ω^{-1}) (Iduma, et. al., 2016). For a sequence of n horizontal stratified, homogeneous and isotropic layered earth model of resistivity ρ_i and thicknesses h_i, are presented as the combinations of the layer parameters (ρ_i and h_i) as:

$$S_i = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho 3} + - - - - + \frac{h_n}{\rho_n}$$

and (2)

$$T_i = \sum_{i=1}^{n} \rho_i h = \rho_1 h_1 + \rho_2 h_2 + \rho_3 h_3 + \ldots + \rho_n h_n$$

where S_i and T_i represent longitudinal conductance (Siemens) and transverse resistance (ohm-m^2) respectively. The combined resistance and thickness of earth layers was necessary because it checks some limitations, such as: heterogeneities effects, topographic effect and assumptions that beddings are horizontal associated with VES data interpretation. There was a need to correct for aquifers' resistivity in order to determine the hydrogeological characteristics of the underground water.(Utom et al., 2012) Hence, transverse resistance (T) was applied to reveal resistive layer confined between two or more conductive layers. While conductive layer sandwiched between two or more resistive layers was unravelled by its horizontal conductance (S).

RESULT AND DISCUSSION

Vertical Electrical Sounding Curves

One of the most important valued parameter in quantitative interpretation is the depth to the aquifer. The depth information is contained in the interpretation of geo-electric curves. In VES1 we encountered six geo-electric layers. The lithology of the study area is characterized as clayey sand as the top layer, mixed medium sand with coarse sand as the second layer, mixed fine sand with medium to coarse sand as the third layer, medium to coarse sand with siltstone as the fourth layer, medium to coarse sand as the fifth layer and Coarse Sand as the sixth layer.

Furthermore, figure 1 shows a typical VES curve with model parameter table for VES 13, VES28 and VES3 respectively.

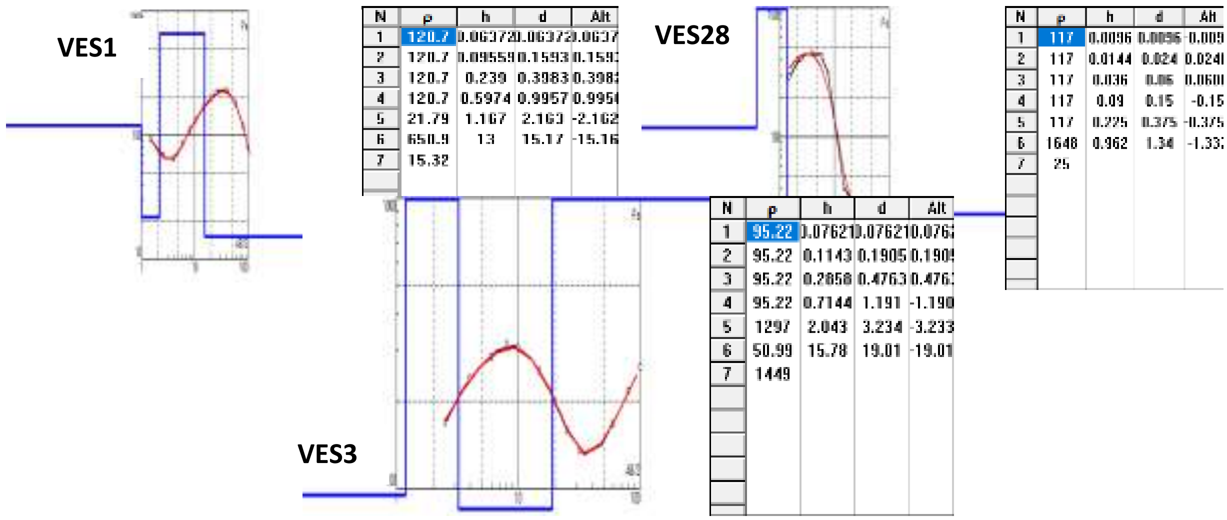

Fig. 4: VES curves and modelled Parameter Table for VES 13, 28 and 3

Assessment of Aquifer Protective Capacity

Longitudinal Conductance

The earth contains different particles of different soil types. This earth particles of different type act as a medium to filter fluids which are dependent on the aquifer thickness, the overburden material and the protective capacity of the overlaying layer of the aquifer. Silts and clayey soils are aquiterds as such they constitute protective ability when are found as an overlaying layer of the aquifer(Lenkey, Hámori, & Mihálffy, 2005). Therefore, they protect the aquifer from the surface infiltration of the contaminant. This is because of their good hydraulic conductivity that leads to their high resistance to percolation.

Protective capacity rating is presented in table 1. This table will allow us to identify or classify our study area into various regions or zones of protective capacity. The areas are classify into excellent, very good, good, moderate, weak and poor zones of protective capacity. Zones or regions classify as poor or weak are vulnerable to contamination due to their low protective capacity. Whereas areas classify as excellent, very good are zones with high protective capacity of contaminations. In a research conducted by Chukwuma E.C et al., (2015) confirmed that the overburden of sandy material has been characterized as low longitudinal conductance, as such aquifer has no or little protection when the overlaying layer of the aquifer is made up of sandy soil. This is as a results of large pore spaces of the sandy material, as such contaminants can easily moves through this spaces there by contaminating the aquiferous regions found in the area.

Table 1: Longitudinal/ Protective Capacity Rating. (Chukwuma E.C et al., 2015)

S/N	Longitudinal Conductance (mhos)	Protective Capacity Rating
1	≥ 10	Excellent
2	5-10	Very Good
3	0.7-4.9	Good
4	0.2-0.69	Moderate
5	0.1-0.19	Weak
6	≤ 0.1	Poor

Table 2 shows geo-electric resistivities, thicknesses, depths, transverse resistances and longitudinal unit conductance of the various VES points within the study area. The longitudinal conductance (S) values obtained from the VES points within the study area ranges from 0.020532Ω*m* to 11.87173Ω*m*. The result obtained shows that about 40% of the total VES points within the study area are classified as poor protective capacity areas. This may be attributed to the fact that most of the lithology of the study area are predominantly of sandy formation. This comprises of VES3, VES5, VES8, VES10, VES11, VES12, VES17, VES119, VES20, VES21, VES27 and VES29. Moreover, sandy formation have larger pore spaces which allow easy passage of fluids through it. About 23% of the whole study area is characterized as week protective capacity. This points comprises of VES32, VES30, VES15, VES 9, VES 7, VES6 and VES 2. This points have weak protective capacity. Therefore areas around this points are prone to contaminations. This is because the overburden thickness are predominantly of sandy formation with very thin clay formation and it appears as the top layer.

When the longitudinal unit conductance of the study area ranges from 0.2Ωm^{-1} to 0.69Ωm^{-1}, this areas are classified as areas with moderate protective capacity. This points constitute 12% of the

VESpoints. These comprises of VES14, VES23, VES25, and VES 26. Areas around these VES points have moderate protection to the aquifer contamination. Longitudinal unit conductance that ranges from 0.7Ωm^{-1} to 4.9Ωm^{-1} are classified as Good protective capacity points. This points constitutes 12% 0f the total VES points conducted in the study area which comprises of VES31, VES18, VES4 and VES1.

An area will be rated with a very good protection from contamination when value of the longitudinal conductance range from 5Ωm^{-1} to 10Ωm^{-1} this constitute only 6% of the total sounding points conducted within the study area. Excellent protective capacity of an area is when the value of the longitudinal conductance is found to be greater than 10ohm (Table1). About 6% of the total VES points constitute excellent protective capacity. These VES points are VES12 and VES28.

Therefore, from the above result we can see that 64% of the total VES points constitute Poor and weak areas of protection against contamination of our aquifers within the study area. This constitute more than half of the total VES point. Only 12% 0f the total VES points constitute moderate protective capacity of the aquifereous zones within the study area. These areas are neither good nor bad in protecting the aquifer units. 12% of the total VES points constitute excellent and very good protection of the aquifer unites of the whole VES points. Therefore only VES12, VES16, VES24 and VES28 are the best locations for very good and excellent protection of aquifer units from contamination. Therefore, the study area is not adequately protected because only four (4) VES points out of thirty two (32) VEs points have very good and excellent protection.

Table 2: Geoelectric Resistivities, Thicknesses, Depths, Transverse Resistances and Longitudinal Unit Conductance of the Various VES Points of the Study Area.

VES NO.	LAYERS	RESISTIVITY (Ω)	THICKNESS (M)	DEPTH (M)	TRANSVERSE RESISTANCE (mΩ)	LONGITUDINAL CONDUCTANCE ($m\Omega^{-1}$)	PROTECTIVE CAPACITY ($m\Omega^{-1}$)
1	1	100.00	0.225	0.225	90.201	0.000225	6.327808 (Good)
	2	378.00	0.456	0.681	3949.92	0.00120635	
	3	28.1.00	2.53	3.21	26150	0.09003559	
	4	633.00	3.03	6.24	2117.5	0.00478673	
	5	2092.00	6.24	12.5	0	0.00298279	
	6	17.50	109	121	40.1466	6.22857143	
2	1	147.00	0.0078	0.0078	40.1466	1.5154E-06	0.108063 (Week)
	2	81.90	0.101	0.109	8.9271	0.00123321	
	3	323.00	0.28	0.389	125.647	0.00086687	
	4	22.20	1.8	2.97	65.934	0.08108108	
	5	178.00	3.78	5.97	1062.66	0.02123596	
	6	9358.00	34.1	40.1	375255.8	0.00364394	
3	1	12.9	0.0084	0.0084	26.3717	6.6575E-06	0.021682 (Poor)
	2	145	0.0097	0.0181	0.239205	0.00273782	
	3	4.31	0.0118	0.0555	70.2438	5.7994E-05	
	4	1.97	0.0555	0.0734	0.144598	0.00908629	
	5	957	0.0179	0.0734	0.234982	0.00979339	
	6	2.42	0.0237	0.0971	26.3717	0	
4	1	43.9	0.56	0.56	147.29	0.00627184	3.302476 (Good)
	2	0.901	0.222	0.782	983.4	0.01381818	
	3	103	0.646	1.43	590.24	0.15020161	
	4	220	3.04	4.47	30.276	3.13218391	
	5	49.6	7.45	11.9	0	0	
	6	1.74	5.45	17.4	57.6288	5.6222E-08	
5	1	32016	0.0018	0.0018	57.6288	2.0519E-06	0.066698 (Poor)
	2	7.54	0.002	0.0038	0.028652	0.00135294	
	3	3.59	0.0034	0.0072	11.9304	0.00031193	
	4	1.70	0.0023	0.0095	0.01615	0.06128134	
	5	327	0.102	0.111	36.297	0	
	6	1657	0.22	0.331	1.18829	0.00375	
6	1	56.8	0.213	0.213	12.0984	0.00375	0.114083 (Week)
	2	224	0.291	0.504	112.896	0.00129911	
	3	12.1	1.08	1.58	19.118	0.0892562	
	4	65.9	0.918	2.5	164.75	0.0139302	
	5	999	0.953	3.46	3958.24	0.00083304	
	6	1144	5.29	8.74	9220.7	0.00501422	
7	1	374.00	0.572	0.572	213.928	0.00152941	0.111242 (Week)
	2	117.00	0.876	1.45	169.65	0.00748718	
	3	100.00	5.05	6.5	656.5	0.05	
	4	700.00	12.7	19.2	13440	0.01814286	
	5	1796	61.2	80.4	144398.4	0.03407572	
	6	15702	0.104	80.5	1264011	6.6234E-06	

8	1	43.00	0.524	0.524	228.988	0.00119908	0.053757 (Poor)
	2	16.2	0.247	0.771	12.4902	0.01524691	
	3	15	0.404	1.17	17.55	0.02693333	
	4	247	0.772	1.95	481.65	0.00312551	
	5	464	1.55	3.5	1624	0.00334052	
	6	1194	4.67	8.17	9754.98	0.00391122	
9	1	851	0.23	0.23	195.73	0.00027027	0.196869 (Week)
	2	129	0.206	0.436	56.244	0.0015969	
	3	129	0.297	0.733	94.557	0.00230233	
	4	24.3	3.49	4.22	102.546	0.1436214	
	5	122	2.63	6.85	835.7	0.02155738	
10	1	568	0.237	0.291	165.288	0.00041725	0.061252 (Poor)
	2	980	0.254	0.545	534.1	0.00025918	
	3	85	0.082	0.627	53.295	0.00096471	
	4	11.5	0.501	1.13	12.995	0.04356522	
	5	102	1.56	2.69	274.38	0.01529412	
	6	2595	1.95	4.64	12040.8	0.00075145	
11	1	1623	0.0183	0.0183	165.288	0.000417254	0.061252 (Poor)
	2	568	0.273	0.292	534.1	0.000259184	
	3	980	0.254	0.546	53.295	0.000964706	
	4	85	0.082	0.628	12.995	0.043565217	
	5	11.5	0.501	1.13	274.38	0.015294118	
	6	102	1.56	2.69	12040.8	0.000751445	
12	1	3405	0.047	0.047	29.7009	1.12754E-05	0.061327 (Poor)
	2	118	0.308	0.355	165.856	0.000480634	
	3	9.1	2.87	3.23	535.08	0.000259184	
	4	1055	21.1	24.3	53.38	0.000964706	
	5	17.4	185	210	12.995	0.043565217	
	6	1041	164	185	274.38	0.015294118	
13	1	11769	0.0385	0.0385	160.035	1.38032E-05	11.87173 (Excellent)
	2	5758	0.0872	0.126	41.89	0.002610169	
	3	11234	0.007	0.133	29.393	0.315384615	
	4	44.6	0.384	0.517	25636.5	0.02	
	5	9.73	3.08	3.59	3654	10.63218391	
	6	948	138	142	192585	0.157540826	
14	1	59.9	0.624	0.624	453.1065	3.27131E-06	0.470745 (Moderate)
	2	15.2	1.34	1.96	725.508	1.51441E-05	
	3	35	2.32	4.28	1494.122	6.23108E-07	
	4	16298	1.72	6.00	23.0582	0.008609865	
	5	4224	3.55	9.55	34.9307	0.316546763	
	6	948	138	142	0.14556962	134616	
15	1	2984.00	0.0948	0.0948	37.3776	0.010417362	0.165807 (Week)
	2	2.04	0.0766	0.171	29.792	0.088157895	
	3	1047.00	0.149	0.32	149.8	0.066285714	
	4	1918.00	1.24	1.56	97788	0.000105534	
	5	12.20	93.2	94.8	40339.2	0.000840436	

	6	4641.00	63.3	158	37.3776	0.010417362	
16	1	910.00	0.0029	0.0029	282.8832	3.17694E-05	7.690643 (Very Good)
	2	973.00	0.188	0.191	0.34884	0.03754902	
	3	39.00	0.115	0.306	3352.64	1.42216E-05	
	4	156.00	0.371	0.677	29920.8	6.46507E-05	
	5	12.20	0.564	1.24	1156.56	7.639344262	
	6	1129.00	0.428	1.67	733278	0.013639302	
17	1	1.56	0.0036	0.0036	2.639	3.18681E-06	0.052132 (Poor)
	2	1070.00	0.0707	0.0744	185.843	0.000193217	
	3	13.30	1.12	1.19	11.934	0.002948718	
	4	4057.0	3.84	5.03	105.612	0.002378205	
	5	774.00	5.24	10.3	15.128	0.046229508	
	6	8.17	33.5	345	1885.43	0.000379097	
18	1	5094.00	0.0062	0.0006	0.005616	0.002307692	4.194668 (Good)
	2	559.00	0.0007	0.0063	79.608	6.60748E-05	
	3	31.40	0.0512	0.0576	15.827	0.084210526	
	4	785.00	0.103	0.16	20406.71	0.000946512	
	5	452.00	0.0702	0.23	7972.2	0.006770026	
	6	11.30	0.961	1.19	2818.65	4.100367197	
19	1	5094.00	0.302	0.302	3.0564	1.21712E-06	0.086964 (Poor)
	2	74.40	0.13	0.432	3.5217	1.25224E-06	
	3	64.10	0.398	0.83	1.80864	0.001630573	
	4	204.00	0.589	1.42	125.6	0.00013121	
	5	102.00	7.44	8.86	103.96	0.00015531	
	6	6673.00	6.12	15.00	13.447	0.085044248	

20	1	1520.00	0.196	0.196	1538.388	5.92854E-05	0.084761 (Poor)
	2	870.00	0.0952	0.291	32.1408	0.001747312	
	3	85.00	0.122	0.413	53.203	0.006209048	
	4	1630.00	0.0731	0.486	289.68	0.002887255	
	5	36.70	0.682	1.17	903.72	0.072941176	
	6	12329.00	2.84	4.71	100095	0.000917129	
21	1	13.10	0.75	0.75	1538.388	0.000128947	0.020532 (Poor)
	2	21.20	0.429	1.18	32.1408	0.000109425	
	3	994.00	1.81	2.99	53.203	0.001435294	
	4	542.00	1.06	4.05	289.68	4.48466E-05	
	5	171.00	2.04	6.10	903.72	0.018583106	
22	1	129.00	0.624	0.624	297.92	0.057251908	0.093194 (Poor)
	2	32.70	1.34	1.96	253.17	0.020235849	
	3	32.70	2.32	4.28	35.105	0.001820926	
	4	1357.00	1.72	6.00	792.18	0.00195572	
	5	8.81	3.55	9.55	42.939	0.011929825	
23	1	4.65	0.75	0.75	9.825	0.004837209	0.520983 (Moderate)
	2	1395.00	2.23	2.98	25.016	0.040978593	
	3	424.00	2.84	5.82	2972.06	0.070948012	
	4	15.00	5.33	11.10	2195.1	0.001267502	
	5	1.21	8.07	19.20	1043.1	0.402951192	
24	1	131.00	0.80	0.80	80.496	0.161290323	7.194342
	2	39.10	2.36	3.16	64.092	0.001598566	

	3	1557.00	3.66	6.83	139.956	0.006698113	(Very Good)
	4	515.00	5.29	12.10	8142	0.355333333	
	5	36.70	5.75	17.90	84.1355	6.669421488	
24	1	131.00	0.80	0.80	80.496	0.161290323	7.194342 (Very Good)
	2	39.10	2.36	3.16	64.092	0.001598566	
	3	1557.00	3.66	6.83	139.956	0.006698113	
	4	515.00	5.29	12.10	8142	0.355333333	
	5	36.70	5.75	17.90	84.1355	6.669421488	
25	1	13.80	0.75	0.75	3.4875	0.00610687	0.235763 (Moderate)
	2	2.95	0.87	1.62	4157.1	0.060358056	
	3	175.00	2.90	4.52	2467.68	0.002350674	
	4	128.00	0.473	5.00	166.5	0.010271845	
	5	108.00	1.01	6.01	23.232	0.156675749	
26	1	399.00	1.37	1.37	104.8	0.054347826	0.378882 (Moderate)
	2	47.40	1.50	2.87	123.556	0.294915254	
	3	131.00	2.49	5.36	10634.31	0.016571429	
	4	372.00	0.704	6.06	6231.5	0.003695313	
	1	399.00	1.37	1.37	104.8	0.054347826	
27	1	16.30	2.12	2.12	10.35	0.003433584	0.060401 (Poor)
	2	1.48	2.64	4.76	4.779	0.03164557	
	3	10.60	8.24	13.00	791	0.019007634	
	4	0.953	20.70	33.70	640	0.001892473	
	5	197.00	50.50	84.30	649.08	0.004422111	
28	1	11.90	0.812	0.812	546.63	0.13006135	24.66843 (Excellent)
	2	29.20	0.815	0.997	136.038	1.783783784	
	3	666.00	2.48	3.48	702.16	0.777358491	
	4	556.00	0.66	4.14	2254.32	21.72088143	
	5	202.00	2.55	6.69	3112.36	0.256345178	
29	1	242.00	1.25	1.25	34.556	0.068235294	0.113681 (Poor)
	2	4145.00	1.06	2.31	7.0448	0.027910959	
	3	1365.00	0.742	3.06	137.8	0.003723724	
	4	47.40	1.05	4.10	32.1161	0.00118705	
	5	40.30	4.88	8.99	16607.1	0.012623762	
30	1	7.53	1.04	1.04	302.5	0.005165289	0.149208 (Week)
	2	108.00	2.26	3.30	9574.95	0.00025573	
	3	1.98	5.45	8.75	4176.9	0.00054359	
	4	175.00	5.20	14.00	194.34	0.022151899	
	5	2876.00	7.85	21.80	362.297	0.121091811	
31	1	234.00	1.89	1.89	7.8312	0.13811421	2.944009 (Good)
	2	153.00	0.174	2.06	356.4	0.020925926	
	3	221.00	1.54	3.60	17.325	2.752525253	
	4	124.00	2.13	5.73	2450	0.029714286	
	5	34.00	3.16	8.89	62696.8	0.002729485	
32	1	37.70	0.75	0.75	442.26	0.008076923	0.126301 (Week)
	2	7.95	0.107	0.857	315.18	0.001137255	
	3	8.35	0.161	1.02	795.6	0.006968326	
	4	10.89	7.55	8.57	710.52	0.017177419	
	5	84.59	8.10	16.70	302.26	0.092941176	

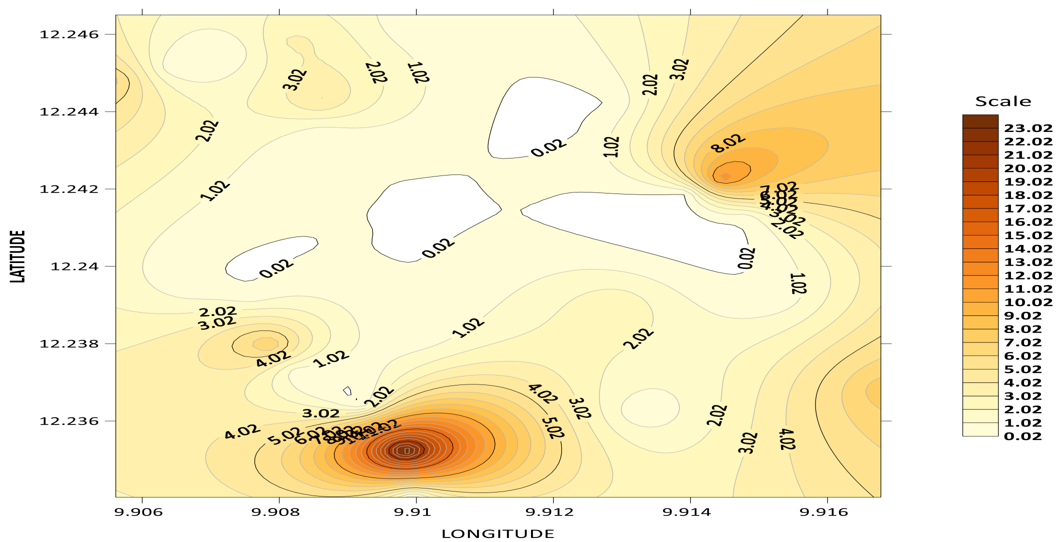

Fig. 5: Aquifer vulnerability Map of the Study Area.

By using the resistivity values obtained 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 4), 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 Southwestern regions or areas has good to Moderate protective capacity rating because of the medium sand with siltstone formation overburdening the region. The Northern zone indicates poor to weak protective capacity, and is characterize by thin clayey sand layer formation and consequently is susceptible to contamination. Northeastern part of the study area is classified as Very good to excellent protection as such aquifers in this regions are protected from any contamination. This may be due to thick overburden of the area and the overlaying layer of the aquifer in this area contain siltstone which is relatively resistive to fluid percolation.

TRANSVERSE RESISTANCE

Transverse resistance is numerically equal to the transmissivity, T. If the transverse resistance values are >400 Ωm^2 and correspond to zones where the thickness and resistivities of the aquifer are large, the aquifer materials are highly permeable to fluid movement within the aquifer, which may possibly enhance the migration and circulation of contaminants in the groundwater aquifer.(Harb. et. al., 2010)Moreover, it has been proven through many different researches on hydrological studies that transverse resistance parameter (T) is the best characteristics for aquifer properties.(Abbas, Atya, Al-Sayed, & Kamei, 2004) This could be pointed out that the higher the value of transverse resistance is, the better the chances of finding high yield of ground water. Figure (6) shows the distribution of transverse resistance over the study area. From our results almost all the VES points shows this complementary future of higher value of transverse resistance. Therefore the study area have abundance of ground water.

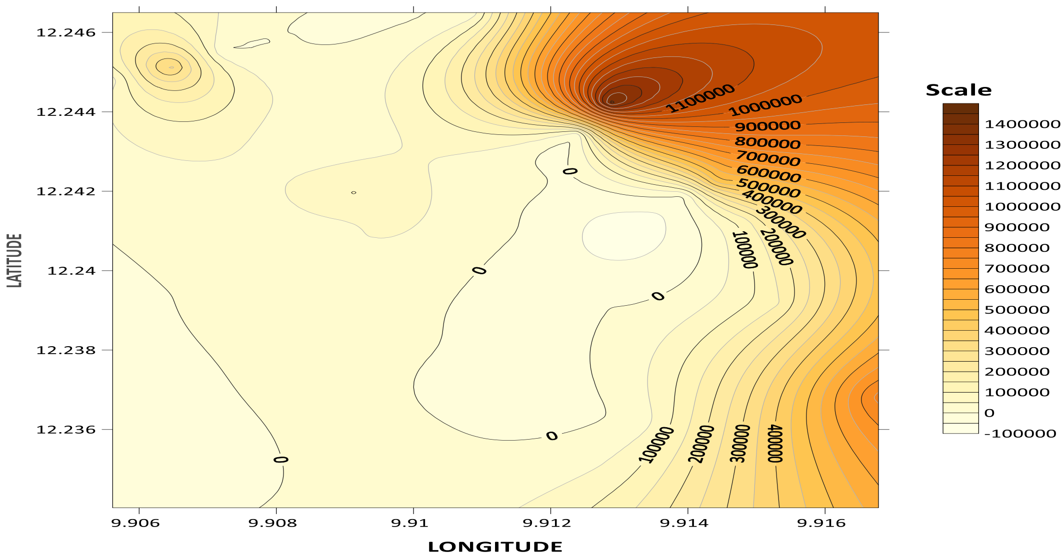

Fig. 6: Transverse Resistance Map of the Study Area.

CONCLUSION

The lithology of the study area is characterized as clayey sand as the top layer, mixed medium sand with coarse sand as the second layer, mixed fine sand with medium to coarse sand as the third layer, medium to coarse sand with siltstone as the fourth layer, medium to coarse sand as the fifth layer and Coarse Sand as the sixth layer.The longitudinal unit conductance of the study area ranges from 0.2 to 0.69ohm, About 40% of the total VES points within the study area are rated as poor protective capacity, 23% of the total VES points are classified as weak protective capacity, 12% of the total VES points are classified as moderate protective capacity, 12% are classified as Good protective capacity, 6% are rated as very Good protective capacity and 6% are rated as excellent protective capacity. Therefore, about 63% of the whole VES points within the study area (more than half) are poorly and weakly protected, as such these areas are vulnerable to contamination. About 12% of the total VES points are neither good nor bad in protecting the aquifer, these areas are rated as moderate protective capacity zones. About 24% of the total VES points are classified as Good, Very Good and Excellent protective capacity areas. These areas are best for locating or citing of boreholes for water harvesting and usage.The transverse resistance of the study area ranges from2206.58$\Omega m^2$to 14228.89Ωm^2**.** All the VES points sounded within the study area have higher value of transverse resistance. Therefore, there are better chances of abundance of ground water within the study area.

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