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Research Article

Hydrogeophysical Assessment and Protective Capacity of Groundwater Resources in Kingsley Ozumba Mbadiwe University Ideato and Environs, Southeastern Nigeria

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Abstract

Geoelectrical investigations were carried out to determine the aquifer potentials and protective capacity of Kingsley Ozumba Mbadiwe University Ideato and environs, Imo State, Southeastern Nigeria. A total of twenty-five (25) Vertical Electrical Sounding survey was conducted using the Schlumberger array to evaluate the characteristics of the aquifers in the studied locations. Geoelectric sections derived from the modeling of the sounding data reveal 7 to 9 subsurface layers and characterized by four main sounding curve types-KH-type, HA-type, HK-type and KA-type. The study area is underlain by alternating layers of shale, sand/sandstone and clay. The aquifer is delineated within the sand/sandstone Formation. The aquifer resistivity ranges from 390 to 450000 Ωm, while the aquifer thickness and depth range from 4.7 to 168.6m and 6.5 to 109m respectively. The Dar Zarrouk parameters of longitudinal conductance ranges from 0.000227 to 0.12134 mhos, whereas the transverse resistance ranges from 1833 to 54223904Ωm^2. The transmissivity in the study area has its highest value of 684.57 m^2/day at Amaikpa Ogboko and its lowest value of 19.08m^2/day at Ogume. Overall, the transmissivity of the study area indicates a relatively high to moderate ability of the aquifer to transmit water, with an exception of Ogume. Furthermore, the aquifer potentials of the study area were shown to differ with aquifer size, structure and characteristics and are influenced by the underlying geology generally. The study area has an overall poor aquifer protective capacity. This suggests that the aquifer is very susceptible to surface contaminants and the groundwater is at risk of pollution. Proper environmental and waste monitoring management is therefore strongly suggested in the study area to protect the groundwater resources.

Keywords

Groundwater, Aquifer, Protective Capacity, Pollution, VES

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1. Introduction

1.1. Background Information

The water that is stored in rocks, soil, and sediment below the surface of the Earth is known as groundwater. It is an essential supply of freshwater for ecosystems, industry, agriculture, and human use. Because it is less contaminated and doesn't need to be thoroughly purified, groundwater is better than surface water [1]. For the majority of applications, groundwater is advised due to its inherent biological quality and general chemical quality, as none of the surface water is as sanitary or cost-effective to exploit as groundwater [2, 3]. In recent years, rapid urbanization, population growth, and surface water contamination have led to a substantial increase in the development of groundwater resources for potable use. Understanding the characteristics of the subsurface aquifer in the study area is essential for effective groundwater development since these characteristics have a big influence on aquifer repositories. These characteristics vary significantly over a study area due to the varied nature of the subsurface [4-6]. A comprehensive understanding of the hydraulic parameters of the aquifer (transverse resistance, transmissivity, hydraulic conductivity, etc.) is essential for the effective exploration, exploitation, and management of groundwater. In various lithological environments, groundwater potential and aquifer protective capacity have been effectively investigated using geophysical techniques, particularly Vertical Electrical Sounding (VES) [7]. Groundwater quality, layer thickness, aquifer protective capacity, and the potential for water-bearing formations can all be mapped spatially using the VES survey data [8]. Assessing the aquifers' susceptibility to surface contamination is just as important as drilling boreholes for groundwater development and exploitation [9].

The study area is a difficult area for groundwater exploitation due to the nature of the depositional environment. Hence, there are limited number of borehole wells. As a result many of the inhabitant of the communities in the area do not have access to potable water. This study therefore aims to characterize the hydrogeological properties of the subsurface and assess their protective capacity, to map out the aquifer horizon for sustainable and quality groundwater development in the study area.

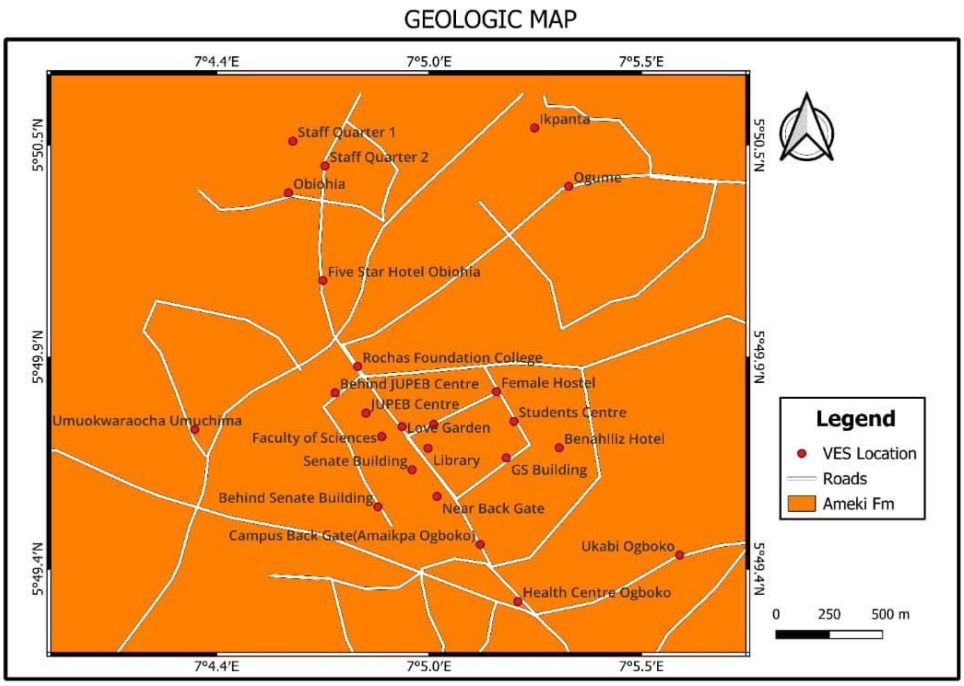

Figure 1. *Accessibility map of the study area with VES locations.*

1.2. Location and Geology of Study Area

Latitude 05°49.14'N to 05°50.64'N and longitude 07°4.02'E to 07°5.76′E define the study area, which is Kingsley Ozumba Mbadiwe University Ideato and environs (Figure 1). The area is primarily a rural area used for farming. Yams, cassava, maize, and palm trees are commonly grown in this area. Ogboko, Umuchima, Urualla, Obiohia, and Ogume are some of the major communities within the study area [10]. Other LGAs, such as Okigwe, Onuimo, Orlu, Nkwerre, and Nwangele, border the study area. The vegetation of the study area is characterized by tropical rainforest, deciduous forest, swamp forest and derived savanna. The vegetation is influenced by factors such as climate (high temperatures, high humidity, and abundant rainfall), soil (fertile soil, with a mix of sand, silt, and clay) and topography (gently sloping terrain, with some areas of low-lying swamp). Overall, the vegetation of the study area is lush and diverse, supporting a wide range of plant and animal species.

The study area, located in the southeastern part of Nigeria, is underlain by sedimentary rocks of the Niger Delta Basin. The Imo River basin is situated within the Niger Delta basin, a sedimentary basin that covers much of southern Nigeria. The Benin Formation, the Ogwashi-Asaba Formation, the Bende-Ameki Formation, the Imo Shale group, the Nsukua Formation, and the Ajali Sandstone Formation are the six main stratigraphic units that make up the Imo River basin. The research area's geological formation is the Ameki Formation, which sits on top of the impermeable Imo Shale group. The Ameki Formation is a sedimentary rock series that was formed between 65 and 55 million years ago, during the Paleocene to Eocene period. The layers of sand/sandstone, shale, and clay alternate in the Formation. The Formation was deposited in a shallow marine to coastal environment and is thought to be between 300 and 400 meters thick. Mollusks, plankton, and benthic foraminifera are among the marine life fossils found in the Ameki Formation. The layers of sand and sandstone in the formation may function as aquifers, supplying groundwater.

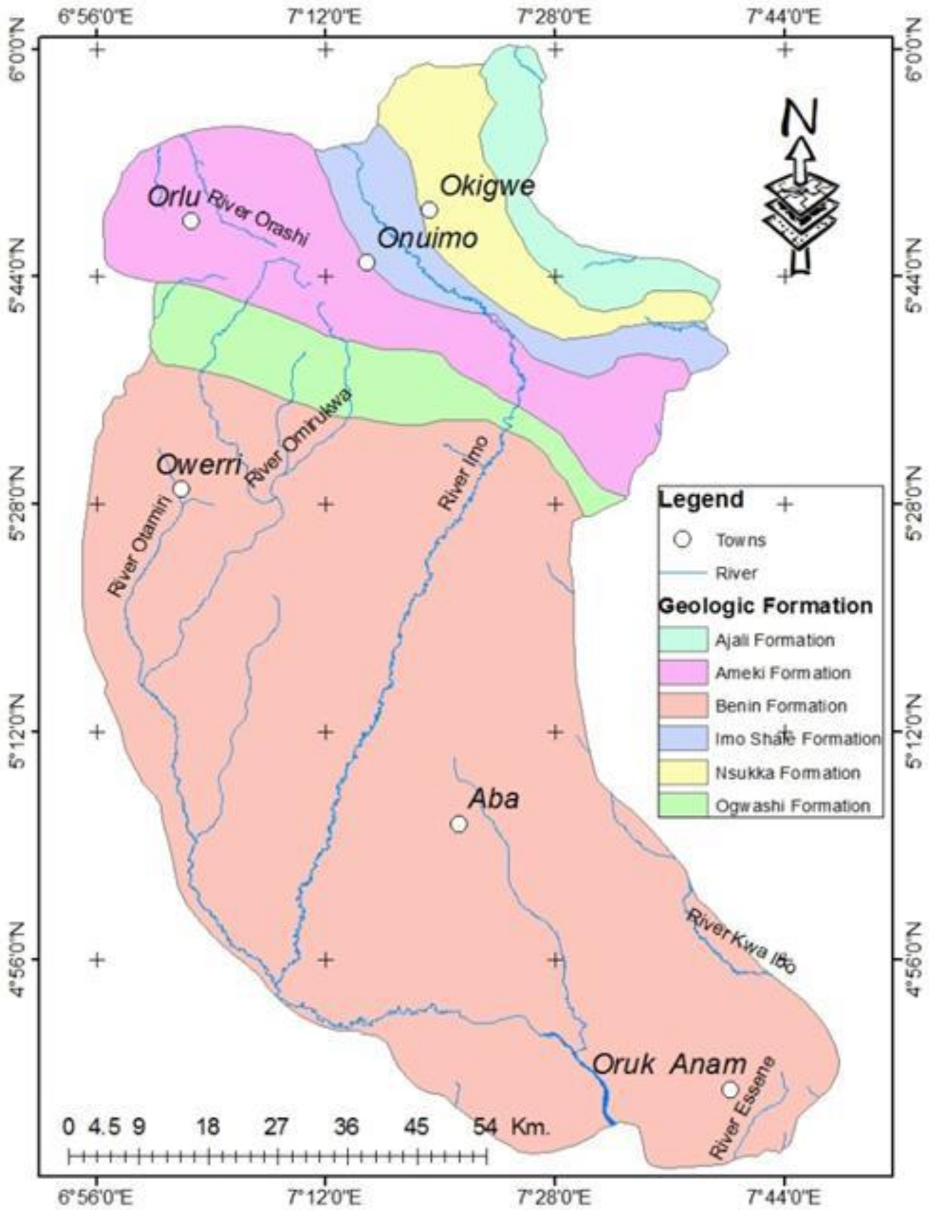

Figure 2. *Geological map of Imo River basin [11].*

2. Materials and Methods

With a maximum current electrode spread of 800 meters, a total of 25 Vertical Electrical Soundings (VES) were conducted utilizing the Schlumberger electrode array. For correlation, a few of the stations were placed close to existing boreholes. The ABEM SAS 300 Electrical Resistivity meter was positioned at the station point between the potential electrodes M and N, with its terminals P1 and P2 attached to the terminals M and N respectively using the ABEM Sounding set. Using the ABEM sounding current cables coiled on two different metal reels mounted on the platform, current electrodes A and B were connected to terminals C1 and C2, respectively. The electrodes, which were roughly 0.7 meters long, were pounded into the ground with a hammer to a suitable depth before connections were completed, making sure that the spacing was precise. Current was introduced into the ground through the two current electrodes and the voltage difference at two potential electrodes was measured. The field resistance using Equation (1) was shown on the resistivity meter and then entered on the data sheet against the appropriate current and potential electrode spacing.

The GPS was used to measure coordinates and elevation at each VES station.

Equation (2) was utilized to calculate the apparent resistivity. Plotting the obtained apparent resistivity values versus the half current electrode separation distance was done using a bi-log graph. By observing how the apparent resisitivity changes as the current electrode increases, qualitative inferences were drawn from these plots, including the resistivity of the top and initial layer, the depth of each layer, and the types or signatures of the curves. The partial curve matching technique, which matched the field curves formed or produced segment by segment with the necessary master curves and auxiliary curves, was used to make the first quantitative interpretations. Using an automatic iterative computer program, the resistivities and thicknesses of the different layers were enhanced in accordance with the key concepts of [12]. The iteration and inversion procedures were performed using the strata 5 computer program to create detailed subsurface visualizations.

$$R = \frac{V}{I} \tag{1}$$

$$\rho_a = kR \tag{2}$$

Where, R = resistance, V = voltage, I = current, ρ_a = apparent resistivity and k = geometry array of the four electrodes.

The Dar-zarrouk parameters of longitudinal conductance and transverse resistance of the overburden unit at each VES were obtained using Equations (3) and (4).

$$R = h\rho \tag{3}$$

$$L = h/\rho \tag{4}$$

Where, R = transverse resistance, h = aquifer aquifer thickness, ρ = aquifer resistivity, and L = longitudinal conductance.

According to [13], the hydraulic and electrical parameters in a porous media are related as follows:

$$T = K\sigma R = KL\rho = Kh \tag{5}$$

Where, T is the transmissivity, K is the hydraulic conductivity, σ the aquifer conductivity, R the transverse resistance, L the longitudinal conductance, ρ the aquifer resistivity and h the aquifer thickness respectively.

Thus, the determination of transmissivity and its variations from place to place, even those areas without boreholes, is made possible by knowing the K values from existing boreholes and the σ values taken from the sounding interpretation for the aquifer at borehole locations. This gives a broad idea of the aquifer's capacity to produce water. Equation (5) was used to determine the transmissivity of the aquifer in the study area using hydraulic conductivity K of 4.06 m/day obtained from the pumping test analysis of the existing borehole in a hereby town (Akokwa).

Evaluation of Aquifer Protective Capacity

Equation (6) was used to calculate the study area's aquifer protection capacity based on the total longitudinal conductance of the overburden unit at each VES point.

$$Pc = \sum [hi/\rho i] \tag{6}$$

Table 1. *Longitudinal conductance / protective capacity rating (Adapted from [14, 15]).*

Longitudinal Conductance (mhos)	Protective Capacity Rating
> 10	Excellent
5-10	Very Good
0.7-4.9	Good
0.2-0.69	Moderate

Longitudinal Conductance (mhos)	Protective Capacity Rating
0.1-0.19	Weak
< 0.1	Poor

3. Results and Discussion

3.1. Interpretation of the Layer Parameters

Curve matching and computer iterative modeling were used in conjunction to handle and interpret data obtained from vertical electrical sounding utilizing the Schlumberger array. Interpreted curves from some of the VES data are shown in Figure 2. The results show that the study area is characterized by four main sounding curve types. These include KH-type, HA-type, HK-type and KA-type. It is observed that the study area is predominantly of A-type curve and a hybrid of HA-type that indicate the Ameki Formation signature. The top layer corresponds to the brown-reddish lateritic overburden as depicted by the lithology logs beneath some of the VES (Figures 4, 5). Below this layer are the fine-medium-coarse sand/sandstone which forms the aquifers and an intercalation of clay/shale, except the North-South study area (Students Center, Behind Stadium, Ikpanta Urualla, Ogume and Umuokwaraonure Ogboko) which does not show the presence of any intercalation. This layer is very thick and may be internally subdivided into two by the value of their resistivities. Below this thick aquifer is the conductive geoelectric layer which was not resolved in this study.

Table 2. *Summary of VES points and their characteristics.*

VESNO	Location	Longitude E (Degree)	Latitude N (Degree)	Elevation (m)	Curve Type	Number of Layers
1	Senate Building KOMU	7.08228	5.82721	164	KH	8
2	Faculty of Science KOMU	7.08100	5.82862	159	HKA	9
3	Library KOMU	7.08295	5.82812	164	KH	7
4	Female Hotel KOMU	7.08585	5.83052	183	HA	8
5	Students Center KOMU	7.08660	5.82927	187	HA	8
6	Back of Senate Building	7.08083	5.82563	162	K	8
7	University Backgate (Amaikpa Ogboko)	7.08517	5.74070	173	KA	8
8	Health Center Ogboko	7.08677	5.82162	175	KH	9
9	Beside Stadium KOMU	7.09363	5.82359	151	HA	8
10	G.S. Building KOMU	7.08628	5.82772	186	KH	7
11	Love Garden	7.08186	5.82905	164	HK	8
12	JUPEB Center KOMU	7.08033	5.82962	163	KH	7
13	Medical Center KOMU	7.08334	5.82608	167	KH	8
14	Benahillz Hotel Ogboko	7.08852	5.82615	195	HA	7
15	Umuduruanyanwu Obiohia	7.07695	5.83897	135	K	7
16	Rochas Foundation College Ogboko	7.08290	5.82771	193	KHA	8
17	Ikpanta Urualla	7.08425	5.84915	198	A	8
18	Ogume	7.06822	5.80798	188	HK	8
19	Umuokwaraonure Ogboko	7.08700	5.81593	179	KH	8
20	Ukabi Ogboko	7.09363	5.82359	193	K	8

VESNO	Location	Longitude E (Degree)	Latitude N (Degree)	Elevation (m)	Curve Type	Number of Layers
21	Staff Quarters 1 KOMU	7.07723	5.84117	152	HA	8
22	Staff Quarters 2 KOMU	7.07859	5.84012	157	HK	8
23	5 Star Hotel Ogboko	7.07850	5.83525	165	HA	7
24	Behind JUPEB KOMU	7.07902	5.83048	160	A	8
25	Umuokwaraocha Umuchima	7.07307	5.82892	126	HA	8

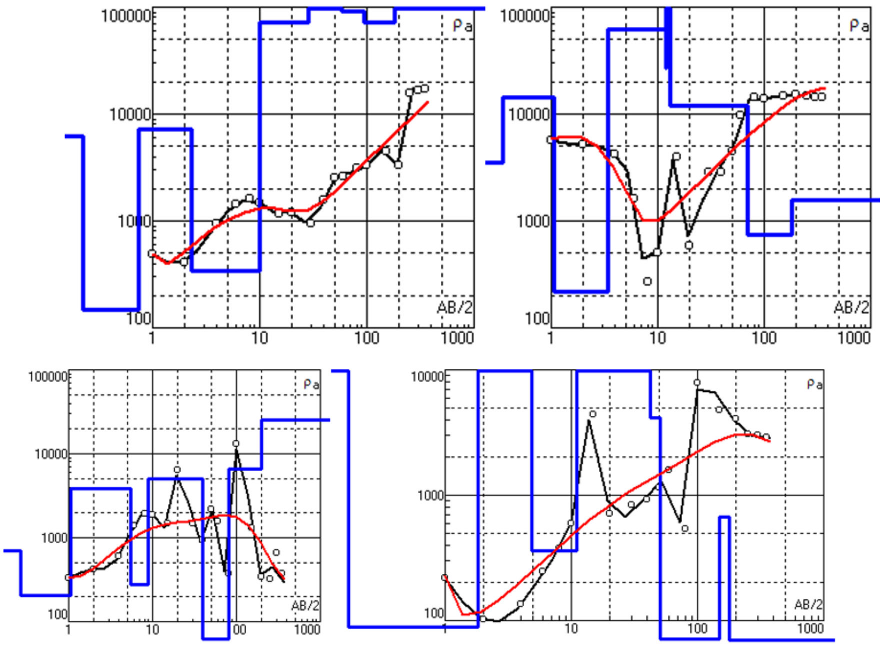

Figure 3. Interpretative curves from some of the VES data.

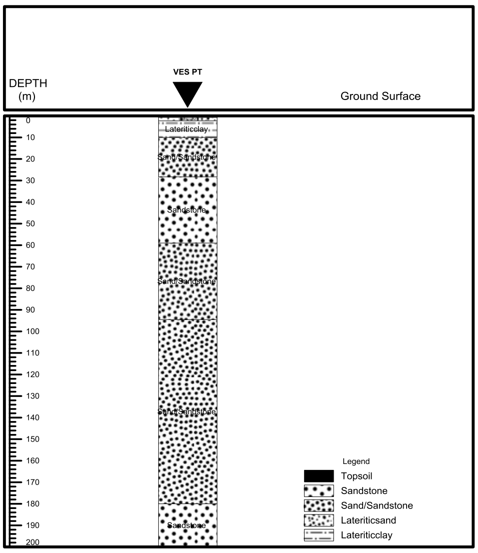

Figure 4. Geoelectric section beneath VES 1 (Senate Building KOMU).

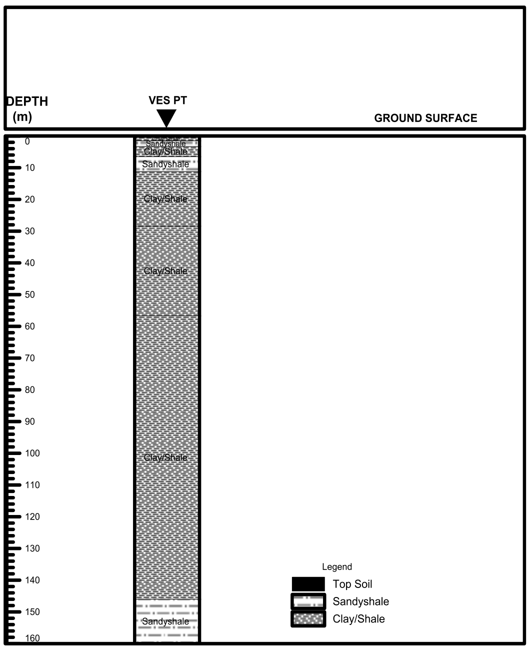

Figure 5. Geoelectric section beneath VES 18 (Ogume).

3.1.1. Aquifer Resistivity

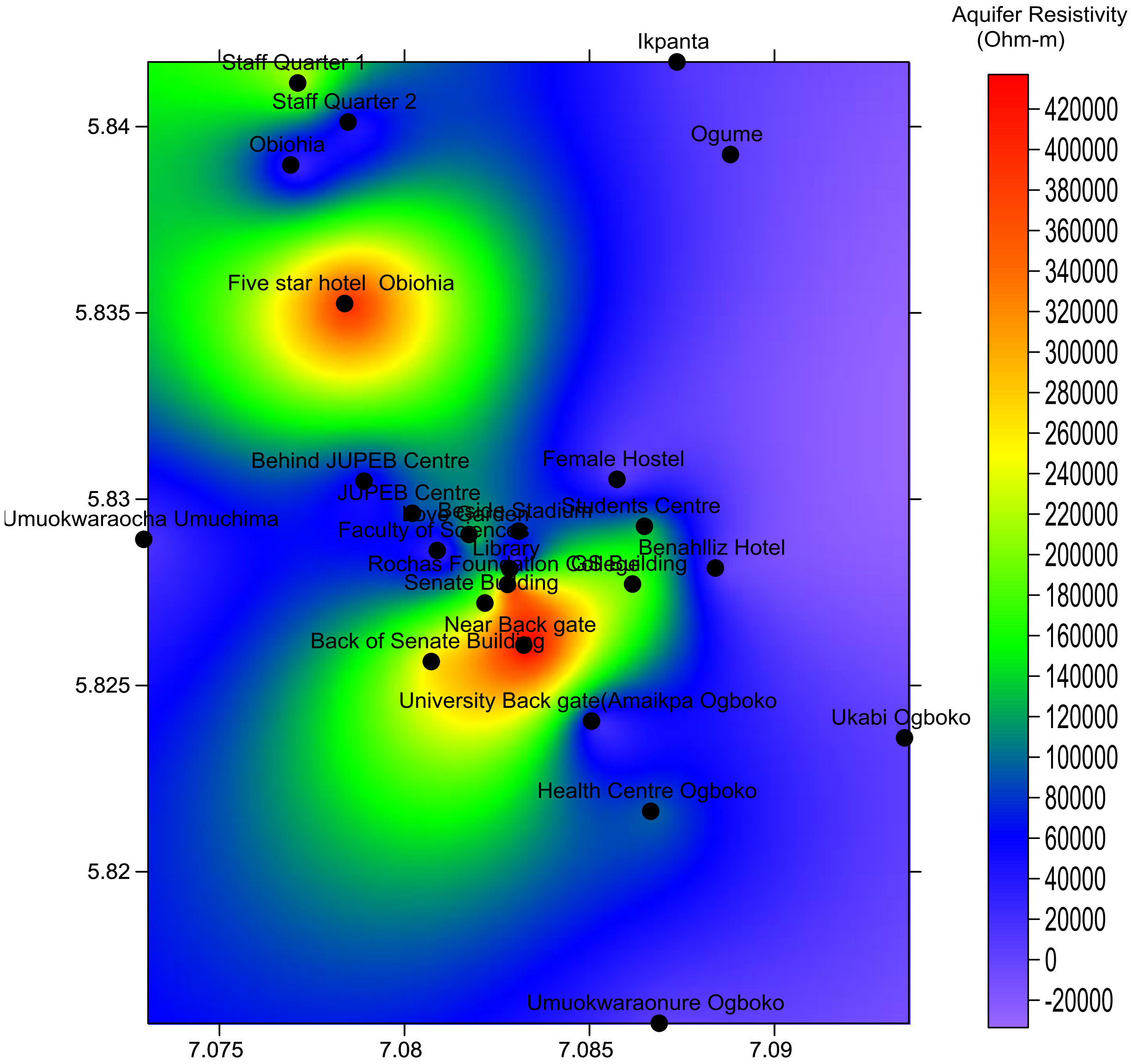

Figure 6. *2D contour map of aquifer resistivity.*

The aquifer resistivity is a measure of how strongly the aquifer resists the flow of electric current. It helps to identify potential aquifers for drilling operations. The aquifer resistivity at Ogume has a low value of 390Ωm indicating clay/shale Formation (aquitard), which may lower the aquifer potentials. The highest aquifer resistivity of 450000Ωm is recorded at Medical Center KOMU, indicating sandstone Formation. This is an indication of good aquifer formation due to its permeability to groundwater transmission.

3.1.2. Depth to Aquifer Table

The depth to aquifer table shows the extent to which we can locate the aquifer in the subsurface soil from the topsoil. The highest depth found in the study area is 109m at JUPEB Center KOMU, while the lowest depth of 6.5m is found at Ogume, which is susceptible to pollution from surface activities and natural processes.

3.1.3. Aquifer Thickness

The aquifer thickness reveals the size of the aquifer for potential groundwater exploration. It was calculated by subtracting the depth to aquifer table from the estimated depth to bottom of aquifer. The aquifer thickness of 168.6m at Amaikpa Ogboko is the highest while the lowest thickness value of 4.7m is found at Ogume which again is not a good aquifer potential zone for groundwater exploration (due to small thickness).

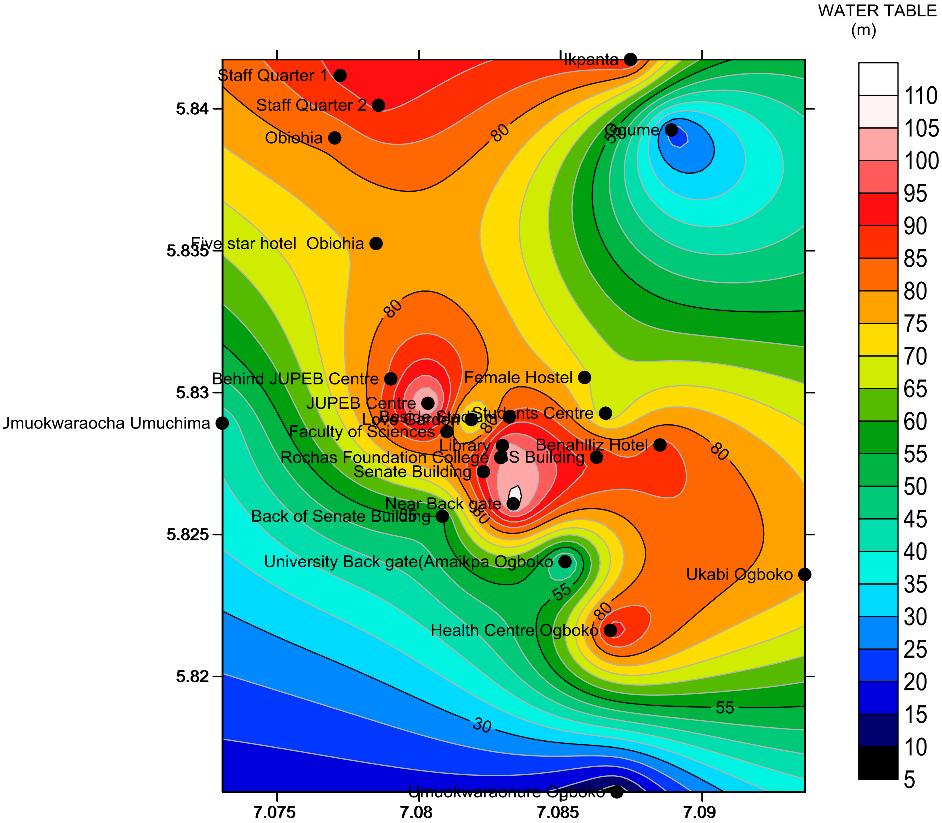

Figure 7. *2D contour map of depth to aquifer table.*

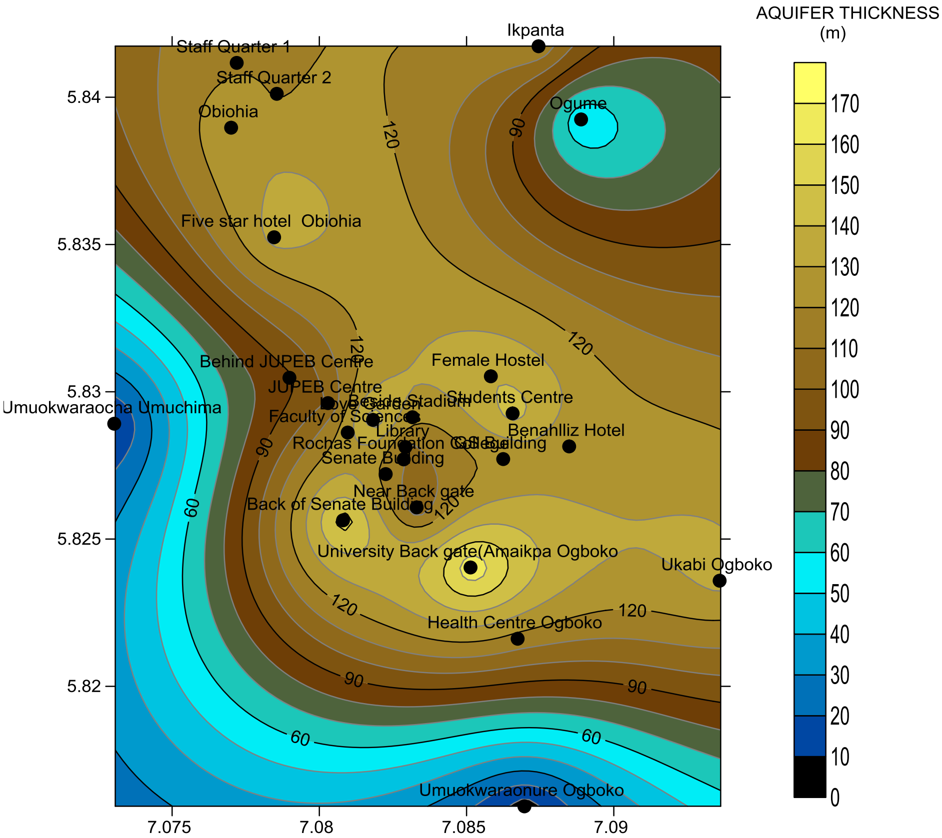

Figure 8. *2D contour map of aquifer thickness.*

3.1.4. Aquifer Conductivity

Conductivity is the reciprocal of resistivity. Aquifer conductivity refers to the ability of an aquifer to conduct electricity, which is influenced by the aquifer's properties. The conductivity of the study area ranges from 2.22222E-06 $(\Omega m)^{-1}$ at Medical Center KOMU to 2.56410E-03 $(\Omega m)^{-1}$ at Ogume. The water potential is high in areas of low conductivity than areas of high conductivity.

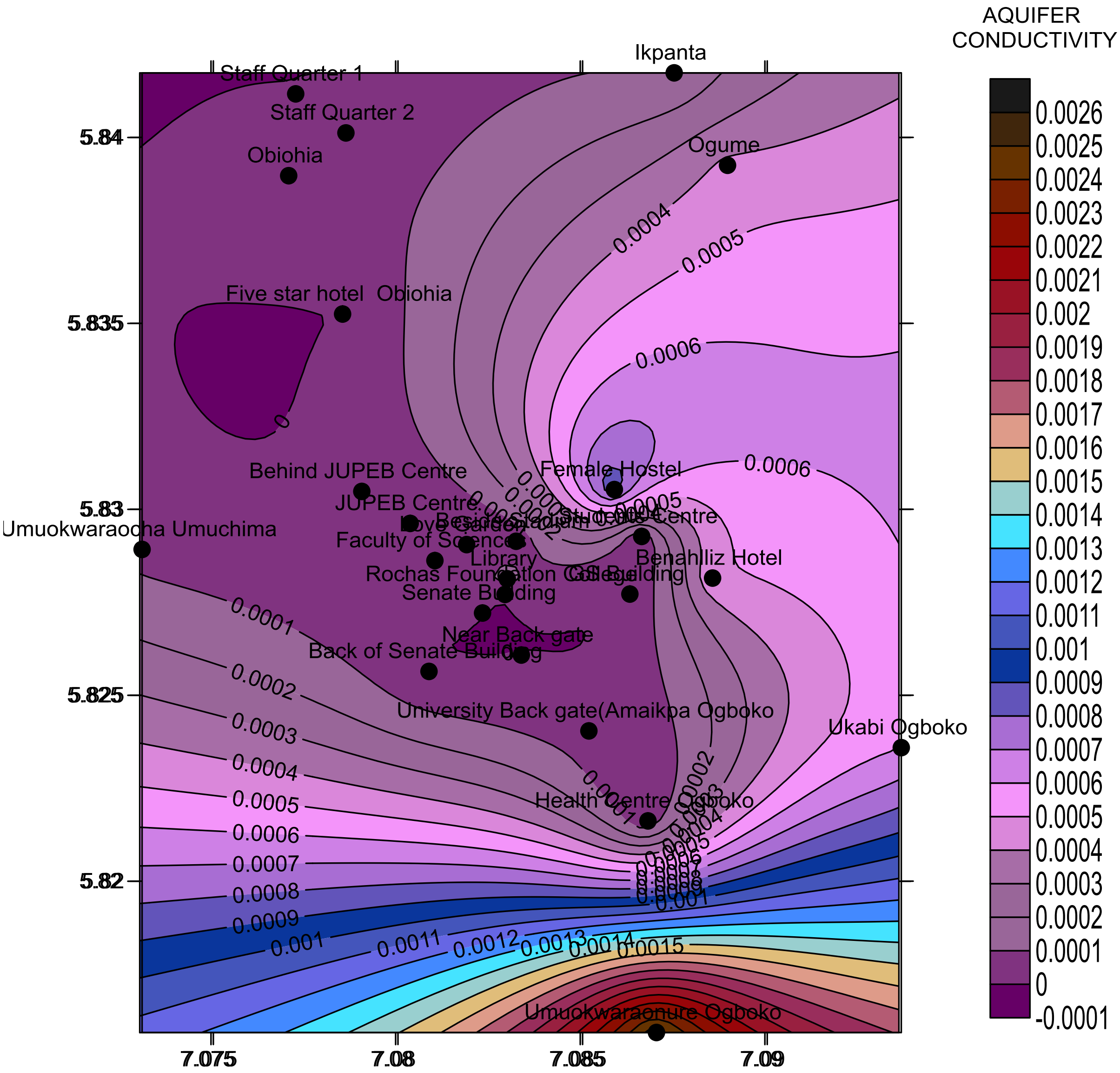

Figure 9. 2D contour map of aquifer conductivity.

3.1.5. Dar-Zarrouk Parameters

The Dar-zurrouk parameter of transverse resistance helps to estimate resistance with depth while the longitudinal conductance determines the ability of the aquifer to conduct water. Results of the estimated Dar-Zarrouk parameters in the study area indicated that the longitudinal conductance varies between 0.000227 mhos at Medical Center KOMU to 0.121341 mhos at Female Hotel KOMU (Figure 11) while the transverse resistance varies between 1833 Ωm^2 at Ogume to 54223904 Ωm^2 at Behind JUPEB KOMU (Figure 10). Higher transverse resistance values indicate greater difficulty for water to flow across the aquifer and higher longitudinal conductance values indicate greater water exchange between the aquifer and the surrounding environment.

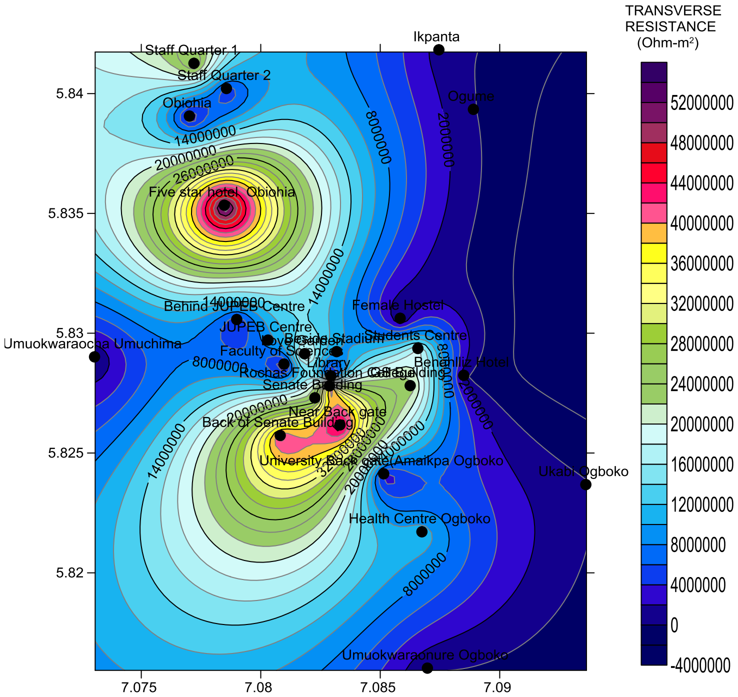

Figure 10. *2D contour map of aquifer transverse resistance.*

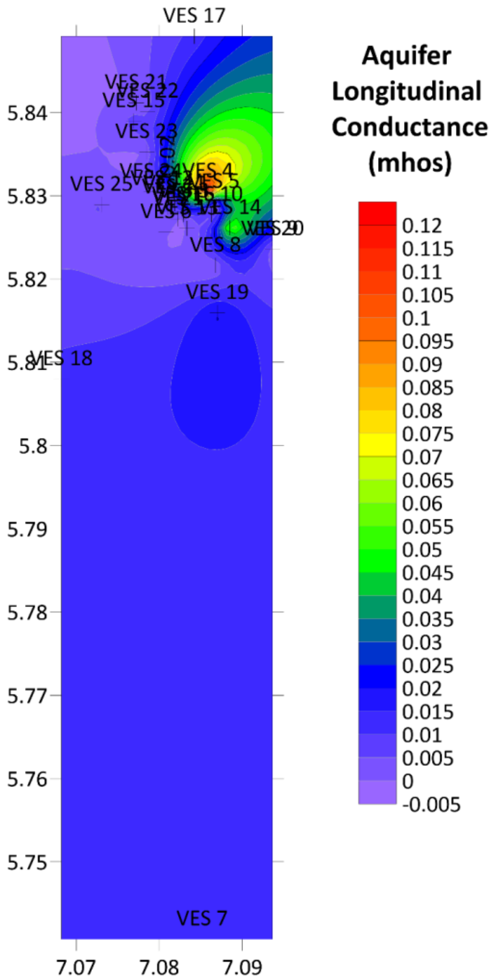

Figure 11. *2D contour map of aquifer longitudinal conductance.*

3.1.6. Estimated Hydraulic Conductivity

Hydraulic conductivity is a measure of how easily water can flow through the aquifer. The hydraulic conductivity is use here to determine the hydraulic potential of the aquifer recharge of the study area. Results of the study revealed that the study area has a fairly uniform hydraulic conductivity ranging from 4.046560 m/day to 4.062916 m/day, indicating that the aquifer has a good ability to transmit water.

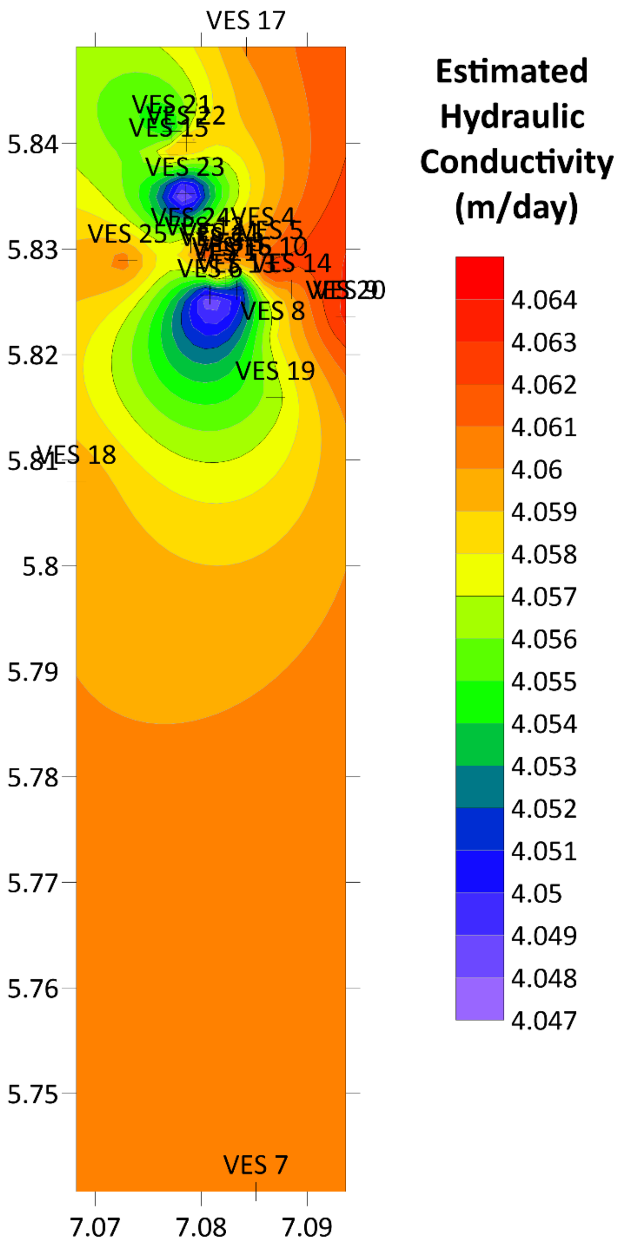

Figure 12. *2D contour map of estimated hydraulic conductivity.*

3.1.7. Transmissivity of the Study Area.

Aquifer transmissivity is a measure of the aquifer's ability to transmit water through its entire thickness. The transmissivity in the study area has its highest value of 684.57 m^2/day at Amaikpa Ogboko and its lowest value of 19.08 m^2/day at Ogume. The transmissivity of the study area indicates a relatively high to moderate ability of the aquifer to transmit water, with an exception of Ogume.

Table 3. Summary results of the aquifer parameters of the study area.

Location	Aquifer Resistivity (Ωm)	Depth to Aquifer Table (m)	Aquifer Thickness (m)	Aquifer Conductivity (Ωm)$^{-1}$	Aquifer Trans-verseResistance (Ωm^2)	Aquifer Longitudinal Conductance (mhos)	Estimated Hydraulic Conductivity (m/day)	Estimated Transmissivity (m^2/day)
Senate Building KOMU	211460	94.5	115.5	4.72903E-06	24423630	0.000546	4.060032	468.93
Faculty of Science KOMU	11740	82.7	127.3	8.51789E-05	1494502	0.010843	4.059692	516.80
Library KOMU	6235	102	108	1.60385E-04	673380	0.017322	4.060232	438.50
Female Hotel KOMU	1148	70.7	139.3	8.71080E-04	1599160	0.121341	4.060017	565.56
Students Center KOMU	130186	65.9	144.1	7.68132E-06	18759803	0.001107	4.061803	585.31
Back of Senate Building	273502	54.6	155.4	3.65628E-06	42502211	0.000568	4.047830	629.03
University Backgate (Amaikpa Ogboko)	15456	41.4	168.6	6.46998E-05	2605882	0.010908	4.060291	684.57
Health Center Ogboko	98012	94	116	1.02028E-05	11369392	0.001184	4.057697	470.69
Beside Stadium KOMU	77843	87	123	1.28464E-05	9576689	0.001580	4.063404	499.80
G.S. Building KOMU	191647	89.4	120.6	5.21793E-06	23112628	0.000629	4.062916	489.99
Love Garden	145000	63	147	6.89655E-06	21315000	0.001014	4.060000	596.82
JUPEB Center KOMU	91912	109	101	1.08800E-05	9283112	0.001099	4.062510	410.31
Medical Center KOMU	450000	108	102	2.22222E-06	45900000	0.000227	4.050000	413.10
Benahillz Hotel Ogboko	2109	87	123	4.74158E-04	259407	0.058321	4.060036	499.38
Obiohia	15764	81.6	128.4	6.34357E-05	2024098	0.008145	4.059230	521.21
Rochas Foundation College Ogboko	389540	99.7	110.3	2.56713E-06	42966262	0.000283	4.051216	446.85
Ikpanta Urualla	9954	91	119	1.00462E-04	1184526	0.011955	4.060237	483.17
Ogume	390	6.5	4.7	2.56410E-03	1833	0.012051	4.059978	19.08
Umuokwaraonure Ogboko	2370	21.5	49.6	4.21585E-04	117651	0.020928	4.056492	201.20
Ukabi Ogboko	1674	76.6	133.4	5.97372E-04	223312	0.079689	4.059952	541.60
Staff Quarters 1 KOMU	222701	91	119	4.49033E-06	26501419	0.000534	4.053158	482.33
Staff Quarters 2 KOMU	36446	91	119	2.74379E-05	4337074	0.003265	4.060084	483.15

Location	Aquifer Resistivity (Ωm)	Depth to Aquifer Table (m)	Aquifer Thickness (m)	Aquifer Conductivity (Ωm)$^{-1}$	Aquifer TransverseResistance (Ωm^2)	Aquifer Longitudinal Conductance (mhos)	Estimated Hydraulic Conductivity (m/day)	Estimated Transmissivity (m^2/day)
5 Star Hotel Ogboko	404656	76	134	2.47123E-06	54223904	0.000331	4.046560	542.24
Behind JUPEB KOMU	44747	86.1	88.9	2.23479E-05	3978008	0.001987	4.058553	360.81
Umuokwarao-cha Umuchima	14750	41.9	83	6.77966E-05	122425	0.005627	4.060675	337.04

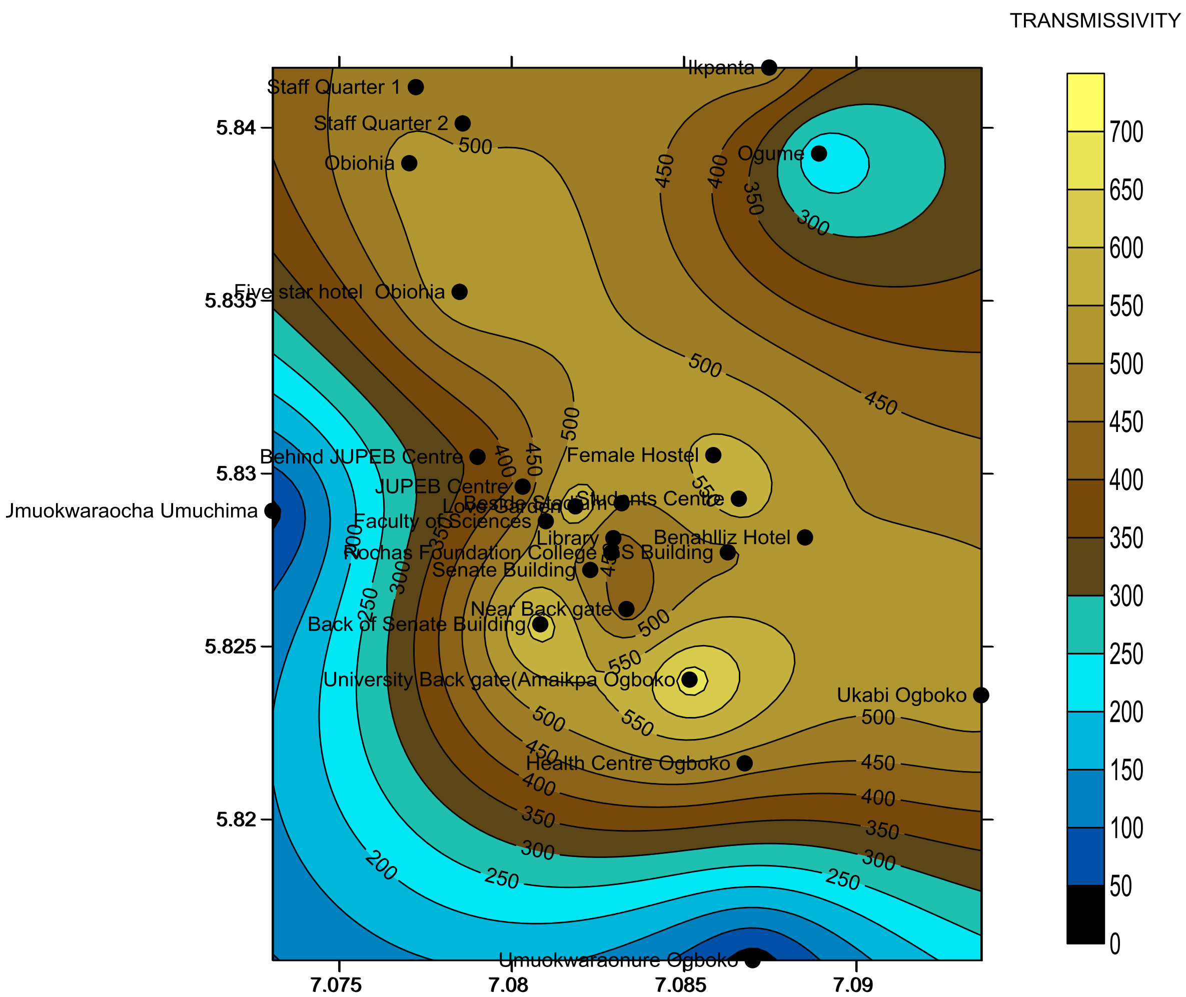

Figure 13. *2D contour map of hydraulic transmissivity.*

3.2. Aquifer Protective Capacity

The analysis of the results showed that the aquifer protective capacity rating in the study area is about 88% poor and 8% weak. Only Umuduruanyanwu Obiohia has a good aquifer protective capacity (Table 4). It is therefore inferred that the aquifer in the study area is more liable to contamination and degradation considering the nature of the overburden thickness (Figure 14). Pollutants can easily infiltrate the aquifer, posing a risk to human health and the environment. There is a need to implement best waste management practices and regulations for agricultural, industrial and domestic activities in order to mitigate the contamination of the groundwater resources in the study area.

Table 4. *Aquifer protective capacities of study area.*

Location	Aquifer Protective Capacity (mhos)	Rating
Senate Building KOMU	0.027149	Poor
Faculty of Science KOMU	0.052318	Poor
Library KOMU	0.101279	Weak
Female Hotel KOMU	0.015501	Poor
Students Center KOMU	0.046855	Poor
Back of Senate Building	0.008424	Poor
University Backgate (Amaikpa Ogboko)	0.022708	Poor
Health Center Ogboko	0.038284	Poor
Beside Stadium KOMU	0.036409	Poor
G.S. Building KOMU	0.024992	Poor
Love Garden	0.074661	Poor
JUPEB Center KOMU	0.021957	Poor
Medical Center KOMU	0.019224	Poor
Benahillz Hotel Ogboko	0.022350	Poor
Umuduruanyanwu Obiohia	1.459034	Good
Rochas Foundation College Ogboko	0.017427	Poor
Ikpanta Urualla	0.029723	Poor
Ogume	0.056567	Poor
Umuokwaraonure Ogboko	0.030222	Poor
Ukabi Ogboko	0.129084	Weak
Staff Quarters 1 KOMU	0.095207	Poor
Staff Quarters 2 KOMU	0.091130	Poor
5 Star Hotel Ogboko	0.043584	Poor
Behind JUPEB KOMU	0.002298	Poor
Umuokwaraocha Umuchima	0.037803	Poor

4. Conclusion

From the results of the geophysical studies carried out in the study area, it can be inferred that Ogume is not a good location for groundwater exploration due to the various hydrogeophysical properties making it unsuitable like the presence of clay formation (aquitard), shallow depth to water table, low aquifer thickness, low transverse resistance and so on.

Other locations in the study area have good water bearing potentials, so are good prospects for groundwater exploration.

The aquifer protective capacity indicates that the study area is highly liable to pollution. Contaminants could migrate to the water table with relative ease due to the various geological factors that make it susceptible to pollution. Only Umuduruanyanwu Obiohia is better protected from surface pollutant and natural processes (low pollution risk).

Since nature is dynamic, it is most expedient to consider conducting periodic geophysical and geological surveys to identify any modification to the subsurface processes, particularly with regards to the groundwater abstraction. Also, studies on the inter-connectivity of the rock matrix and porosity of the formations could be carried out to further investigate the groundwater potential of the area.

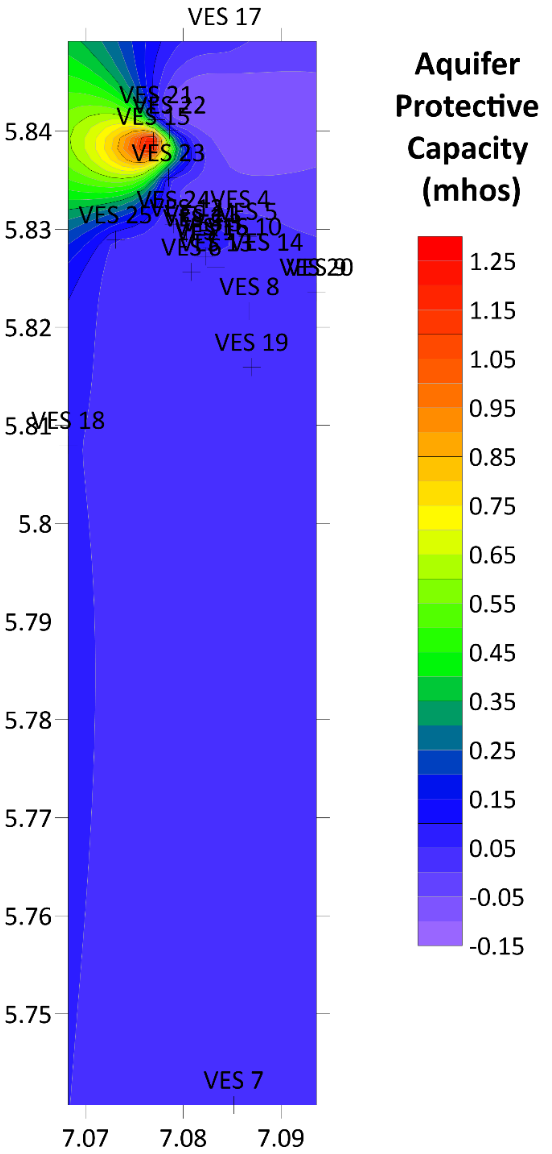

Figure 14. *Spatial distribution of aquifer protective capacity in the study area.*

5. Recommendations

Based on the findings from this work, the following are therefore recommended:

1) Borehole wells should not be cited at Ogume as it contains no potential groundwater zone.
2) The aquifer table is very liable to contamination when exposed to contaminant waste products. To avoid leachates, wastes should be properly disposed to avoid contamination of the aquifer in the study area.
3) Subsequent boreholes in the area should be drilled to a suggested depth of 150m and above due to the high pollution risk of the area. This will help prevent contaminants from surface activities reaching the water table and prevent future dry well occurrence.
4) Government can identify high-risk areas, prioritize protection and management efforts, develop targeted strategies for pollution prevention and remediation and ensure sustainable groundwater resource management from this work.

Abbreviations

VES	Vertical Electrical Sounding
GPS	Global Positioning System
KOMU	Kingsley Ozumba Mbadiwe University
JUPEB	Joint Universities Preliminary Examinations Board
GS	General Studies

Author Contributions

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Conflicts of Interest

The authors declare no conflicts of interest.

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