Hydrogeological Studies for Groundwater Resource and its Vulnerability to Contamination in Owo, Southwestern Nigeria

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Abstract: ***Hydrogeological investigations were conducted at Rufus Giwa Polytechnic, Owo, Southwestern, Nigeria with the aim of evaluating the groundwater resource and vulnerability of the aquifers to contamination in the area. The geophysical survey involved Vertical Electrical Sounding (VES). The hydro-geological survey includes measurements of thickness of the vadose water, static water level determination, and hydraulic head in existing wells across the study area. A total of twenty seven (27) traverses were established in the studied area. The geoelectric section revealed 3 to 5 major layers comprising the topsoil, clay, laterite, weathered layer, partly weathered layer/fractured basement, and fresh basement rock. The Iso-resistivity map and isopach maps shows that the northeastern and southwestern parts of the institution show a high overburden thickness suggesting a high degree of weathering. Transverse unit resistance map shows that the northwest through the central to the southeastern part of the study area constitute the medium groundwater development areas, while the northeastern and southwestern parts are high groundwater development areas. The longitudinal unit conductance map shows low – high L.U.C. values observed around southwestern and northeastern/eastern part of the area. The overburden protective capacity map shows a moderate protective at the southwestern and northeastern/eastern parts, while all other areas have poor/weak protective capacity. The static water level, water column and depth to water level vary between 316.9 m and 330.5 m, 1.3 m and 4.8 m, and 8.1 m and 10.5 m respectively. The average depth to the water level is about 9.4 m. This implies that the vadose zone is fairly thick; hence less vulnerable to contamination. Therefore considering the thickness of the vadose zone across the area, the resistivity parameters of the topsoil and the longitudinal conductance of the geomaterials; the southwestern and northeastern/eastern parts have would be fairly protected from contaminants arising from anthropogenic activities (moderate protective capacity) while other areas have poor/weak protective capacity.***

Keywords: hydrogeology, contamination, groundwater, vulnerability

1. Introduction

It has been reported that at least 1.1 billion people across the world lack access to safe, clean drinking water. Nigeria with a population of over 120 million people have invested heavily in borehole Projects throughout the Country to satisfy the fast growing demand for safe water and to improve the socioeconomic development of its populace especially in the rural areas. The tasks of achieving the Millennium Development Goals (MDGs) in the area of groundwater exploitation therefore present an enormous challenge to the Country and the international community.

Despite huge investment by the government in the area of water supply, there is still severe scarcity of water supply for domestic, agricultural and industrial purposes. In addition, most of the drilled boreholes are failing at a very alarming rate. Some of the reasons for this failure rates could be due to technical, political and financial constraints. In order to meet the MDGs especially in the area of water supply, there is the need to adopt and develop mechanisms or strategies to improve construction quality and functionality of borehole projects in the research environment and in Nigeria as a whole.

Groundwater occurrence in the crystalline basement terrain of Nigeria can be very irregular due to abrupt discontinuity in lithology, thickness, and electrical properties of the overburden and weathered bedrock [9], [15]. However, the groundwater obtained from basement complex area is generally known to be of good quality [8]. Consequently, groundwater exploration within such geologic setting requires integration of geophysical data types to effectively characterize the hydrogeologic zones and to enhance successful identification of well locations.

1.1. Description of the Project Environment

The study area is Rufus Giwa Polytechnic, Owo, Ondo State "Fig. 1", which is within the south western part of Nigeria. It lies within longitudes 6°00' E and 5°30' E and latitudes 7°30' N and 7°00' N. The study area is easily accessible by roads like Ikare – Owo highway, Benin – Ifon highway and Akure – Owo highway.

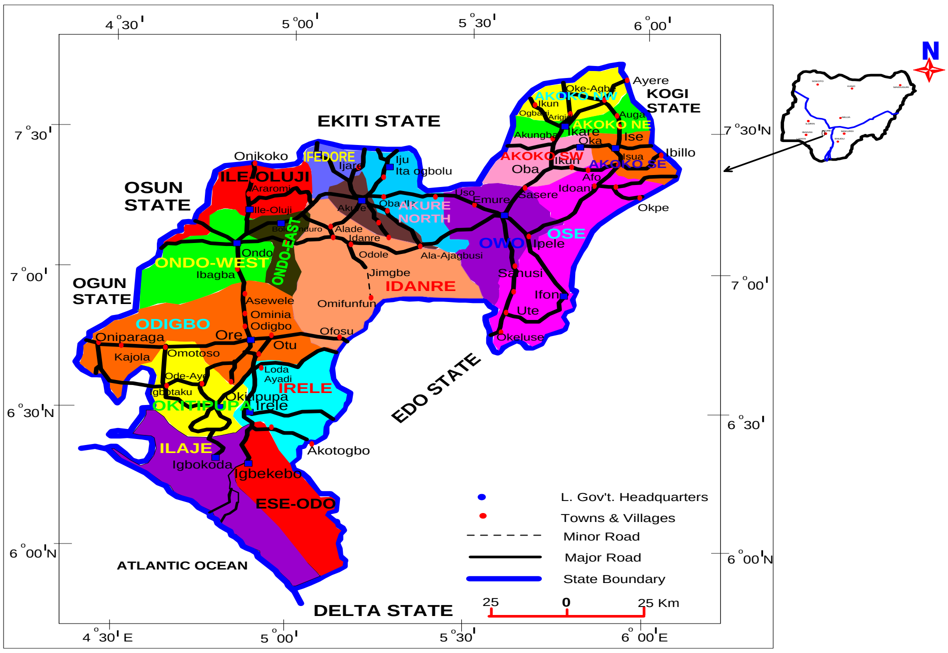


Figure 1: Road/Administrative Map of Ondo State

Owo is relatively flat, as the terrain ranges from 940 ft to 1100 ft. However, the study area has a gently undulating topography as it ranges from 311 m to 342 m above the sea level. The area lies geographically within the tropical rain forest belt of hot and wet equatorial climatic region characterized by alternating wet and dry climate seasons [5], which is strongly controlled by seasonal fluctuation in the rate of evaporation.

The available rain data shows that mean annual rainfall ranges from 1000 mm - 1500 mm and mean temperature of 24˚C to 27˚C. There is rapid rainfall during the month of March and cessation during the month of November. June and September are the critical month when rainfall is usually on the high side. The vegetation is of tropical rainforest and is characterized by thick forest of broad-leaved trees that is ever green. The vegetation of the area (especially in undeveloped areas) is dense and made up of palm trees, kolanut trees and cocoa trees. Part of this area is also made the school farm.

1.2 Geology of the Studied Area

The area of study falls within the Southwestern basement rock, which is part of Nigerian Basement complex. The area is underlain mainly by rocks of the Migmatite - Gneiss Complex with is predominated by quartzite, granite and granite gneiss "Fig. 2". Quartzite is the most widespread rock in the area; which mineralogically contains quartz dominating mineral, other minerals such as muscovite, tremolite, microcline and biotite are common as well. Quartzites which are prominent as ridge vary in texture from massive to schistocity due to the presence of flaky minerals like mica.

2. Method of Study

Twenty Seven traverses were established in the investigated area. Seventy five (75) sounding stations were occupied at the study area. The location of each sounding stations in both geographic and Universal Traverse Mercator (UTM) coordinates was recorded with the aid of the GARMIN 12 channel personal navigator - Geographic Positioning System (GPS) - unit. The instrument used for the resistivity data collection was the Ohmega Resistivity meter. The current electrode spacing (AB/2) was varied from 1 m to 65 m and 1 m to 225 m. The metal electrodes were driven into the ground with hammers to ensure good contact with the ground. The measurements were taken at all stations with in-line arrangement of the electrode with respect to the traverse lines and the apparent resistivity values were calculated.

The apparent resistivity measurements at each station were plotted against electrode spacing (AB/2) on bi-logarithmic graph sheets. The resulting curves were then inspected visually to determine the nature of the subsurface layering. In each way, each curve was characterized depending upon the number and nature of the subsurface layers. Partial curve matching [13] was carried out for the quantitative interpretation of the curves.

The results of the curve matching (layer resistivities and thicknesses) were fed into the computer as starting model parameter in an iterative forward modeling technique using RESIST version 1.0 [16]. From the interpretation results, geoelectric sections along the traverses were produced. The interpreted result was considered satisfactory where a good fit of RMS between the field curves and computer generated curves is generally less than 10 %; as it ranges between 1.8 – 10.7. The results were also used to generate layer parameter histograms.

Also three hand dug wells were logged to reveal estimation of depth to the water level, depth to the bedrock and water table elevation. The surface elevation at different points vary due to topographic variation, the true water level were obtained by subtracting the measured depth to the water

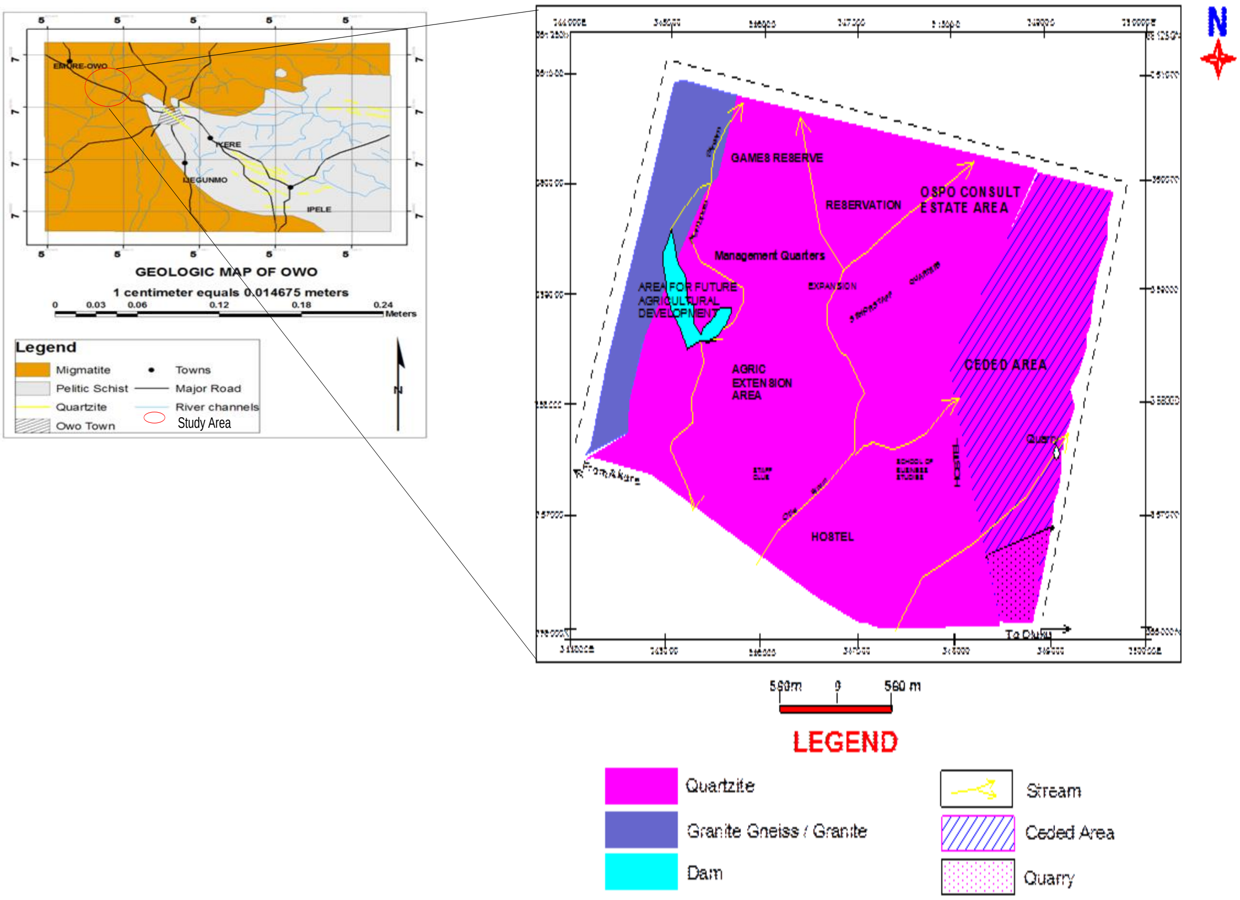


Figure 2: Geology of the Study Area

level in the hand-dug wells from the surface elevation to get uniform water levels otherwise known as the elevation of the water level [3].

Mathematically, $S_{wl} = E - D_{wl}$ (1)

Where: S_{wl} is the true or uniform water level otherwise known as the static water level in the case of unconfined aquifer

E is the surface elevation with respect to the mean sea level

D_{wl} is the depth from the surface of the earth to the water level (Well Head) in the hand-dug wells (Direct borehole logging)

The water column was calculated from the static water level data gathered from the wells using the formula;

$$WC = TD - S_{wl} \quad (2)$$

Where, WC is the Water Column (m)
TD is the Total Depth of the well

3. Results and Discussion

3.1 Vertical Electrical Sounding (VES) and Field Curve

Table 1 gives a summary of the results of the VES curves obtained from the study area. The number of layers varies between 3-layers and six-layers. Nine curve types have been identified in the study area: KH, HKH, H, KHKH, QH, HK, KQ, AKQ, and KQH. The most occurring curve types identified are KH and HKH. The root mean square (RMS) error of the generated curves ranges between 1.8 and 10.7; this shows models of well smoothened, iterated curves [2]. The type curves can be classified into four distinct classes as follows:

Class 1: KQ and AKQ
Class 2: H and QH
Class 3: KH, KQH, and KHKH
Class 4: HK and HKH

Examples of the Class 1 type curve (KQ and AKQ) are illustrated in "Fig. 3". The class represents a subsurface condition in which there is a highly resistive hard pan underlines a low resistive clayey soil, and the weathered layer underlines the former. The weathered layer overlies the partly weathered/fracture basement rock depending on this layer resistivity. This group of curves account for just 3.9% of the total.

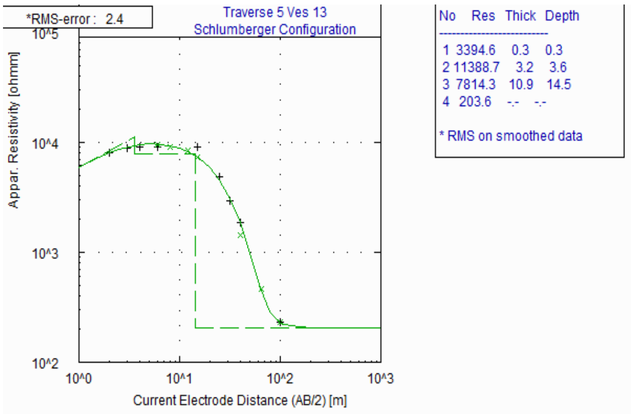
The VES curves of Class 2 (H and QH) are characteristics of the Basement Complex saprolite produced from in-situ weathering. Examples of the sounding curves are shown in "Fig. 4". In this profile, the upper horizons, when not leached, are usually clayey and the main aquifer zone is found at the base where selective mineral decomposition has produced a gravel-like material [6]. Immediately underlying the usually low resistivity, high porosity, and low permeability weathered zone is the fresh basement. This classic architecture of the profile produces an H-type curve

Table 1: Summary of VES results obtained in the study area

Traverse	*VES*	*RESISTIVITY (Ohmns-meter)*	*THICKNESS (m)*	*DEPTH (m)*	*Curve*

No.	NO.	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	ρ_6	h_1	h_2	h_3	h_4	h_5	d_1	d_2	d_3	d_4	d_5	Type
1	1	203	123	598	491			2.5	4.0	1.3			2.5	6.5	7.8			HK
	2	341	189	145	499			1.0	14.3	12.2			1.0	15.3	27.5			QH
	3	594	107	469	92			0.8	2.0	3.4			0.8	2.8	6.2			HK
	4	840	114	671	35	5899		0.9	1.0	5.2	11.4		0.9	1.9	7.1	18.5		HKH
	5	814	157	48	10176			2.2	43.8	3.2			2.2	46	49			QH
2	6	199	575	52	3061	10	26570	0.9	1.9	3.7	1.9	3.0	0.9	2.8	6.5	8.4	11.4	KHKH
	7	1644	283	136	661			1.1	4.4	8.1			1.1	5.5	13.6			QH
3	8	237	176	322	71	678		0.8	1.5	22	10.7		0.8	2.3	24.3	35.1		HKH
	9	1210	45	416				1.2	13.5	14.7			1.2	14.7				H
	10	1462	244	12528				1.9	11.5				1.9	13.4				H
4	11	785	6048	108	11179			1.6	1.7	6.5			1.6	3.4	9.9			KH
5	12	778	1633	49	10372			1.5	13.3	18.2			1.5	14.8	33.0			KH
	13	3395	11389	7814	204			0.3	3.2	10.9			0.3	3.6	14.5			KQ
	14	253	1208	253	27561			0.6	7.0	55.3			0.6	7.6	62.9			KH
	15	1464	2029	13798	680	158		19.8	1.2	22.0	1.9		19.8	20.9	43.0	44.9		AKQ
6	16	895	378	633	226	542		1.0	2.6	5.5	9.2		1.0	3.6	9.1	18.3		HKH
	17	110	164	58	167			1.0	13.3	20.5			1.0	14.2	34.8			KH
	18	46	264	47	12325			1.0	6.9	14.6			1.0	7.9	22.5			KH
7	19	667	353	852	244	7097		1.0	1.3	17.9	88.8		1.0	2.3	20.2	109		HKH
	20	180	31	3858	12	652		1.4	2.0	1.5	3.3		1.4	3.3	4.8	8.1		HKH
	21	415	219	857	222	5432		0.7	1.2	4.0	65.0		0.7	1.9	5.9	70.9		HKH
8	22	171	719	141	1406	40	376	0.5	1.0	3.0	2.3	9.1	0.5	1.5	4.5	6.8	15.9	KHKH
	23	219	1474	60	562	84	327	0.4	0.4	1.1	8.2	8.3	0.4	0.8	1.9	10.1	18.4	KHKH
	24	270	64	522				3.9	26.9				3.9	30.8				H
9	25	254	535	131	44	955		0.9	1.0	12.7	38.6		0.9	1.9	14.6	53.2		KQH
	26	200	3039	141	361			0.5	0.3	41.7			0.5	0.8	42.4			KH
	27	286	716	18	1579			1.1	2.9	6.0			1.1	4.0	10.0			KH
10	28	331	50	229	16	2498		1.3	1.3	3.1	7.6		1.3	2.6	5.8	13.4		HKH
	29	82	726	46	284			0.5	1.3	24.5			0.5	1.9	26.4			KH
11	30	120	441	20	301	52	4638	0.9	1.2	1.5	8.7	22.8	0.9	2.0	3.5	12.2	35.0	KHKH
12	31	516	83	14979	19	3941		2.5	2.8	2.3	20.3		2.5	5.3	7.5	27.8		HKH
	32	65	1258	20	14478			0.4	1.0	6.3			0.4	1.4	7.8			KH
13	33	515	587	104	430			1.0	7.4	47.4			1.0	8.4	55.9			KH
14	34	262	353	69	849			0.8	9.5	15.5			0.8	10.3	25.8			KH
	35	135	39	477	24	1280		0.9	1.0	2.6	13.8		0.9	1.9	4.5	18.3		HKH
15	36	183	41	338				1.0	8.0				1.0	9.0				H
	37	658	448	206	986			0.9	3.3	7.7			0.9	4.3	11.9			QH
16	38	332	492	104	2289			0.9	2.9	64.5			0.9	3.8	68.3			KH
	39	328	211	256	71	9122		1.8	13.4	21.2	54.4		1.8	13.4	21.2	54.4		HKH
	40	396	472	114	678			0.9	3.1	87.3			0.9	4.0	91.3			KH
17	41	80	106	63	269			0.7	2.2	19.8			0.7	2.9	22.7			KH
	42	227	138	97	394			1.2	1.9	30.4			1.2	3.1	33.6			QH
18	43	274	460	68	2382			0.7	0.8	15.9			0.7	1.5	17.4			KH
	44	97	95	149	108	10441		1.6	9.3	5.9	28.8		1.6	10.8	16.8	45.6		HKH
	45	118	337	48	772	41	3527	0.6	0.5	2.1	2.2	21.5	0.6	1.2	3.3	5.5	27.0	KHKH
19	46	304	790	165	535			1.0	1.4	30.4			1.0	2.4	32.8			KH
	47	338	740	336	1132	382	757	0.9	1.5	6.5	2.0	41.7	0.9	2.3	8.8	10.8	52.5	KHKH
20	48	147	297	59	579			1.0	1.3	18.5			1.0	2.3	20.8			KH
	49	243	479	82	337			1.0	2.7	19.2			1.0	3.5	22.8			KH
	50	342	322	138	1362			1.3	1.4	46.9			1.3	2.7	49.6			QH
	51	543	780	264	11207			0.5	3.9	144.2			0.5	4.4	148.6			KH
21	52	369	259	93	17578			5.1	2.4	29.9			5.1	7.5	37.4			QH
	53	538	105	240				1.2	25.7				1.2	26.9				H
	54	305	38	278				0.9	13.8				0.9	14.7				H
22	55	554	823	60	3520			1.1	3.0	24.8			1.1	4.1	28.9			KH
	56	294	183	445	57	487		1.0	1.3	3.2	21.7		1.0	2.3	5.5	27.2		HKH
	57	727	28	1410				1.5	11.5				1.5	13.0				H
	58	275	33	1420				1.1	15.5				1.4	16.9				H
	59	117	202	40	1480			0.8	2.8	26.9			0.8	3.5	30.4			KH
23	60	227	652	134	3029			1.0	11.4	59.2			1.0	12.4	71.7			KH
	61	593	987	111	3126			1.0	19.1	52.9			1.0	20.1	73.0			KH
24	62	347	653	65	3421			1.1	11.1	43.9			1.1	12.1	56.0			KH
	63	301	583	77	402			1.1	7.1	26.8			1.1	8.2	35.0			KH
25	64	229	901	207	907			0.9	2.3	28.8			0.9	3.2	32.1			KH
	65	247	501	163	752			1.0	4.7	34.1			1.0	5.7	39.8			KH

	66	302	618	252	914			2.8	9.2	15.6			2.8	12.0	27.6			KH
	67	627	936	355	7581			1.1	10.6	43.5			1.1	11.7	55.2			KH
26	68	277	1050	558	1185	106	776	1.1	0.6	5.3	2.1	24.7	1.1	1.7	7.0	9.1	33.8	KHKH
	69	91	298	43	401			1.2	6.6	18.2			1.2	7.8	26.0			KH
	70	167	952	54	919			1.0	0.9	30.6			1.0	1.9	32.5			KH
	71	309	3017	38	233			0.5	0.8	10.0			0.5	1.3	11.2			KH
27	72	308	1019	130	463			1.1	3.6	39.9			1.1	4.7	44.6			KH
	73	862	1223	119	383			1.0	1.7	16.4			1.0	2.7	19.1			KH
	74	340	994	35	1872			1.0	0.3	21.5			1.0	1.2	22.8			KH
	75	223	51	242				1.7	21.3				1.7	23.0				H



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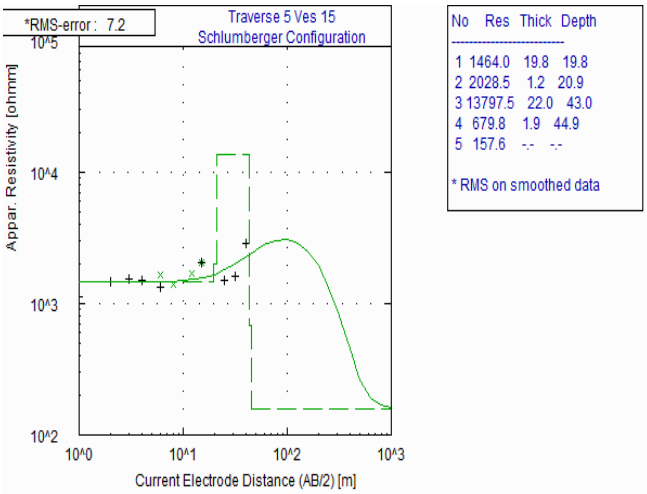
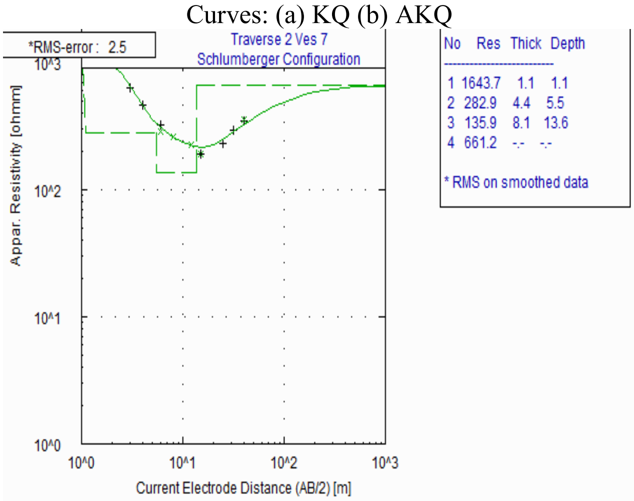


"(b)"

Figure 3: Interpretation Model of Typical Class 1 Type Curves: (a) KQ (b) AKQ



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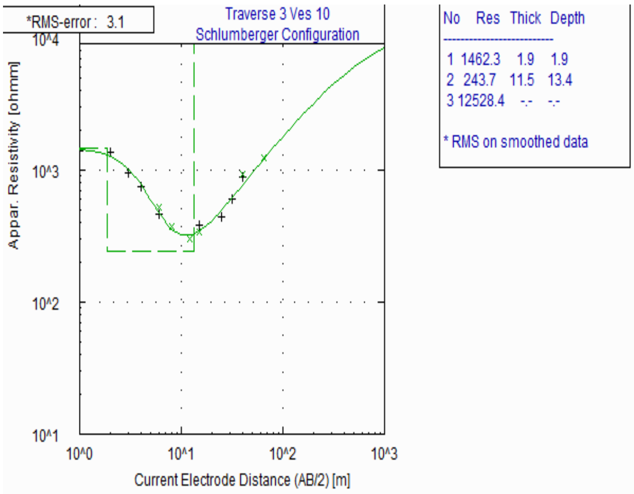

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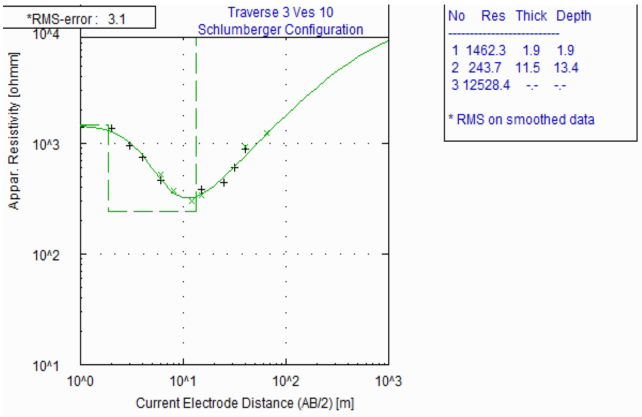
Figure 4: Interpretation Model of Typical Class 2 Type Curves: (a) QH (b) H

Signature, which was found to be 16% of the total curve types. In the QH, the topsoil may be divided into two horizons with the lower one being more conductive. This may be common in areas where there is regolith (transported material) in addition to the usual in-situ saprolite. The QH is symptomatic of a succession in which a more conductive clayey weathered layer lies directly on the fresh basement. This curve type account for 9% of the total curve types.

Types curves of Class 3 (KH, KQH, and KHKH) "Fig. 5" which account for 47.3% of the total, are typical of a succession of relatively low and high resistivity layer. The KH four-layer setting which constitutes about 46.7% of the curves is found where a highly resistive lateritic hard pan underlies low resistivity clayey topsoil, and the weathered layer in turn underlies the former. The weathered layer overlies the fresh basement. In the KHKH type, the fifth layer is a confined fracture basement. The curves in Class 4 (HK and HKH) are shown in "Fig. 6". Here the succession of the subsurface layers starts with highly resistive topsoil followed by a more conductive horizon and then another less conductive layer underlines the latter, which overlies the fresh basement. HKH type is a succession of five layers i.e. the topsoil, weathered layer, fresh basement, confined fracture basement and fresh basement. The HK and HKH account for 2.7% and 16% of the total curve types respectively.



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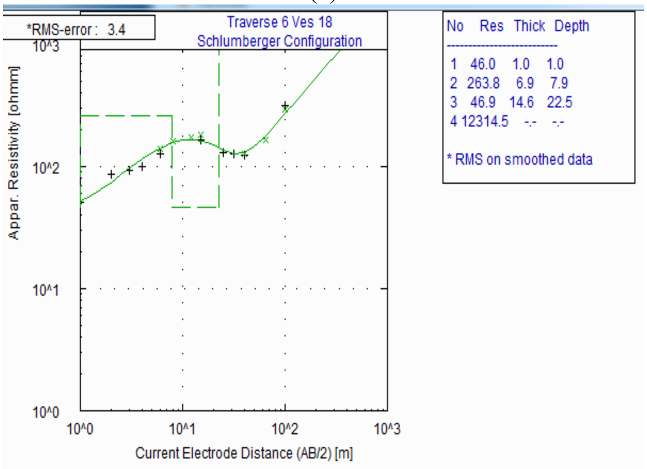

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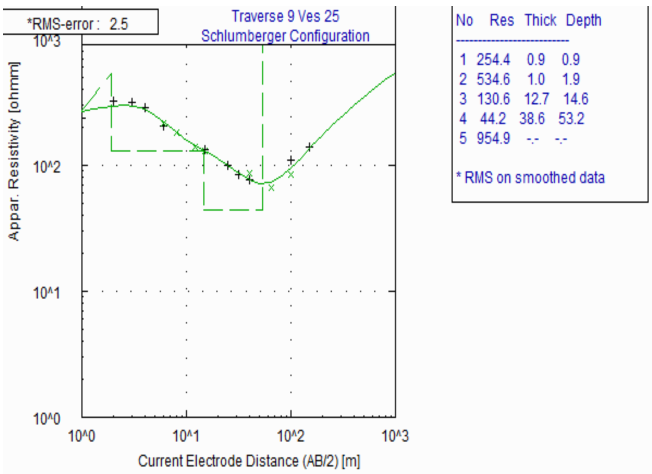

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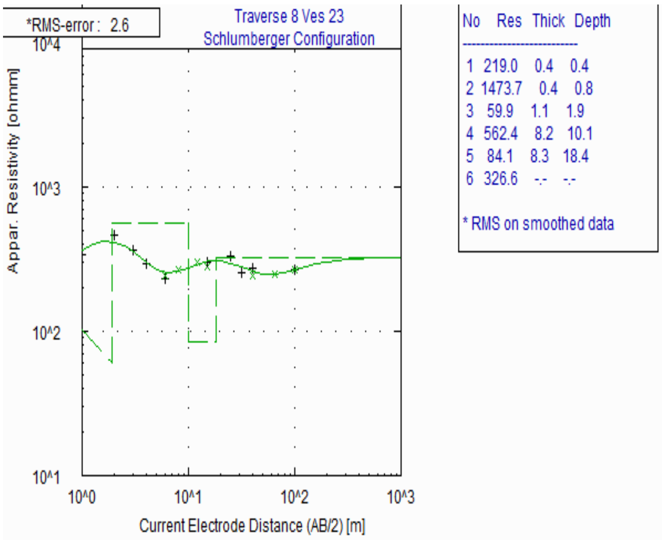

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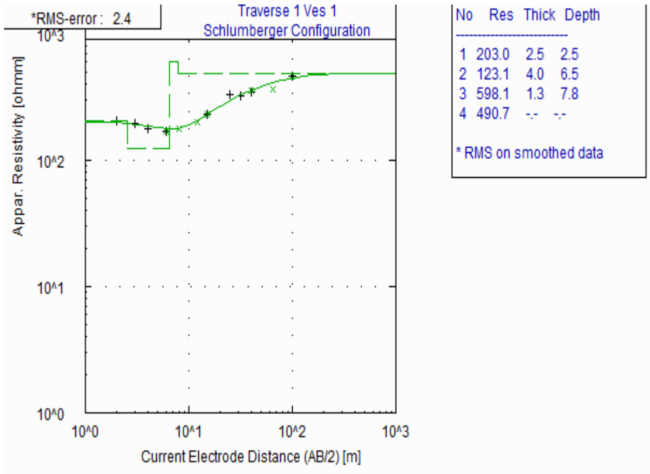
Figure 5: Interpretation Model of Typical Class 3 Type Curves: (a) H (b) KH (c) KQH (d) KHKH



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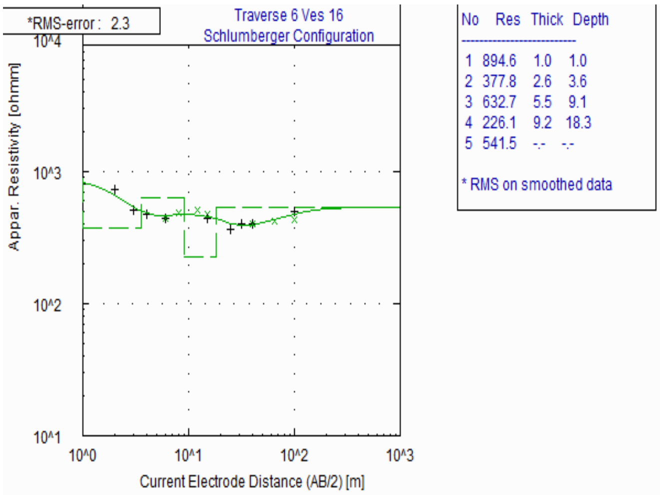

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Figure 6: Interpretation Model of Typical Class 4 Type Curves: (a) HK (b) HKH

3.2 Geoelectrical Maps

Iso-resistivity Map of the Topsoil

Aquifer vulnerability study was done by assessing the topsoil resistivity distribution. "Fig. 7" shows the isorestivity map of the topsoil in the study area. The topsoil resistivity varies between 46 Ω-m and 1644 Ω-m. The map shows that the topsoil resistivity is generally between 300 Ω-m and 600 Ω-m indicating clayey sand; while the southwestern part is generally ranging from 600 Ω-m to 900 Ω-m indicating a composition of clayey sand and laterite. The central part and far southeastern region of the institution are characterized by high degree of inhomogeneity.

Iso-restivity Map of the Layer overlying the Weathered Layer

The isorestivity map of the layer above the weathered layer in the study area is shown in "Fig. 8". The map shows resistivity ranging from 39 Ω-m to 3039 Ω-m. There are pockets of low resistivity values observed mostly towards the southeastern part of the institution, while high resistivity values (greater than 600 Ω-m) are found around the central area. However resistivity values in the range of 200 Ω-m to 1000 Ω-m is the most dominant in the study area. This implies that the layer above the weathered layer is generally clayey sand/lateritic clay in composition.

Iso-resistivity Map of the Weathered Layer

The resistivity of the weathered layer determined the degree of saturation of weathered zone. "Fig. 9" shows the resistivity distribution of the weathered layer in the study area. The resistivity ranges from 31 to 1258 Ω-m. The map shows high degree of variation in resistivity values in the area. However, the resistivity is generally between 100 Ω-m and 500 Ω-m typical of clayey sand (aquitard) i.e. a subsurface formation that stores but fairly transmit water. The best aquiferous zone is around north-eastern part, which is characterized by resistivity values in the range 200 to 700 Ω-m.

Isopach Map of Overburden

The isopach map of the overburden "Fig. 10" was obtained from the contour of the thickness of all the materials overlying the bedrock beneath the VES points against their geographic locations. The map shows overburden thickness varying from 0.8 m to 144.2 m. The overburden thickness is generally greater than 20 m except the southeastern part which is characterized by thickness values less than 20 m. The northeastern and southwestern parts of the institution show a high overburden thickness suggesting a high degree of weathering; which also implies that the basement rock is deep seated, while shallow in other parts of the institution.

Isopach Map of the Fractured Basement

The fractured basement forms one of the aquifers observed in the study area. The thickness distribution of the fractured basement is shown in "Fig. 11". The thickness varies between 0.8 m and 148 m. The low thickness values in the range of 0 m 20 m trends in southwestern to northeastern direction, while the high thickness values (greater than 50 m) characterized the northeastern to southwestern direction of the study area.

3.3 Transverse Unit Resistance Map

"Fig. 12" is the total transverse unit resistance map of the study area. The map shows that the transverse resistance is predominantly between 1000 and 10,000 Ωm² indicated as medium groundwater development zone, this resistance values is found around the northwest through the central to the southeastern part of the study area. The high transverse resistance values (greater than 10,000 Ωm²) are found in northeastern and southwestern part of study area, these zones are the best area for groundwater development. However, pockets of low resistance values are observed around the southeastern part and central area of the study area.

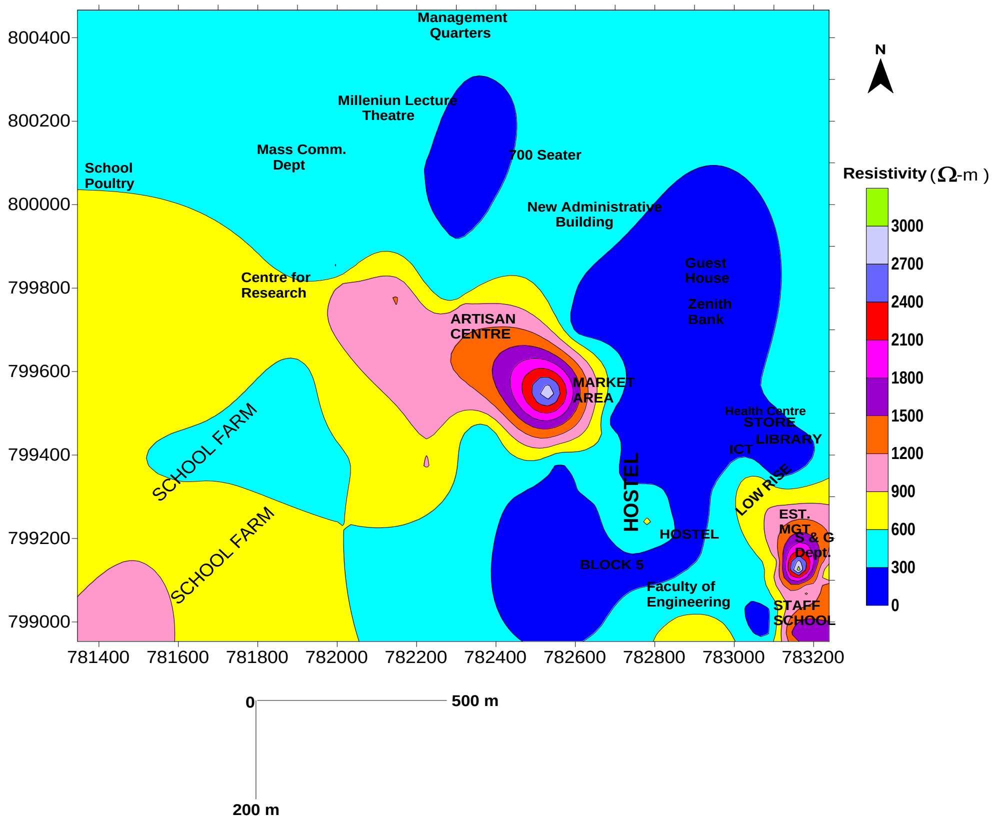

Figure 7: Isoresistivity Map of the Topsoil

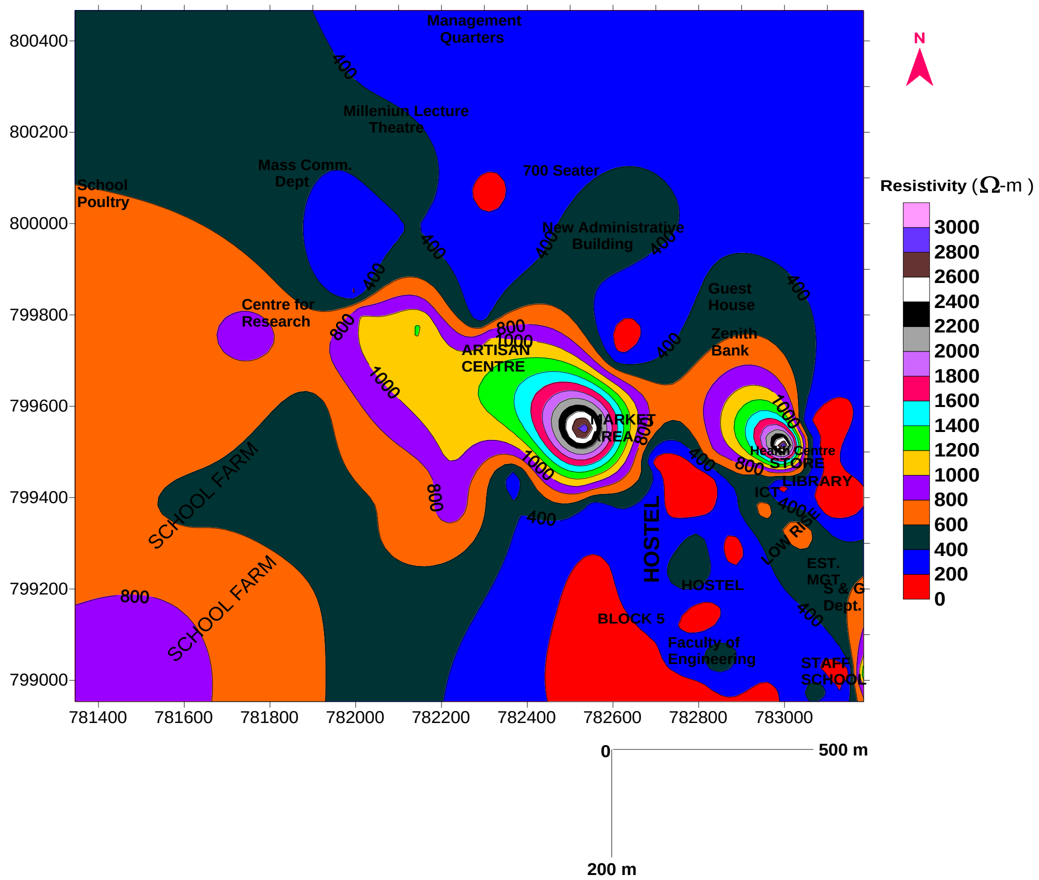

Figure 8: Isoresistivity Map of the layer above the Weathered Layer

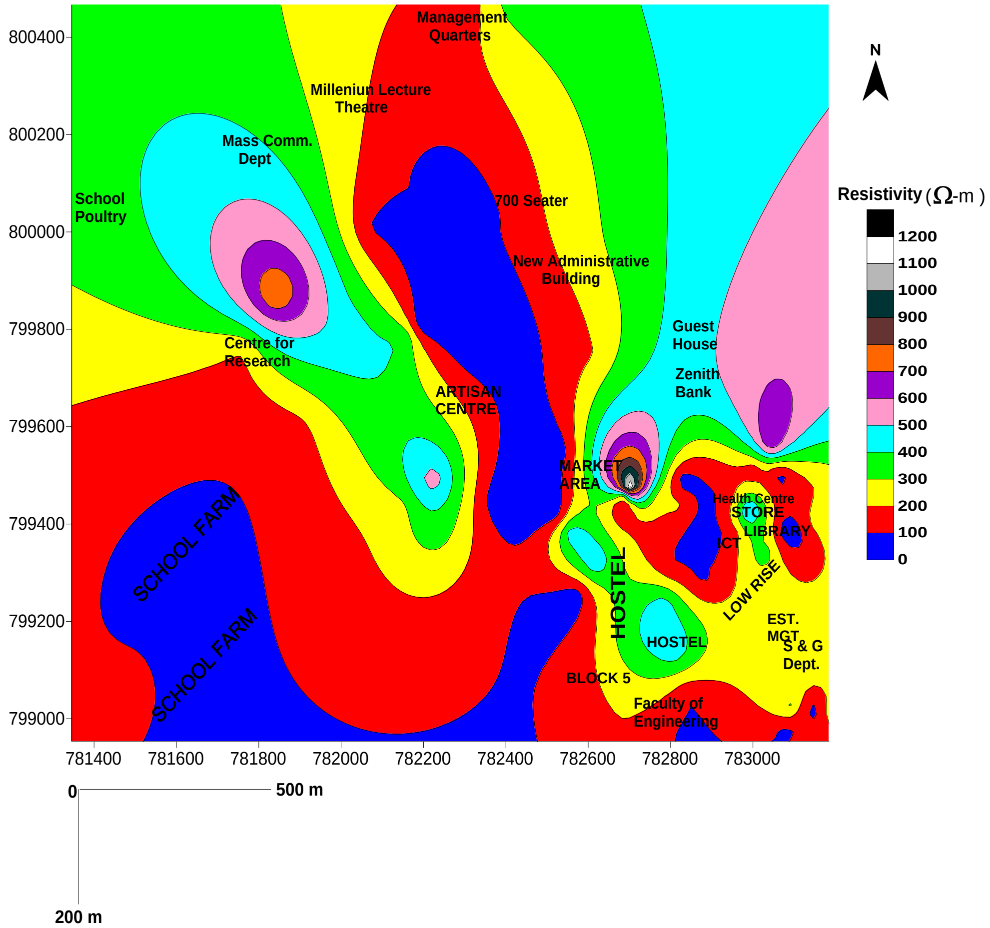

Figure 9: Isorestivity Map of the Weathered Layer

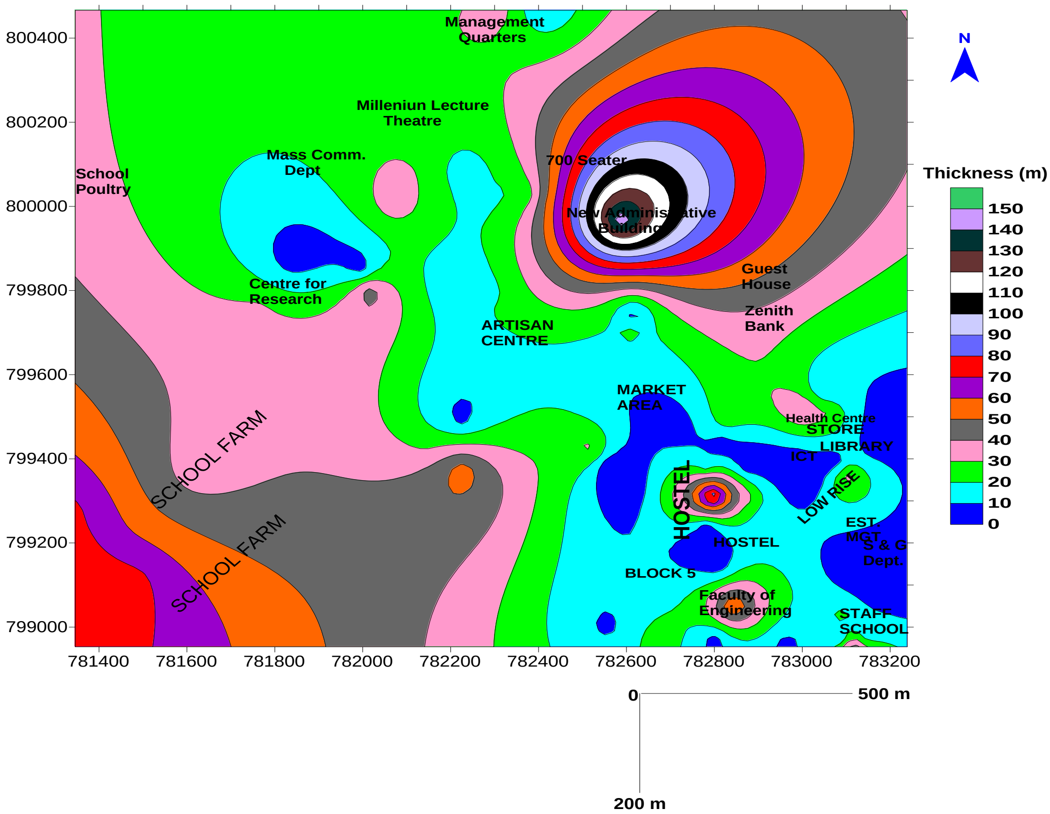

Figure 10: Isopach Map of the Overburden

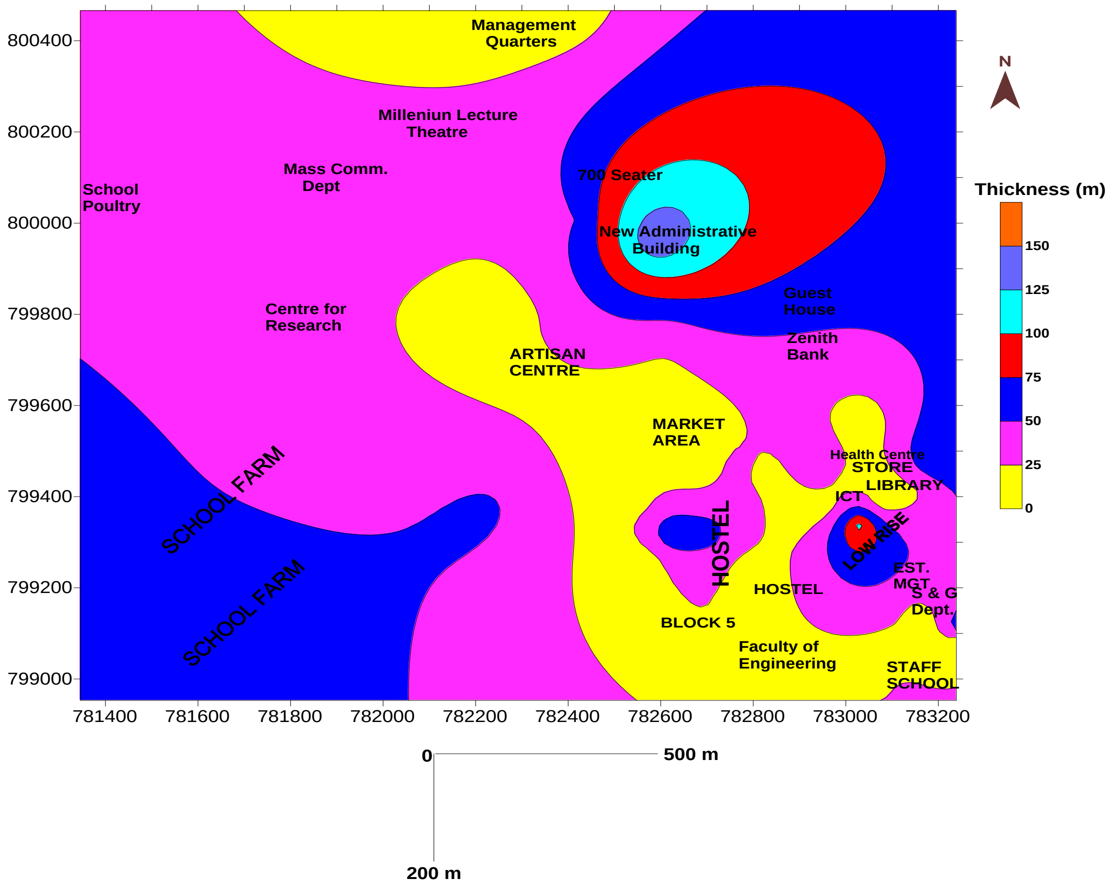

Figure 11: Isopach Map of the Fracture Basement

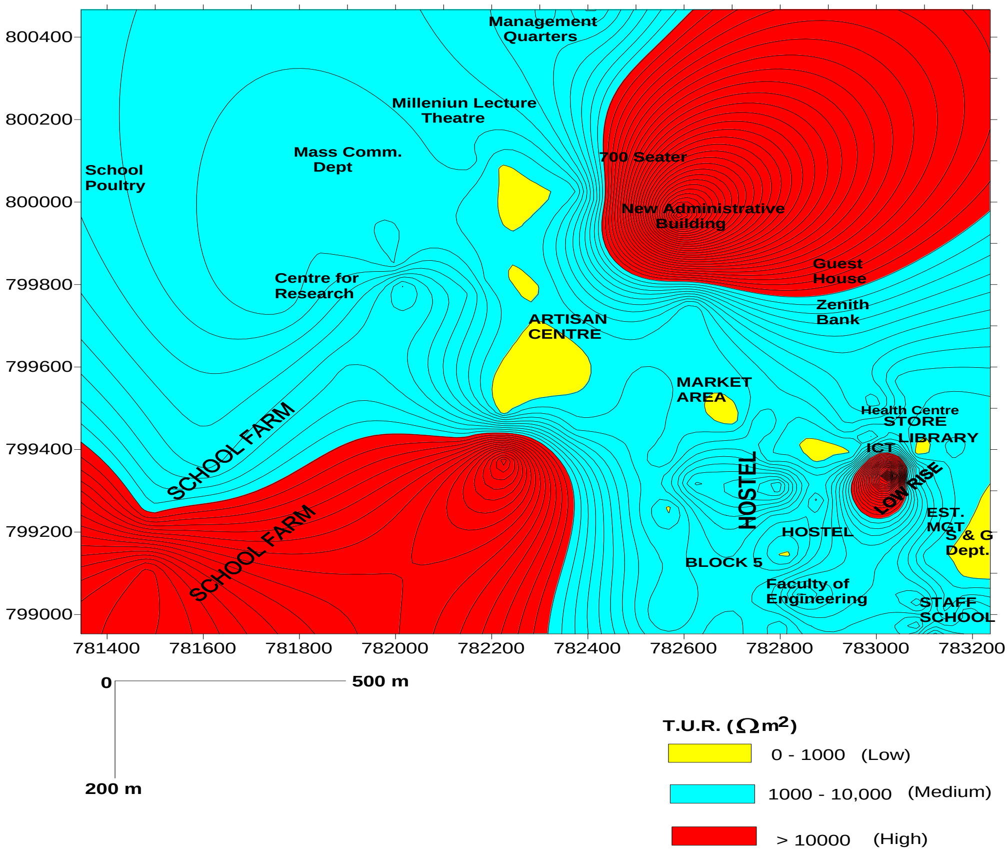

Figure 12: Transverse Unit Resistance Map of the Studied Area

3.5 Longitudinal Unit Conductance (L.U.C.) / Overburden Protective Capacity Evaluation

The longitudinal unit conductance map “Fig. 13” shows the distribution of the longitudinal conductance within the study area. The map shows small closures of very high unit conductance (> 0.6 mhos) in the southwestern, central and southeastern parts. Longitudinal unit conductances in the range of 0.15 – 0.5 mhos is the most predominant in the study area.

Due to the filtering effect of the earth, the total longitudinal unit conductance values were used to evaluate the overburden protective capacity of the area, [12], [1]. [4] relate the protective capacity of an overburden overlying an aquifer to its hydraulic conductivity. The higher the clay content which impedes the fluid movement, characterized by low resistivity and low hydraulic conductivity, the higher the longitudinal unit conductance the better the protective capacity.

Table 2 shows the [4] longitudinal unit conductance classification as modified by [7] which is adopted in evaluating the protective capacity [1], [7], [12] in the study area. The overburden protective capacity map “Fig. 14” shows a moderate protective at the southwestern and northeastern/eastern parts, while all other areas have poor/weak protective capacity. A small closure of good protective capacity is observed in the eastern part.

The overburden protective map of the area shows that about 60 % of the area falls within the moderate/good protective capacity, while 40 % constitutes the poor/weak overburden protective rating. This suggests that the study area has weathering materials of good/moderate protective capacity.

3.6 Coefficient of Anisotropy Map

“Fig. 15” shows the coefficient of anisotropy map. This parameter describes the amount of subsurface layer anisotropy and generally lies in the range 1 – 2 [14]. [10], [11] also revealed that the degree of subsurface inhomogeneity correlates linearly with groundwater yield.

The map shows that the coefficient of anisotropy values ranging from 0.16 to 33.8 units. The area is predominantly covered by low anisotropy coefficient (< 2.5) which indicates that the major aquifer present in the area is the weathered layer aquifer. Moderate anisotropy zone (2.5 – 5 units) is observed in the southeastern part, indicating presence of weathered/fractured basement aquifer. Closures of high anisotropic zones (> 5 unit) are observed within the moderate anisotropic zones; these zones suggest a highly fractured basement aquifer zones. It was also observed that most of the values (85 %) fall within the range of 1 – 2 [14].

3.7 Hydro-geological Measurements

Measurement was taken on three (3) hand dug wells to reveal the depth of unsaturated zone (vadose water zone) and the water column. Tables 3 shows the data collected from hydrogeological measurement. The unsaturated zone (vadose) is the geologic materials between the earth’s surface and the water table and can also be referred to as zone of aeration. The thickness of this zone determines the transit time, which is the time it will take for percolating water to reach the water table. It takes effluents one foot per year to migrate in the subsurface, therefore the thicker the vadose zone, the lesser the groundwater would be vulnerable to contaminants. This is because the effluents must have been filtered (attenuate) before reaching the aquifer.

The static water level, water column and depth to water level vary between 316.9 m and 330.5 m, 1.3 m and 4.8 m, and 8.1 m and 10.5 m respectively. The average depth to the water level is 9.4 m. This implies that the vadose zone is fairly thick; therefore the aquifer in the area would be less vulnerable to contamination. The average water column is 3.1 m indicating a medium water column.

4. Conclusion

Hydrogeologic studies and aquifer vulnerability studies of Rufus Giwa Polytechnic Owo has been carried out, which would provide a database for hydrogeological decisions like drill hole positioning or action plans for groundwater protection in the area. The findings of the study are:

1) The geoelectric sections generally revealed four (4) major layers comprising the topsoil, weathered layer, partly weathered/fractured basement, and fresh basement rock. The Weathered layer and unconfined basement are the two aquiferous zones observed in the area.
2) The geoelectrical maps show that best aquiferous zones with appreciable thickness are southwestern and northeastern parts of the area.
3) The average depth to the water level is 9.4 m. This implies that the vadose zone is fairly thick; therefore the aquifer in the area would be less vulnerable to contamination. The average water column is 3.1 m indicating a medium water column.
4) The overburden protective map of the area shows that about 60 % of the area falls within the moderate/good protective capacity, while 40 % constitutes the poor/weak overburden protective rating. This suggests that the study area generally has weathering materials of good/moderate protective capacity.

The results of the study revealed that the aquifers within the study area are weathered layer and unconfined fractured basement. Considering the thickness of the vadose zone across the area, the resistivity parameters of the topsoil and the longitudinal conductance of the geomaterials, the best groundwater development areas with good/moderate protective capacity (from contaminants arising from anthropogenic activities) are northeastern and southwestern parts of the studied area.

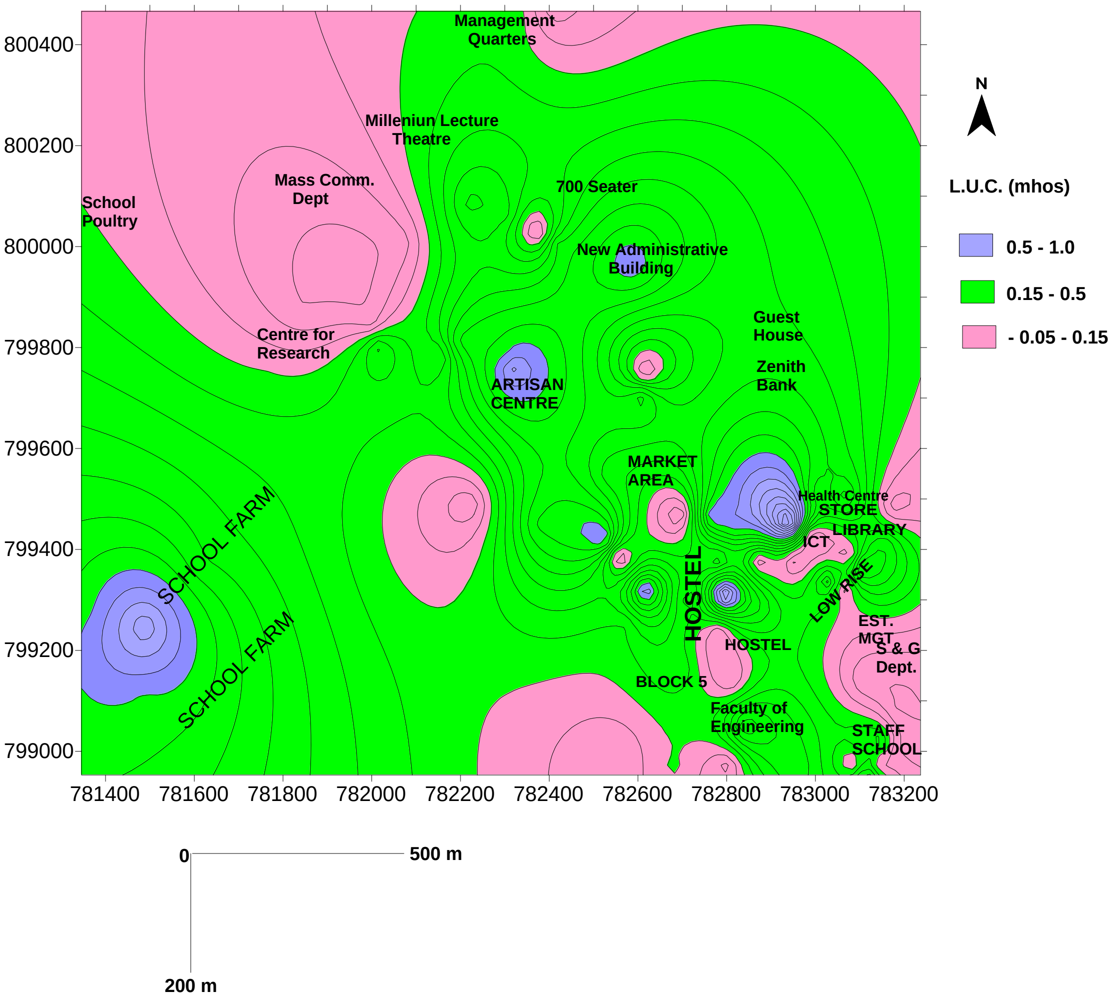

Figure 4.94: Longitudinal Unit Conductance Map

Table 2: Modified Longitudinal Conductance / Protective Capacity Rating

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

5. Recommendation

1) Pre-drilling geophysical investigations including borehole logging should be conducted in the area to enhance or facilitate well design and completion processes for optimization of resulting borehole yield. This will prevent the common occurrence of borehole failure and lost of money.
2) Water quality analysis and complete borehole documentation should be carried out. This should be in accordance with known professional practice.
3) Groundwater monitoring should be conducted regularly in the area.

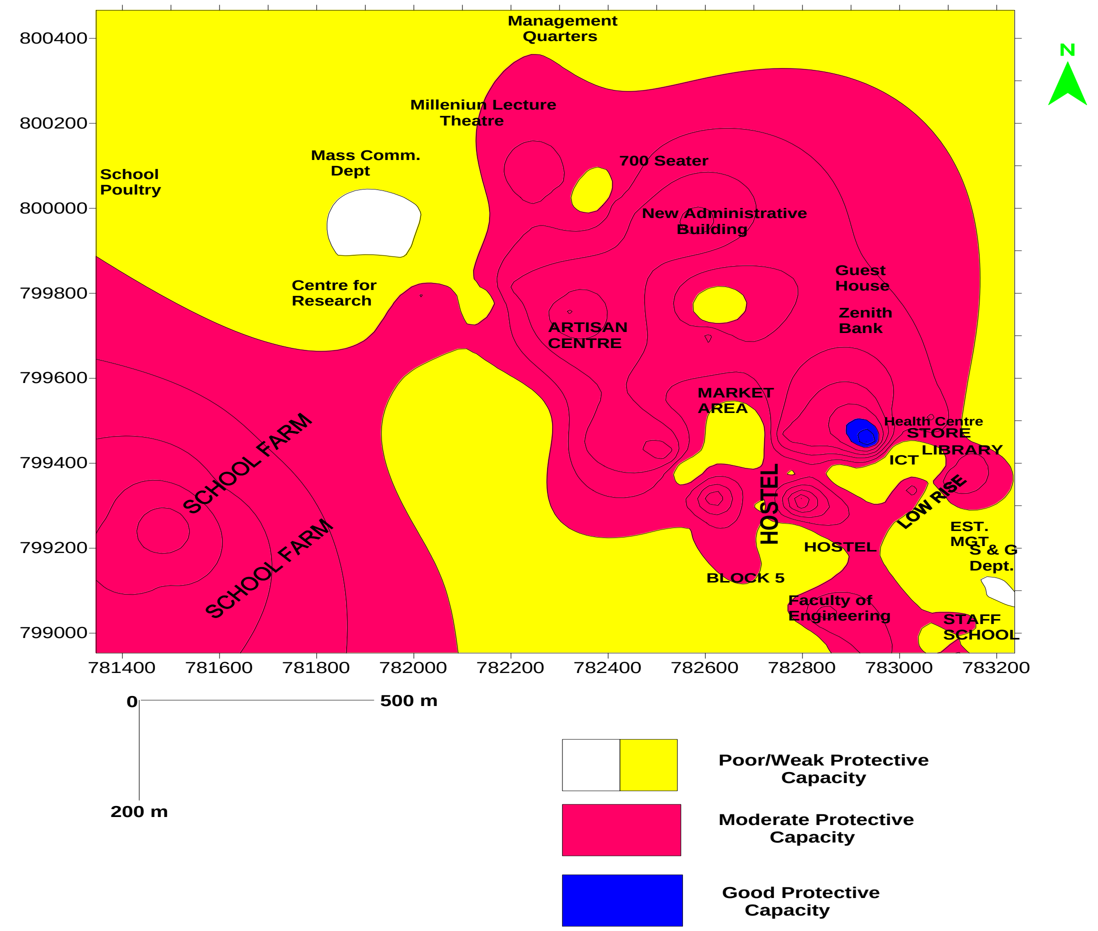

Figure 4.95: Overburden Protective Capacity Map

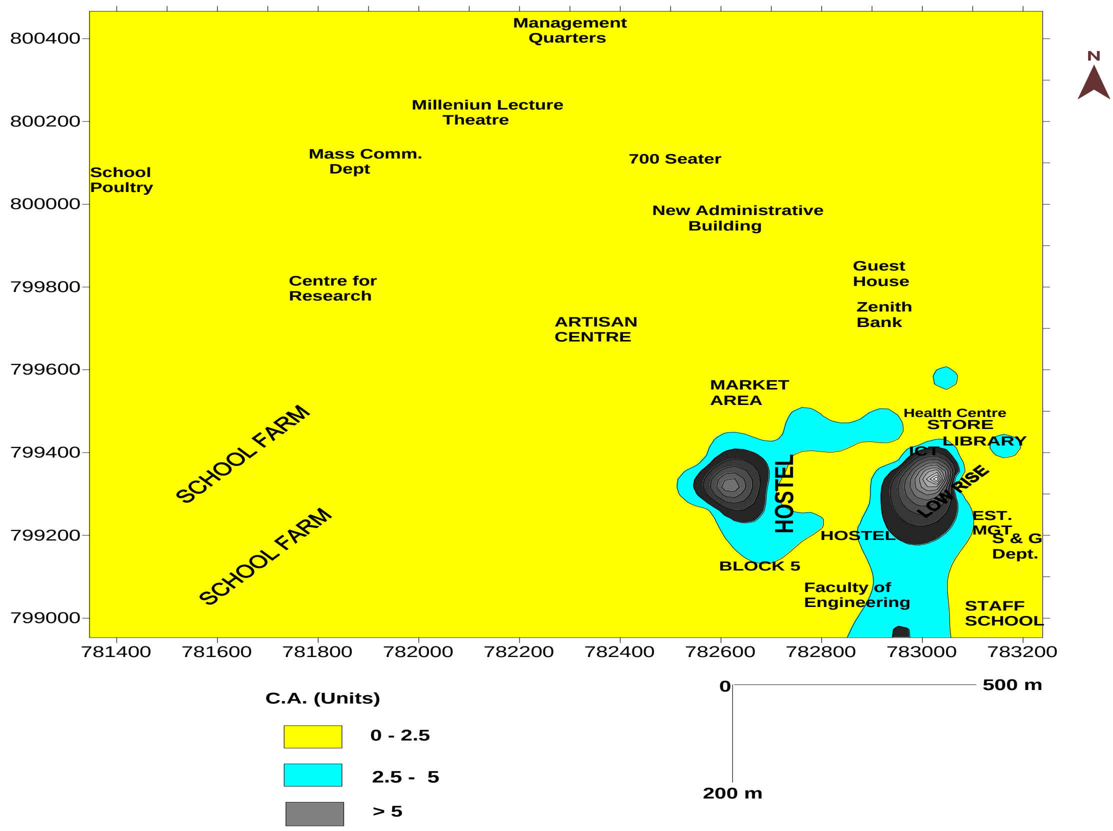

Figure 4.96: Coefficient of Anisotropy Map

Table 3: Hydro-geological Field Data Obtained within the Study Area

Well No./ Location	Easting	Northing	Elevation (m)	Depth to Water Level (m)	Total Depth (m)	Water Column (m)	Static Water Level (m)
1 (SE)	0781976	0799863	325	8.1	11.2	3.1	316.9
2 (SE)	0783358	0799585	331	9.7	12.2	1.3	321.3
3 (NE)	0782782	0799244	341	10.5	15.3	4.8	330.5

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