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Full Length Research Paper

Groundwater potential and aquifer protective capacity of overburden units in Ado-Ekiti, southwestern Nigeria

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The study of the groundwater potential and aquifer protective capacity of overburden units in Ado-Ekiti, Ekiti State, southwestern Nigeria have been undertaken. The area is underlain by the Precambrian basement complex of southwestern Nigeria with local geology predominantly granite-gneiss and migmatite. 51 Schlumberger vertical electrical soundings (VES) were covered. The interpretation revealed three distinct geoelectric layers overlying the resistive basement, the topsoil, the weathered layer and the partially weathered/fractured basement. The depth to the top of basement (overburden thickness) varied from 1.0 to 74.8 m across the study area. Groundwater potential and overburden protective capacity maps were prepared. The former assisted in the categorisation of the area into high, medium and low groundwater potential zones. The clay content of the overburden was high, which informed the low groundwater potential rating but enhanced the overburden protective capacity. The characteristic longitudinal unit conductance (ranging from 0.004 to 2.11 mhos) of the area enabled the overburden protective capacity rating into good, moderate and weak. About 60% of the area falls within the good/moderate rating, suggesting a generally good overburden protective capacity around the study area.

Key words: Geoelectric, vertical electric sounding, longitudinal unit conductance, overburden protective capacity.

INTRODUCTION

The successful exploitation of basement terrain groundwater requires a proper understanding of the geo-hydrological characteristics of the aquifer units in relation to its environmental susceptibility. This is particularly important in view of the discontinuous (localized) nature of the basement aquifers, (Satpatty and Kanugo, 1976). The use of vertical electrical sounding (VES) for groundwater exploration is popular in the basement complex rocks of Africa (Palacky, 1989; Benson and Jones, 1988). The method has been used extensively in groundwater investigation in the basement complex terrains (Barongo and Palacky, 1991; Olayinka and Olorunfemi, 1992; Olorufemi et al., 1993; Omosuyi, 2000) and also in the sedimentary basins (De Beer and Blume, 1985; Mbonu et al., 1991; Shemang, 1993). Hence, drilling programmes for groundwater development in areas of basement terrain are generally preceeded by detailed geophysical investigation areas of basement terrain are generally preceded by detailed geophysical investigations.

The study area is underlain by Precambrian basement complex rocks. These rocks are inherently characterized by low porosity and near negligible permeability. The highest groundwater yield in basement terrains is found in areas where thick overburden overlies fractured zones. These zones are often characterized by relatively low resistivity values. (Olorunfemi and Fasuyi, 1993). The most probable use of the electrical resistivity survey is in hydrogeological investigation in relation to aquifer delineation, lithologic boundaries and geological structures to provide subsurface information (Bose et al., 1973). However, groundwater occurs either in the weathered mantle or in the joints and fractured system in the un-weathered rocks (Olorunfemi and Olorunniwo, 1985; Ako and Olorunfemi, 1989; Olayinka and Olorunfemi, 1992).

The population of Ado-Ekiti has increased tremendous-ly in the last one decade. This is due to its new status of being the capital of Ekiti-State, carved out of the old Ondo State in 1996. It has therefore witnessed an influx of people from far and near and emergence of many Industries. Hence, there has been an increase in water demand by the people in the area for both domestic and industrial usage.

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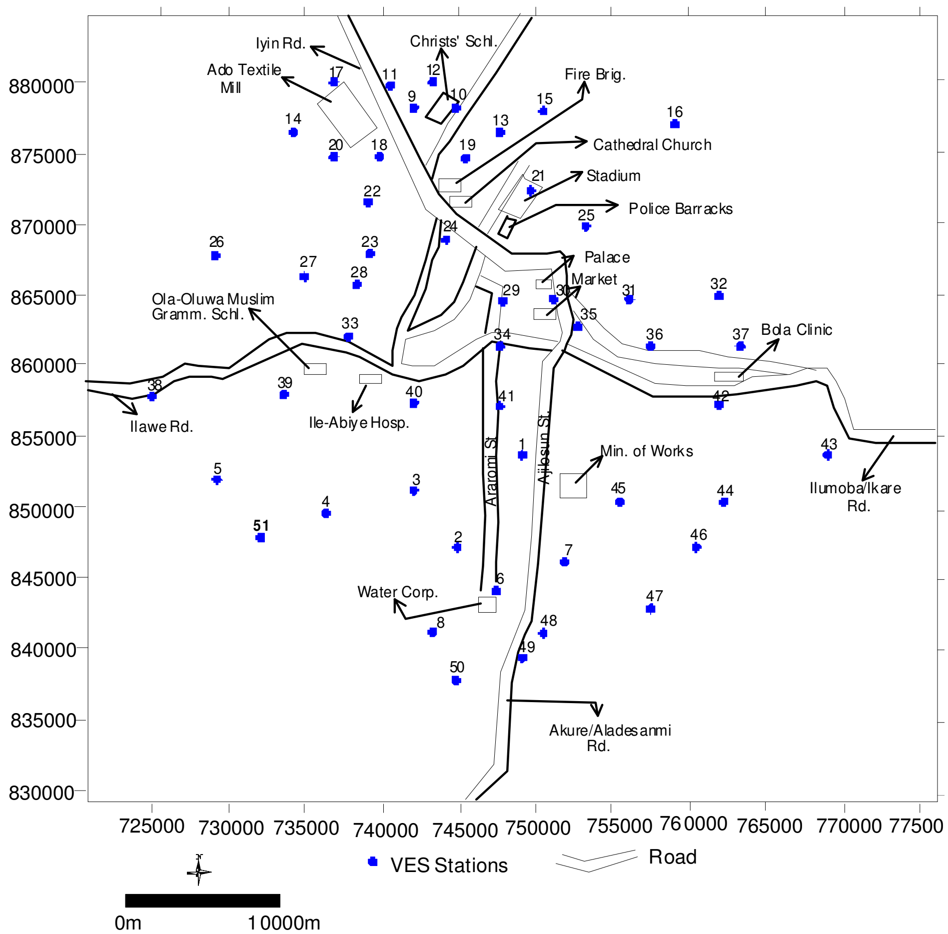


Figure 1. Base map of the study area showing the distribution of VES stations.

Consequently upon this, a detailed geoeletric survey covering Ado-Ekiti, southwestern Nigeria was carried out to determine the geoelectric parameters (resistivities and thicknesses) of subsurface layers and their hydrogeologic properties. The study is also aimed at evaluating the groundwater potential of the area and establishing the aquifer protective capacity (insulation from pollution) of the overlying formations.

The study area is located between latitudes 7°15'N and 7°16.8'N and longitudes 5°19'E and 5°23.2'E (Figure 1). Information on the local geology of the area was sourced principally from the numerous rock outcrops observable in the area. It falls within the context of the geology of the basement complex of southwestern Nigeria, (Odeyemi, 1989; Rahaman, 1989). The major rock units distinguished are the undifferentiated migmatite-gnesis-quartzite complex, charnokitte, older granite and unmetamorphosed dolerite dykes believed to be the youngest. The Precambrian basement complex of southwestern Nigeria underlies the area with local geology essentially granite-gneiss and migmatite. The area is located within the western uplands (uplifted areas) of southwestern Nigeria. It is about 300 m above mean sea level, with some dome-shaped hills at the outskirt. The hills are of granite and metamorphic gnesis and quartzite forming residual hills. The topography is gently undulating, consisting of gravel, lateritic soil, alluvial soil, clay, sandy clay, and top-soil and low lying outcrops at the lowland area. Three major rivers - Osin, Ureje and Omisanjana - and other seasonal streams and springs, dominate the drainage system.

MATERIALS AND METHOD OF STUDY

The geophysical resistivity data was acquired with the R-50 d.c. resistivity meter which contain both the transmitter unit, through which current enters the ground and the receiver unit, through which the resultant potential difference is recorded. Other materials include: two metallic current and two potential electrodes, two black coloured connecting cable for current and two red coloured cable for potential electrodes, two reels of calibrated rope, hammer for driving the electrodes in the ground, compass for finding the orienttation of the traverses, cutlass for cutting traverses and data sheet for recording the field data. The Schlumberger array was adopted. The electrode spread of AB/2 was varied from 1 to a maximum of 150 m. The expected depth of investigation was (D) = 0.125 L, where L = AB/2 and AB the current electrode separation. Sounding

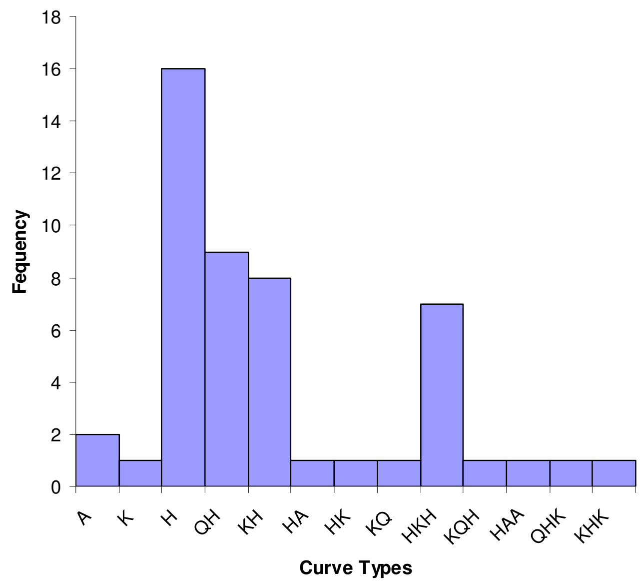


Figure 2. Frequency distribution of observed curve types in the study area.

data were presented as sounding curves, by plotting apparent resistivity against AB/2 or half the spread length on a bi-log paper. Ground resistance (R) measurements were recorded with the R–50 d.c resistivity meter. The electrical resistances obtained were multiplied by the corresponding geometric factor (k) for each electrode separation to obtain the apparent resistivity (ρ = kR) in ohm-meter. The models obtained from the calculations above were used for computer iteration to obtain the true resisitivity and thickness of the layers. Computer-generated curves were compared with corresponding field curves by using a computer program "Resist" version 1.0. The software was further used for both computer iteration and modeling. Computer iteration of between 1 - 29 were carried out to reduce errors to a desired limit and to improve the goodness of fit.

Areas where the overburden thickness was greater than 25 m and are of low clay content (resistivity above 100 Ω-m) were considered zones of high groundwater potential while those within 10 and 25 m are zones of medium groundwater potential and less than 10 m are of low groundwater potential (Oladapo and Akintorinwa, 2007).

The aquifer protective capacity characterization is based on the values of the longitudinal unit conductance of the overburden rock units in the area. The longitudinal layer conductance (S) of the overburden at each station was obtained from the equation:

$$S = \sum_{i=1}^{n} \frac{hi}{\rho i} \tag{1}$$

where h_i is the layer thickness, ρ_i is layer resistivity while the number of layers from the surface to the top of aquifer varies from i = 1 to n. Where the longitudinal unit conductance value is greater than 0.7 mhos, the layers are adjudged zones of good protective capacity. The portion where the conductance value ranges between 0.2 and 0.69 mhos is classified as zones of moderately protective capacity. The zones which have conductance value ranging from 0.1 and 0.19 mhos is classified as zones of weak protective capacity and where it is less than 0.1 mhos is considered as poor aquifer protective capacity (Oladapo and Akintorinwa, 2007).

PRESENTATION OF RESULTS

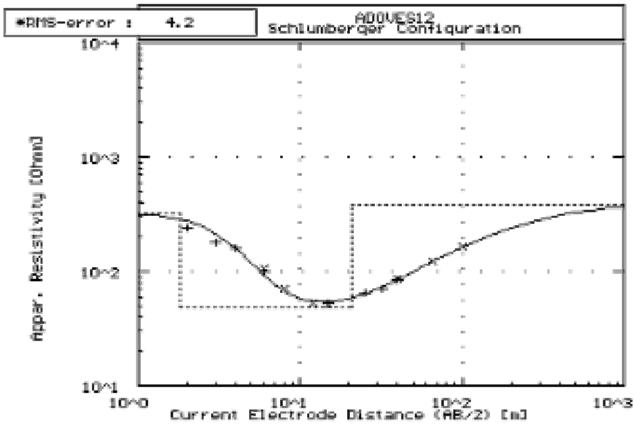
In all, a total of 51 VES locations, spread over the study area (Figure 1) were covered. The processed data were subjected to both detailed interpretation aimed at unraveling the subsurface groundwater potential and aquifer protective capacity of overburden units in the study area.

The interpretation assessed the prevalent type curves in the study area, determined the geoelectric properties of the subsurface layers and delineated the aquifers in terms of the thickness and cleanliness. The nature of the overburden cap rock was also assessed. The results were presented in form of histogram, geoelectric sections, isoresistivity, isopach and groundwater potential and protective capacity maps.

Vertical electrical sounding (VES) curves

It could be observed that the H-type curve (Figure 2 and 3) is the most dominant; accounting for about 29.41%. Approximately 37.25% of the soundings are 3-layered that is A, K and H-types (Figure 4a) while 37.25% also are 4-layered, that is QH, KH, HA, HK and KQ-types (Figure 4b) and the balance of 25.50% are 5-layered, that is HKH, HAA, KQH, QHK and KHK-types (Figure 4c).

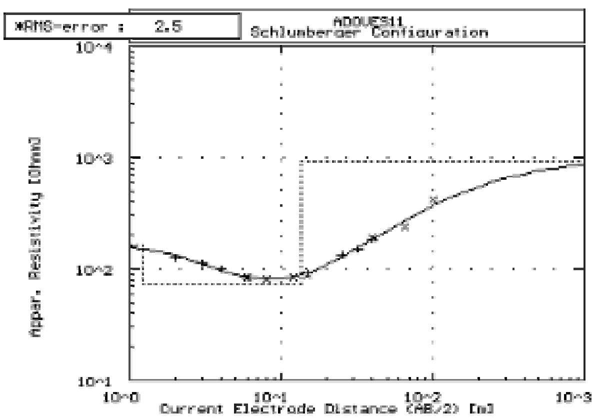
According to Olorunfemi and Olorunniwo (1985), Idornigie and Olorunfemi (1992), Olayinka and Olorunfemi (1992), it is possible to classify the curve types into four distinct classes as follows: Class 1 type curve, represents a subsurface condition in which there is an increase in resistivity values from the topsoil to the basement rock, example is the A-type curve. In class 2 curve types, the upper horizons when not leached are usually clayey and of low resistivity. Immediately underlying this usually low resistivity,



No	Res	Thick	Depth
1	323.9	1.8	1.8
2	48.0	19.0	20.8
3	386.8	-.-	-.-

* RMS on smoothed data

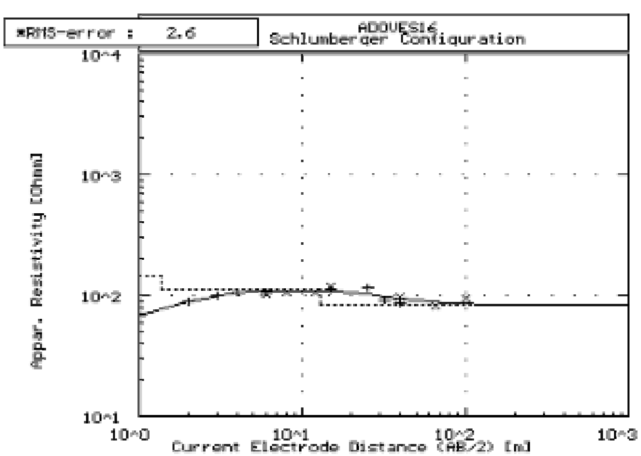
Figure 3. Typical Observed H-type curve.



No	Res	Thick	Depth
1	162.5	1.2	1.2
2	72.5	12.4	13.6
3	906.6	-.-	-.-

* RMS on smoothed data

Figure 4a. Typical type curves for 3 layered earth.



No	Res	Thick	Depth
1	58.5	0.7	0.7
2	144.4	0.7	1.4
3	112.8	11.4	12.8
4	93.8	-.-	-.-

* RMS on smoothed data

Figure 4b. Typical type curves for 4 layered earth.

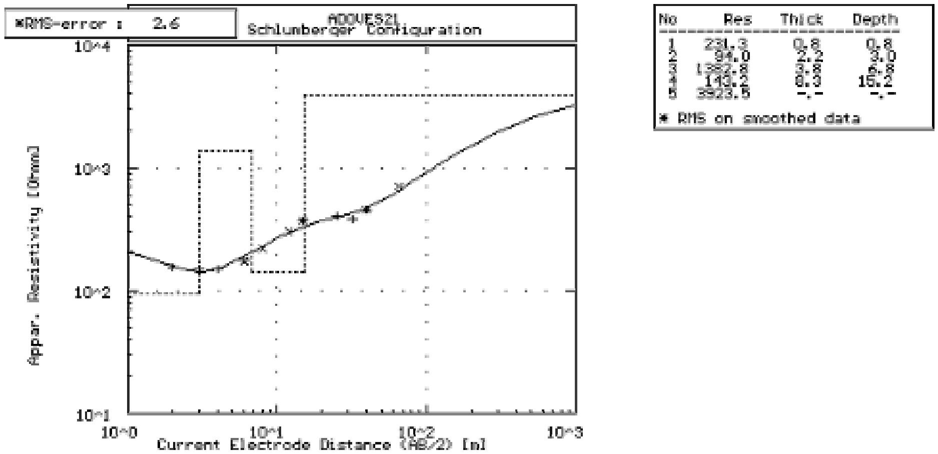


Figure 4c. Typical type curves for 5 layered earth.

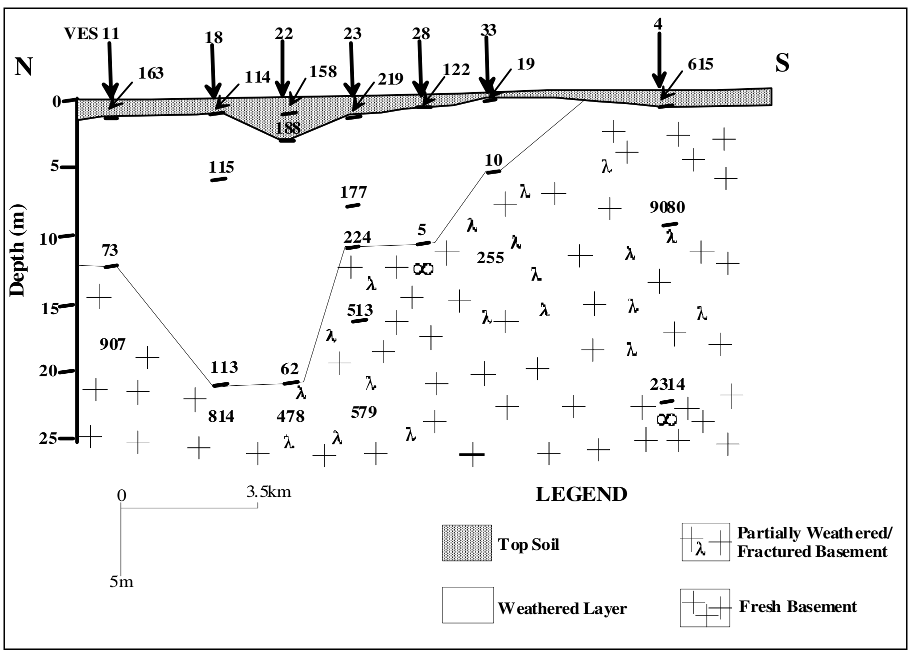


Figure 5a. 2-D Geoelectric sections along north south, (N-S) directions.

high porosity, low specific yield and low permeability aquiferous zone is the fresh basement. This classic architecture of the profile produces an H-type curve signature, which is found to be most preponderant in the area. Curve types of class 3 are typical of a succession of relatively low and high resistivity layers. The K type is found where a highly resistive lateritic layer underlies low resistivity clayey topsoil and weathered zone in turn underlies the former. Or it may result from where the basement, fractured at depth, underlies the topsoil. In the curve type in class 4, the succession of the subsurface layers starts with a highly resistive topsoil followed by a more conductive horizon and then another less conductive layer underlies the latter example is the HKH-type curve.

A summary of the results of interpretation, on which the following findings were hinged, is shown in Table 1.

Geoelectric sequences

The geoelectric sections (Figures 5 a and b) show the variations of resistivity and thickness values of layers within the depth penetrated in the study area at the indicated VES stations. The profiles were taken along the N-S and W-E directions.

Generally, the profiles revealed four subsurface layers: the top-soil, the weathered layer, partially weathered/fractured basement and the presumed fresh basement.

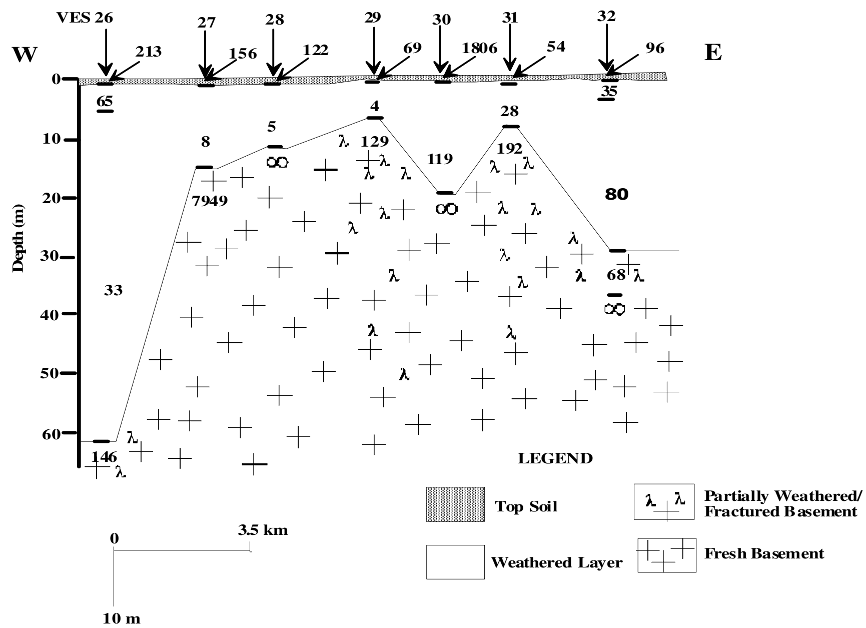


Figure 5b. 2-D Geoelectric sections along west east (W-E) directions.

The topsoil

The topsoil thickness is relatively thin along these profiles and ranges between 0.1 and 1.8 m while the resistivity values range between 19 and 1806 ohm-m, which indicated that the predominant composition of the topsoil is lateritic clay, sandy clay and clayey sand. However, at VES 30 along W-E direction the resistivity value (1806 ohm-m) suggesting that the VES station is located barely on a basement outcrop.

The weathered layer

The thickness of the weathered layer ranges from 1 to 19 m along the profiles. The resistivity values also range from 3 to 188 ohm-m, which indicated that the material composition is largely clay, sandy clay and clayey sand.

The partially weathered/fractured layer

The partially weathered/fractured basement resistivity values range between 48 and 940 ohm-m which indicate high degree of fracture and/or water saturation. It is of infinite thickness where it is the last observable layer and when it is underlain by the fresh basement the thickness is greater than 15 m.

The fresh bedrock

The fresh bedrock is the last layer and has resistivity values that range between 346 ohm-m and infinity (fresh basement). At most of the VES stations, it is infinitely resistive because of its crystalline nature.

Isopach and isoresistivity maps of the topsoil

Figure 6a is the isopach map which shows the thickness distribution of the topsoil in the study area. It could be observed that the thickness is greater than 1.4 m at the northern, southern and the eastern parts and less at other parts of the area. The isoresistivity map (Figure 6b) shows the resistivity values, ranging from 11 to 1806 ohm-m, while the most frequently occurring resistivity values are between 11 and 300 ohm-m. This revealed the highly heterogeneous variation in the composition of the topsoil from clay, sandy clay, clayey sand and laterite. The southern and northeastern parts of the area have resistivity values greater than 300 ohm-m, while the remaining parts have resistivity values less than 300 ohm-m.

The weathered layer

Figure 7(a) is the isopach map of the weathered layer depicting the variations in the thickness over the area. It varied from 1.4 to 60.4 m thickest at the western, northern and southern parts of the study area. Figure 7(b) is the isoresistivity map of the layer, considered the main aquifer unit in the area. The resistivity value of the layer lies between 3 and 313 ohm-m, while the most frequently occurring resistivity values are between 3 and 100 ohm-m, typical of clay which may be constantly saturated but poorly permeable to the interstitial formation water for abstraction.

Isopach map of the overburden

The overburden in assumed to include all materials above the presumably fresh basement. The depth to the bedrock

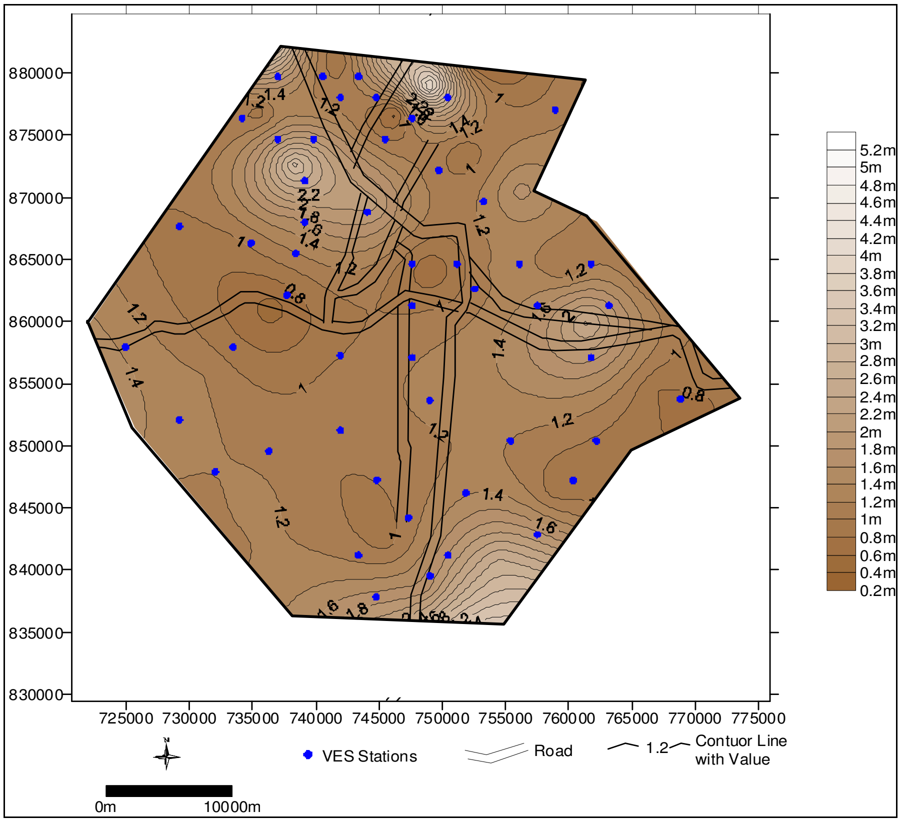


Figure 6a. Isopach map of the top soil.

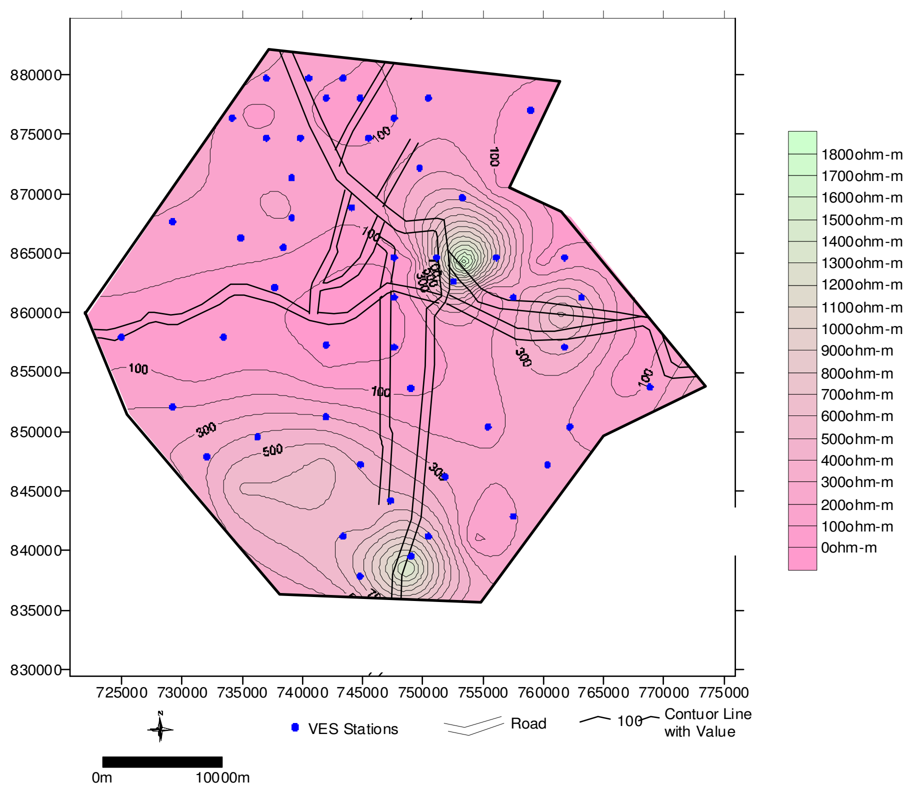


Figure 6b. Isoresistivity map of the topsoil.

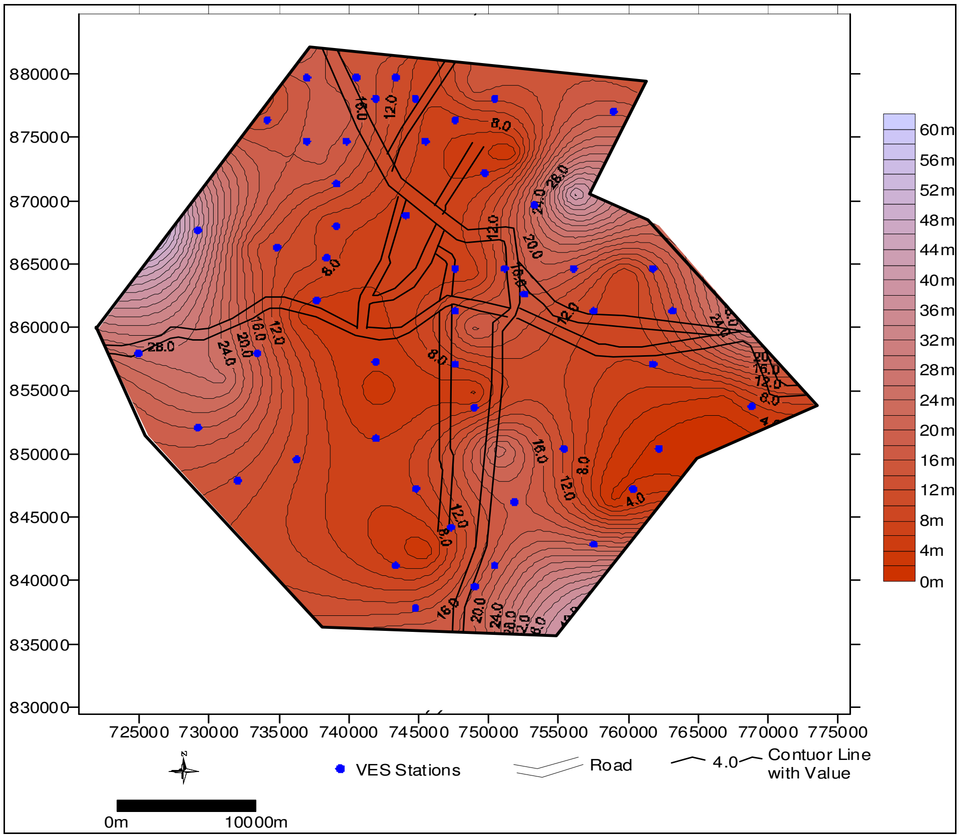


Figure 7a. Isopach map of the weathered layer.

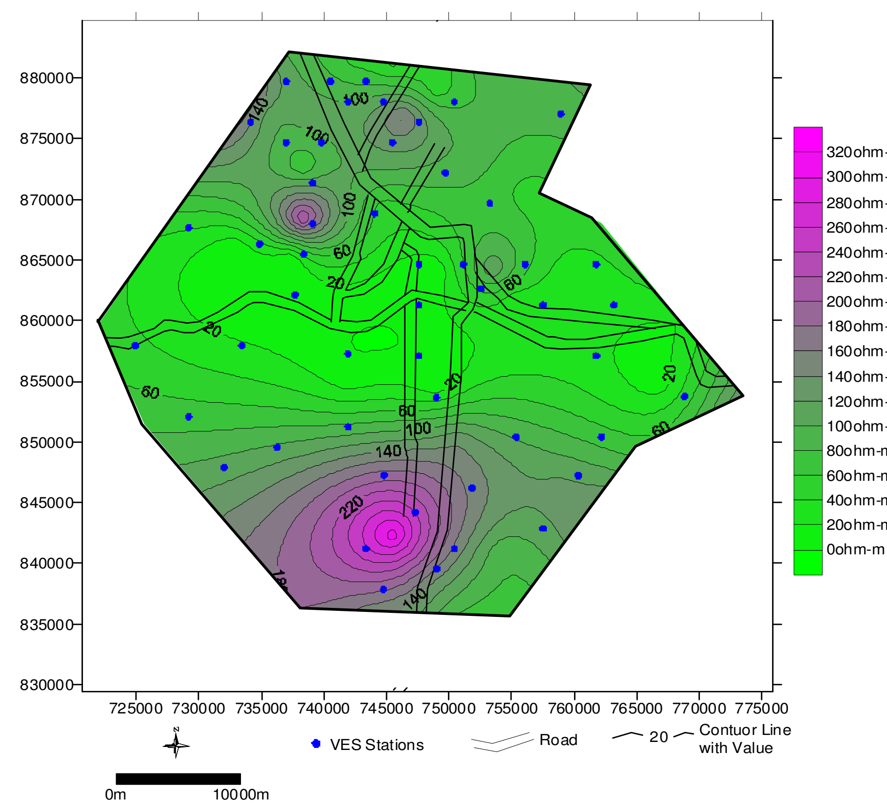


Figure 7b. Isoresistivity map of the weathered layer.

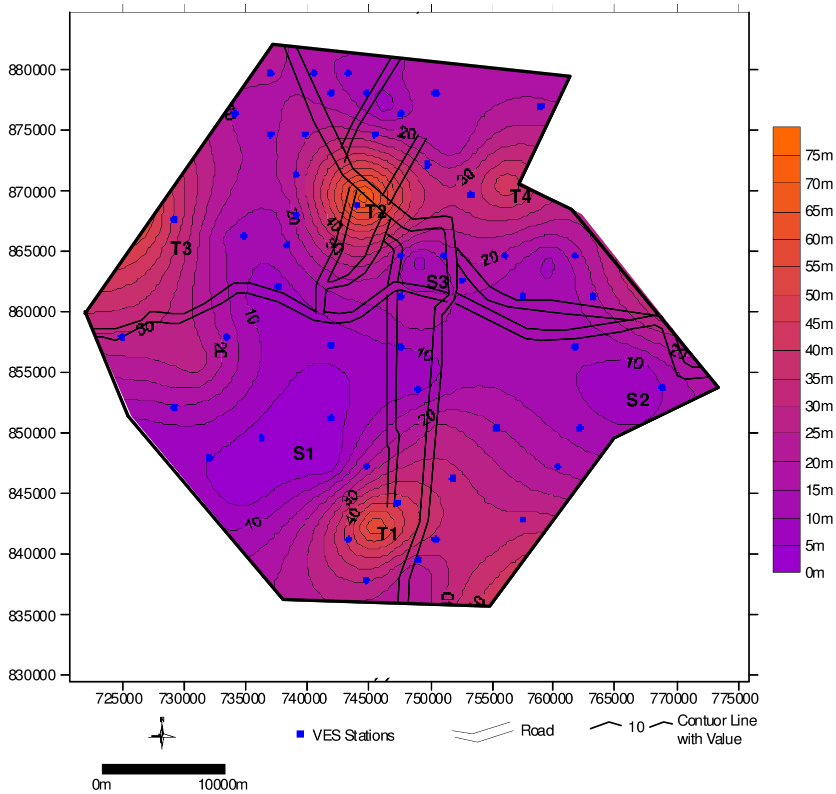


Figure 8. Isopach map of the overburden.

varies from 1.0 to 74.8 (Figure 8). The result agrees with Okhue and Olorunfemi (1991) who predicted a possible depth to bedrock ranging from 4 to 79.2 m in the basement complex area of Ile-Ife, SW Nigeria.

Generally, areas with thick overburden and low percentage of clay in which intergranular flow is dominant are known to have high groundwater potential particularly in basement complex terrain (Okhue and Olorunfemi, 1991).

Groundwater potential evaluation

Figure 9 is the groundwater potential map of the study area. The above observed thickness and nature of the weathered layer are important parameters in the groundwater potential evaluation of a basement complex terrain (Clerk, 1985; Bala and Ike, 2001). The horizon is also regarded as a significant water-bearing layer (Shemang, 1993; Bala and Ike 2001) especially if significantly thick and the resistivity parameters suggest saturated conditions. The groundwater prospects of the study area are zoned into high, medium and low potentials. In this study, zones where thickness of the aquifer is greater than 25 m and of low clay content (average resistivity values between 100 and 300 ohm-m) are considered zones of high groundwater potentials.

The north central and southern parts of the study area constitute the high potential zones. The extreme northern and southeastern patches (Figure 9), which have aquifer thickness ranging from 10 – 25 m and are of moderate clay contents (average resistivity values lies between 80 - 100 ohm-m), are classified under medium groundwater potential. The net southwestern and the central portions of the study area fall within the low groundwater potential rating where the thickness of aquifer is below 10 m and with average resistivity value less than 80 ohm-m (Oladapo and Akintorinwa, 2007). This constituted a sizeable chunk of the segmentation.

From the isoresistivity maps of the topsoil and weathered layer, Figures 6(b) and 7(b), it was observed that the clay content of the overburden was high, which informed the low groundwater potential rating of the study area owing to low permeability usually associated with clay.

It was observed that about 75% of the area falls within the low/medium groundwater potential rating while only about 25% constitutes the high potential rating. This suggests a generally low groundwater prospect of the study area.

Aquifer protective capacity evaluation

The characteristic longitudinal unit conductance map (Figure 10), prepared from equation 1 and shown in Table 1 for all the VES locations, was used for the overburden protective capacity rating of the study area. The total longitudinal unit conductance values can be utilized in evaluating overburden protective capacity in an area. This is because the earth medium acts as a natural filter to percolating fluid. Its ability to retard and filter percolating gro-

Table 1. Summary of interpreted results for the study area.

VES stations	Layer resistivity (Ohm-m)					Layer thickness (m)				Curve type	Longitudinal conductance (S) (mhos)
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4		
1	179	172	93	2419		1.2	3.1	22.6	-	QH	0.267737918
2	542	313	8315	587	ω	0.9	2.4	20.2	37.8	HKH	0.076152821
3	637	1799	ω	-	-	1.0	12.3	-	-	A	0.00840699
4	615	9080	2314	ω	-	1.3	9.5	12.6	-	KH	0.008505192
5	328	25905	5107	-	-	1.4	4.4	-	-	K	0.004438144
6	1175	1782	140	1250	-	1.0	1.7	18.3	-	KH	0.131958165
7	91	52	83	903	-	0.9	1.7	29.2	-	HA	0.394389645
8	285	252	126	1260	-	1.7	0.5	20.1	-	QH	0.167472848
9	145	60	1704		-	0.8	14.0	-	-	H	0.247183908
10	80	75	36	3066	-	1.5	1.1	8.3	-	QH	0.263972221
11	163	73	907	-	-	1.2	12.4	-	-	H	0.177224976
12	324	48	387	-	-	1.8	19.0	-	-	H	0.401388888
13	202	164	48	ω	-	1.5	2.7	15.3	-	QH	0.342639157
14	336	119	392	46	236	1.1	3.0	3.4	13.7	HH	0.334683449
15	203	100	90	346	-	0.1	0.2	15.2		QH	0.171381498
16	59	144	113	84	-	0.7	0.7	11.4	-	KQ	0.117610472
17	246	481	97	647	-	1.1	4.0	28.6	-	KH	0.307632913
18	114	115	113	841	-	1.3	5.1	15.1	-	KH	0.189379652
19	33	166	430	-	-	0.5	7.0	-	-	A	0.057320189
20	64	133	81	4114	-	0.9	2.9	13.3	-	KH	0.200006454
21	231	94	1383	143	3924	0.8	2.2	3.8	8.3	HKH	0.087757066
22	158	188	62	478	-	1.3	1.8	18.0	-	KH	0.308224896
23	219	177	274	513	579	1.6	6.6	2.6	5.7	HAK	0.065194233
24	112	163	53	45	739	1.0	1.1	6.7	6.6	KQH	0.608758798
25	92	45	22	87	4	1.7	4.1	13.1	25.7	QHK	0.000446216
26	213	65	33	146	-	1.0	4.0	56.7	-	QH	0.775324206
27	156	8	7947	-	-	0.9	14.6	-	-	H	0.830769231
28	122	5	ω	-	-	1.1	10.5	-	-	H	0.109016393
29	69	4	129	-	-	0.6	6.9	-	-	H	0.73369565
30	1806	119	ω	-	-	1.2	19.3	-	-	H	0.162849325
31	54	28	192	-	-	1.0	7.5	-	-	H	0.286375661
32	96	35	80	68	ω	0.8	3.0	24.9	4.1	HKH	0. 524415266
33	19	10	255	-	-	0.5	5.2	-	-	H	0.546315789
34	25	15	ω	-	-	1.1	18.8	-	-	H	0.29733333
35	131	24	ω	-	-	1.3	12.7	-	-	H	0.53909033
36	535	977	29	575	-	0.7	1.8	10.6	-	KH	0.368568026
37	29	26	16	274	-	1.1	3.7	28.6	-	QH	0.967738726
38	46	86	42	1622	81	1.7	9.3	6.7	4.7	KHK	0.307517522
39	24	18	23	79	-	1.2	3.1	23.4	-	HA	0.239613526
40	11	9	ω	-	-	1.1	3.1	-	-	H	0.4444444
41	41	3	ω	-	-	1.3	3.4	-	-	H	0.16504065
42	25	10	ω	-	-	0.8	3.9	-	-	H	0.422
43	707	222	646	91	ω	0.9	1.8	3.9	11.3	HKH	0.139594067
44	203	88	940	68	1009	0.9	1.9	2.3	12.3	HKH	0.210253567
45	239	127	431	98	932	0.9	1.4	5.5	14.3	HKH	0.1734687
46	450	211	1473	-	-	1.0	23.8	-	-	H	0.1150184
47	635	337	96	ω	-	1.4	1.8	57.5	-	QH	0.60807090
48	426	246	64	ω	-	1.1	2.6	35.8	-	QH	0.57252625
49	82	98	28	ω	-	1.2	2.9	9.3	-	KH	0.37636884
50	171	143	294	259	-	1.4	4.3	21.2	-	HK	0.110365907
51	123	135	231	-	-	0.9	12.1	-	-	H	0.096946702

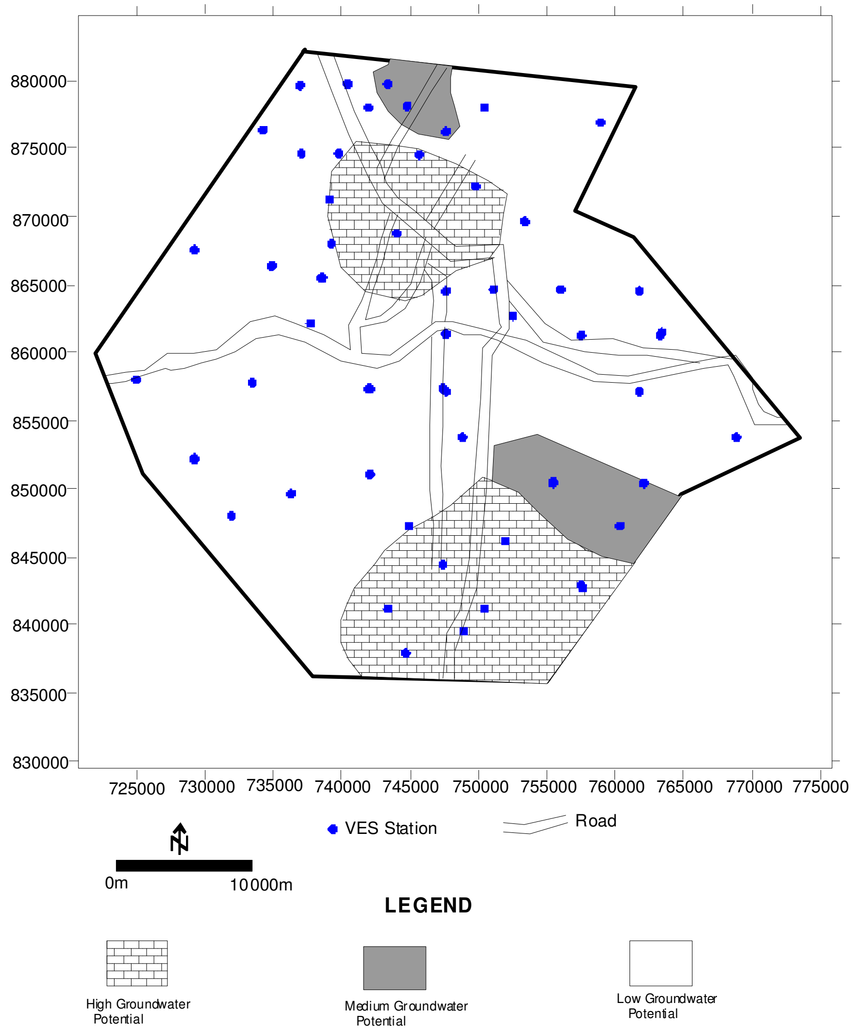


Figure 9. Groundwater potential map of the study area.

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

und surface polluting fluid is a measure of its protective capacity (Olorunfemi et al., 1999). The highly impervious clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underlying aquifer.

The longitudinal unit conductance (S) values obtained from the study area, ranging from 0.004 to 2.11 mhos, were used to generate the longitudinal unit conductance map (Figure 10).

Clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underlying aquifer.

According to Oladapo and Akintorinwa (2007), Table 2, the protective capacity of the overburden could be zoned into good, moderate, and weak protective capacity. Zones where the conductance is greater than 0.7 mhos are considered zones of good protective capacity. The portion having conductance values ranging from 0.2 to 0.69 mhos was classified as zone of moderate protective capacity; that ranging from 0.1 to 0.1 9 mhos was classified as of weak protective capacity and the zone where the conductance value is less than 0.1 mhos was considered poor.

Generally, the study has revealed that the overburden materials in the area around the north central, western and eastern portions have good to moderate protective capacity. The extreme northern, southern and south-eastern.

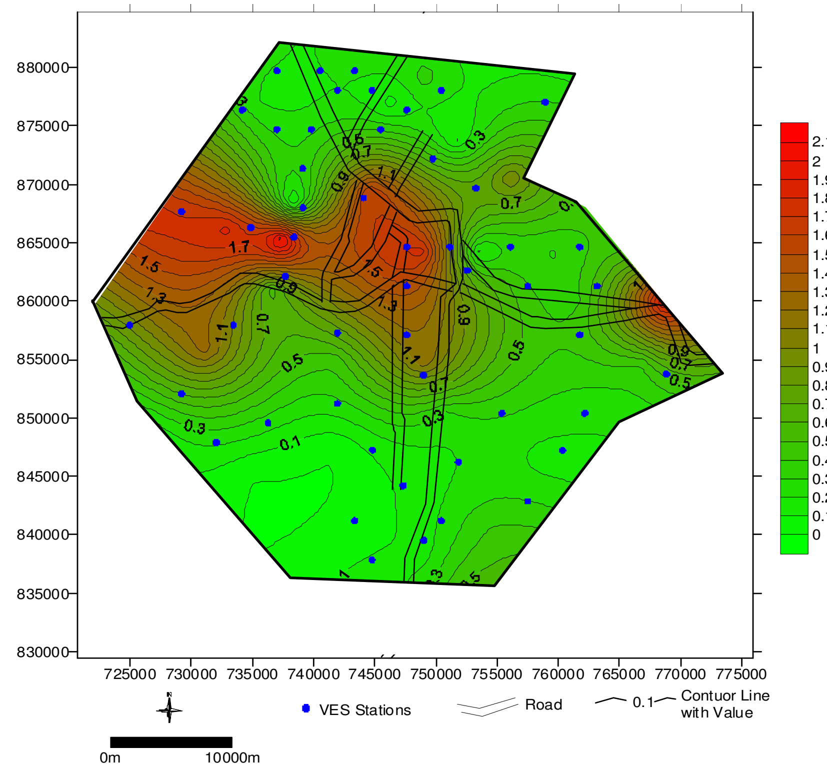


Figure 10. Longitudinal unit conductance map.

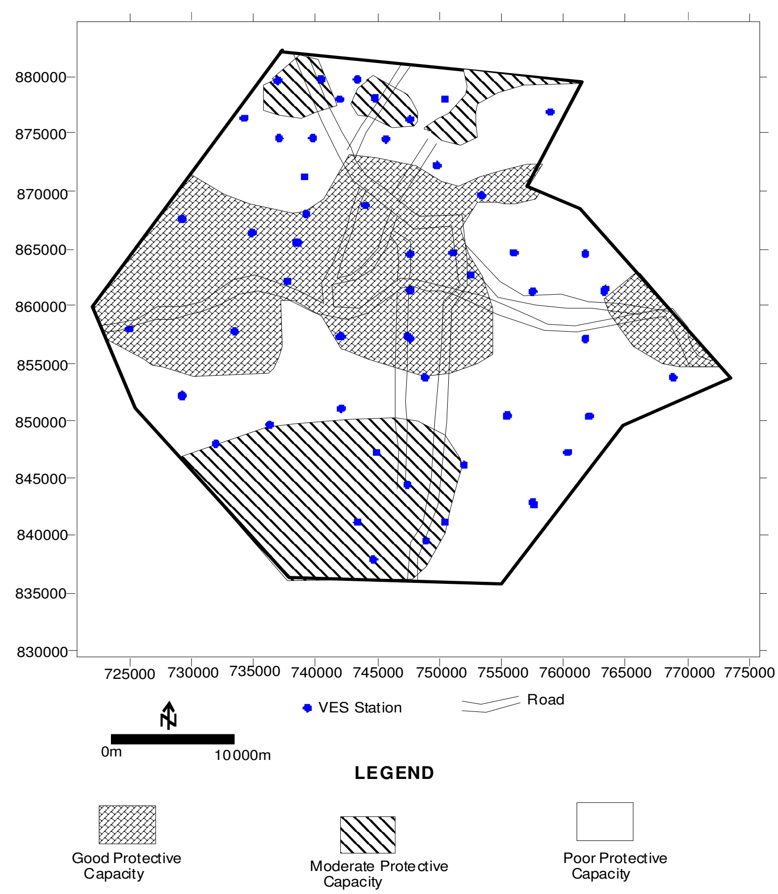


Figure 11. Overburden protective capacity map of the study area.

portions have weak protective capacity materials. The overburden protective capacity map (Figure 11) of the study area shows that about 60% of the area falls within the good/moderate overburden protective capacity, while about 40% constitutes the weak/poor protective capacity rating. This suggests that the areas are underlain by materials of good/moderate overburden protective capacity.

Conclusion

In this study, the groundwater potential and protective capacity evaluation of the rock units around Ado-Ekiti, southwestern Nigeria was undertaken using 51 Schlumberger vertical electrical soundings (VES). The curve type varied from simple three-layer A, K and H-types to the complex HQ, KH, HA, KQ, HK, HKH, HAA, KQH, KHK and QHK-types. The computer assisted sounding interpretation revealed subsurface sequence composing topsoil with limited hydrologic significance, weathered layer, partially weathered/fractured basement and the fresh basement. The high variability of the thickness of the top soil appeared responsible for the observed overlapping resistivities across the study area. The weathered layer constituted the sole aquifer unit in the area; the yield being dependent on degree of the clay content. The higher the clay content, the lower the groundwater yield.

The characteristic geoelectrical parameters of the delineated aquifer at each sounding station were used to produce the groundwater potential map of the area. About 75% of the study area falls within the low/medium rated groundwater potential zone while the remaining 25-% constituted the high groundwater potential zone. Hence, the groundwater potential rating of the area is considered generally low.

The study also revealed that most parts of the area are underlain by materials of moderate to good protective capacity. The western, central and southwestern portions of the area are underlain by materials of moderate to good protective capacity. Most of these areas coincide with zones of appreciable overburden thickness with clayey columns thick enough to protect the aquifer in the area from the surface polluting fluid.

The groundwater in the area of weak protective capacity is therefore vulnerable to pollution if, for example, there is leakage of buried underground storage tanks; a source of serious environmental hazard. Vulnerable zones include the east central, southern, southwestern and northern segments.

The results of this study have provided reliable information for an elaborate groundwater abstraction and environmental factors necessary for planning and development of residential and industrial estates by the urban planning authorities. For effective groundwater development programmes in the study area, it recommended that predrilling geophysical investigations be carefully conducted for economic and environmental purposes.

Future groundwater development in the study area by government should be concentrated within the high/medium groundwater potential zones with good/moderate aquifer protective capacity. Also, a review of licenses for location of underground petroleum storage tanks in the town is imperative. Areas for locating such facilities should be confined to zones of moderate/good ground water protective capacity.

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