International Journal of Water Resources and Environmental Engineering Vol. 5(1), pp. 12-28, January 2013
Available online at http://www.academicjournals.org/IJWREE
DOI: 10.5897/IJWREE12.031
ISSN 1991-637X

Full Length Research Paper

Geoelectric evaluation of groundwater prospect within Zion Estate, Akure, Southwest, Nigeria

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Accepted 8 June, 2012

Electrical Resistivity method involving Vertical Electrical Sounding (VES) have been used to evaluate the groundwater potential and aquifer protective capacity of the overburden units within Zion Estate area. Sixty-eight Vertical Electrical Soundings were carried out using Schlumberger configuration with AB/2 varying from 1 to 65 m. The generated geoelectric section from the interpretation of the sounding curves revealed four layers - the top soil, the weathered layer, the partially weathered/fractured basement and the fresh basement. The weathered layers constitute the major aquifer unit in the area but are generally thin. The groundwater potential map revealed that about 85% of the study area falls within the low groundwater potential rating while about 10% constitutes the medium groundwater potential rating and the remaining 5% constitutes high groundwater potential rating. Hence the groundwater potential of the area is generally rated to be low. The overburden protective capacity map of the study area shows that about 75% of the area falls within the poor overburden protective capacity, while the remaining 25% constitutes the moderate/weak protective capacity rating. This suggests that the area is characterized by low longitudinal conductance which informed weak protective capacity rating of the area. Therefore the study area can be vulnerable to pollution from contaminant sources such as industrial waste, septic tanks, underground petroleum storage tanks and landfills when located close to the study area.

Key words: Groundwater, geoelectric, sounding, Schlumberger.

INTRODUCTION

In many developed and developing countries there is not only a heavy reliance on ground water as a primary source for the supply of drinking water but also as a source of water for both agricultural and industrial uses. The reliance on groundwater is such that it is necessary to ensure that there are significant quantities of water. The continuous increase in population growth and of large industrial and agricultural complexes has led to large demand for water within Akure and its environs. There is inadequate supply of water at Zion estate as water from hand-dug wells, the only existing borehole and a stream can no longer serve the general needs as a result of their seasonal variations and hence, there is need for proper geophysical investigation of the area. The present study aims to evaluate the groundwater potential of the study area for proper groundwater development. Groundwater resources account for about 98% of the world's fresh water needs and is fairly evenly distributed throughout the world. Groundwater provides a reasonable constant supply which is not completely susceptible to drying up under natural conditions unlike surface water (Korzun and Komitel, 1978).

In the basement terrain, groundwater development may be primarily restricted to the aquifer in the weathered overburden or complemented by fractured crystalline rocks which are mainly of Precambrian age (Olayinka and Olorunfemi, 1992; Wright, 1992). The concealed basement rocks may contain faulted areas, incipient joints and fractured systems derived from earlier tectonic events. The detection of and delineation of these hydrogeologic structures may facilitate the location of groundwater prospect zones in typical basement settings (Omosuyi et al., 2003). Fractured crystalline bedrock remains good sources for drinkable water but siting of highly productive wells in these rock units remains a challenging and expensive task because fractured

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developments on the regional scale are both heterogeneous and anisotropic. However, fractured viable aquifers wholly within the fractured bedrock are of rare occurrence because of the typically low storativity of fracture systems (Clark, 1985).

This study presents the use of an electrical resistivity method as a geophysical tool for the delineation of basement aquifers which are potential reservoirs for groundwater. Electrical resistivity survey is widely employed in the delineation of basement regolith and location of fissured media and associated zones of deep weathering in crystalline terrains (Benson and Jones, 1988; Hazell et al., 1988; Olayinka, 1990; Olayinka et al., 2004). Drilling programmes for groundwater development in areas of basement terrain are generally preceded by detailed geophysical investigations.

Description of the study area

Figure 1 shows the location of the study area along Ilesha-Akure expressway, Akure, southwestern, Nigeria. It lies within latitude 7° 18' 17" N and 7° 18' 59" N and longitude 5° 08' 28'' E and 5° 08' 54'' E. The study area is about 32 km^2. The terrain is gently undulating with topographic elevation ranging between 330 and 376 m above sea level. The area is traversed by Ala stream which flows approximately in the east-west direction.

The area is underlain by the Precambrian basement complex of southwestern Nigeria (Rahaman, 1989). The lithologic units identified in the area include migmatite-gneiss and charnokites. The charnokites are the predominant rock units in the study area, covering more than half of the area and underlies the southern and north-eastern parts of the area. The other parts of the area are underlain by the magmatite-gneiss (Figure 2). The study area is situated within the tropical rain forest region, with a climate characterized by wet and dry seasons. The wet season usually occurs from March to October and is dominated by heavy rainfall. The dry season occurs from November to March when the area is under the influence of north-easterly winds. The annual rainfall ranges between 1000 and 1500 mm. The annual temperature is from 18 to 34°C with relatively high humidity during the wet season and low humidity during the dry season (Iloeje, 1981).

MATERIALS AND METHODS

The Vertical Electrical Sounding (VES) using Schlumberger configuration was adopted for the study. A total of 68 stations were occupied across the area (Figure 1). The electrode spacing (AB/2) was varied from 1 to 65 m. The R50 DC resistivity meter was used for the data acquisition and the position of the occupied sounding stations in Universal Traverse Mercator (UTM) was recorded using the GARMIN 12 channel personnel navigation Geographic Positioning System (GPS) unit. The field curves were generated by plotting of the apparent resistivity values against the electrode spacing (AB/2). The curves were interpreted using the partial curve matching technique. The geoelectric parameters obtained from manual interpretation of VES data were refined using the software algorithm RESIST version 1.0 (Van der Velpen, 1988). Second order geoelectric parameters called Dar Zarrouk parameters were determined from the iterated geoelectric parameters (Mallet, 1947). The second order parameter of interest in this study is the longitudinal conductance (S_i). This second order parameters are derived using equations developed by Zohdy et al. (1974) such as:

For n layers, the total longitudinal unit conductance is given by:

$$S = \sum_{i=1}^{n} \frac{h_i}{\rho_i} = \frac{h_1}{\rho_1} + \frac{h_2}{\rho_2} + \frac{h_3}{\rho_3} + ...\frac{h_n}{\rho_n} \qquad (1)$$

where: h_i is the layer thickness, ρ_i is layer resistivity and the number of layers from the surface to the top of aquifer varies from i = 1 to n.

RESULTS AND DISCUSSION

The results of this work are presented as sounding curves, geoelectric sections, maps, charts and tables. Curve types identified ranges A, H, K, KH, QH, and HK (Table 1). The predominant curve type is the A curve type having percentage frequency of 41.2%, H curve type has 40% and KH curve type has 8.8% of the total occurrence while HKH, QH, and K have 7.4, 1.5 and 1.5% respectively (Figure 3). Typical curve types are as shown in Figure 4.

Geoelectric sequences

Figures 5a to 5d show four geoelectric sections generated in the N-S, W-E, SW-NE and NW-SE directions respectively. The geoelectric sections show the variations of resistivity and thickness values of layers within the depth penetrated in the study area at the indicated VES stations. The geoelectric sections revealed four subsurface geologic/geoelectric layers consisting of topsoil, weathered layer, partly weathered/fractured basement and fresh basement. The topsoil is relatively thin and the thickness ranges between 0.3 and 7.6 m while the resistivity values range from 27 to 1829 Ωm. This indicates that the predominant composition of the topsoil is clay, sandy clay, clayey sand and bedrock which were outcropping in some places and leads to high values of topsoil resistivity in some places. The weathered layer thickness ranges from 0.6 to 12.4 m and the resistivity values range from 37 to 848 Ωm, which indicate that the weathered layer material composition is of clay, sandy clay, clayey sand and laterite. The partially weathered/fractured basement resistivity values range between 51 and 78 Ωm which either indicates high degree of fracturing or water saturation. It is of infinite thickness where it is the last observable layer and where it is underlain by fresh basement, the thickness ranges from 6.6 to 32.9 m. The fresh basement is the last

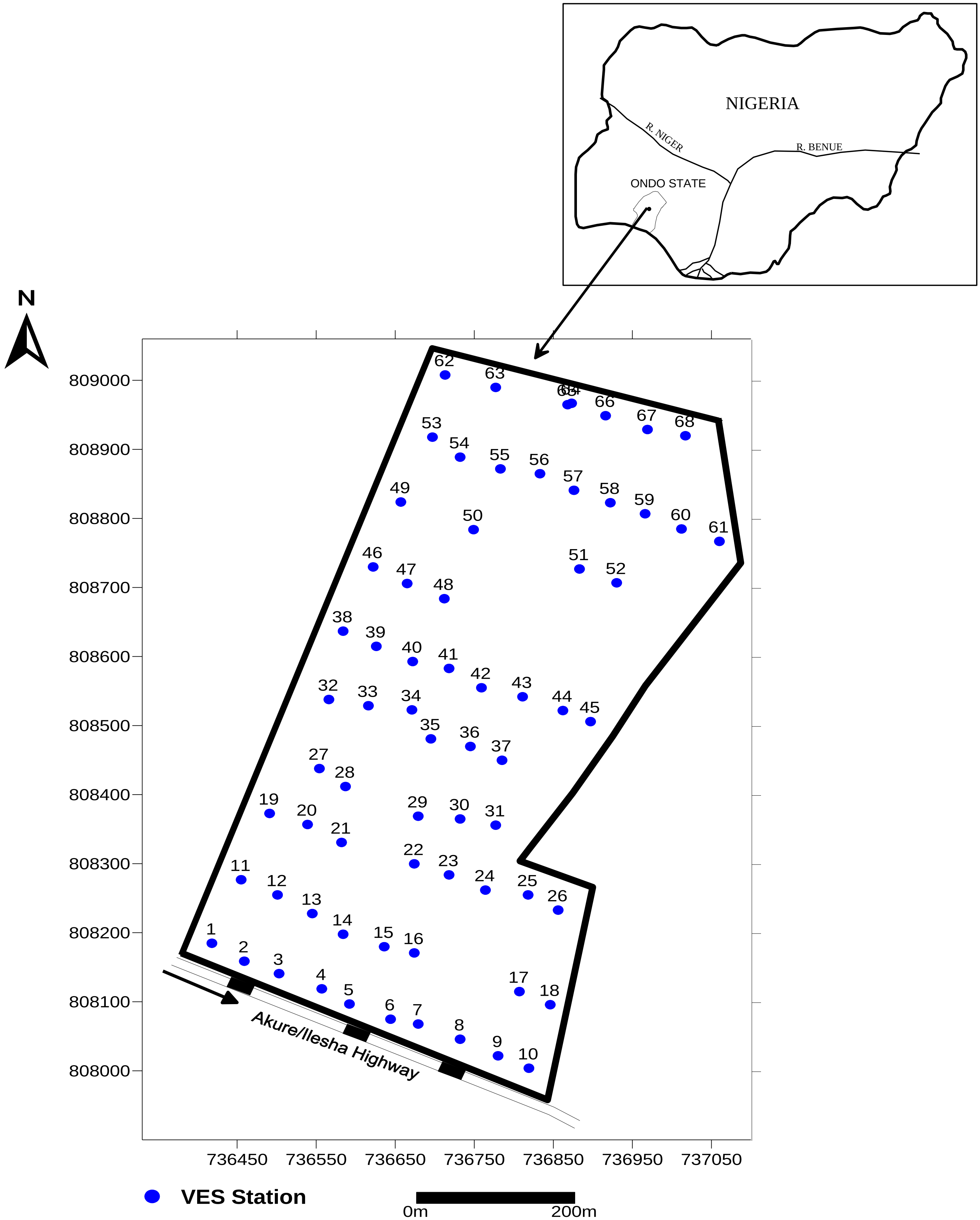

Figure 1. Geophysical data acquisition map of the study area.

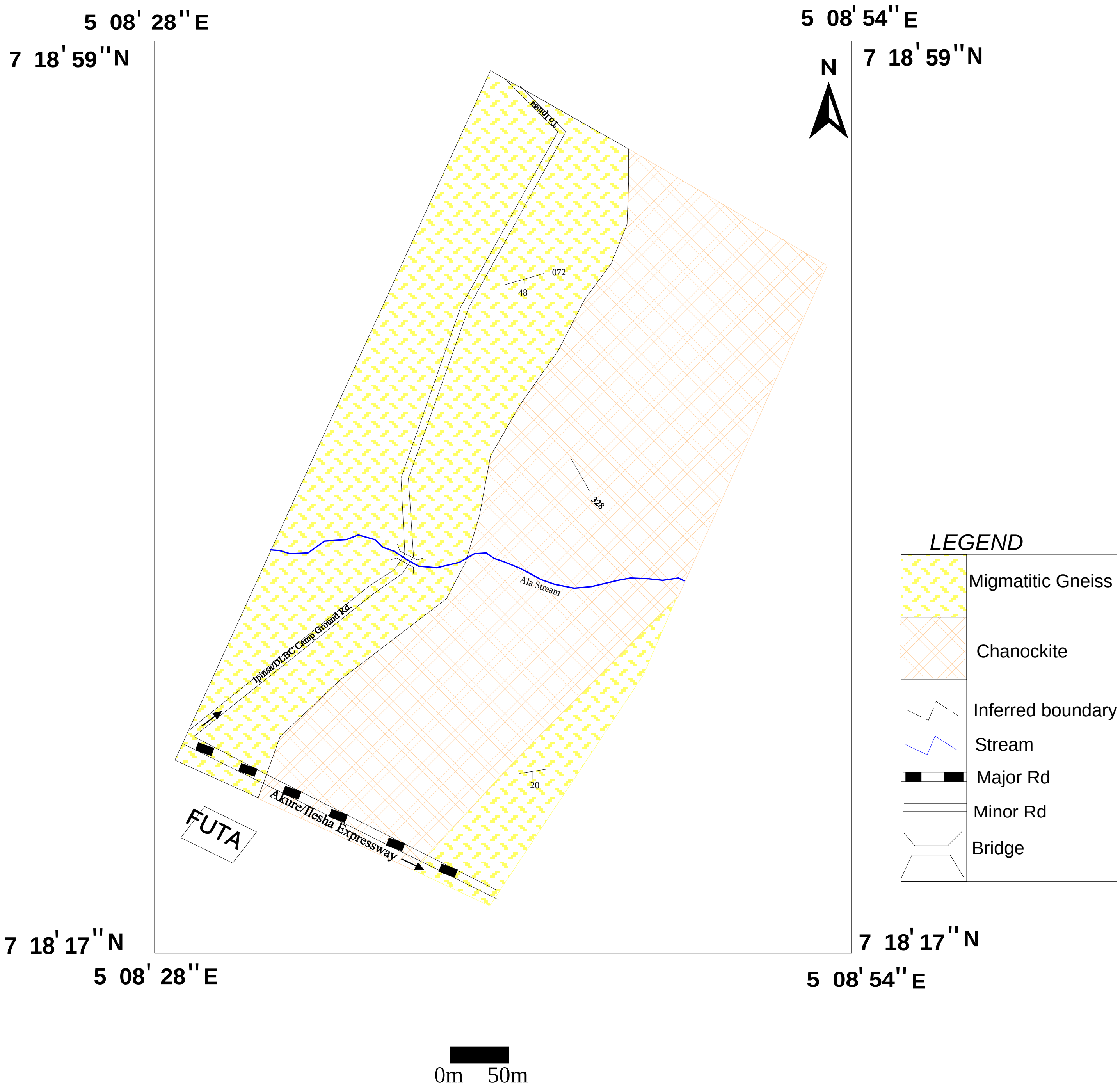

Figure 2. Geological map of the study area.

observable layer with resistivity values ranging between 950 Ωm and infinity. At most VES station, it is infinitely resistive because of its crystalline nature.

Isopach and isoresistivity maps of the topsoil

The thickness and the resistivity maps of the topsoil are presented in Figures 6 and 7 respectively. The isopach map of the topsoil reveals that the thickness distribution of the topsoil within the study area ranges from 0.3 to 5.1 m but generally less than 3.5 m. This indicates that the topsoils are generally thin with no hydrogeological significance. The isoresistivity map of the topsoil is shown in Figure 7. It shows that the resistivity values range from 17 to 758 Ωm (mostly < 500 Ωm). This reveals the high

Table 1. Summary of VES interpretation results.

VES	Resistivity (Ωm)					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	202	91	2687			1.0	8.3			H	0.10
2	539	145	1049	10	∞	0.5	0.8	2.0	0.9	HKH	0.10
3	550	234	992			3.1	38.6			H	0.17
4	658	483	27	∞		4.3	0.9	5.3		QH	0.20
5	236	65	505	62	∞	0.5	0.8	2.1	3.2	HKH	0.07
6	517	211	1130			0.8	7.2			H	0.04
7	231	69	∞			0.8	1.6			H	0.03
8	151	1291	2313			1.8	0.7			A	0.01
9	225	64	3048			0.7	1.7			H	0.03
10	93	362	∞			3.5	6.3			A	0.06
11	162	72	821			0.9	3.2			H	0.05
12	290	412	101	950		0.9	1.7	16.8		KH	0.17
13	347	219	414			1.3	19.8			H	0..09
14	520	91	208			1.0	1.6			H	0.02
15	256	69	4452			2.0	10.6			H	0.16
16	303	36	5434			3.4	4.2			H	0.13
17	165	578	1470			1.8	5.8			A	0.02
18	239	78	1463			0.5	2.3			H	0.03
19	145	508	1800			2.1	6.3			A	0.03
20	207	1403	2134			2.1	1.5			A	0.01
21	588	277	5685			0.6	1.8			H	0.01
22	242	1718	4209			1.6	0.5			A	0.01
23	346	471	∞			0.6	8.2			A	0.02
24	380	475	299	1850		1.6	3.6	9.0		KH	0.04
25	109	36	2559			0.9	6.5			H	0.19
26	284	58	749			2.0	5.1			H	0.09
27	17	1250	6984			0.3	0.1			A	0.02
28	350	128	4751			0.8	1.2			H	0.01
29	340	221	1855			0.8	1.4			H	0.01
30	286	411	1270			1.6	1.0			A	0.01
31	758	201	3065	360	∞	0.6	1.1	5.7	13.3	HKH	0.05
32	88	274	35	∞		0.3	2.3	5.4		KH	0.17
33	226	52	190	36	594	0.5	0.8	2.5	5.5	HKH	0.18
34	41	105	244			2.0	1.3			A	0.06
35	145	508	840			1.9	1.5			A	0.02
36	174	845	439			0.8	11.8			K	0.02
37	188	1829	165	625		0.5	1.1	3.1		KH	0.02
38	123	1711	∞			1.8	1.2			A	0.02
39	150	96	3513			2.6	2.1			H	0.04
40	300	163	7133			0.7	3.8			H	0.03
41	269	47	1753			0.9	1.4			H	0.04
42	199	390	4042			3.8	12.4			A	0.05
43	121	299	78	637		0.7	6.9	13.6		KH	0.20
44	208	848	78	2762		0.9	2.9	32.9		KH	0.43
45	298	37	543	51	3291	0.4	0.4	1.3	6.6	HKH	0.14
46	99	457	∞			5.1	2.5			A	0.06
47	133	292	2305			1.8	2.4			A	0.02
48	127	254	6732			4.2	4.6			A	0.05
49	99	597	∞			2.9	1.9			A	0.03
50	251	505	∞			1.7	3.0			A	0.01

Table 1. Contd.

51	219	663	∞	1.7	3.7	A	0.01
52	36	360	∞	1.9	0.4	A	0.05
53	282	39	∞	0.5	1.2	H	0.03
54	27	307	∞	0.3	7.3	A	0.04
55	165	184	2900	2.5	3.0	A	0.03
56	103	124	2153	1.7	3.2	A	0.04
57	440	132	3400	0.9	3.7	H	0.03
58	133	588	∞	1.1	6.0	A	0.02
59	215	437	5683	2.9	2.0	A	0.02
60	223	1102	8504	1.0	6.9	A	0.01
61	611	2406	∞	0.8	11.5	A	0.01
62	373	69	1680	0.8	2.9	H	0.04
63	133	293	1335	2.8	2.8	A	0.03
64	309	53	1478	0.7	3.5	H	0.07
65	210	73	7148	1.6	5.5	H	0.08
66	730	213	1165	0.6	4.9	H	0.02
67	292	64	1777	0.6	2.2	H	0.04
68	71	23	5693	1.3	1.7	H	0.09

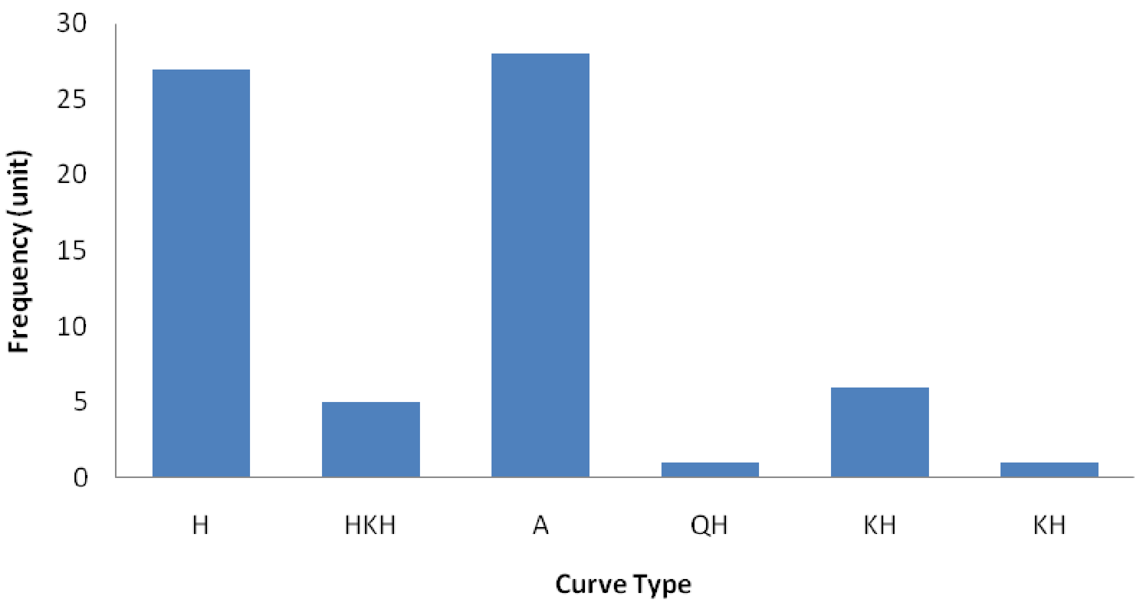

Figure 3. Frequency distribution of the observed curve types.

heterogeneous variation in the composition of the topsoil from clay, sandy clay, clayey sand and laterite. This lithology has limited hydrogeological significance due to its small thickness.

Isopach and isoresistivity maps of the weathered layer

Figure 8 isopach map of the weathered layer within the study area. It shows that the thickness of the weathered layer over the study area varies from 0.4 to 29 m but generally less than 10 m, indicating thin weathered layer across the area. The highest thickness (localized) occurs at the portion marked X_1 (Figure 8). The resistivity values in the study area vary from 100 to 600 Ωm (Figure 9). This indicates low clay content and shows a fairly saturated formation which is able to accumulate water and is also able to transmit it. The weathered layer constitutes the main aquifer unit in the area. However,

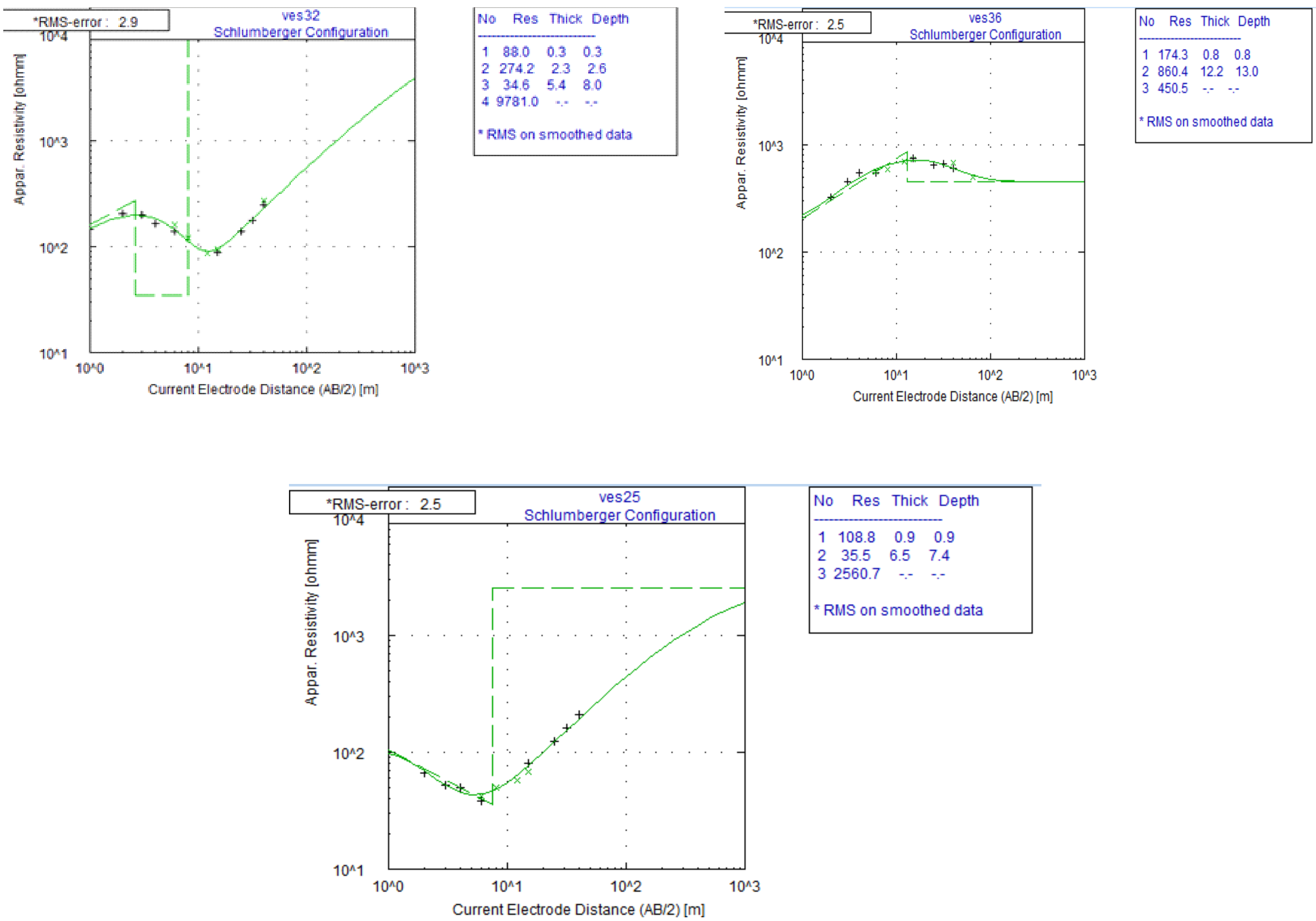

Figure 4. Typical VES curves from the study area.

because of its thinness it has little hydrogeological significance.

Isopach map of the overburden

Figure 10 shows the depth to the top of the fresh bedrock beneath the sounding stations. The overburden is assumed to include the topsoil and the weathered layer. The depth to the bedrock varies from 4 to 35 m. From the area marked X_2, it can be said to have a relatively thick overburden (>20 m).

Groundwater evaluation

Figure 11 shows the groundwater potential map of the study area. The evaluation of the groundwater potential of the study area is based on the thickness of the overburden and the resistivity of the weathered layer, since the nature of the weathered layer and its thickness are important parameters in the groundwater potential evaluation of a basement complex terrain (Clark, 1985; Bala and Ike, 2001). The horizon is also regarded as a significant water bearing layer especially if significantly thick and the resistivity parameters suggest saturated conditions (Shemang, 1993; Bala and Ike, 2001). The groundwater potential of the study area was zoned into high, medium and low potentials.

In this study, zones where the thickness of the overburden (which constitutes the major aquifer unit) is greater than 25 m and of low clay content (average resistivity values between 200 and 300 Ωm) are considered zones of high groundwater potentials. Areas where the aquifer thickness ranges from 10 to 25 m with less clay contents are considered to have medium groundwater potential and the areas where the aquifer thickness is less than 10 m are considered to have low groundwater potential.

From Figure 11, about 85% of the study area falls within the low groundwater potential rating, while about 10% of the study area constitutes the medium groundwater

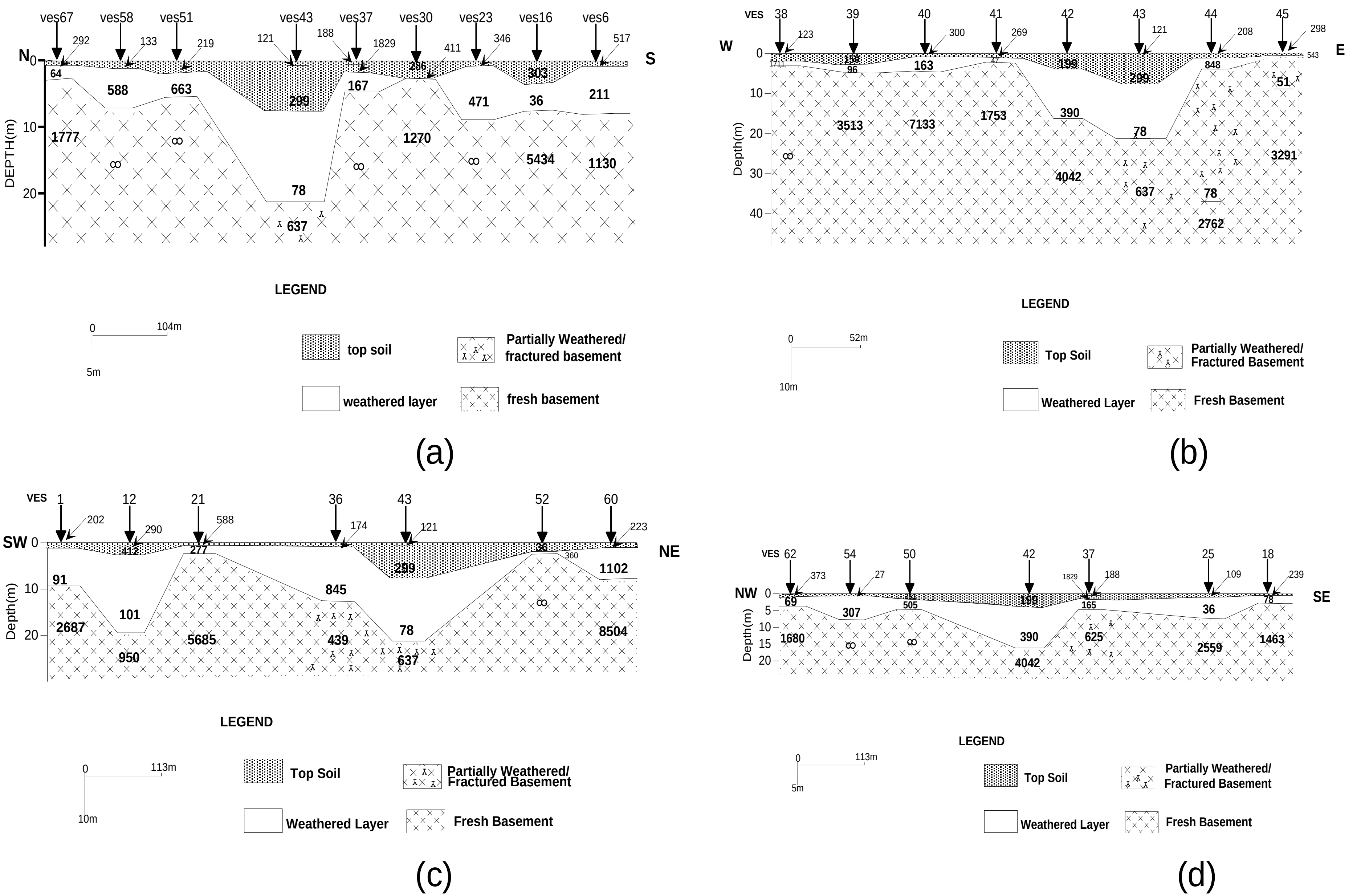

Figure 5. Geoelectric sections along (a) North South (N-S) (b) West-East (W-E) (c) Southwest-Northeast (SW-NE) and (d) northwest southeast (NW-SE) direction.

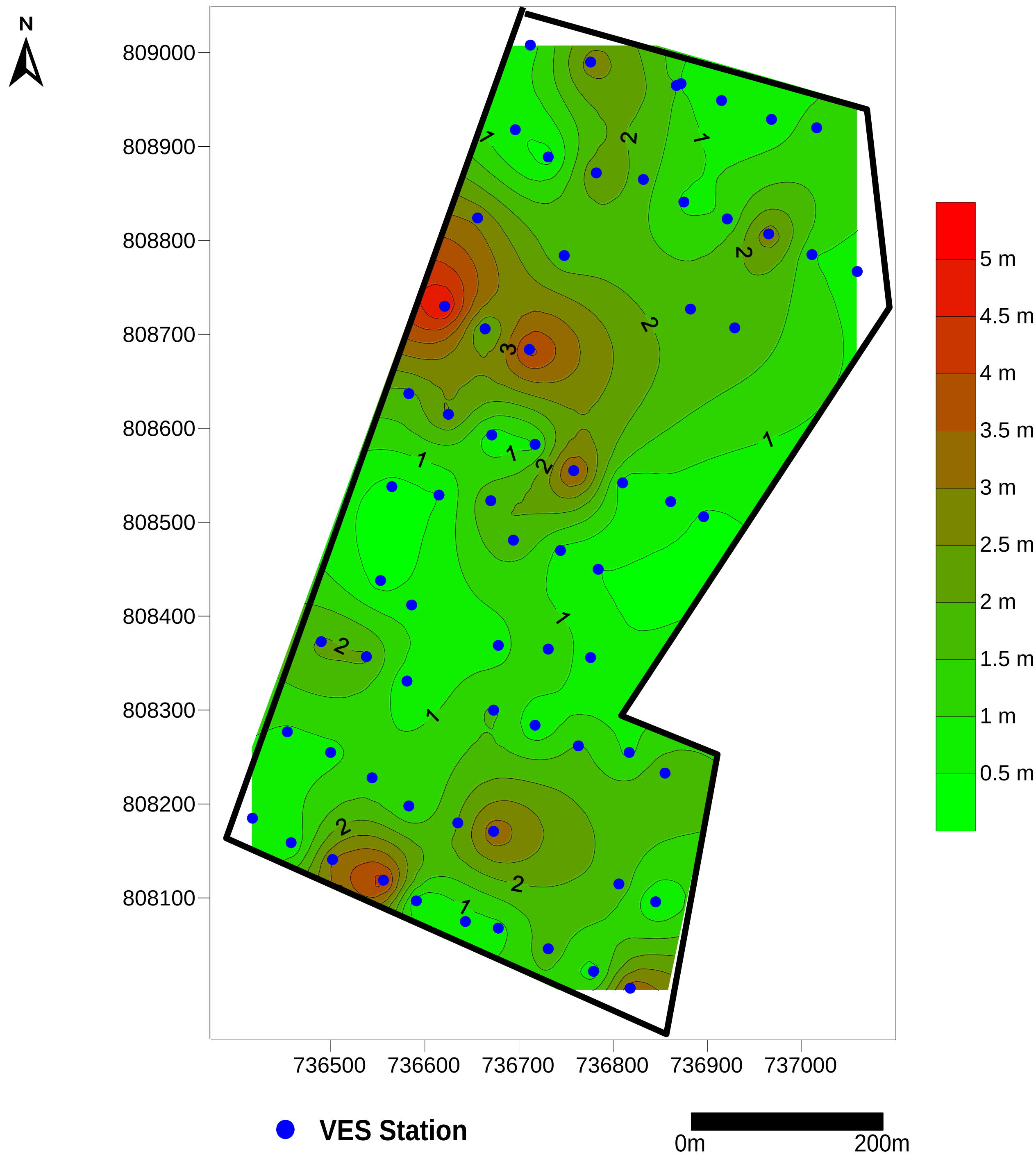

Figure 6. Isopach map of the top soil.

potential rating and the remaining 5% has high groundwater potential rating. The fractured basement is unconfined, thin to moderately thick and localized (delineated beneath VES 36, 37, 43 and 44). The resistivity values of the fractured layer are relatively high (439 - 637) indicating possibly low fracture density which is also unsaturated.

Aquifer protective capacity evaluation

The longitudinal conductance map generated in the study area is as shown in Figure 12. This map was used for the overburden protective capacity rating of the study area. The longitudinal conductance values obtained from the area range from 0.01 to 0.4 mhos (Figure 12).

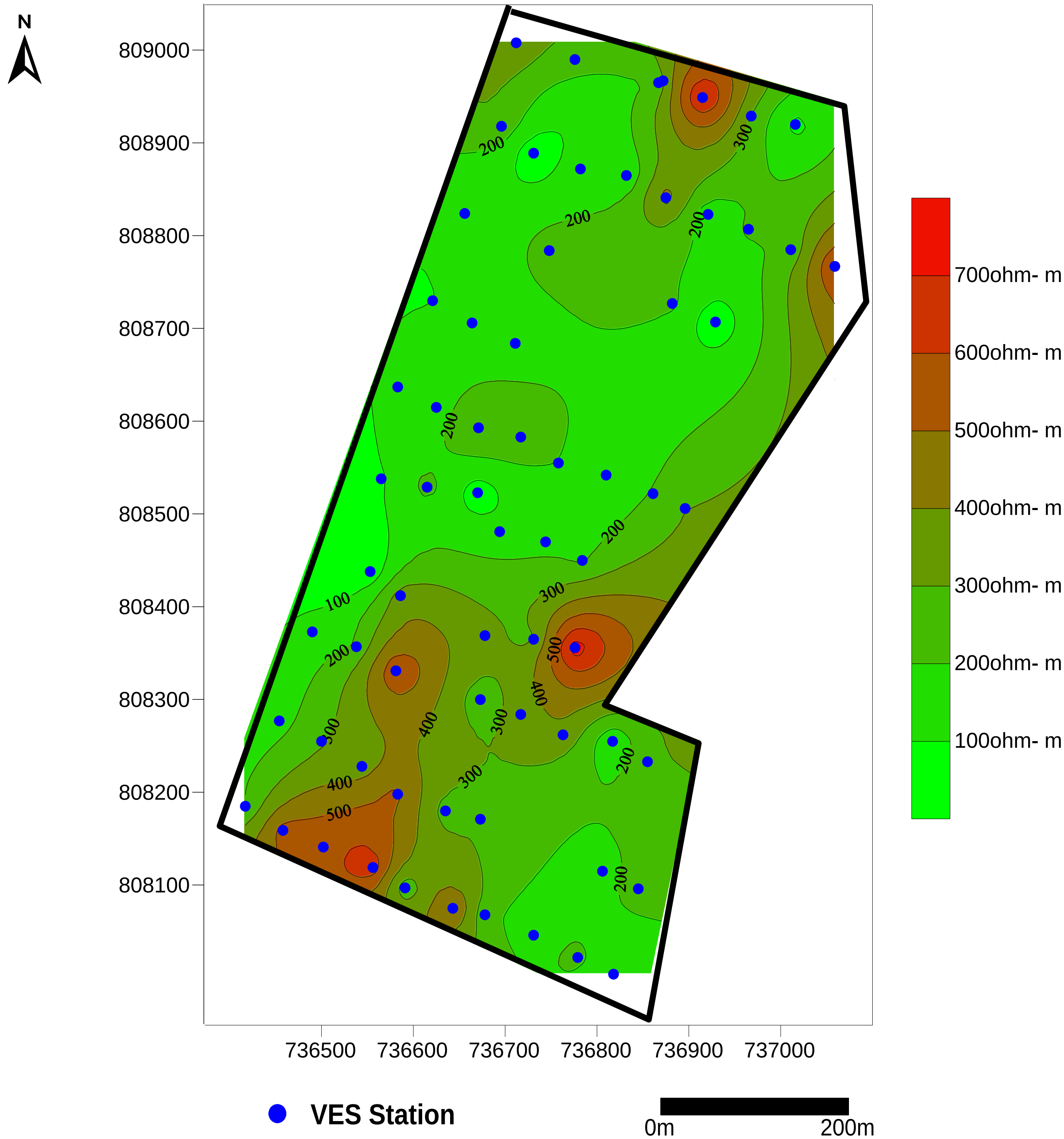

Figure 7. Isoresitivity map of the top soil.

The protective capacity of an overburden could be considered proportional to the longitudinal conductance (Oladapo and Akintorinwa, 2007). Clayey overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underlying aquifer. According to Oladapo and Akintorinwa (2007), 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 capacities (Figure 13 and Table 2). The portions having conductance values ranging from 0.2 to 0.69 mhos were classified as zones of moderate protective capacity (Figure 13 and Table 2), the zones whose conductance ranged from 0.1 to 0.19 mhos were classified as of weak protective capacity while the zones where the conductance is less than 0.1 mhos

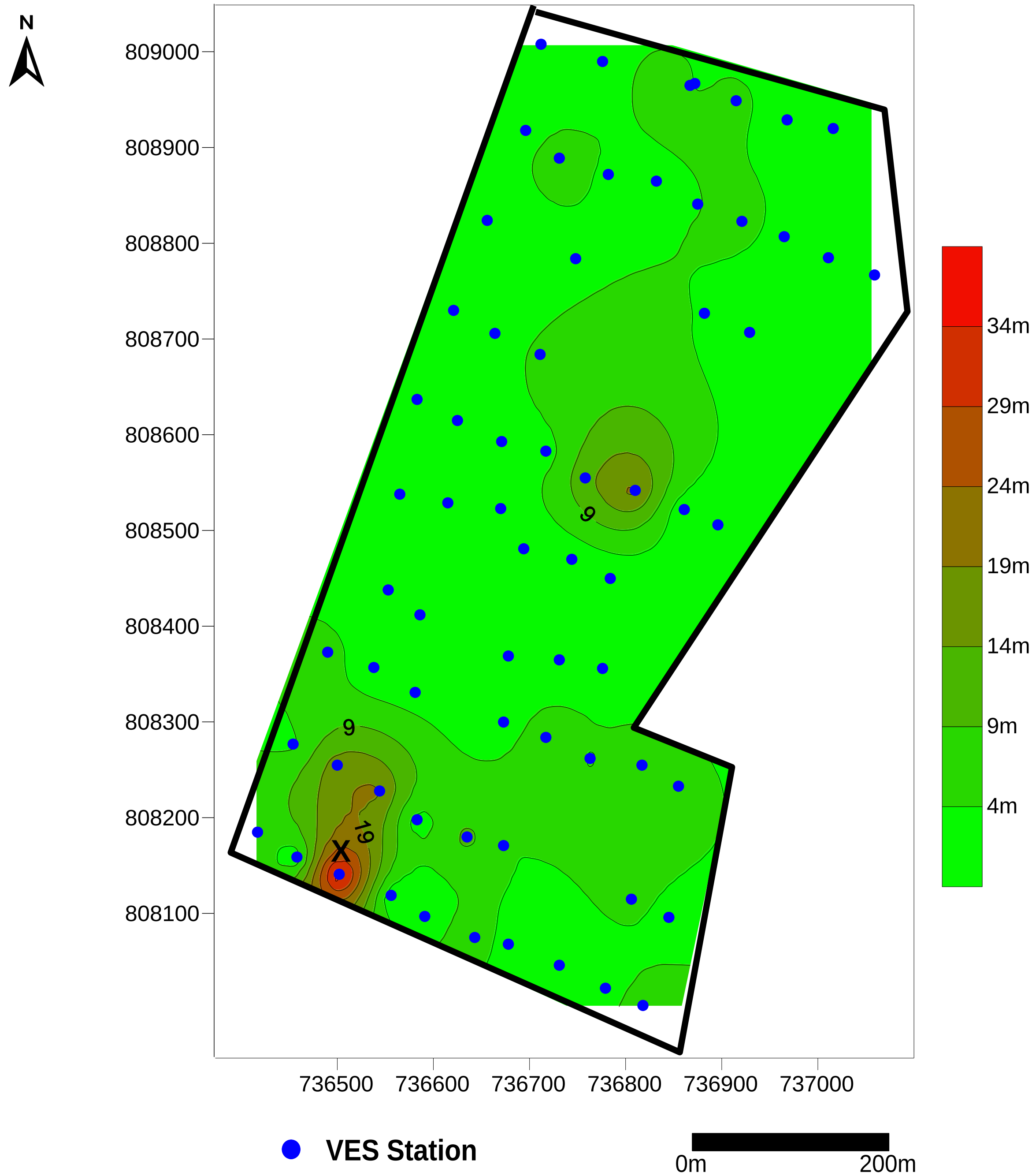

Figure 8. Isopach map of the weathered layer.

were considered to have poor protective capacity (Figure 13 and Table 2). The map of the study area shows that about 75% of the area falls within the poor protective capacity, while the remaining 25% constitutes the moderate/weak protective capacity rating (Figure 13). This suggests that the area is characterized by low longitudinal conductance which informed weak protective capacity rating of the area. Therefore the study area is vulnerable to pollution from contaminant sources such as industrial waste, septic tanks, underground petroleum storage tanks and landfills if located close to the study area.

Conclusions

Electrical Resistivity Method involving Vertical Electrical Sounding (VES) has proved useful in the evaluation of groundwater potential and overburden protective capacity of Zion estate. The Vertical Electrical Sounding data were

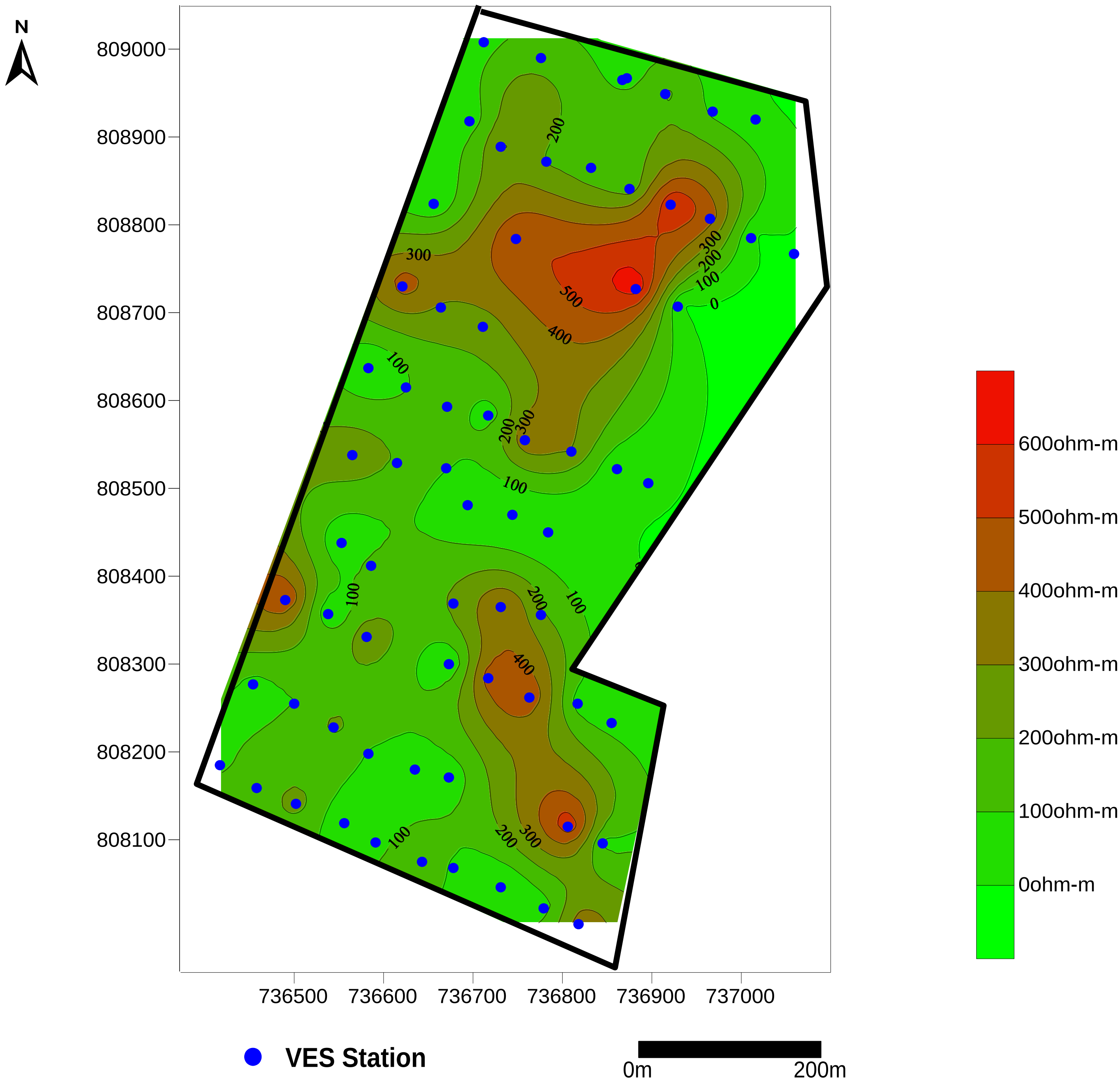

Figure 9. Isoresistivity of the weathered layer.

quantitatively interpreted using partial curve matching and the results were refined using WinResist software. The first order geoelectric parameters obtained from the interpretation of the vertical electrical sounding data and the second order Dar Zarrouk parameter (longitudinal conductance S_i) were used to generate various maps and sections which were analyzed with respect to the groundwater potential and overburden protective capacity of the study area. The results show that the weathered layer (which generally has a small thickness <10 m) constitutes the major aquifer unit in the area, has little hydrogeologic significance. However, a localized part of the area marked X has significant hydrogeologic significance with weathered layer thicknesses up to 34 m.

Generally the area was zoned into high, medium and low groundwater potential and about 85% of the area falls within the low groundwater potential rating, while about 10% constitutes the medium groundwater potential rating

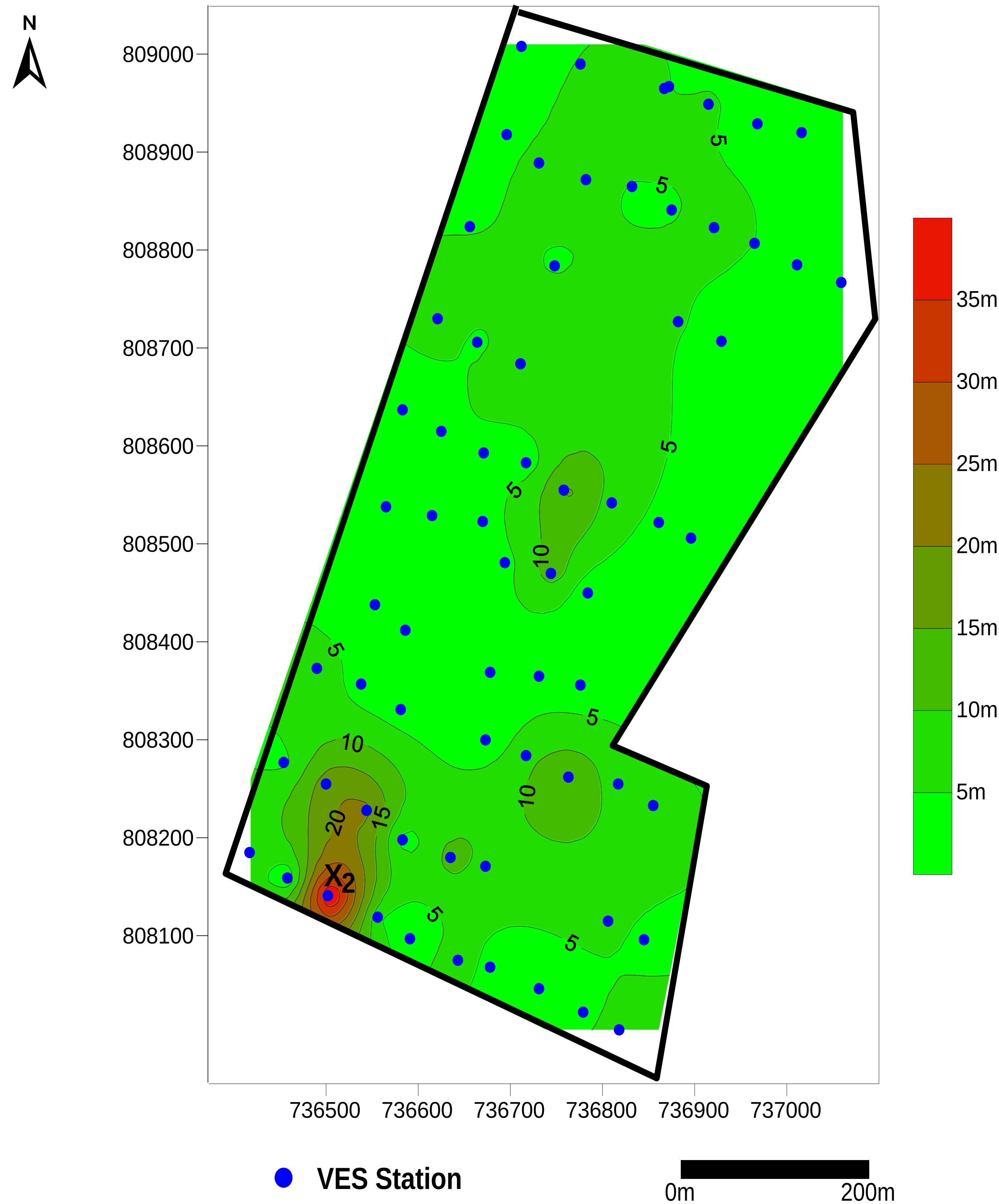

Figure 10. Isopach map of the overburden.

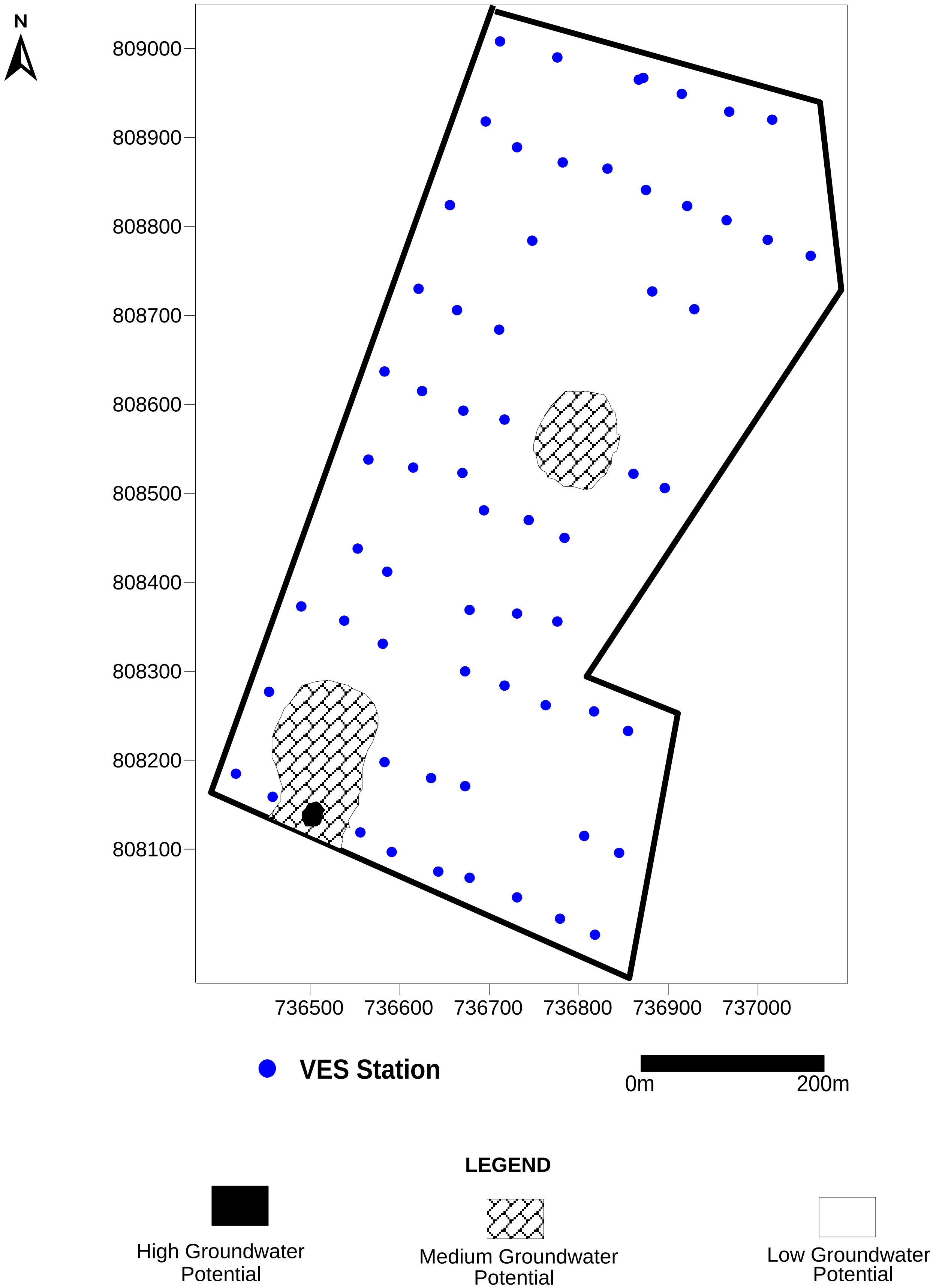

Figure 11. Groundwater potential map of the study area.

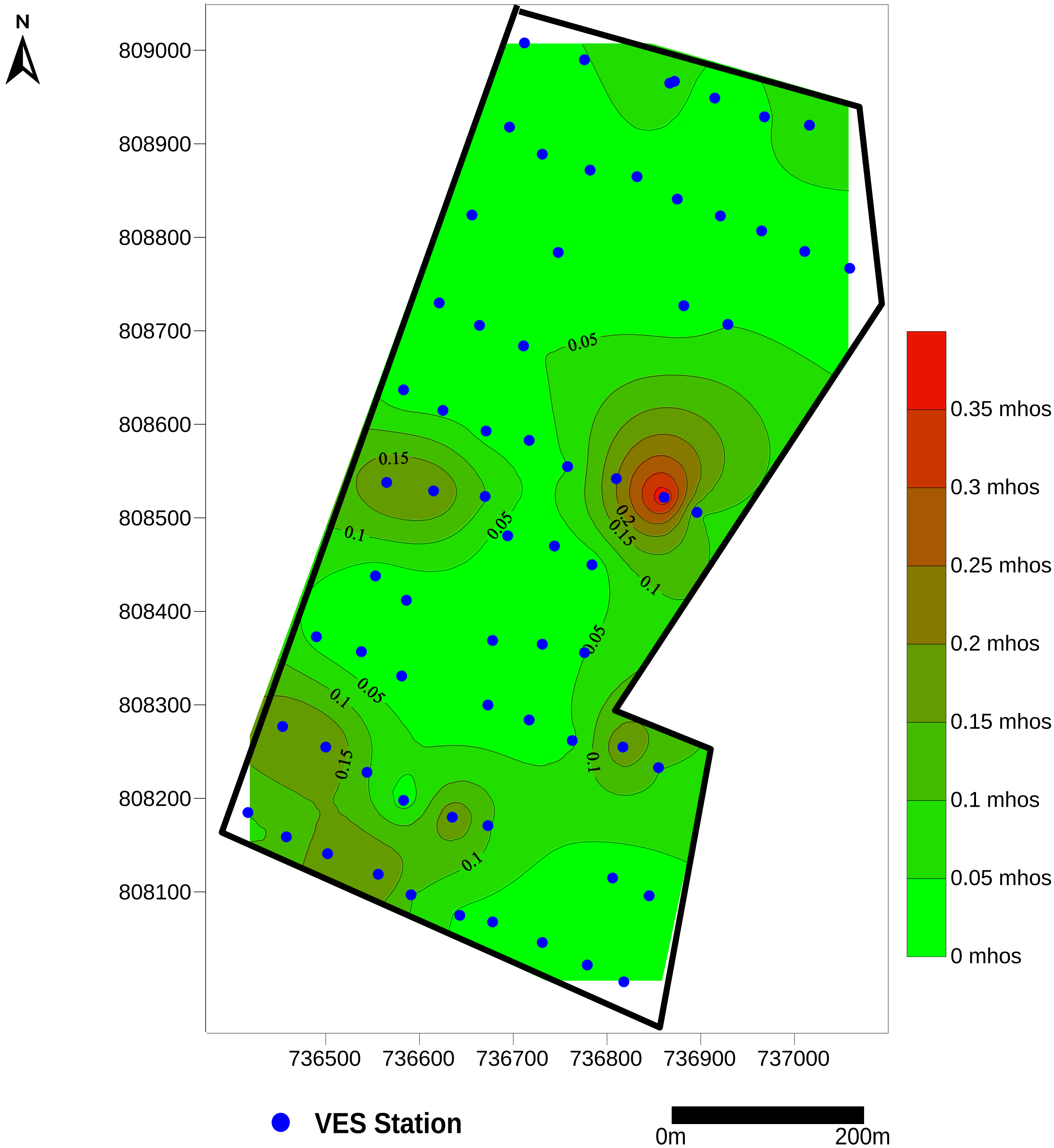

Figure 12. Longitudinal conductance map of the study area.

and the remaining 5% constitutes high groundwater potential rating. Hence the groundwater potential of the area was generally rated to be low. The VES stations underlain by high and medium groundwater potential zones are envisaged to be viable for groundwater development within the area. The protective capacity of the overburden in the study area was zoned into moderate, weak and poor protective capacity. About 75%

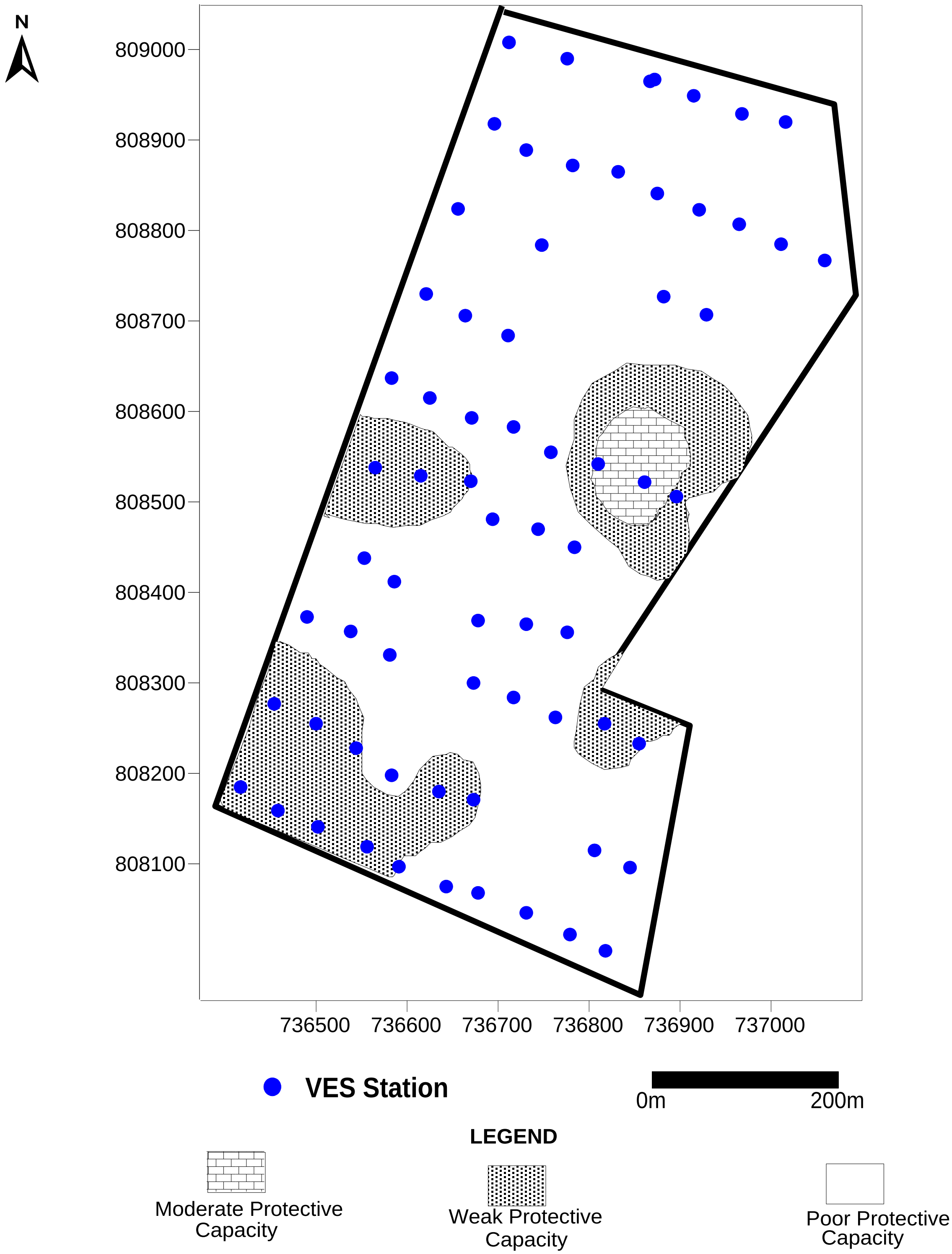

Figure 13. Overburden protective map of the study area.

of the area falls within the poor protective capacity, while the remaining 25% constitutes the moderate/weak protective capacity rating. This suggests that the area is characterized by weak protective capacity rating. Therefore, the study area is vulnerable to pollution from contaminant sources such as industrial waste, septic tanks, underground petroleum storage tanks and landfills if located close to the study area.

The results of this research have provided reliable information on the groundwater potential and overburden

Table 2. Modified longitudinal conductance/protective capacity rating (Oladapo and Akintorinwa, 2007).

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

protective capacity necessary for proper planning and development of groundwater within the study area. It is therefore recommended that groundwater exploration and development be restricted to the area zoned into medium/high groundwater potential. Also the location of septic tanks, petroleum storage tanks, shallow subsurface piping utilities and other contaminant facilities should be confined to zones of moderate protective capacity.

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