

Full length article

Assessment of groundwater prospect and aquifer protective capacity using resistivity method in Olabisi Onabanjo University campus, Ago-Iwoye, Southwestern Nigeria



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ABSTRACT

Electrical resistivity investigation was carried out at Olabisi Onabanjo University campus, Ago-Iwoye, Southwestern Nigeria with the aim of evaluating groundwater potential and aquifer protective capacity of the overburden units in the area. The underlain rocks are predominantly porphyroblastic and banded gneiss, quartz-schist and biotite-hornblende granite.

Twenty-Four Vertical Electrical Sounding (VES) were probed using Schlumberger array with maximum current electrode spacing (AB/2) of 100 m at each point using the OHMEGA Allied resistivity meter. The data were interpreted using the partial curve matching and computer iteration programme using WINRESIST. Parameters such as overburden thickness, basement resistivity, reflection coefficient and longitudinal conductance were calculated and used for evaluating the groundwater potential and aquifer vulnerability of the study area.

The predominant VES curve types obtained are KH, H, A, AKH, HKH and HA. The geoelectric sections show that the area is underlain by 3–5 layers: the topsoil (72.4–1735.6 Ω m), clay/clayey sand/sand/laterite (18.9–1349.5 Ω m), fractured basement (430.7–1021.4 Ω m) and the fresh basement (433.3–7146.4 Ω m). The plotted isopach map showed an overburden thickness range of 4.9–28.2 m with values greater than 20 m at the south-eastern and south-western parts of area. The reflection coefficient range is between 0.62 and 0.98 while protective capacity range is between 0.03 and 0.28. Groundwater potential of the area were classified as high (overburden thickness > 13 m and reflection coefficient < 0.8); medium (overburden thickness > 13 m and reflection coefficient $\geq$ 0.8); and low (overburden thickness < 13 m and reflection coefficient > 0.8). The protective capacity rating falls between poor to moderate, thus, vulnerable to infiltration of leachate and other surface contaminants.

The study therefore helped in identifying favourable groundwater potential and the aquifer vulnerability of the area.

1. Introduction

The advantages of groundwater over other sources have been severally emphasized in literatures. High percentage of water users in the world rely substantially on groundwater (Reilly et al., 2008). Groundwater contributes substantially to meet the water needs for most do-

mestic, municipal and industrial purposes worldwide, due to its availability in almost all parts of the world. In addition, and most importantly, very minor water treatment is often required to make it potable. Groundwater is largely protected from pollution by natural barriers however, in areas with thin weathered layers and where aquifers are in hydraulic continuity with the ground surface, ground-

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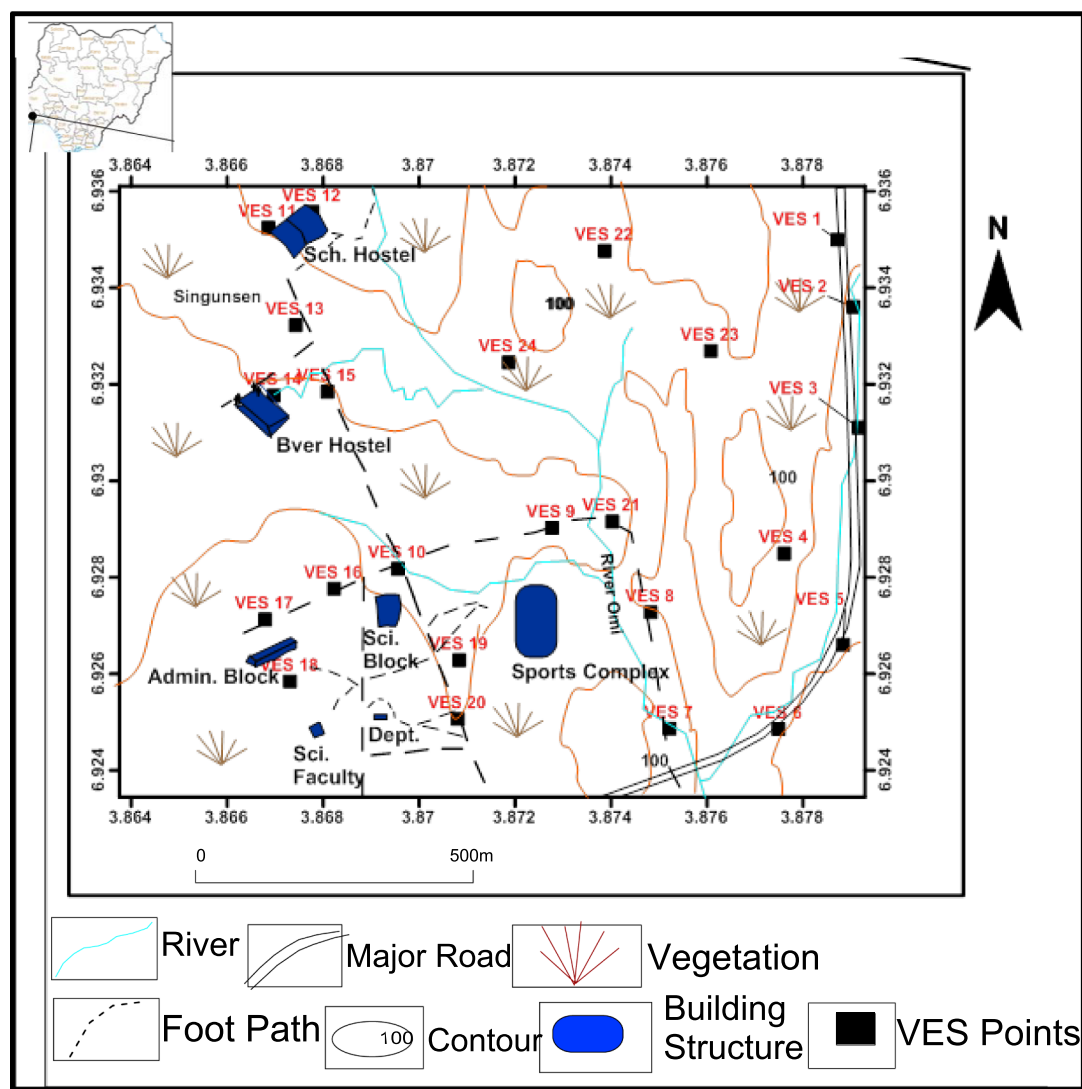


Fig. 1. Location Map of the Study area showing the VES points.

water could be vulnerable to pollution from surface sources. Geologically, in the basement terrain, groundwater is believed to occur within the overlying unconsolidated material derived from in-situ weathering of rocks and perhaps the fractured/faulted bedrock while in the sedimentary terrain, it is accumulated within the porous and permeable layer of the saturated zone in the subsurface (Clark, 1985; Jones, 1985; Bala and Ike, 2001). Although water is a renewable resource, yet its supply in suitable quality is steadily decreasing due to poor groundwater management and effect of poor waste water management, especially in developing countries like Nigeria. Moreover, the demand of this resource has increased significantly throughout the world due to population growth, socio-economic development, technological and climatic changes (Olayinka et al., 1999; Alcamo, 2007). The urge to sustain groundwater need by people has strengthened the application of appropriate geophysical and/or hydrogeologic search (Olayinka et al., 1999; Olorunfemi et al., 1999; Lashkaripour, 2003; Batayneh, 2010;

Omosuyi, 2010; Anudu et al., 2011) to locate areas of high and reliable groundwater prospect or characterize seasonal changes in the near-surface aquifer (Webb et al., 2011).

During the last century, studies show that high rate of urbanization, industrialization and other human activities have resulted into the release of toxic material into the ground as discharge material which percolate into the aquifer. Aquifers in the Precambrian Basement Complex usually occur at shallow depths and hence, are vulnerable to surface or near-surface contaminants. As part of groundwater exploration programme, the need to assess the protective capacity of groundwater becomes very important. Groundwater vulnerability assessment is vital for management of groundwater resources and subsequent land use planning (Rupert, 2001; Babiker et al., 2005).

Olubisi Onabanjo University, Ago-Iwoye, is a fast-growing State University in Nigeria. It lies in a basement terrain and has been experiencing problem of decrease in the quality and quantity of

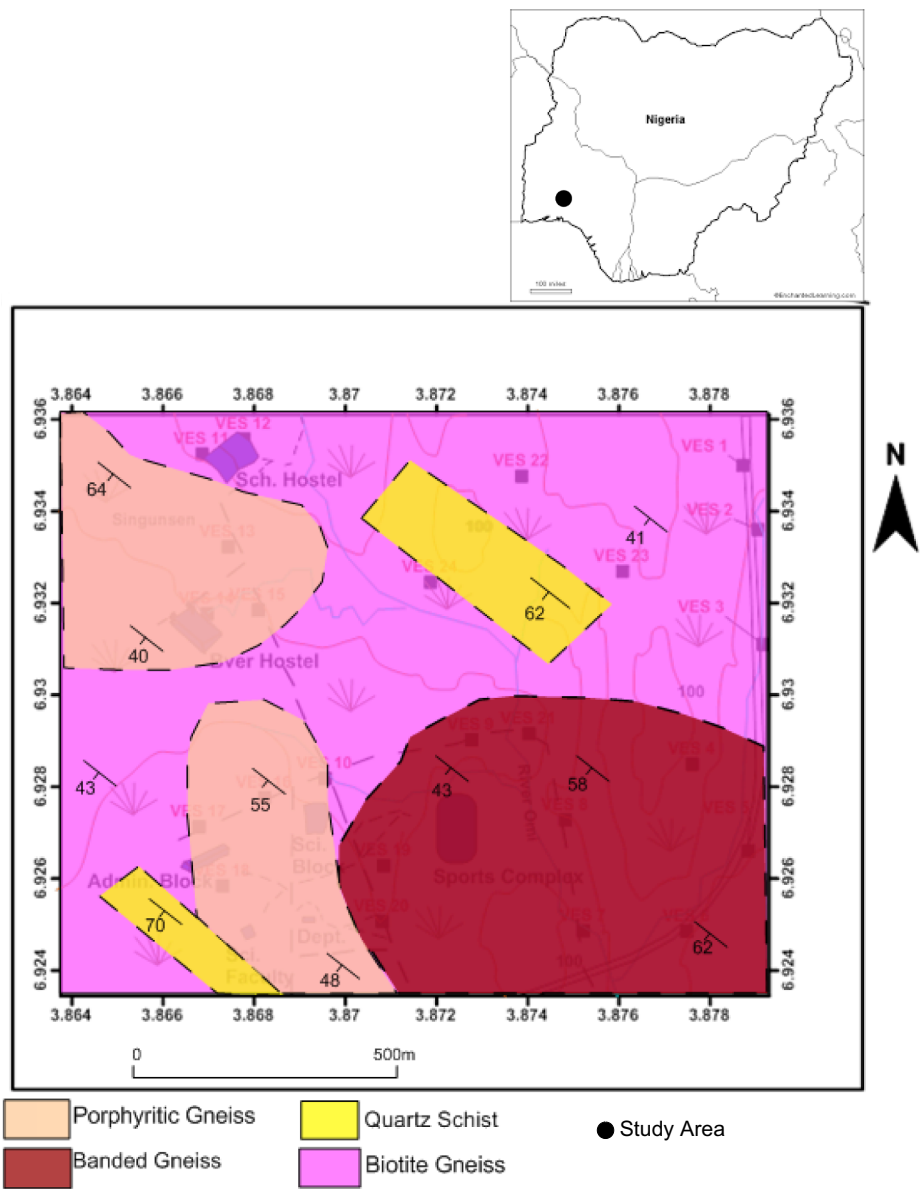


Fig. 2. Geological Map of the Study area.

Table 1
Modified longitudinal conductance/protective capacity rating (Oladapo and Akintorinwa, 2007).

Total longitudinal unit conductance (mhos)	Overburden protective capacity rating
< 0.10	Poor
0.1–0.19	Weak
0.2–0.79	Moderate
0.8–4.9	Good
5–10	Very good
> 10	Excellent

groundwater. The continuous increase in population and the progressive infrastructural development within the campus emphasize the need for the development of a sustainable water supply network. The cost and labour involved in developing surface water is higher when compared to groundwater, hence, emphasis is placed on the development of groundwater which can be achieved within a short time.

Groundwater exploration within the Basement Complex rocks of Africa is usually carried out with the use of Vertical Electrical Sounding (VES) (Omosuyi et al., 2003; Olasehinde and Bayewu, 2011; Oloruntola and Adeyemi, 2014). This is because the successful exploitation of groundwater in basement terrain requires a reliable understanding of the hydrogeological characteristics of the aquifer units viz-a-viz its

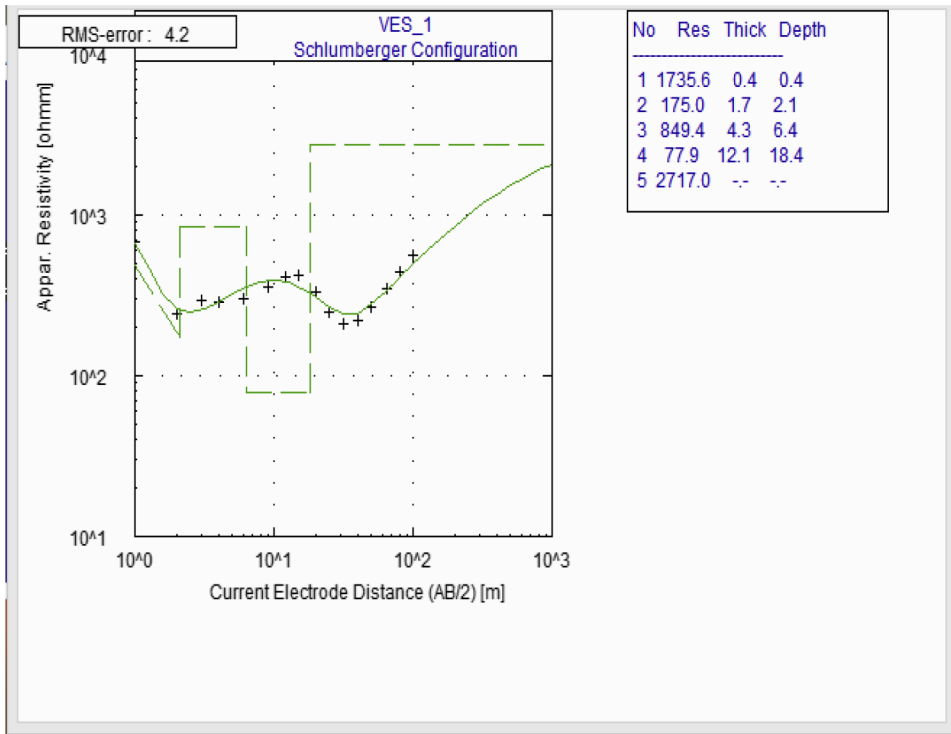


Fig. 3a. Typical HKH iterated curves in the Study area.

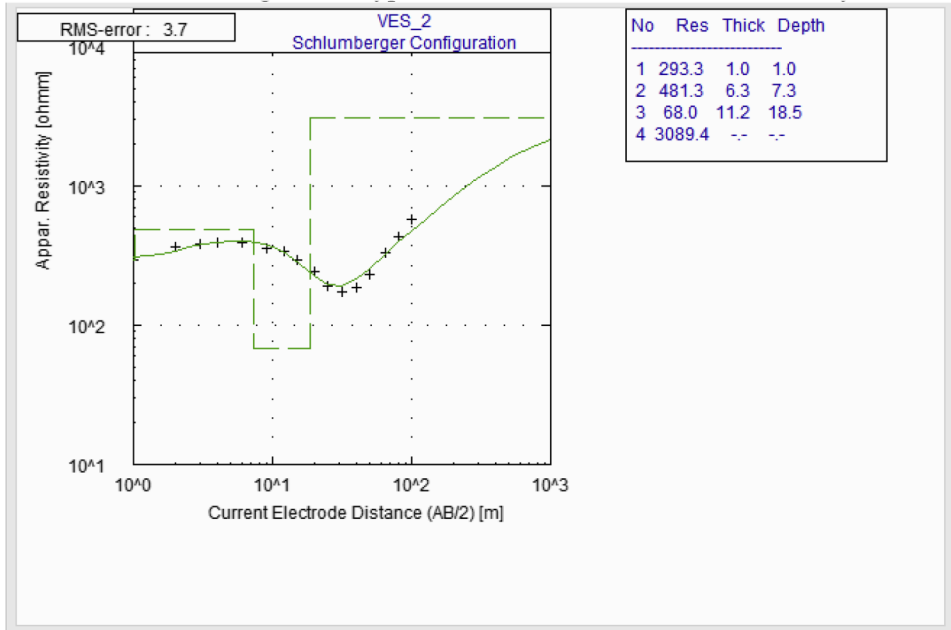


Fig. 3b. Typical KH iterated curves in the Study area.

Table 2
Geoelectric interpretation and their inferred lithologies.

VES No.	No of Layers	Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Reflection coefficient	Inferred Lithology
1	1	1735.6	0.4	0.4	0.9442	Top Soil
	2	175	1.7	2.1		Clayey Sand layer
	3	849.4	4.3	6.4		Sandy layer
	4	77.9	12.1	18.4		Clayey layer
	5	2717				Fresh Basement
2	1	293.3	1	1	0.9569	Top Soil
	2	481.3	6.3	7.3		Sandy layer
	3	68	11.2	18.5		Clayey layer
	4	3089.4				Fresh Basement
3	1	98	1	1	0.7882	Clay Top Soil
	2	386.4	7.9	8.9		Sandy layer
	3	51	7.3	16.2		Clayey layer
	4	430.7				Fractured Basement
4	1	150.3	0.7	0.7	0.7691	Top Soil
	2	772.3	5.9	6.6		Sandy layer
	3	126.2	12.5	19.2		Sandy Clayey layer
	4	967.3				Fractured Basement
5	1	442.3	0.5	0.5	0.8147	Top Soil
	2	1349.5	9.4	9.9		Laterite
	3	91.4	14.3	24.2		Clayey layer
	4	895.6				Fresh Basement
6	1	156.2	0.2	0.2	0.9256	Top Soil
	2	891	3.5	3.7		Sandy layer
	3	137	8.5	12.2		Sandy Clayey layer
	4	3547.7				Fresh basement
7	1	285.2	0.7	0.7	0.8847	Top Soil
	2	165.1	3.3	3.9		Clayey Sandy layer
	3	205.4	12.4	16.3		Sandy layer
	4	3359.8				Fresh Basement
8	1	401.6	2.9	2.9	0.9217	Top Soil
	2	78.3	2	4.9		Clayey layer
	3	1922.7				Fresh Basement
9	1	532.5	1.8	1.8	0.9906	Top Soil
	2	33.7	5.4	7.2		Clayey layer
	3	7146.4				Fresh Basement
10	1	263.9	0.6	0.6	0.9123	Top Soil
	2	60.9	6.4	7		Clayey layer
	3	1328.4				Fresh Basement
11	1	610	0.7	0.7	0.9090	Top Soil
	2	97.5	5.5	6.2		Clayey layer
	3	2046.7				Fresh Basement
12	1	93.2	0.7	0.7	0.9538	Top Soil
	2	58.2	6.1	6.8		Clayey layer
	3	2464.8				Fresh Basement
13	1	229.4	0.7	0.7	0.9485	Top Soil
	2	46.3	6.8	7.6		Clayey layer
	3	1751.9				Fresh Basement
14	1	623.5	0.9	0.9	0.9788	Top Soil
	2	71.3	8.6	9.5		Clayey layer
	3	6656.1				Fresh Basement
15	1	213.9	1.2	1.2	0.9330	Top Soil
	2	78	6.7	7.8		Clayey layer
	3	2251				Fresh Basement
16	1	191	0.2	0.2	0.9116	Top Soil
	2	373.8	3.8	4		Sandy layer
	3	68.2	9.2	13.3		Clayey layer
	4	1476.1				Fresh Basement
17	1	220.1	0.4	0.4	0.6178	Top Soil
	2	1022	6	6.4		Laterite
	3	232.4	21.9	28.2		Sandy layer
	4	983.8				Fractured Basement
18	1	86.6	0.2	0.2	0.9366	Top Soil
	2	121.7	1.9	2		Sandy Clayey layer
	3	572.9	2.3	4.4		Sandy layer
	4	46.7	12.1	16.4		Clayey layer
	5	1427.7				Fresh Basement

(continued on next page)

Table 2 (continued)

VES No.	No of Layers	Resistivity (Ohm-m)	Thickness (m)	Depth (m)	Reflection coefficient	Inferred Lithology
19	1	155.2	0.5	0.5	0.8469	Top Soil
	2	563.1	1.3	1.8		Sandy layer
	3	148.9	14.4	16.2		Sandy Clayey layer
	4	1796				Fresh Basement
20	1	164.4	0.4	0.4	0.9164	Top Soil
	2	232.8	2.9	3.3		Sandy layer
	3	18.9	2.6	5.9		Clayey layer
	4	433.3				Fresh Basement
21	1	361.2	1	1	0.9292	Top Soil
	2	50.5	8.9	9.9		Clayey layer
	3	1378				Fresh Basement
22	1	72.4	0.5	0.5	0.9082	Top Soil
	2	1072	2.5	3		Laterite
	3	167.3	10.8	13.8		Clayey Sand
	4	3477.9				Fresh Basement
23	1	217	1	1	0.9646	Top Soil
	2	299.2	1.4	2.4		Sandy layer
	3	45.4	3.2	5.5		Clayey layer
	4	2526.4				Fresh Basement
24	1	82.7	0.7	0.7	0.7385	Top Soil
	2	418.1	3.1	3.8		Sandy layer
	3	153.6	10.0	13.8		Sandy Clayey layer
	4	1021.4				Fractured Basement

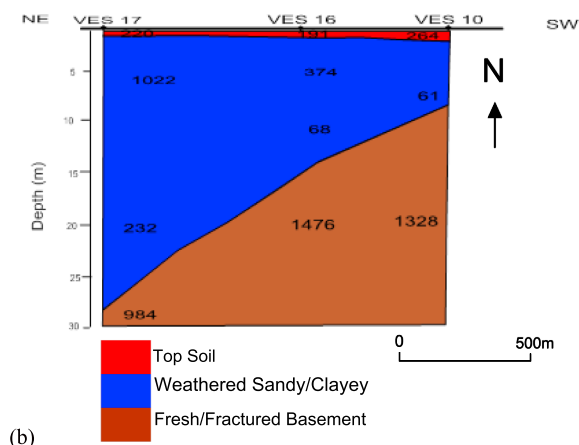
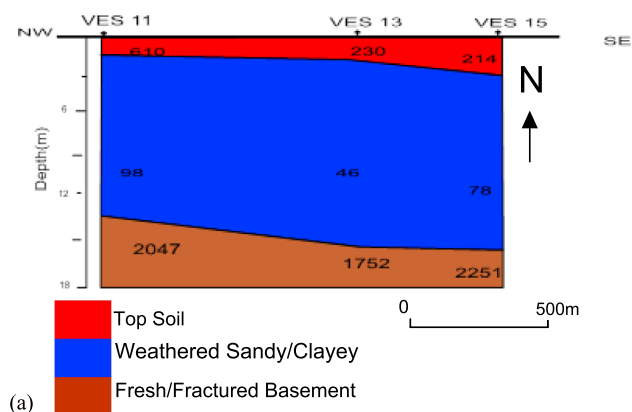


Fig. 4. The goelectric sections plotted in the study area.

susceptibility to environmental pollution.

Consequently, a detailed geoelectric survey of the study area was carried out to determine the geoelectric parameters (resistivities and thicknesses) of subsurface layers and their hydrogeological properties. The study is also aimed at evaluating the groundwater potential of the area, establishing the aquifer protective capacity (insulation from pollution) of the overlying formations and recommending appropriate points for groundwater abstraction. The resistivity geophysical approach is used as the key to exploration because it can give detailed information about the subsurface layer by passing electrical current down the subsurface and also, its low cost of exploration. This method has been used successfully for several research works.

2. Location and geology of the study area

Olabisi Onabanjo University main campus is situated in Ago-Iwoye, between longitude 3°51'49.32"E and 3°52'45.12"E and latitude 6°55'24.24"N and 6°56'9.96"N (Fig. 1). The study area lies within the crystalline basement complex terrain of the South-western Nigeria. The Olabisi Onabanjo University main campus is accessible via the Illisan-Ago-Iwoye road. One major road, few minor roads and footpaths make movement easier and the area accessible. According to Akanni (1992), the physiography of the study area results from the geomorphic processes that have shaped the terrain. The topography is undulating, and ranges from high to low relief. The average rainfall noticed annually ranges from 1100 mm to 1850 mm. The mean temperature is 26 °C and varies from 21 °C in December to 24.34 °C in April (minimum), to 33.92 °C to 37.1 °C at the onset of wet season (maximum) (Onakomaiya et al., 1992; Ogunrayi et al. 2016). The area mapped is drained by a few seasonal rivers with dendritic drainage pattern flowing northwest to southeast. The most popular river within the area is the River Omi.

Geological mapping of Olabisi Onabanjo University campus was carried out in order to have the first-hand knowledge of the rock types

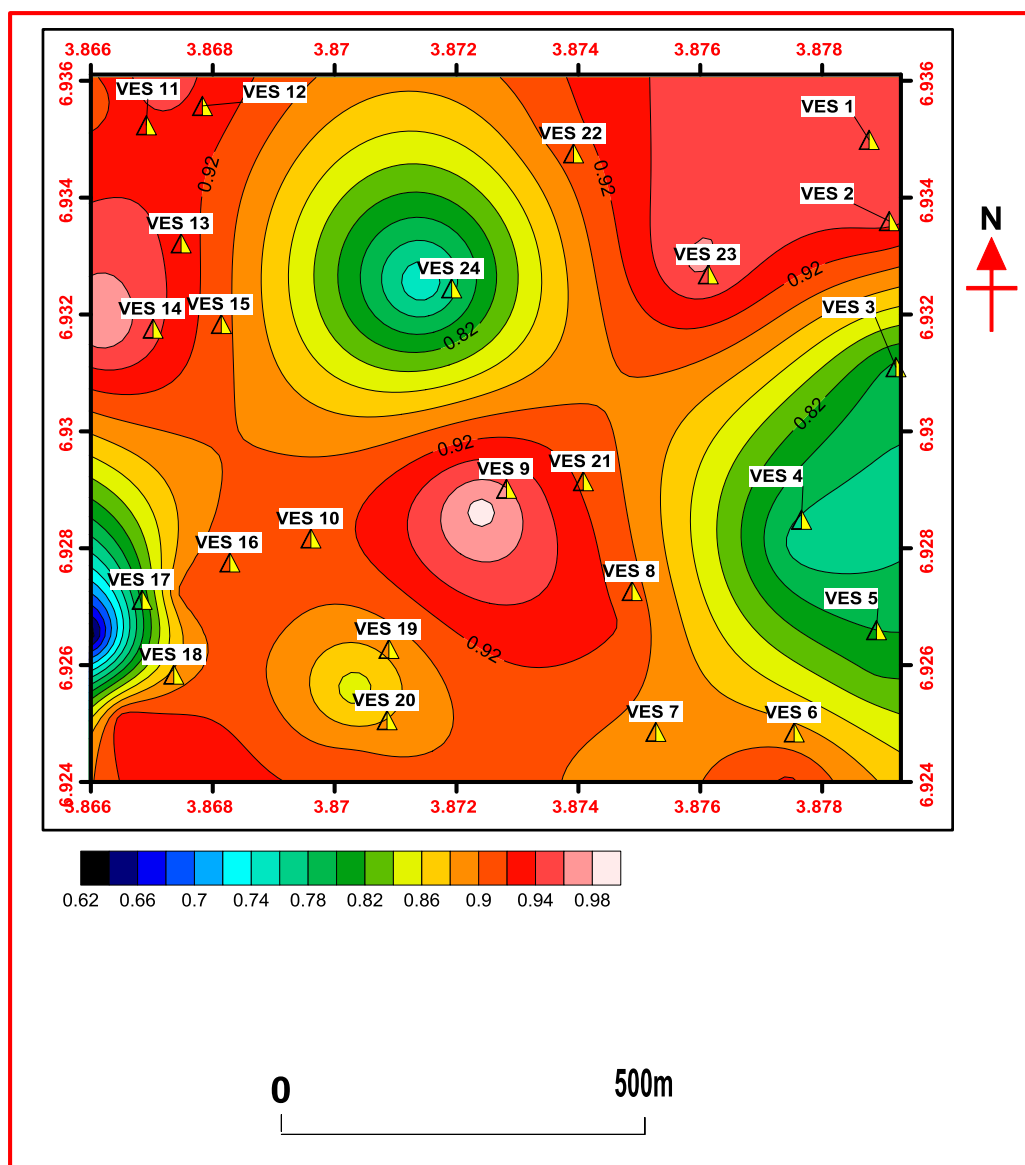


Fig. 5. The reflection coefficient map of the study area.

in the area. Optical study of the thin sections prepared from five rocks samples collected revealed four distinct rock units which are porphyroblastic (augen) gneiss, hornblende-biotite gneiss, banded gneiss and quartz schist (Fig. 2). Rose diagram plotted from these data revealed a NW-SE trending (for the foliations and veins).

3. Methodology

The electrical resistivity of the area was measured using ALLIED OHMEGA resistivity meter (REV G 0414). Schlumberger array was used to carry out twenty-four (24) Vertical Electrical Sounding (VES) with maximum current electrode (AB/2) spacing of 100 m across the area (Fig. 1). The apparent resistivity (ρ_a) values were obtained as the product of the resistance read from the resistivity meter and its corresponding geometric factor calculated (Zohdy et al., 1974). These were

then plotted against their corresponding half current electrode spacing (AB/2) on a bi-logarithm paper. The plotted field curves were therefore interpreted manually by partial curve matching using different master curves (Koefoed, 1979; Orellana and Mooney, 1966; Zohdy, 1965; Keller and Frischknecht, 1966). The geoelectric parameters from the partial curve matching interpretation then served as an input model for computer-assisted iteration of the Vander Velpen (2004) WINRESIST version 1.0 program. The reflection coefficients (r) of the study area were calculated using the method of Olayinka (1996), Bhattacharya and Patra (1968), and Loke (1999) as seen in Eq. (1).

$$r = \frac{(\rho_n - \rho_{(n-1)})}{(\rho_n + \rho_{(n-1)})} \quad (1)$$

where ρ_n is the layer resistivity of the n th layer, $\rho_{(n-1)}$ is the layer resistivity overlying the n th layer.

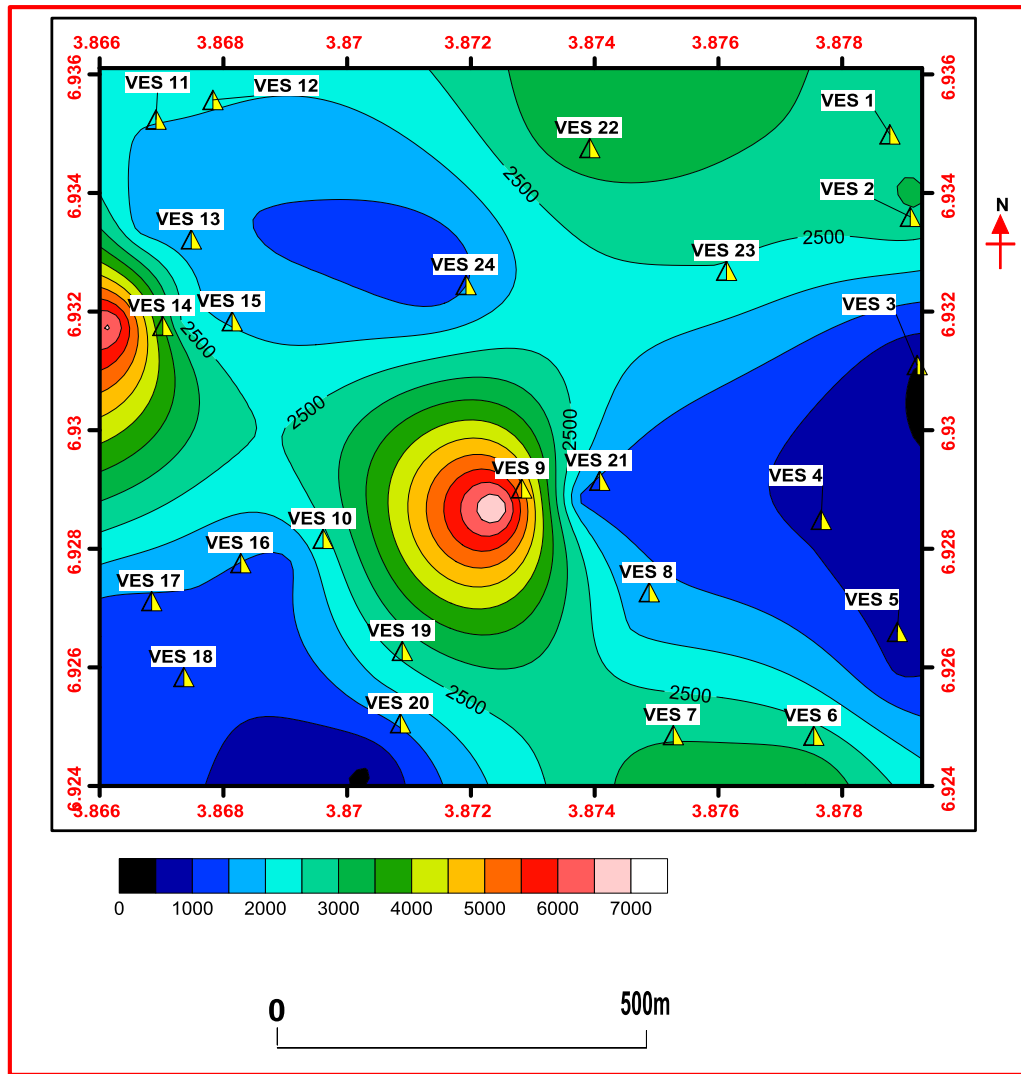


Fig. 6. The isoresistivity map of the bedrock of the study area.

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 Eq. (2) (after [Henriet, 1976](#)):

$$S = \sum_{i=1}^n \frac{h_i}{\rho_i} \quad (2)$$

where S is the total longitudinal conductance, Σ is summation sign, h_i is the thickness of the i th Layer and ρ_i is the resistivity of the i th layer.

Using [Oladapo and Akintorinwa \(2007\)](#) classification, the results of longitudinal conductance was used to classify areas into good, moderate, weak and poor protective capacity ([Table 1](#)).

4. Results and discussion

The curve types obtained after partial curve matching range from simple 3-layers H type (25%), and A type (13%), 4-layers HA type (4%)

and KH (50%) to complex 5-layers curve HKH (4%) and AKH (4%). Typical iterated curves generated from the field measurements are shown in [Figs. 3a and 3b](#). [Table 2](#) shows the inferred lithologies from the geoelectric interpretation. The geoelectric interpretation revealed 3–5 geoelectric layers namely: Top soil (72.4–1735.6 Ω m), the weathered layer which comprises of clayey sand/clay/sand/laterite (18.9–1349.5 Ω m), underlying this layer are the fractured basement (430.7–1021.4 Ω m) and the fresh basement (433.3–7146.4 Ω m). Typical geoelectric sections are shown in [Fig. 4](#). The nature of the basement is not dependent on the absolute resistivity values but rather dependent on its reflection coefficient values, which measures the competency of the rock ([Olayinka, 1996](#)). From the calculated reflection coefficient, the reflection coefficient map was produced ([Fig. 5](#)) and it shows a value which range from 0.62 to 0.99. Areas with relatively lower reflection coefficient represents areas where the bedrock is fractured/weathered. The lower values (i.e. < 0.8) were observed at VES 3 (resistivity of 430.7 Ω m; thickness of 16.2 m); VES 4 (resistivity of 967.3 Ω m; thickness of 19.2 m), VES 17 (resistivity of 983.8 Ω m;

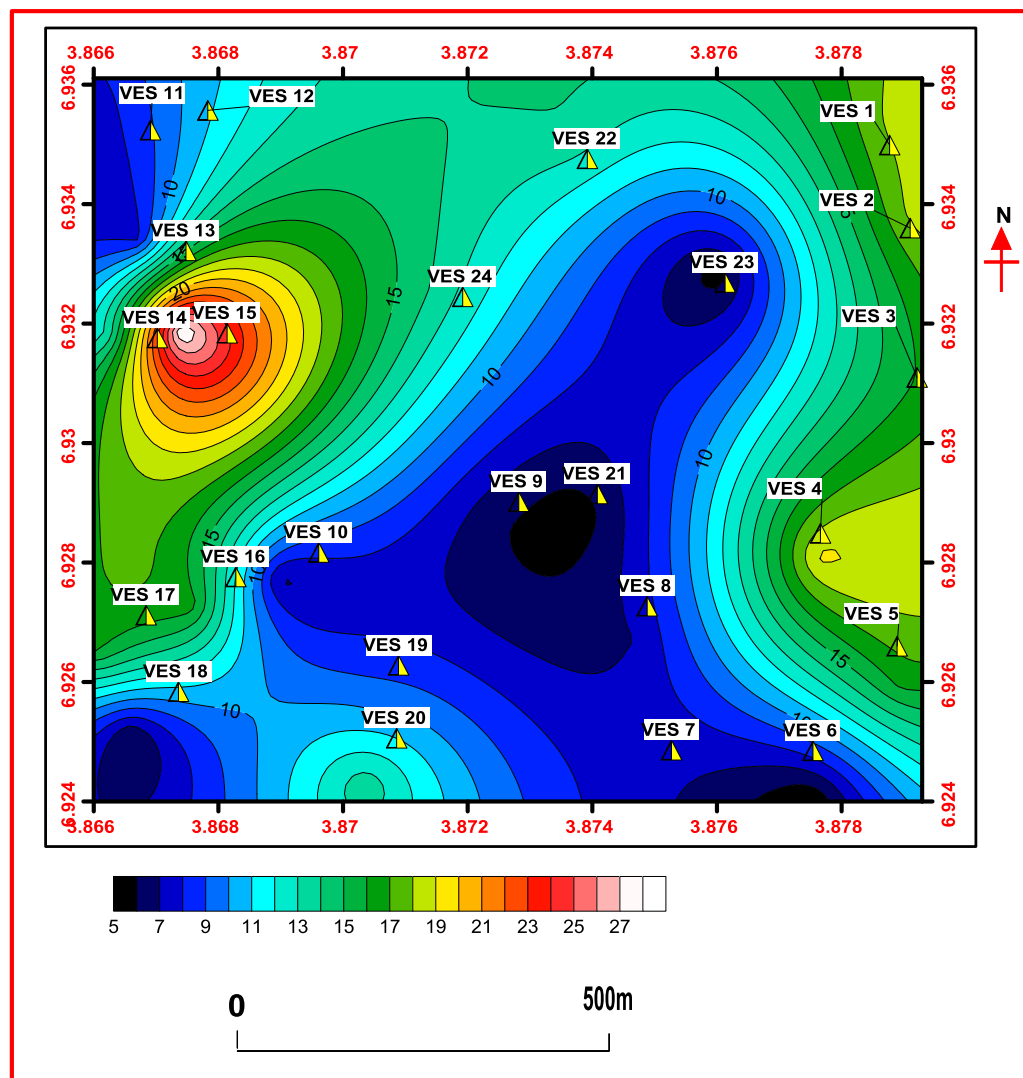


Fig. 7. The isopach map of the overburden thickness of the study area.

thickness of 28.2 m), VES 24 (resistivity of 1021.4 Ω m; thickness of 13.8 m) which suggest that those points have less competent underlying basement, thus, are referred to as the fractured basement.

The isoresistivity map of the subsurface basement produced in Fig. 6 showed the resistivity range of 430.7–7146.4 Ω m. The higher resistivity values were observed in the northwestern (VES 14) and central part (VES 9) while the lower values occupied the north eastern, south eastern and south western parts. The isopach overburden map produced for the area (Fig. 7) showed value range of 4.9–28.2 m. The area is covered by relatively thick overburden but shows greater overburden thickness (> 20 m) in the south eastern and south western parts (VES 5 and 17).

5. Groundwater potential evaluation

The cardinal focus on groundwater assessment in the crystalline

basement area is where the overburden and the fractured basement aquifers are complementary or connected (Lenkey et al., 2005; Meju et al., 1999; Omosuyi, 2000). Olayinka (1996) observed that the resistivity of the basement cannot be solely relied on to identify areas of promising aquifer within the basement terrain, hence, the consideration of its reflection coefficient in evaluating the groundwater potential of the study area. Reflection coefficients show the degree of fracturing of the underlying basement better than depending solely on the resistivity values. In the basement terrain, good aquiferous zones are usually found either where the overburden is relatively thick and/or where the reflection coefficient is low (< 0.8). Three basic criteria were considered in evaluating promising points for groundwater potential:

- i. Areas with high groundwater yield: These are the areas with overburden thickness greater than > 13 m and with reflection coefficient less than 0.8.

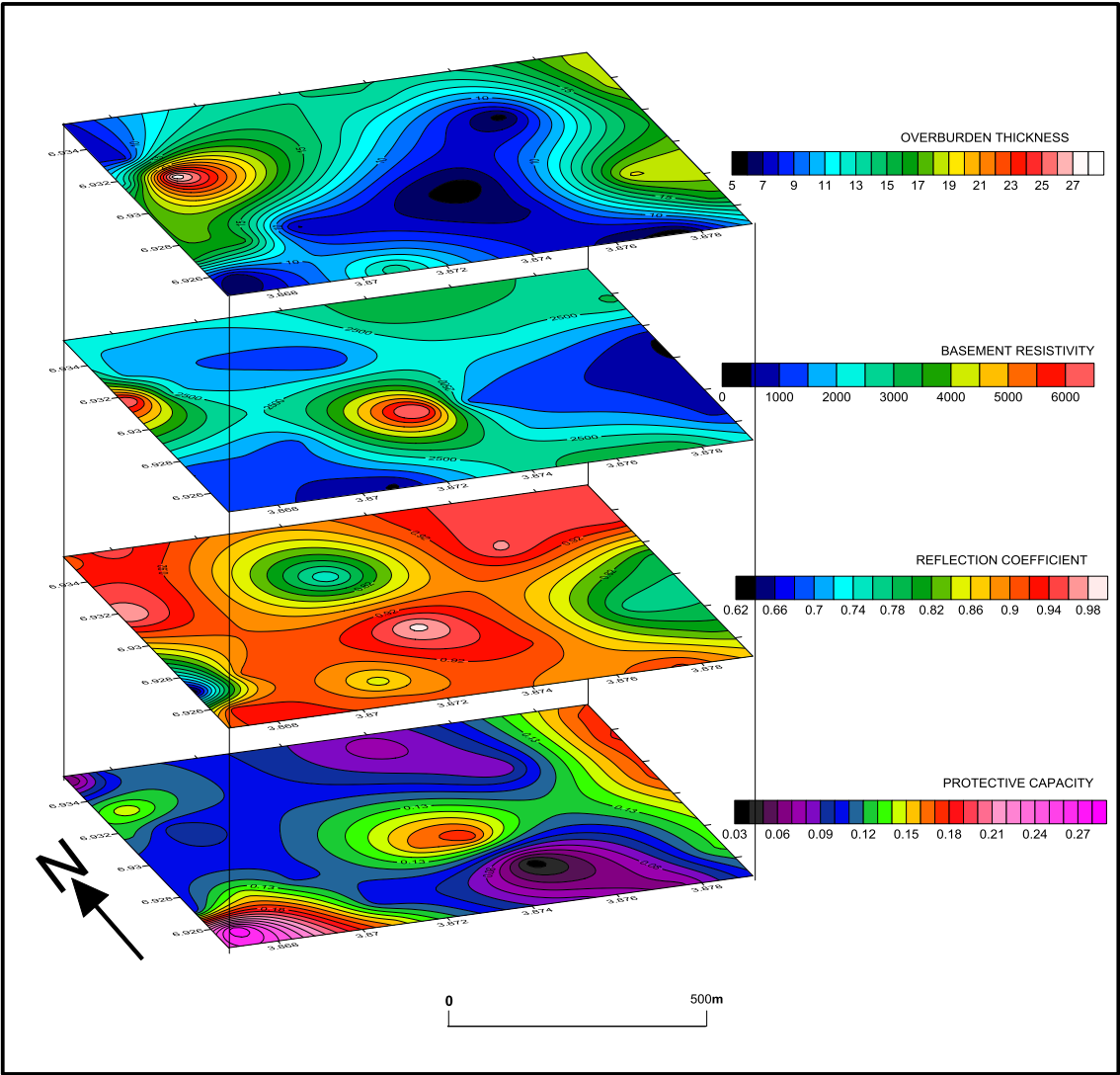


Fig. 8. Stacked maps of the basement resistivity, overburden thickness, and reflection coefficient plotted for categorizing the groundwater potential yield in the study area.

- ii. Areas with medium groundwater yield: Areas with overburden thickness greater than 13 m and with reflection coefficient greater than or equal to 0.8
- iii. Areas potential with low groundwater yield: Areas with overburden thickness less than 13 m and with reflection coefficient greater than or equal to 0.8.

Based on these, stacked maps of the basement resistivity, overburden thickness, and reflection coefficient (Fig. 8) were used to produce the parameters (Table 3) for categorizing the groundwater potential yield into high, medium and low. The parameters were then used to plot the groundwater potential distribution map of the study area (Fig. 9).

6. Aquifer protective capacity evaluation

The combination of the resistivity and layer thickness was used to compute the longitudinal conductance of the layers (Golam et al., 2014; Oborie and Udom, 2014). High longitudinal conductance indicated relatively high protective capacity. The protective capacity map provides visual information for more vulnerable zones which help to protect groundwater resources and also employed to evaluate the potential for water quality improvement.

The calculated longitudinal conductance for the study area is

Table 3			
Groundwater potential across the VES points.			
VES Points	Overburden thickness (m)	Reflection coefficient	Remarks
1	18.4	0.9442	Medium yield
2	18.5	0.9569	Medium yield
3	16.2	0.7882	High yield
4	19.2	0.7691	High yield
5	24.2	0.8147	High yield
6	12.2	0.9256	Low yield
7	16.3	0.8847	Medium yield
8	4.9	0.9217	Low yield
9	7.2	0.9906	Low yield
10	7	0.9123	Low yield
11	6.2	0.9090	Low yield
12	6.8	0.9538	Low yield
13	7.6	0.9485	Low yield
14	9.5	0.9788	Low yield
15	7.8	0.933	Low yield
16	13.3	0.9116	Medium yield
17	28.2	0.6178	High yield
18	16.4	0.9366	Medium yield
19	16.2	0.8469	Medium yield
20	5.9	0.9164	Low yield
21	9.9	0.9292	Low yield
22	13.8	0.9082	Medium yield
23	5.5	0.9646	Low yield
24	13.8	0.7385	High yield

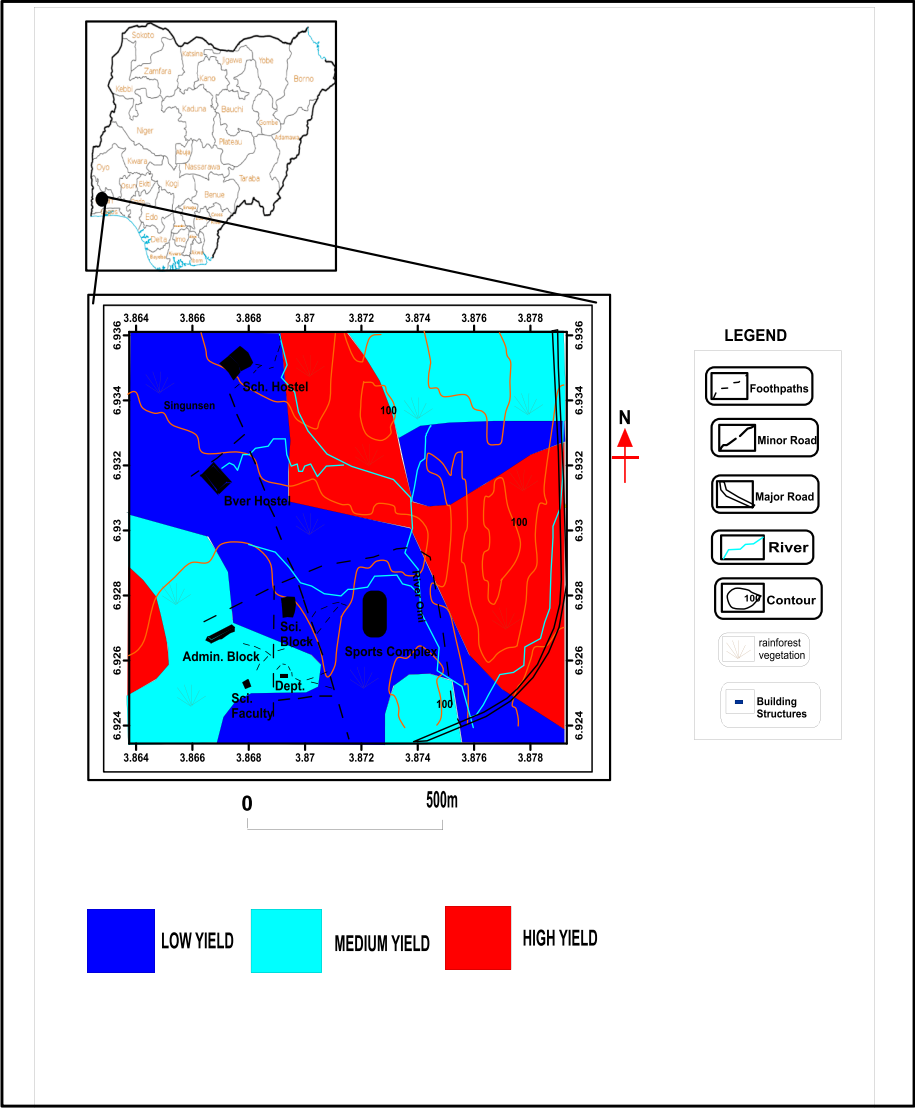


Fig. 9. Groundwater potential distribution of the study area.

Table 4
Longitudinal conductance and protective capacity rating in the study area.

VES No.	Longitudinal conductance	Protective capacity rating
1	0.170	Weak
2	0.181	Weak
3	0.174	Weak
4	0.111	Weak
5	0.129	Weak
6	0.067	Poor
7	0.083	Poor
8	0.033	Poor
9	0.164	Weak
10	0.107	Weak
11	0.058	Poor
12	0.112	Weak
13	0.150	Weak
14	0.122	Weak
15	0.092	Poor
16	0.146	Weak
17	0.102	Weak
18	0.281	Moderate
19	0.102	Weak
20	0.152	Weak
21	0.179	Weak
22	0.074	Poor
23	0.080	Poor
24	0.107	Weak

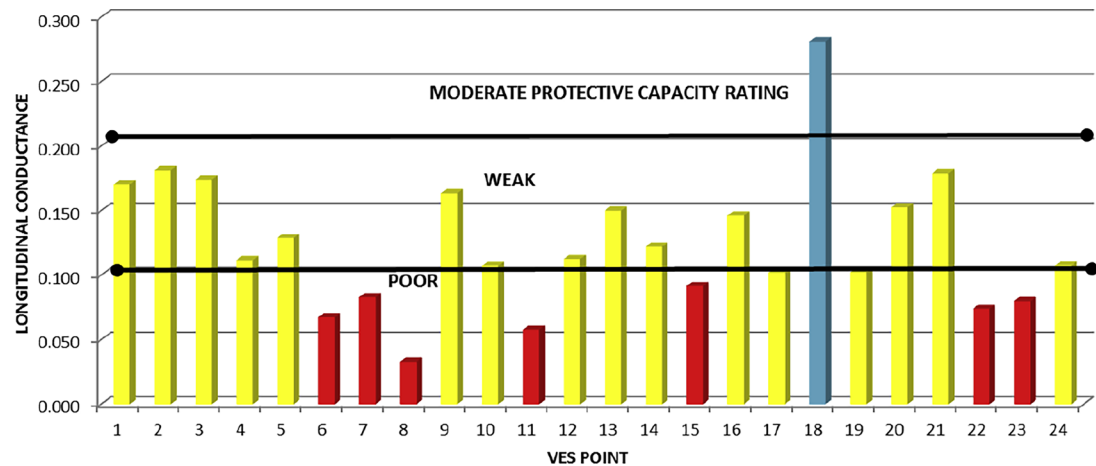


Fig. 10. Bar chart representation of the protective capacity of the VES points.

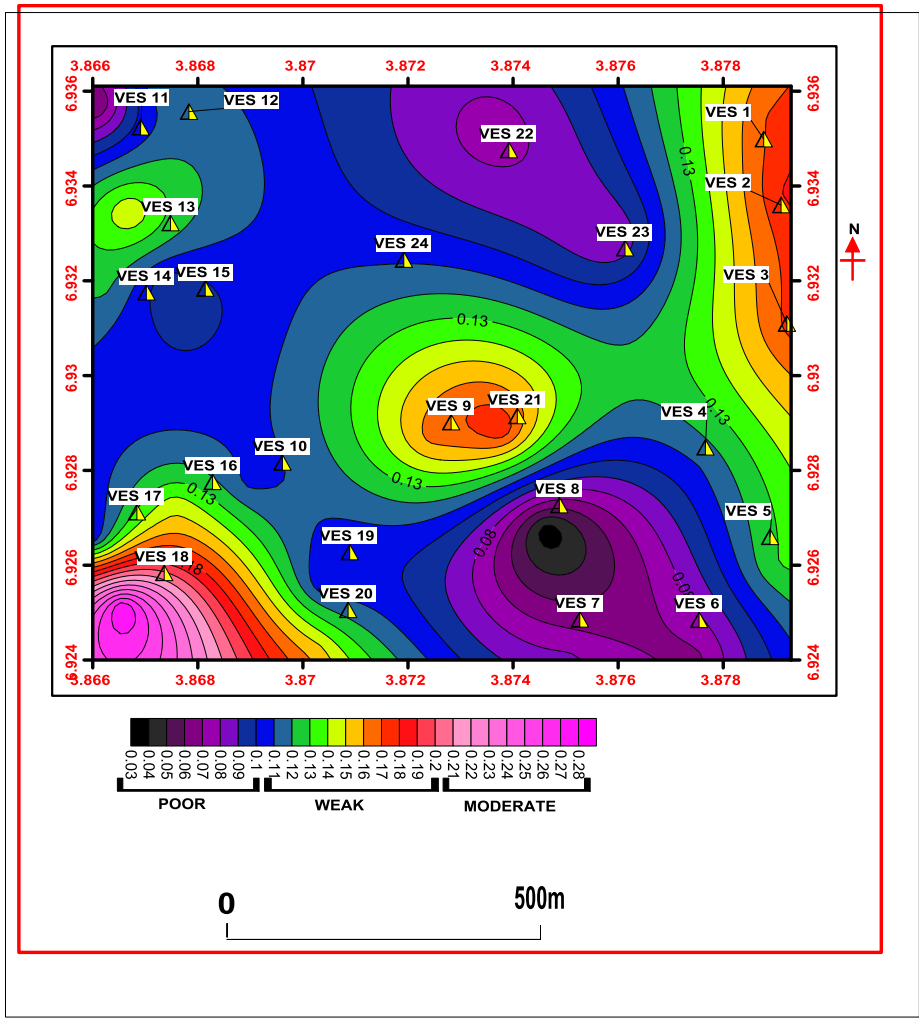


Fig. 11. The protective capacity map of the study area.

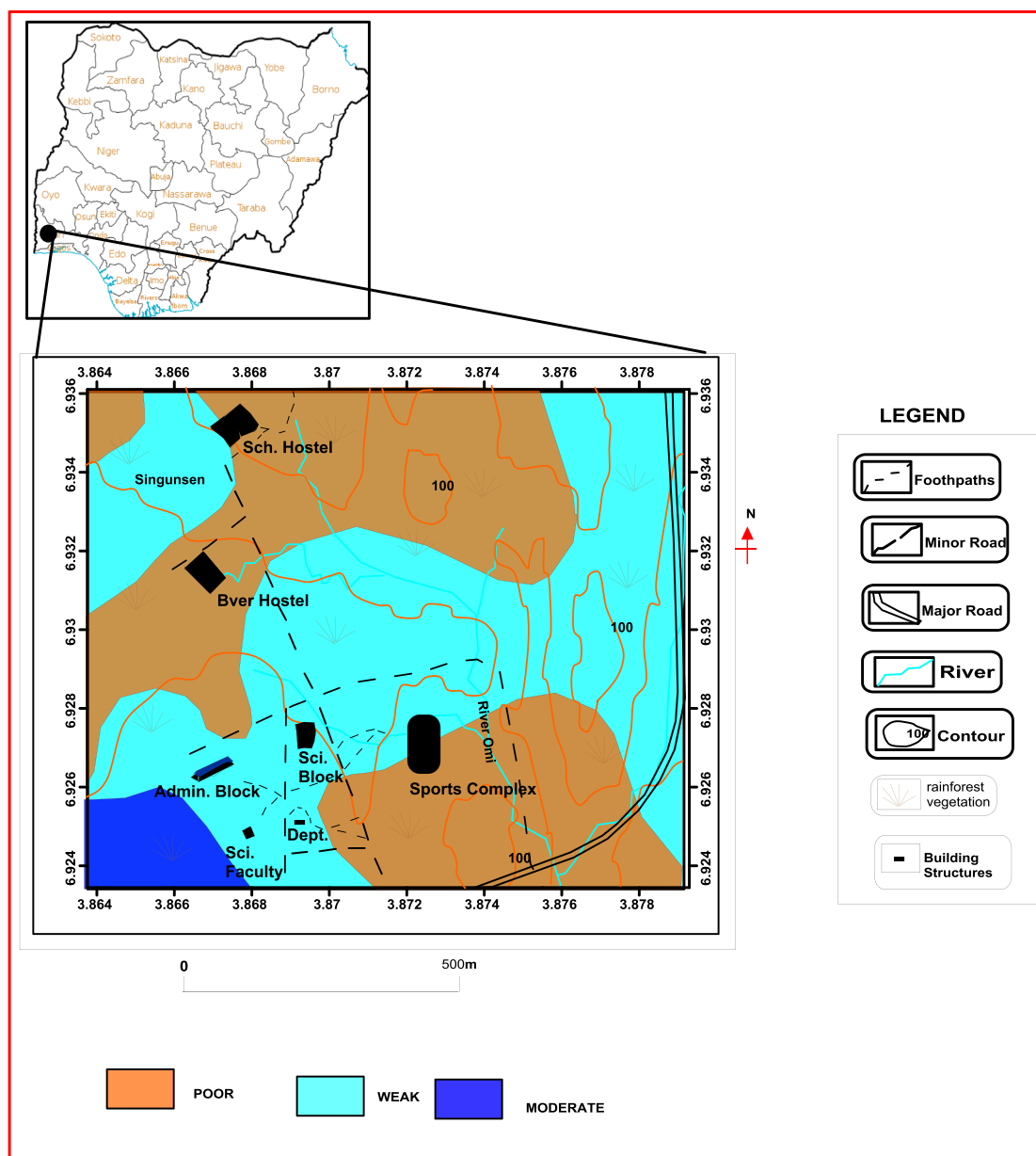


Fig. 12. The protective capacity distribution of the study area.

presented in Table 4. The calculated longitudinal conductance compared favorably with the standard rating by (Oladapo and Akintorinwa, 2007). It can be observed from Table 4 that the protective capacity rating of the study area shows a poor, weak and moderate protective capacity rating. Seven (7) VES stations have poor protective capacity, sixteen (16) VES station shows weak protective capacity and only one (1) VES station shows a moderate protective capacity rating. This is expressed in a bar chart in Fig. 10. The protective capacity map in Fig. 11 shows that the protective capacity within the study area is poor in some part of the south eastern and north western section of the study area. Other parts show a weak protective capacity rating except for VES 18 which falls within some part of the south western area. Areas that are classified as poor and weak are indicative of zones of high infiltration rates from precipitation. Such areas are vulnerable to infiltration of leachate and other surface contaminants. Fig. 12 shows the protective capacity distribution of the study area.

Areas delineated as low groundwater yield are mainly occupied by banded gneiss and biotite gneiss, areas mapped as medium groundwater yield are observed at the southwestern section of the study area

and are mainly covered with porphyritic gneiss and some occurrences of quartz schist while areas delineated as high yield groundwater yield are seen in the northeastern section of the study area and are predominantly occupied with quartz schist. This groundwater yield however agrees with the geology of the area.

7. Conclusion

It can be concluded from the qualitative and quantitative data processing and interpretation that the north, northeastern and south-western parts of the study area are characterized to yield more water than the other part of the study area. This however agrees with the geology in the study area. The study area is overlain mostly by materials of weak protective capacity and only a small area of the south-western part is of moderate protective capacity. It is therefore evident that groundwater in most part of the area is vulnerable to pollution that may arise from runoff water, sewage, effluent and indiscriminate waste disposal in the study area.

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