



Assessment of groundwater potential and quality using geophysical and physicochemical methods in the basement terrain of Southwestern, Nigeria

A. A. Alabi¹ · O. I. Popoola² · O. T. Olurin¹ · A. S. Ogungbe³ · O. A. Ogunkoya¹ · S. O. Okediji¹

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Abstract

An integrated approach involving geophysical and physicochemical methods was undertaken to assess the potential availability of groundwater and its quality was carried out at Akole, Abeokuta Southwestern Nigeria. A combination of electrical resistivity and natural electric field methods were used in delineating the sub-surface lithology, determining potential groundwater-bearing zones, and the potential availability of groundwater for a community water supply. Laboratory analyses of samples from existing wells in the area was also carried out to determine the groundwater quality index (GWQI). Four vertical electrical sounding (VES) stations and nine profiles were surveyed using the Omega Campus and PQWT 150 instruments, respectively. The VES results delineated a maximum of five geo-electric sub-surface layers. A sudden change in the stratigraphy view of the rock formation from soft to very hard formation was observed in profile map L2. Profile map L7 and VES 2 has the highest potential for future groundwater exploration. Areas under VES 3 and profile maps L2, L3, L4, L5, L6, L8 and L9 are categorized as having a “medium” groundwater potential while the low yield water potential are areas under VES 1 and 4 and, profiles maps L1 and L10. The majority of groundwater in the weathered/fractured aquifer of the study area is slightly acidic. The GWQI values were less than 100, an indication that the analysed water samples fall within the “excellent” and “good” quality categories, implying that the groundwater is fit for domestic purposes. A combination of geophysical and physicochemical techniques has been successfully used to provide useful information for the assessment of groundwater potential and quality of the community.

Keywords Groundwater quality index · Physicochemical · Sub-surface lithology · Basement terrain · Geophysical techniques and exploration

Introduction

Water is an important necessity for the sustenance of life and two third of the World’s total land space is covered by water (Shiklomanov 1993). The availability of clean freshwater is one of the great issues facing mankind today, in some ways the greatest, because problems associated with it affect lives of many millions of people (Geyh 2000). However, it

is becoming increasingly difficult in many parts of the world to find sufficient water of a suitable quality for potable use to rapid population increases. This is particularly the case in regions underlain by crystalline basement rocks where it can be difficult to locate suitable groundwater resources within basement fracture zones or in the overlying profile.

These problems can be partially overcome with the use of geophysical techniques. Groundwater exploration has become increasingly dependent on the use of geophysical techniques to gain insight into subsurface conditions. Some of the common techniques used in determining groundwater potential include electrical resistivity, seismic refraction, electromagnetic and sometimes magneto-telluric methods (Todd 2004).

In this study, an integrated magnetic and electrical resistivity survey involving magnetic profiling and 1D VES/2D electrical imaging techniques was carried out to delineate

✉ A. A. Alabi
derylab@yahoo.com

¹ Department of Physics, Federal University of Agriculture, Abeokuta, Nigeria

² Department of Physics, University of Ibadan, Ibadan, Nigeria

³ Department of Physics, Lagos State University, Lagos, Nigeria

the characteristics of subsurface materials. These methods were used to site productive boreholes at two sites underlain by grey gneiss and pegmatized schist, respectively, within the Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria (Olorunfemi and Oni, 2019).

Geophysical investigation methods have been previously used for groundwater exploration in areas underlain by crystalline basement rocks in Nigeria. For example, Bayewu et al. (2017) used Very Low Frequency electromagnetic (VLF-EM) and Vertical Electrical Sounding (VES) geophysical methods to assess the groundwater potential in Awa-Ilaporu, near Ago Iwoye south-western Nigeria. Twenty-three VES stations were established using Campus Ohmega resistivity meter at the areas with high conductive zone, earlier delineated by VLF-EM survey. The VES results inferred 3 to 4 geoelectric layers. Applications of the two methods has been therefore used to identify prospecting location for the groundwater yield in the study area.

Similarly, Moroofo and Gabriel (2014) carried out geophysical investigation for the assessment of groundwater resources in some parts of Abeokuta with a view to highlight the provenance of the groundwater resources and the potential of the aquifers. Seventy-five Vertical Electrical Soundings (VES) were distributed across areas underlain by different rock types and was complemented with 50 groundwater samples collected from wells and analysed for the major ions and seventy two minor constituents. Three to five subsurface geo-electric layers were delineated from the VES. The study aim to evaluate the groundwater potential and quality of groundwater resources of Akole community situated on basement terrain. Geophysical and physicochemical techniques were employed to probe the sub-surface to locate, determine the size and quality of the aquifer zones for groundwater exploration.

Materials and methodology

Description of the study area

The study area is Akole community in Oke Ata (Abeokuta North), Southwestern Nigeria. It is a typical basement area, located between latitudes $07^{\circ} 08' 16.8''$ and $07^{\circ} 08' 24.0''$ and longitudes $03^{\circ} 17' 07.8''$ and $03^{\circ} 17' 15.0''$ (Fig. 1a, b). The area is profound for its undulating rocky terrain with certain gravel and magnetite outcrops. The area has a hilly topography with a surface elevation that varies between 55 to 90 m above sea level around the community.

Hydrogeological setting of the study area

The study area is characterized by an undulating topography and located in the basement complex terrain of

South-western Nigeria. The area is underlain mainly by crystalline basement rocks described as older granites (Rahaman 1988). The crystalline basement rocks lack primary permeability and porosity when fresh, though it can store and transmit groundwater after the development of regolith and discontinuities in their rock mass due to weathering and fracturing (Omada and Obayomi 2012).

The basement rocks in the study area mainly consists of migmatites and migmatite gneisses. As these crystalline rocks have no primary porosity, groundwater occurs within fractures in fresh bedrock and in partially decomposed rock (saprock) near the base of the weathered profile. According to Clark (1985), groundwater development might be predominantly restricted to the aquifer in the weathered overburden or completed in the fractured bedrock in locations where the overburden is relatively thin also, viable aquifers wholly within the fractured bedrock are of rare occurrence because of the typically low storativity of fracture systems. An intrinsically low porosity limits the quantity of water stored in fractured crystalline rock. Sustainable well yields for bedrock, therefore, may strongly depend on the quantity of water stored in surficial materials that can leak downward into bedrock and on periodic replenishment by recharge (Lyford, 2004). The groundwater is contained in the weathered/fractured formations and is primarily recharged through surface precipitation and secondarily through lateral flow from rivers and tributaries.

The region has a wet-dry tropical climate (Aw in the Koppen-Geiger classification system) where amount of rainfall varies 750–1000 mm in the rainy season (March–October) and 250–500 mm in the dry season (November–March) (Akanni 1992).

Field work procedure for geophysical survey

Natural electric field (NEF)

Nine profiles were established using PQWT–TC 150 m equipment. Twenty five points were sounded per profile with an interval spacing of 2 m and a probing depth of 150 m. PQWT is a sensitive automatic geophysical prospecting instrument which uses the earth's electromagnetic field as the source field and it is used to measure the potential difference between any two points on the ground produced by natural electric current that occurs beneath ground. These underground natural currents are generated by electrochemical processes between different conductive mineral bodies that are in contact, and by the flow of groundwater through porous materials in the subsurface. By principle, the electric components of the earth electromagnetic field at different frequencies are being measured in millivolt (mV) to determine the resistivity contrast of the varying geologic structures in relation to the lithological

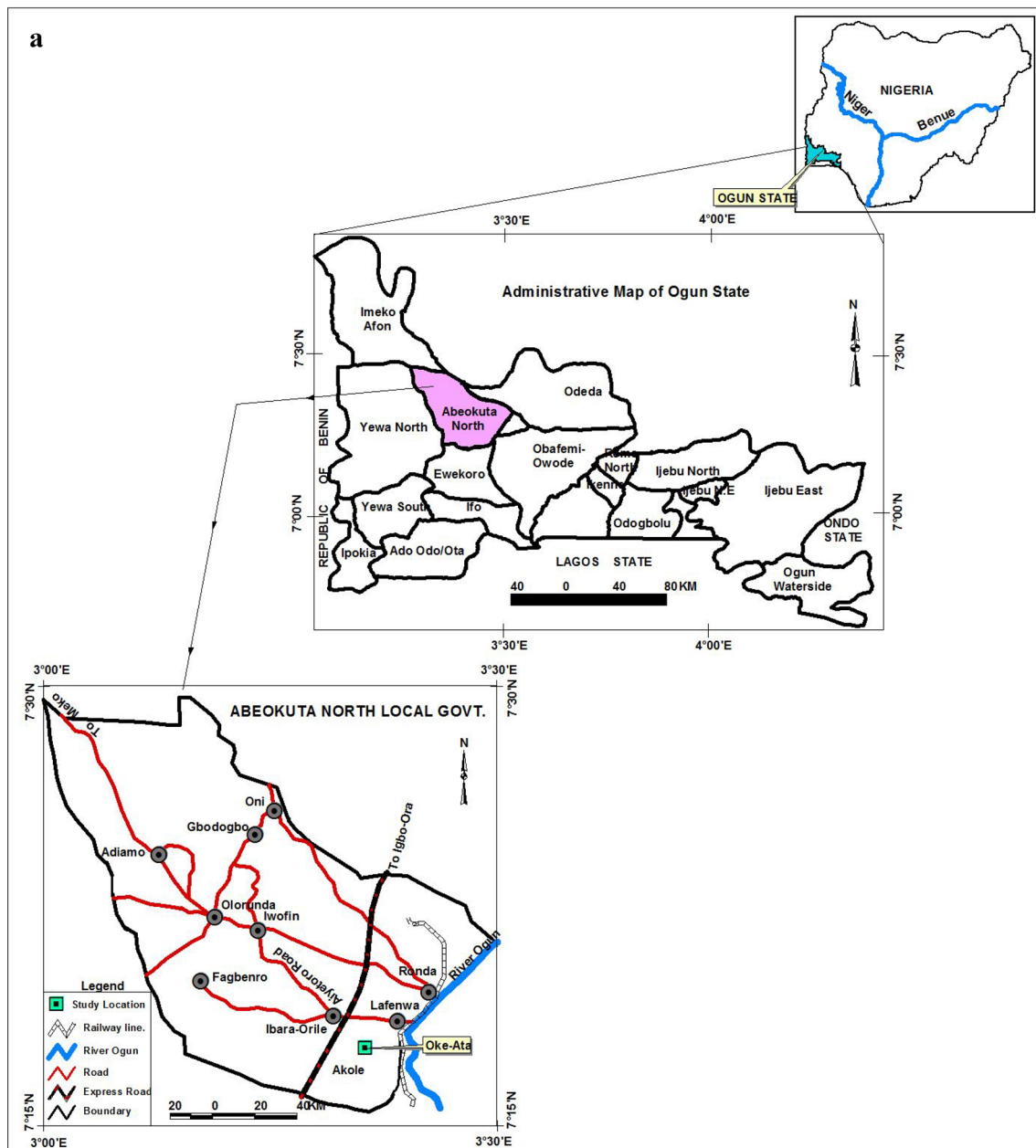


Fig. 1 a Map of Nigeria showing the community where the study area is located (Alabi et al. 2018). b Geological map showing the rock type that underlies the study area

bodies under interaction (Hunan 2018). The resistivity of the medium (ρ_m) is given by Eq. (1).

$$\rho_m = \frac{1}{\partial f} \left(\frac{E_x}{H_y} \right)^2 \tag{1}$$

where; f —Operating frequency, H_y —Magnetic field component and E_x —Electric field component

Vertical electrical sounding (VES)

Four vertical electrical soundings (VES) were carried out at different locations and interpreted with the aid of IPI2WIN software using an interactive semi-automated technique (Bobachev 2003). The root mean square (RMS) error obtained for each iteration process conducted for each sounding station was lower than 5%. The VES data were both interpreted quantitatively and qualitatively, which involves the determination of the resistivity and

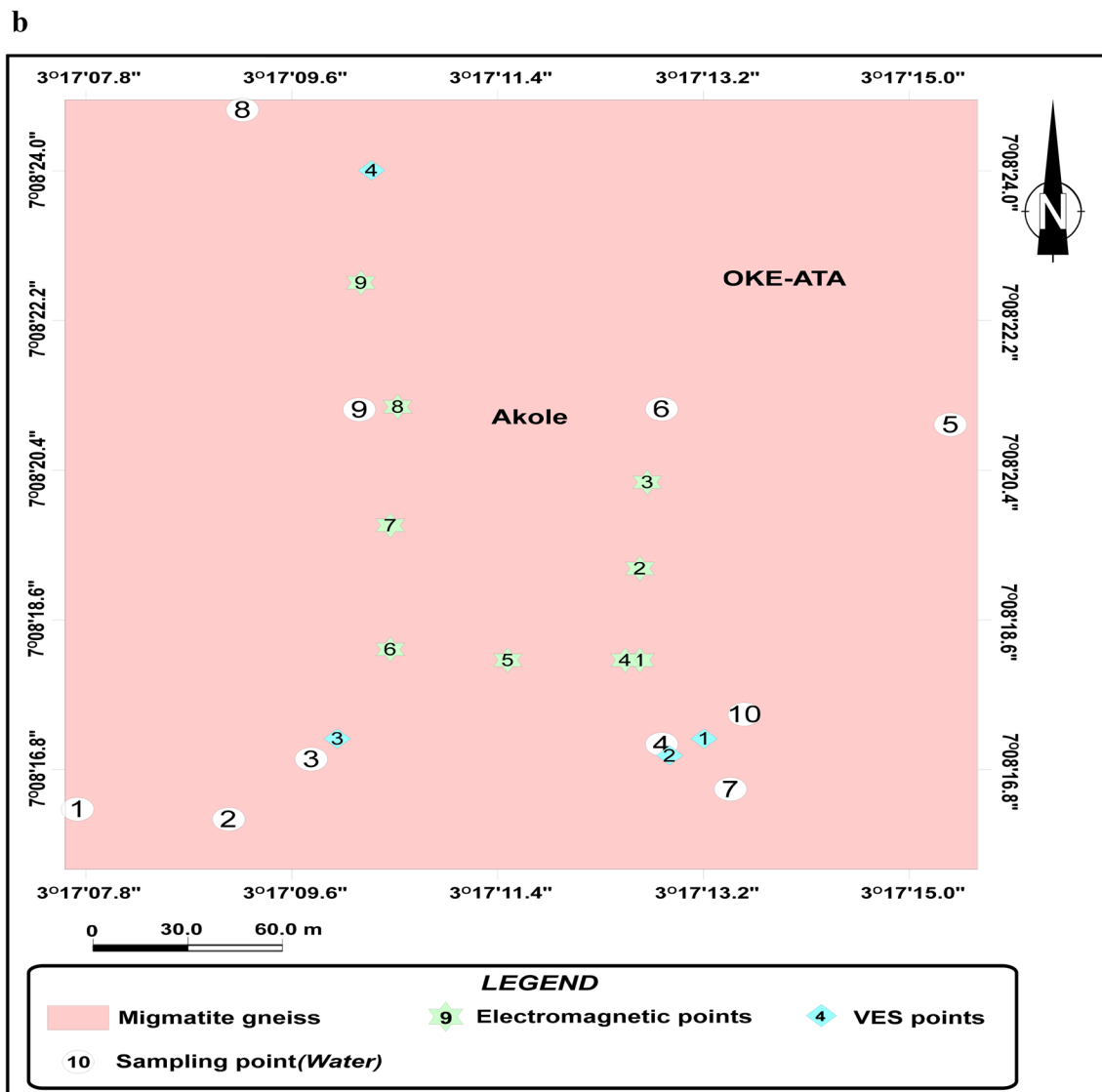


Fig. 1 (continued)

thickness of different horizons. The reflection coefficient (R_c) values of the fresh basement rock of the study area were calculated using Bhattacharya and Patra (1968); Olayinka (1996) and the Loke (1999) method as expressed by Eq. (2).

$$R_c = \frac{\rho_n - \rho_{n-1}}{\rho_n + \rho_{n-1}} \tag{2}$$

where, ρ_n is the layer resistivity of the n th layer and ρ_{n-1} is the layer resistivity overlying the n th layer. Mathematical relations were used to determine two secondary parameters (longitudinal conductance (S_i) and transverse resistance (T_i)) from the layers' resistivities and thicknesses (Zohdy et al. 1974).

$$S_i = \sum_{i=1} \frac{h_i}{\rho_i} \tag{3}$$

$$T_i = \sum_{i=1} h_i \rho_i \tag{4}$$

Laboratory testing of groundwater samples

Water samples were collected from different ten sampling points (along different streets) within the community that is situated in a site of different aquifers types, nine of the sampling points are from hand-dug wells and one from borehole (were labelled A–J). Two water samples were taken from each

sampling point, one sample was used for non-metallic analysis while the other sample employed for heavy metal analysis was filtered using 0.45 µm membrane filter and acidified with small amount of concentrated nitric acid, to reduce the pH below pH 2 to limit metal sorption on the sample container. Labelled clean sterilized 2.5 L polythene kegs were used to collect the samples. The hand-dug well are constructed in a perched ferricrete aquifer. The samples were packed under controlled temperature to avoid destabilization and the co-ordinate location of their respective sampling points were taken. The analysis was carried out at Ogun State Water Cooperation laboratory Oke Mosan, Abeokuta. The chemical analysis of samples was extended to include: heavy metals, chlorides, sulphate, and phosphate concentrations. Also analysed were: dissolved oxygen (DO) and chemical oxygen demand (COD), pH, temperature, electrical conductivity, total dissolved solids (TDS), total hardness and turbidity. The dissolved oxygen (DO), temperature and pH were determined and recorded immediately at the site. Other tests were subsequently conducted in the laboratory.

Weighted arithmetic groundwater quality index method

Water quality is categorised based on the degree of purity using the most commonly measured water quality variables under the weighted arithmetic groundwater quality index method (GWQI). This method has been widely used (see e.g., Rao et al. 2010; Balan et al. 2012; Chowdhury et al. 2012) and the calculation of WQI was done using Eq. 5 (Brown et al. 1972a, b).

$$GWQI = \frac{\sum q_n w_n}{\sum w_n} \tag{5}$$

where, q_n is the quality rating scale and w_n is the unit weight.

The quality rating scale (q_n) for each parameter is calculated using Eq. (6)

$$q_n = 100 \left[\left(\frac{V_n - V_o}{S_n} \right) \right] \tag{6}$$

where, V_n : estimated concentration of nth parameter in the analyzed water, V_o : the ideal value of this parameter in pure water, $V_n = 0$ (except pH=7.0 and DO= 14.6 mg/l), S_n recommended standard value of nth parameter. The unit weight (w_n) for each water quality parameter is calculated using Eq. (7).

$$w_n = K / S_n \tag{7}$$

where, k = proportionality constant and can also be calculated using Eq. (8)

$$k = \frac{1}{\sum (1/S_n)} \tag{8}$$

The rating of water quality according to WQI values is given in Table 1 (Mishra and Pancel 2001)

Results and discussion

VES results

The curve types observed in the area are 4-layer HA-type (75%) and 5-layer HKH (25%). It is often possible to make qualitative hydrologic deduction from curve type (Worthington 1993). The geo-electric parameters, i.e., the resistivity, layer thickness and depth of the various layers and the inferred lithology’s are shown in Table 2.

The geo-electric interpretation revealed 4–5 geo-electric layers: The topsoil layer consists of sandy clays, clayey sands and lateritic soils with resistivity values ranging between 200 and 280 Ωm. The layer thickness varies between 0.5 to 1.33 m; the sand/clay which is composed of sandy clay and clayey sand. This layer is characterized with resistivity values varying from 116 to 148 Ωm with layer thickness varying between 0.55 and 5.72 m; the lateritic soil layer with resistivity value and layer thickness of 275 Ωm and 1.77 m, respectively (under VES 1 only); the weathered basement layer with resistivity values ranging from 157 to 623 Ωm and the thickness of this unit varies between 4.19 and 18.17 m. The overburden thickness varies from 0 to 7.04 m; and lastly fresh basement layer which is characterized by resistivity values varying from 1135 to 5854 Ωm with an infinite thickness.

NEF results

The NEF data processing was enhanced by the PQWT’s unique in-built computing software which uses analogue to digital sampling to generate automatically a frequency curve graph with profile map (Kearey 2012).

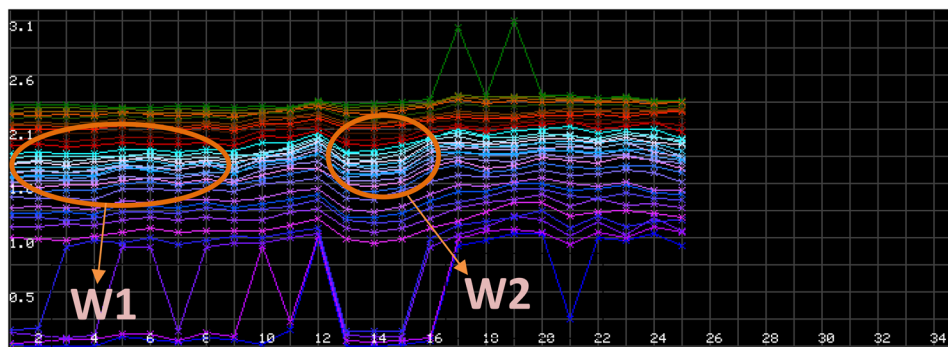
Where lines of low resistivity converge or intersect (W1 and W2) in Fig. 2a, indicate a weathered rock formation (zone with a high probability of getting groundwater/ water bearing zone). Profile L1 (Fig. 2b) generally consists of a soft to medium rock formation. There is very

Table 1 Water quality classification based on GWQI value (Mishra and Pancel 2001)

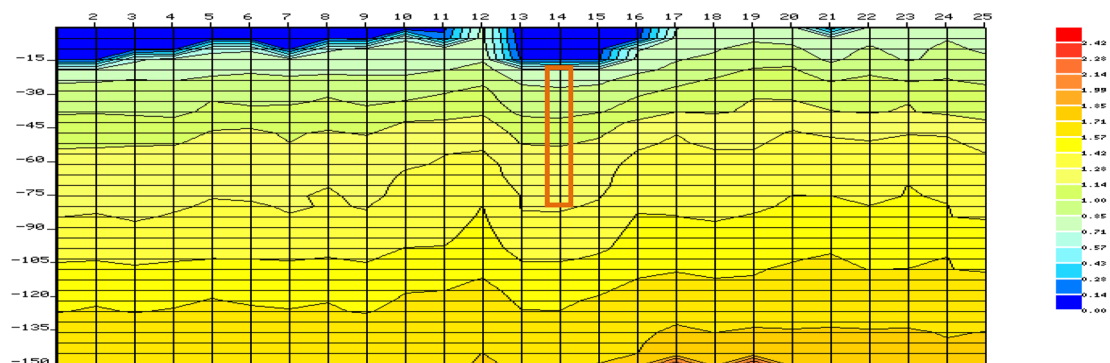
GWQI	Water quality
0–25	Excellent
26–50	Good
51–75	Fair
76–100	Poor
100 and above	Unfit for drinking

Table 2 Summary of VES points, number of layers, resistivity, thickness, depth, inferred lithology of sub-surface and typical sounding curve

VES No	No of layers	Resistivity (Ωm)	Thickness (m)	Depth (m)	Inferred lithology	Curve type
1	1	200	0.5	0.5	Topsoil	HKH
	2	148	1.48	1.98	Sand clay	
	3	276	1.77	3.75	Lateritic soil	
	4	157	5.63	9.37	Weathered basement	
	5	1146	–	–	Fresh basement	
2	1	244.71	1.3271	1.3271	Topsoil	HA
	2	131.98	5.7164	7.0435	Sandy clay	
	3	307.88	18.174	25.217	Weathered basement	
	4	1135	–	–	Fresh basement	
3	1	273	0.604	0.604	Topsoil	HA
	2	117	0.535	1.14	Sandy clay	
	3	623	8.46	9.6	Weathered basement	
	4	2569	–	–	Fresh basement	
4	1	280	1.06	1.06	Topsoil	
	2	116	0.75	1.81	Sandy clay	
	3	412	4.19	6	Weathered basement	
	4	5854	–	–	Fresh basement	



a



b

Fig. 2 **a** A frequency curve graph with profile map of L1. **b** Result for profile L 1

low or zero chance of getting groundwater at the depths of 55–150 m because of its high resistivity, high density, high potential value and hard rock formation/basement

rock. Point 14 at a depth of 55 m can be suggested for drilling well with an overburden of 5 m. A fairly good yield should be expected.

A sudden change occurs in the homogeneity of the resistivity lines of the subsurface material ranging from low to high S values at point 11 (Fig. 3a) which implies a sudden change from soft to very hard rock formation on point 11 at a depth from 15 to 150 m (Fig. 3b). Profile L 2 has two major fracture bearing zones F1 and F2 (Fig. 3a) on point 2 at 10 m depth and on point 4 at 8 m depth with an additional minor fracture at 20 m depth. Point 4 at a depth of 45 m is a good point for well recommendation with an overburden of 8 m. A fairly good—moderate yield should be expected at this site.

The subsurface material formation is homogeneous in profile L5 due to the series of straight/parallel resistivity lines one—one except W3 and W4 at points 4 and 28 where the lines curve (Fig. 4a); which indicates a variation in the subsurface properties. Profile L5 generally consists of a soft to very hard rock formation. At a depth 1–30 m the subsurface materials are likely to consist of materials that are

of low resistivity, low density, soft and low potential value while depths 30–75 m have medium resistivity, medium density and medium potential value subsurface materials. Depth of 75–150 m are characterized with a high resistivity, high density, high potential value and hard rock formation/basement rock (Fig. 4b). Point 20 at a depth of 40 m seem suitable for drilling a well with an overburden of 5 m. A fairly good yield should be expected at this site.

Profile L10 (Fig. 5a, b) is predominantly dominated by a very hard rock formation. It is not suitable for well recommendation as the yield maybe very low or there may be no yield.

There are three major fracture zones F3, F4 and F5 delineated on point 12 at profile L7 (Fig. 6a). A major outcrop was noted at point 8 which was also observed (visible) during the field work (Fig. 6b). Profile L7 generally consists of very hard (high resistivity, high density and high potential

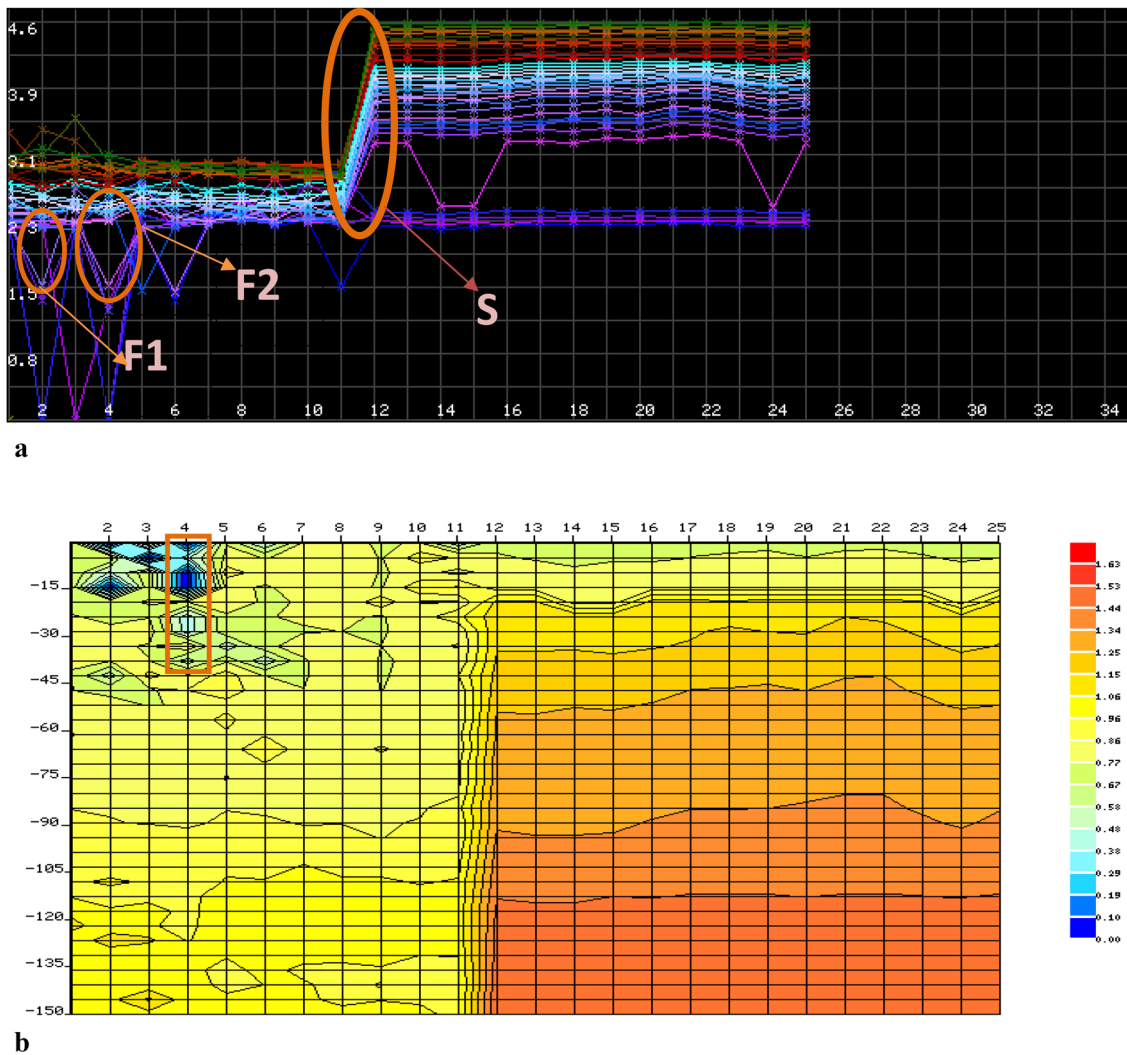


Fig. 3 a A frequency curve graph with profile map L2. b Result for profile L 2

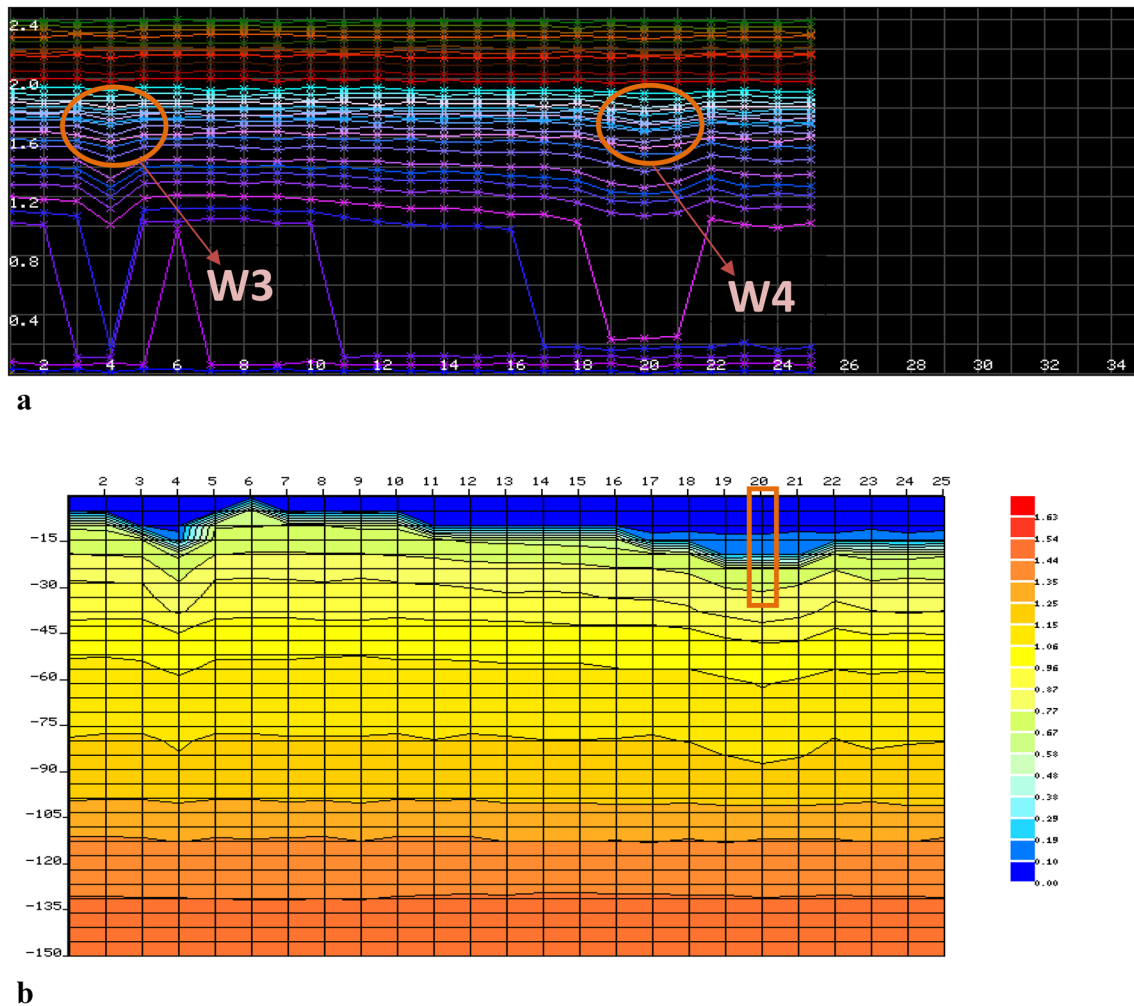


Fig. 4 **a** A frequency curve graph with profile map L5. **b** Result for profile L 5

value) rock formation. The three overlying fracture zones are on point 12 at depths 10–20 m, 45–50 m and 105–120 m. Point 12 at a depth of 120 m is good for well recommendation with an overburden of 5 m. A moderate–high yield should be expected.

Groundwater potential evaluation

The weathered layer thickness and resistivity, overburden thickness, transverse resistance, reflection coefficient, longitudinal conductance, presence of fracture/weathered rock (Table 3) and the NEF profile map were employed for the evaluation of the groundwater potential of the area. Anudu (2011), observed that transverse resistance (T_i) has a direct relation with transmissivity (T) and that the highest T_i values reflect the highest T values of the aquifers and vice versa. VES stations having computed transverse resistance values greater than $5000 \Omega\text{m}^2$ (2 and 3) are defined as areas of high groundwater potential.

A lower coefficient value exhibits a fracture of the basement rock, and hence, has a higher water potential (Olayinka 1996).

The potential of groundwater in the study area is delineated into three (3) segments using VES parameters and NEF profile maps: the “high” groundwater potential, “moderate” groundwater potential and the “low” groundwater potential zones. Three basic criteria were considered in evaluating promising points for groundwater drilling targets (Olayinka et al. 1996; Adeniji et al. 2013; and Bayewu et al. 2017):

- i. Areas with high yield: These are areas with a transverse resistance greater than $5000 \Omega\text{m}^2$, a reflection coefficient less than 0.7 and a weathered layer thickness greater than 15 m.
- ii. Areas with medium yield: These are areas with a transverse resistance greater than $5000 \Omega\text{m}^2$, a reflection

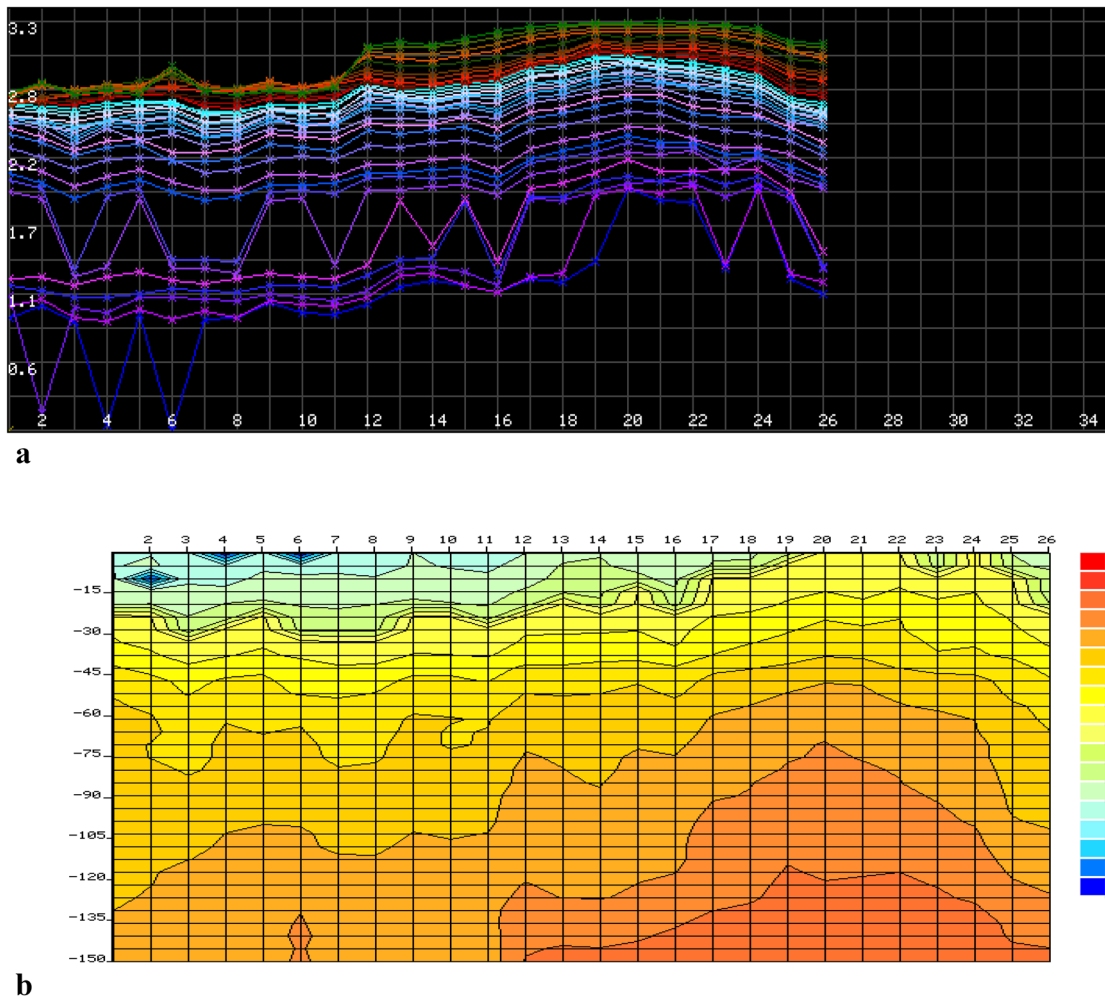


Fig. 5 **a** A frequency curve graph with profile map L10. **b** Result for profile L 10

tion coefficient less than 0.7 and a weathered layer thickness less than 15 m.

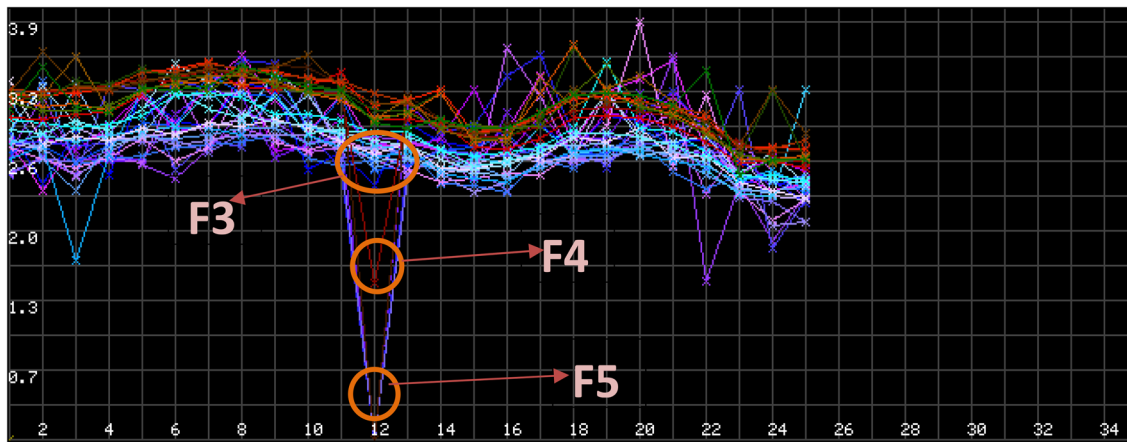
- iii. Areas with low yield potential: These are areas with a transverse resistance less than $5000 \Omega\text{m}^2$, a reflection coefficient greater than 0.7 and a weathered layer thickness less than 15 m.

Areas under VES 2 and NEF profile map L7 have the best potential for future groundwater exploration. Areas under VES 3 and NEF profile maps L2, L3, L4, L5, L6, L8 and L9 are categorized as having a moderate groundwater potential while area under VES 1 and 4 and profiles map L1 and L10 are suspected to have a low groundwater potential. The community borehole of the study area is located at point 15 on Fig. 2b which is found to be under medium groundwater potential category. However the rate of water supply from this well has reduced greatly and is no longer able to serve the community efficiently especially during the dry season.

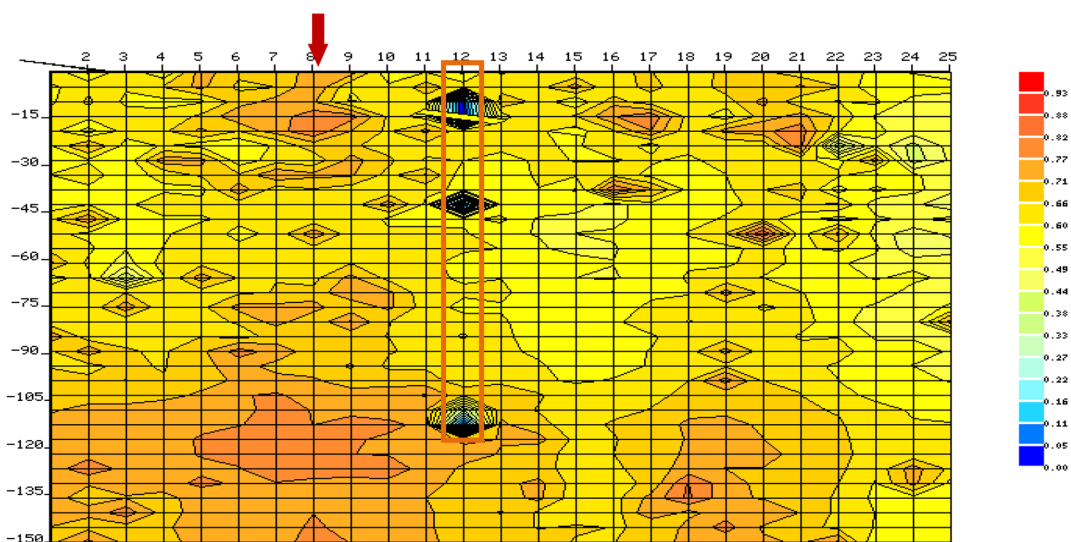
Results of the physicochemical parameter testing

Iron concentrations and E coli levels in all samples were below detection limits (Table 4). Only sample G falls within the standard values of the Nigerian Standard for Drinking Water Quality (NSDWQ) and World Health Organization (WHO) for all the parameters tested for in Table 5. All the remaining water samples had one or more parameters, which did not comply with the drinking water guidelines, which implies that only water sample G is considered to be suitable for potable use without treatment. The remaining samples would need to be treated before they could be used for potable use.

Statistically only the mean of the pH values and turbidity did not fall within the permissible limit set by WHO and NSDWQ which suggests that majority of the water samples investigated were slightly acidic (Table 5). Although both pH and turbidity have no direct health impact (NSDWQ 2015), the water samples with



a



b

Fig. 6 **a** A frequency curve graph with profile map L7. **b** Result for profile L 7

Table 3 Groundwater potential across the VES

Parameter	VES 1	VES 2	VES 3	VES 4
Weathered layer thickness (m)	5.630	18.174	8.460	4.190
Overburden thickness (m)	1.960	7.044	1.139	1.810
Reflection coefficient	0.759	0.573	0.610	0.869
Longitudinal conductance (Ω^{-1})	0.056	0.108	0.020	0.020
Transverse resistance (Ωm^2)	1691.47	6674.62	5498.07	2110.08
Presence of fracture/weathered rock	Weathered rock	Fracture present	Fracture present	Weathered rock
Remark	Low yield	High yield	Medium yield	Low yield

turbidity values above the WHO and NSDWQ standard can serve as host for microorganisms thereby protecting water from disinfection and can also entrap heavy metals and biocides. This can bring problem in water treatment process and can also be a potentially risk of pathogen

contamination in treated water. While water with acidic pH levels can leach metal from pipes and can also corrode plumbing materials.

Table 4 Summary of result of the physicochemical parameter test

Parameter	A	B	C	D	E	F	G	H	I	J
Temperature	26.90	25.70	26.00	25.40	25.50	25.10	24.90	25.60	26.10	27.00
pH value	5.70	5.98	5.38	5.67	5.95	6.60	7.01	6.44	6.45	5.93
Dissolve oxygen	5.87	5.50	6.22	6.34	5.91	5.94	5.86	5.92	6.57	5.80
Conductivity (µs/cm)	170.70	168.70	98.80	84.40	76.40	243	355	238	139.40	213.00
Colour (TCU)	5.00	10.00	25.00	5.00	5.00	5.00	10.00	5.00	10.00	35.00
Turbidity (NTU)	0.98	0.72	1.44	11.5	37.6	1.25	1.39	2.78	14.80	1.16
Total solids(mg/l)	185.70	200.00	150.00	150.00	180.00	200.00	275.00	200.00	220.00	180.00
Total dissolved solids (mg/l)	81.20	75.80	44.30	39.90	35.80	118.10	151.80	108.60	61.30	101.30
Total suspended solids (mg/m3)	104.50	124.20	105.70	110.1	144.20	81.90	113.20	91.40	158.70	78.70
Acidity (mg/l)	20.00	19.00	26.00	27.00	9.00	21.00	12.00	6.00	18.00	26.00
Alkalinity (mg/l)	23.00	25.00	14.00	22.00	28.00	77.00	92.00	67.00	20.00	40.00
Calcium hardness (mg/l)	48.50	28.50	11.60	14.60	64.70	20.80	76.20	47.00	16.20	25.40
Magnesium hardness (mg/l)	16.90	4.60	3.10	6.90	26.20	43.90	13.90	14.60	3.80	14.60
Chloride (mg/l)	3.96	17.60	10.70	8.80	10.10	13.60	20.20	12.80	12.30	16.70
Iron(mg/l)	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL
Sulphate (mg/l)	51.00	33.00	27.00	11.00	8.00	13.00	25.00	19.00	11.00	1.00
<i>E. coli</i> (24 h)	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL	NIL

Table 5 Descriptive statistics of physicochemical analyses

Parameters	Range	Mean ± Std	WHO (2017) Guide-lines		NSDWQ (2015) MPL
			RL	MPL	
Temperature	24.90–27.00	25.82 ± 0.70	Variable	Variable	Ambient
pH value	5.38–7.01	6.11 ± 0.50	6.50	8.50	6.50–8.50
Dissolve oxygen	5.50–6.57	5.99 ± 0.30	–	–	7.50
EC (µS/cm)	76.40–355.00	178.74 ± 86.51	< 750.00	1000.00	1000.00
Colour (TCU)	5.00–35.00	11.50 ± 10.29	15.00	–	15.00
Turbidity (NTU)	0.72–37.60	7.36 ± 11.73	< 1.00	5.00	5.00
TS (mg/l)	150.00–275.00	194.07 ± 36.02	–	–	–
TDS (mg/l)	35.80–151.80	81.81 ± 38.08	< 500.00	1000.00	500.00
TSS (mg/m3)	78.70–158.70	111.26 ± 25.61	< 500.00	1000.00	–
Acidity (mg/l)	6.00–27.00	18.40 ± 7.32	–	–	–
Alkalinity (mg/l)	14.00–92.00	40.80 ± 27.6	< 300.00	–	–
Ca ²⁺ (mg/l)	11.60–76.20	35.35 ± 22.5	< 75.00	200.00	–
Mg ²⁺ (mg/l)	3.10–43.90	14.85 ± 12.5	< 50.00	150.00	20.00
Chloride (mg/l)	3.96–20.20	12.68 ± 4.71	< 200.00	250.00	250.00
Iron (mg/l)	0.00	0.00 ± 0.00	< 0.30	1.00	0.30
Sulphate (mg/l)	1.00–51.00	19.90 ± 14.61	< 200	400.00	100.00
<i>E.coli</i> (24 h)	0.00	0.00 ± 0.00	0.00	–	0.00

Groundwater quality index results

The result of groundwater quality index value for individual water samples (Table 6) which range between 19.9 and 34.6. Based on groundwater quality classification by Mishra and Pacel (2001) (Table 1), the calculated values of

GWQI, Which, is a mathematical instrument used to transform large quantities of water quality data into a single number that represents the water quality level fall within the “excellent” and “good” categories, which implies that the water is fit for domestic purpose since the groundwater quality index is less than 100.

boreholes especially for commercial purpose like the community borehole.

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