RESEARCH PAPER

APPLICATION OF GEOELECTRICAL AND CHEMICAL METHODS FOR GROUNDWATER ASSESSMENT IN ISHERI-NORTH, OGUN STATE, NIGERIA

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ABSTRACT
Geoelectrical investigation and chemical analyses were carried out at Isheri North area of Ogun State in order to assess the groundwater quality at shallow depth and its deep potential zone for groundwater development. The study area has been selected for investigation due to infiltration of the polluted Ogun River. Forty-three (43) Schlumberger Vertical Electrical Soundings (VES) and chemical analyses of water samples from one hand dug well and two shallow boreholes in the study area were carried out. Four to five geoelectric layers which correspond to top soil, clayey sand, sandy clay, clay and sand were delineated. The longitudinal conductance values (0.02 - 0.106mhos) of the topsoil in the area reveal its poor to weak protective capacity, thus exposing the underlying clayey sand to contamination as reflected from its resistivity values ranging from 4.8-15.1Ωm. This low resistivity zone at shallow depth (3 – 26m), occasioned by infiltration, was further ascertained by high values of conductivity, turbidity, total hardness, TDS, Cl, Fe, and Mn ions in the analyzed water samples taken at depth ranges from 9 – 16m. The results of the analyzed water samples from this shallow zone are beyond international standards for drinking water. The underlying clay resistivity values ranged between 1.9 - 6.1Ωm and thickness varied from 50.8 - 100.5m. This acts as the seal for the underlying aquifer (sand layer). The resistivity of the sand layer varied from 91.7-159Ωm with a depth interval of 101.7-109.4m and 73.4-82.3m in VES 1 and VES 14 respectively. This constitutes the deep aquifer units in the study area. The longitudinal conductance values of the overburden above the profound aquifer units varied between 10.5-33.0 mhos and are indicative of very good to excellent protective capacity rating. Thus, the underlying deep aquifer units are well protected from being contaminated.

Keywords: *Electrical Resistivity, Groundwater, Aquifer, Geoelectric Section*

INTRODUCTION
The urban and rural residents in several parts of Nigeria are battling with inadequate availability of potable water for domestic and industrial usage. This difficulty increases daily due to the continuous increase in population and industri-

alization across the country. As a consequence, the demand for clean water is on the increase and the available surface water cannot be depended on because they have been highly polluted and also the supply is inadequate. In addition to being vulnerable to pollution, surface water sources are also easily affected by extreme weather conditions consequent upon which they are considered as unreliable, unsuitable and unsustainable in many parts of the world (Adiat *et al*., 2012). Hence, the need to look for other alternatives to supplement surface water. In order to meet both industry and local demands, groundwater exploration and development are needed. Groundwater is the water held in the subsurface within the zone of saturation under hydrostatic pressure below the water table (Ariyo and Banjo, 2008).

The identification of damages/changes that are affecting the underground water quality due to the effect of contaminants is often done after environmental problems have become evident in the water (Rao *et al.,* 2014). The widespread development of ground water is due to the fact that it is the only affordable and sustainable way of improving access to clean water to meet the Millennium Development Goals for water supply by 2015 (Macdonald *et al*., 2008). Groundwater occurrence depends on geology, geomorphology/weathering and rainfall. The interplay of these three factors gives rise to complex hydrogeological environments with some variations in the quality, quantity, ease of access and renewability of ground water resources (Adelana and Macdonald, 2008).

Groundwater is characterized by a certain numbers of parameters that geophysical methods are trying to determine from surface measurements, mostly indirectly, but sometimes directly. The most usual parameters are porosity, permeability, transmissivity and resistivity or conductivity. The electrical resistivity method has been successfully employed in the delineation of subsurface geological sequence, geological structures/features of interest, aquifer units, types and depth extent in almost all geological terrains (Ajayi and Adegoke, 1988; Olayinka, 1990; Olorunfemi and Okhue, 1992; Emenike, 2001; Shaaban, 2002; Ibrahim *et al*., 2004; Oladapo *et al*., 2004; Israil *et al*., 2007; Oyedele *et al*., 2007; Adeoti and Ishola, 2008; Atakpo, 2009; Osazuwa and Chii, 2010; Singhal *et al*., 2010).

Groundwater abstraction intensifies migration of contaminants to the subsurface, activates salt water encroachment into pumped aquifers from neighboring ones, and sea water intrusion into coastal wells (Kalimas and Gregorauskas, 2002). In geophysical prospecting, the contrast between physical properties of the target and the environment is measured. The larger the contrast or anomaly, the better the geophysical response and hence the easier it is to identify. Hence, for groundwater exploration, integration of techniques is most essential for success to be achieved economically (Rosli *et al*., 2012). The application of geophysics for the successful exploration of groundwater in sedimentary terrain requires a proper understanding of its hydro-geological characteristics. Evidence has shown that geophysical methods are the most reliable and the most accurate means of all surveying methods of subsurface structural investigations and rock variation (Emenike, 2001). Geophysical and hydro-chemical methods were carried out to identify the saline water intrusion and salinity origin in the Central Godavari delta, Bay of Bengal Coast in Andhra Pradesh, India. The study shows that the large thickness of clay formations is responsible for groundwater salinity in the Godavari delta. The marine clays possess the palaeo salinity due to the recession of the sea level. The depositional history and the elevated values of TDS, Na, SO_4, Cl concentrations indicated that salinity is due to in-situ salinity of groundwater in the marine clays rather than lateral movement of sea water from Bay of Bengal (Lagudu *et al*., 2013).

Akankpo and Igboekwe (2011) used electrical resistivity and hydrochemical analyses to access the level of contamination of the groundwater in Uyo, Southwestern Nigeria. The study

exemplified that the combination of electrical tomography and hydrochemical analysis is a unique and powerful technique for monitoring the groundwater contamination at dumpsites as well as examining shallow complex subsurface structures; an approach suitable in the studies of water quality. Choudhury and Saha (2004) used the integration of a combined geophysical survey (DC resistivity profiling, resistivity sounding, and shallow seismic refraction methods) and periodic chemical analysis for ground water and saline contamination studies at Digha -Shankarpur area, West Bengal, India. The study proved to be a powerful method for identification of the subsurface formations, ground water zones, the subsurface saline/brackish water zones, and the probable mode and cause of saline water intrusion in an inland aquifer. Geophysical techniques combined with geochemical methods are effective tools to investigate the saline water intrusion and salinity source. The resistivity tomography tool has been successfully used to demarcate the saltwater–freshwater interface in different coastal settings (Frohlich *et al.*, 1994; Nowroozi *et al.*, 1999).

Surface electrical resistivity has been proved as a practical method in detecting industrial waste seepage in order to locate and define the extent of the contaminated body of ground water (Stollar and Roux, 1975). The electrical resistivity method is a viable tool to investigate groundwater exploration in the sedimentary area and this has proven consistent (Emenike, 2001). Oyedele (2001) integrated geophysical and hydrogeochemical investigations of groundwater quality in some parts of Lagos, South-Western Nigeria. The study showed a means of delineating zones of good quality fresh groundwater from the polluted groundwater and also indicated a high degree of success when compared with the quality of the water obtained from the drilled wells. Adeoti *et al.* (2008) assessed the leachate effect on groundwater using electrical resistivity imaging and hydrochemical methods in a dumpsite in order to determine the level of contamination of

groundwater within some distance away from the vicinity of the dumpsite.

The electrical resistivity method of geophysical technique happens to be the most preferred method in groundwater contamination studies and hydrological investigations. Several researchers addressed the similar problems of groundwater studies within and outside Nigeria using geophysical methods (Gnanasundar and Elango, 1999; Carrasquilla *et al.,* 2007; Abiola *et. al.*, 2009; Oyedele *et al.*, 2011).

In Isheri North, the situation is challenging as many citizens mainly depend on water supply from hand dug wells and boreholes constructed by private individuals. The study area has also been selected due to infiltration of the polluted Ogun River. In this study, vertical electrical sounding using Schlumberger array, chemical analyses and borehole log information in the area were employed to assess the groundwater quality at shallow depth and its potential zone in the deeper region in Isheri-North area of Ogun-State, Nigeria.

Geology of the study area
The study area is within the tropical rain forest zone of Nigeria. The area is generally characterized by trees and shrubs. Tropical rain forest areas are characterized by long wet season spanning from April to October and short dry season spanning from November to March (Olumayede and Okuo, 2013). The study area has an average temperature between 25 to 27° C. The topography is relatively flat with elevation differential over long distances. The area of investigation is located in Ifo Local Government Area of Ogun State, Southwestern Nigeria. Isheri-North is a sedimentary part of Ogun State environment situated on the Dahomey Sedimentary Basin (Alluvium) and underlain by Ilaro Formation and followed by Ewekoro Formation (Jones and Hockey, 1964) which has been subdivided into the Ewekoro and Oshosun (Reyment, 1965) and later into the Ewekoro, Akinbo and Oshosun. The Imo shale in the Osse Basin appears to transform laterally into

the Ewekoro Formation in the Ogun Basin (Offodile, 2002). The Map of Nigeria showing Ogun State where the study took place is shown in Fig. 1a. The geological map of Ogun State (Olabode and Adekoya, 2007) reflecting the study area is presented in Fig. 1b while the base map of the study area showing the sampling points is displayed in Fig. 1c.


(a)

(b)

(c)

Fig. 1: (a) Map of Nigeria; (b) Geological map of Ogun State *(Olabode and Adekoya, 2007)* **and (c) Map of the study area**

METHODOLOGY
Data acquisition
Electrical resistivity survey
PASI 16GL Resistivity Meter was used to acquire the apparent ground resistivity data at each of the sounding points. A total of 43 vertical electrical soundings were carried out along six traverses in the study area. Schlumberger electrode array was adopted for maximum current penetration into the subsurface to acquire the VES resistivity data. The current electrode spread varied from 2m to a maximum of 700m. The sounding points were selected randomly based on the positions of aborted boreholes, contaminated hand dug well and available spaces for deeper probing within the study area. VES 1 in traverse one and VES 14 in traverse two were carried out at the two accessible borehole points.

Chemical analyses of water samples
The location coordinates of the three sample points (A, B and C) were taken with a Global Positioning System (GPS). Location A has latitude 6°38′44.70²N and longitude 3°24′03.4²E, location B has latitude 6°38′58.7²N and longitude 3°24′31.2²E and location C has latitude 6°39′47.20² N and longitude 3°24′20.07²E. Water sample A was collected in a hand dug well of 9m deep located at South eastern part of the area, while water sample B was collected from a borehole 14m deep located at the South western part of the area. Water sample C was collected from a borehole at 16m deep located at the Northern part of the study area. The three water samples were collected using one litre of cleaned plastic bottle for each and later sealed. The physical parameter observed in the field was the colour of the water. The collected samples were not preserved due to the fact that the samples were sent to the laboratory immediately that day for analyses. The collected samples were filtered by Whatman filter paper prior to their analyses in the laboratory except for turbidity. The water samples were filtered to remove suspended particulates from the samples before analysis. This is to reduce possible interferences from the particles especially in the

colorimetric analysis for phosphate, nitrate and sulphate.

Data processing and interpretation
Electrical resistivity method
The processing of the depth sounding curves was carried out by adopting the partial curve matching technique. In order to do this, the VES data were plotted on a transparent overlay. The partial curve matching technique involved the use of a standard two (2) layer master curve and four (4) auxiliary type curves (H, K, A, and Q). The apparent resistivity values were plotted against the current electrode separation for each VES point using a log-log graph to obtain the resistivity curve type for the area reflective of the subsurface geology. This procedure required segment-by-segment curve matching starting from the position with shorter electrode spacing and moving towards those with longer spacing. Preliminary interpretation of the resistivity curves using partial curve matching technique to obtain the layer resistivity and layer thickness was used as an initial model for a computer iterative software known as WINRESIST. In order to correlate the resistivity response, two of the VES point data were acquired in the vicinity of an existing borehole in the study area which serves as control.

The estimation of the aquifer protective capacity was 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 by using the equation numbered 1 below (Abiola *et al.*, 2009).

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

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.

Zohdy *et al.* (1993) presented the resistivity differences as a function of water quality in

Oxnard Plain, California. The modified form of the interpretation is presented in Table 1 below. This was used as a guide with the well log data in Fig. 2 for the interpretation of VES results.

The modified longitudinal conductance/ protective capacity rating as shown in Table 2

was used as a guide for the classification of the protective capacity rating. The topsoil and the overburden longitudinal conductance values were obtained from equation 1.

Chemical analyses of water samples
The detailed analytical procedures of chemical

Table 1: Resistivity of water and sediments

| Resistivity, Ohm-m	Sediments	Interpretation
0.5 – 2.0	Very porous sand or saturated clay	Seawater very saline water
2.0 – 4.5	Porous sand or saturated clay	Saline water
5 – 15	Sand, clayey sand, sandy clay	Brackish water
15 – 30	Sand, gravel, some clay	Poor quality fresh water
30 – 70	Sand, gravel, minor clay	Intermediate quality fresh water
70 – 100	Sand, gravel, no clay	Good quality fresh water
More Than 100	Coarse sand, gravel, no clay	Very good quality fresh water

Modified from Zohdy et al. (1993)
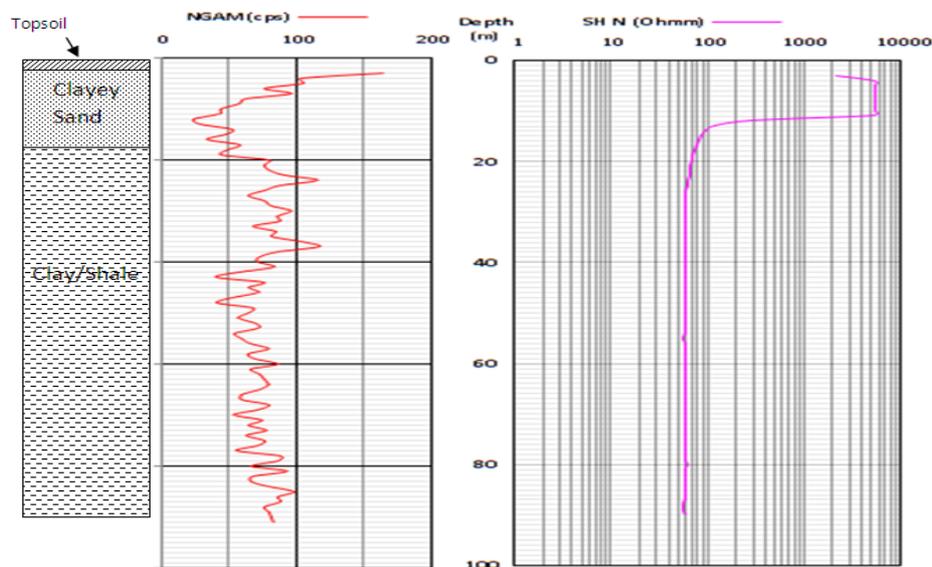
Fig. 2: Result of the natural gamma and resistivity log of a failed borehole along traverse one

Table 2: Modified longitudinal conductance/protective capacity rating

Longitudinal conductance (mhos)	Protective capacity rating
>10	Excellent
5-10	Very good
0.8-4.9	Good
0.2-0.79	Moderate
0.1-0.19	Weak
<0.1	Poor

(Oladapo and Akintorinwa, 2007)

analyses of the water samples were carried out using the standard methods for chemical analysis of water and wastes (USEPA, 1983). The pH was done by the use of pH meter, Conductivity was carried out using a conductivity meter and TDS (Total Dissolve Solid) was done using a TDS Meter. Turbidity was determined using a Spectrophotometer. Total Hardness and Alkalinity were carried out using Titrimetric method. Anions (Nitrate, Chloride, Sulphate, Phosphate, and Bi carbonate) were done by Colorimetric method. Cations (Sodium, Potassium, Magnesium, Calcium and Iron) were analyzed using Atomic Absorption Spectrophotometer.

RESULTS AND DISCUSSION
Geoelectric section
In the North-South direction, VES 1-17 and VES 23-39 were carried out along four traverses (T1, T2, T4 and T5). The geoelectric section along traverse 1 (Fig. 3) is presented as a sample because the geoelectric layers along the four traverses show similar trend except variation in resistivity and thickness values. However, the geoelectric layers across the four traverses are discussed. The subsurface information along the four traverses comprises four to five geoelectric layers which correspond to topsoil, clayey sand, sandy clay, clay and sand. The first horizon is topsoil that has a layer thickness

which ranges between 0.6 to 2.1m and corresponding resistivity ranging from 9.1 to 65.5Ωm. This suggests that the topsoil is predominantly clay, sandy clay, laterite and clayey sand. The second stratum which represents clayey sand (brackish) has a layer thickness from 1.6 to 26.9m and resistivity ranges between 3.1 to 15Ωm while sandy clay has layer thickness 4.9 to 8.9m and resistivity ranges 13.5 to 48.2Ωm. The third surface layer constitutes clay with the layer thickness from 50.8 to 100.5m while the corresponding resistivity ranges from 1.9 to 6.1Ωm. The fourth geologic unit along this section is interpreted as sand and has a resistivity ranging from 92 to 159Ωm, and this layer constitutes the aquifer. The thicknesses of the fourth layer in VES 1 and VES 14 are 7.7m and 9m respectively while the thickness values in others could not be determined because the current terminated within this zone. The fifth layer in VES 1 is representative of clay with resistivity values of 9.1 to 9.5Ωm. Its thickness could not be determined because current terminated within this zone.

In contrast, along East-West direction, VES 18-22 and VES 40-43 were carried out along the two traverses (T3 and T6). In this direction, the geoelectric section along traverse 6 (Fig. 4) is displayed as a sample because the geoelectric layers along the two traverses exhibit similar
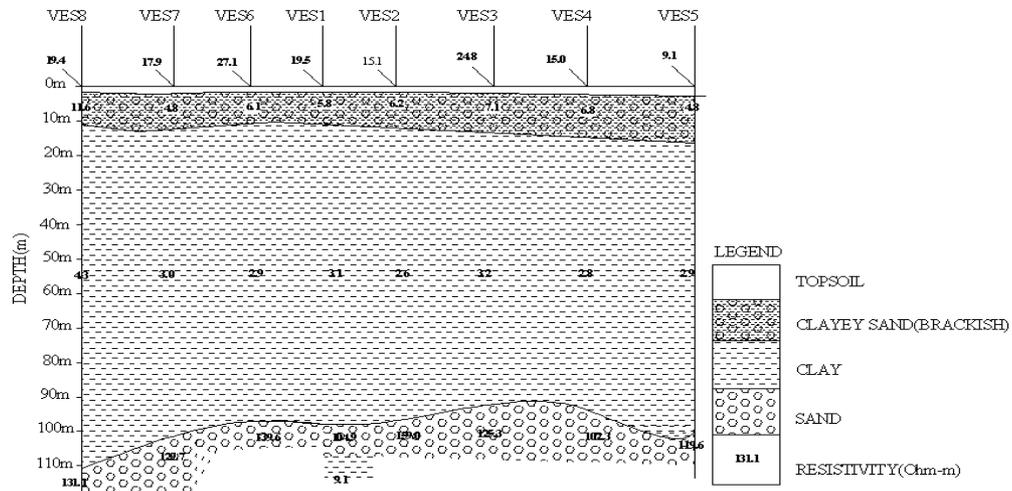
Fig. 3: Geoelectric section along traverse one (North-South direction)
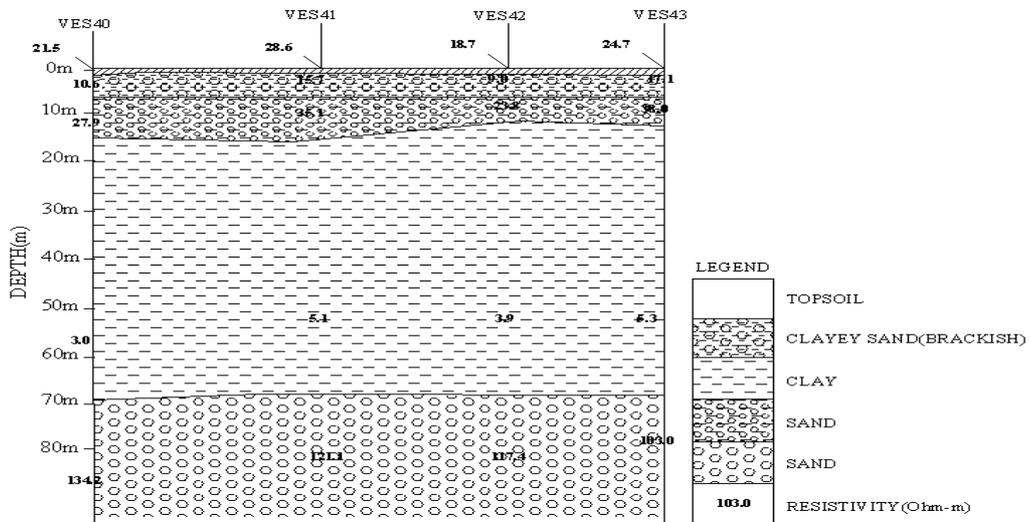
Fig. 4: Geoelectric section along traverse six (West-East Direction)

pattern except variation in resistivity and thickness values. Also, the subsurface strata along the traverses denote four to five geologic units which indicate topsoil, clayey sand, sandy clay, clay and sand. The first geologic unit along this

section is interpreted as topsoil that has resistivity ranging between 10.4 to 28.6Ωm and a layer thickness ranging from 0.8 to 1.3m. The topsoil is composed of clay, sandy clay and laterite. The second layer which represents clayey sand

(brackish) has a layer thickness ranging from 4.5 to 12.4m and corresponding resistivity values ranging from 5.6 to 15.1Ωm. The third stratum is composed of sandy clay with the resistivity ranging from 23.8 to 36Ωm and layer thickness ranging from 6.7 to 11.8m. The fourth horizon consists of clay with the layer thickness ranging from 51.3 to 60.4m while the corresponding resistivity ranges between 2.8 to 5.3Ωm. The fifth geoelectric layer is symptomatic of sand which has a resistivity ranging from 103 to 136.1Ωm. The current terminated within this layer; hence the thickness could not be determined. The layer indicates the potential groundwater zone.

Topsoil and overburden protective capacity ratings
Table 4 shows that the topsoil conductance values oscillate between 0.02 and 0.11mhos. The values are indicative of weak to poor protective capacity rating based on the modified longitudinal conductance/protective capacity rating in Table 1. Thus, the second layer (clayey sand) is susceptible to contamination. Table 5 reveals that the overburden longitudinal values vary between 10.7 and 40.1 mhos. The thickness of the highly impervious clayey/shale overburden, which is characterized by relatively high longitudinal conductance, offers protection to the underlying aquifer. This denotes an excellent protective capacity rating and hence, indicates that the possible sand layer is prevented from contamination.

Chemical analyses of water samples.
Table 6 reflects the chemical results of three water samples obtained within the study area. Results of water sample A collected from the south-eastern part of the study area indicate that some test parameters such as PH (5.42), turbidity, chloride and iron levels are beyond the internationally accepted standards (WHO, 1993). For water sample B obtained from south-western part of study area, and water sample C from the northern part of the study area, test parameters such as PH (6.04 for sample B only), conductivity, turbidity, total dissolved solid (TDS), total hardness, chloride, iron and manganese levels are also beyond the internationally accepted limits (WHO, 1993). Most of groundwater samples indicate slightly acidic in nature with pH varying from 5.42 to 6.04. High TDS and chloride contents can be attributed to possible contaminated river water intrusion in the area. The high concentrations of the TDS and chloride in samples mentioned above denote brackishness of the groundwater. Thus, the depth where water samples were obtained ranged between 9 – 16m from the aforesaid results correlate well with the low resistivity (4.8 – 15.1Ωm) clayey sand zone, which denotes the vertical electrical sounding interpreted results at the shallow depth (3 – 28 m) of the contaminated zone/layer. The analysis shows that the water samples from the three sampling points are contaminated and unfit for domestic use.

CONCLUSION
In this study, the assessment of groundwater contamination at shallow depth and its potential zone for groundwater development around Isheri-North, Ogun State, Southwestern Nigeria was carried out using the application of 43 Schlumberger Vertical Electrical Soundings (VES) and chemical analyses of water samples from one hand dug well and two shallow boreholes. Four to five geoelectric layers were delineated. These layers correspond to top soil, clayey sand, sandy clay, clay and sand. The topsoil thickness values range from 0.6- 2.1m while the resistivity values ranged between 9.1 and 65.5 Ωm. The longitudinal conductance values (0.02 - 0.106 mhos) of the topsoil in the area reveal its poor to weak protective capacity. The clayey sand has resistivity values ranging from 4.8-15.1 Ωm with thickness between 3.7 and 26.9m. This low resistivity from this zone is attributable to the infiltration of the contaminated nearby river water into the layer. The water quality analyses were made for major ions which revealed brackish nature of groundwater at shallow depth (9 – 16 m). Chemical analyses of groundwater samples have been correlated with the electrical resistivity data in

Table 4: Topsoil longitudinal conductance of each VES station

VES Stations	Resistivity(ohm-m)	Thickness m)	Topsoil conductance $S= h_{ts}/\rho_{ts}$	Protective Capacity Rating
1	19.5	0.8	0.04	Poor
2	15.1	1.2	0.08	Poor
3	24.8	0.6	0.02	Poor
4	15	1.2	0.08	Poor
5	9.1	0.6	0.07	Poor
6	27.1	0.6	0.02	Poor
7	17.9	1.1	0.06	Poor
8	19.4	1.2	0.06	Poor
9	30.8	1.8	0.06	Poor
10	23	1.2	0.05	Poor
11	47.6	1.2	0.03	Poor
12	24.6	2.1	0.09	Poor
13	18.7	2	0.11	Weak
14	24.6	0.7	0.03	Poor
15	28.3	1.3	0.05	Poor
16	35.5	0.8	0.02	Poor
17	39.2	1.1	0.03	Poor
18	19.6	0.9	0.05	Poor
19	11.7	1.1	0.09	Poor
20	15.6	1.1	0.07	Poor
21	14.1	1	0.07	Poor
22	10.4	0.8	0.08	Poor
23	21.9	1.2	0.05	Poor
24	12.2	1.3	0.11	Weak
25	51.5	0.9	0.02	Poor
26	33.1	0.8	0.02	Poor
27	24.5	1.2	0.05	Poor
28	65.5	0.8	0.01	Poor
29	24.8	0.9	0.04	Poor
30	23.4	1	0.04	Poor
31	48.3	0.9	0.02	Poor
32	31.9	0.7	0.02	Poor
33	28.6	0.6	0.02	Poor
34	32	0.7	0.02	Poor
35	30.6	0.6	0.02	Poor
36	29.6	0.6	0.02	Poor
37	26.4	0.9	0.03	Poor
38	20.4	1.1	0.05	Poor
39	16.5	1.1	0.07	Poor
40	24.7	1.3	0.05	Poor
41	28.6	1.3	0.05	Poor
42	18.7	1.1	0.06	Poor
43	21.5	1.2	0.06	Poor

Table 5: Summary of the overburden longitudinal conductance

Ves Station	Resistivity (ohm-m)					Thickness (m)					Over-burden longitu-dinal conduc-tance (mhos)	Protective Capacity Rating
	ρ_1	ρ_2	ρ_3	ρ_4	ρ_5	h_1	h_2	h_3	h_4	h_5		
1	19.5	5.8	3.1	104.9	9.1	0.8	26.9	73.9	7.7	∞	28.6	Excellent
2	15.1	6.2	2.6	159		1.2	15.1	80.6	∞		33.5	Excellent
3	24.8	7.1	3.2	125.3		0.6	14.3	77.5	∞		26.3	Excellent
4	15.0	6.8	2.8	102.3		1.2	9.1	81.3	∞		30.5	Excellent
5	9.1	4.8	2.9	119.6		0.6	15.0	76.6	∞		29.6	Excellent
6	27.1	6.1	2.9	139.6		0.6	11.4	89.8	∞		32.9	Excellent
7	17.9	4.8	3.0	129.7		1.1	12.6	91.0	∞		33.0	Excellent
8	19.4	11.6	4.3	131.1		1.2	9.4	100.5	∞		24.2	Excellent
9	30.8	15.9	5.6	101.4		1.8	10.5	60.1	∞		11.5	Excellent
10	23.0	8.4	3.4	105.2		1.2	9.9	62.0	∞		19.5	Excellent
11	47.6	17.1	5.7	122.0		1.2	10.1	63.1	∞		11.7	Excellent
12	24.6	15.2	5.4	121.3		2.1	10.9	60.0	∞		11.9	Excellent
13	18.7	12.8	6.1	121.0		2.0	12.0	57.7	∞		10.5	Very good
14	24.6	6.0	3.0	101.8	9.5	0.7	10.6	62.2	8.9	∞	22.5	Excellent
15	28.3	13.8	5.4	117.2		1.3	13.5	65.4	∞		13.1	Excellent
16	35.5	4.7	2.9	157.9		0.8	9.4	70.4	∞		26.3	Excellent
17	39.2	10.8	3.9	131.9		1.1	16.7	63.0	∞		17.7	Excellent
18	19.6	9.6	3.6	111.1		0.9	12.4	54.5	∞		16.5	Excellent
19	11.7	6.7	3.0	107.2		1.1	10.5	58.9	∞		21.3	Excellent
20	15.6	9.6	4.4	136.1		1.1	11.8	57.0	∞		14.3	Excellent
21	14.1	8.2	3.6	129.6		1.0	10.0	54.5	∞		16.4	Excellent
22	10.4	5.6	2.8	129.5		0.8	9.1	57.2	∞		22.1	Excellent
23	21.9	8.9	19.1	4.2	120.4	1.2	7.6	8.0	63.0	∞	16.3	Excellent
24	12.2	5.6	23.9	3	122.6	1.3	3.7	7.2	67.6	∞	23.6	Excellent
25	51.5	6.6	48.2	5.8	104.0	0.9	1.6	4.9	70.2	∞	12.5	Excellent
26	33.1	10.5	26.3	5.1	116.3	0.8	4.1	6.6	62.8		13.0	Excellent
27	24.5	12.8	35.6	5.2	91.7	1.2	4.5	6.2	60.7	∞	12.2	Excellent
28	65.5	7.0	28.2	4.1	123.2	0.8	4.4	8.1	54.6	∞	14.2	Excellent
29	24.8	10.2	24.6	3.1	133.4	0.9	6.2	7.6	50.8	∞	17.3	Excellent
30	23.4	10.8	23.2	3.5	127.3	1.0	5.7	7.9	51.2	∞	15.5	Excellent
31	48.3	14.7	36.2	3.9	116.7	0.9	3.8	8.9	51.5	∞	13.7	Excellent
32	31.9	5.0	13.5	1.9	126.1	0.7	7.0	8.0	71.4	∞	39.6	Excellent
33	28.6	5.5	18.9	4.4	122.3	0.6	8.8	7.5	69.3	∞	17.8	Excellent
34	32.0	5.0	15.8	1.9	119.9	0.7	7.4	6.6	72.6	∞	40.1	Excellent
35	30.6	4.5	14.8	3.6	115.4	0.6	4.9	7.3	72.0	∞	21.6	Excellent
36	29.6	4.5	15.3	3.5	115.2	0.6	5.1	7.0	71.8	∞	22.1	Excellent
37	26.4	5.5	23.8	4.2	141.4	0.9	3.7	7.3	71.7	∞	18.1	Excellent
38	20.4	4.5	33.0	2.2	123.6	1.1	3.1	6.6	67.7	∞	31.7	Excellent
39	16.5	4.8	20.9	4.1	133.4	1.1	7.6	6.6	62.3	∞	17.2	Excellent
40	21.5	10.6	27.9	3.0	134.2	1.2	4.8	8.2	54.5	∞	19.0	Excellent
41	28.6	15.7	35.1	5.1	121.1	1.3	4.5	11.8	51.3	∞	10.77	Very good
42	18.7	9.0	23.8	3.9	117.4	1.1	4.7	6.7	60.4	∞	16.4	Excellent
43	24.7	17.1	36.0	5.3	103.0	1.3	4.7	9.8	56.1	∞	11.2	Excellent

Table 6: Chemical analyses of water samples

S /N	TEST	Water Analysis			
		A	**B**	**C**	**WHO(1993)**
1	pH	5.42	6.04	6.85	6.5-8.5
2	Conductivity(µs/cm)	140	2100	4230	250
3	Turbidity (FTU)	20.92	23.48	85.10	Less than 5
4	Total Dissolved Solid (mg/L)	95	1400	2820	-
5	Total Hardness (mg/L $CaCO_3$)	80	376	944	150
6	Total Alkalinity (mg/L $CaCO_3$) (Methyl Orange)	28	144	448	-
7	Chloride (mg/L)	251.36	261.99	274.08	250
8	Nitrate (mg/L)	6.15	<1.00	<1.00	50
9	Hydroxide (mg/L $CaCO_3$)	-	-	-	-
10	Bicarbonate (mg/L $CaCO_3$)	34.16	175.68	546.56	-
11	Carbonate (mg/L $CaCO_3$)	-	-	-	-
12	Sulphate (mg/L)	26	3	6	-
13	Phosphate (mg/L)	0.18	0.21	7.20	-
14	Calcium (mg/L)	3.92	42.33	60.12	75
15	Magnesium (mg/L)	8.79	43.96	124.24	50
16	Sodium (mg/L)	-	21.30	45.40	200
17	Potassium (mg/L)	-	10.40	32.50	-
18	Iron	0.81	11.62	1.78	0.3
19	Manganese	0.08	4.56	0.41	-

the study area predicting the contaminated zones at shallow depth (3 – 28m). The results of the analyzed water samples from this shallow zone are beyond international standards for drinking water. The resistivity values of the underlying clay range between 1.9 - 6.1Ωm and thickness varied from 50.8 - 100.5m. This serves as the main seal for the underlying aquifer (sand layer). The resistivity of the sand layer varies from 91.7 – 159 Ωm and this constitutes the aquifer potential units in the study area. The depth to the top of the aquifer zones ranged from 67.8-111.1m. The longitudinal conductance values of the overburden which vary between 10.5-33.0 mhos are indicative of very good to excellent protective capacity rating. Thus, the underlying aquifer potential units are well protected from being contaminated.

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