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Geophysical and Hydrogeologic Mapping of Groundwater Resources of Ero, Ondo State, Southwestern Nigeria

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Abstract

Geophysical and hydrogeological investigation was employed in Ero, Southwestern, Nigeria in order to evaluate the groundwater potential and its vulnerability to contamination. The aim of the project is to map the groundwater resources of the study area through delineation of hydrogeologic structures and evaluation of the vulnerability of these structures to near-surface contaminants. The survey utilized the Schlumberger depth sounding method integrated with hydrogeological measurement such as the static water level, well depth measurement in collaboration with hydrochemical analysis of wells in the study area. The geophysical investigation shows three to five distinct geoelectric units which include the topsoil, weathered layer, weathered basement, fractured basement and fresh bedrock. The top soil resistivity is in the range of 24 to 1112 Ohm-m with thicknesses 0.4 to 1.3m while the weathered layer ranges from 12 to 1402 Ohm-m with a thickness range of 0.7 to 10.2m. The weathered basement has resistivity values in the range of 575 to 913 Ohm-m with a thickness range of 0.4 to 3.5m while the fractured basement resistivity is in the range of 61 to 533Ohm-m with a thickness range of 3.5 to 16.2m. The fresh basement resistivity is in the range of 1020 to ∞ Ohm-m. The overburden thickness ranges between 1.7m to 40m. The resistivity distribution values of the aquifer units in combination with the thicknesses of the aquifer units and overburden shows that most of the study areas have low groundwater potential. The hydrogeological measurements reveal that water column thickness ranges between 0.1 - 1.7 indicating relatively thin water column in the sampled area. The groundwater in the study area flows from the northern and southwestern part into the southeastern and western part of the sampled area. The longitudinal unit conductance values which are corroborated by the top soil resistivity and vadose zone thickness was employed in the aquifer vulnerability assessment of Ero. It was revealed that the overburden protective capacity of the area can be classified into poor, weak and moderate protective capacity zones. The hydrochemical analysis reveals that the physico-chemical parameters in the three wells is portable because the results falls within the recommended safe value for drinking water by WHO and other health organizations.

Keywords

Groundwater, Hydrochemical, Geoelectric, Vadoze Zone, Unit Conductance

1. Introduction

Groundwater is commonly understood as water occupying the voids or pores within a geologic structure. It is generally free from suspended matter and bacteria. It can be said to be pure, clear and colourless. Groundwater is considered to be of high quality than surface water and generally considered to the best quality water for irrigation and drinking around the world [7]. In many developed and developing countries, ground water is heavily relied on, not only as a primary source of drinking water but as a source of water for both agricultural and industrial uses. Due to the dependence on groundwater, it is necessary to ensure that there are sufficient quantities to sustain the reliance, in addition to being of high quality. Groundwater is also believed to recharge lakes, rivers, and wetlands [9]. Some geologic structures which are favorable to the accumulation of groundwater in the basement terrain include: faults, fractures, lithological contacts/boundaries and shear zones. The quantity of the groundwater stored is usually dependent on the extent of the secondary porosity.

Geophysics has been used as a tool for groundwater resource mapping or groundwater characterization. It is a technique usually employed for the delineation of the properties of the earth that could be diagnostic of the characteristic of the subsurface for a particular investigation [4]. Electrical methods have proved particularly applicable to groundwater studies as many of the geological formation properties that are critical to hydrogeology such as the porosity and permeability of rocks can be correlated with electrical conductivity signatures [8]. The use of the technique in hydrogeological investigations is in relation to aquifer delineation, lithological boundaries and geological structures to provide subsurface information [1, 6]. Water contains a variety of chemical, physical and biological substances which are either dissolved or suspended in it. These dissolved solids and gases usually act as impurities. The chemical composition of natural water is derived from its interactions and reactions with the atmosphere, hydrosphere, lithosphere and the anthropogenic factors operating in the area [5]. Water can contain living organisms which react with its physical and chemical elements. The resultant effect of these reactions can be observed from hydrochemical analysis. The portability status of the groundwater is carried out by comparing the chemical anomalies with the Federal Environmental Protection Agency, World Health Organization and other available guidelines.

2. Location and Geological Setting

The study area, Ero, is located in Ifedore local government area of Ondo State, Southwestern Nigeria (Figure 1). It is easily accessible through Akure – Ilesha expressway (Figure 2) and bounded on the north-west by Ilara Mokin town and on the south-west by Irese area. The study area lies within the Pan African southwestern basement complex of Ondo state Nigeria and characterized predominantly with crystalline igneous and metamorphic rocks. The geology of Ero comprises of various lithology mostly of Migmatite – gneiss, Quartzite, granite and charnockite.

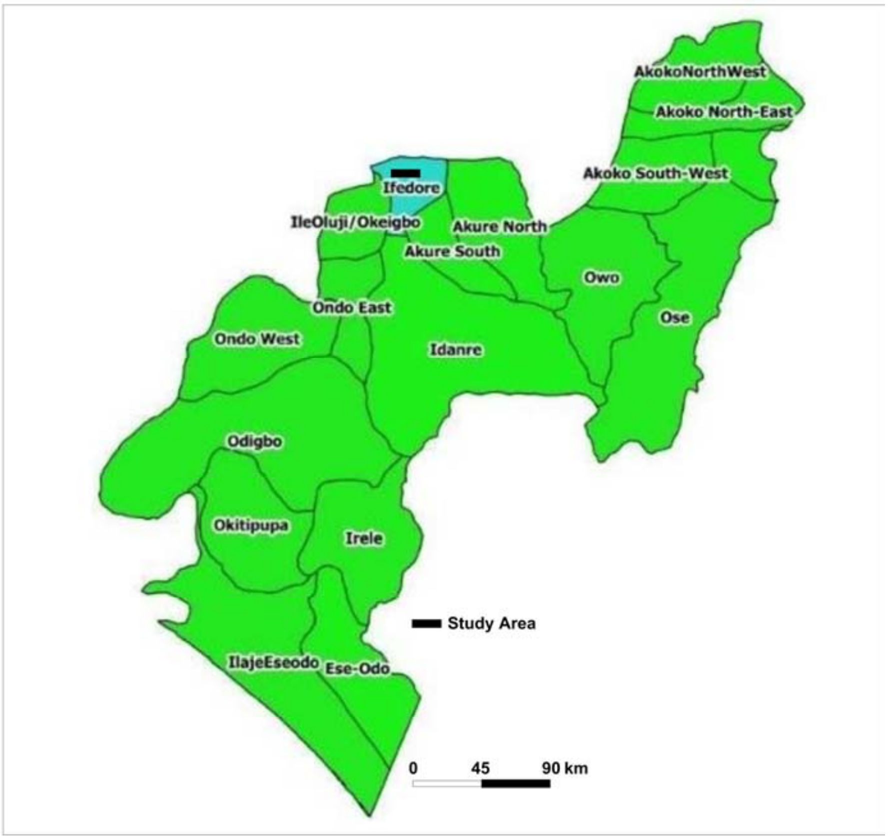


Figure 1. *Map of Ondo State Nigeria showing the study area.*

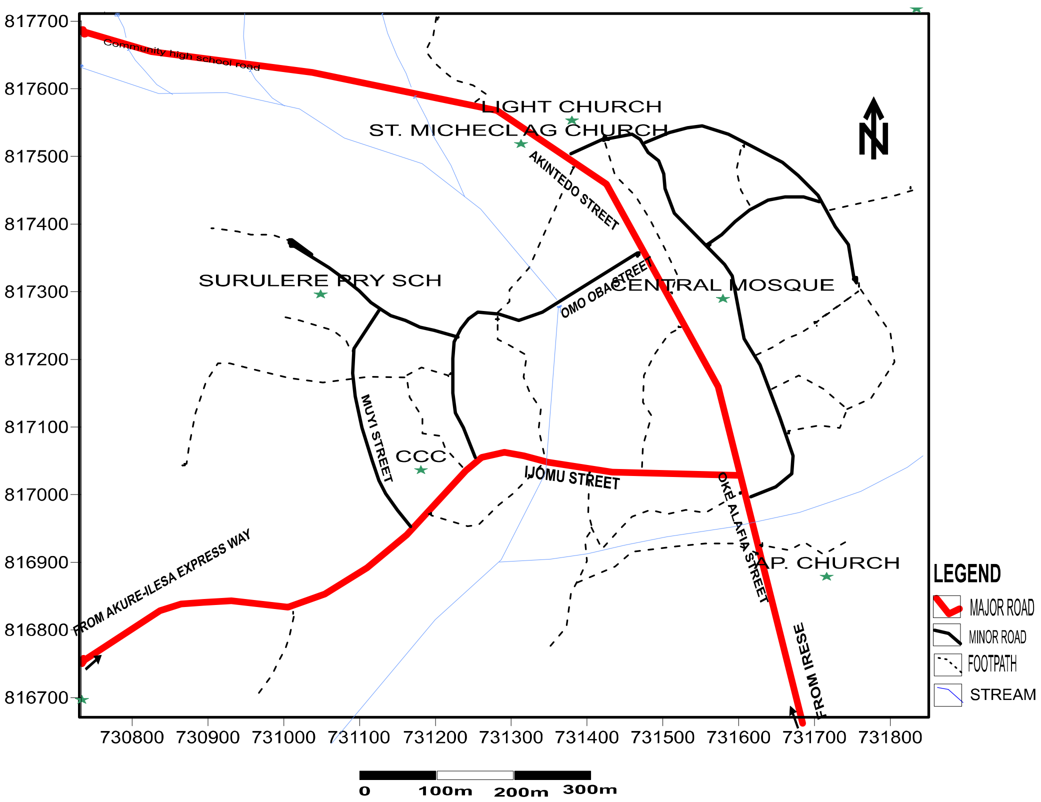


Figure 2. *Field location map of the study area.*

3. Material and Methods

The basic geophysical method used is the Electrical resistivity method. The Vertical Electrical Sounding technique using the Schlumberger electrode configuration was employed. This Method has the widest adoption in groundwater exploration [2]. Electrical resistivity data were acquired within the study area using the Ohmega Resistivity meter. Fifty (50) VES stations (Figure 3) were occupied within the study area using the Schlumberger Electrode Array. The maximum half-way spread length (AB/2) ranges from 80-120 m. The co-ordinates of each VES station were recorded with their respective elevation above sea level using the GPS (GARMIN 12, Global Positioning System) device. VES data were processed by calculating the resistivity from the product of the resistance and the geometric factor at each spread length. The field data was interpreted qualitatively by partial curve matching. It involves segment by segment matching of a field curve starting from small electrode spacing to large spacing with theoretical two layer model and auxiliary curves (K, H, Q and A type). This technique adopts the Principle of Superposition of layers or Replacement Resistivity and Thicknesses. The result of the layer resistivity parameters (resistivities and thicknesses) derived from the partial curve matching technique are used as initial interpretation of the field curves for the computer iteration. These parameters are supplied into the WinRESIST software for a particular input data which then display the corresponding theoretical curves. The theoretically generated parameters were subsequently varied until a best possible fit between the field and the model curves are obtained. The final theoretically generated parameters are the layer resistivities and thicknesses for each VES Station.

Due to limited wells in the study area, twenty (20) wells were sampled for the hydrogeological survey. These wells are majorly located in the central and eastern part of the study area (Figure 3). Hydrogeologic investigation involves the measurements of Static Water Level and Well Depth. Water samples were collected from three representative hand-dug wells within the study area for detailed chemical analysis (for the determination of the physico-chemical parameters (anions and cations) in order to know the portability status of groundwater in the area) was carried out on the samples. The quality of the groundwater was determined by comparing the concentration levels of the parameters obtained with that of the World Health Organization (WHO) recommended values [3, 10].

4. Results and Discussion

The geoelectric field data obtained from the Vertical Electrical Sounding (VES) result is presented as sounding curves, geoelectric sections and maps. The typical curve (Figure 4) types are the HKH-, AKH-, KH-, H-, A- and K-curves types. The most prominent of the curve types is the H curve with percentage frequency of 40% (Figure 5), followed by the A curve constituting 34% of the total curve type in the area. The HKH curve accounted for 10%, KH curve is 8%, HA curve is 4%, while the K and AKH curve accounted for 2% of the total.

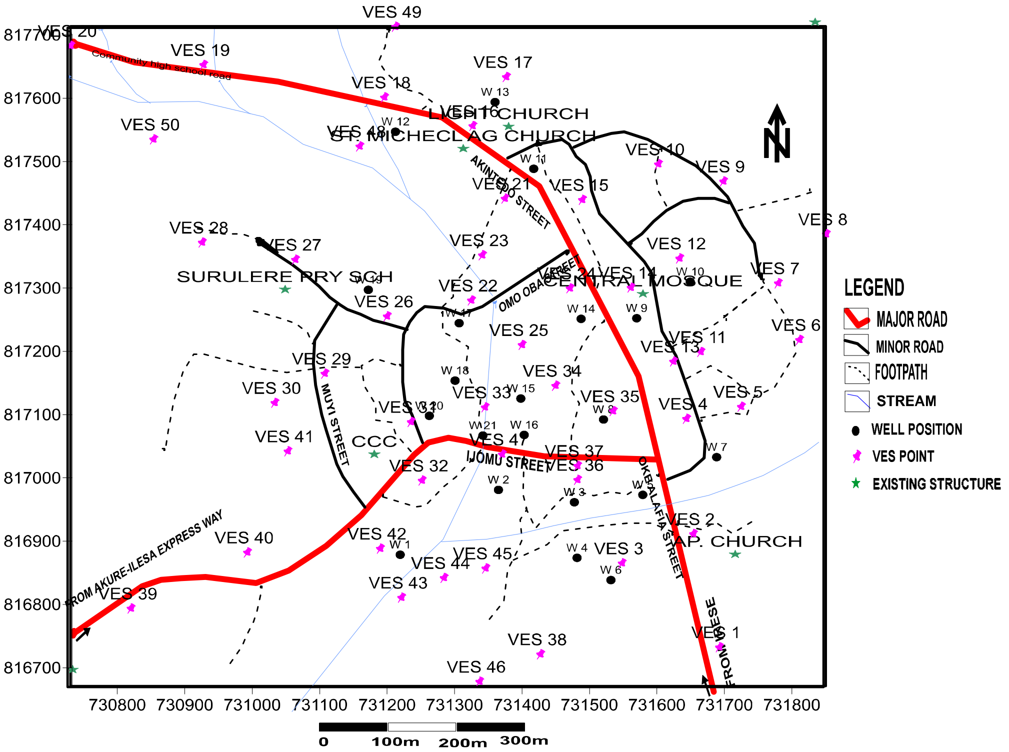
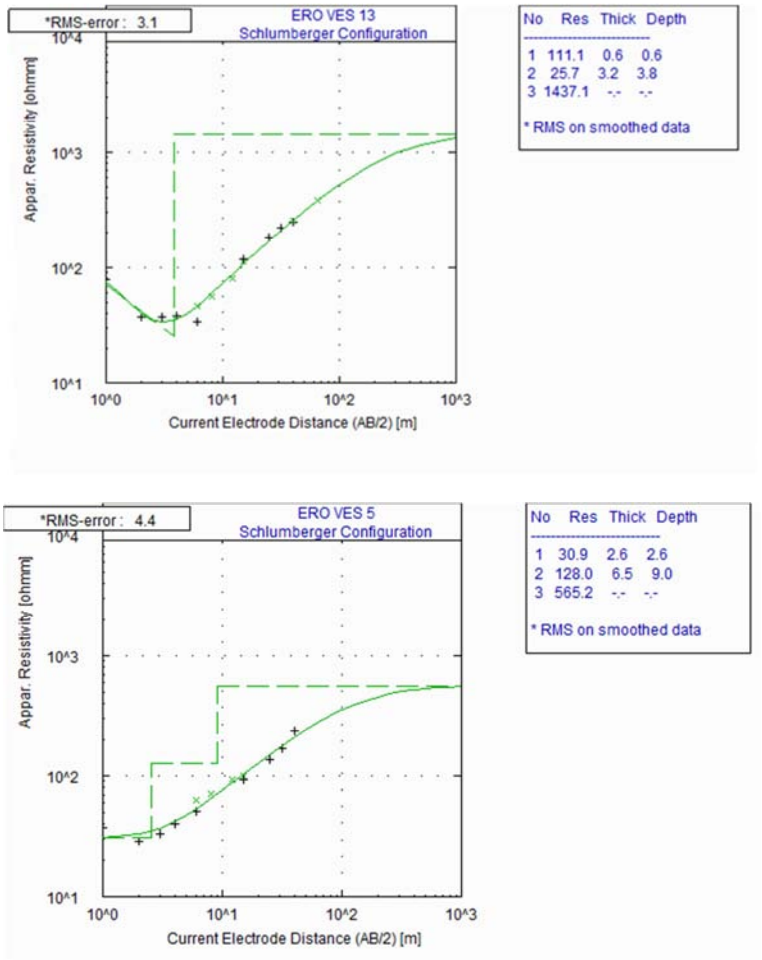


Figure 3. *Field location map showing well positions.*



No	Res	Thick	Depth
1	111.1	0.6	0.6
2	25.7	3.2	3.8
3	1437.1	-.-	-.-

* RMS on smoothed data

No	Res	Thick	Depth
1	30.9	2.6	2.6
2	128.0	6.5	9.0
3	565.2	-.-	-.-

* RMS on smoothed data

Figure 4. *Typical sounding curves from the study area.*

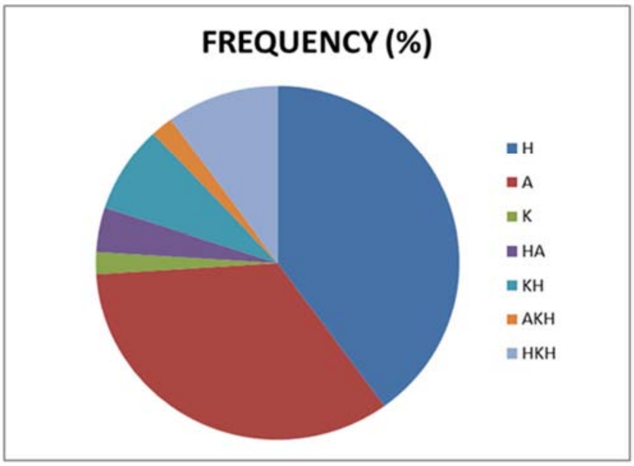


Figure 5. *Pie chart showing the distribution of curve types within the study area.*

The generated geoelectric sections shows the 2-D representations of the VES curves obtained within the study area showing the lateral correlation between geoelectric sequences within the subsurface beneath the VES points along chosen direction. The geoelectric section (Figure 6 & 7) along the N-S and W-E directions respectively shows three to five geoelectric/geologic layers which include the top soil, weathered layer, partly weathered basement, fractured basement and fresh bedrock. The top soil resistivity varies from 41 to 598 Ohm-m with thickness values in the range of 0.3 to 1m. The low resistivity values (< 350 Ohm-m) are diagnostic of clay, clayey sand, sandy clay materials while the higher resistivity values (> 350 Ohm-m) indicate dry sand or laterite. The weathered layer beneath the top soil consists of clay, clayey sand and sandy clay with resistivity values ranging from 12 to 186 ohm-m with thickness ranging.

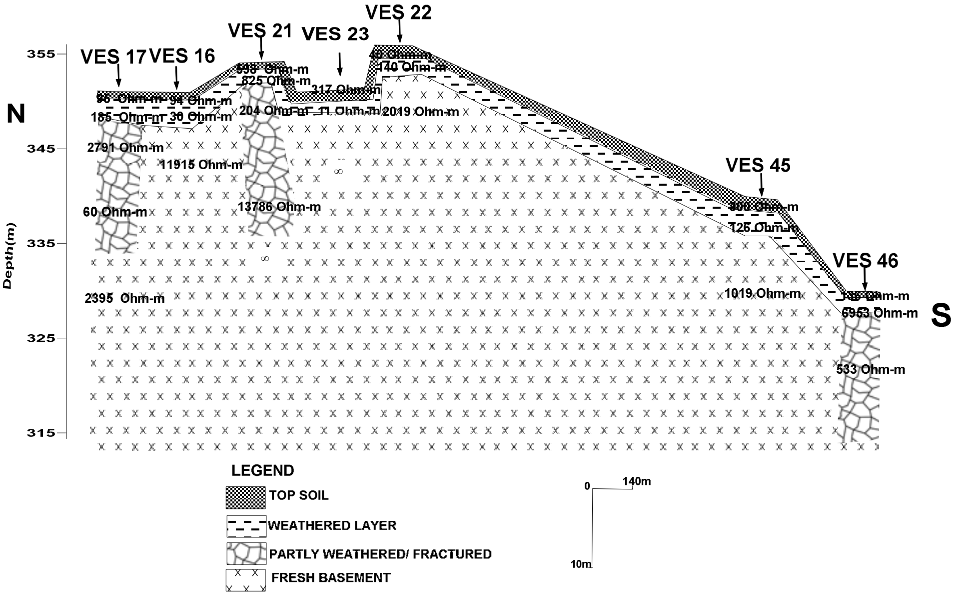


Figure 6. *Geoelectric section along the N-S direction of the study area.*

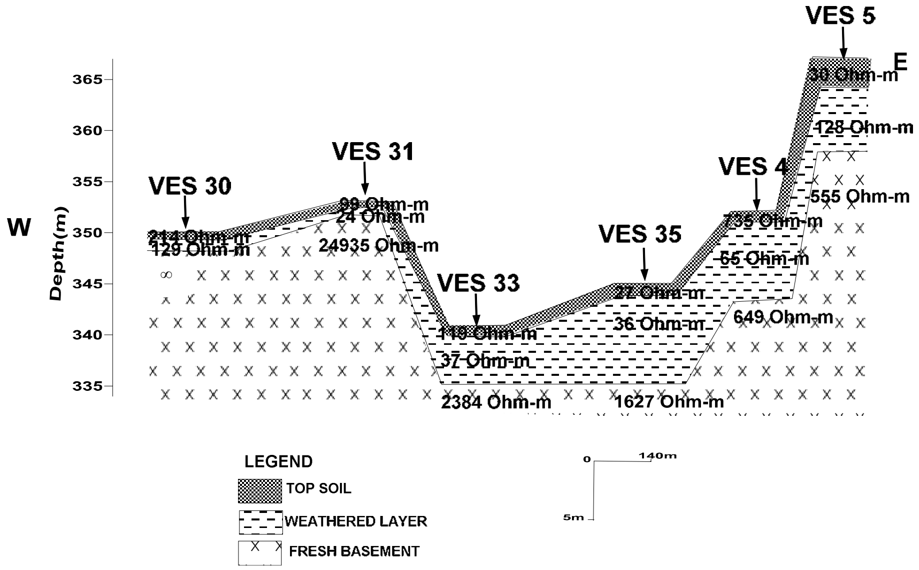


Figure 7. *Geoelectric Section along the W-E direction of the study area.*

from 0.7 to 3.6m. The third layer is indicative of fresh basement with resistivity range of 1020 to ∞ Ohm-m. However, the third layer shows the presence of the basement rocks which is partly weathered in some areas with resistivity values ranges between 825 and 6953 Ohm-m and thickness range of 1 to 2.4m. This is followed by the fractured basement with resistivity in the range of 61 and 533 Ohm-m and thickness ranging between 13.1 and 16.2m. The fifth layer is the fresh bed rock with a resistivity range of 2396 Ohm-m to ∞.

The generated geoelectric maps include the aquifer resistivity map, aquifer thickness map and groundwater potential map and are presented as contour map. The distribution of aquifer resistivity in the area is shown in Figure 8. The resistivity of the aquifer unit ranges between 11 – 1400 Ohm-m. Very low resistivity values (< 200 Ohm-m) were observed in the northeastern, central and southeastern parts of the area. This is closely followed by the resistivity values ranging from 200-400 Ohm-m. High resistivity values (> 400 Ohm-m) is delineated in the western part of the area trending from the north to south. The thickness of the aquifer units was computed using the thickness of the weathered and fractured geoelectric layers (Figure 9). The thickness ranges between 0.7m to 20m. Thickness in the range of 0.7 to 5m is deciphered at the western, central and some part of the northeastern part of the study area while thickness in the range of 5m to 15m is observed in the northern and southeastern parts of the area.

The zones of fairly thick overburden underlain by fractures are of medium groundwater potential while zones of relatively thin overburden correspond to low groundwater potential. The groundwater potential map (Figure 10) reveals that the northwestern, western part, central and southwestern segment of the study areas aquifer unit has low ground water potential. Thread of medium ground water potential is observed in the some parts of the northeastern part of the study area while zones of high groundwater potential are confined to the southeastern part of the area. Hydrogeologic data was obtained from twenty one existing wells. The depth of wells across the study area varies between 3.9 – 10.7m while the static water level in the area ranges between 2.96m – 10.55m. The hydraulic head computed from the measured static water levels showed values in the range of 318m to 347m above sea level while the computed water column thickness ranges from 0.1m to 1.7m.

The results of the hydrochemical analysis (Table 1) carried out on the water samples from the wells within the study area showed that the physicochemical parameters in the three wells analyzed falls within the recommended safe value for drinking water by SON (2007) and WHO (2006).

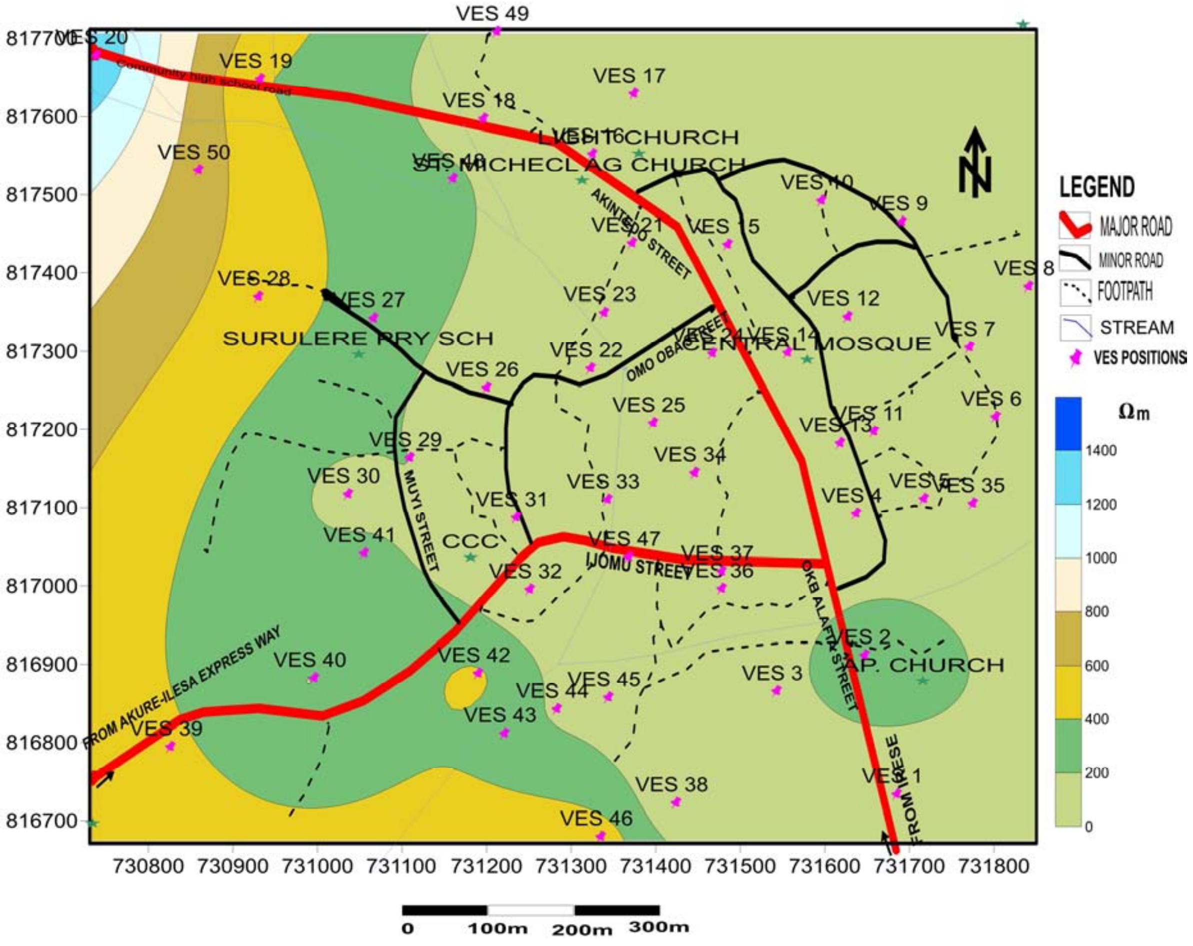


Figure 8. *Map of the study area showing the aquifer resistivity.*

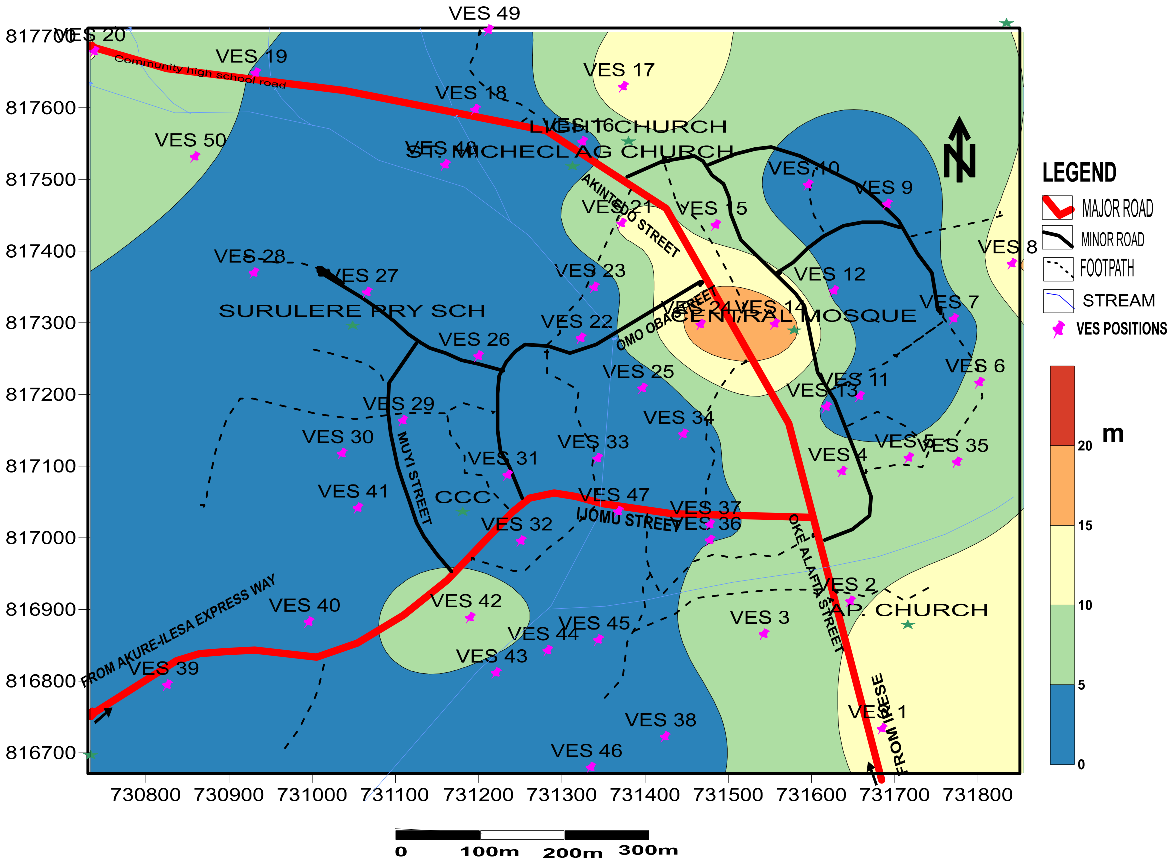


Figure 9. Map of the study area showing aquifer thickness.

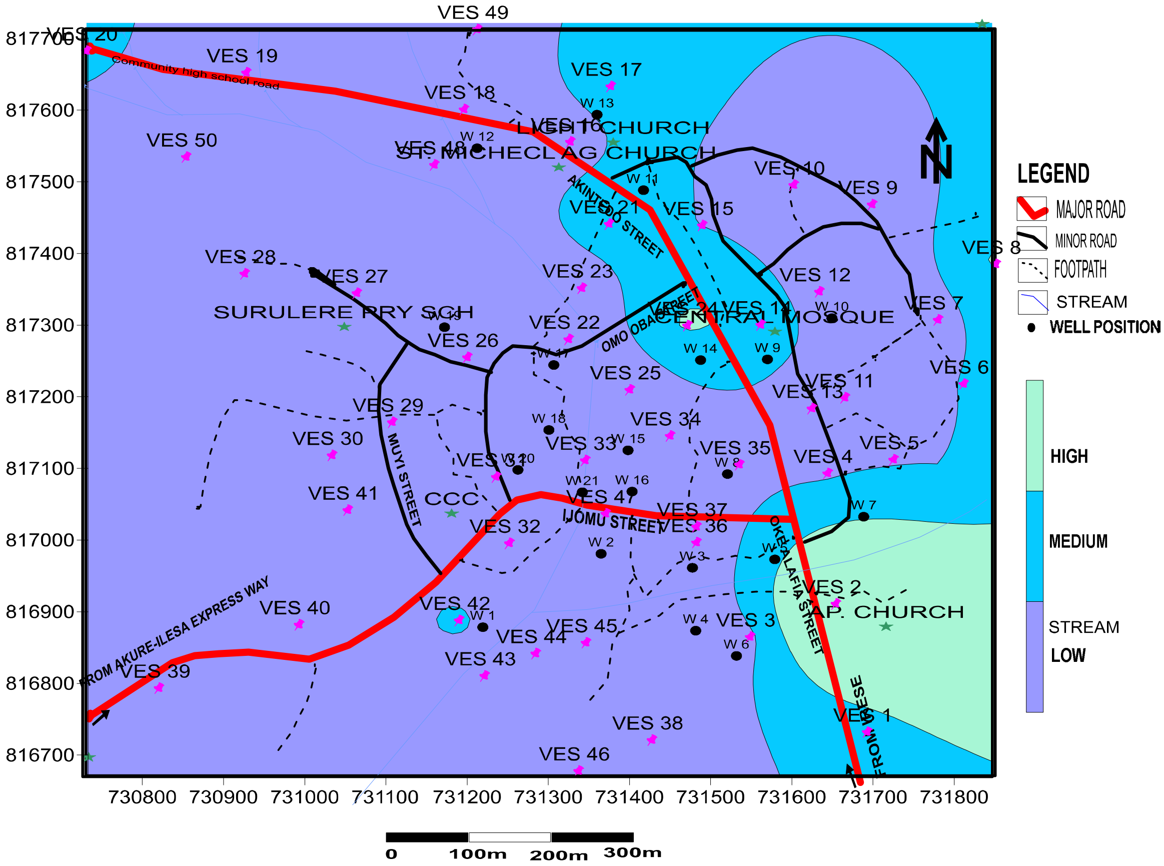


Figure 10. Map of the study area showing the groundwater potential.

Table 1. *Hydro-chemical parameters of groundwater obtained from the study area.*

Well Samples **Parameters**	**WELL A**	**WELL B**	**WELL C**	**WHO (2006) Standard**	**SON (2007) Standard**
Temperature	29.6°C	29.30°C	29.30°C	-	-
pH	7.60	7.40	7.23	6.5-8.5	6.5-8.5
Conductivity (µS/cm)	185	281	428	500	1000
Total Dissolved Solid (mg/l)	60	110	200	1000	500
Total Solids (mg/l)	20	17	17	1000	-
Dissolved Oxygen (mg/l)	9	8.50	9.75	-	-
Biological Oxygen Demand (mg/l)	4.50	2.60	3.55	-	-
Alkalinity (mg/l)	108	112	108	100	100
Cl^- (mg/l)	51.02	76.53	156.70	400	500
NO_3^{2-} (mg/l)	-	0.12	0.09	10	10
SO_4^{2-} (mg/l)	4.64	9.28	18.56	400	500
Ca^{2+} (mg/l)	9.62	16.03	32.87	150	150
Mg^{2+} (mg/l)	7.78	4.86	13.62	100	-
PO_4^{3-}(mg/l)	57.97	56.68	57.36	-	>50
Hardness	58.8	63.00	144.90	-	-

5. Conclusion

Combinations of hydrogeologic and geophysical methods were deployed in the investigation of Ero, Southwestern Nigeria in an attempt to evaluate the area groundwater potential as well as aquifer vulnerability to contamination. The schlumberger depth soundings interpretation reveal relatively thin overburden materials in most parts of the area although moderately thick overburden materials were observed at the central segment of the area. The water column thickness ranges between 0.1 - 1.7m indicating relatively thin water column within the sampled area. The groundwater in the study area flows from the northern and southwestern part into the southeastern and western part of the sampled area. The resistivity distribution values of the aquifer units in combination with the thicknesses of the aquifer units and overburden shows that most of the study areas have low groundwater potential.

In term of aquifer vulnerability, it was revealed that the overburden protective capacity of the area can be classified into poor, weak and moderate protective capacity zones. The study showed that the entire western part of the study area has a poor protective capacity suggesting a high degree of susceptibility to contamination while north and southeastern part are fairly shielded. Hydrochemical analysis reveals a higher physio-chemical parameter concentration in the southern part than the northern part of the area. The groundwater resources in the area is presume portable due to hydrochemical analysis results which falls within the recommended safe value for drinking water by WHO and other health organizations.

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