Geophysical investigation of groundwater resources integrating seismic refraction tomography and resistivity data in Ibadan West, Nigeria

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Summary

Secondary porosity formed within hard rock formations as a result of weathering, jointing, faulting or fracturing constitutes areas of special interest in groundwater prospecting. In this study, integrated electrical resistivity and seismic refraction surveys were carried out within the subsurface strata of Ibadan West, Nigeria, to delineate the groundwater potential and aquifer characteristics of the area. The integrated interpreted results revealed four layers overlying the resistive basement: the topsoil, dry sand, saturated sand and the weathered basement. The investigation also revealed the presence of a potential aquifer in the area, with resistivity values of 95 – 295 Ωm, and velocities range of 1650 – 2800 m/s while the depth of the aquifer ranged between 2.8 and 10.4 m. The forth lithological unit which has velocities ranging from 2500 – 3500 m/s and a resistivity value of 1124 – 1946 Ωm is considered the weathered basement. Comparing lithological logs from drilled boreholes with acquired geophysical data, the study area is considered suitable for groundwater development via shallow borehole construction.

Introduction

Hydrogeological and geophysical investigations are often conducted to assess groundwater potential and distributed information on subsurface hydrogeology (Kearey and Brooks, 1991). A number of geophysical means are commonly applied to image subsurface layers some of which include; seismic refraction tomography, electrical resistivity, ground penetrating radar, electromagnetic, geographic information system, remote sensing and gravity methods (Comair et al., 2012). Considering data accuracy, cost and location specificities (such as area geology), electrical resistivity method remains the best alternative and the most popularly used (Sirhan et al., 2011; Anomohanran, 2013).

However, reliable assessment of groundwater potentials and accurate identification of subsurface structure geometries and their corresponding hydrogeological parameters often requires the integration of proven geophysical techniques. Seismic refraction tomographic measurements are an alternative method of obtaining additional information between boreholes when uncertainties in the parameterization of other survey data exist.

In this paper, characterization of subsurface structures integrating information from different geophysical techniques to overcome some of the limits associated with subsurface structures interpretation is presented. Further, the groundwater potential and aquifer characteristics of the district are accessed to determine its suitability for groundwater development via shallow borehole construction.

Location geology and investigation technique

Field studies were undertaken in Ibadan West, situated in Southwestern area of Nigeria (Fig. 1). It lies at approximate latitude of 7° 24' and 7° 26' N and longitude 3° 29' and 3° 34' E. The area is characterized by undulating topography and the drainage pattern is generally dendritic where the streams flow over uniform bedrock. The average annual rainfall is about 1200 mm with a range of vales from 803.2 mm to 1800 mm and a standard deviation of 230.4 mm. Movement of groundwater follows the surface topography with seasonal variations in water levels.

The study area is underlain by Migmatite Gneiss complexes to late intrusive rocks (Fig. 1). Rock types present include migmatite gneiss (granite gneiss), porphyritic micro-granites, and pegmatite. These rocks are associated with brittle and ductile structures such as joints, fractures, faults and lineation.

Resistivity data acquisition was conducted using ABEM SAS 1000 Terrameter (Dahlin, 1996) to obtain the apparent resistivity values along three siesmic refraction traverses (Fig. 1). Siesmic refraction data were acquired on 15 profiles using a twenty four channel Seismograph with 10 Hz geophones (ABEM Instrument AB, 1994). The geophones were spaced at 2 meters intervals and planted for optimum physical contact with the ground, making a total of 50 meters profile length. The trigger mode was manual (geophone input). Information contained in the traveltime data obtained from the seismic refraction survey was used to determine the depth and configuration of refracting layers (Kilthy et al., 1986).

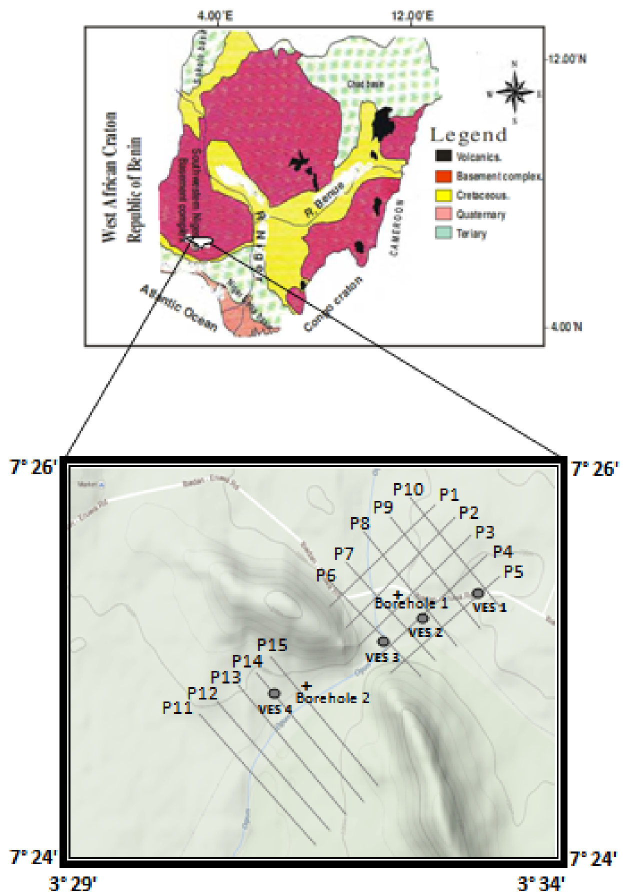

Figure 1: Location geology (adapted from Elueze, 1982,) and map of the study area showing seismic traverses, VES points and borehole locations

The aim had been to map fractures and weak formations (loose grounds) for further electrical soundings. Four vertical electrical sounding (VES) of the Schlumberger configuration was carried out with a maximum current electrode separation of 100 m. VES data were first interpreted by the conventional partial curve matching technique with two-layer master curves (Mooney et al., 1966) in conjunction with an auxiliary point diagram (Ebert, 1943) and afterward inputed for computer-assisted interpretation with RESIST software to obtain the true resistivity and thickness of the various layers.

Seismic refraction data were processed with tomographic inversion methods, using Pickwin and Plotrefa Software. In addition, two boreholes were drilled to determine the lithological characteristics of the subsurface zones.

Result and discussion

Quality siesmic tomography sections were generated and results of the interpretations are typically presented in color bar form, with different velocities shown in varied colors expressing the presence of either saturated, unsaturated, consolidated or unconsolidated layer(s). Fifteen tomographic model results are interpreted and sample profiles are shown in Fig. 2. Presence of low velocity zones in form of local depressions (Palmer, 1991 and Sheehan and Doll, 2003) and variable strata thicknesses within the overburden were detected. The raypath coverage plots of each model were generated to determine which part of the tomography sections are well defined. Table 1 shows the comparison of the tomographic model results with lithological log data obtained from the two drilled boreholes in the area, which was used as control for interpreting the tomography models. Data from the resistivity survey are also presented in Table 1.

The results of the analysis showed that the average depth to the weathered basement in the area is aprroxmately 10.4 m, with multiple interval velocities obtained from the surface to the basement. This implies that there are several strata within the overburden, which overlay the basement in the study area with variable thicknesses and velocities, presumably associated with dry, wet, and consolidated to unconsolidated sediments. In Fig. 2, profile 5, traverse 1, there are indications of depressions at two points, which shows a probable loose and unconsolidated ground characterized by sand and clayey materials. This low velocity zone be can be conveniently interpreted as a high permeable zone. By comparing the interpreted lithology of the profiles with the borehole report in Table 1, it is noticeable that the obtained seismic models clearly mapped most particularly, semi loose weathered formations in form of depressions, from which further resistivity sounding were conducted for detailed interpretation.

Apparent resistivity data obtained from the fitting curves and geo-electric section are shown in Fig. 3 & 4 respectively. Results from the fitting curves suggests that the resistivity model whose calculated apparent resistivity best fit the measurements, with a RMS-error of 2.7 and 3.0 respectively is characterized by; a top layer with a thickness of 1.0 and 1.4 m and apparent resistivities of 1606 and 1677.8 Ωm, a value typical of top soil. The second layer is approximately 1.3 and 1.4 m thick, with apparent resistivities of 935.8 and 1840 Ωm respectively, characteristics of dry sand. The third layer comprise a thickness of 2.8 and 10.4 m with apparent resistivities of 198.1 and 95.2 Ωm respectively. The range of apparent resistivity values and thickness of the third layer is

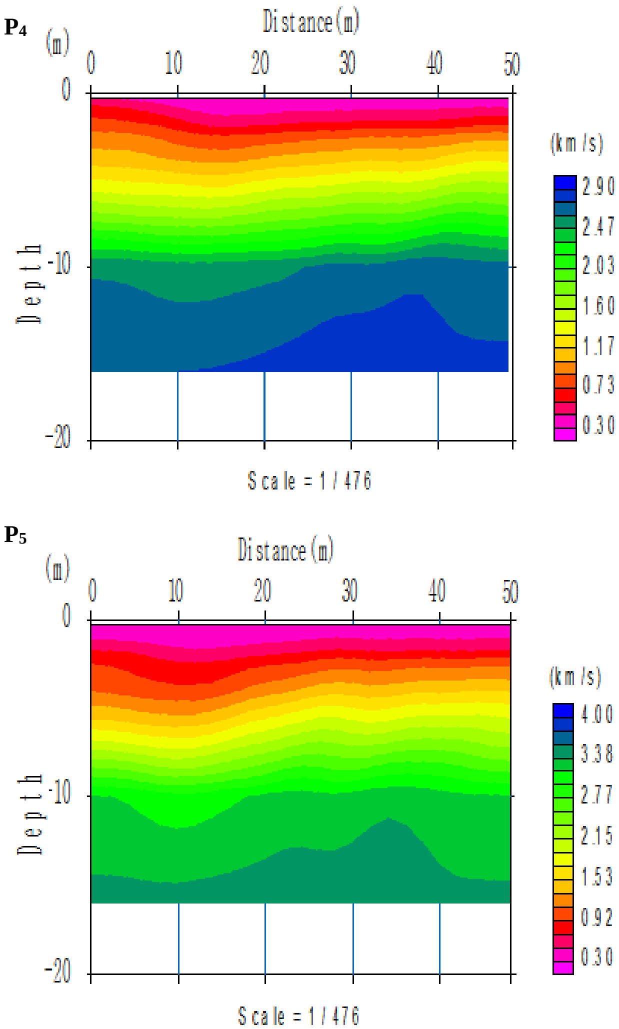

Figure 2: Seismic tomography imaging of profile 4 and 5.

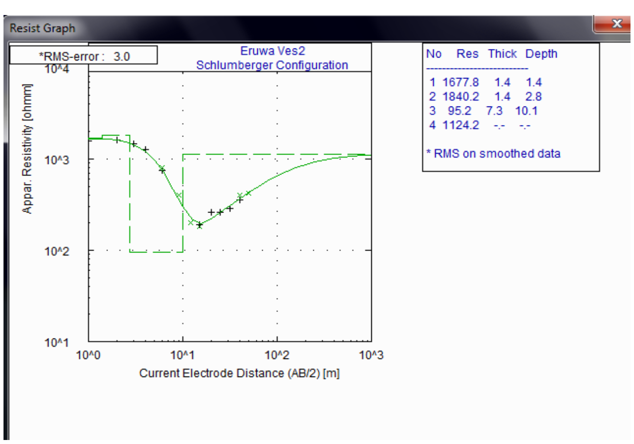

Figure 3: Vertical electric sounding curve obtained from the study area

Table 1: Results of seismic velocities, resistivities and depths from geophysical models correlated with two available Boreholes log data.

Depth (m)	P-wave velocities (ms^{-1})	Resistivity data (Ωm)	Geologic Interpretation	Borehole one		Borehole two	
				Depth (m)	Lithology	Depth (m)	Lithology
0 – 1.4	300 – 1700	1607 – 2992	Lateritic top soil	0 – 1.2	Lateritic clay	0 – 0.5	Lateritic clay
0.8 – 2.1	1200 – 1900	935 – 1840	Dry sand	1.2 – 2.3	Coarse sandy clay	0.5 – 1.4	Lateritic sandy clay
2.8 – 10.4	1650 - 2800	95 – 295	Saturated sand or weathered basement	2.3 – 4.6	Fine sand (brownish)	1.4 – 4.0	Medium to fine saturated sand
10.4 – down	2500 – 3500	1124 – 1946	Weathered basement/ Basement rock	4.6 – 7.0	Medium to fine saturated sand	-	-

interpreted as the weathered overburden saturated with pore water, as suggested by some authors (Ndlovu et al., 2010; Martinelli and Hubert, 1985). The forth layer have apparent resistivity values of 1683 and 1124.2 Ωm for VES 1 and 2 respectively and is presumed to be a weathered bedrock.. Other VES points show similar results as shown in Fig. 4.
Comparison of the results of the seismic tomography and the geo-electrical sections with the borehole lithogic logs shows that different features from each of the models are incorporated to give a better interpretation of the subsurface characteristics of the study area.

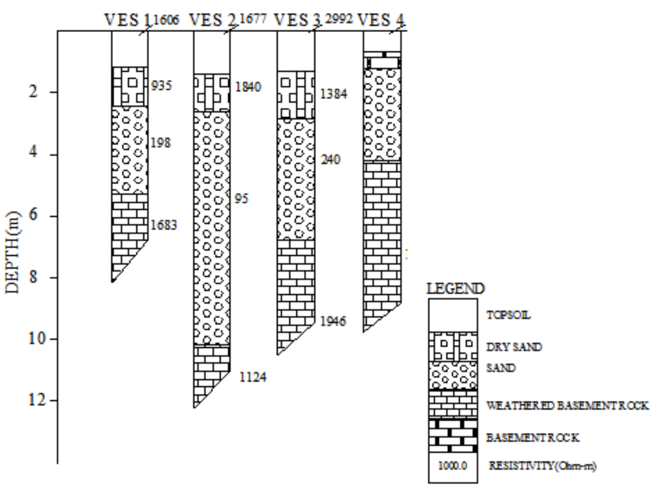

Figure 4: Schematic geoelectric section of the VES conducted in the study area

Conclusions

An integrated approach to describing subsurface heterogeneities by combining high resolution geophysical methods, such as seismic tomography and electrical resistivity technique, with borehole lithological logs was presented. Tomographic and curve matching models were employed for the interpretation of the geophysical data. The application of the approach was consistent for identifying potential permeable zone which exhibits realistic heterogeneities. Hence, integrated geophysical approach appears to be capable of identifying subsurface structures relevant for the prediction of groundwater bearing zones.

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