Seismic Refraction Investigation for Groundwater Potential in Parts of Rivers State, Nigeria.

Cyril N. Nwankwo, Ph.D.[1*]; Godwin O. Emujakporue, Ph.D.; Leonard I. Nwosu, Ph.D.

Department of Physics, University of Port Harcourt, Nigeria.

E-mail: cyrilnn@yahoo.com

ABSTRACT

A twelve channel digital signal enhancement Terraloc ABEM Seismograph was used in a continuous forward profiling to determine the depth to aquifer in Rukpokwu area of Rivers State, Nigeria. The geophones were fitted to the ground at an interval of 10m along the line which gives a total spread of 120m. The seismic spread was connected to the Seismograph which records the signal from the energy source. The first breaks seismic traces were picked with the aid of Reflex 2D Quick software, and the time-distance graph plotted. The results of the survey gave a three-layer model. The seismic P-wave velocity of the weak overburden sediments varies between 100 m/s and 200m/s with an average of 150 m/s. The thickness ranges between 0.69 and 3.32 m. The second layer has velocity that varies from 181.8 to 384.6 m/s with a simple average thickness of 17.68 m. The depth to bedrock (which is the aquifer layer) ranges from 12.52 to 26.56 m while the layer velocity varies from 275.0 m/s to 714.3 m/s. Comparison of this survey with the depths of existing water boreholes in the area and geoelectric resistivity data shows that the result is reliable. Therefore the seismic refraction method has proved to be a useful tool in defining the depth to aquifer in the study area.

(Keywords: seismic refraction, groundwater, velocity, thickness, geoelectric section)

INTRODUCTION

Many geophysical methods find application in locating and defining subsurface water resources. They provide rapidly collected information on the geological structures and prevailing lithologies of a region without the large cost of an extensive drilling program. The geophysical survey results determine the location of the minimum numbers of exploration boreholes required for both essential aquifer tests and control of the geophysical interpretation (MacDonald et al., 2001; Milson, 1996, Nwankwo, et al., 2009).

Seismic methods are very useful in hydrogeological investigations, but although the reflection technique would certainly provide more than adequate structural information, the method is uneconomically expensive. Seismic refraction methods, however, are widely used as they provide direct information on the level of water table since an increase in water content causes a significant increase of seismic velocity in a homogenous lithology (Murad et al., 2010; Ugwu and Nwankwoala, 2008).

The study area, Rukpokwu is located within Port Harcourt, Rivers State Nigeria. The area lies on latitude $4^o53'$ and longitude $6^o57'$ (Figure 1), and forms part of the coastal plain of southern Nigeria. High productivity of many boreholes already drilled in the area supports the prolific nature of the coastal plain sands as an aquifer. This study is aimed at utilizing seismic refraction method to delineate the depth to aquifer that can be used for domestic and agricultural purposes in Rukpokwu town, Nigeria.

GEOLOGY AND HYDROGEOLOGY OF THE STUDY AREA

The underlying sediments in Rukpokwu forms part of the stratigraphic sequence in the Niger Delta complex. The Niger Delta has been described as a prograding depositional complex within the Cenozoic Formation of southern Nigeria (Etu- Efeotor, 1997; Ofodile, 1992). The Niger Delta is a sedimentary basin with complex regressive off lay sequence of clastic sediments ranging in thickness from 9000-12000 meters.

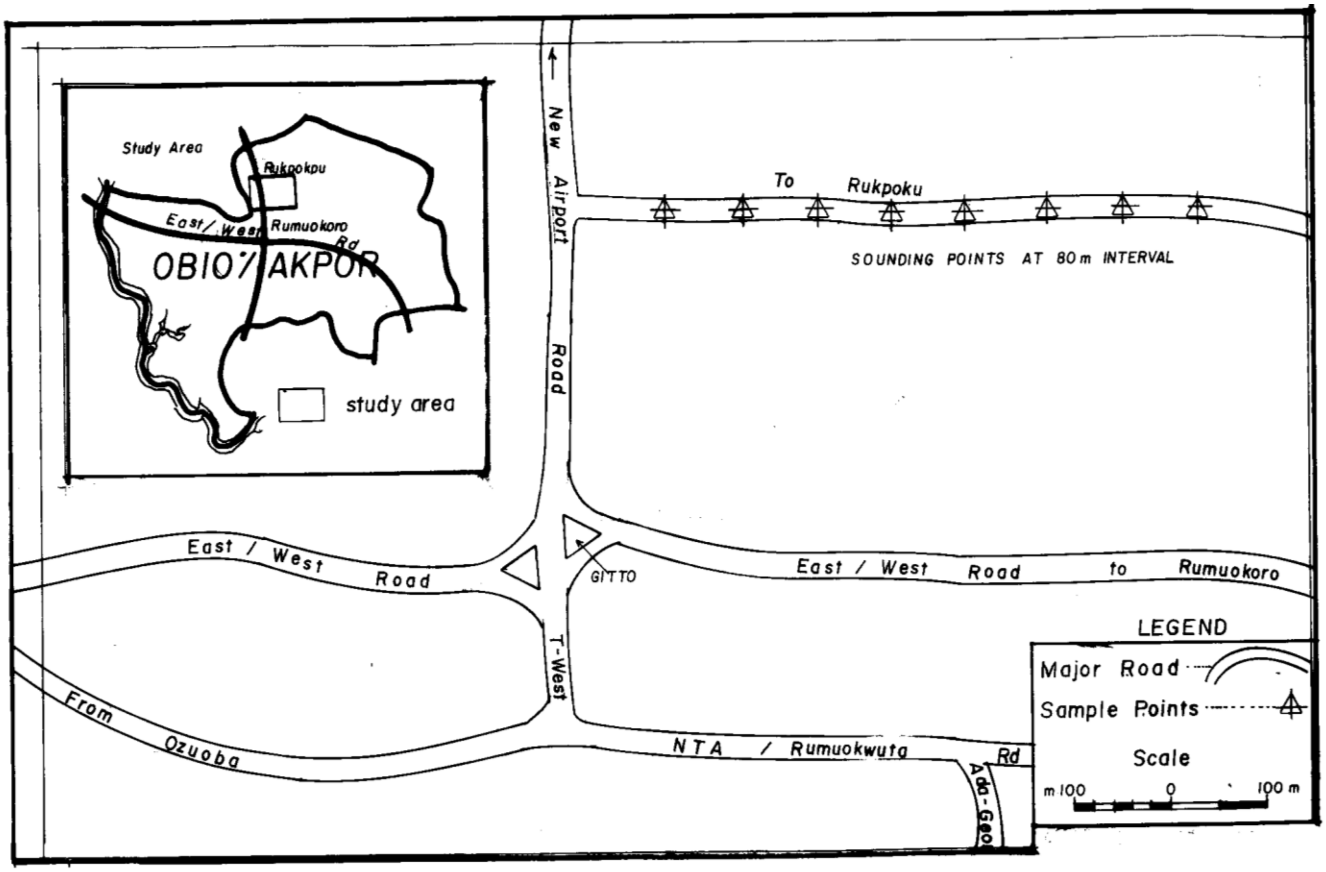

Figure 1: Location Map showing Sounding Points at Rukpokwu, Nigeria.

The study area is underlain by the Benin Formation which is a stratigraphic unit that was laid down during the end of the Tertiary and early Quatenary period (Figure 2). It consists of lenticular, unconsolidated coarse to medium fine sands and clayey shale.

The sands are generally moderately sorted, poorly cemented and angular in shape. The Benin Formation is overlain by a considerable thickness of lateritic red earth formed by weathering and subsequent ferruginization of the weathered older sequences. The high permeability of the Benin Formation, the overlying clay-shale member of the Bende-Ameki series provides the hydrologic conditions favoring aquifer formation in the area. The high annual rainfall ensures adequate groundwater recharge.

METHODOLOGY

In order to determine the thickness, distribution and possible nature of the overburden, a geophysical investigation involving seismic refraction was carried out. The seismic refraction investigation was carried out using a 12-channel Mark Terraloc MK III ABEM Seismograph.

The continuous profiling, in-line shot seismic refraction method was used. The technique consisted of laying out 12 geophones in a straight line and recording arrival times from shot points produced by striking a 16kg sledge hammer into a steel plate at the end of the geophone spread.

Twelve geophones were spaced 10 metes apart to form a continuous profiling of 120 meters length. The distance between the shot point and the first (closest) geophone is 10 meters. The geophones were connected to the seismograph through the geophone cable. Seismic waves were produced by striking the sledge hammer on the steel plate at the shot point. The signal was enhanced by striking 4 to 6 shots until the record showed satisfactory signal-to-noise ratio.

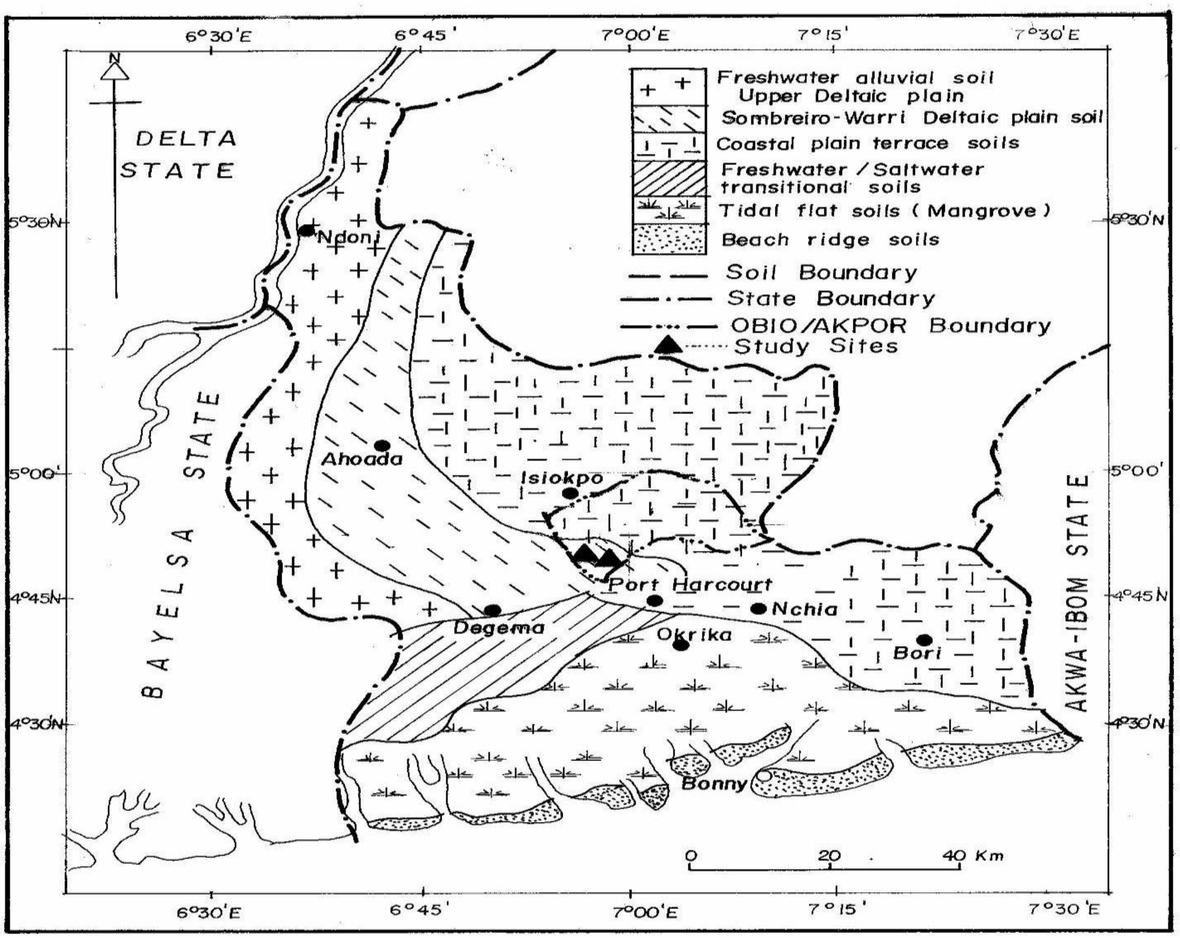

Figure 2: Geological Map of Niger Delta (Adapted from Ehirim et al., 2009).

A total of 8 shots points (records) were completed along the surveyed line using the techniques of continuous profiling. The distance between subsequent shot points were 80 meters. Therefore, the total transverse line covered was about 720 meters. The choice of the continuous profiling was guided by accessibility as the area is heavily built-up. The acquired data were stored in a magnetic tape for processing.

Four vertical electrical sounding locations were also occupied along the same profile line, utilizing the Schlumberger electrode configuration. An ABEM Terrameter 1000C aided with a 2000C booster for better penetration was used, with a current electrode separation of 400m and half potential electrode of 15.0 m. This is aimed at verifying the reliability of the results of the refraction survey.

DATA ANALYSIS AND INTERPRETATION

Seismogram was the main result of the refraction field work; it represents the analog recording of the received signals. The recorded seismic traces reflect the response of the subsurface interfaces. The seismic field data was processed using Reflex2D-Quick software. The first arrival time obtained by each geophone was plotted against the geophone location in each array and the plotted points were best fitted to reflect layers' interfaces (Figure 3). By analyzing the travel-time curves of the direct and refracted arrivals, the number of layers, velocity and thickness of each layer was obtained (Figure 4). The layers velocities were estimated from the inverse of the slope of the straight lines fitted to the data points while the layer thicknesses were obtained from the cross-over and intercept times. The result of the data interpretation is shown in Table 1.

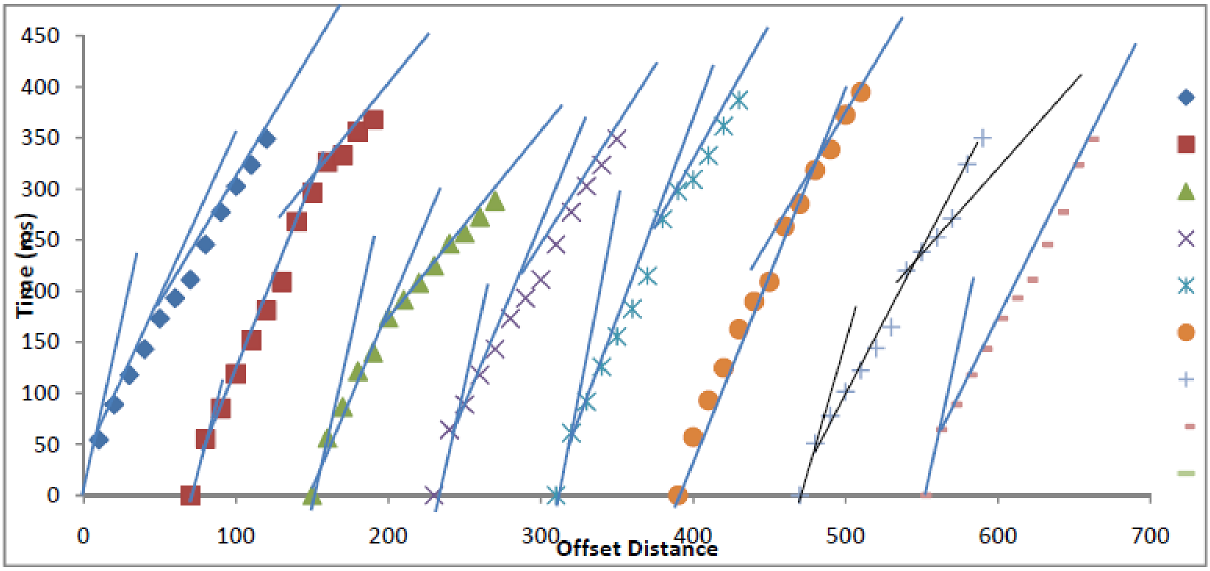

Figure 3: Time-Distance Plot of the Survey Results.

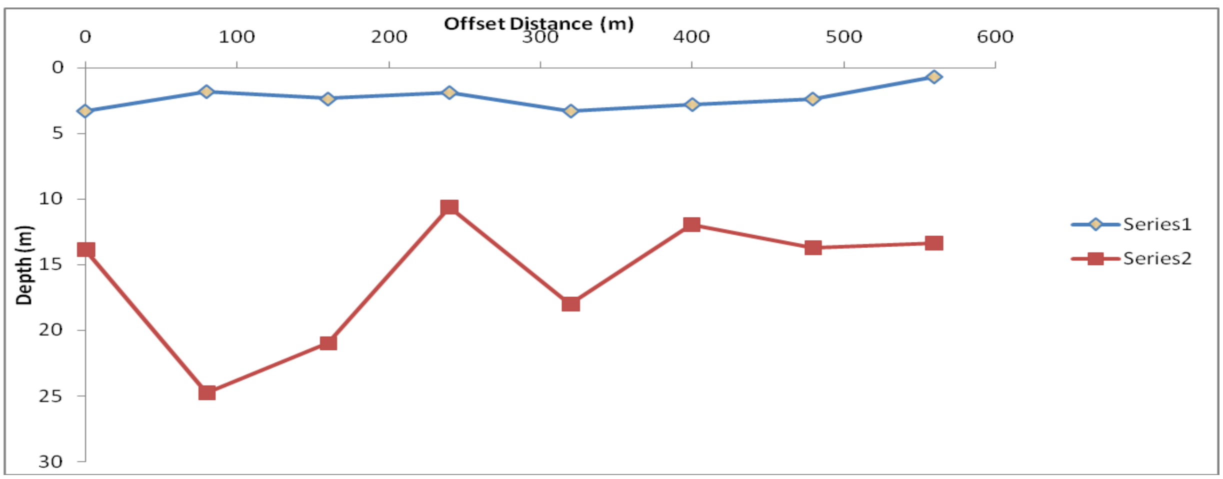

Figure 4: Interpreted Seismic Section.

Table 1: Results of Data Interpretation.

Shot point (m)	Layer 1 thickness (h_1) m	Layer 2 thickness (h_2) m	Layer 1 velocity (V_1) m/s	Layer 2 velocity (V_2) m/s	Layer 3 velocity (V_3) m/s
0	3.25	13.85	191.6	384.6	500.0
80	1.746	24.76	100.0	181.8	400.0
160	2.354	20.98	192.3	333.3	714.3
240	1.916	10.6	104.8	183.3	275.0
320	3.3	18.0	142.9	285.7	470.6
400	2.79	11.93	157.9	300.00	400.0
480	2.364	13.72	200.0	375.00	600.0
560	0.69	13.35	121.2	250.0	363.6

Computer model software (IP12WIN) version 3.0 (2003) was used to invert the field measured apparent resistivity data in order to estimate the true thickness, resistivities and depth to the aquiferous zones in the area (Figure 5). The initial quantitative interpretations were made using partial curve matching technique in which the generated field curves were matched segment by segment with the appropriate master curves and auxiliary curves.

The resistivities and thicknesses of the various layers then served as inputs to an automatic iterative computer program following the main ideas of Zohdy and Martin (1993). Each iteration process was conducted for each sounding station until the root mean square (RMS) error of lower than 5% was obtained.

DISCUSSION OF RESULTS

The results of the refraction survey as depicted in Figure 3 shows a three-layer model. The seismic velocities in the top layer vary between 100 to 200 m/s with an average of 150 m/s. This low velocity layer is the top soil and it is made up of loose humus materials. The thickness ranges between 0.69 to 3.32 m (Table 1).

The second layer has velocity which ranges from 181.8 to 384.6m/s with an average of 300m/s. Comparing the velocity with the established standard P-wave velocity in Table 2 shows that velocity falls within the range of sandy clay. The thickness of this layer ranges between 10.6 to 24.76 m.

The third layer has a velocity which ranges between 275.0 to 714.3 m/s. This layer is assumed to be the basement rock which is made up of weathered materials. With reference to Table 2.0, the third layer is assumed to be made up of wet sand with gravel. This third layer is the aquifer unit in the subsurface and its depth vary between 12.52 to 26.56 m. The interpreted seismic section shows that aquifers of the soundings placed at locations 80, 160 and 320 m are thickest, ranging from 24.76 m around station 2 and 18.0 around station 5. These locations are therefore best recommended sites for drilling boreholes within the study area.

The interpreted seismic result compared well with that of the resistivity (Figure 5). Ambiguity in interpretation of resistivity data was resolved with the aid of geological information from the available shallow borehole (Figure 6).

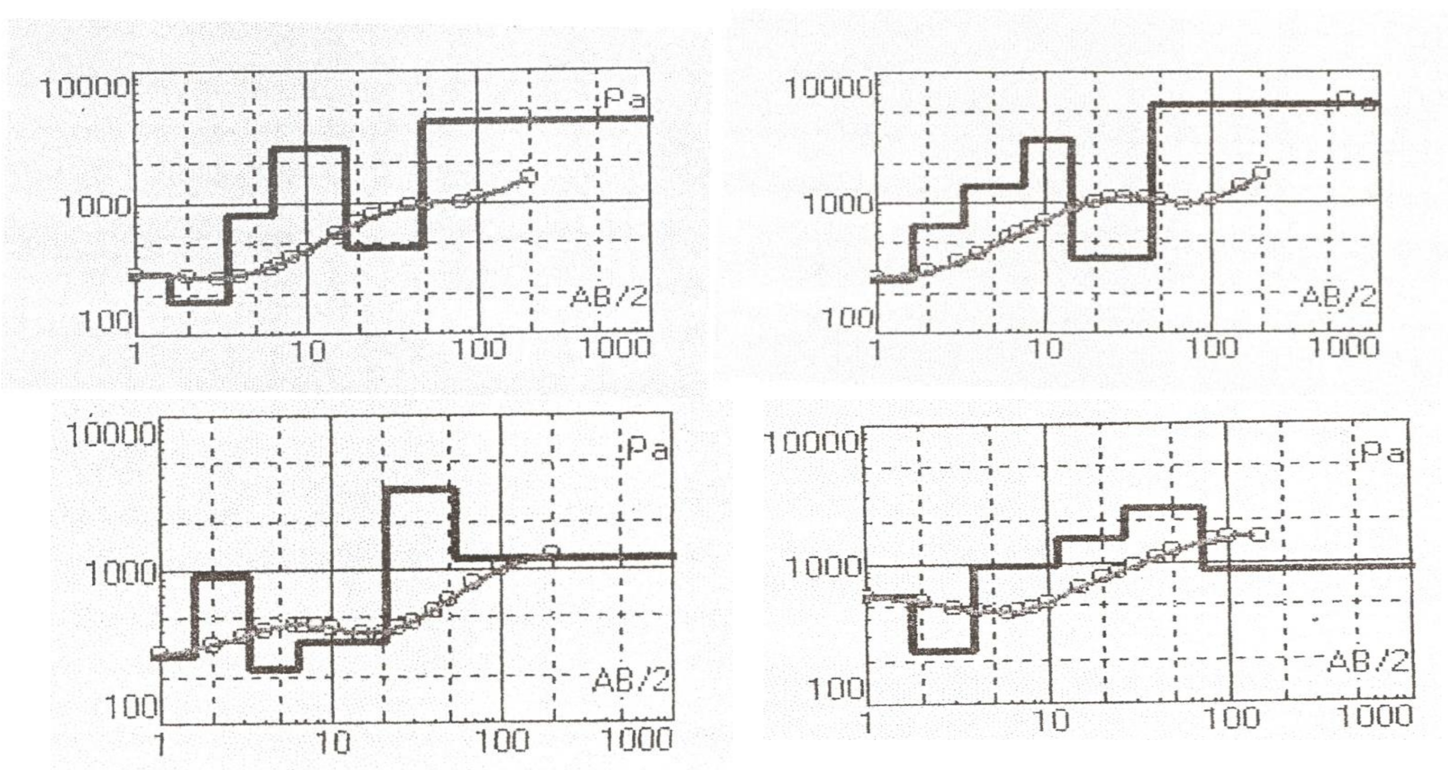

Figure 5: Interpreted Geoelectric Model Curves.

Table 2: Established Standard P – Wave Velocities.

Rock Type	Standard P-Wave Velocity (m/s)
Sandy clay	360-430
Sand with gravel (dry)	490-690
Sand with gravel (wet)	690-1150
Coarse sand (wet)	1150-1670
Clay	1100-4200
Sandstone	1400-4300
Loose sand	1800

(Modified from Ugwu, 2010)

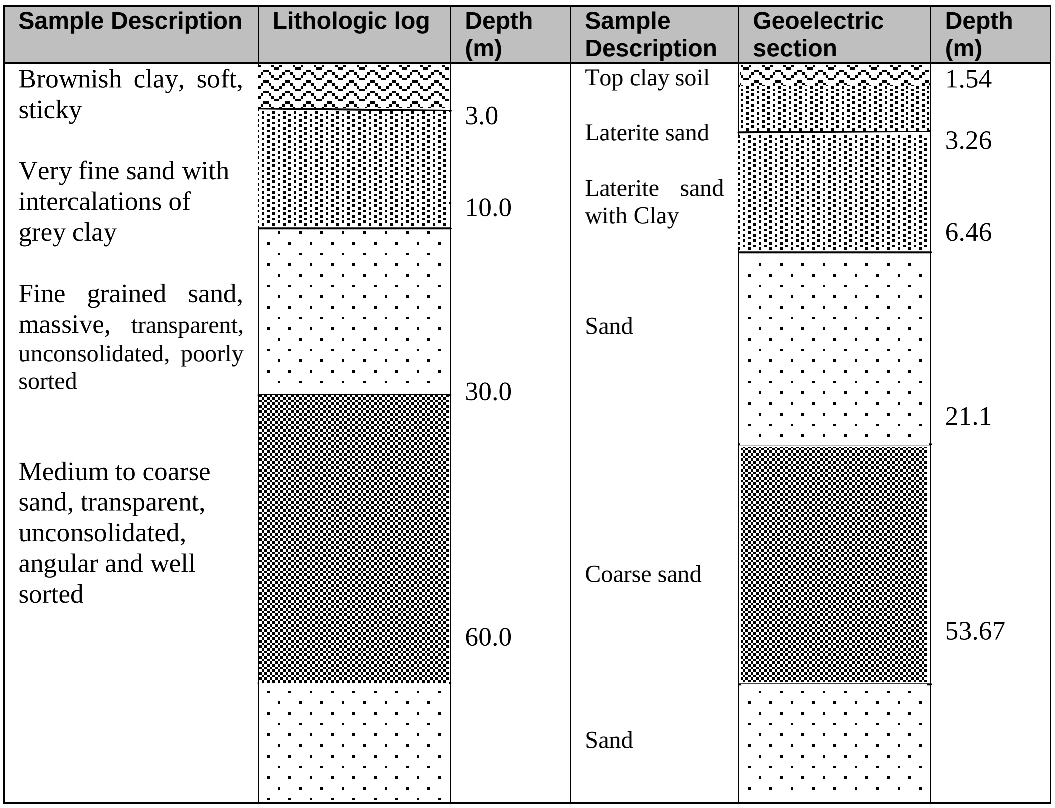

Figure 6: Lithologic Log and Interpreted Geoelectric Sections.

A quantitative interpretation of the resistivity survey show that the rock formations consist mainly of laterite, clayey sands, and fine to coarse sands. The main aquiferous zones occur between the 4th and 5th layers with a resistivity range of 372-3262 Ω-m. The last geoelectric layer could represent yet another saturated aquifer. Deep drilling information would be required to define this layer precisely. The depths to aquifer vary from 14.48 m to 53.68 m while the thickness ranges from 6.99 to 32.57 m. These results are in conformity with the known geology of the study area.

CONCLUSION

The seismic refraction method has been used in defining the depth to aquifer in the Rukpokwu community. The seismic data reveal a three layer model with the basement rock, which is the aquifer having an average velocity of about 500m/s. The depth to the aquifer in the area from refraction survey ranges from 12.52 to 26.56 m. This refraction results correlates closely with aquifer depth range of 14.48 m to 53.68 m from the resistivity data and borehole information.

These findings can be considered as preliminary data to help the decision makers on the depth to which water boreholes should be drilled in the area. It is also useful in Civil Engineering works in determining the depth of the foundation rock.

REFERENCES

1. Ehirim, C.N., J.O. Ebeniro, and D.A. Ogwu. 2009. "A Geophysical and Hydro-Physiochemical Study of the Contaminant Impact of a Solid Waste Landfill (SWL) in Port Harcourt Municipality, Nigeria". *Pacific Journal of Science and Technology*. 10(2):596-603.

2. IP12WIN Software. 2003. Version 3.0. Moscow State University.

3. MacDonald, A.M., J. Davies, and R.J. Peart. 2001. "Geophysical Methods for Locating Groundwater in Low Permeability Sedimentary Rocks: Examples from Southeastern Nigeria". *Journal of African Earth Science*. 32:1-17.

4. Milson, J. 1996. *Field Geophysics (2nd Edition)*. The Geological Field Guide Series. John Wiley & Sons: London, UK.

5. Murad, A., H. Baker, S. Mahmoud, and A. Gabr. 2010. "Groundwater Level Prediction at a Pilot Area in Southeastern, Part of UAE using Shallow Seismic Method. *World Academy of Science, Engineering and Technology.* 71.

6. Nwankwo, C.N., J.O. Ebeniro, and A.S. Ekine. 2009. "The Use of Uphole Method in the Mapping of the Thickness and Velocity of the Low Velocity Layer in parts of Eastern Niger Delta, Nigeria". *Nig. Jour. Phy.* 21(1):64-71.

7. Ofodile, M.E. 1992. *An Approach to Groundwater Study and Development in Nigeria.* Mecon Services Limited: Jos, Nigeria.

8. Ugwu, S.A. and H.O. Nwankwoala. 2008. "Application of Seismic Refraction Method in Groundwater Studies in Calabar, Southeastern Nigeria". *Scientia Africana,*.7(2):73-80.

9. Ugwu, S.A. 2010. "Determination of Depth to Bedrock in Afikpo Syncline of the Benue Trough Nigeria, using Seismic Refraction Methods". *World Journal of Appl. Sci. and Tech*. 2(1):19-25.

10. Zohdy, A.A.R. and R.J. Martin. 1993. "A Study of Sea Water Intrusion using Direct Current Sounding in the Southern Part of the Ox Ward Plain, California". Open-File Reports 93 – 524. US Geological Survey: Washington, D.C. 139.

ABOUT THE AUTHORS

C.N. Nwankwo, has a B.Sc. (Hons) in Physics from the University of Ibadan, a PGD in Computer Science from the University of Lagos, and an M.Sc. and Ph.D. in Applied Geophysics from the University of Port Harcourt, Nigeria. He is currently a Lecturer at the University of Port Harcourt. His research areas of interest are geoelectric studies and exploration geophysics.

G.O. Emujakporue, is a Lecture at the University of Port Harcourt. He holds a B.Tech, in Applied Geophysics from Federal University of Technology, Akure, Ondo State, and an M.Sc. and Ph.D. in Applied Geophysics from the University of Port Harcourt, Nigeria. He has research interests in basin and reservoir modeling, and environmental geophysics.

L.I. Nwosu, has a B.Sc. (Hons) in Physics from the University of Nigeria, and an M.Sc. and Ph.D. in Applied Geophysics from the University of Port Harcourt, Nigeria. His research interests are in hydrological studies and environmental geophysics.

SUGGESTED CITATION

Nwankwo, C.N., G.O. Emujakporue, and L.I. Nwosu. 2013. "Seismic Refraction Investigation for Groundwater Potential in Parts of Rivers State, Nigeria". *Pacific Journal of Science and Technology*. 14(2):505-511.

Pacific Journal of Science and Technology