AQUIFER CHARACTERIZATION AND GROUNDWATER POTENTIAL ASSESSMENT OF THE SEDIMENTARY BASIN OF ONDO STATE

Faleye, E. T.[1] and Olorunfemi, M. O.[2]

[1]Dept. of Physical Sciences, Wesley University of Science and Technology, Ondo, Nigeria

[2]Dept. of Geology, Obafemi Awolowo University, Ile-Ife, Nigeria

(Corresponding Author: topefaleye@yahoo.com)

(Received: 7th May, 2015; Accepted: 1st July, 2015)

ABSTRACT

The sedimentary basin of Ondo State, underlain by the Coastal Alluvium, Coastal Plain Sands, Imo Shale Group, Upper Coal Measures and Nkporo Shale, was investigated using integrated electrical resistivity and borehole lithologic logs with a view to characterizing the aquifer and assessing the groundwater potential. One hundred and four Vertical Electrical Soundings (VES) were quantitatively interpreted using the partial curve matching technique and computer assisted 1-D forward modeling. Fourteen (14) borehole lithologic logs were used to generate columnar sections from which aquifer units were delineated. Geoelectric sections were generated from the VES interpretation results, constrained by borehole lithological logs, for aquifer identification and geoelectric parameter determination. Depths to top and thicknesses of the aquifer units within each geologic unit were determined. Four aquifer units were identified within the Coastal Alluvium/Coastal Plain Sands. The depths to top/thicknesses of the aquifer units were 5–23 m (7–26 m); 7–80 m (6–67 m); 63-188 m (20-143) and 245–261 m (61–117 m) respectively. Within the Upper Coal Measures, two aquifer units were identified. The depths to the top/thicknesses of the aquifer units were 9.8 m (1.7 m) and 23 m (5.3 m) respectively. The Nkporo Shale had depth to top and thickness of the only identified aquifer unit as 10 m and 16 m respectively. The study concluded that the groundwater potential of the Coastal Alluvium and Coastal Plain Sands was high while the groundwater potential of the Imo Shale Group, the Upper Coal Measures and Nkporo Shale was adjudged low.

Keywords: Aquifer Characterization, Groundwater Potential, Electrical Resistivity, Lithologic Logs

INTRODUCTION

The sedimentary basin of Ondo State is underlain by the Coastal Alluvium at the extreme south and along major river flood plain, the Coastal Plain Sands, the Imo Shale, Upper Coal Measures and Nkporo Shale. These formations have variable hydrogeological characteristics. The shallow aquifers within the southern sedimentary portion of Ondo State have been investigated and found to be vulnerable to near-surface contaminants (Ako, 1982; Omosuyi *et al.,* 1999; Omosuyi, 2001; Omosuyi *et al.,* 2008 and Bello, 2011). Oteri and Atolagbe (2003) observed that potable water supply to inhabitants in some of the communities in the sedimentary rock underlain southern (coastal belt) part of Ondo State had been a major problem due to salt water intrusion. The Ondo State Water Corporation currently cannot meet the daily water need of the growing population within the state from its surface water schemes. Only 70.2 million litres of potable water out of the state water requirement of 598 million litres is supplied (BECANS, 2007). This has made groundwater development through borehole drilling inevitable. However, many of the moderately deep (< 100 m) boreholes drilled in the coastal area had yielded saline water. Siting of deep boreholes in this area requires adequate knowledge and characterization of the aquifer units of the Coastal Plain Sands and the Alluvial deposits. The Imo Shale is predominantly an aquiclude and aquitard of low permeability with low groundwater yielding capacity. The Upper Coal Measures is made up of fine sandstones at the top with aquiclude and aquitard at the base, and tendency for low groundwater yield. There is therefore the need to characterize the aquifers underlying the study area and assess the groundwater potential. This will enhance our knowledge of the hydrogeology of the study area and assist groundwater development (Singh, 1984).

Geographic Description of the Study Area/Drainage/Climate

The sedimentary basin of Ondo State is bounded by Latitudes 5° 52' and 7° 00' N and Longitudes 4° 23' and 5° 54' E (Fig. 1). The terrain is flat with gently undulating topography. The

geomorphologic units include sand ridges, lagoons, swamp flats and creeks. Numerous rivers flowing southwards to the Atlantic Ocean drain the basin. These rivers include the Owena, Oluwa, Oni, Ogbese, Ose, Ominla, Akeun and Ufara. The major rivers flow through the sedimentary rocks in deeply incised valleys aligned in a north-south direction, into the coastal lagoons. The mean monthly temperature is 27°C, with a mean monthly range of 2°C. The mean annual total rainfall exceeds 2000 millimeters (Iloeje, 1981).

Geology and Hydrogeology

The sedimentary terrain of Ondo State falls within the eastern portion of the Dahomey Basin. The geologic sequence is composed of the Nkporo Shale, Upper Coal Measures, Imo Shale Group, Coastal Plain Sands (Benin Formation) and Quarternary Coastal Alluvium (Fig. 2).

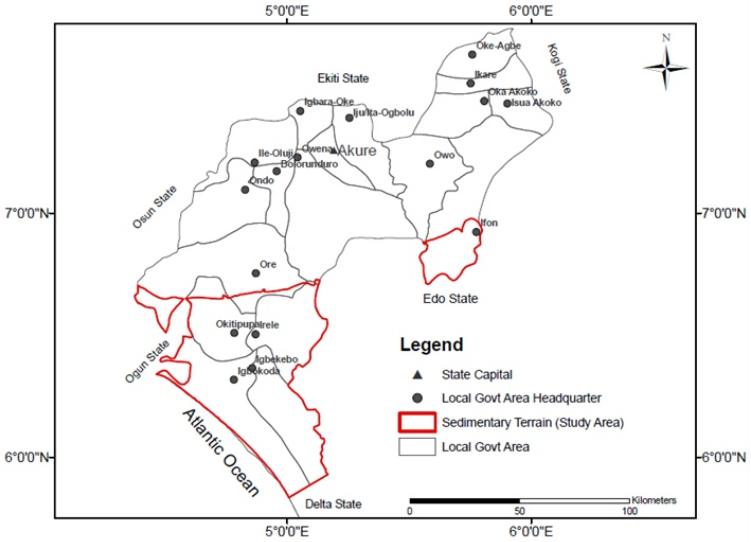


Figure 1: Administrative Map of Ondo State (Modified from Administrative Map of Ondo State published by the Office of the Surveyor General of Ondo State, 1998)

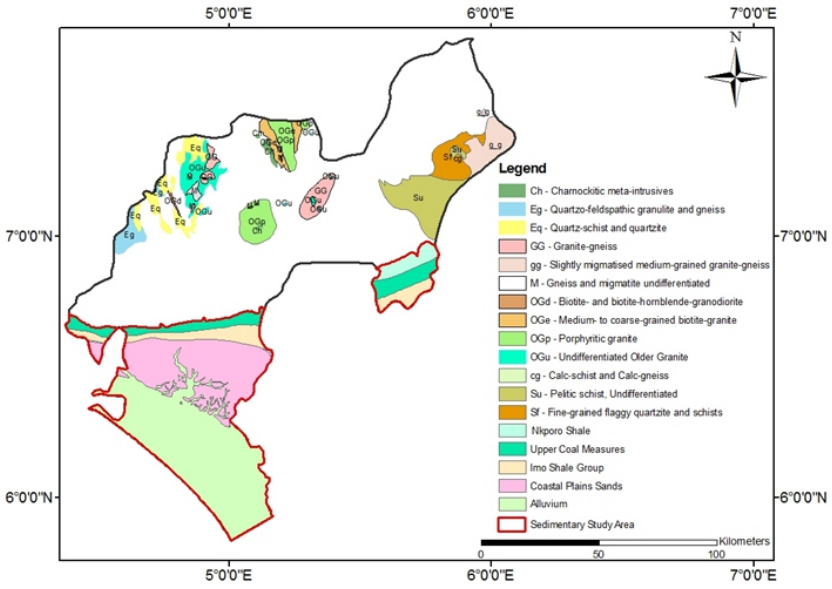


Figure 2: Generalized Geologic Map of Ondo State (Adapted from the Geological Survey of Nigeria (GSN, 1966))

The Nkporo Shale is made up of shale, sandy clay and lenses of sand. The Upper Coal Measures consists of clay/sandy clay, sand, limestone and shale. The Imo Shale Group is composed of shale while the Coastal Plain Sands has alternations of clay/sandy clay and clayey sand/sand. The Quarternary Coastal Alluvium is composed of an alternating sequence of sand and silt/clay (Jones and Hockey, 1964 and Etu-Efeotor and Akpokodje, 1990). The aquifer units are sand, sandstones, clayey sand and dissolved/fractured limestone which are unconfined and confined in nature.

METHOD OF STUDY

One hundred and four Vertical Electrical Soundings (VES) involving the Schlumberger array with maximum electrode spacing (AB) ranging from 650 m to 1000 m were acquired in the study. The geoelectrical soundings covered the entire sedimentary basin of Ondo State (Fig. 3). Fourteen borehole logs prepared from lihological samples recovered from mechanised rotary drilling were involved in the study. The columnar sections of these logs were used to identify aquifers (sand units), aquiclude or aquitard (clayey) units. Based on the depths of occurrence, the delineated aquifers were categorized into units (upper, middle and lower aquifers). Depths to the top and base of each aquifer unit were computed. Aquifer identification and correlation were based on lateral lithologic homogeneity expected in a tectonically stable basin.

The apparent resistivity values obtained from the VES were used to generate sounding curves which were subsequently interpreted both qualitatively and quantitatively. The qualitative interpretation involved visual inspection of the curves to determine the nature of subsurface layering. The quantitative interpretation involved

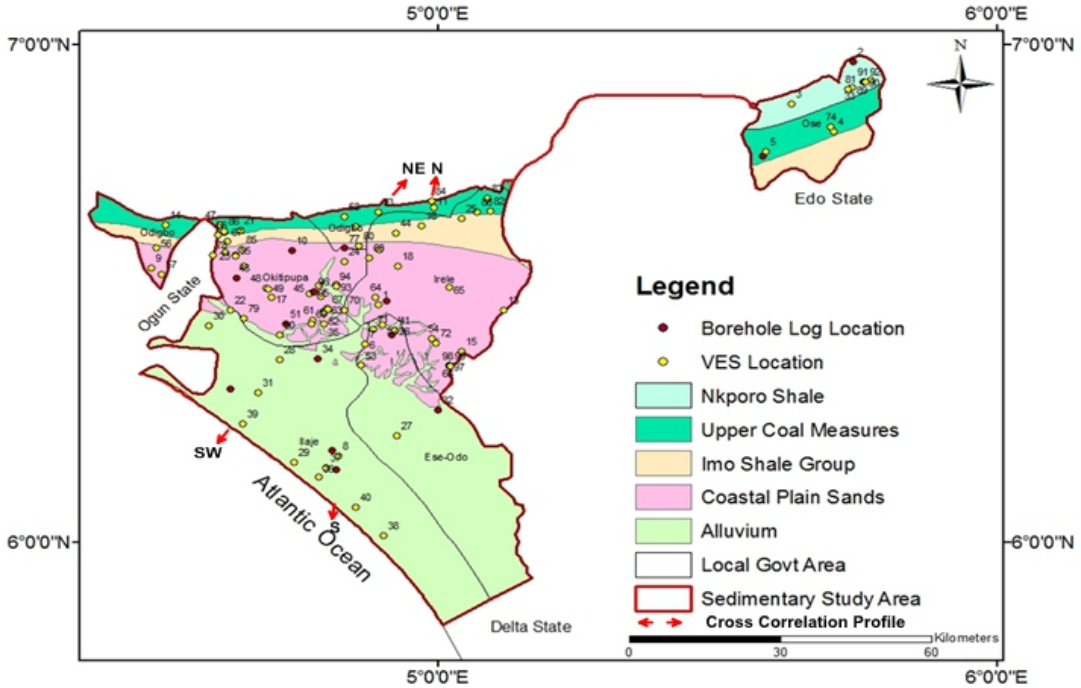


Figure 3: Map of the Study Area showing the VES and Borehole Logs Distribution Overlay on Geology

partial curve matching and computer assisted 1-D forward modeling with WinRESIST software (Vander Velpen, 2004). The interpreted results of the VES curves were used to prepare geoelectric sections which were constrained with the available borehole logs.

RESULTS AND DISCUSSION

Characteristics of the VES Curves

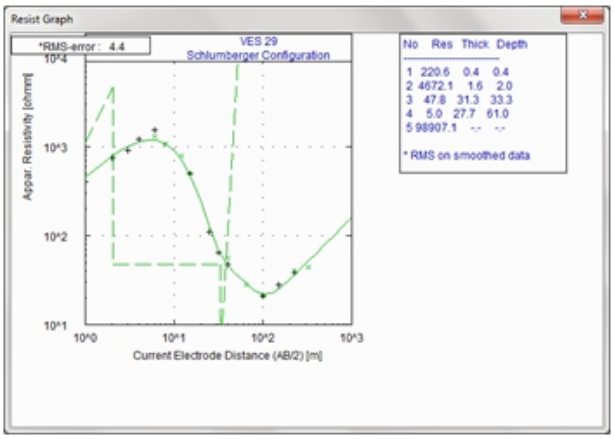
The depth sounding type curves obtained from the study area ranged from simple A, H, K, Q, AK, HA, HK, KH, KQ and QH type to complex AAK, AKH, HAK, HKH, HKQ, KHA, KHK,

KQH, HKHK, HKQH, KHAK, KHKH, KQHK and KHKHK types. The type curves are similar to those obtained by Omosuyi *et al.* (2008). The typical sounding curves obtained from each geological unit are shown in Figures 4 (a) – (d). Figure 5 shows the various type curves and their frequencies of occurrences. The KHK type curve was the most predominant, accounting for 15.38% of the total sounding curves. The HK, AK, KH, QH, HA and KHKH type curves accounted for 13.46%, 12.5%, 9.62%, 6.73%, 5.77% and 4.81% respectively. The other seventeen type curves accounted for the remaining 32%.

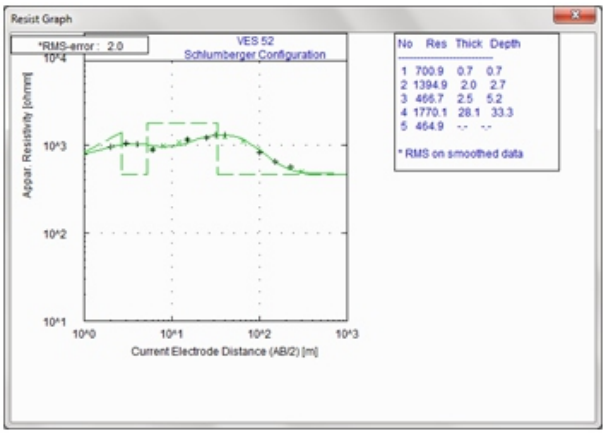
Aquifer Identification and Correlation from Borehole Lithologic logs

Borehole litholigic logs are often used for subsurface layer delineation, aquifer identification and correlation (Fatoba and Olorunfemi, 2004). The subsurface layers delineated from all the borehole lithologic logs are clay, sandy clay, clayey sand, sand and limestone. The main aquifer units are predominantly clayey sand/sand and limestone within the Upper Coal Measures.

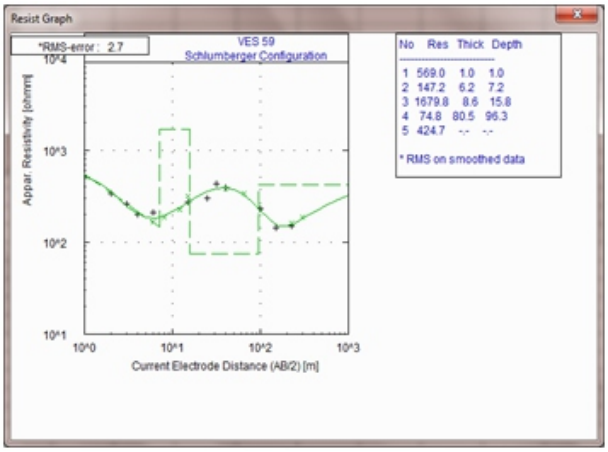
The correlated lithologic logs from the Coastal Alluvium are from boreholes located at Zion-Pepe, Igbokoda, Ugbonla, Aiyetoro and Arogbo (Fig. 6). Three main aquiferous zones were delineated in the upper 370 m of the subsurface sequence.



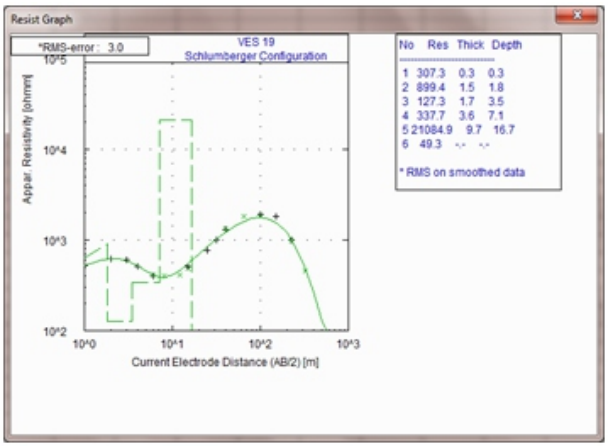
(a)



(b)



(c)



(d)

Figure 4: Typical VES Type Curves (a) KQH from Coastal Alluvium and (b) KHK from Coastal Plain Sands (c) HKH from Imo Shale Group and (d) KHAK from Upper Coal Measures

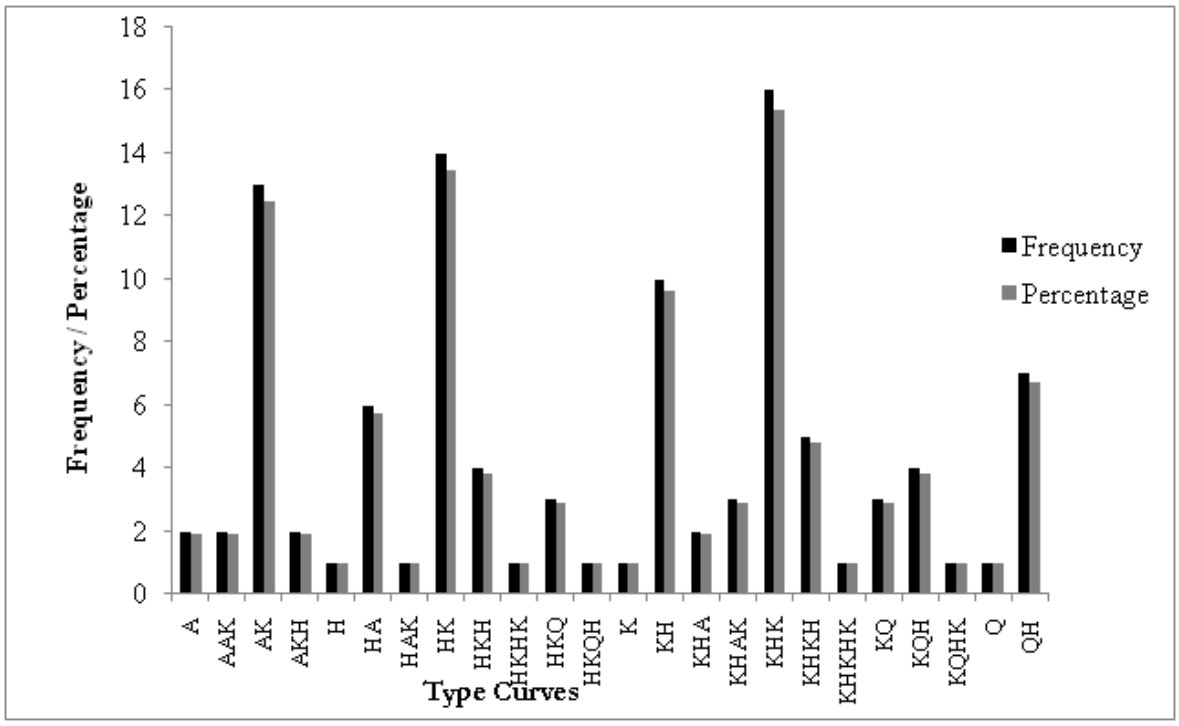


Figure 5: Type Curve Frequency and Percentage of Occurrence

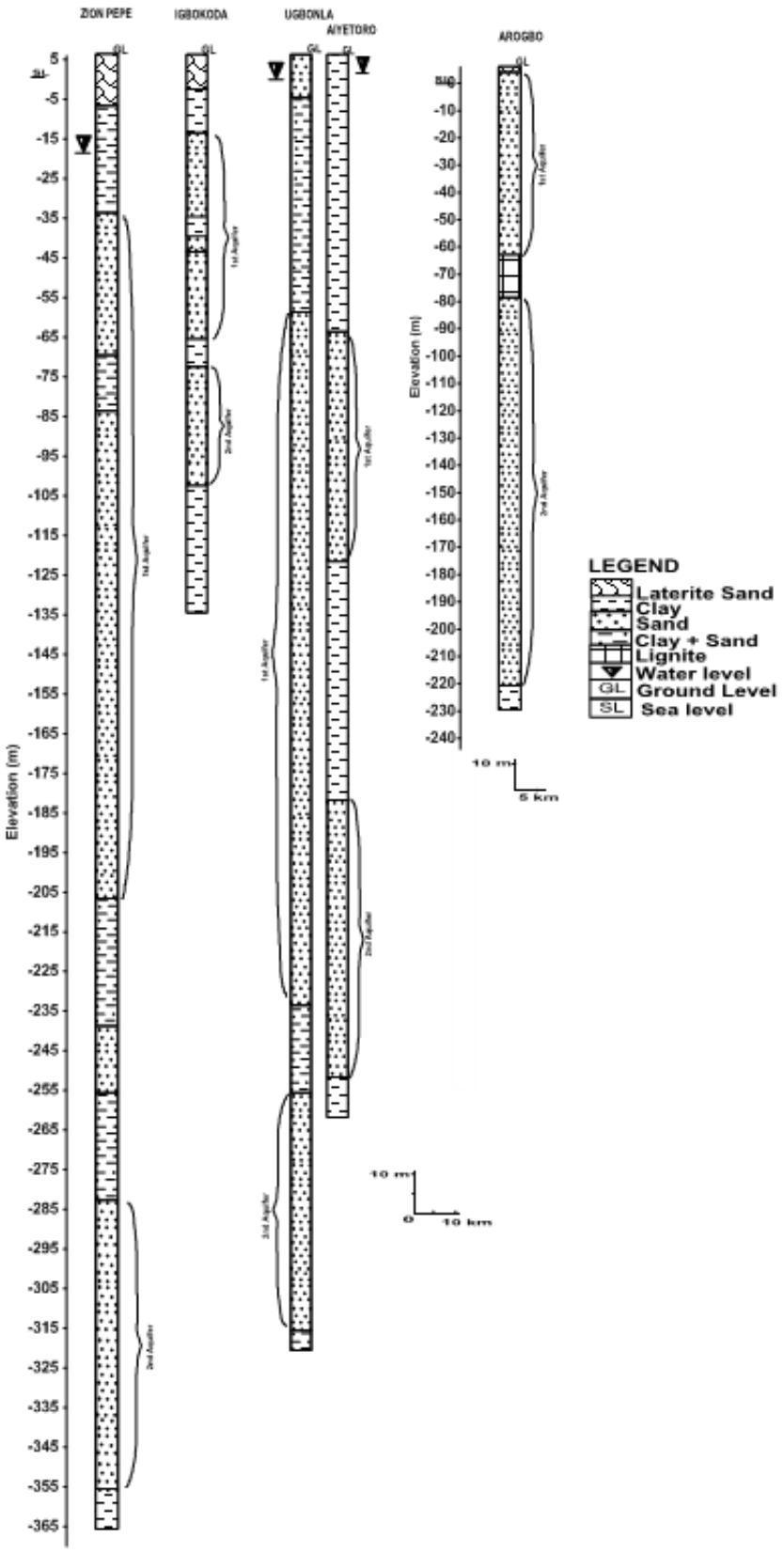


Figure 6: Borehole Lithologic Logs from Locations Underlain by Coastal Alluvium – Zion-pepe, Igbokoda, Ugbonla, Aiyetoro and Arogbo.

The depth to the top of the first aquifer unit varies from 20-70 m while the aquifer thicknesses range from 37-67 m. This aquifer unit is confined. Depths to top of the second aquifer unit range from 79 m at Igbokoda to 188 m at Aiyetoro with thicknesses of between 27 and 143 m. The identified third aquifer unit could only be correlated beneath the relatively deep Zion-Pepe and Ugbonla boreholes. The depth to the top of the third aquifer is 245 m at Zion-Pepe with thickness of 117 m; and 261 m at Ugbonla with thickness of 61 m.

Within the Coastal Plain Sands, borehole logs from Agbabu, Ode-Aye, Okitipupa and Erinje were correlated along a north-south direction (Fig. 7). Three aquifer units were delineated in the upper 175 m of the subsurface sequence. Depths to the top of the first aquifer vary from 7 m at Erinje to 23 m at Agbabu. The thicknesses of the aquifer range between 10 m and 24 m. The second aquifer unit was correlated at depths of 40-80 m while the thicknesses range from 6 m to 17 m. The depth to the top of the third aquifer ranges from 63-167 m with thicknesses of 26 m at Okitipupa and Erinje. This aquifer unit is confined.

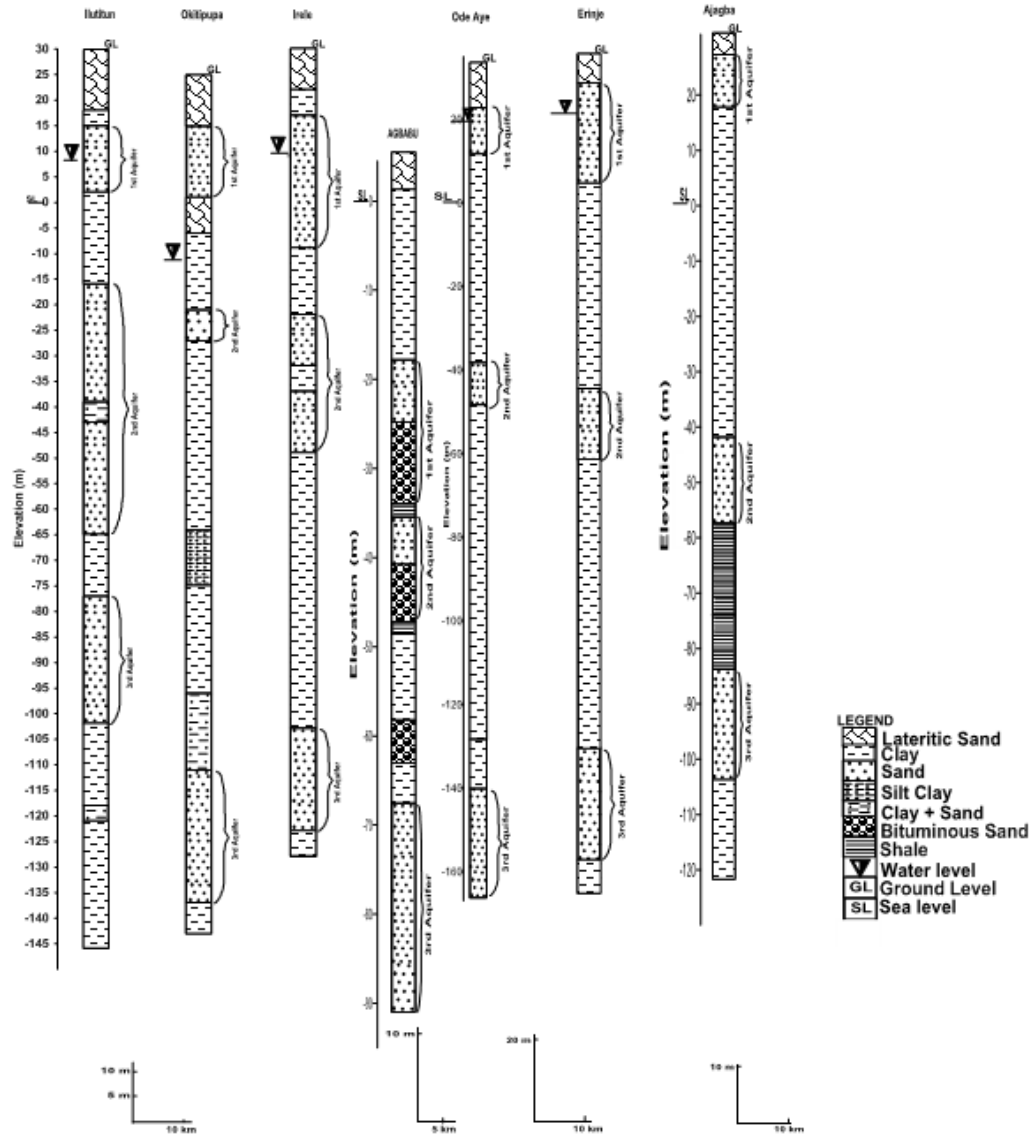


Figure 7: Borehole Lithologic Logs from Locations Underlain by Coastal Plain Sands – Ilutitun, Okitipupa, Irele, Agbabu, Ode-Aye, Erinje and Ajagba.

The lithologic log from the Upper Coal Measures (Fig. 8a) shows a sequence composed of shale, lenses of sand and limestone. The depths to the top and thicknesses of the first and second identified aquifer units are 9.8 m (1.7 m) and 23 m (5.3 m) respectively. The aquifer units are generally thin and embedded within low permeability confining clayey formation.

The Nkporo Shale has poor hydrogeological characteristics because of its clayey nature. However, the lithologic log of the borehole drilled at Ori Ohin (Fig. 8b) identified sand at depth of 10 m with thickness of about 16 m.

Geoelectric and Litho-Stratigraphic Correlation

In this study, Vertical Electrical Sounding interpretation models were integrated with the borehole lithologic logs to allow for cross correlation of the identified aquifer units. The geoelectric and litho-stratigraphic correlation was carried out along SW – NE and S – N direction respectively (see Fig. 3).

The SW – NE section (Fig. 9) cuts across the Coastal Alluvium, Coastal Plain Sands, Imo Shale Group and the Upper Coal Measures and relates VES 39, 31, Zion-Pepe Borehole, VES 28, Erinje Borehole, VES 61, 20, 24, Agbabu Borehole, VES 59 and 73. The N – S section (Fig. 10) also cuts across the same geologic formations and relates VES 36, Aiyetoro Borehole, VES 37, 8, Ugbonla Borehole, VES 53, 7, Irele Borehole, VES 64, 43, 44, 11 and 84.

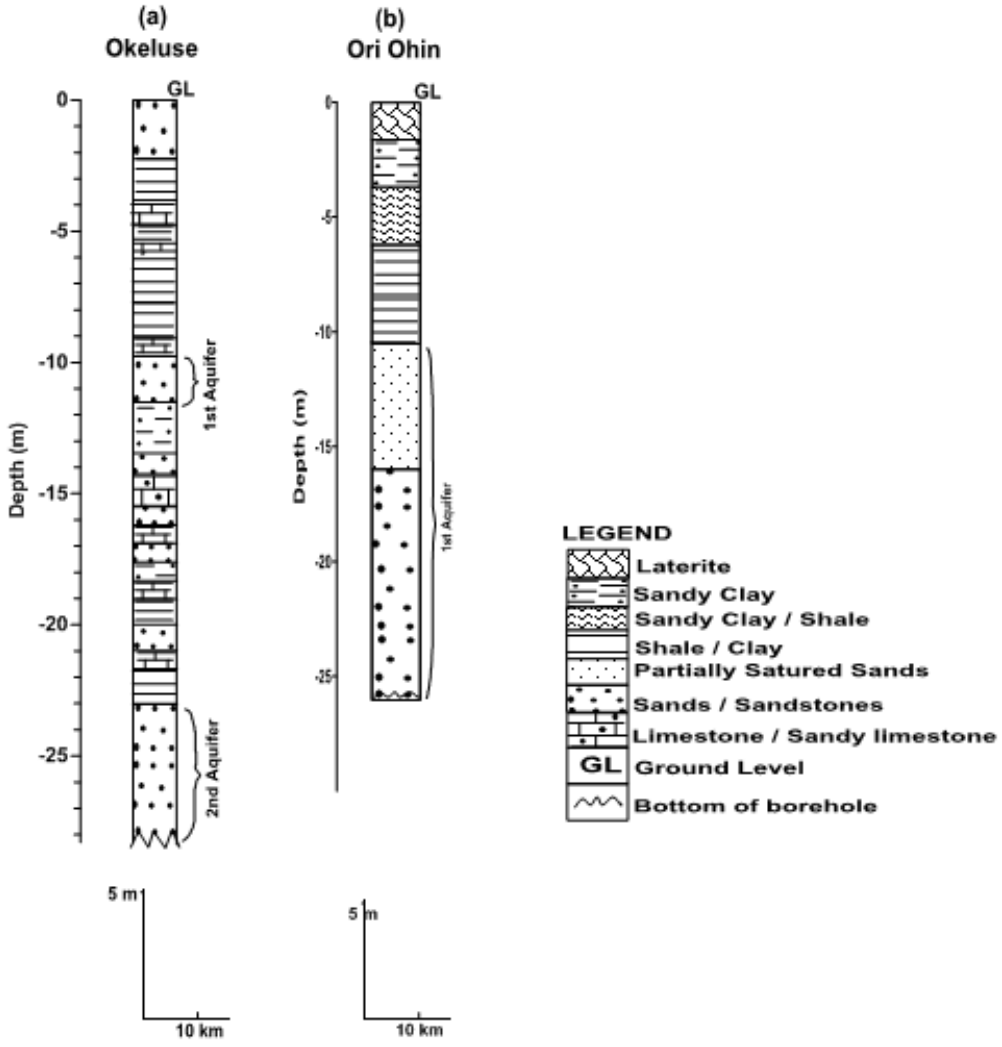


Figure 8: Borehole Lithologic Logs from Locations Underlain by (a) Upper Coal Measures - Okeluse (b) Nkporo Shale – Ori-Ohin.

Both geoelectric/geologic sections show that the first sand aquifer unit identified has resistivity range of 237 ohm-m to ∞. Depth to top of the aquifer unit ranges from 5 to 23 m with thicknesses of between 7 and 26 m. The second aquifer unit correlated has resistivity range of 37 to 6200 ohm-m and depth to the top of between 2 to 80 m, while the thickness ranges from 6 to 67 m. The third aquifer unit identified was delineated at depth range of 63 to 188 m with thicknesses of between 7 m and 143 m. The fourth aquifer unit was encountered at depth range of 245 to 261 m with a thickness range of 61 to 117 m. The depth of investigation of the geoelectric sounding was too shallow to delineate the third and fourth aquifer units. Figures 9 and 10 show that the first and second aquifer units beneath the Coastal Alluvium are laterally equivalent to the second and third aquifer units beneath the Coastal Plain Sands.

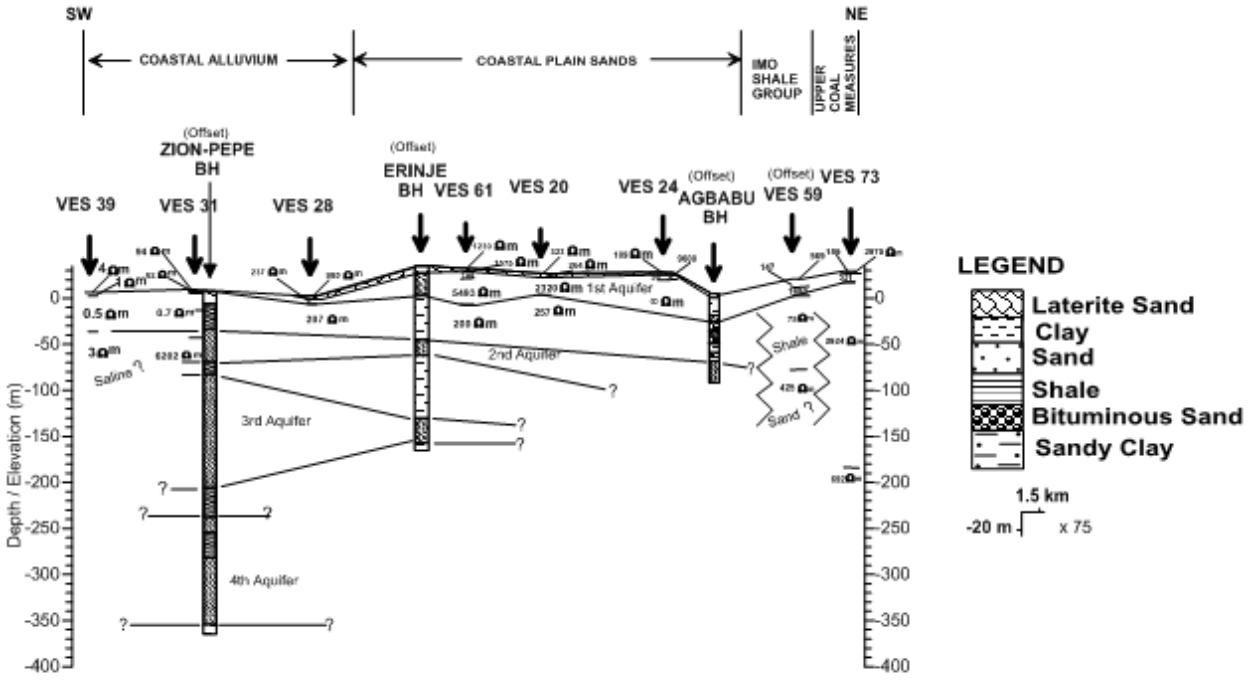


Figure 9: Geoelectric and Litho-Stratigraphic Correlation along Southwest-Northeast Direction

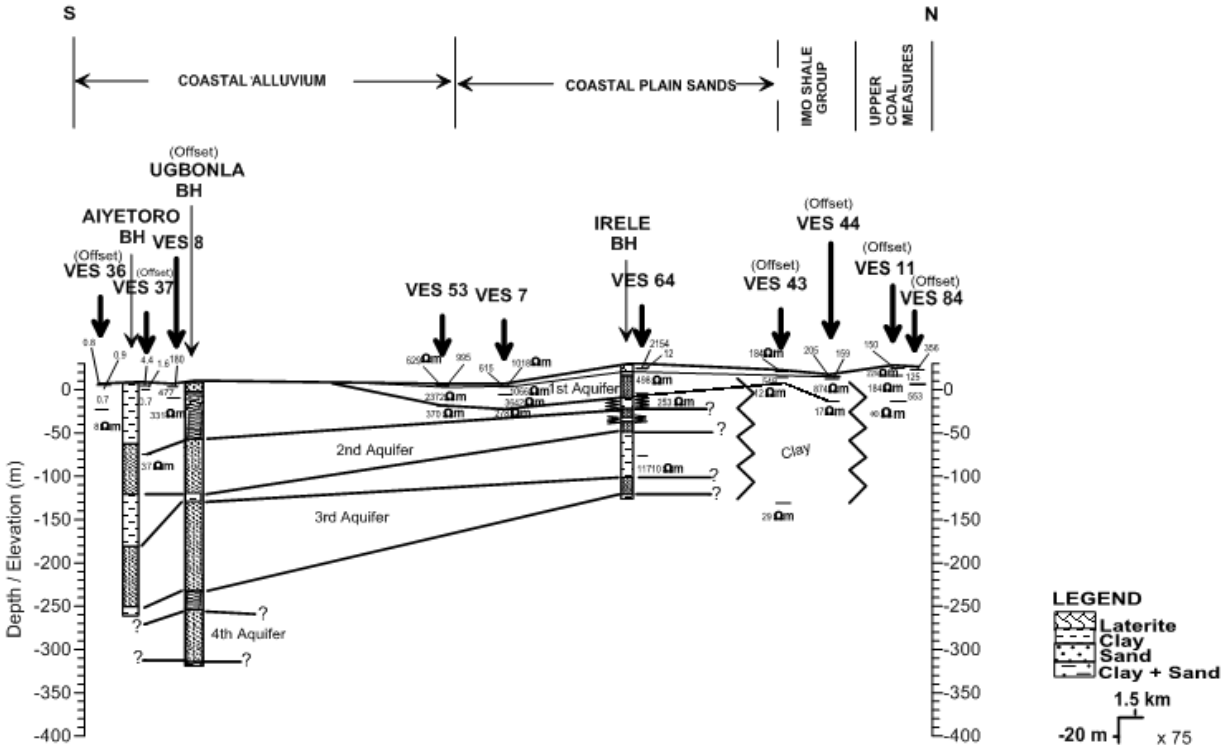


Figure 10: Geoelectric and Litho-Stratigraphic Correlation along South - North Direction

Groundwater Potential Assessment

Within the Coastal Alluvium and Coastal Plain Sands, the aquifer units identified are predominantly sands with high porosity and permeability. The aquifer system is a multi-storey type. Maximun of four aquifer units have been delineated within the Coastal Alluvium/Coastal Plain Sands. The depths to top and aquifer thicknesses are 5 - 23 m (7 – 26 m); 7 – 80 m (6 – 67 m); 63 – 188 m (20 – 143 m) and 245 – 261 m (61 – 117 m) for the first, second, third and fourth aquifer units respectively. Based on the aforementioned, the groundwater potential of the Coastal Alluvium/Coastal Plain Sands can be rated high.

The Imo Shale Group contains thick layers of porous but impermeable shale thus making the groundwater yielding capacity to be of a very low rating. However, limited groundwater yield could be obtained from lenses of sand/sandstone within the shale. Within the Upper Coal Measures, lenses of sand, dissolved or fractured limestone constitute the aquifer units. Limited groundwater yield is expected from the lenses of sand. Groundwater potential is also adjudged low. The Nkporo Shale has lenses of sand as its aquifer unit. Within the Nkporo Shale, thin layers of sand constitute the aquifer units with consequently low groundwater potential.

CONCLUSION

The five geologic units within the Ondo State sedimentary basin are composed of different lithologic sequence. Beneath the Coastal Alluvium and Coastal Plain Sands are alternations of clay/sandy clay and sand/clayey sand. The sand and clayey sand constitute the aquifer units. Maximum of four sand aquifer units were delineated beneath both formations. The Imo Shale Group is made up of thick layers of porous but impermeable shale. The Upper Coal Measures is composed of clay/sandy clay, sand, limestone and shale. The lenses of sand and dissolved or fractured limestone constitute the aquifer unit. The Nkporo Shale is composed of shale, sandy clay and lenses of sand. The sands constitute the aquifer unit. The groundwater potential rating for the Coastal Alluvium/Coastal Plain Sands is high while the groundwater potential of the Imo Shale Group, Upper Coal

Measures and Nkporo Shale is rated low.

REFERENCES

Ako, B. D. 1982. Geophysical Prospecting for Groundwater in an Area without Adequate Geological Data Base. *Journal of Mining Geology*. 18(2):88-105.

BECANS, 2007. Business Environmental Report. *African Institute for Applied Economics*, 1: pp 30.

Bello, A. J. 2011. Geoelectric Investigation of Saline Water Intrusion in the Coastal Area of Ondo State, Southwestern Nigeria, M.Tech. Thesis, Department of Applied Geophysics, Federal University of Technology Akure, Nigeria, (Unpubl.) p 115.

Etu-Efeotor, J.O. and Akpokodje, E.G. 1990. Aquifer systems of the Niger Delta. *Jour. Mining Geology*. Vol. 26 (2), pp 279 – 285.

Fatoba, J. O. and Olorunfemi, M. O. 2004. Subsurface Sequence Delineation and Saline Water Mapping of Lagos State, Southwestern Nigeria. *Global Journal of Geological Science,* 2 (1): 111-123.

Iloeje, M. P. 1981. *A New Geography of Nigeria*. Longman: Nigeria. 26 – 28.

Jones, H. A. and Hockey, R. D. 1964. The Geology of Part of Southwestern Nigeria. *Geological Survey of Nigeria (GSN) Bulletin,* 31, 101p.

Omosuyi, G. O. 2001. Geophysical and Hydrogeological investigations of Groundwater prospects in the southern part of Ondo State, Nigeria, Ph.D. Thesis, Department of Applied Geophysics, Federal University of Technology Akure, Nigeria, (Unpubl.), p 195.

Omosuyi, G. O., Ojo, J. S. and Olorunfemi, M. O. 1999. Borehole lithologic correlation and aquifer delineation in parts of the coastal basin of SW Nigeria. *Journal of Applied Sciences*, 2, 617-626.

Omosuyi, G. O., Ojo, J. S. and Olorunfemi, M. O. 2008. Geoelectric Sounding to Delineate Shallow Aquifers in the Coastal Plain Sands of Okitipupa Area, Southwestern Nigeria. *Pacific Journal of Science and Technology*. 9(2):562-577.

Oteri, A. U. and Atolagbe, F. P. 2003. Saltwater Intrusion into Coastal Aquifers in Nigeria. *The Second International Conference on Saltwater Intrusion and Coastal Aquifers-Monitoring, Modeling, and Management. Mérida, Yucatán, México*, March 30 - April 2, 2003.

Singh, C. L. 1984. Role of Surface Geophysical Methods for Groundwater Exploration in Hard Rock Areas. *Proceedings of International Workshop on Rural Hydrology and Hydraulics in Fissured Basement Zones*. 59-68.

Vander Velpen, B. P.A. 1988. RESIST Version 1.0" Resistivity Depth Sounding Interpretation software, *M.Sc. Research Project,* ITC, Delft, Netherlands.