Comparative Investigation of Prospecting Accuracies of Resistivity Instruments in Subsurface Groundwater Delineation in Basement Complex of South Western Nigeria

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ABSTRACT

Geophysical investigation of groundwater potential was carried out within Osun State University, Main Campus, Osogbo, South-western Nigeria using ABEM, PASI and IGIS resistivity instruments with the aim of investigating their prospecting accuracies for groundwater. Vertical electric sounding (VES) and 2D Wenner array techniques were employed in the investigation with the central reference located close to an already drilled borehole. The data obtained were first subjected to partial curve matching and later iterated and modeled using the WinResisit software. Using ABEM SAS, the topsoil was predicted to be composed of sandy layer of resistivity value of 207.5 Ωm and of about 1.0 m, PASI predicted a clayey topsoil of 30.8 Ωm and about 1.0m thick while the IGIS instrument revealed a concretional lateritic topsoil of about 817.7 Ωm and 2.4 meters thick. The aquiferous layer was predicted by ABEM SAS to be clayey sand and conformably overlie the basement rock with resistivity of 98.3 Ωm and about 18 m thick. PASI revealed a water-bearing zone to be a clay interval with resistivity of 25 Ωm and of about 1.7 m thick. The output of the three instruments do not correlate. The geoelectric interpretation of ABEM data closely correlates with that of the existing borehole but PASI and IGIS data do not. This is probably because the ABEM has signal averaging sensor which records four consecutive cycles of resistivity values before display their mean value but PASI and IGIS have one-shot voltage-current signal stacking. The ABEM instrument gave resistivity and geoelectric values closest to that of the existing borehole. Hence, it is a more reliable instrument than PASI or IGIS that operate on single-shot voltage-current signal stacking.

Keywords: ABEM, PASI, and IGIS, Comparative, Instrument, Schlumberger, Wenner, Basement Complex, Osogbo

Introduction

Electrical method in geophysical prospecting has found application in groundwater studies for many years. It was first used for mineral exploration but over the years, it has been preferred for use in groundwater exploration to other geophysical methods. This is because electrical resistivity instruments (terrameter) have ease of logistics and are readily available than most other instruments used in groundwater exploration such as seismograph for refraction studies, magnetometer for very low frequency electromagnetic studies remote sensing radar for very high electromagnetic method (using the ground penetrating radar machine).

A good resistivity meter (either foreign made or locally fabricated) should be able to possess high accuracy and precision leading to better subsurface imaging even at far depths. The most popular big names in the manufacturing of resistivity meters include Campus Omega, ABEM Company, PASI Geophysically, Syscal Incorporated, Integrated Geophysical Instruments (IGIS) in Hydrabad, India, Omega Incorporated, BISON and SCINTREX. All these have been found to be useful not only in mineral exploration but also in groundwater exploration and engineering studies studies. In Nigeria, upcoming resistivity meters makers include such names as Petrozenith Incorporated (maker of Petrozenith resistivity meter), Herojeath Limited (makers of Rhomega terrameter) and others locally fabricated measuring devices.

A number of workers have fabricated local resistivity meters and their accuracies have been tested with that of major resistivity meters. For instance, Adegoke *et al* (2020) carried out horizontal profiling (HP), using Wenner and Schlumberger configurations with fabricated resistivity meter and the ABEM SAS 300 terrameter from basement complexes to sedimentary formation. The obtained results from the fabricated meter and from the ABEM SAS 300c terrameter were comparable and correlated only for spreads up to AB/2 = 100 m. Beyond this spread, they discovered that the difference in readings is much and tend not to correlate anymore. Hence, the use of the fabricated meter was limited to shallow investigations. Also, Awotoye and Selemo (2006) made a local resistivity meter and compared its accuracy and precision with that of ABEM SAS 300c resistivity meter as the standard meter. They deduced that the results/data from the two instruments are comparable and correlate only for a spread of AB/2 = 100m as well. Beyond this spread, they discovered that the difference in readings is much and tend not to correlate anymore. Hence, the use of this system is limited to shallow investigations where the target depth is not more than 50 m. Other makers include Igboama and Ugwu (2011), Clark and Page (2011) and Badmos and Kilaso (2013).

In this investigation, - a comparison of the accuracy and precision of ABEM SAS 1000, PASI and IGIS terrameters was made from Schlumberger array and the 2-D Wenner profiling technique to delineate the subsurface lithology and groundwater near existing borehole of known data in Osogbo. This is significant because a resistivity meter with accuracy and precision is the desire of the geologists and geophysicists.

Location of the Study Area

The study area is located at Osun State University-Main Campus, Osogbo, Southwestern Nigeria. The study area is within longitude N 07º 45’ 50.976” and N 07º 45’ 51.384” and latitude E 04º35 ’58.452”and –E 04º35 ’58.074” (Figure 1). It is specifically sited beside the Olagunsoye Oyinlola Auditorium and Hall along the road that leads from the auditorium to the Maintenance section of the university. The traverse is represented by the line A-B on the location map. Accessible of the area is easy as there exist minor roads, major roads, access roads and footpaths that passes beside diverse academic buildings. Geologically, the study covers the area that is underlain by part of crystalline Precambrian Basement complex rocks of Southwestern, Nigeria (Oyinloye, 2011). This Basement Complex is made up of the undifferentiated gneiss consisting migmatite gneiss, banded gneiss and quartzites and pegmatite which intrude the undifferentiated gneiss (Figure 2). The gneissic component possess light and dark minerals that aligned in a preferred orientation that is characterized the gneissic rock. Gneissosity, micro folds, joints and minor fractures characterize the various structures observed on the rock surface. Generally, the rocks are oriented approximately in N – S direction while the structures on the rock run parallel and at right angle to the general strike. Most of the rocks in the study area are slightly exposed. On the local level, the study area is composed of quartz schist to the North and quartzites to the southern part. The degree of weathering in quartzites is believed to be much less pronounced or it is not present at all. However, the effect of weathering most times is that joints and fractures are not only developed but further opened-up such that there occur interconnectivity among the pore spaces in the minerals that make up the bedrock. (Johannes 2003). Hence they are (partly and gradually) transformed first into gravels, sands, clays and finally laterites. These processes tend to increase the porosity and the permeability of the quartzite rocks.

The study area is mainly drained by River Osun which flows in many smaller streams which are dry from November to May. The drainage pattern is mainly dendritic and controlled by structures and local geology. It is located close to the upper boundary of the tropical hinterland climatic region and has a humid tropical climate with distinct wet and dry seasons (United Nations Human Settlements Programme, 2014).

Figure 1: Location Map of the area within UNIOSUN Campus in Osogbo, Osun state showing geological components (adapted from NGSA, 2009).

Materials and Methods

A preliminary reconnaissance study was

carried out within the university environment to establish beforehand the coordinates of the study area, the area of coverage, and the likely points where geophysical survey is to be carried out. The geophysical survey data of an already existing drilled borehole with known geo-electric parameters and core logs carried out close to the Auditorium was accessed from the university's Works Department. A single traverse of about 150 meters was established while the central reference of the two arms of the traverse was sited close to the existing borehole in order to use the existing borehole as a reference point of investigation. From one end of the traverse, Wenner profiling survey were conducted first with ABEM, second with PASI and finally with IGIS. This is followed by the vertical electrical sounding (VES) also along the same traverse using the Schlumberger technique. These two surveys were recorded on separate data sheet and later subjected to interpretation and iteration using Microsoft Excel (Wenner) and partial curve matching and iteration (Schlumberger) respectively. Filtering was done by plotting the direct field data on Microsoft spreadsheet and editing points with spikes and reducing the extreme values to best fit. The geophysical survey data previously obtained from the existing borehole was interpreted and iterated. The delineated depth to aquifer, resistivities and thicknesses of the geoelectric layers were compared with the result obtained from the interpretation of the geophysical survey data previously obtained from the existing borehole prior to drilling.

Results and Discussions

The results of this study are presented as tables, Vertical electrical sounding iterative curves and 2-dimensional profile curves. The iterative curves were those of the Schlumberger sounding data while the profile curves were those of the 2-D Werner array horizontal profiling data. The iterative curve for the geophysical data from the existing borehole is as shown in figure 2 while the sounding curves obtained using the equipment as shown in Figure 3, 4 and 5. Figure 6,7 and 8 represent the 2-D Werner profiles obtained for the three profiling surveys collected using the three equipment while Figure 9 represent the plot of all the raw data collected on the field using the various equipment compared with the data from existing borehole. Figure 10 is the geo-electric section of all the interpreted data compare with that of existing borehole. The summary of the curve types, resistivity values and thicknesses using the three equipment is as shown in Table 1.

Interpretation of the previous geophysical investigation done for the drilled borehole produced a KHA curve. The result showed that the first layer represent the sandy topsoil of about 1m thick with resisitivity value of 209.2Ωm. The second and third layer were inferred to be lateritic geo-electric layers having a resistivity of about 332.05 Ωm and a thickness of about 4.5 m thick. Underlying the lateritic layer is the clayey sand of about 4.9 m thick clayey sand interval and a 117.1 Ωm aquiferous layer of 16.1 m thick. The aquiferous layers is sitting directly on top of the basement with resisitivity as high as 795.1Ωm. The result reveals that the aquiferous layer is within the fourth and the fifth geo-electric interval. Close result was observed using the ABEM SAS 1000c equipment but the result showed slight variation in the apparent resistivity values and the thickness of the geo-electric layers. The iterative curve using the ABEM SAS instrument also gave a typical KHA curve at first attempt without filtering of the acquired data; an observation which is closer to the geoelectric parameters obtained for the existing borehole as at the time it was explored prior to drilling. The lithology inferred from the resistivity value using the ABEM SAS 1000 (207.5 Ωm) were similar that of the existing borehole data. (209.2 Ωm). There exists a strong correlation between the data collected using the

ABEM SAS 1000 and that of the existing borehole.

The PASI and IGIS instruments both displayed a typical A-curve after filtering the data, a situation totally different from what is obtained using the ABEM SAS instrument. Prior to filtering, the resistivity values obtained using the two instruments were observed to be erratic and not consistent with the result obtained using ABEM SAS instrument. Using the ABEM SAS equipment, six geo-electric layers were encountered. The aquiferous layer sit conformably on top of the basement rock below the subsurface with resistivity as low as 98.3 Ωm. The topsoil is composed of sandy layer of resistivity value of 207.5 Ωm and of about 1.0 m thick. Underlying this layer is the lateritic layer which continues to a depth of 5.6 m and average resistivity value of 339.5 Ωm. Below this layer is a clayey sand interval of about 5.2 m thick having a resistivity value of 184.3 Ωm. Lithologically, the progression of the geoelectric upward from the oldest to the youngest at the surface were inferred to commence the basement rock underlying the sandy clay weathered layer, followed by clayey sand, lateritic layer and finally sandy topsoil. This behavior correlates almost perfectly with the vales obtained for the existing boreholes.

However, using the PASI equipment, the topsoil revealed that a 30.8 Ωm clay topsoil of about 1.0m thick overlay the investigated traverse while using the IGIS instrument, the topsoil revealed a concretional lateritic topsoil of about 817.7 Ωm and 2.4 meters thick.

The output of the two instruments do not correlate. This observed result is totally different from what is obtained using the ABEM SAS instrument. The data collected using PASI and IGIS instrument continue to increase in resistivity to produce an A curve, the interpretation of which would show no sign of positive groundwater prospecting. Compared with the resistivity measurement acquired using the IGIS, the curve revealed a typical A-curve also with the geo-electrical parameter increasing down the subsurface strata, with topmost layer having a resistivity of 817.7Ωm, underlain immediately by a high resisitivity interval of 6186Ωm and also underlain with the oldest geo-electric layer having a resistivity of 4198Ωm. This was obtained after the IGIS acquired data have been filtered of the effect of noise. The results obtained is totally different from what was obtained using the ABEM SAS equipment. The PASI and IGIS exaggerated the resistivity values even after processing and the result do not correlate with that of ABEM SAS instrument.

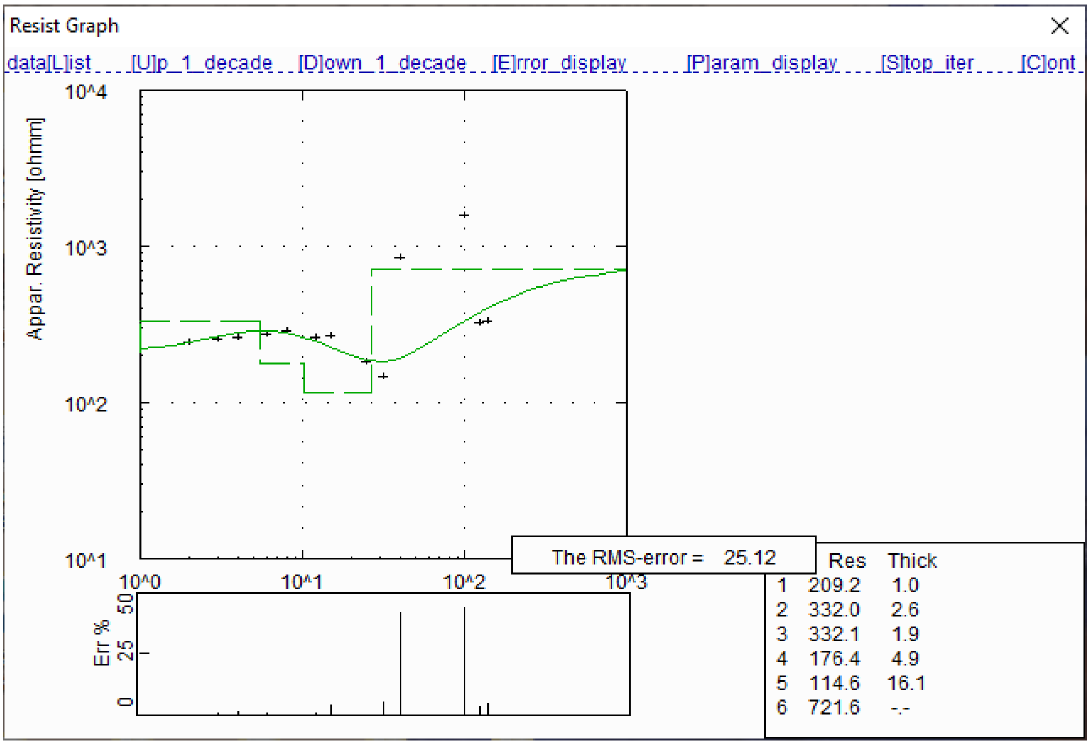

Figure 2: Iterative Curve for Geosurvey of the existing Borehole

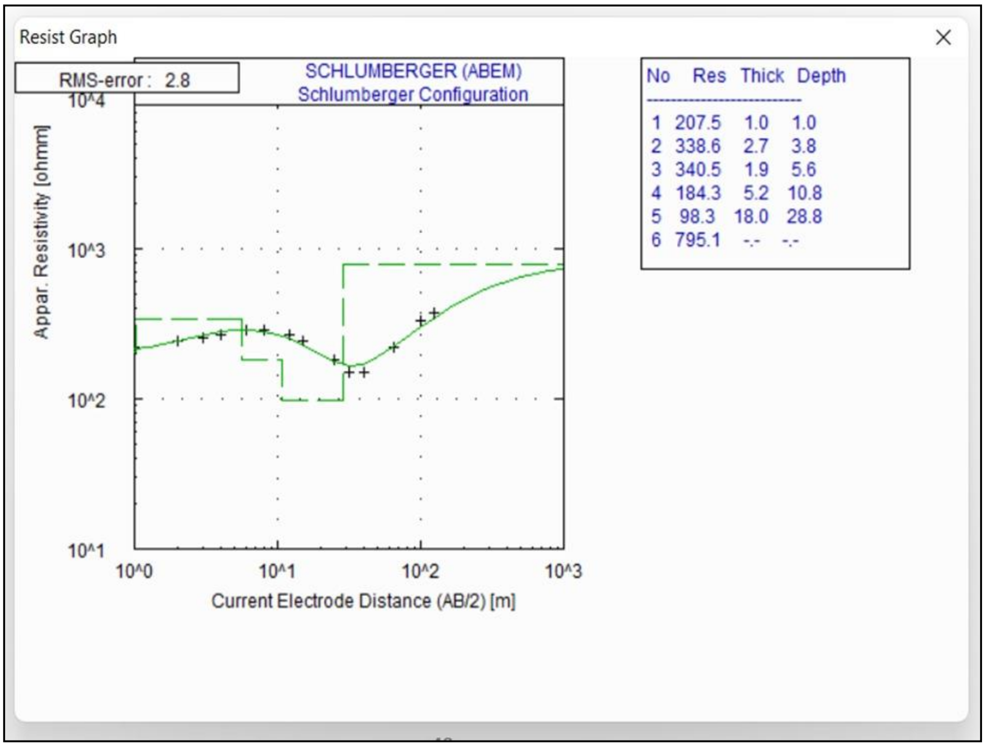

Figure 3. Iterative curve for ABEM VES data

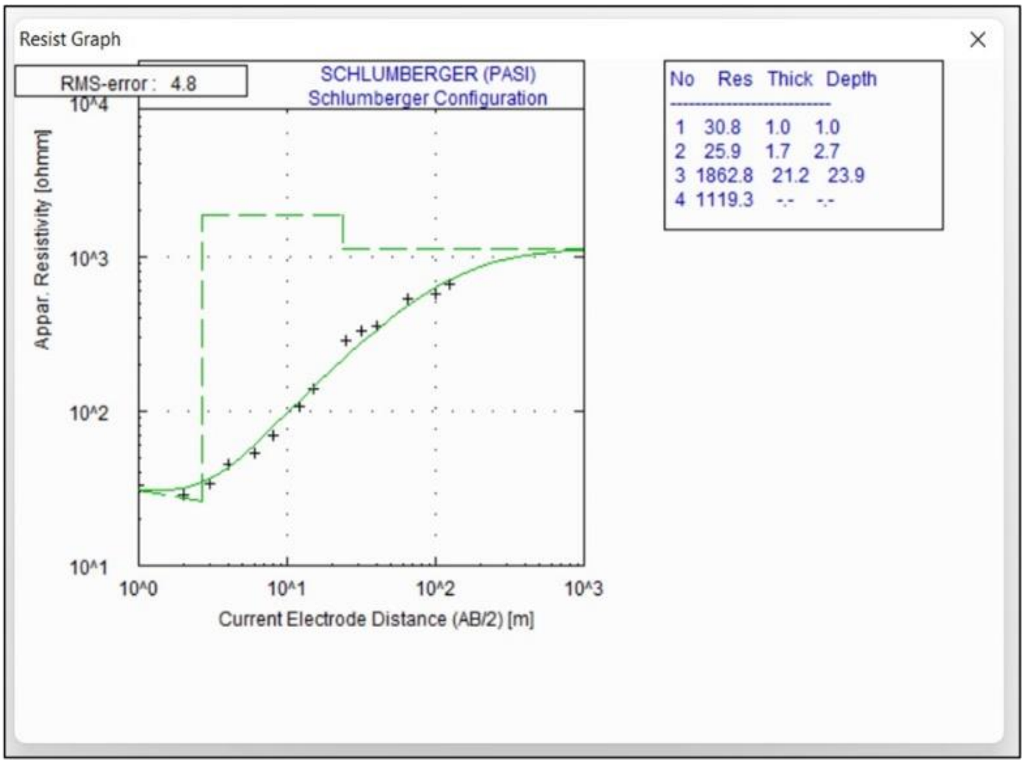

Figure 4: Iterative curve for PASI VES data

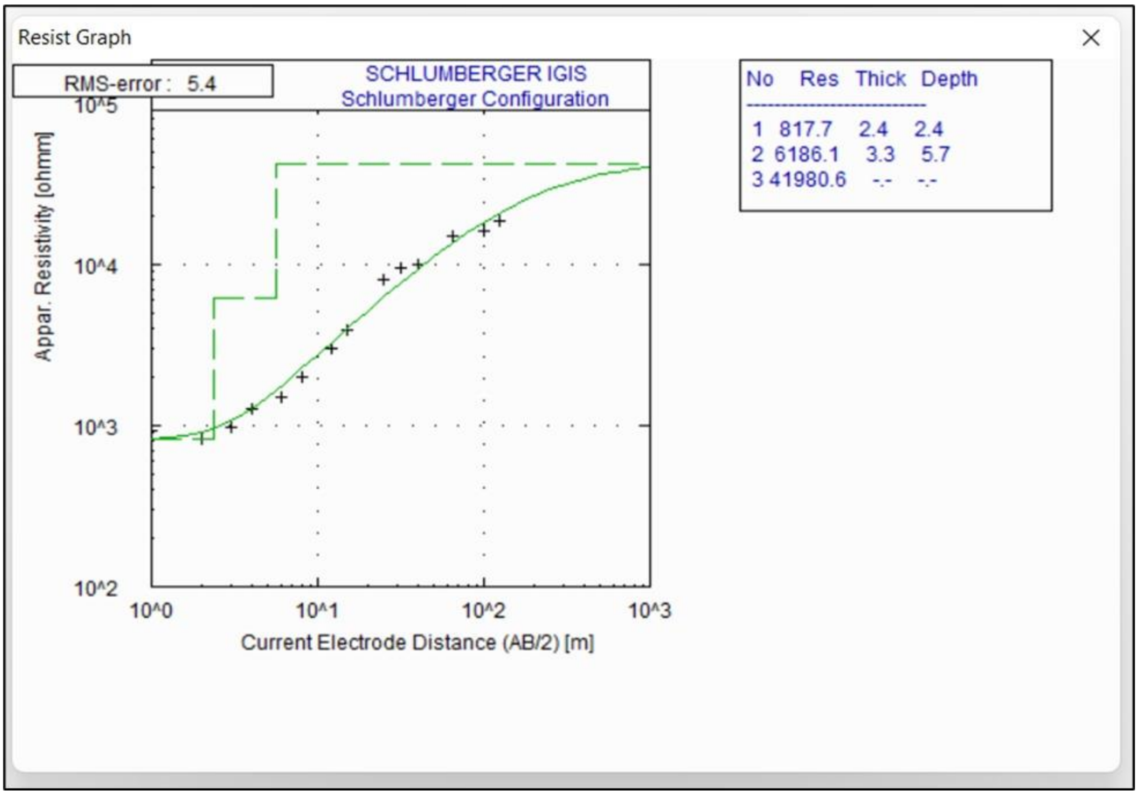

Figure 5: Iterative curve for IGIS VES data

Table 1: Comparative Results of the Geo-electric Parameters with Existing Borehole

Data.

SN	Instrument	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
1	Existing Borehole	209.2	1.0	1.0	Sandy topsoil
		332.0	2.6	3.6	Lateritic layer
		332.1	1.9	5.5	Lateritic layer
		176.4	4.1	9.6	Clayey sand
		113.8	16.9	27.5	Weathered layer
		721.6	-	-	Fresh basement
2	ABEM	207.5	1.0	1.0	Sandy topsoil
		338.6	2.7	3.8	Lateritic layer
		340.5	1.9	5.6	Lateritic layer
		184.3	5.2	10.8	Clayey sand
		98.3	18.0	28.8	Weathered layer
		975.1	---	---	Fresh basement
2	PASI	30.8	1.0	1.0	Clayey topsoil
		25.9	1.7	2.7	Clayey subsoil
		1862.8	21.2	23.9	Fresh basement
		1119.3	---	---	Fresh basement
4	IGIS	817.7	2.4	2.4	Concretional laterite
		6186.1	3.3	5.7	Fresh basement
		41980.6	---	---	Fresh basement

Wenner Profiles of Data sets

Generally, the resistivity values of the IGIS, ABEM and PASI obtained from 2D Wenner profiling are different. The Wenner profile from ABEM machine closely correlated with that of the existing borehole, slightly with the PASI tool but not with IGIS tool (Figures 6 & 7). ABEM resistivity varies from 431.8 Ωm, 375.2 Ωm, 265.2 Ωm, with an average of 375 Ωm but PASI resistivity varies from 186.8 Ωm, 1121.3 Ωm, 138.6 Ωm, with an average of 365Ωm. This layer is interpreted by ABEM and PASI to be lateritic layer with almost the same thickness. The lateritic interval continues to a depth of 6 m using ABEM but not so with PASI. The interval underlying the lateritic topsoil using PASI is a sand bearing. Therefore both the first layer and second layers using ABEM are interpreted as lateritic to a depth of between 5.5 and 5.6 m. The third layer is lateritic sand of resistivity of 294 Ωm using ABEM and 315 Ωm using PASI. The fourth is lateritic sand layer having resistivity of 231 Ωm and 253 Ωm using ABEM and PASI respectively (Figure 7 and 8). These layers are interpreted to be of same lithology - sandy interval. This interval is underlain by lateritic sand interval of resistivity 291 Ωm and 277 Ωm using ABEM and PASI respectively. Whereas the depth of the topmost lateritic sand is about 60 m thick, ABEM SAS, PASI and IGIS instruments gave thickness values of 58 m, 35 m and 37 m respectively. Generally, the interpretations of Wenner plot for both ABEM and PASI data are similar although with slight difference in depths. The similarity in the interpretations of both ABEM and PASI instruments were possible after subjecting the initially erratic PASI data to pre-filtering using the Microsoft Excel spreadsheet. The entire data collected using the ABEM machine did not need filtering or noise remover because the ABEM machine is a SAS instrument (signal averaging sensor) which takes resistivity measurement using sensor that undergo four different cycles of measurements concurrently before displaying the average result presented automatically. The interpretation of Wenner plot for IGIS Figures 8 and 9 reveals very high value of resistivities in some layers. This vary from 78 Ωm to 7234 Ωm. For instance, the resistivity recorded for the first layer using the IGIS were observed to be 180.8571 Ωm, 200.7 Ωm, 617 Ωm,1820 Ωm,2941 Ωm, 2628 Ωm, with an average of 1152 Ωm. This average value is higher than what is observed using the ABEM SAS. 1000. From all these Wenner interpretations, it is evident that with pre-filtering, PASI gives a closer resistivity values to those of ABEM whereas the IGIS seems to exaggerate the resistivity values (Figure 10) and (Figure 11).

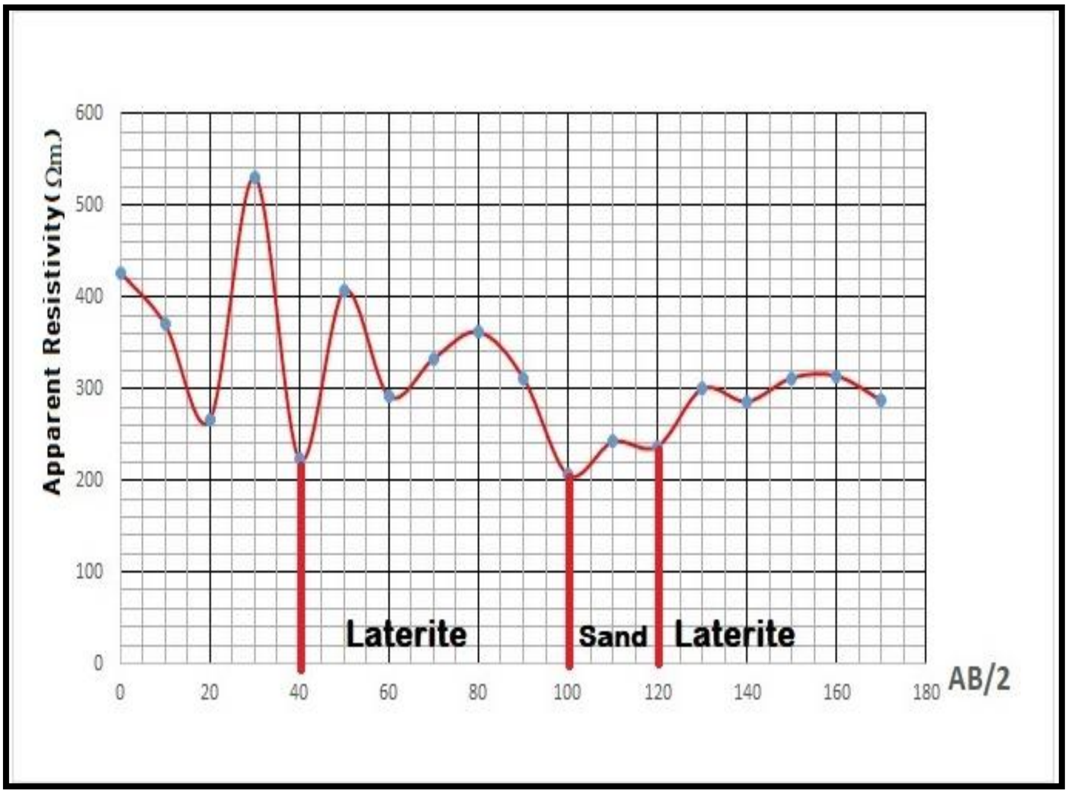

Figure 6: Wenner profile for Existing Borehole data

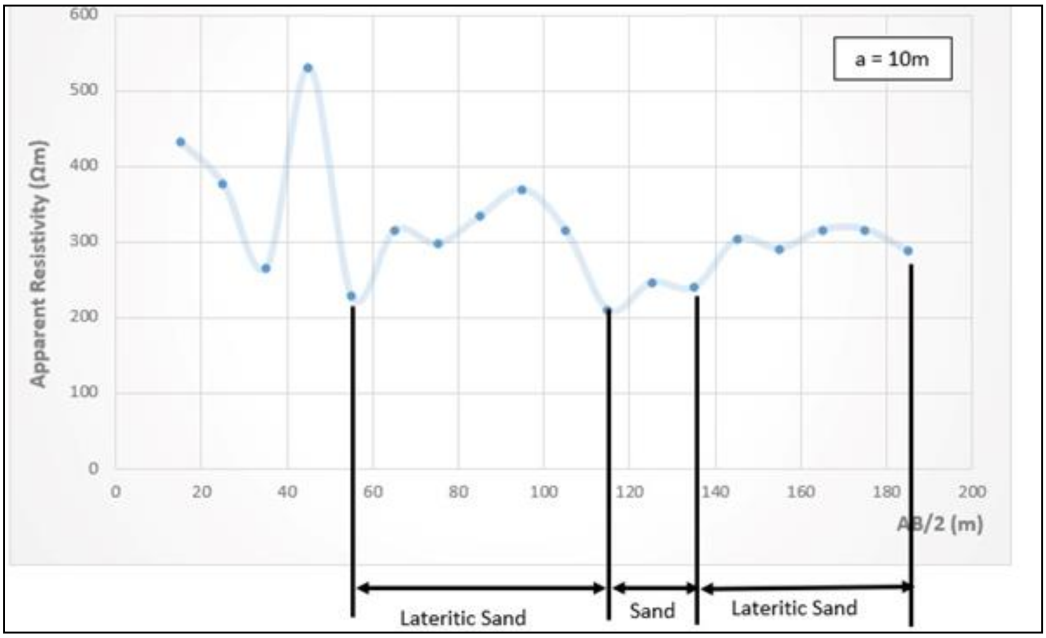

Figure 7: Werner profile for ABEM field data

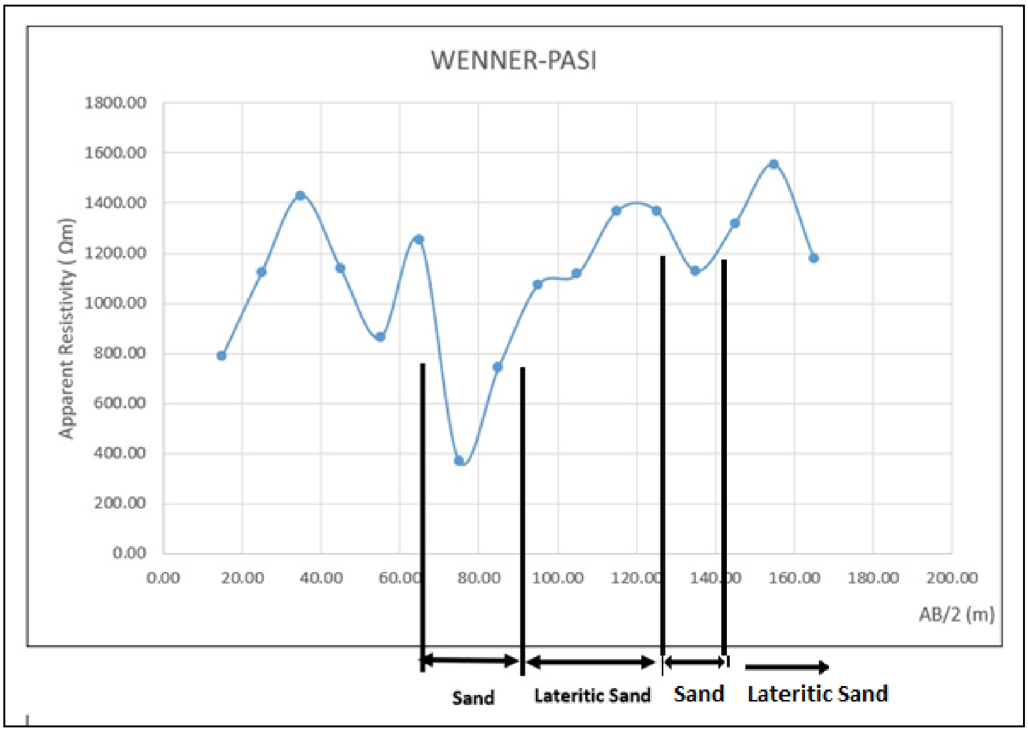

Figure 8: Werner profile for PASI field data

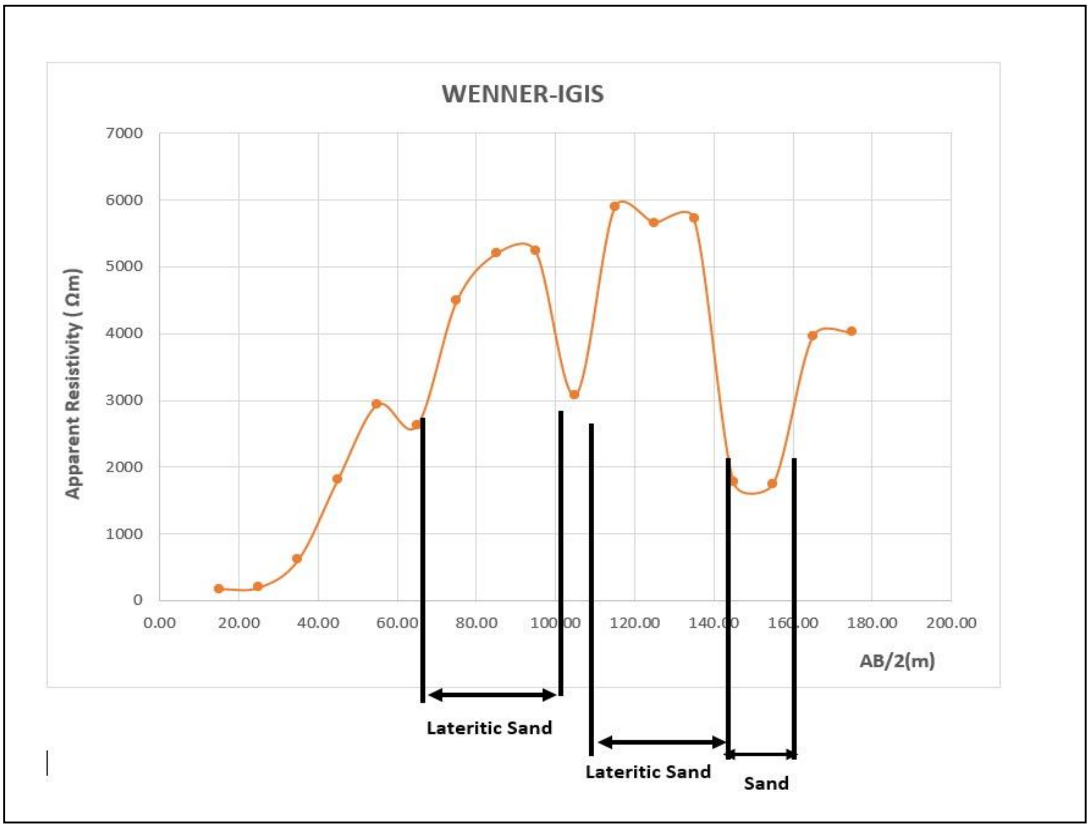

Figure 9: Werner profile for IGIS field data

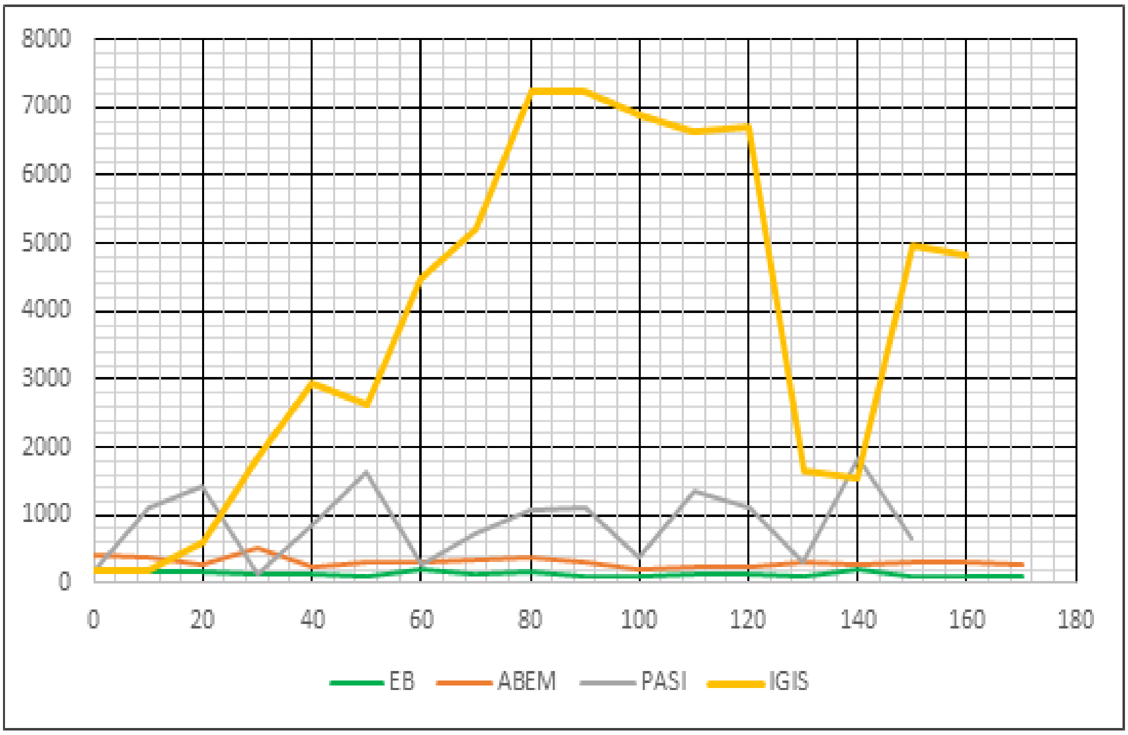

Figure 10: Werner profile for Existing Borehole, ABEM, PASI and IGIS field data

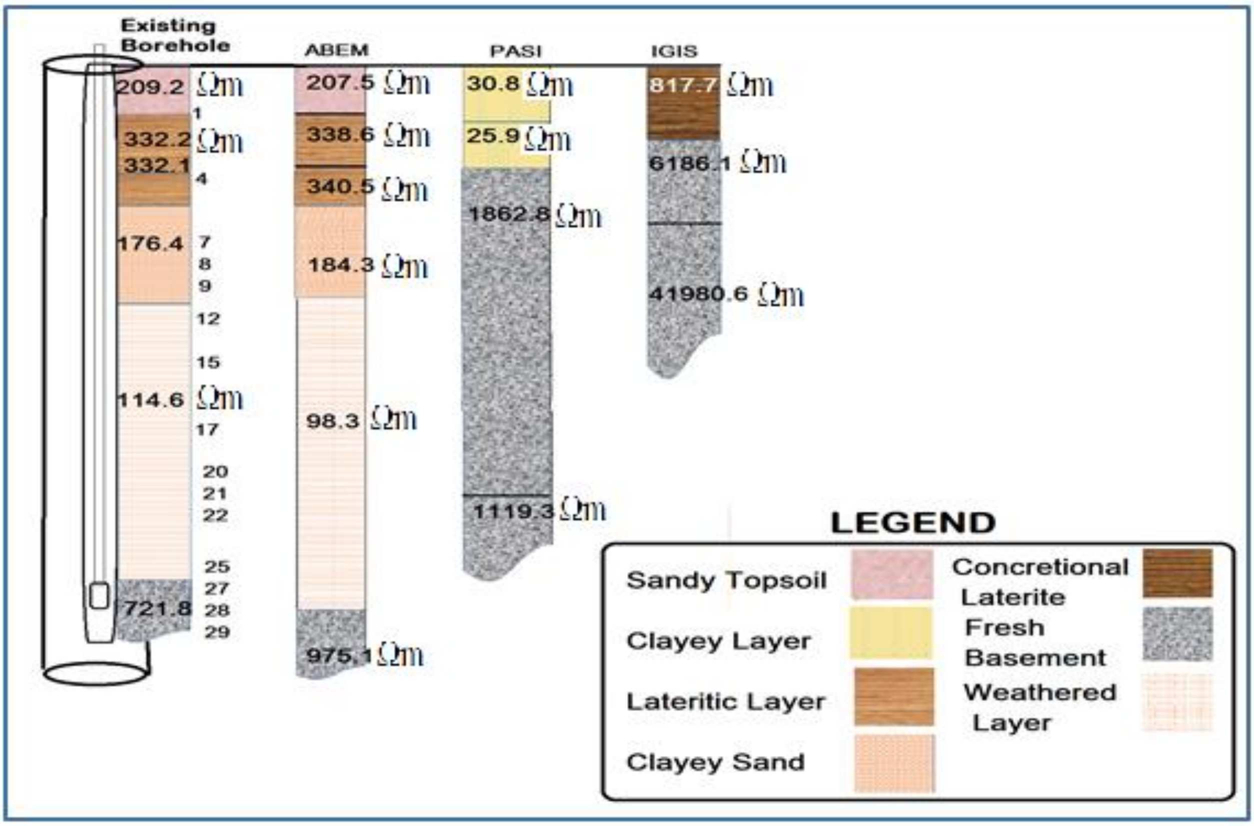

Figure 11: Geo-electric section through the subsurface using the three equipment

Conclusion

An integrated geophysical investigation of groundwater potential was carried out within Osun State University, Main Campus, Osogbo, Southwestern Nigeria using the vertical electrical sounding and 2-D Wenner profiling to compare the accuracy of ABEM (SAS), PASI and IGIS resistivity meters in subsurface measurements. The results obtained showed that the results of VES sounding using the three instruments do not correlate. This is because ABEM measurement gave close and reliable result when compared with the result obtained in an existing borehole while PASI and IGIS tool gives exaggerated values. The Wenner array measurements using the three equipment when interpreted revealed that the result obtained using the PASI instrument give a close correlation with the ABEM measurement only after filtering of noise. However the IGIS instrument exaggerated all the resistivity values even after filtering the data of noise. This is because the ABEM SAS instrument records four consecutive resistivity measurement under four signal cycles before averaging the signals to obtain the accurate resistivity measurement. The IGIS tool is unlike ABEM in that it operates on voltage-current principle whose values are subject to the operator’s conclusion.

The results have shown that the ABEM instrument is a reliable tool in resistivity measurement within the subsurface even at greater depth. ABEM SAS products are recommended resistivity meters that is advised to be used for professional works to avoid all necessary errors and inconsistent values. There is a limitation to the depth of investigation of the two other terrameters. The depth to which they can operates is limited to AB/2=100m. As a result they are useful for very shallow investigations. Efforts must be made to improve on the performances of other terrameters in order to image the subsurface to a greater depth.

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Disclosure of conflict of interest

All authors declare that there is no conflict of interest whatsoever as regards the publication of this paper.

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