CORRELATION OF 1-D GEOELECTRIC DATA TO DELINEATE GROUNDWATER POTENTIAL OF ULI AND ENVIRONMENT, SOUTHEASTERN NIGERIA.

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Abstract

A study of the correlation of 1-D geoelectric data from Uli and its environment southeastern Nigeria was carried out. The study area lies within latitude 5°45'N and 5°50'N and longitude 6°47'E and 6°54'E. The objective of this study was not only to delineate the subsurface rock types and depth to water table in the area but also to correlate geoelectric and geologic sections of the sounding stations using existing boreholes as a guide. The geoelectric data was acquired using the vertical electrical sounding (VES) technique. The study area is underlain by one geological Formation namely the Benin Formation which is Miocene to Recent sediments of alluvium and sandstone. Data obtained from the sounding locations were analyzed, from which the geoelectric sections were deduced and lithologic successions established. The sounding results consist of between four to six geoelectric layers. The area is characterized by the multiple layer curve types, the KH and KHK curve types which have an apparent resistivity arrangement of $\rho_1 < \rho_2 > \rho_3 < \rho_4$ and $\rho_1 < \rho_2 > \rho_3 < \rho_4 > \rho_5$ respectively. The delineated layers resulting from the interpretation of the VES include: sandstone, clay, shaly sand, lignite and gravel/pebbles, which is consistent with the known lithologies of the geologic Formation in the area. The average depth to the top of the aquifer in the study area is 36 m and the average resistivity of the aquifer in the study area is 1883 Ω-m. The water table contour map was drawn and it shows that the average flow direction is southwest. It is expected that the results of this study will impact positively on the quest for sustainable development of water resources in the area, which could be useful in future studies of the aquifer characteristics.

Introduction

The daily use of good quality water is required by humans due to its basic need for life. Water is very essential to all things and the importance to man is so numerous that the value of water cannot be neglected.

Water could be surface water like rivers, streams, lakes, springs and subsurface water such as provided by boreholes, dug wells etc. Groundwater is an important source of fresh water but the need to consider the purity and availability of fresh water needs to be highly emphasized because it is a consumable resource. Most surface waters especially in the study area are far from the community settlements and are being contaminated by anthropogenic activities like washing of cassava and breadfruit in the water, defecating close to the water bodies due to poor sanitation conditions and in most cases organic pollution of surface water bodies in the study area. Ibe and Njemanze (1998) have shown in their publication that the Atanmiri River in the study area is negatively affected by the development of the town and human activities. All these pose danger and stress to the people and therefore have to be addressed quantitatively and qualitatively.

The solution then lies in drilling boreholes within different communities from where good quality aquiferous water can be obtained. Now to drill a borehole, the subsurface resistivity studies of the area have to be determined to avoid waste of time, energy and resources. For this reason, the need to carry out a geophysical investigation is advised for the purpose of determining the aquiferous zones. The correlation and interpretation of field data investigation will provide a good insight into the subsurface aquifer for drillers on the depth to water table and areas that are prone to good water quality and quantity.

Objectives of the work

The objective and scope of this study is to carry out an integrated geological and geophysical study of the area, with the intention of understanding its groundwater potentials. The results will include the determination of vertical succession of strata in the area, thickness of saturated horizons, correlation of resistivity parameters with litho - logs of existing boreholes, water table map of the study area and depict depth to the aquifer in the area.

Geology of the study area

The geology of the study area is deduced to be a mappeable unit of the Benin Formation. The Benin Formation is the youngest rock stratigraphic unit in the Tertiary Niger Delta Basin; it extends from the west across the Niger Delta and southward beyond the present coastline. It consists predominately of yellow and white continental sand, alternating with pebbly layer and a few clay beds (Reyment, 1965). The Benin Formation is a continental deposit of alluvial and upper coastal plain sands that are up to 2000 m thick (Avbovbo, 1978). It consists of over 90% sandstone with local thin shale interbeds which are considered to be braided stream origin (Akpoyovobike, 1978). The age of the formation is about 23.7 million years to 10,000 years (Miocene to Recent). An outcrop of this formation occurs at Amamputu Uli. Other outcrops of the Benin Formation were observed at Ubahudara stream and Atanmiri River.

Methodology

The electrical resistivity method which makes use of direct current or low frequency alternating current was used to investigate the electrical properties of the subsurface in the study area. It is mostly applicable in the search for groundwater due to the simple fact that it requires low capital, a less time consuming technique and a simple instrument. Electrical resistivity methods in geophysical exploration for groundwater in a sedimentary environment have always been proven to be reliable. Records show that the depths of aquifers differ from place to place because of variations in geologic and structural occurrence (Alile *et al*, 2012). Figure 1 shows the Schlumberger configuration method that was applied during the field work.

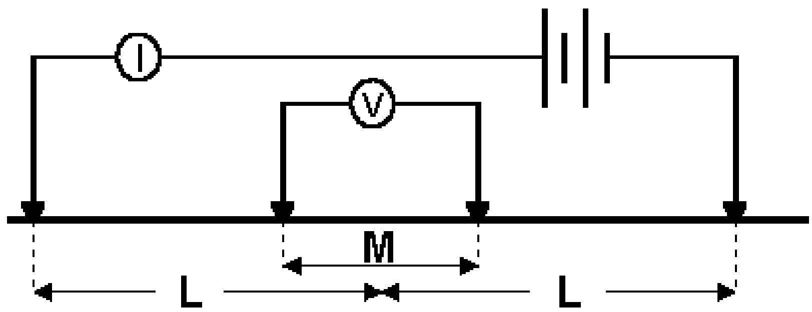

Fig. 1: The Schlumberger configuration.

The equipment's used during the VES field work include: ABEM Terrameter SAS (Signal Averaging System) 300B model with a built in battery, current and potential cables, four non polarizing electrodes, hammer, tape, writing materials and bottle of water which at some time was used around electrodes where contact was very poor.

Four electrode arrays are where used at the surface, one pair for introducing current into the earth, the other pair for measurement of the potential associated with the current. The maximum electrode spread for the sounding locations was 400 m while AB/2 = 200 m. AB/2 means half of the maximum spread of the current electrodes as shown in Figure 1 and it ranged from 1 to a maximum of 200 m in this study.

Data analysis and interpretations

The direct computer interpretation was the method adopted in analyzing the resistivity data obtained during the field work. The raw field parameters include: the apparent resistivity and current electrode separation at specified intervals. The values of these parameters were fed into the 1-D computer software called VES4 for evaluation. The computer software evaluates true resistivity of the different layers and their corresponding thickness.

The true resistivity and thickness of the layers were corrected with available borehole data and then used for interpretations. The process involved a trial-and-error interpretation of the VES data. Starting values of the layer parameters were guessed, checked with a computed apparent resistivity curve, and adjusted to make the field and computed curves agree. The geoelectric sections are not synonymous with geologic sections. The geologic section is determined by the rock type (lithology), while the geoelectric section provides the resistivity and thickness of the layers within a section. The resistivity contrast is caused by changes in the lithology or the presence or absence of conductive fluids in the pore space. In addition to the conductive fluids, other factors that can cause a resistivity contrast include the porosity, saturation and texture of the rock materials, which the authors believe played a significant role in this study.

Results and discussion

Figure 2 shows the sounding locations, existing well locations in red spots and the topographic map of the study area.

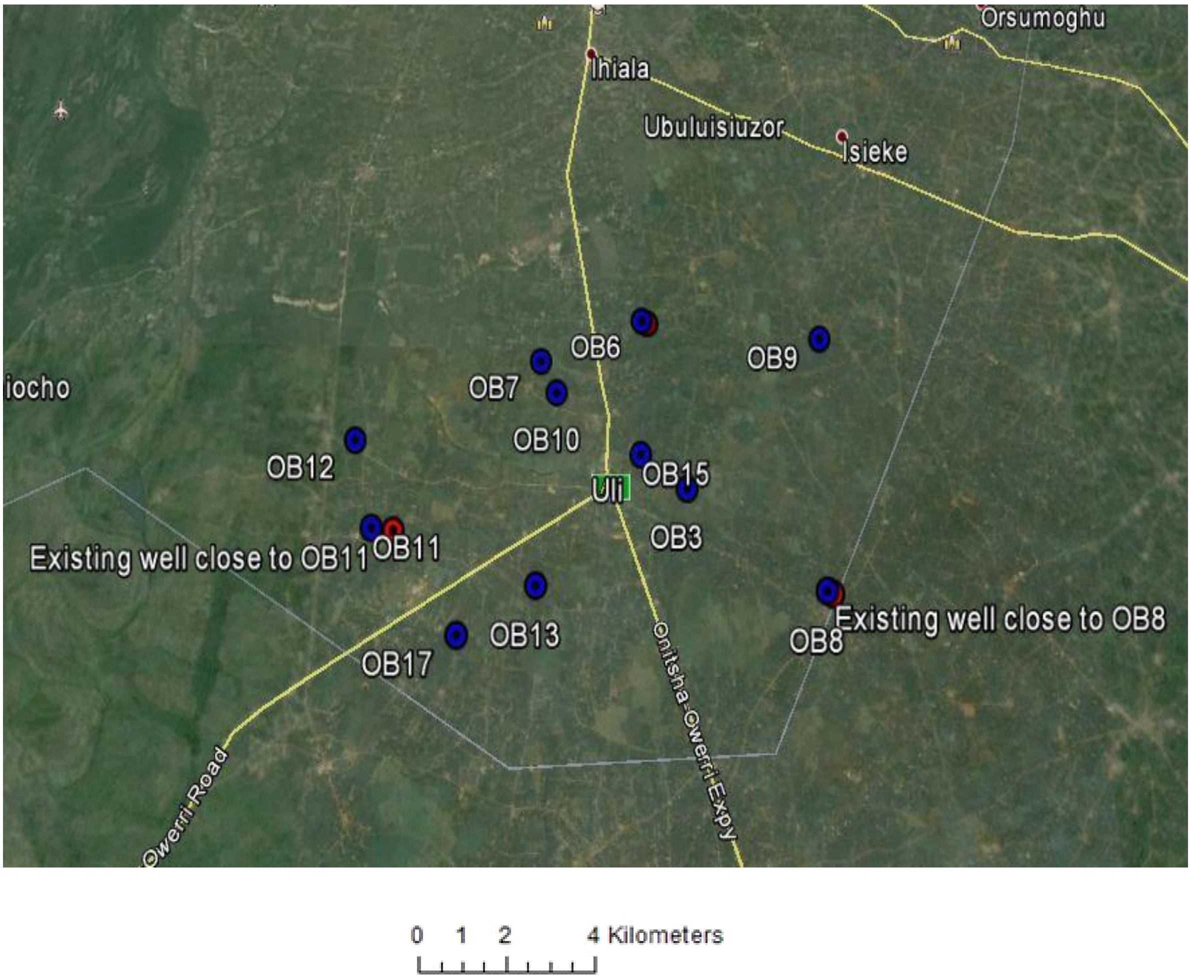

Fig. 2: Topographic map of the study area showing sounding stations.

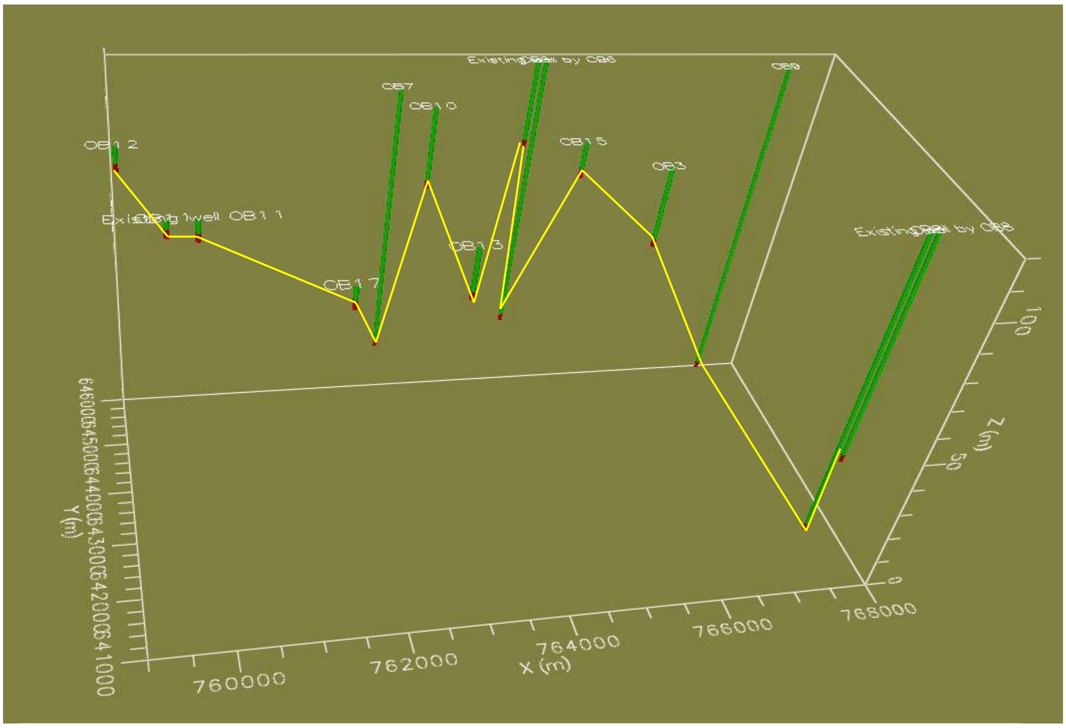

Fig. 3: Cross section showing variations in depth to water table of sounding locations and depth to water table of existing boreholes.

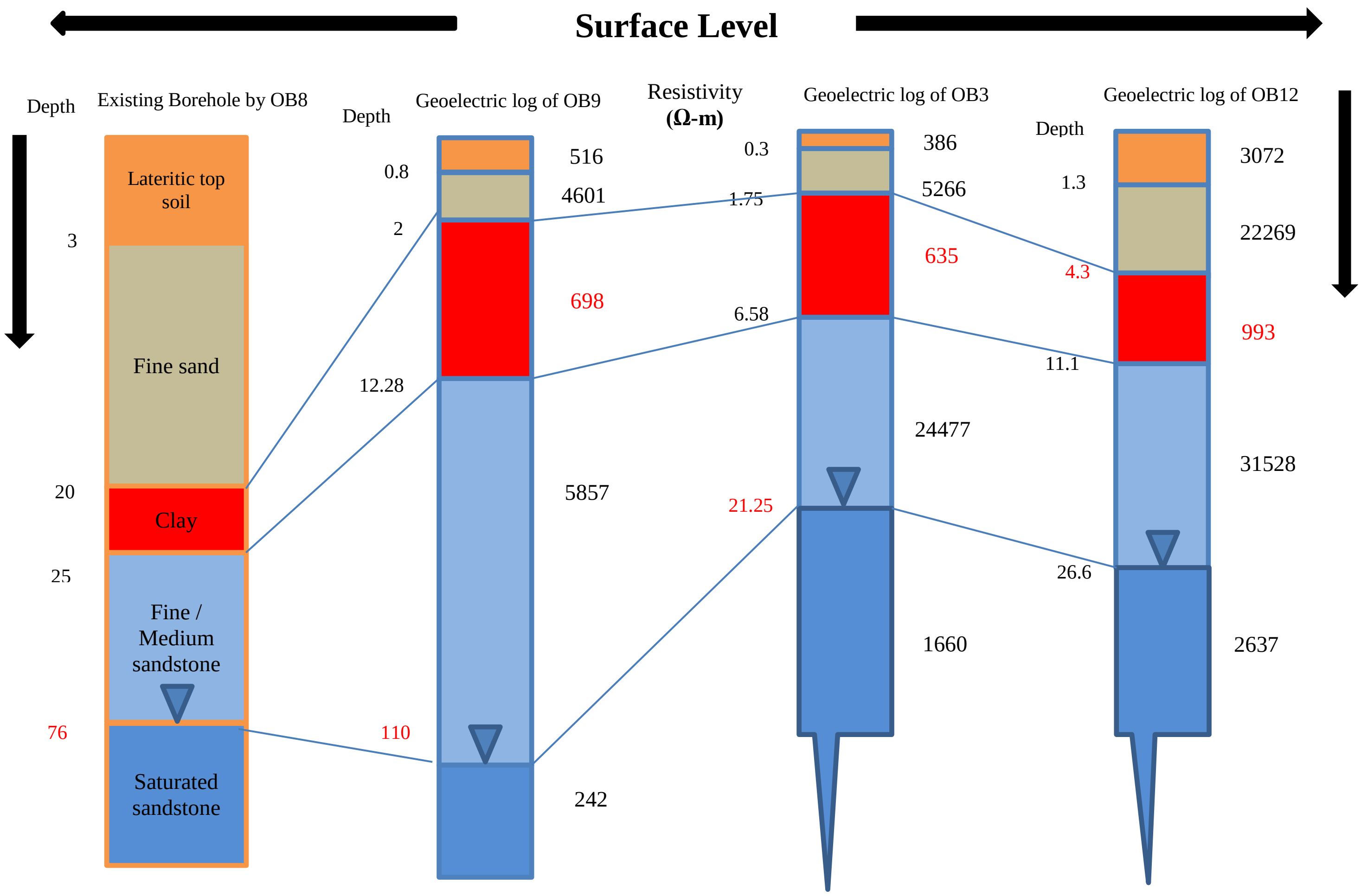

Fig. 4: Cross section showing a combination of some selected VES sounding and existing boreholes.

Figure 3 and 4 is an attempt to show the structural variations existing in the study area as a result of heterogeneity and anisotropy. Figure 3 is a sketch using visual modflow software to show depths to water table of all sounding points and existing boreholes. It can be seen from Figure 6 that towards the western direction, the depth to water table reduces which is consistent with Figure 10. While in Figure 4, one can see some slight correlation between OB9, OB3 and OB12 with the existing borehole nearby OB8. It is evident from Figure 4 that the clay layer has an average resistivity of 700 Ω-m. The increase in resistivity to 993 Ω-m observed in OB12 at the clay layer could be as a result of anisotropy or type of clay at that point. Also the variations in resistivity and thickness observed in layers with same lithologies like the aquifers are possibly caused by issues of rock size, orientation, fluid content and surface conduction. In total, about 11 VES sounding was carried out in the study area.

Geoelectric and geologic correlation of VES OB6, OB8 and OB11 was also carried out with the aid of existing nearby borehole information available at those sites. Figure 5, 6, and 7 show these correlations. This aided in resolving the exact depth to water table at the above mentioned sounding stations during interpretation.

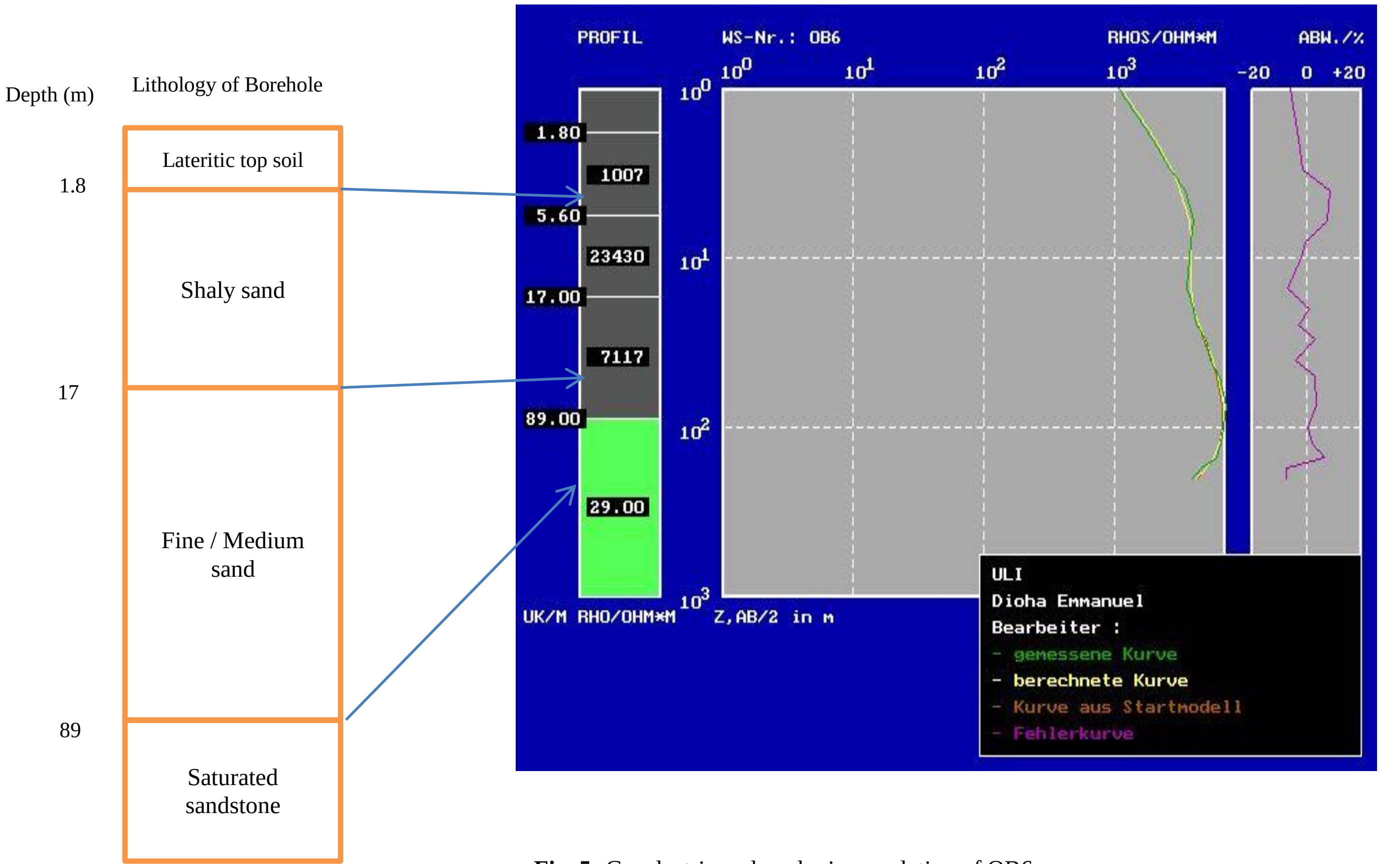

Fig. 5: Geoelectric and geologic correlation of OB6

An attempt to correlate the geoelectric and geologic sections of OB6 sounding station was made with the aid of an existing borehole data (Figure 5). The sections were highly correlated. The lithologic log however showed greater details of the rock types and these include the shaly sand and other sand materials. This correlation aided the authors during the interpretation of this sounding location; it also gave an insight into the possible resistivity values of the different rock materials which was useful during the interpretation of other sounding stations without borehole information.

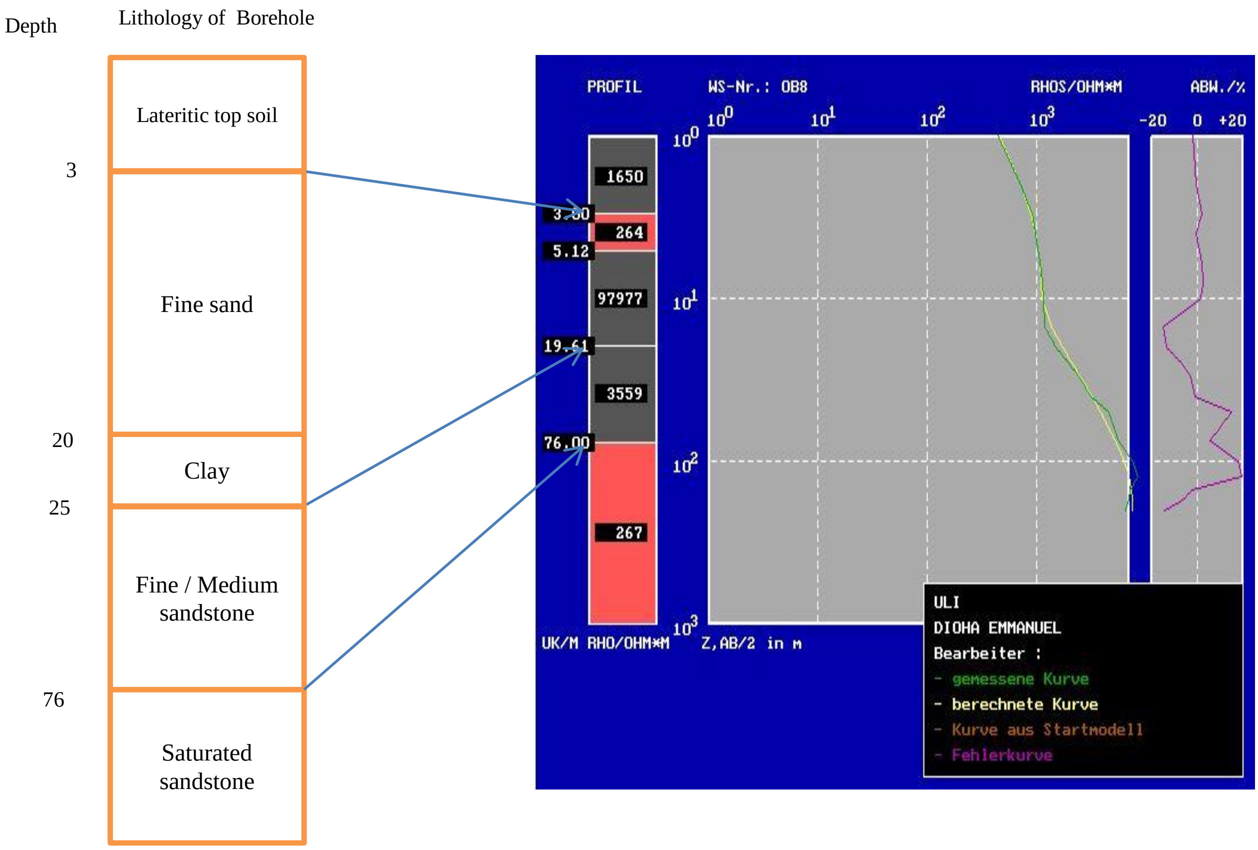

Fig. 6: Geoelectric and geologic correlation of OB8

Figure 6 shows the correlation of geoelectric and geologic sections of OB8 sounding station using information available from a borehole close to the site. Looking left at the borehole log, details of the vertical succession of rock types which include the clayey sand and other sand materials could be seen. In spite of the slight difference in details of the two logs, there were some similarities and correlation, particularly in the depth to water table.

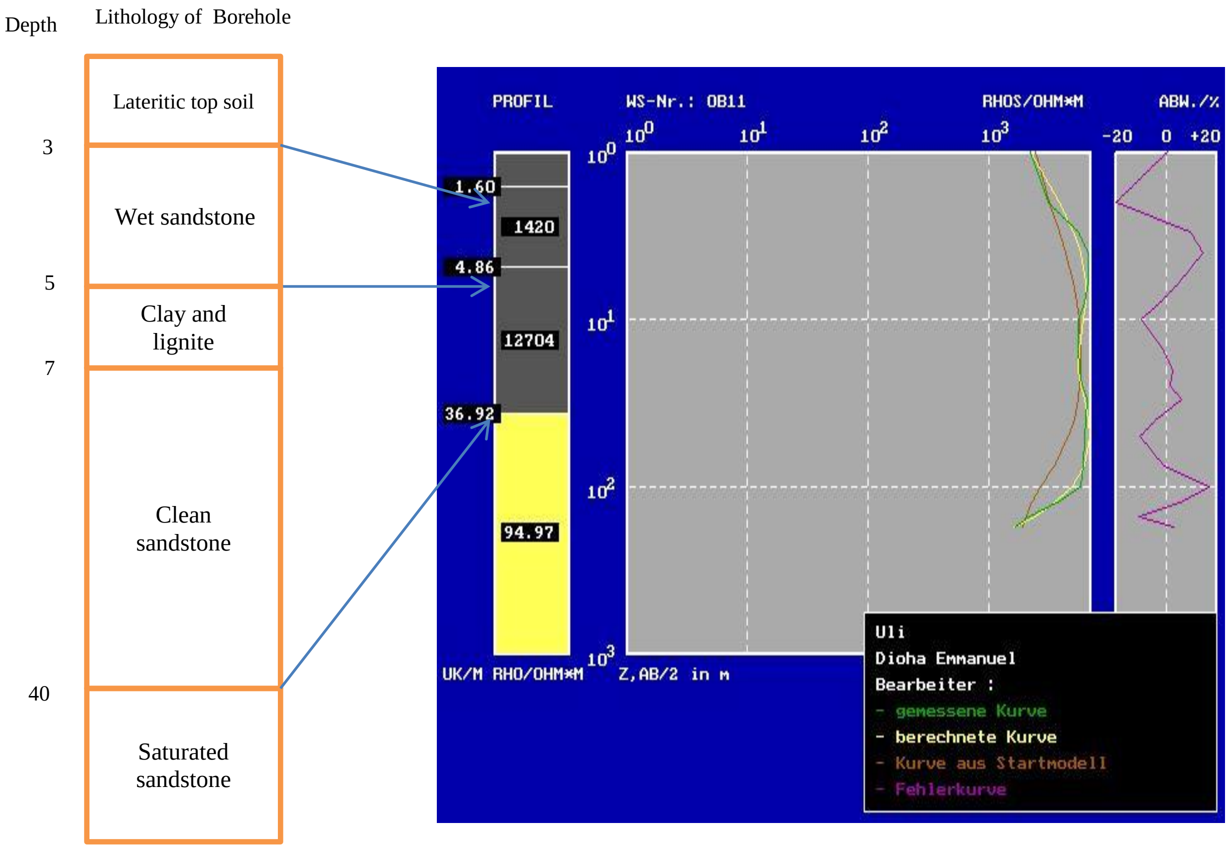

Fig. 7: Geoelectric and geologic correlation of OB11

Figure 7 shows the correlation of geoelectric and geologic sections of OB11 sounding station. The geologic section showed greater details of the lithology traversed by the borehole, amongst this traversed lithology is the clay and lignite layer observed. But comparing the litho-log with the geoelectric log, one could see that the clay lignite layer was not picked up by the geoelectric sounding, this may be due to the manifestation of the equivalence principle. But despite the differences in both sections, there were still some fair correlations.

Water table map

Figure 8 and 9 are a display of the water table map with respect to ground level and with respect to mean sea level. Also shown is the aquifer resistivity distribution map of the study area (figure 11).

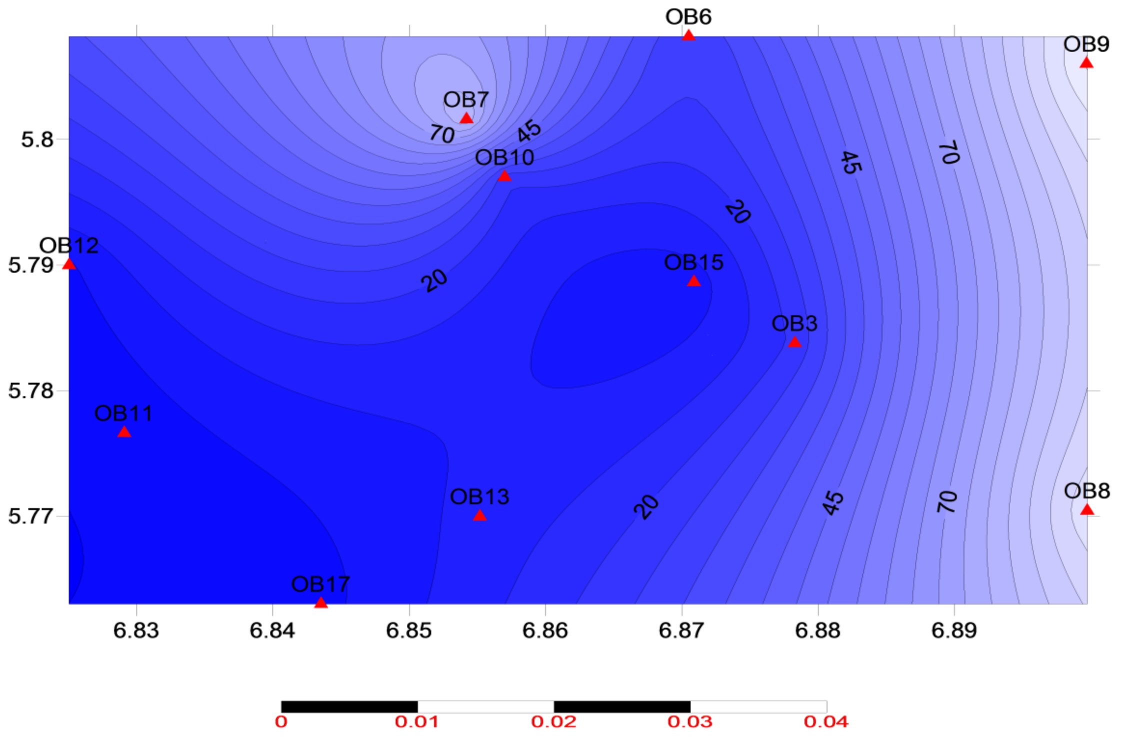

Fig. 8: Water table map of study area with respect to ground level.

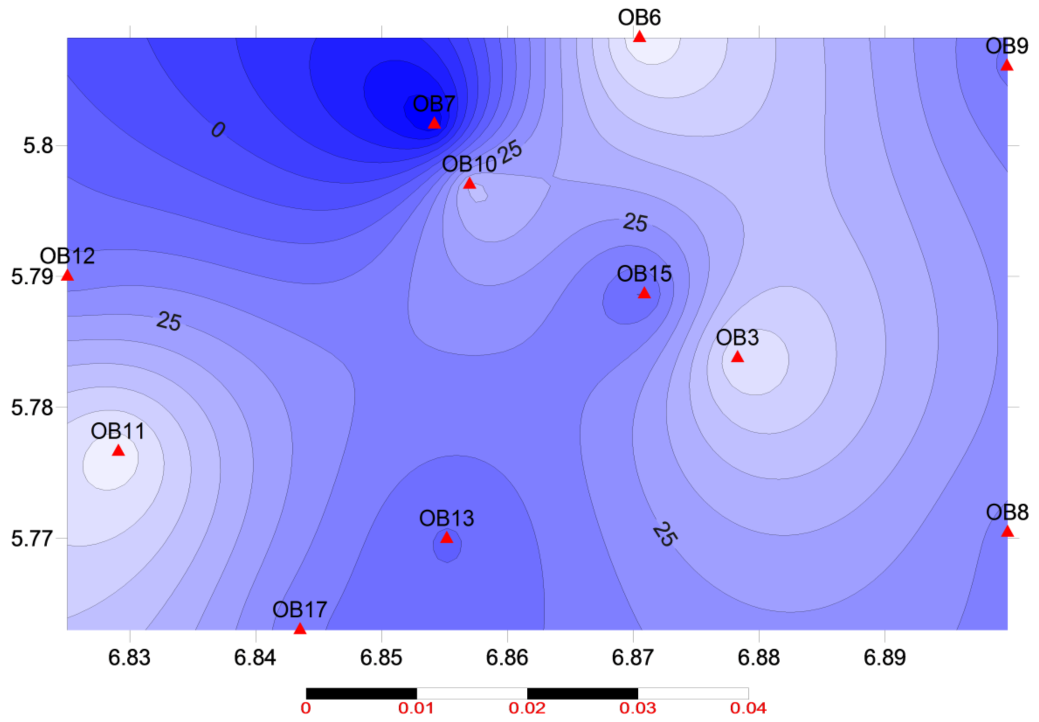

Fig. 9: Water table map of study area with respect to mean sea level.

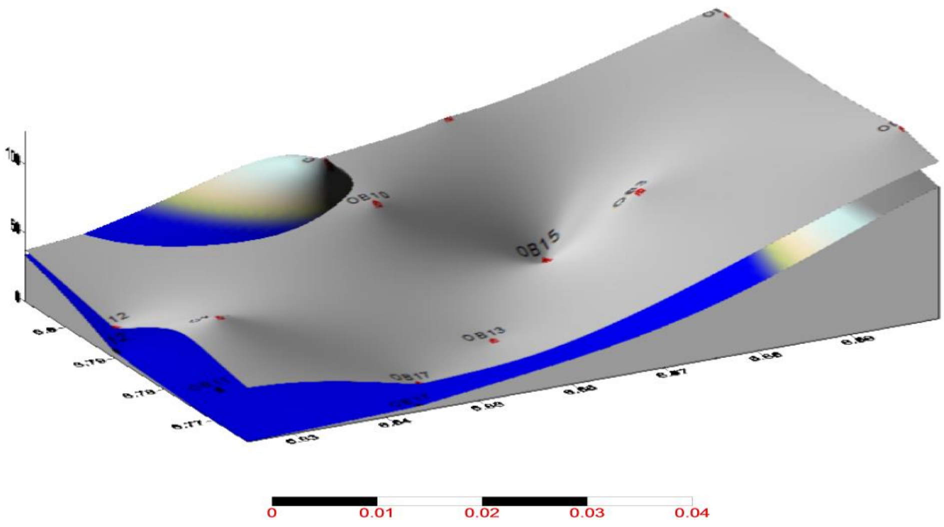

Fig. 10: A 3D relationship between elevation and water level.

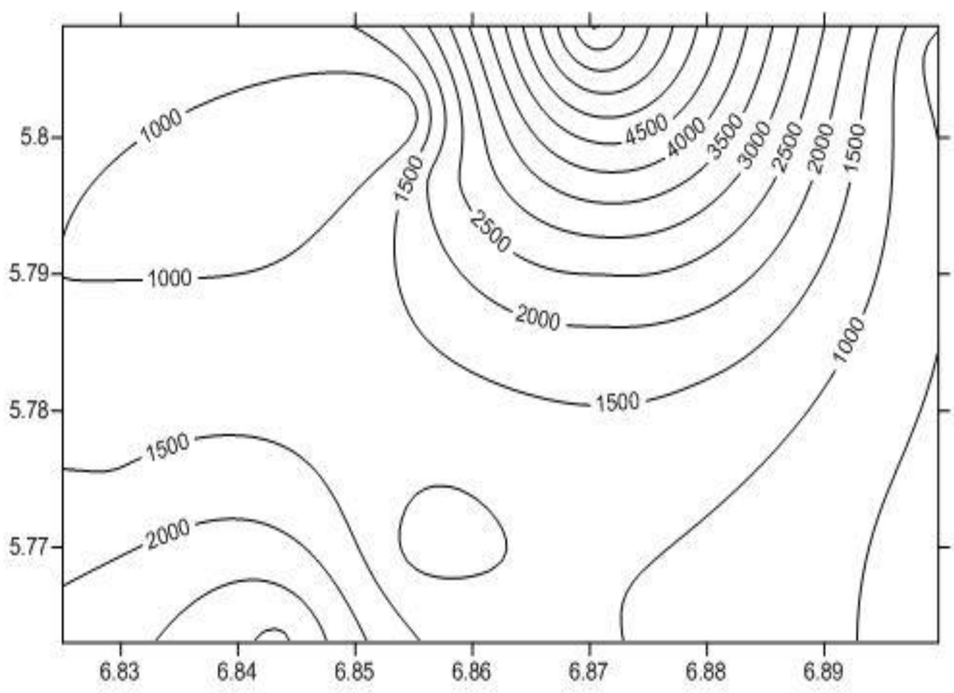

Fig. 11: Aquifer resistivity map of study area.

The meaningful delineation of the aquiferous layer requires that the layer has to be wholly or largely located below the water table. Therefore, water table forms the upper part of the saturated zone in an unconfined aquifer. Water table level is usually controlled by topography, nature of the near rocks and also by local climate condition. Water table map of the study area as shown above was generated from the topographic map and geoelectric sections. Depths to the top of water table deduced from geoelectric section were subtracted from the surface elevation measured from the mean sea level. This produced the water table map with respect to mean sea level as shown in Figure 9. Water table map with respect to ground level as shown in Figure 8 was obtained from the depth to the water table of the geoelectric sections.

From the above figures, it can be seen that the water table flow direction in the area is southwest. When compared with the topographic map, some similarities could be observed. A simple deduction of the hydrology could be made, which is, that all waters in the study area empty into the Osiam Lake and also a nearby river called Atanmiri. This river thereafter discharges into the bigger River Niger from where it finally discharges into the Atlantic.

Looking at the resistivity map of aquifers in the study area, it could be observed that it follows almost the same pattern as the water table map. The northeastern part of the study area have very high resistivity values, while towards the river and lake in the southwest, the resistivity goes down, given an insight of approaching a conductive system. The high resistivity values in the northeastern part of the resistivity map are indications of high resistive and less conductive rocks. Most water bearing rocks naturally have a negligible conductivity, but they become very conductive when water flow through their pores.

Due to limitations in the demo surfer 11 software, a correlation of the resistivity distribution of the sounding stations in the study area could have been done by inserting the VES points on the above map and looking out on which resistivity they fall on and see if there could be a resistivity correlation with its neighbour or adjacent sounding station. For instance, from the map (Figure 11), one could see a resistivity of 1000 Ω-m towards the southeast direction and also towards the northwest direction. This simply means that the aquifers at these points could have similar hydrogeological properties.

Acknowledgment

The authors will like to thank most gratefully Professor Dr. Andreas Weller of the Technical University of Claustal Germany for the software VES4 which was used for this study. The program was produced by Professor Dr. Andreas Weller in the year 1994. Like other 1-D resistivity software's, it could be used to interpret any sounding data resulting from a resistivity measurement. The slight difference in the program with other recent 1-D programs is that it runs on DOS (Disk Operating System) and not windows operating system which most modern computers use. But the VES4 program could be run on even modern computers with the aid of a free software online called DOSBox.

The program has a German and English version. But the German version was used during this study for interpretation of the VES data. The program is quite easy and

flexible, on the dialog window, the user have the option of loading all resistivity data, selecting the configuration type used in the field, viewing the raw data in a graph format and making possible changes. Contained also in the program dialog window is the inversion button which when clicked shows the number of iteration and RMS value resulting from a particular inversion. An output button is also available in the program window where the user can view the results of the inversion in a log-log graphic pattern, the error, observed and computed plots etc.

Conclusion

The study area was characterized by the Benin Formation whose age is Miocene to Recent. The area is located in the Niger Delta Basin in Southeastern Nigeria. The hydrological properties of the subsurface of the study area needed to be determined and as a result eleven VES were obtained from various locations within the study area to ascertain the problem of groundwater development in the area and proffer innovative solutions. Field curves were obtained, analyzed and interpreted. The interpretation gave a geoelectric section for each location. Each section of the geoelectric layer had a boundary thickness and resistivity value. The average resistivity value of the delineated aquifers in the study area is 1883 Ω-m and the average depth to the top of the aquifer is 36 m. The delineated geoelectric layers include: clay, lignite, shaly sand, sandstone and gravel/pebbles materials, which are consistent with the known lithologies of the geologic Formation in the area. The results have shown that the curve types obtained from the soundings is a combination of the KH and KHK multiple curve types. The water table map of the study area was produced and it shows that the groundwater flow direction is southwest. Further research on this study area is advised in order to characterize the aquifer. Since each aquifer from the above results have a resistivity value and a thickness, a research could further be done using the Dar-Zarrouk parameters to properly characterize the aquifer and ascertain its transmissivity (T) and hydraulic conductivity (K). This could be useful for groundwater modeling of the study area, especially because of the environmental pollution of water bodies by hydrocarbon spillage and other human activities in the study area.

With an average aquifer thickness of 37 m, this study has shown that the area has a relative high groundwater potential for both domestic and commercial use and this information is going to be relevant in the development of an effective water scheme for the area and possibly beyond other areas underlain by the Benin Formation.

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