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SALINE WATER INTRUSION IN THE COASTAL AREAS OF ONDO STATE, NIGERIA

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ABSTRACT

Saline water intrusion occurs in virtually all coastal aquifers when they are in hydraulic continuity with seawater. In continuation of efforts to supply the communities of the coastal areas of Ondo State in Nigeria with reliable freshwater, the Ondo State government through the Ondo State Oil Producing Area Development Commission, decided to drill water boreholes in Asisa, Zion-Pepe and Ajapa in Ilaje and Ese-Odo local government areas of the State. Zion Pepe rests on a sand beach ridge; Ajapa and Asisa are on clays. Saline water intrusion is known to occur in surrounding communities. This study is meant to delineate the fresh water aquifers in the three coastal communities. VES 1 in Asisa was located on the coast within the brackish/saline surface water zone, and VES 2 at Asisa-Zion is on an area with fresh water vegetation. The very low resistivity value of the surficial clay at both VES stations at Asisa and Asisa-Zion masked the sands below. Using the S-rule method of interpretation, fresh water sand is likely at depths greater than 154 m. It was recommended that a borehole be drilled to a depth of 300 m at Asisa Zion. In Zion Pepe, a deep fresh water aquifer mapped at a depth of 152 m was recommended. The borehole should be logged and screened at the fresh water interval identified from the borehole geophysical logs. In Ajapa, the space available for geophysics coupled with the screening effect of the low resistivity upper layers did not allow mapping of the deeper layers. However the data obtained indicate the occurrence of a fresh water-bearing aquifer underlying the clays and saline water sands. Ajapa is quite close to Bolowo Zion and from the results obtained at Bolowo the drilling of a borehole at VES 1 was recommended, to a depth of 200m. Nigeria has a long coastline which borders eights States, greater attention should be given to pre-drilling geophysical investigation for fresh water aquifer.

Key words: Saline water intrusion; Potable water; geoelectric layer.

INTRODUCTION

Potable water supply in coastal environments throughout the world, face the constraints poised by saline water intrusion. Saline water intrusion consists to saline water from the sea flowing inland into the freshwater aquifers with the consequent mixing or displacement of fresh water. It is a natural process that occurs in virtually all coastal aquifers when they are in hydraulic continuity with seawater (Bear et al. 1999). It is a problem that has been and continues to be a focus of considerable research efforts because a scientific understanding of the occurrence of saline water and freshwaters in a particular coastal area is essential for the development and management of the water resources.

In continuation of efforts to supply the communities of the coastal areas of Ondo State in Nigeria with reliable freshwater, the Ondo State government through the Ondo State Oil Producing Area Development Commission (OSOPADEC), decided to drill water boreholes in Asisa, Zion-Pepe and Ajapa in Ilaje and Ese-Odo local government areas of the State (Fig. 1). Although these towns have abundant surface water resource, the rivers and canals are polluted, with contamination ranging from high iron content to high salinity. The only alternative source is groundwater. The quality of groundwater however varies because of facies changes in the sediments during deposition (Ako et al 1985).

Previous works in this area either for research or in an attempt to provide portable water to the people indicated that most parts of the coastal areas have saline water with the salinity level being unacceptably high thereby rendering them unsafe for human consumption. Ondo State water Corporation has boreholes in the following locations Zion-Pepe, Agadagba, Obo, Ugbo well, Arowogbo, Ugbo-Nla and Aiyetoro. Unfortunately the records were not available despite several visits, but the common feature of the water is their salinity and high iron content (private communication). Chevron Nig. PLC has a 396.2 m (1300 ft) borehole in Ikorigbo which is equally saline. From the available data, the log suggested that the depth should have been between 152.4 - 182.9 m (500 – 600 ft) rather than 396.2 m.

A study of the well completion record and borehole geophysical log of Akodo water well by the Atlantic coast in Lagos State, some kilometers from the Ondo State border, showed the occurrence of a confined fresh water aquifer at depths of between 110 and 195 m sandwiched between saline water aquifers.

Therefore in assessing groundwater resources in this area, the determination of the freshwater/saline water interface is of paramount importance, hence the need for pre-drilling geophysical survey to locate the fresh water aquifers. This paper discusses the mapping of the boundary between freshwater and saline water in this part of Ondo State coastal area and thus locate appropriate areas for the siting of boreholes.

STUDY AREA DESCRIPTION

The study area is within the coastal area of Ondo State between latitudes. 5° 45'N and 6^0 30'N and longitude 4^0 30'E and 5^0 15'E bordering the Atlantic Ocean. The communities live along the coast and the adjoining creeks (fig. 1). The topography of the area is generally flat, and of low relief. The total relief is less than 1.5 meters above sea level in most cases. Settlements are usually linearly distributed along the waterways in scattered manner making water distribution extremely difficult.

There are no rainfall data available for the entire coverage area. However from records within the rainforest belt of Nigeria and especially Lagos and its environs with similar climate, and weather conditions, the following annual rainfall data is estimated at 1841.7mm with average max rainfall of 457.6mm in June. The lowest

relative humidity values were recorded in December and the highest values in June as obtained from the monthly Relative Humidity Pattern for Ondo State Synoptic Station (1986 – 1990) which coincide with the annual rainy and dry season cycles (Fig. 2 and Fig. 3). Temperatures are uniformly high between 25 – 30^{0}C. The vegetation is the rain forest type. It is characterize by dense evergreen forest of tall trees with thick vegetation (Mohammed, 1992)

GEOLOGY

Ondo State is underlain by two distinct geological rock terrains: crystalline rocks of the Basement Complex consisting of granites, gneisses and schists; and sedimentary rocks consisting of sands, clays, shales and some limestone (Jones and Hockey, 1964). Sedimentary rocks underlie the southern coastal belt while crystalline rocks occupy the northern zone. Figure 4 a geological map of part of Ondo State showing the distribution of the rock types. The State straddles the two sedimentary basins in the coastal area of Nigeria. These are the Benin basin and the Niger Delta basin separated by the Okitipupa hinge line (ridge).

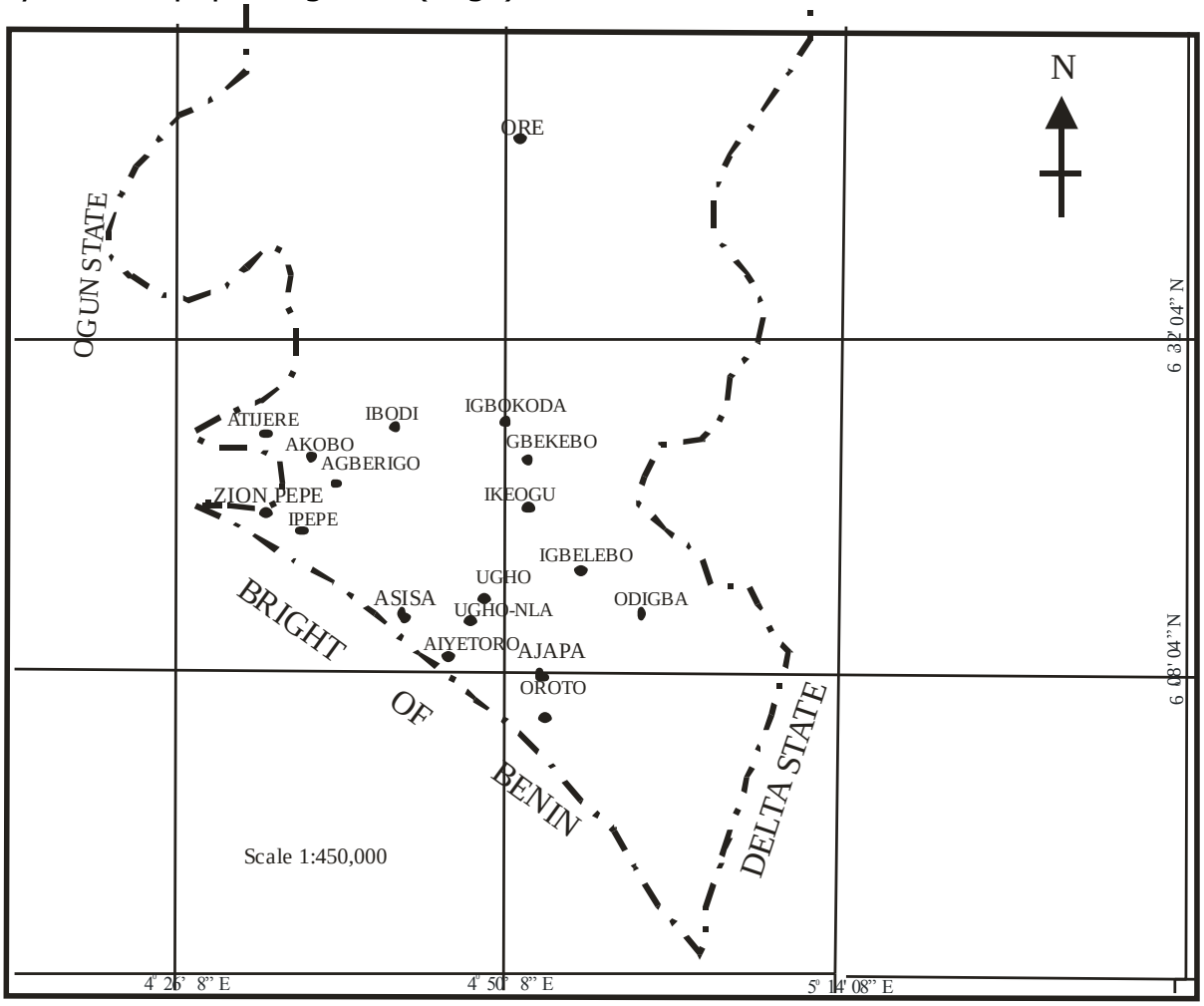

Fig. 1: The Map showing the survey area in Ondo State.

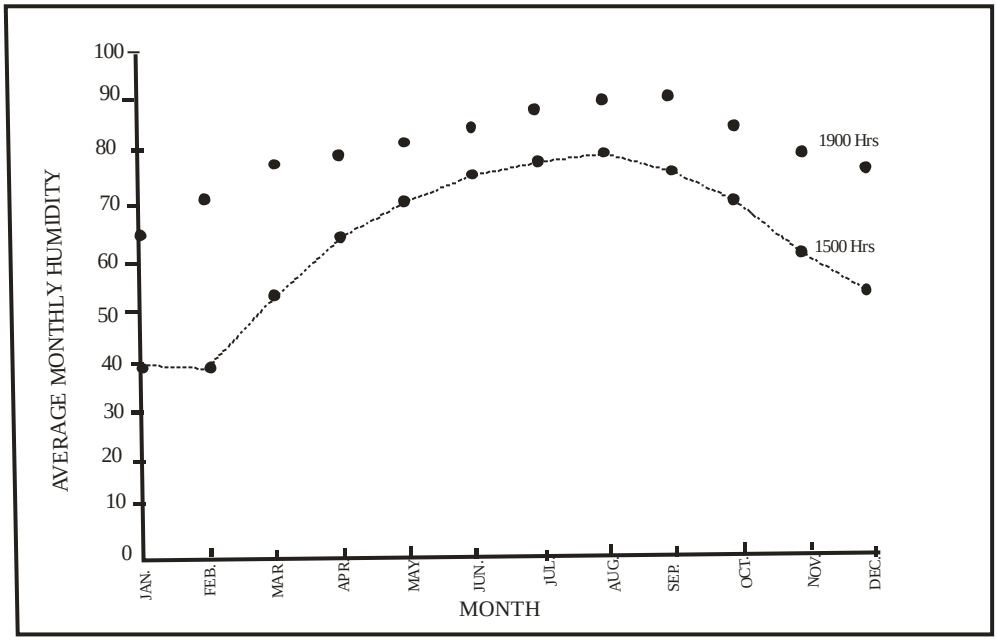

Fig. 2: Monthly Relative Humidity Pattern for Ondo State Synoptic Station (1981-1986)

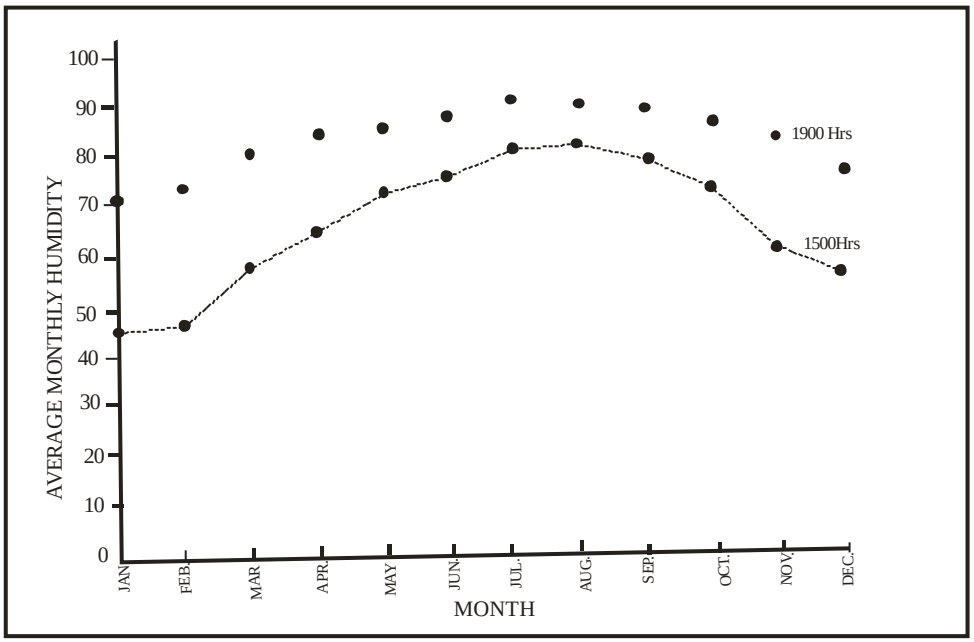

Fig. 3: Monthly Relative Humidity Pattern for Ondo State Synoptic Station (1986-1990).

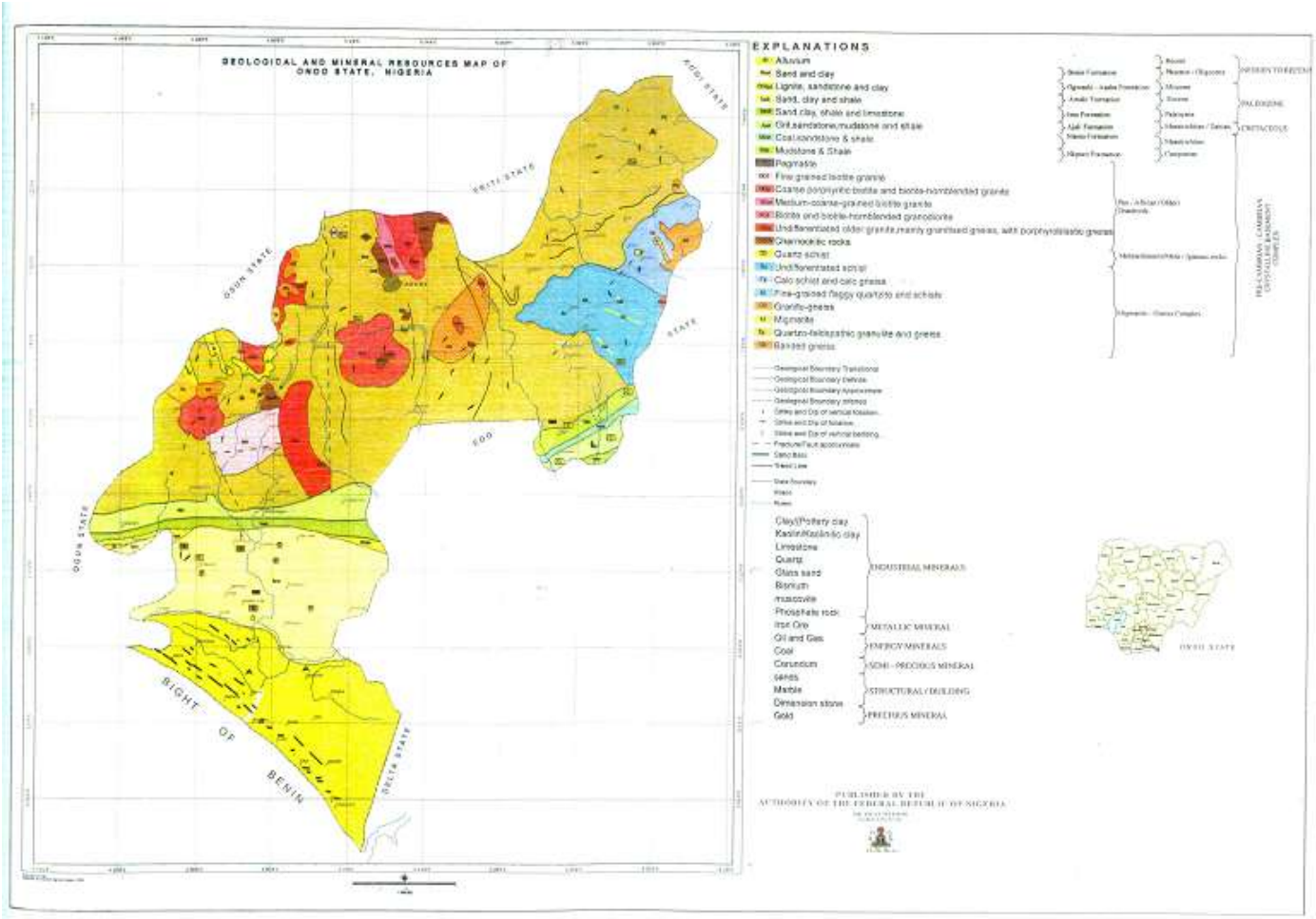

Fig. 4. Geological Map of Ondo State (After Geological and Mineral Resources Map Album 2006).

The sedimentary rocks which are mainly sands, clays, shales and some limestone thicken towards the west and to the coast (south). They are subdivided into various formations which are: Recent Sediments, Coastal Plains Sands of Benin Formation, Ilaro Formation, Ewekoro Formation and Abeokuta Formation (Jones and Hockey, 1964). The aquifers are the sands in the Recent sediments, Benin and Abeokuta Formation. All three communities of Asisa, Zion Pepe and Ajapa are in the Recent alluvium underlain by Benin Formation or Coastal plains sands and Alluvial deposits (Fig.4). While Zion Pepe rests on a sand beach ridge, Ajapa and Asisa are on clays. Saline water intrusion is known to occur in the Benin Formation in Lagos area, as well as in Ondo State at Atijere, Agerige, Ikorigho and Ayetoro (Oteri and Atolagbe, 2003). Consequently this study is meant to delineate the fresh water aquifers in three coastal communities of Ondo State.

METHOD OF STUDY

The method of study include an evaluation of existing geophysical and hydrogeological data in coastal areas of the State and neighboring Lagos State, which included interpretation of well logs in the Opuama - Opuekeba - Molume area of the State; Ikorigho water well and well logs of offshore and onshore oil wells in the State. A study of the well completion record and borehole geophysical log of Akodo water well by the Atlantic coast in Lagos State, some kilometers from the Ondo State border, was also carried out.

Reconnaissance geological fieldwork was also carried out by our team who visited each town and interacted with the people to gather as much information as available on previous geological work in their towns. In addition the mapping assisted the team in the choice of stations for geophysical work.

Geophysical methods because of their cost effectiveness have been successfully used by several authors (Ako, 1976; Olorunfemi and Meshida, 1987; Olorunfemi and Olorunniwo, 1985; and Olorunfemi et al. 2000) in various parts of Southwestern Nigeria, including the study of saline water intrusion (Swartz 1937; Flathe, 1967; Zohdy, 1967; Gorham, 1976; Ako et al. 2005). The fieldwork was carried out in the month of September – during the raining season. The Schlumberger electrode configuration was used with half-current electrode separation (AB/2) varying from 1 to 225 m. in Asisa and and Zion Pepe and 1 to 150 m at Ajapa. This was because the space available for data acquisition is rather restricted. Only two VES sounding points were occupied in each community. The ABEM 300C Terrameter with Booster was used to collect the VES data. The obtained results were plotted and the resulting Vertical electrical sounding (VES) curves were interpreted by partial curve matching (Keller and Frischkneckt, 1966; Orellana and Mooney, 1966; Zohdy, 1965), and computer iterated software (INTERPEX, 1992).

GEOPHYSICAL INTERPRETATION: SURVEY AND RESULTS.

ASISA

Asisa is on the Atlantic coast. The surficial rock is mud. VES station 1 was located on the slut ridge with GPS position of 6^0 09.688' N and 40 42.981' E whilst VES station 2 was located at Asisa-Zion some 4km inland away from Asisa. The GPS position is 6^0 10.792' N and 4^0 44.050' E. Whereas VES 1 was located on the coast within the brackish/saline surface water zone, VES 2 at Asisa-Zion is an area with fresh water vegetation.

Figure 5 shows the VES curve and geoelectric section for Asisa VES station 1. The curve is KHA type curve representing five subsurface geoelectrical layers. The first layer is 0.78 m thick and has a resistivity value of 0.87 Ohm-m. The underlying layer has a resistivity value of 34 Ohm-m and it is 0.41 m thick. It is in turn underlain by a very low resistivity layer (ρ = 0.08 Ohm-m) which is 2.74 m thick. The next layer is 874 m thick with resistivity value of 1.80 Ohm-m and it rests on the geoelectric basement with a resistivity value of 2793 Ohm-m.

Figure 6 shows the VES curve and geoelectric section for VES station 2 located at Asisa-Zion. Four geoelectrical layers are mapped. The curve is QQ type with resistivity decreasing with depth. The resistivity values are lower than those obtained at Asisa VES l. Using the S-Rule interpretation method the geoelectric basement is mapped at a depth of 154 m.

Boreholes drilled at Aiyetoro about 10 km south of Asisa to depths between 85 and 113.4 m respectively had saline water. At Aiyetoro 40m of clay overlie alternating sands and clays. At Ikorigho 45 km south of Asisa, the borehole showed fresh water at a depth of 152 m. This is close to the value of 154m obtained at Asisa Zion (VES 2). The value of 874 m obtained at VES1 is too deep and thus rather expensive to drill.

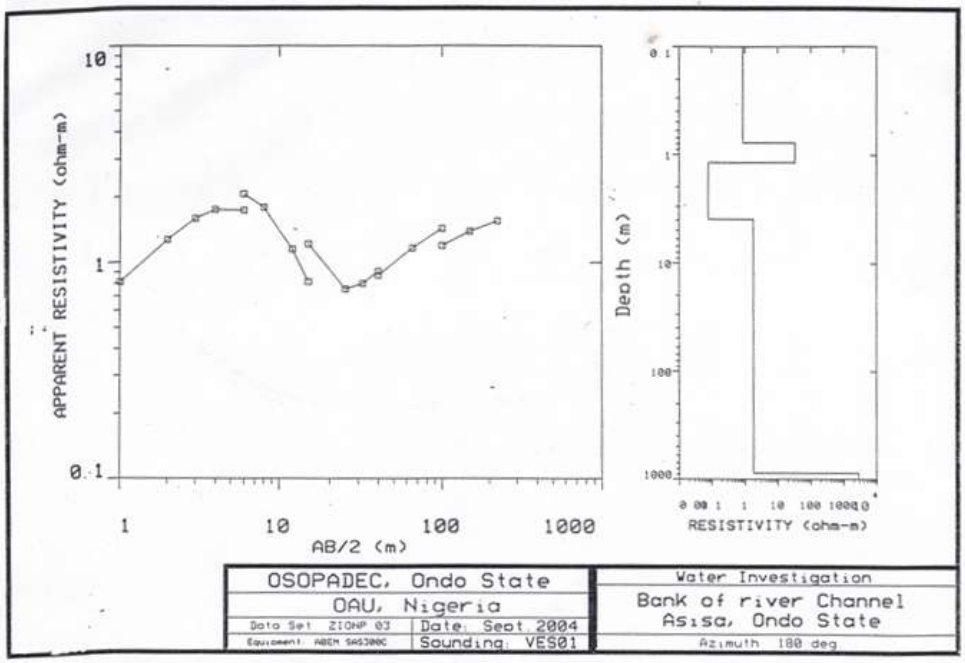

Fig. 5: Vertical Electrical sounding (VES1) curve and geoelectric section, Asisa Ondo State.

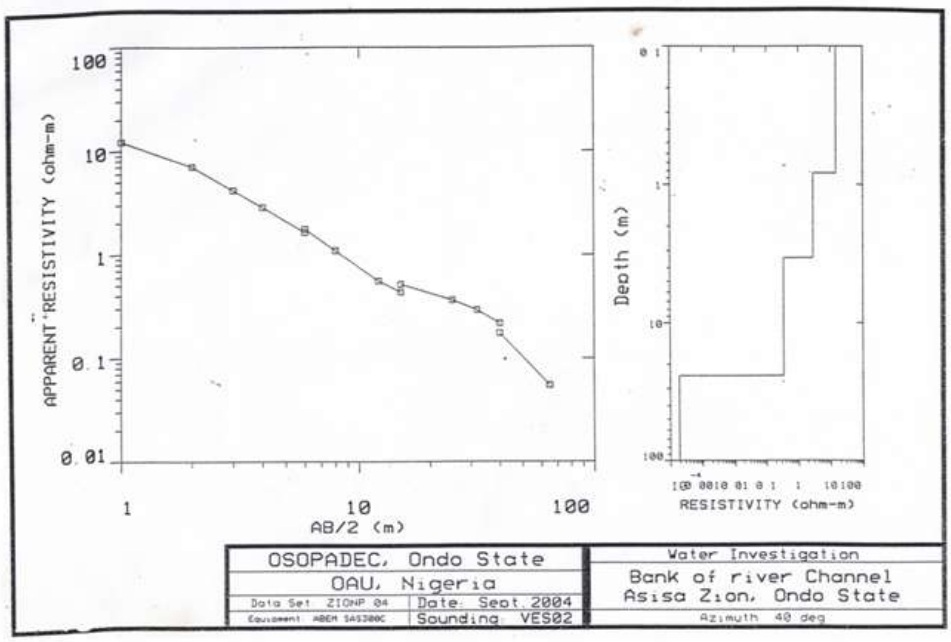

Fig. 6: Vertical Electrical sounding (VES2) curve and geoelectric section, Asisa-Zion Ondo State

It was recommended that a borehole be drilled to a depth of 300 m at Asisa Zion and borehole geophysical logging carried out. The target aquifer is between 140 m to 200 m but it is essential to investigate any deeper aquifers present in the area to a depth of 300 m. The result of borehole geophysical logging will show the appropriate interval for screening during borehole completion.

ZION-PEPE

Zion-Pepe is on the barrier beach sands which are recent sediments. It is located within the Benin basin aquifers. In the Benin basin are the sands of the Benin Formation and the Abeokuta Group. Because the aquifers in the Abeokuta Group are very deep (>800 m) it is not cost effective to tap such aquifers. The target aquifers are therefore those within the Benin Formation.

VES station 1 was located close to a shallow hand dug well with fresh water with GPS position of 6^0 17.619' N and 4^0 35.910'E. Figure 7 shows the VES curve and the geoelectric section for VES1. The curve is QH type depicting four geoelectric layers. The top layer with resistivity value of 781 Ohm-m represents the beach sand and is 2.8 m thick. It is underlain by a 9.9 m thick clay/sand with resistivity value of 81 Ohm-m.

The third layer has a resistivity of 8 Ohm-m suggesting that the layer contains saline water. It is 26.6 m thick and is underlain by the geoelectric basement (ρ = 18 Ohm-m) which is brackish to saline water saturated sand or clay.

Figure 8 shows the VES curve and geoelectric section for VES station 2 located 53 m south of VES 1. The GPS location is 6^0 17.599' Nand 4^0 35.896' E. The curve is of KHA type representing a five layer section. The first layer with resistivity of 176 Ohm-m is the beach sand (h = 1.2 m). It is underlain by a fresh water saturated sand (ρ = 733 Ohm-m) having a thickness of 1.3 m which is in turn underlain by a 1. 9 m saline water saturated sand (ρ = 2 Ohm-m). The underlying layer is about 146 m thick and the resistivity value (ρ = 25 Ohm-m) suggests either alternating sequence of sand and clay with brackish water. The geoelectric basement (ρ = 2302 Ohm-m) mapped at a depth of about 152 m is likely to be fresh water saturated sand. A borehole drilled about 50 m south of VES 2 was abandoned as a result of saline water intrusion. Unfortunately we do not have information regarding the drilled depth of the borehole.

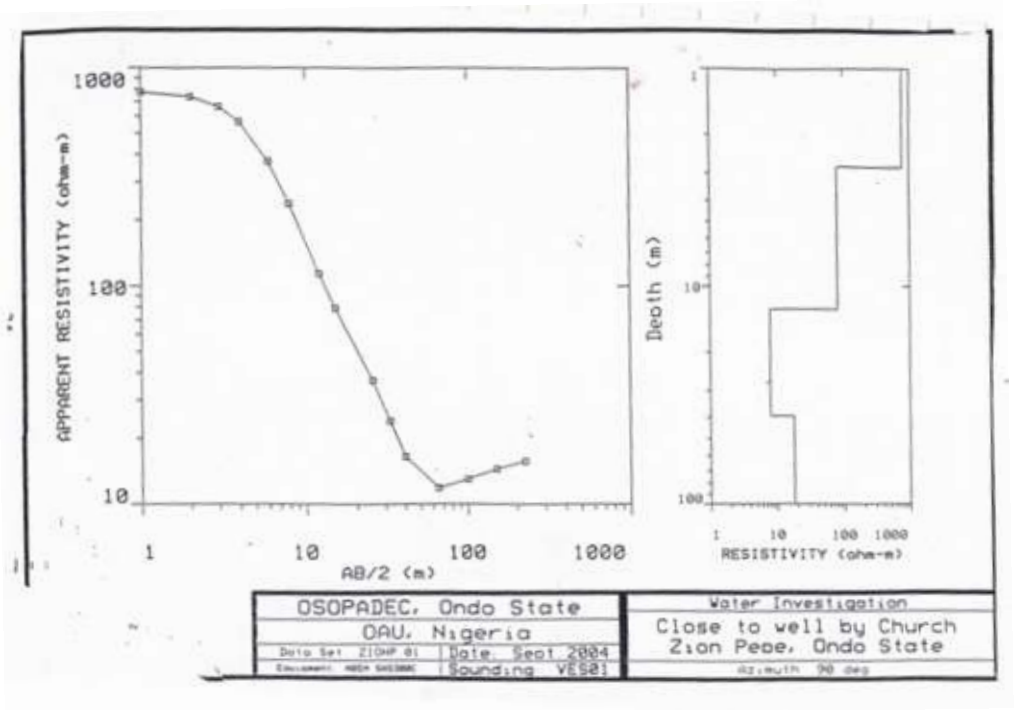

Fig. 7: Vertical Electrical sounding (VES1) curve and geoelectric section, Zion-Pepe Ondo State.

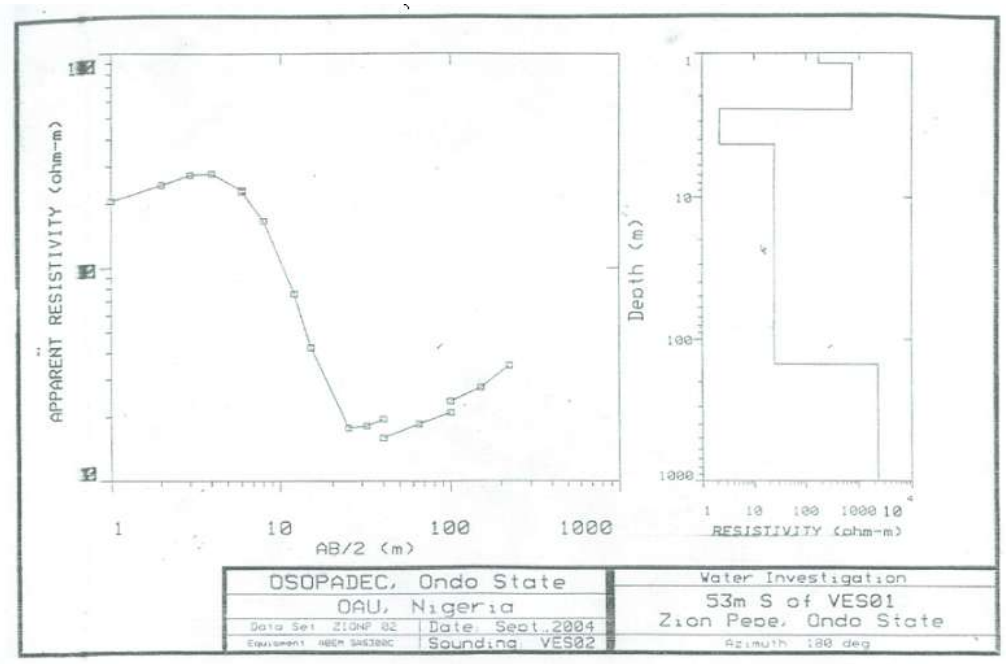

Fig. 8: Vertical Electrical sounding (VES2) curve and geoelectric section, Zion-Pepe Ondo State.

Zion-Pepe is a large community and the shallow water table aquifer though useful, will not meet the fresh water requirements of the community. Consequently, we recommended utilizing the deep fresh water aquifer mapped at a depth of 152 m. We

thus recommend the drilling of a borehole close to VES 2 to a depth of 190 m. The borehole should be logged and the fresh water interval identified from the borehole geophysical logs should be screened.

AJAPA

Ajapa is a large community and suffers from potable water supply with attendant cholera epidemic especially during the dry season. The GPS locations of the two VES stations occupied in Ajapa are 6^0 05.071'N and 4^0 50.948' E for VES 1 and 6^0 05.298' Nand 4^0 50.276'E for VES 2 respectively. Both stations were located on the surficial clay.

Figure 9 shows the VES curve and the geoelectric section obtained at VES station 1. The curve is QH type showing a four layer subsurface. The top soil is saturated mud/clay with resistivity of 21 Ohm-m and thickness of 0.76 m. The second and third layers have very low resistivity values ρ = 3 and 0.13 Ohm-m respectively) suggesting that they are both saline water saturated. They are both 303 m and 3.1 m thick respectively. The geoelectric basement with a resistivity value of 1612 Ohm-m is mapped at a depth of 7 .3 m. The geoelectric basement probably contains fresh water. This shallow fresh water aquifer is probably underlain by another saline water zone. Figure 10 shows the VES curve and geoelectric section for Ajapa VES 2. The curve is also QH type representing a four layer subsurface. The top layer is also of low resistivity (ρ = 16 Ohm-m) and is 0.63 m thick. It is underlain by saline water saturated sand to a depth of about 5.0 m which is in turn underlain by a fresh water saturated layer ρ = 81 Ohm-m) which is the geoelectric basement. These data indicate the occurrence of a fresh water-bearing aquifer underlying the clays and saline water sands.

Unfortunately the space available for geophysics coupled with the screening effect of the low resistivity upper layers did not allow mapping of the deeper layers. Ajapa is quite close to Bolowo Zion where there is a borehole with fresh water but with high iron content. Iron removal treatment has been carried out at Bolowo. It is thus expected that a deep fresh water layer also exists at Ajapa.

From the results obtained at Balowo which is close to Ajapa the drilling of a borehole at VES 1 was recommended, to a depth of 200m and borehole geophysics carried out. The result of the borehole geophysical logging will delimit the fresh water aquifer to be screened.

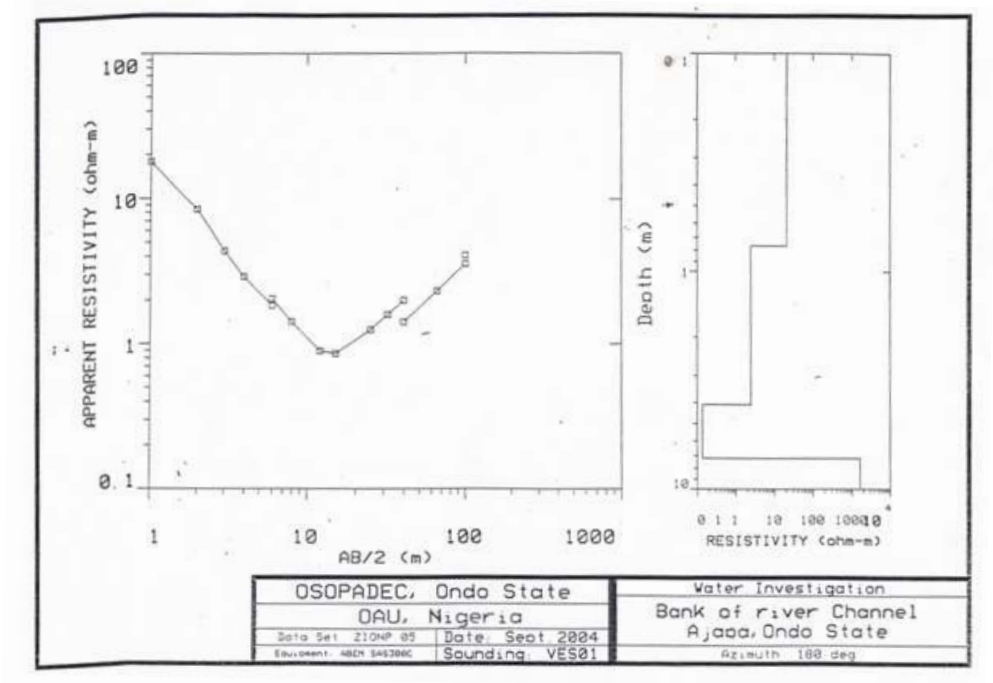

Fig. 9: Vertical Electrical sounding (VES1) curve and geoelectric section, Ajapa Ondo State.

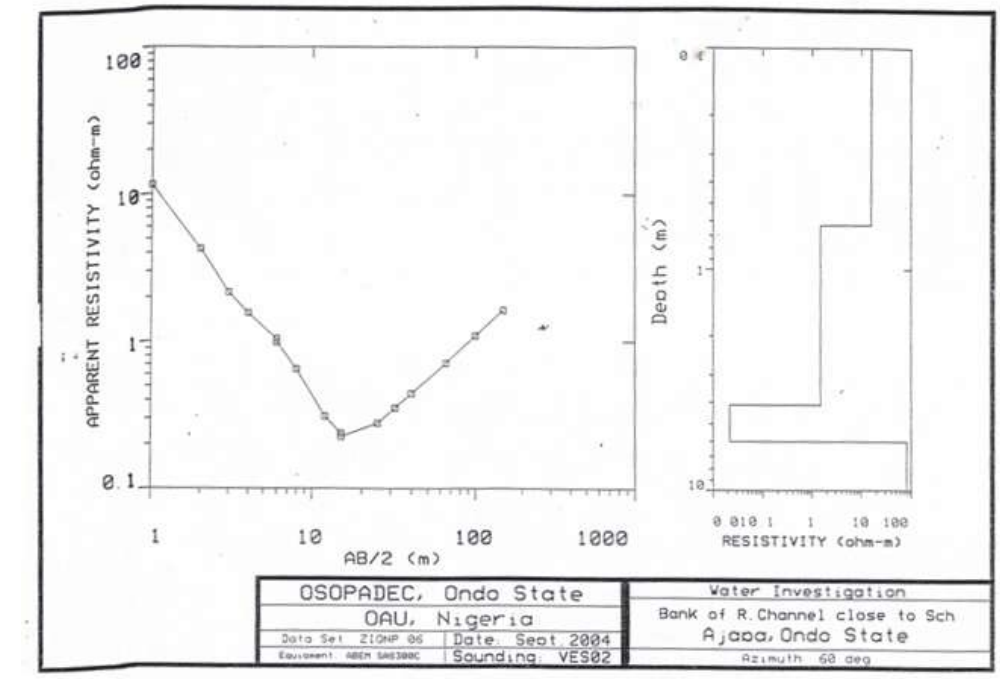

Fig. 10: Vertical Electrical sounding (VES2) curve and geoelectric section, Ajapa Ondo State.

CONCLUSIONS AND RECOMMENDATIONS

Preliminary investigation revealed that the study area falls within the sedimentary area of south western Nigeria underlain by Benin Formation or Coastal plains sands and Alluvial deposits. The total thickness of the entire series is estimated to be about 2400 m. The facies changes in the sediments during deposition, affect the quality of groundwater which thus varies. Contamination ranges from high iron content to high salinity.

The very low resistivity value of the surficial clay at both VES stations at Asisa and Asisa-Zion masked the sands below. Using the S-rule method of interpretation, fresh water sand is likely at depths greater than 154 m. It was recommended that a borehole be drilled to a depth of 300 m at Asisa Zion. The value of 874 m obtained at VES1 is too deep and will be rather expensive to drill. Borehole geophysical logging should also be carried out. The target aquifer is between 140 m to 200 m but it is essential to investigate any deeper aquifers present in the area to a depth of 300 m.

In Zion-Pepe a borehole drilled about 50 m south of VES 2 was abandoned as a result saline water intrusion. However, there is a shallow well (3m) that has been in existence for about Twenty years and has been the only source of drinking water for the community and its environs. Zion-Pepe is a large community and the shallow water table aquifer though useful, will not meet the fresh water requirements of the community. Consequently, a deep fresh water aquifer mapped at a depth of 152 m was recommended. The borehole should be logged and screened at the fresh water interval identified from the borehole geophysical logs.

In Ajapa, the space available for geophysics coupled with the screening effect of the low resistivity upper layers did not allow mapping of the deeper layers. However the data obtained indicate the occurrence of a fresh water-bearing aquifer underlying the clays and saline water sands. Ajapa is quite close to Bolowo Zion where there is a borehole with fresh water but with high iron content. It is thus expected that a deep fresh water layer also exists at Ajapa. The drilling of a borehole at VES 1 was recommended, to a depth of 200 m and borehole geophysics carried out.

In spite of a long coastline which borders the States of Ondo, Lagos, Ogun, Delta, Bayelsa, Rivers, Akwa Ibom and Cross Rivers States, and the abandonment of many water wells in the area as a result of high salinity, saline water intrusion into coastal water resources is yet to be accorded the attention it deserves. It is thus a welcome development that Ondo State has taken the right steps and other governments with coastline should take steps to commission pre-drilling geophysical investigation for freshwater aquifers in their communities.

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