2-D Electrical Resistivity Tomography (ERT) For Delineating Saltwater Intrusion in the Coastal Region of AKWA IBOM State, Nigeria

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Abstract: *Recently, the deterioration of water quality in the coastal areas of Akwa Ibom State, Southeastern, Nigeria due to saltwater infiltration into the freshwater aquifer has become a major concern. In this study, the geophysical method we adopted was the 2-D Electrical Resistivity Tomography (ERT) using resistivity meter and other accessories to obtain the field data. Wenner electrode configuration with electrode spacing ranging from 5 to 200m was used for field measurement and a total of twenty (20) randomly distributed ERT profiles were covered. The modeled field data revealed the resistivities and depth to bottom layer distribution across the study area with predominant lithologies being coastal plain sands. The interpretation showed upper resistivity limit of 232.5* ***Ω****m for medium to fine grained sands; 3,959* ***Ω****m for lateritic sands; 1,580* ***Ω****m for gravelly sands and 185.5* ***Ω****m for sandy/clayey sand and clay soils. The depth of inverse models from the geoelectrical resistivity data obtained in the area revealed significant impact of the saline water in delineated aquifer with very low resistivity values uniquely below 3.24* ***Ω****m. ERT results also shows the lateral invasion and upconing of saline water within the aquifer systems. Both natural and anthropogenic factors are responsible for saline intrusion across the study area. The uniqueness of the techniques and investigations through field data analysis showed the extent a saltwater intrusion into the freshwater aquifer along the interface.*

Keywords: *Electrical Resistivity Tomography (ERT); Coastal Aquifer, Saltwater Intrusion; Wenner Array; Nigeria*

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I. Introduction

Contamination of freshwater bodies caused by saltwater intrusion (SI) is a global issue, affecting water quality, vegetation and soil conditions along coastal lines. Nigeria has a coastline that is 1,000km long boarding some states in the South with the Atlantic Ocean. There are Lagos, Ogun, Ondo, Delta, Bayelsa, Rivers, Cross Rivers and Akwa Ibom State (1). Saline intrusion into the coastal aquifers in these region has become a major concern (2) because it contribute the readily pollutions in freshwater. Hence, the understanding of saline intrusion is essential for the management of coastal water resources (3). According to (4), there are two fundamental sources of information in groundwater saline intrusion investigations, the geophysical and the hydrochemical methods. Data acquired with these techniques separately or ideally coupled together, can successfully delineate the freshwater/saltwater interfacial configuration in a coastal aquifer system. Among them, the geophysical methods present significant advantages over the geochemical ones, since they involve lower cost and less time in their application (5). Another critical advantage is that they are non-destructive and they incorporate the ability to produce continuous datasets over large areas, while geochemical analyses are limited only to point of interest where boreholes exist (6).

Coastal sedimentary basin the world over have been inundated by saline oceanic seawater intrusion which leads to the invasion of wells drilled to the surface to yield freshwater by saline water and Nigeria has not been an exception (7). Saltwater intrusion in coastal aquifer in Nigeria have been a source of public grievance as several wells drilled to the groundwater table were abandoned only a few months after due to saline water intrusion. Even in some areas freshwater supplies from groundwater sources have been impossible due to saline water dominating aquifer.

Basically, freshwater is less dense than saltwater and so it floats on top. Therefore, saline water is found below freshwater discharge from higher altitude in coastal areas. Also, the boundary between saltwater and freshwater is not distinct; the zone of dispersion, transition zone, or saltwater interface is brackish with saltwater and freshwater mixing (8). It then means that salinity will increase with depth where both freshwater and saline water occur. As such, the increase in salinity will produce consequent decrease in electrical resistivity of water and thus resistivity varies with depth within groundwater well in coastal aquifer. These variations could then be interpreted by methods capable of detecting differences in salinity. Therefore, within the purview of this research, geophysical technique involving 2-D Electrical Resistivity Tomography (ERT) using wenner array was conducted to delineate possible saltwater intrusion in coastal alluvial aquifers, map the lateral and vertical extent of groundwater contamination, and assess the groundwater quality in coastal aquifer of the study area.

II. Location and Geology

The study area cuts across ten Local Government Area (LGAs) comprising Mkpat Enin, Onna, Eket, Eastern Obolo, Mbo, Udung Uko, Esit Eket, Ibeno, Oron and Ikot Abasi (Figure 1) within the coastal region of Akwa Ibom State.

The area falls within longitude 7.30^{I} to 8.20^{I} E and latitude 4.30^{I} to 5.30^{I} N in Nigeria (Figure 1) around the Gulf of Guinea with a total land area of 8,412 km^2, the state falls within the sedimentary area of Nigeria (9). The terrain of the study area is generally flat with elevation ranging between less than zero and above 30 m above sea level. The area has a humid tropical climate with temperatures (annual mean 26^{0}C) and high relative humidity (annual mean 85%). Precipitate is also high arranging about 3,855 m, annually and greatly exceeding the annual evaporation (1,680 m) (10).

Geologically, the study area belongs to the coastal region dominated by coastal main sands (CPS) otherwise called the Benin Formation (11). The major aquiferous formations are the deltaic planes and Benin Formation. Both confined and unconfined aquifers are encountered at vary saline and clay groundwater (12). The Benin Formation consists predominantly of massive highly porous sands and gravels with locally thin shales and clay interbeds to form a multiaquifer system in the Delta (13). Many quality water yielding boreholes have been drilled to tap water from the Benin Formation. However, many of these boreholes have been abandoned due to salinity problems (14).

In the Benin Formation, salt water intrusion into the recent sedimentary aquifers occurs below the freshwater lens stretching from the coast to about 5 km in some place (15). The coastal plan sands (CPS) forms the major hydrogeologic units in the area. It comprises poorly sorted continental (fine-medium-coarse) sands and gravels that alternate with lignite streaks, thin clay horizon and lenses at some locations. The thin clay/shale horizons truncate the vertical and lateral extents of the sandy aquifers thereby buildings up multi-aquifer systems in the area (16,17).

The temperature is uniform throughout the year. But on the other hand, the high permeability of Benin Formation, the overlying lateritic earth and weathered top of the Formation as well as the underlying clay shale provide the hydrogeological condition favouring the aquifer formation in the area (18).

The study area is drained southward flowing rivers like the Imo River and their tributaries that empty directly into the bright of Bonny. The brackish/saline water in Imo River interacts with the freshwater aquifer through the geologic divides thereby causing serious health threats to lives. This provokes the choice of the study in the region characterized by high population density (19).

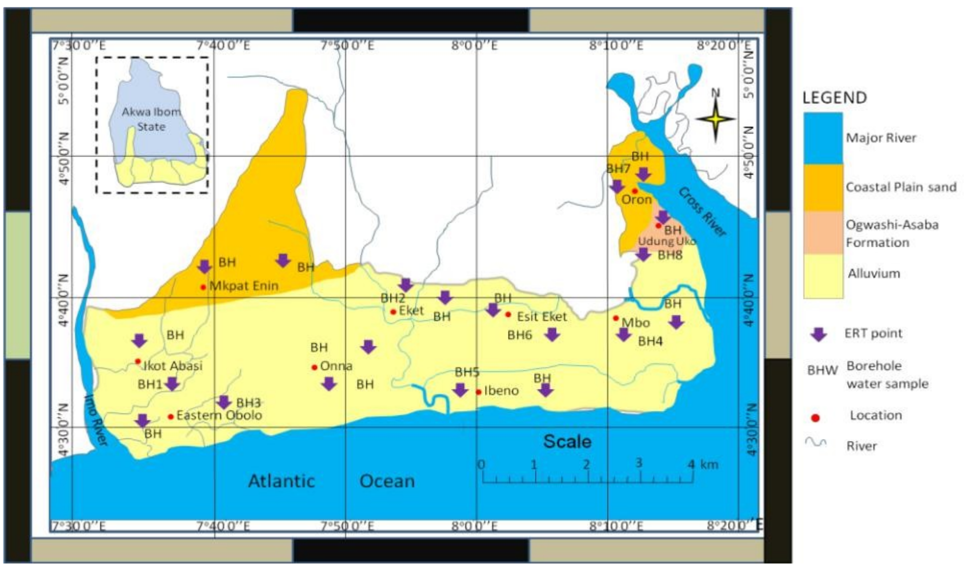

Fig.1: Location map of the study area and field measurement points

III. Materials and Methods

The purpose of geoelectrical survey is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements the true resistivity of the subsurface can be estimated. The ground resistivity is related to various geological parameter such as the mineral and fluid content, porosity and degree of water saturation in the rock (20).

Four parallel 2-D electrical resistivity tomography (ERT) surveys were performed at the proposed sites using the SSP-ATS-MRP model of an IGIS (integrated Geo-instruments and services) resistivity meter and multicore cable to which electrodes were connected at takeouts moulded on predetermined equal interval. A computer controlled system then used to select the active electrodes for each electrode set-up automatically. By using wenner configuration, current was injected into C_1 electrode to the ground and received from the ground through C_2 electrode. The potential difference was measured between two inner electrodes P_1 and P_2. The configuration was kept constant and moved along the profile until all possible measurements have been made with the electrode spacing (Figure 2). There were variations in the profile length, 200 m with electrode spacing of 5 m for ERT profile points 1, 2 and 9 while for the ERT points 3, 4, 5, 6, 7, 8 and 10– 20, the profile were 150 m long; owing to constraint in space. Notwithstanding, a fairly deeper depth were probed in the transverses having used expansion factor n =38

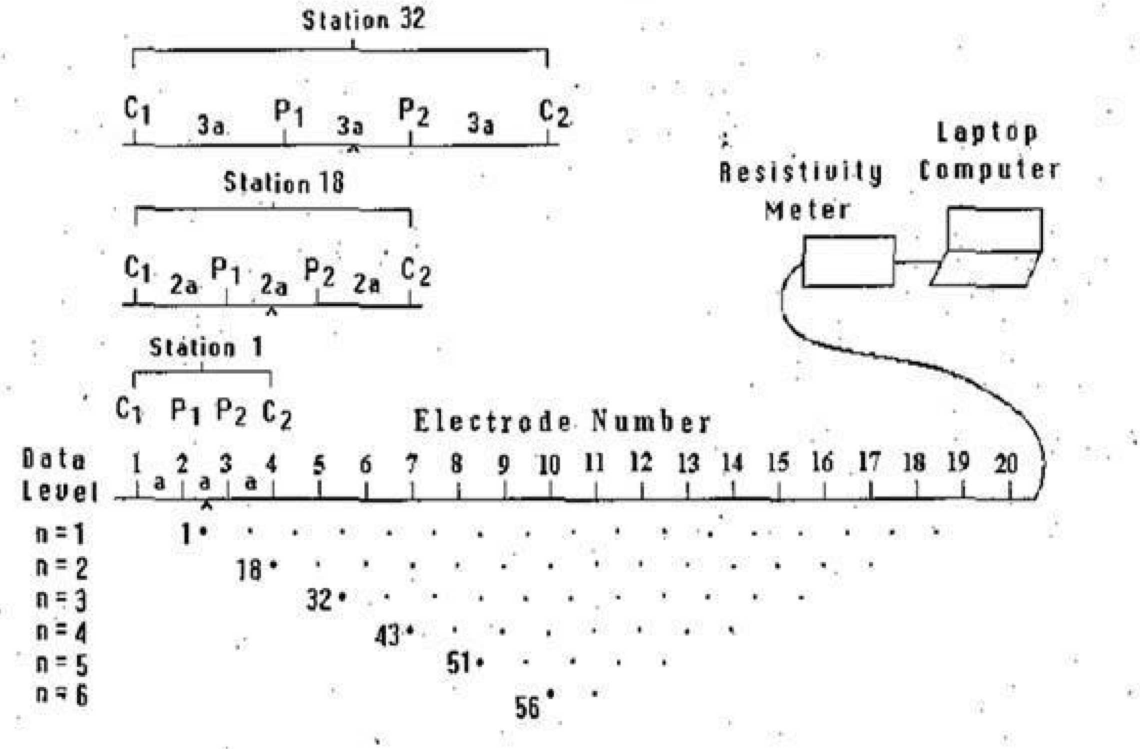

Fig.2: The arrangement of electrodes for 2-D electrical survey and the sequence of measurements used to build up a pseudo section (21)

Among the common arrays, the wenner has the strongest signal strength. This can be an important factor, if the survey is carried out in areas with high background noise as attributed to the coastal regions of this research work. The choice of array for the survey was based on our desire to have good sensitivity to vertical and horizontal changes in the subsurface resistivity at both shallow and deeper depths, at the same time probe into the deeper depth and to have good vertical and horizontal data coverage under each ERT profile. The wenner array system is of added advantage because of its sensitivity to detect geologic noise and other abundant interpretational materials (22).

In all, twenty (20) 2-D ERT profile (Figure 3- 22) were measured covering the whole coastal area. One of the latest softwares for the inversion of 2-D data, RES2DINV, was used to invert the apparent resistivity profiles to obtain a 2-D images of the subsurface resistivity distributions. In the section, horizontal axis is the electrodes spacing and vertical axis is the depth. The ERT profiles were inverted using an iterative smoothness constrained least-squares inversion algorithm otherwise known as „OCCAM‟ inversion‟ after (23, 24). These inversion routines involve a cell based inversion techniques; it subdivides the subsurface into a number of rectangular cells in which resistivities are varied to obtain the best fit with the observed data (25). The differences between the observed and calculated data are minimized to obtain an acceptable agreement (26). A measure of this difference is given by the root-mean-square-error (RMS%). However, smoothness constrained models do not allow for large and unreasonable variations in the output models as its name suggests.

IV. Results and Discussion

Twenty (20) sites were selected for resistivity imaging surveys. These sites include Effiong Usung Street, Usung Close, Usun Road, Eniong, Coconut Plantation (Ikot Akpaden), Ikot Oyoro, Onna Head Bridge, Edem Idim Ishiet, Uta Ewa Beach, Ette Town along E-W Road, Okoroette, Iko Town, Ikot Ebok, Esit Urua, Abighe Asang Uquo, Ikpa, Unyenghe, Udung Ejo, Ibeno Beach and Ukpenekang Communities. ERT points were coded 1 to 20, showing locations and GPS co-ordinates of the study area taken by twelve channels global positioning system (GPS) set the "GARMIN GPS 12" (Table 1). The location of ERT points is shown in Fig.1. Profile lengths were 200 m electrode spacing of 5 m for ERT profile point 1, 2 and 9 while for the ERT points 3, 4, 5, 6, 7, 8 and 10-20 the profiles were 150 m long. Penetration depths were from the 2-D images to be either 38.8m for the 200m long profiles and between 21.5 m and 26.2 m for the 150 m long profiles.

Fig. 3 and 4 shows a typical 2-D resistivity subsurface image with characteristics features of the different geologies materials mapped across the profile locations. The top layer of the profile (fig.3) is dominated with sandy/clay soils, followed with lateritic/gravelly soil and fine/medium grained sands at the bottom of the profile. The resistivity of the sandy/clay soil ranged between (8.0-47.6 Ωm) with depth to bottom distance of (125-5.13 m). It is this sandy/clay material that form the protective cap layer and protects the underlying sandy aquifer from contamination. Thus, the area is less vulnerable to contamination. This sandy/clay is underlain by a layer with high resistivity ($70.6 < \rho < 395.5$ Ωm). These high resistivity materials are exposed at the beginning of the profile between 0 and 45 m and also at the central part of the profile (between 55 m and 180 m). The second layer which is more pronounced at a depth of about 6.35 m from the beginning of the profile tappers off at a depth of 19.8 m at a distance of 144 m. This layer was identified as lateritic/gravelly materials. It reoccurs at a depth of about 11.7 m around 60 m along the profile. The electrical resistivity values of materials in this layer were observed to vary from 587 to 23,260 Ωm. This third layer corresponds to fine-to-medium-grained sand and is the water-bearing unit (aquifer). It is also the most prominent layer that cuts across the entire profile. Fig.4 with ERT point 2 also shows a 2-D resistivity derived subsurface images with sandy/clay soil at the left portion of the profile with low resistivity value between (3.0-14.0 Ωm) structure reflective of saline water incursion into the aquifer. Fine grain sand with resistivity values between (14.9-232.5 Ωm) and lateritic soil with resistivity values between (317-870 Ωm). The other locations like Usun Road, Udung Uko, Ikot Oyoro/Coconut Plantation, Mkpat Enin, Ette Town along E-W Road, Ikot Abah, Okoroette, Eastern Obolo and Udung Ejo, Mbo Local Government Areas, the top most layers are dominated by high resistivity materials with resistivity values ranging from 420-5,500 Ωm. ERT results also shows the lateral invasion and upconing of saline water within the aquifer systems.

However, the electrical resistivity tomography profiles at different locations across the study area shows that freshwater aquifer have been impacted by saline water due to natural and anthropogenic activities. Generally, the contaminated regions were characterized with very low resistivity values of less than 3.24 Ωm structured, reflective of saline water incursion into the aquifer in some locations such as ERT point 1, 2, 7, 8, 9, 10, 11, 12, 13, 14, 15, 17, 19 and 20.

From the 2-D images in the study area, intrusion was noticed to originate from both the surface layers of the profiles and bottom sections of the geologic formations. Other sources of pollution of freshwater aquifer observed from the results include brackish water intrusion from the creeks in the swamp areas, waste water accumulated from the heavily industrial area and percolation through poor drainage/canal within the coastal area. Also noticed were sources like leachate from dumpsites and infiltration from polluted streams. Daily excessive groundwater extraction for domestic and industrial purposes from functional boreholes springing up every day is enough to aggravate the saline intrusion with time. Geologic structure with resistivity value ranging from (232.5-3,959 Ωm) were interpreted as lateritic sand and those with (4.9 - 232.5 Ωm) as fine grained sand; Sandy/clayey sand and clay soil dominate many 2-D images with very low resistivity values ranging from (3.25-185.5 Ωm), while the most highly resistive materials with resistivity values ranging from (11.0 to 1,580 Ωm) revealed the presence of gravelly sands. In general, the ERT, profiles across the study area reflects similar geologic Formation with resistivity values ranging from low to high values respectively for the subsurface materials. The commonly interpreted geologic materials within the subsurface in the study area include gravelly sand, lateritic sand, fine to medium grained sands and intercalations of clayey and sandy sand/clay soil base on the resistivity values.

V. Conclusion

A 2-D electrical resistivity tomography survey by using Wenner array has revealed the pattern of resistivity variations within the study area. The inverted section for the twenty investigated sites revealed essentially the lithology changes at each sites. These inferred lithologies changes from the 2-D ERT imaging including the top soil are characterized by their various resistivity values as lateritic sand; gravelly sand; fine-medium-grained sands and intercalation of clay soil and sandy/clayey sands. Hence, the resistivity result, revealed the fresh groundwater reservoirs in the coastal formation consists of fine to medium grained and gravelly sands. They store water at commercial quantity for domestic and industrial purposes. Hence, the resistivity result revealed a dominant trend of decreasing resistivity with depth which indicates increase of salinity with depth. Thus, the invasion of the freshwater aquifer units within the study areas by saline water intrusion is perhaps due to increase in groundwater extraction for industrial and domestic purposes, uncontrolled discharge of waste, oil spillage and hydraulic connection between freshwater and seawater thereby allowing saltwater to push further inland beneath the freshwater. The saline water intrusion mechanisms are both lateral and upconing. These findings provide useful guidelines to formulate appropriate strategies for proper management and control of saltwater intrusion to ensure a sustainable source of fresh groundwater for the future. Also, the results of this study will form a baseline geophysical data within the study area and will assist individuals, non-governmental organizations, industries and government on mapping and development of the transition zones or contamination zones in the coastal region of Akwa Ibom State.

Table 1: Coordination/Elevation of profiles (1 – 20) as taken by twelve channels global positioning system (GPS) set the "GARMIN GPS 12"

Profile No.	Elevation (m)	Northing	Easting
1	10.00	4.8134	8.2259
2	7.00	4.8190	8.2314
3	38.00	4.7638	8.2539
4	15.00	4.7459	8.2771
5	15.00	4.5940	7.7596
6	24.00	4.6136	7.7639
7	150.00	4.6381	7.9123
8	20.00	4.9686	7.8564
9	4.00	4.5482	7.5509
10	16.00	4.6000	7.6898
11	10.00	4.5631	7.7474
12	12.00	4.5863	7.7641
13	9.00	4.6335	7.9014
14	3.00	4.6001	7.958
15	38.00	4.6598	8.0554
16	17.00	4.6732	8.0554
17	20.00	4.6333	8.1873
18	36.00	4.6340	8.1831
19	6.00	4.5390	8.0015
20	7.00	4.5824	7.9878

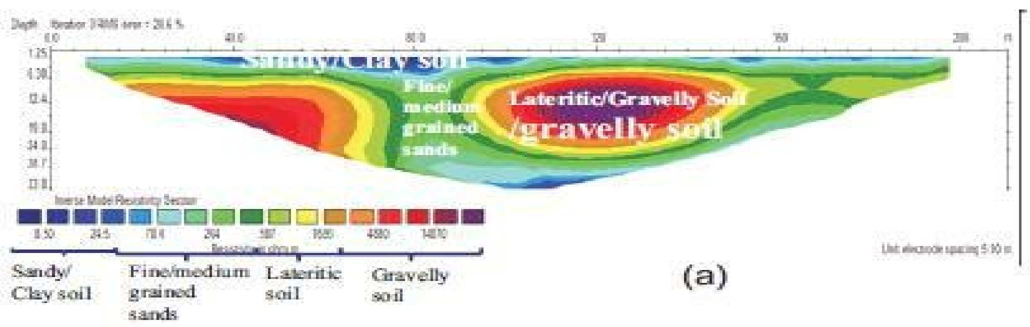

Figure 4.1a: Subsurface image obtained along ERT point 1 (Effiong Usung Street, Oron L. G. A)

Fig. 3

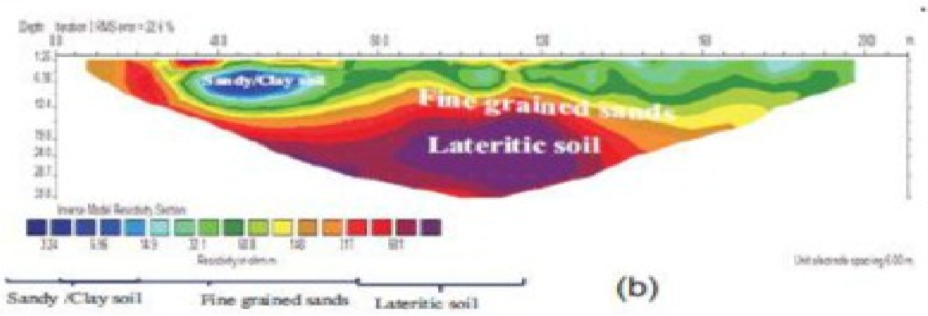

Figure 4.1b: Subsurface image obtained along ERT point 2 (Usung close, Oron L. G. A)

Fig. 4

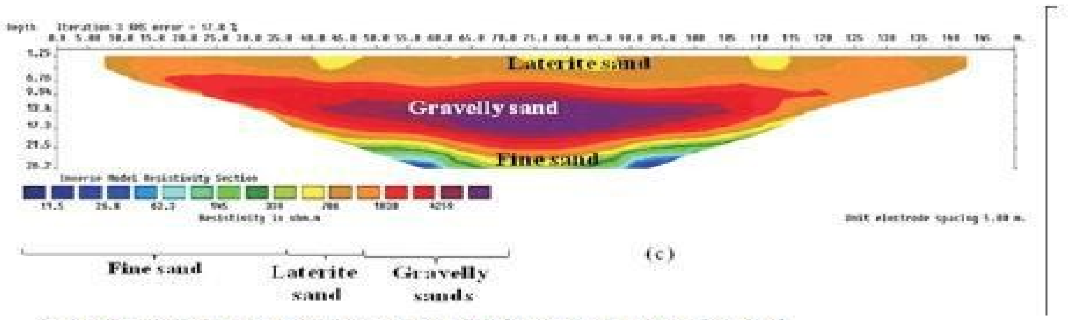

Fig.4.1c: Subsurface image obtained along ERT point3 (Usung Road, Udung UkoL. G. A)

Fig. 5

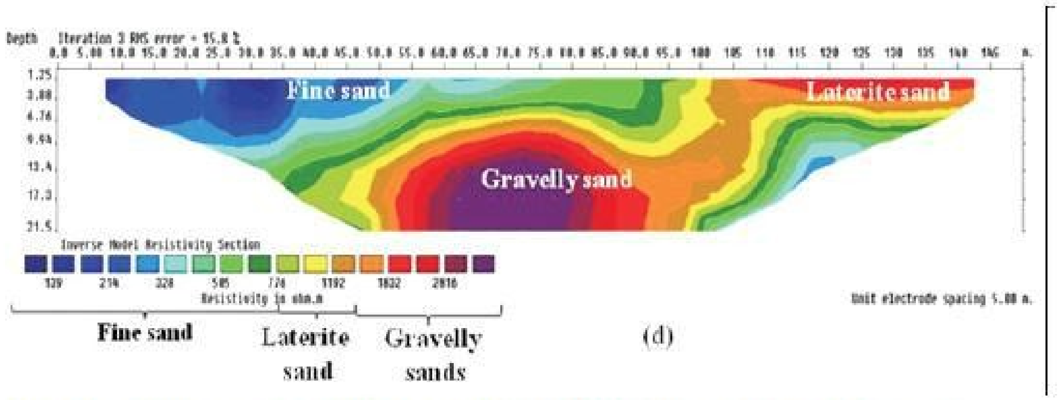

Fig.4.1d: Subsurface image obtained along ERT point4 (Eniong, Udung UkoL. G. A)

Fig. 6

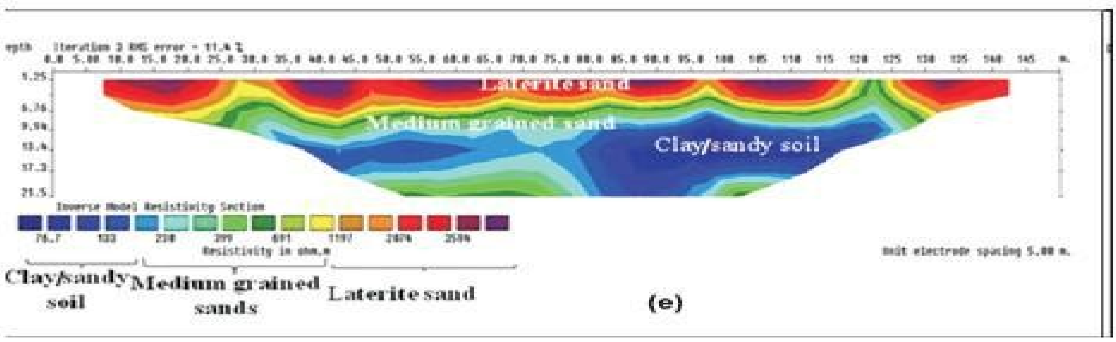

Fig.4.1e: Subsurface image obtained along ERT point 5 (Coconut Plantation, Ikot Akpaden, Mkpat Enin L. G. A.)

Fig. 7

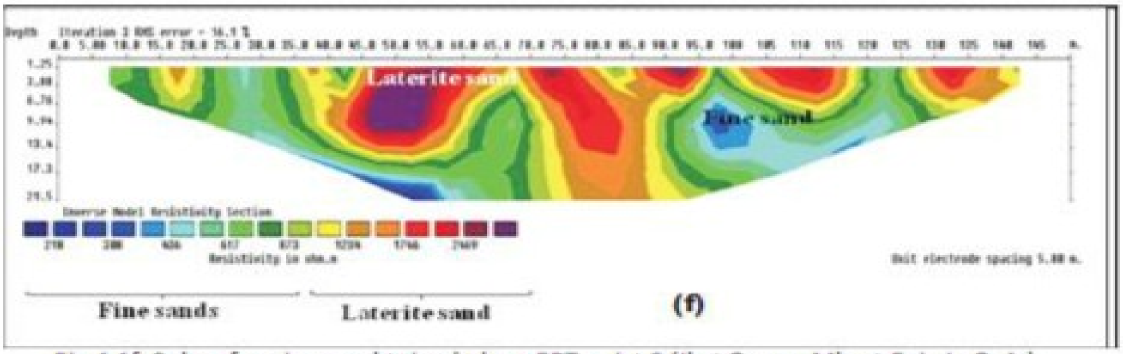

Fig.4.1f: Subsurface image obtained along ERT point 6 (Ikot Oyoro, Mkpat Enin L. G. A.)

Fig. 8

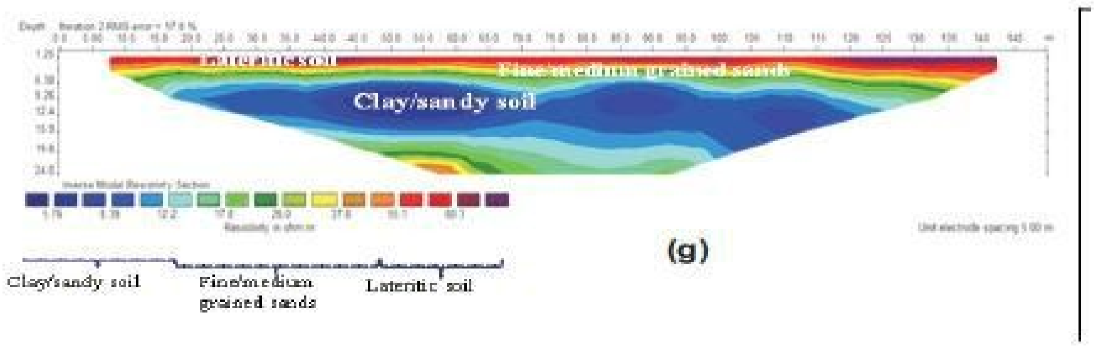

Fig.4.1g: Subsurface image obtained along ERT point 7 (Onna Head Bridge, Onna. G. A)

Fig. 9

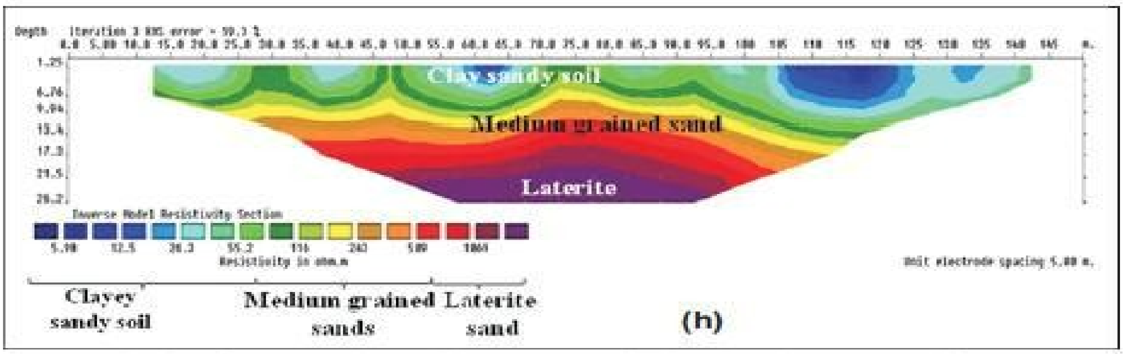

Fig.4.1h: Subsurface image obtained along ERT point 8 (Edem Idim Ishiet, Onna G. A)

Fig. 10

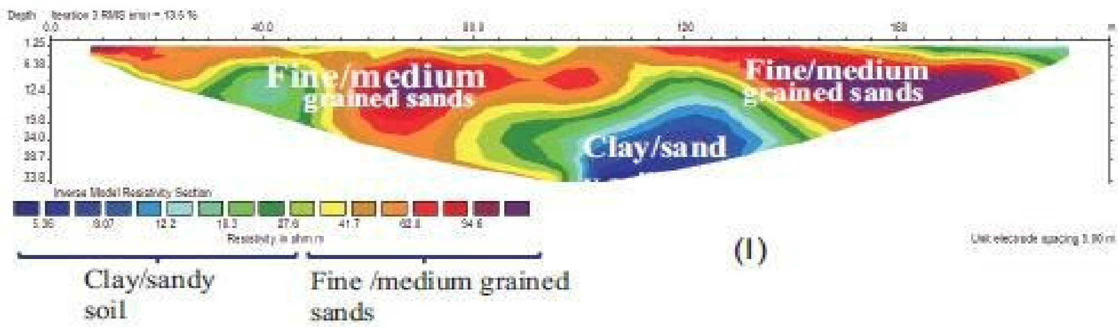

Fig.4.1i: Subsurface image obtained along ERT point 9 (Uta Ewa beach, Ikot Abasi L. G. A.)

Fig. 11

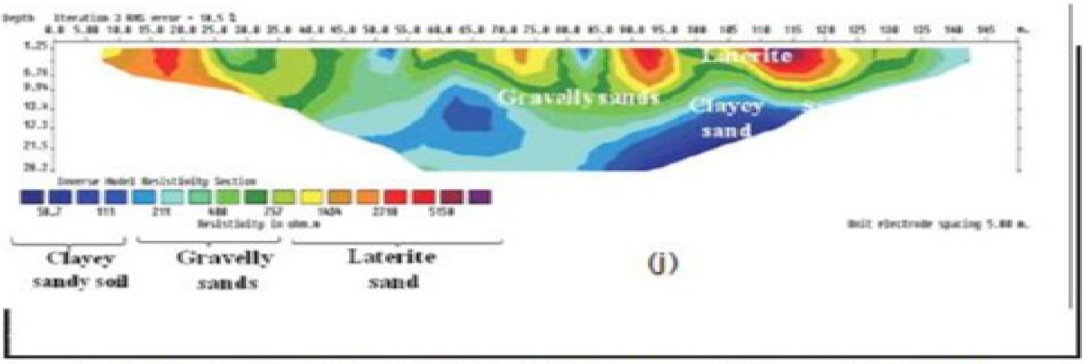

Fig.4.1j: Subsurface image obtained along ERT point 10 (Ette town along E-W raod, Ikot Abasi L. G. A.)

Fig. 12

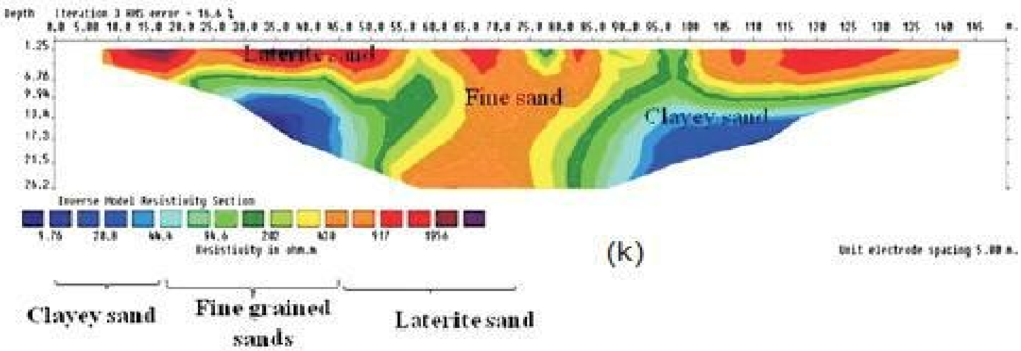

Fig.4.1k: Subsurface image obtained along ERT point 11 (Okoroette, Easten Obolo L. G. A.)

Fig. 13

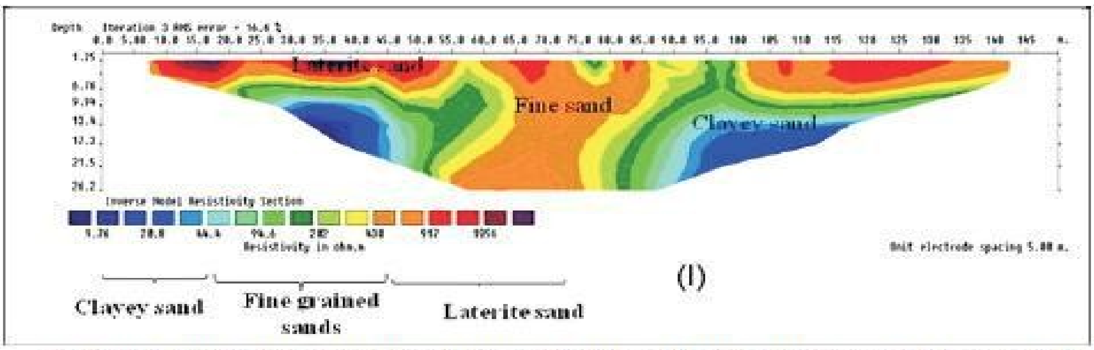

Fig.4.1l: Subsurface image obtained along ERT point 12 (Iko Town, Easten Obolo L. G. A.)

Fig. 14

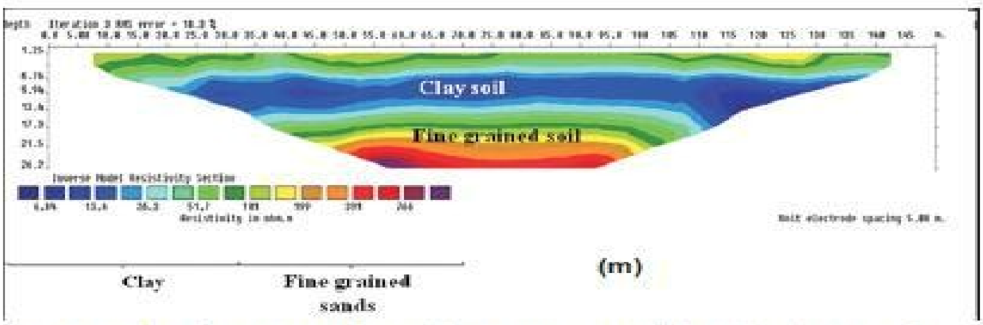

Fig.4.1m: Subsurface image obtained along ERT point 13 (Ikot Ebok, Eket L. G. A)

Fig. 15

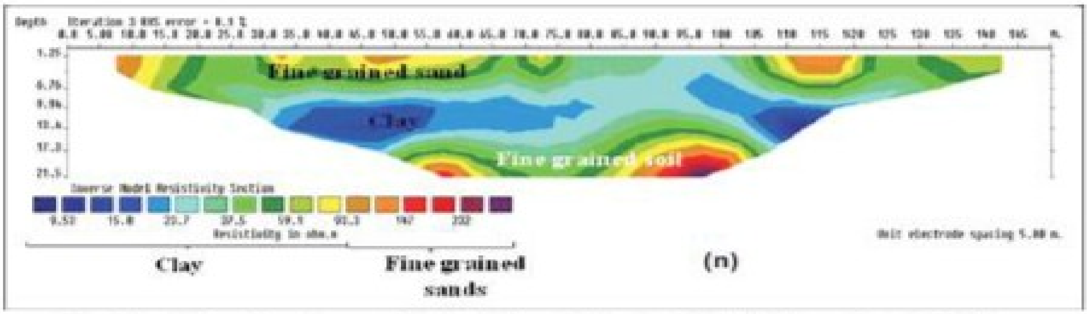

Fig.4.1n: Subsurface image obtained along ERT point 14 (Esit Urua, Eket L. G. A)

Fig. 16

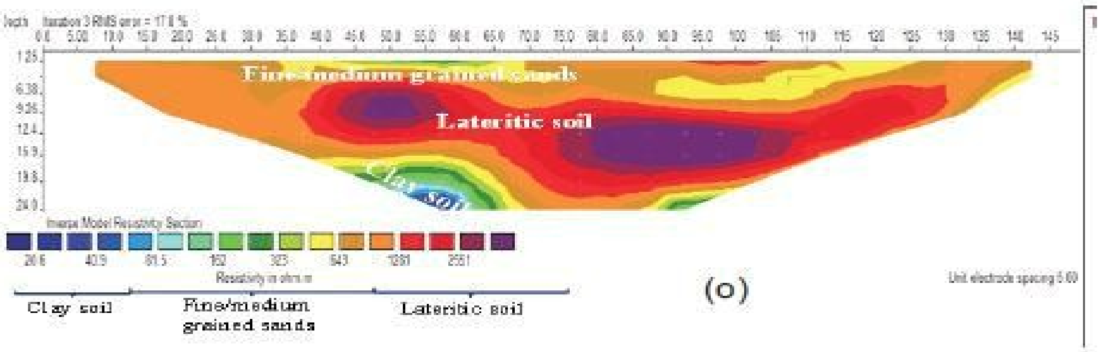

Fig.4.1o: Subsurface image obtained along ERT point 15 (Abighe Asang Uquo, Esit Eket L. G. A.)

Fig. 17

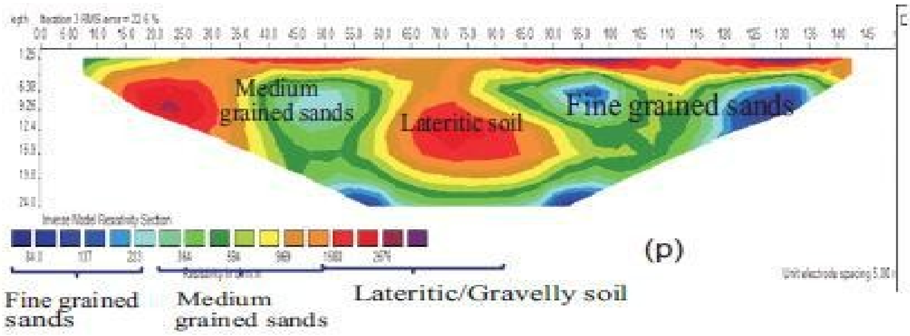

Fig.4.1p: Subsurface image obtained along ERT point 16 (Ikpa, Esit Eket L. G. A.)

Fig. 18

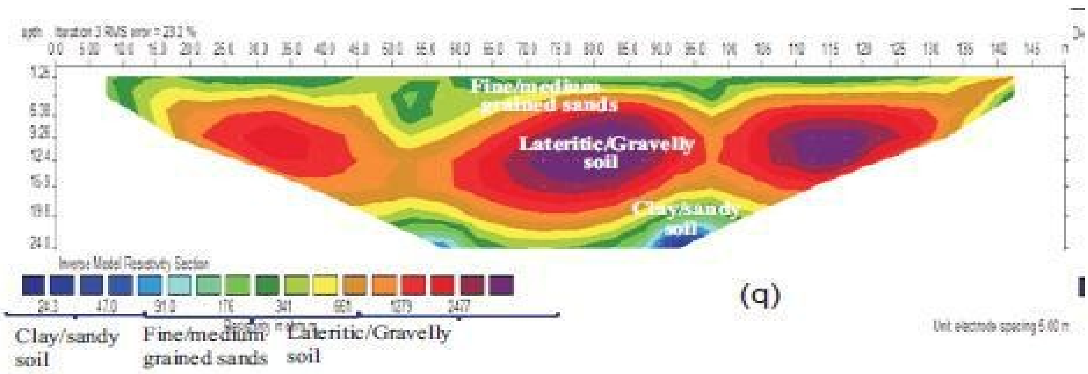

Fig.4.1q: Subsurface image obtained along ERT point 17 (Unyenghe, Mbo L. G. A.)

Fig. 19

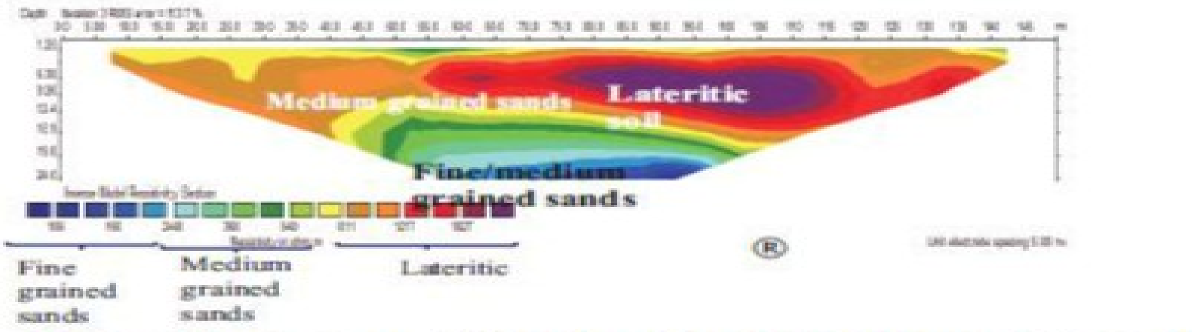

Fig.4.1r : Subsurface image obtained along ERT point 18 (Udung Ejo, Mbo L. G. A.)

Fig. 20

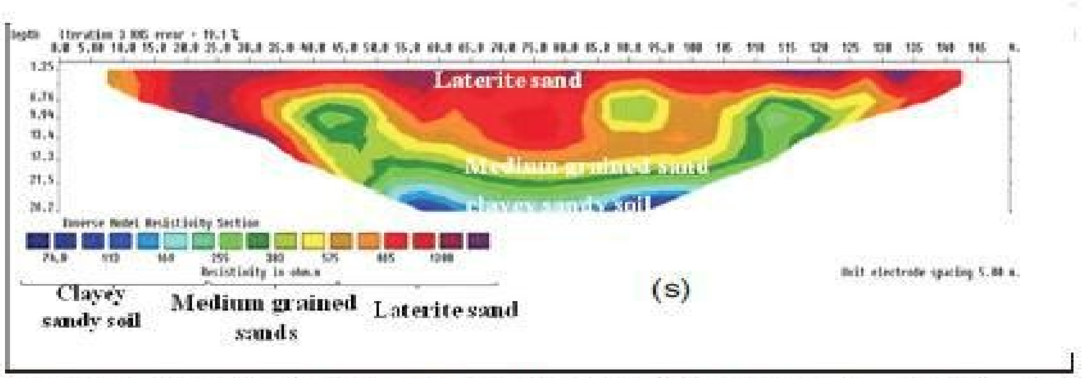

Fig.4.1s: Subsurface image obtained along ERT point 19 (Ibeno beach, Ibeno L. G. A)

Fig. 21

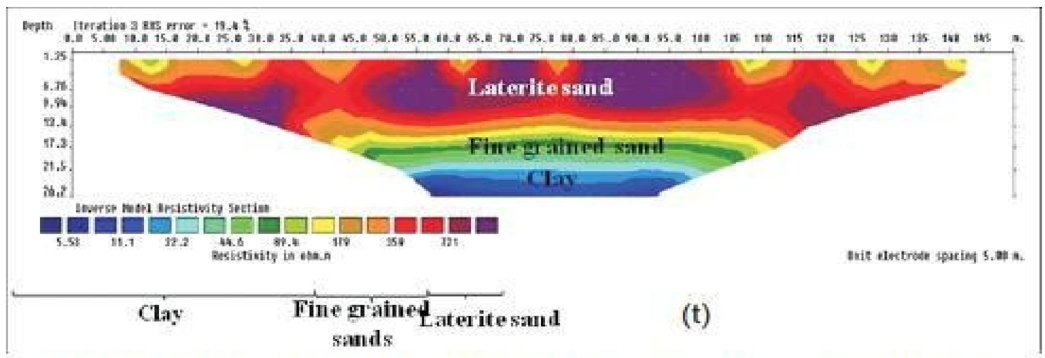

Fig.4.1t: Subsurface image obtained along ERT point 20 (Upenekang, Ibeno L. G. A)

Fig. 22

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