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Investigating Internal Geometry of a Flood plain in Basement Complex Terrain of South-western Nigeria using Electrical Resistance Tomography

M. A. Adabanija[*] and M. A. Oladunjoye[#]

[*]Department of Earth Sciences, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.
[#]Department of Geology, University of Ibadan, Ibadan, Nigeria.

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Abstract

The subsurface internal geometry of Odo Oba river flood plain located southwest of Ogbomoso southwestern Nigeria was investigated employing Electrical Resistivity Ground Imaging (ERGI) technique using Wenner array. The depth profile of the plain was obtained using Schlumberger array while seven pits were dug along the profiles to ground truth the interpreted results. Interpretation of the inverted apparent resistivity sections indicated a more resistive material (dry sand bodies) with resistivity ranging between 500 Ωm and 2000 Ωm abounds in the study area. Low resistivity (<100 Ωm) observed on some of the profiles is an indication of clay material sandwiched between the sand bodies. The lithology profiles obtained from the pits indicated three distinct layers comprising fine sand, coarse sand and clay. In most cases, the clay is sandwiched between sand bodies within the flood plain. The result of the VES showed a system of three geoelectric layers. This has been interpreted as topsoil, clay and weathered basement. The strong correlation between the lithology profile obtained from the pits, and interpreted results of the inverted apparent resistivity section has demonstrated the efficacy of electrical resistance tomography as a remarkable geophysical tool for detecting and delineating resistive bodies buried in conductive sediments.

Keywords: *electrical resistivity tomography, sediments, flood plain, basement complex terrain, Nigeria.*

1. Introduction

The significance of mapping the lithology and geometry of sand and gravel, channels- and valley-fills cannot be over-emphasized. This is based on their economic importance as reservoirs for groundwater and hydrocarbons; as sources of economic placer deposits such as gold, diamonds and tin; use as construction aggregates; and as modern analogues of ancient deposits. These are accomplished using either boreholes technique or ground-penetrating radar (GPR) method. Whilst the application of boreholes approach can be attributed to its ability to reveal accurate representation of vertical facies change through extensive coring; GPR can be used to obtain vertical and horizontal sedimentological information about the shallow subsurface rapidly. However, the boreholes technique is inhibited by poor cross holes stratigraphic connection Baines et al. [1]. It is also expensive and time consuming. On the other hand, GPR is hindered by its limited application to "clean" sand and gravel exposed at the surface as well as its inability to detect channel - or valley-fills beneath even very thin layers of silt and clay because of its high attenuation effect [2]. It is therefore imperative that an alternative procedure capable of circumventing all or most of the limitations above and applicable under a wide variety of conditions is devised. This led to the emergence of Electrical Resistivity Ground Imaging (ERGI), a form of geoelectrical imaging technique and an evolution of direct current electrical prospecting method.

Electrical Resistance Tomography (ERT) is a method that calculates the subsurface distribution of electrical resistivity from a large number of resistance measurements made from electrodes Daily et al., [3]. It is a relatively new imaging tool whose concept was first described by Jeff Lytle and Kriz Dines in 1980 [3] as a marriage of conventional electrical probing introduced by Comrad and Marques Schlumberger in 1930 [4] and the new data inversion methods of tomography. The early application of geophysical ERT was the imaging of laboratory core samples under test. The practical field scale use of ERT was delayed until Daily William and Ramirez Alberado [3] constructed the first system for practical application in 1989 at Lawrence Livermore National laboratory USA.

ERT requires the same four electrodes resistance measurements used by the Schlumberger brothers Stefanesco *et al.*[4]. However, tomography requires the use of tens or hundreds of electrodes and the corresponding hundreds or thousands of such measurements. Hence, the initial field application of ERT was tedious. However, with the development of high-speed automated system, robust inversion routines and suitable data acquisition systems, ERT becomes applicable to a wide range of environmental and engineering problems. Though it is an offshoot of direct current (d.c) resistivity technique, the data interpretation does not require the use of curve matching technique [5,6,7]. Instead, it uses two-dimensional finite difference inversion technique to produce 2-dimensional models of ERGI profile [8,9,10].

ERT applications are not constrained to near-surface investigations, it can be used for characterization of oil reservoirs Daily et al., [3,11] employing a modified form of ERT known as Long Electrode Electrical Resistance Tomography (LEERT). Other applications include monitoring of vadose zone water movement Daily et al.,[12]; monitoring of steam injection and air sparging Ramirez et al., [13]; tank leak detection and leakage plume imaging [14,3]; and monitoring of carbon dioxide (CO_2) floods in secondary recovery of hydrocarbon Ramirez et al., [15]. Due to the sensitivity of resistivity to porosity, pore connectivity, amount and ionic strength of pore fluids, ERT can be used to complement seismic velocity measurement [3]. These wider applications and good attributes earlier enunciated put ERT in a vantage stead for wider applications in geohydrology and environmental studies [16]. Hence in this study, it has been used to investigate the subsurface internal geometry of Odo Oba river flood plain.

Oba is one of the major rivers that drains southwards and runs 5km west of Ogbomoso with many adjoining streams and rivulets. It is located between longitude 4^o 8.553'E and 4^o 8.627'E and latitude 8^o 2.776' N and 8^o 2.975'N southwest of Ogbomoso metropolis, southwestern Nigeria (Figure 1).

Over the years most of the materials being carried by the river several kilometers are deposited around Oba village along Oyo-Ogbomoso road probably because of the relatively planar surface of the area. This has resulted to alluvial plain (quarternary sediments) which are likely to be made up of different materials. Cultivation of vegetables during the dry season is prominent on the flood plain. Elevation measurement with eTrex Legend GPS within the area is about 267m above mean sea level. The dendrite pattern is observed to be the dominant drainage pattern in the area.

The climate of Ogbomoso is characterized by a fairly high uniform temperature, moderate to heavy seasonal rainfall of March-July resulting to mean annual rainfall of 1,247mm. The relative humidity is high in the early mornings throughout the year with a marked decrease in the afternoons. The highest relative humidity occurs from July through September and the lowest from December to February. During the dry season, the tropical continental air mass (harmattan winds) which picks up little or no moisture and therefore very dry blows across the region. It is also influenced by the tropical air mass during the wet season. The natural vegetation is of derived savannah type between rain forests of Ibadan geographical region and the northern savannah zone [17]. Geologically, Ogbomoso is regionally concealed within the southwestern Nigeria basement complex comprising rock units comprise ancient gneiss-migmatite series e.g gneiss; meta-sedimentary series namely quartzite and quartz-schists; and older granites [18,19]. The gneisses are the most dorminant rock type and occur mainly as granite gneiss and banded gneiss with medium to coarse-grained textures and no definite foliation pattern. They contain biotite, hornblende, quartz, plagioclase, microcline and rarely pyroxene Afolabi et al., [20]. Locally, Odo-Oba is underlain by banded gneiss and quartzite (Figure 2) with pegmatite as minor rock. The weathered profiles developed over the basement rocks is relatively shallow and corroborated by shallow hand-dug wells (depth less than 5m) resting directly on the basement rocks within the vicinity of the survey area.

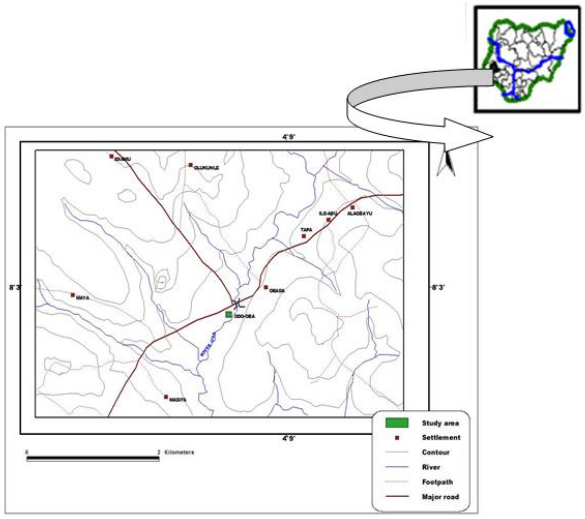


Figure 1: Location map of the study area

2. Materials and Method

Like its direct current resistivity contemporary, it involves the introduction of electric current into the ground via two current electrodes (one acts as the source and the other as sink) and measuring the voltage drop ΔV across the ground surface between two potential electrodes from which the apparent resistivity can be calculated. These measurements could therefore provide information about the electrical properties of materials in the subsurface and can be carried out using Wenner, Schlumberger and double-dipole array. The field procedure employed in this study involves the use of Wenner electrode configuration with electrode spacing "a" of 1m for the first level. The electrodes were moved in a successive manner until the entire traverse line which length varies from 65 to 85m was occupied. The spacing was increased to 2m, 3m, 4m, 5m and 6m and the same procedure was repeated to obtain apparent resistivity values for the second, third, fourth, fifth and sixth levels respectively. The apparent resistivity values (ρ_a) were obtained at each sampling point by inserting the resistance values R measured in the field into equation

$$\rho_a = 2\pi aR \quad (1)$$

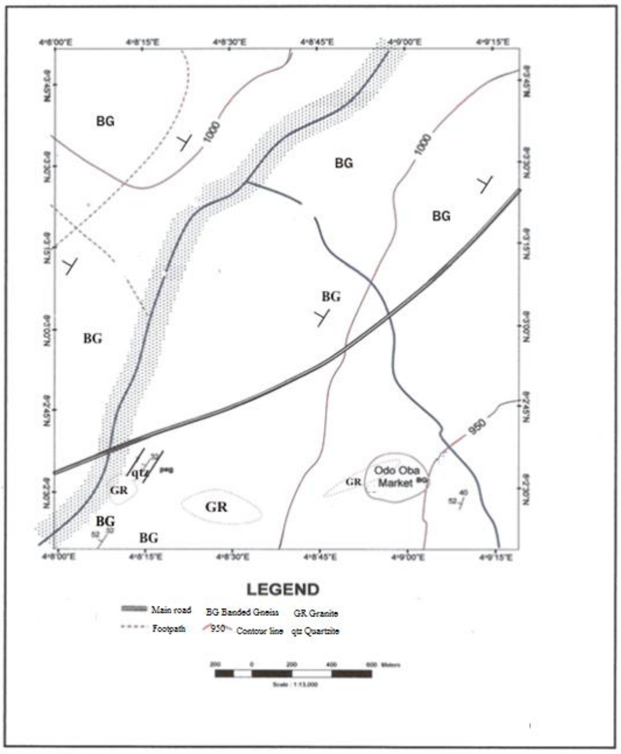


Figure 2: Geologic map of Odo Oba, Southwestern Nigeria.

The survey was carried out along three profiles, one in east-west azimuth and the remaining two in a north-south (Figure 3). The Geopulse Tigre Resistivity meter was used for resistance measurement. Good quality data were measured with the observational errors less than 2% in most cases. The computed apparent resistivity values were used to construct 2D electrical resistivity pseudo section using RES2DINV software by Loke and Barker [10]. Vertical electric sounding (VES) was also carried out using Schlumberger electrodes configuration with a maximum half current electrode (AB/2) of 56m at sampling points having the lowest apparent resistivity on Wenner apparent resistivity profiles. The apparent resistivity values (ρ_a) were then computed at each sampling point by inserting the resistance values R measured in the field into equation

$$\rho_a = KR \quad (2)$$

where K is the geometric factor and dependent of the distances between the adjacent electrodes.

The apparent resistivity values were then plotted against half the current electrodes spacing (AB/2) on bi-logarithmic coordinates. A preliminary interpretation was carried out using partial curve matching involving two-layer master curves and the appropriate auxiliary charts. The layered model thus obtained served as input for an inversion algorithm by Loke and Barker [10] as a final stage in the quantitative data interpretation. Computer iteration was done by the use of the WinRest software and was used to correct manual errors in the geoelectric parameters from the result of partial curve matching. Seven pits were dug along the profiles, three on the profile along east-west azimuth and two each on two profiles along north-south (Figure 3) to ground truth the interpreted results.

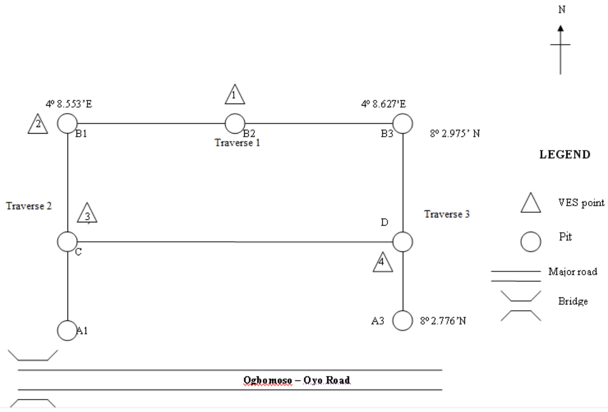


Figure 3: Outlines of profiles, pits and Vertical Electrical Sounding points in the study area.

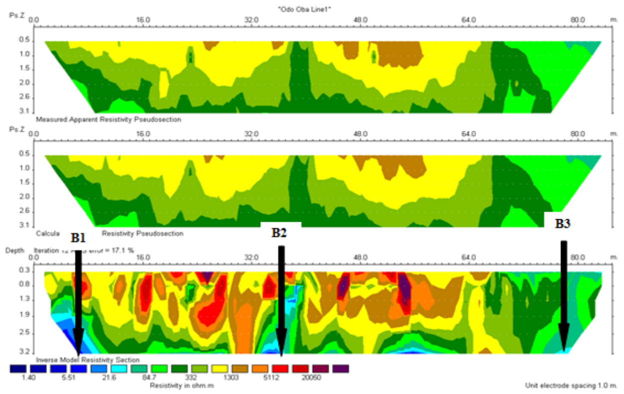
3. Results and Analysis

The subsurface geometry of the flood plain is as shown by the inverted sections in Figure 4a, Figure 5a and Figure 6a; while the corresponding soil profiles obtained from the dug pits are as depicted in Figure 4b, Figure 5b and Figure 5c. Variations in the modeled resistivity values represent different lithologies whilst zones of similar resistivity values represent geometries of homogeneous deposits. Generally, the layering consists of dry sand, a more resistive material with resistivity which ranges between 500 and 2000 Ωm, grading into clayey sand as resistivity values decrease and eventually becomes clayey at low resistivity values. This submission is based on Baines et al [1] that under any set of moisture conditions; gravel always has a higher resistivity than sand, sand has a higher resistivity than silt and silt has a higher resistivity than clay, that is $\rho_{gravel} > \rho_{sand} > \rho_{silt} > \rho_{clay}$. However, for brevity and purposeful interpretations, the inverted section obtained for each profile has been discussed separately and compared with lithological horizon obtained from the pits dug along each traverse. This is followed by the interpretation of the resistivity curves.

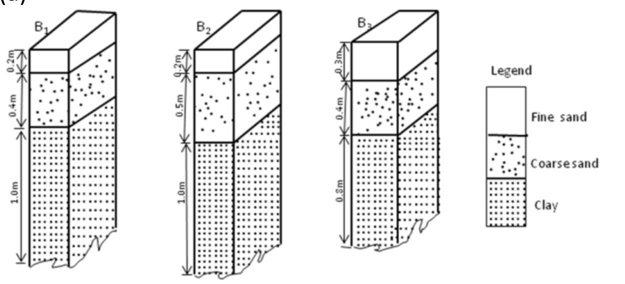
3.1 Electrical Resistivity Tomography

Traverse 1(E-W)

The inverted section for this profile is as shown in Figure 4a. It indicates the presence of sand-filled channels having high resistivity (>332 Ωm) with intervening dyke-like clayey sand at estimated horizontal distance between 36 m and 40 m. The sand-filled channel has an interpreted width of about 66 m, shallowest on top of the intervening clayey sand at a depth of about 0.8m and deeper elsewhere (>1.9m). The resistivity decreases downward away from the channel indicating decrease in sand content and increase in clay. This was supported by the lithological horizon of pits B1, B2 and B3 (Figure 4b) revealing fine sand (0.2m to 0.3m thick), coarse sand (0.4m to 0.5m thick) and clay (0.8m to 1.0m thick) respectively. This indicates a remarkable correspondence between the inverted section and the interpreted lithological horizon of the pits.



(a)

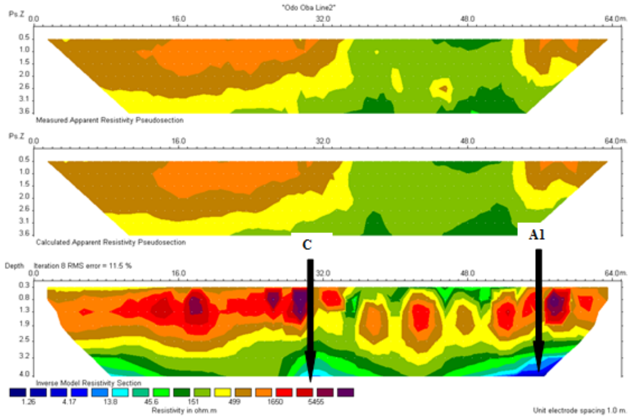


(b)

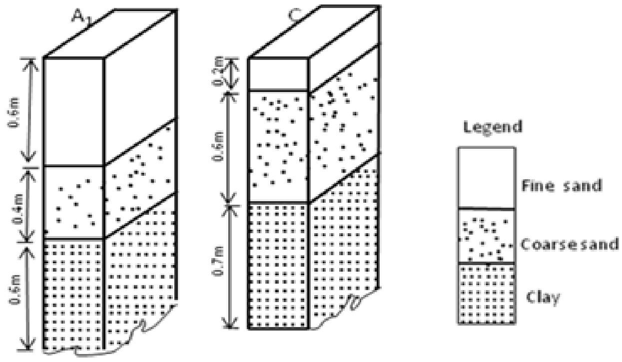
Figure 4: (a.) Field data pseudosection, theoretical pseudosection and ERT of Traverse 1; (b) Soil Profile in pits B_1, B_2 and B_3 on Traverse 1, Odo-Oba Flood plain, South-western Nigeria

Traverse 2 (N-S)

Traverse 2 is one of the north-south profiles located on the western portion of the flood plain (Figure 3). The inverted section shown in Figure 5a depicts the presence of a channel-fill at the northern end of the profile. It is approximately about 35 m wide and flanked by pockets of sand bodies at the southern end of the profile. The lithological horizon of pits A1 and C (Figure 5b) indicates clay (pit C), fine sand (pit A1) in the first horizon whose thickness varied between 0.2 m and 0.6 m; coarse sand, 0.4m - 0.6 m thick for the second horizon; and clay as the third horizon. These results corroborate the geometry of sand bodies observed on the inverted section thereby corroborating information obtained from lithological horizon of the pits.



(a)



(b)

Figure 5: Field data pseudosection, theoretical pseudosection and ERT of Traverse 2; (b) Soil profile in pits C and A_1, on Traverse 2, Odo-Oba Flood plain, South-western Nigeria

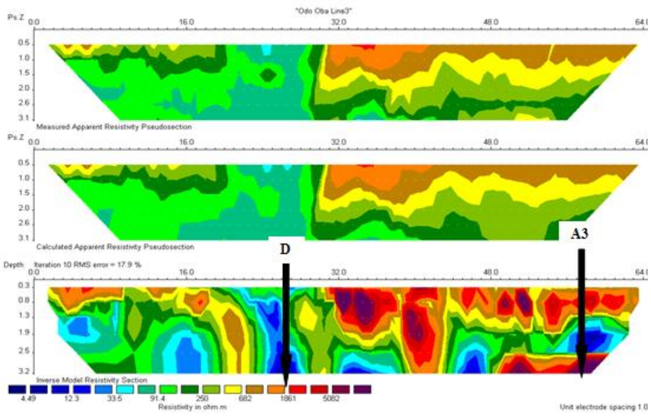
Traverse 3(N-S)

The inverted section of this profile located on the eastern portion of the flood plain is as shown in Figure 6a. The central portion of the section between 32 m and 42 m of the profile comprises of dry sand of about 10 m wide and 2.2 m thick; and clay of lateral extent of about 10 m at horizontal distance of 20-30 m along the profile. The clay covers entire depth of 6 m at this location but occupies only 1.6m - 6.0 m depth (4.4 m thick) around the northern end of the profile. Towards the southern end of the profile of the section, there was a more gradational pattern in the horizon of the materials as exemplified by increase in resistivity values in a SE-NW direction with a pinch out of dry sand at lateral distance between 30 m and 40 m. The basal portion of the section consists of alternating band of sand and clay The lithological horizon (Figure 6b) of pits A3 and D dug along the traverse, depicts three horizon comprising fine sand (0.3m – 0.6m thick), coarse sand (0.3m – 0.4m thick) and 0.8 m thick clay. This corresponds with the result of interpretation of the inverted section as the basal portion is predominantly clayey because the resistivity value is less than 100 Ωm

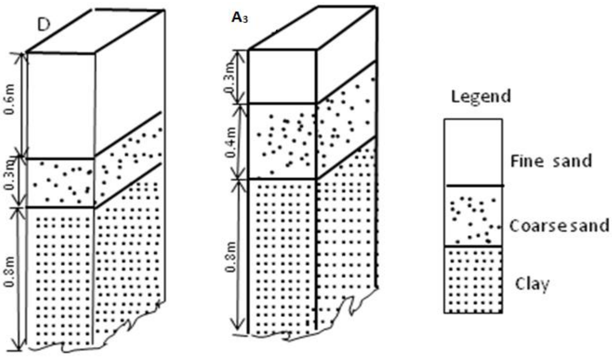
Table 1 Layering Parameters and lithology characteristics of the apparent resistivity curves obtained from Odo Oba Flood plain, South-western Nigeria

VES	Layer	Resistivity (Ωm)	Apparent Resistivity Curve type	K^*	Thickness (m)	Depth to Interface (m)	Lithology
1	1	1200	QH-type	0.81	1.1	-	Top soil
	2	960			1.5	1.1	Sand
	3	67			11.6	2.6	Sandy clay
	4	672			-	14.2	Fractured Basement
2	1	620	KH-type	0.67	0.75	-	Top soil
	2	2170			2.00	0.75	Sand
	3	109			21	2.75	Clayey sand
	4	543			-	23.75	Fractured Basement
3	1	1450	H- type	0.67	2.4	-	Top soil
	2	145			12.6	2.4	Clayey sand
	3	725			-	15.0	Fractured Basement
4	1	180	KH-type	0.88	0.9	-	Top soil
	2	450			1.6	0.9	Sand
	3	180			8.5	2.5	Clayey sand
	4	2700			-	11.0	Fractured Basement

and graduated upward into sand as resistivity values increase.



(a)



(b)

Figure 6: Field data pseudosection, theoretical pseudosection and ERT of Traverse 3; (c.) Soil profile in pits D and A_3, on Traverse 3, Odo-Oba Flood plain, South-western Nigeria

3.2 Apparent Resistivity Curves Interpretation

The apparent resistivity curves obtained from Odo Oba river flood plain are as shown in Figure 7 while the results of interpretation of the curves are as depicted on Table 1.

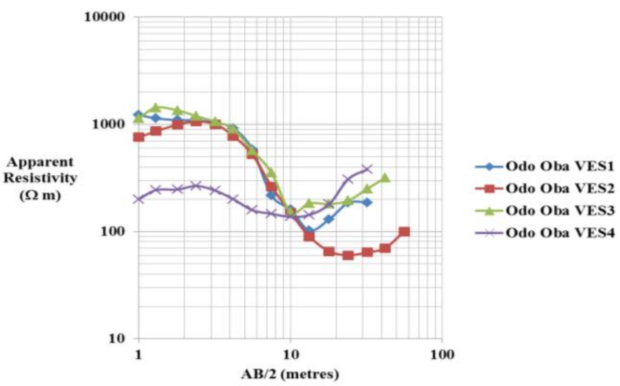


Figure 7: Apparent Resistivity curves obtained from Odo-Oba Flood plain, South-western Nigeria

The apparent resistivity curves were of QH-type, *resistive-resistive-conductive-resistive* (25%); H-type, *resistive-conductive-resistive* (25%) and KH-type, *conductive-resistive-conductive-resistive* (50%) with 4-layers earth model (QH- and KH-type) constituting 75% of the total curve (Figure 8).

QH-type Apparent Resistivity Curve (Odo Oba VES1)

The apparent resistivity curve obtained at Odo Oba VES1 from VES conducted along traverse 1 (Figure 3) is as shown in Figure 7. The results of interpretation indicated the layer parameters consist of reworked top soil, resistive sand, conductive sandy clay and fractured basement with overburden of about 14.2m (Table 1)

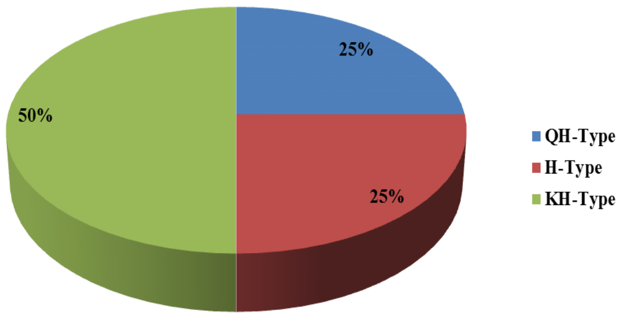


Figure 8: Pie chart distribution of apparent resistivity curves obtained from Odo-Oba Flood plain, South-western Nigeria

$$\text{Reflection Coefficient, } K = \frac{\rho_n - \rho_{n-1}}{\rho_n + \rho_{n-1}}$$

where ρ_n is the resistivity of last layer-n; and ρ_{n-1} is the resistivity of the penultimate layer.

H-type Apparent Resistivity Curve (Odo Oba VES3)

The results of interpretation (Table 1) of H-type apparent resistivity curve (Figure 4) obtained at Odo Oba VES3 location indicated 3-layers earth model comprising 2.4m thick resistive top soil, probably dry or reworked due to its high value 1450 Ωm; 12.6m thick intermediate conductive layer which is probably weathered comprising clayey sand; and fractured basement. The overburden is about 15m thick.

KH-type Apparent Resistivity Curve (Odo Oba VES2 & Odo Oba VES4)

The geoelectric succession comprises 0.75 – 0.90m thick topsoil which resistivity ranged between 180 and 620 Ωm; 1.6 – 2.0m thick resistive sand having resistivity values ranging from 450 to 2170 Ωm; 8.5 – 21.0m thick clayey sand; and fractured basement which resistivity and reflection coefficient varied from 543 Ωm to 2700 Ωm and 0.67 to 0.88 respectively.

Conclusion

The internal geometry of Odo Oba river flood plain located in Ogbomoso, a crystalline basement complex in southwestern Nigeria has been investigated. The study vindicated the efficacy of electrical resistance tomography as a remarkable geophysical tool for detecting and delineating resistive bodies buried in conductive sediments. The interpreted results of inverted apparent resistivity section indicated the presence of sand-filled channels having resistivity anomaly ranging between 600 Ωm and 900 Ωm. Pocket of sand lens and clay sandwiched between sand bodies were also detected and delineated. The soil horizon of the pits on the flood plain depicted three horizons comprising fine sand, coarse sand and clay which corroborates the geometry interpreted from the inverted apparent resistivity section.

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