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Integrating Resistivity Techniques for Optimum Groundwater Exploration and Development within a Hotel Facility in Osogbo, Southwestern Nigeria

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ABSTRACT: This work is an attempt to combine dipole-dipole profiling and vertical electrical sounding techniques of electrical resistivity methods to investigate the groundwater potential within the premises of a 3-star hotel facility in Osogbo, Nigeria by delineating the geoelectric layers, delineating the low resistivity layers, determining the lithologies and hence, delineating the groundwater bearing zones. The five vertical electrical sounding data were collected along two pre-surveyed dipole-dipole traverses at right angle to each other beside the fences of the premises using the ABEM SAS 300c terrameter. The observed data were interpreted quantitatively using curve matching and computer-assisted iteration method using the WinResist and Dipro software. The results of the inversion show that the lithology comprises of the top soil and an intermittent sequence of sand and lateritic clay having varying resistivity and thickness. The aquiferous layer was observed to be located at a depth of 23 m to 25 m due to the low resistivity and high thickness of the aquiferous layer. The result of the 2-D imaging closely correlates with the result of the vertical electrical sounding. Thus, combining these techniques in groundwater investigation has achieved similar result as the Werner technique and has reduced ambiguity and error in positioning for drilling.

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The use of groundwater in virtually all sectors of human endeavor cannot be over-emphasized. Hotel and tourism industry are not left alone in this quest for groundwater resources. Hotel and resorts centers in recent times constitute large users of water (Tang 2012, Bohdanowicz, 2005). The World Travel and Tourism Council (WTTC) in 2013 noted that the travel and tourism industry has outperformed the global economy; growing faster than manufacturing, retail, financial services and communications. This is due to increasing number of hotels, motels and guest houses constructed to meet the need of tourists worldwide. Hotels and guest houses possess a number of facilities and provide a variety of functions that requires the use of large amount of water. They are normally operated 24 hours a day throughout the year (Deng & Burnett, 2002). Therefore, a considerable amount of water is required for daily operation in its various functional areas such as laundry, kitchens and guestrooms, restaurants, public areas, swimming pools to name a few. The composition of a hotel's water consumption in Germany, for instance, can be presented as 34% guest rooms, 22% kitchen, 20% public bathrooms, 17% laundry, 1% heating, ventilating and air conditioning, 4% steam generation and 2% for swimming pool (ITP, 2008; Silva-Afonso & Pimentel-Rodrigues, 2011). A tourist's water consumption is higher than a resident's water consumption (Styles *et al.* 2013). A European tourist consumes around 300 litres of water per day compared with a European resident consumption of 100-200 litres per day, averaging approximately 150 litres (Gössling *et al.* 2011). The average medium to large hotel uses 79,000 litres per day or 301 litres per room, which is the equivalent of using 29 Olympic pools of water each year (Smart Water Fund, 2007). In the Philippine hotels, water consumption is about 1,800.252 litres per day and this amount of water can support fourteen people at their current standard of living (Kim, 2005). Further, sustainability is increasingly becoming one of the most relevant issues to hoteliers in the 21st century as costs continue to rise, demand becomes

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increasingly sensitive and the pressure on being economically, socially and environmentally responsible grows (Bader, 2005). Therefore, conserving water should be an important priority for hotels. Apart from the environmental and social benefits, improved water use and direct water saving can also make a noticeable difference to a hotel's bottom line (Deng & Burnett, 2002).

Most times, most workers combine the Werner array profiling survey with the vertical electrical sounding technique in groundwater investigation and end up sounding points of low resistivity on the Werner profiles. This research desire to combine other resistivity technique in the place of the Werner technique. The aim of carrying out this research is to investigate if any other method would achieve similar result as the Werner approach in locating appropriate areas within the premises of the 3-star hotel that would yield groundwater in economic quantity for consumption of local and international tourists that would use the facility.

MATERIALS AND METHOD

Location of The Study Area: The study area is located within the premises of a 3-star hotel facility at Owode-Ilesha at the suburb of Osogbo township along Ilesha-Osogbo road. (Figure 1). Osogbo is a state capital of Osun State and possesses a population density of about 500 people/square meter (Adegoke and Sojobi (2015). It is bordered by the following coordinates: N07.738316, E004.586367/N07.737903, E004.586726 and between N07.738320, E004.587068/N07.738680, E004.586829. Geologically, the study area is underlain by the Pre-Cambrian basement complex rock of the western Nigeria schist belt which lies within the Pan-African mobile belt, east of the West African craton. The belt is believed to be divided into the frontal region and the internal region and Nigeria is located in the internal region which was affected by deformation and thermal reactivation during the Pan African Orogeny[13]. The Nigerian basement rocks are thought to result from at least four major orogenic cycles of deformation, metamorphism and remobilization, corresponding to the Liberian (2,700 ± 200 Ma), the Eburnean (2,000 ± 200 Ma), the Kibaran (1,100 ± 200 Ma) and the Pan-African (600 ± 150 Ma) orogenies (Ajibade *et al.* 1987). Local geology is typical of the geology of Ilesha schist belt which is composed primarily of banded gneiss to the south eastern part and schist to the western part. The climate of the study area also is typical of the climate of the western part of Nigeria, a tropical climate with a tropical rain forest (Akpootu and Rabiu, 2019). The climate has more wet season months that run from April to October every year than the dry season months which run from November to March each year. The climate around the study area has been classified as Aw (tropical wet and dry or savanna) according to the Köppen-Geiger climate classification, an indication of a tropical wet and dry or savanna having an extended dry season where precipitation during the wet season is usually less than 1000 millimeters, and only during the summer season. Average annual temperature in in the study area is about 27 °C while the average annual rainfall is about 1300 mm. On a yearly basis, every January records the least amount of rainfall although precipitation peaks every September with an average of 222 mm. On the average, the highest temperature is about 33°C around March while the coldest month is about 21 °C on average around August every year. The study area is drained by an offshoot of a bigger River Osun which runs along the eastern part of the study area in North-East- South-West direction. The river separates between Osun-Jela village from Osogbo metropolis. Smaller rivers as well as drainages from local culverts all empty their contents into the river.

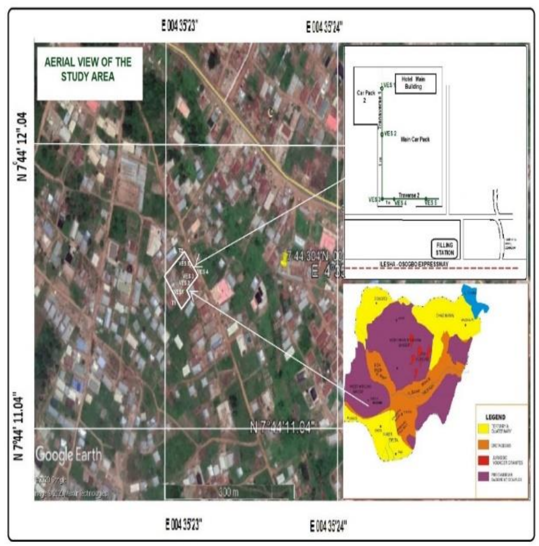

Fig 1: Modified Location Map of the Study Area showing the VES Positions (modified after Opara *et al.* 2015)

The investigation involved the use of the ABEM SAS 300c resistivity equipment with associated accessories including the Garmin Global Positioning System (GPS) which was employed to record the geographic coordinates of each VES positions. Total length of transverse 1 and 2 were 110 m and 70 m respectively. The investigation employed the 2-D imaging techniques and the vertical electrical sounding techniques, both of electrical resistivity method. An L-shaped traverse was established within the study area such that it runs 1-meter away from the fence but within the hotel premises. One dipole-dipole survey each was carried out along traverse 1 and traverse 2, because it gives good information of the subsurface in both vertical and horizontal directions (Ward, 1990). During the dipole-dipole survey, direct current was injected into the subsurface with current dipole (C1 and C2) and resulting ground voltage measured with the potential dipole (P1 and P2). Increase in separation between the dipoles (C1–C2 and P1–P2) results to increase in depth of investigation (Anudu *et al.* 2012). The inter-electrode spacing (a) = 10 m was employed, whereas the expansion factor (n) was varied from 1 to 5. The apparent resistivity values obtained were plotted on a depth section along intersecting 45° beneath the centre of the dipoles. The apparent resistivity (ρ_a) in ohm meters at each dipole separation (Barker, 2007, Seidel and Lange, 2007) was calculated using equation given by

$$\rho_a = \pi a n(n+1)(n+2)R \qquad (1)$$

where a is inter-electrode spacing, n is expansion factor and R is resistance which is voltage (V) divide by current (I). Points 1, 2, 3, 4, and 5 of resistivity lows were selected on each dipole-dipole traverse (profiles) and these points served as points for carrying out the vertical electrical soundings (VES) survey. The sounding surveys were carried out over a maximum electrode spacing of 210 metres along traverse 1 and 140 metres in traverse 2. Points of VES 1, VES 2, VES 3 were all selected along the first traverse while the points VES 4 and VES 5 were selected along the second traverse situated perpendicular to the first traverse (Figure 1). The VES sounding data acquired were subjected to analysis and iterative modeling to identify the layer resistivity and layer thickness (both known as geoelectric parameters) of each layer and lithology inferred from these parameters were used to delineate the aquiferous layer using the Excel spread sheet and WinResist software.

RESULTS AND CONCLUSIONS

Results of interpreted resistivity data for the investigation are presented as curves, tables, geoelectric sections and 2-D resistivity profile image. The curve types obtained from the interpreted VES data are 5-layer with QHA (VES 1), KHAA (VES 2), QQH (VES 3), KHA (VES 4) and KQH (VES 5). This is as shown in Figures 2 to 5. Computer interpretation of the observed curve resolved the penetrated layers beneath each VES into five (5) in all the VESes except in VES 2 where it was resolved into six (6) geoelectric layers (Figure 3). Table 1 represent the summary of the results obtained from the analysis and interpretation of the vertical electrical sounding data. Figure 6 represent the geo-electric sections obtained from the results in Table 1. However, figures 7 and 8 shows the 2-D inversion image of the subsurface correlated with the geo-section column along the profile.

Table 1: Summary Table of all Interpreted VES data

VES No	Geoelectric Layer	Resistivity (Ωm)	Thickness (m)	Depth (m)	Lithology
VES 1	1	563.8	1.1	1.1	Topsoil (lateritic)
	2	250.3	12.1	13.2	Sandy layer
	3	209.8	9.8	23.0	Weathered layer
	4	379.8	14.5	37.5	Fractured Basement
	5	897.6	-	-	Fresh Basement
VES 2	1	319.4	1.7	1.7	Topsoil
	2	642.3	1.4	3.1	Lateritic layer
	3	159.3	14.9	18.0	Weathered layer
	4	416.5	11.7	29.7	Fractured Basement
	5	621.1	19.0	48.7	Basement Rock
	6	1258.8	-	-	Fresh Basement Rock
VES 3	1	308.5	1.1	1.1	Topsoil (lateritic)
	2	257.9	4.5	5.6	Sandy layer
	3	191.8	5.5	11.2	Weathered layer
	4	144.7	12.7	23.8	Fractured Basement
	5	572.2	-	-	Basement Rock
VES 4	1	311.5	0.5	0.5	Topsoil
	2	2148.7	1.6	2.1	Lateritic hardpan
	3	168.0	4.6	6.7	Weathered Basement
	4	79.6	12.2	18.9	Fractured Basement
	5	2397.5	-	-	Fresh Basement
VES 5	1	250.3	1.0	1.0	Topsoil (lateritic)
	2	1631.7	2.4	3.4	Lateritic hardpan
	3	267.0	2.7	6.0	Weathered Basement
	4	90.4	10.5	16.5	Fractured Basement
	5	932.7	-	-	Fresh Basement Rock

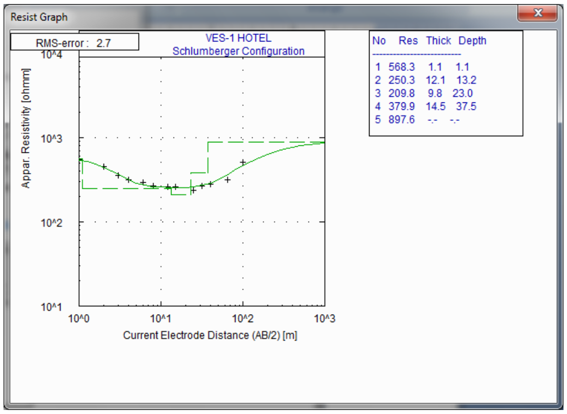

Fig 2. Iterative Curve in VES 1

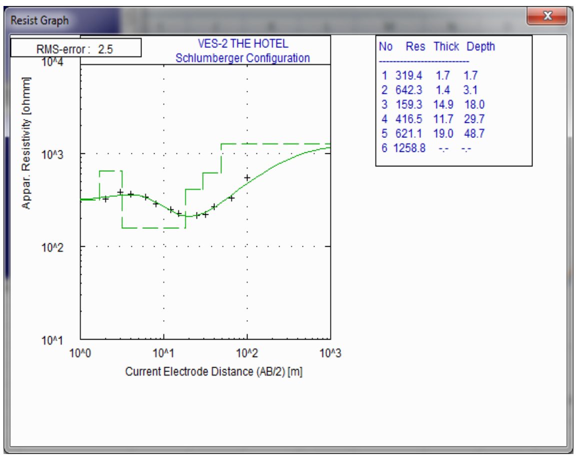

Fig 3: Iterative Curve in VES 2

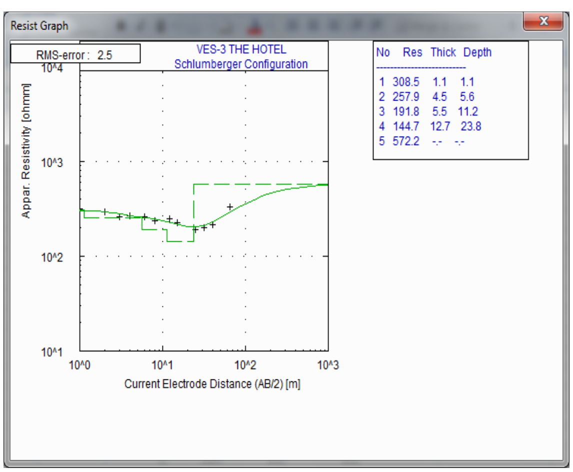

Fig 4: Iterative Curve in VES 3

Geoelectric Section: The geo-electric section generated for the data obtained from VES 1, VES 2, VES 3, VES 4 and VES 5 is as shown in Figure 6. The geoelectric section is represented in 3D showing the orientation of the two traverses perpendicular to each other. The section clearly reveals a relatively thin layer of resistive materials as the topsoil, with resistivity ranging from 308 to 563 Ωm and approximate thickness ranging from 1.1 to 1.7 m.

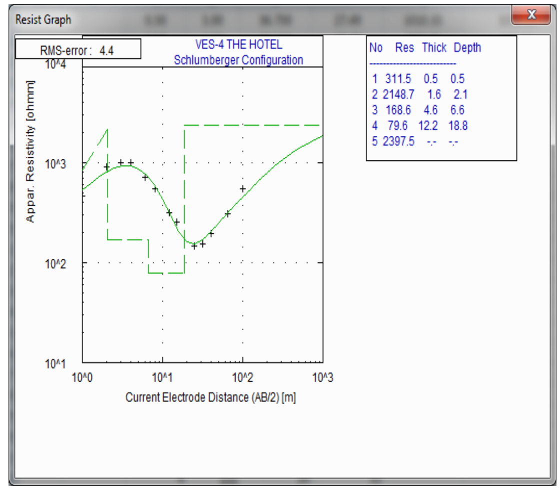

Fig 5: Iterative Curve for VES 4

This highly resistive formation is thought to compose of lateritic formation which dominates and overlie the area. Underlying this unit is a layer exhibiting resistivity variations which ranges from 250 Ωm to 642 Ωm with an increasing thickness from1.4 m at VES 2 to 12.5 m at VES 1, toward the northeastern part of the study area (Figure 1).

It represents the sand clayey sand layer. The third layer seem to have lower resistivity compared to the second geo-electric layer with resistivity value ranging from 151 Ωm at VES 2, 191 Ωm at VES 3 and 209 Ωm at VES 1. This layer is the weathered layer, which has hydrogeological significance with groundwater prospect. Below the weathered unit, fractured basement layer is observed at a depth of 14.5 m in VES 1, 19m in VES 2 and 12.7 m in VES 3 and this layer lies directly above the fresh basement whose thickness is undetermined. On the second traverse as well, the topmost topsoil layer was observed to be relatively thin, with thickness of about 0.5 m in VES 4 to 1.0 m in VES 5.

The aquifer layer along this traverse, as clearly displayed in Figure 5, commences at a depth of 6.7 m to 18.9 m in VES 4 and a depth of 6.0 m to depth of 16.5 m at the top of the fresh basement. Lateritic hardpan of resistivity values of 2148.7 Ωm and 1631.7 Ωm directly overlie the aquiferous layer at VES 4 and VES 5 respectively. Along this traverse, VES 4 position show evidence of groundwater potential. However, due to the fact that the water bearing layer is located at shallow depth, the point can only be suited for construction of hand-dug well rather than a borehole.

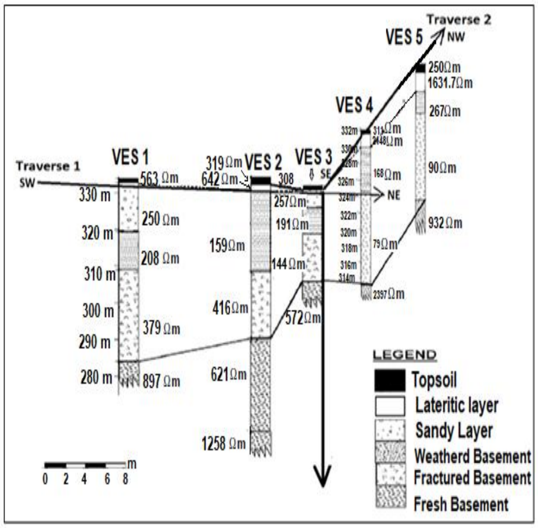

Fig 6: Geoelectric section generated for the data obtained from VES 1, VES 2, VES 3, VES 4 and VS 5.

*Pseudo-Section 1***:** The first traverse was located towards the southern part of the premises but runs in the NE-SW direction within the investigated premises. Pseudo section 1 was obtained by carrying out 2D inversion of dipole-dipole profiles along the traverse 1 (Figure 4). Three VES soundings were carried out along traverse one, out of which two of the VES showed good groundwater potential (portion coloured with deep blue and green). Interpretation of the pseudo-section revealed two groundwater productive areas having resistivity values of as low as 209 Ωm within the weathered layer and 379 Ωm within the fractured basement layer. The two points were observed to be potentially productive at depths of 23 m n VES 1 and 18 m in VES 2. This is as shown in Figure 5 (blue portion of the pseudosection). The aquiferous layer was observed to have been overlain by a relatively high resistivity sandy layer of about 209.8 Ωm in VES 1 and a fairly high resistivity lateritic layer of about 642.3 Ωm in VES 2. (Table 1).
*Pseudo-Section 2***:** The pseudo-section represents the inversion of the dipole-dipole along traverse 2 (Figure 5). The traverse trend in the NW-SE direction and perpendicular to traverse 1. The inverted section (Figure 5) clearly shows a general resistivity variation that ranges from about 65 Ωm to as high as 4183 Ωm. At VES 4, there exist a low resistivity layer at shallow depth (blue colour) having a resistivity of about 168 Ωm at a depth of 6.7 m. (Table 1). This also continues to a depth of 18.9 m where the resistivity drops down to 79.6 Ωm. These two regions constitute the weathered layer which seats conformably on the basement rock in the studied area. The resistivity modeled data lying within these two zones are inferred as the prospect and potential groundwater zone (blue portion on the inverted section Figure 5).

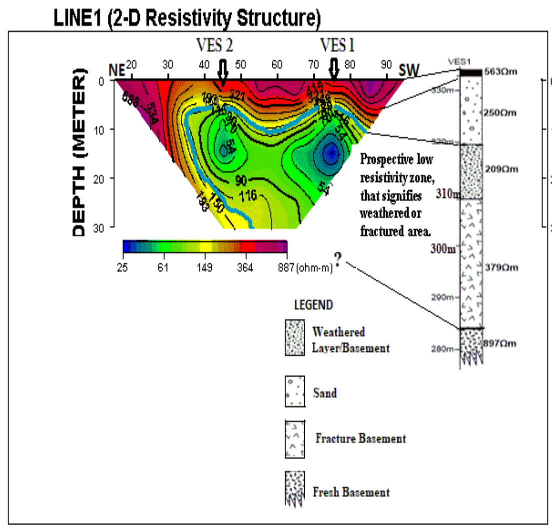

Fig 7: Combined Pseudo-section and Geo-section along Traverse 1

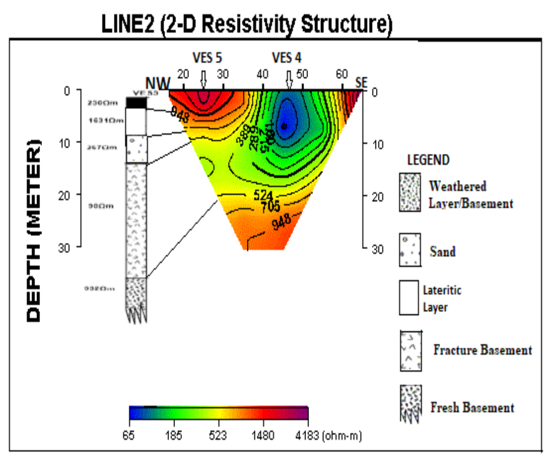

Fig 8: Pseudo section along Traverse 2

Conclusions: Integrated geophysical investigation was carried out within the premises of a 3-star hotel, in Owode-Ilesha in the suburb of Osogbo using the combined VES technique and 2-D imaging techniques of electrical resistivity method with the aim of delineating the depth to groundwater within the hotel facility. The result of the investigation revealed that the water-bearing aquiferous layer is at a depth of 23 m in VES 1 while it is at a depth of 11.2 m in VES 3. The result obtained from the geophysical investigation using the two approaches generally correlate with one another by revealing significant variations of electrical resistivity measurement of the subsurface.

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