Electrical Resistivity Tomography and VLF-EM techniques for locating groundwater prospect in basement complex terrain of Ibadan South-west, Nigeria

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Summary

Delineating optimal drill location for groundwater prospect in basement complex terrain is an element of concern. The study area which is situated in the hard rock landscape of Ibadan, South-west, Nigeria is posed with water scarcity due to frequent seasonal variation. To address this dilemma, integrated geophysical technique with geological observation was adapted. A major lineament direction in the study area was found parallel to the geologic strike trending in the NW-SE direction. A total of eight (traverses 1, 3, 5 and 7 parallel to the strike direction while traverse 2, 4, 6, and 8 is perpendicular to it) 250 m long very low-frequency electromagnetic (VLF-EM) profile integrated with 2-D electrical resistivity tomography (ERT) along the VLF traverses were collected to optimize the subsurface target zone. The result interpreted from the integrated geophysical technique with two open hand dug wells constitutes three layers overlaying the fresh basement rock. The top soil, weathered saturated layer and dry weathered basement. The aquifer region is the weathered saturated zone resulting from the low resistivity value between 90 - 370 Ωm and positive Karous-Hjelt current density distribution with depth variation from 4 – 13 m. Data consistency was observed along the lineament direction parallel to the geologic strike (NW-SE) which correlated well with the hand dug well II (NW) along traverse 3. Thus, the use of integrated geophysical approach along with geologic investigation is a reliable tool to predict groundwater bearing zones in hard rock terrains.

Introduction

Groundwater constitutes major part of freshwater resources around the world and is obviously a dependable source (Adeoti et al., 2015). However, borehole failure in hard rock terrains has been a major issue. An example is the two failed dry wells dug in Khammam, Andra Pradesh, India stemming from the interpreted result of vertical electrical sounding (VES) data during groundwater exploration (Sundarararajan et al., 2007). Meanwhile, geologic study alone is inadequate and therefore, requires additional geophysical investigative tools to identify promising water-bearing zones.

Very low frequency electromagnetic method (VLF-EM) has been successfully applied to hydrogeological, engineering, and environmental problems, and it is relatively fast and cost effective compared to other geophysical methods (Pazzi et al., 2016). Hence, this technique has gained popularity for quick mapping of near-surface geologic structures. However, due to the uncertainty accompanying the complex variability of hard rock formations in the search for groundwater aquifers, integration with other geophysical methods becomes necessary. Besides, integrative techniques are thought to be advantageous for precise subsurface structure delineation.

Several studies have utilized integrated approach to optimize exploration success. For instance, Abass and Bello (2015) employed integrated electrical resistivity and seismic refraction surveys to delineate permeable zones with a precise determination of the subsurface heterogeneities. In another study, Ammar and Kruse (2016) utilized resistivity sounding and VLF profile to locate groundwater well in an Arabian Shield of Saudi Arabia.

In this study, an integrated geophysical (2D ERT and VLF-EM) approach in conjunction with geological observation was carried out to accurately delineate subsurface structure with groundwater prospect and also to identify optimal drilling site.

Geology settings and methodology

The area of investigation is covered by the southwestern Nigeria basement complex which lies between latitudes 7° 29'N and 7° 32'N and longtitudes 3° 25'E and 3° 27'E in the equatorial rain forest region of Africa (Fig.1). Water resources found in the region are open hand-dug wells which are inadequate due to seasonal limitation. The study area topography is generally flat with few undulations particularly in the Northeastern flank. The drainage pattern is dendritic with an average annual rainfall of 1200mm.

The area consists of the Migmatite Gneiss complexes to the late intrusive rocks and Pegmatite rock occurring within the core of the migmatite gneiss and the porphyritic granite (Akindele, 2011). These rocks are related with brittle and ductile structures such as joints, fractures and faults. The major lineament in the study area is in the NW-SE direction.

In this study, very low frequency electromagnetic (VLF-EM) data was measured along eight traverses using Geonics EM 16 portable hand held receiver. A VLF transmitting (HWU France) signal at a frequency 21.75 kHz was implemented as the source for the entire VLF investigation. Traverses 1, 3, 5 and 7 are oriented along NW-SE direction while traverses 2, 4, 6 and 8 in the NE-SW direction. The VLF-EM instrument acquires tilt angle (the polarization ellipse of the inclined major axis) data which is denoted as the in-phase (real) parameter while the ellipticity (the proportion between the minor and major axis of the ellipse) is known as the quadrature (imaginary) component (Bayrak and Senal, 2012). The VLF receiver measures at an interval spacing of 5 m along each profile at a distance of 250 m. In addition, to reduce the effect of unwanted geologic noise and interference of electrical activities in the area of investigation, filtering of the acquired VLF-EM data was necessary. The Karous and Hjelt (1983) filter was employed. The results displayed the pictorial representation of the spatial variation of the geologic structure and the changes of the current density with depth.

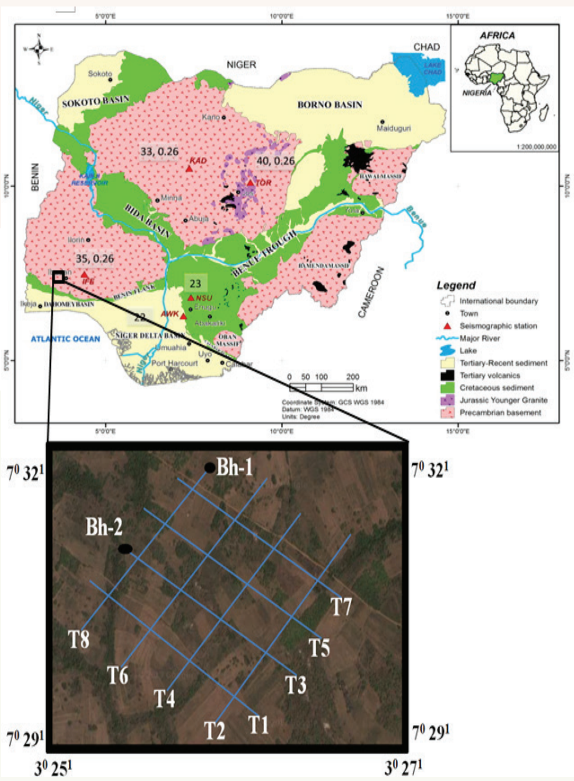

Figure 1: Geological settings (Adapted from NGSA, 2006) and base map of the study area displaying the VLF-EM and 2D-ERT profile and borehole information.

The field 2D-ERT data were obtained using ABEM SAS 1000 Lund-Imaging Terrameter (Dahlin, 1996) to determine the apparent resistivity value along the VLF-EM traverse. The Wenner electrode configuration array was utilized (Loke, 2012). Further, the apparent resistivity data were filtered to remove bad data points using RES2DINV commercial software, the inversion approach constitutes the smoothness-constrained least-squares method (Sasaki 1992) to estimate the true resistivity of the subsurface structure. Two open hand dug wells were correlated to delineate the subsurface lithofacies variation.

Results and discussion

The VLF-EM filtered data were presented to show the pseudo-section of the formation in terms of the variation in current density and depth (Karous and Hjelt, 1983). The amplitude response of the EM anomaly is dependent on the resistivity of the host rock, the depth and geometry of the aquifer/clay content. Eight VLF-EM tomographic model results were interpreted, and the sample of interest is displayed in Fig. 2, 4 and 6.

Santos et al. (2006) reported that conductive subsurface structures such as weathered zone and fracture have a high value of current density. This zone indicates water bearing region in basement complex terrain. The high current density value (red colored) is the anomaly of interest. The traverse one and three trend in line with the geologic strike NW-SE, while traverse eight is perpendicular to the geologic strike NE-SW. The anomaly was observed in traverse one at an interval distance 60 – 100 m and 190 – 230 m while in traverse three, it was detected in the range of 60 - 90 m and 210 – 250 m and traverse eight at distance of 170-190 m.

For reliable interpretation, VLF results are inadequate, and thus, require the need for an integrated approach with the electrical technique (2D electrical resistivity tomography) to reduce ambiguity. The geoelectric horizon (Fig. 3, 5 and 7) interpreted from the electrical resistivity tomography results were validated with two open hand dug well (Table 1). The study area had four layers including the top soil, weathered saturated layer, dry weathered basement and fresh basement rock. The first layer denotes the topsoil with resistivity value ranging between 106 - 4818 Ωm and thickness of 0.6 – 1.5m. The weathered saturated horizon has resistivity value between 90 - 370 Ωm, and has thickness variation from 3.5 - 15 m. This represents the aquifer unit in the area of study. The dry weathered basement has resistivity value between 1359 – 6000 Ωm, and has thickness 2.5 - 15 m across the profile line. The last layer with resistivity value of 5000 Ωm and above marked the fresh basement. The overburden thickness to the basement rock varies from 4 m - 20 m along the profiles.

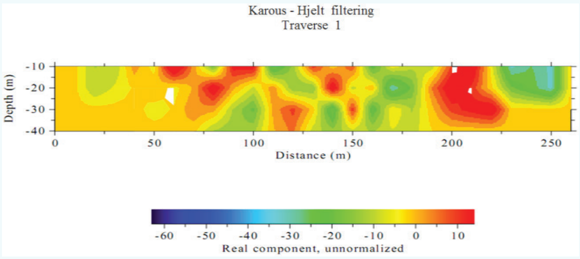

Figure 2. Traverse one VLF-EM pseudo-section along the Northwest- Southeast Direction.

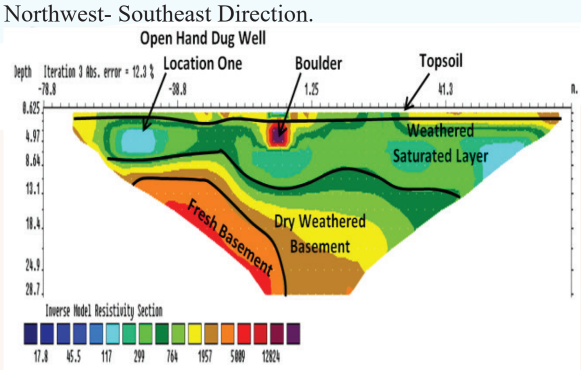

Figure 3. Traverse one 2D ERT along the Northwest-Southeast Direction.

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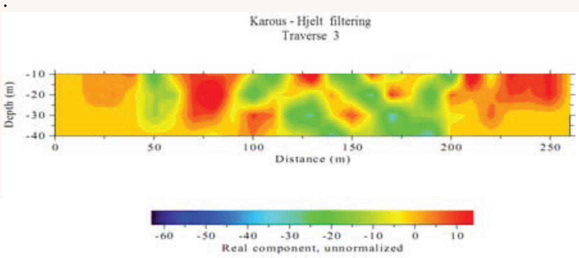

Figure 4. Traverse three VLF-EM pseudo-section along the Northwest- Southeast Direction.

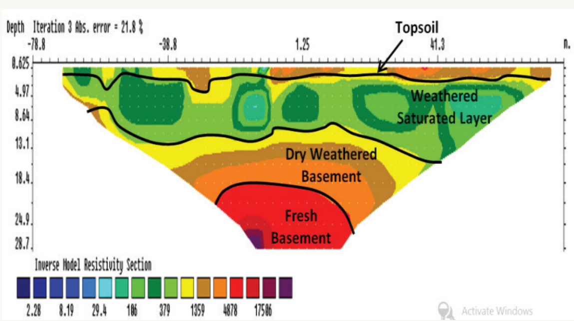

Figure 5. Traverse three 2D ERT along the Northwest-Southeast Direction.

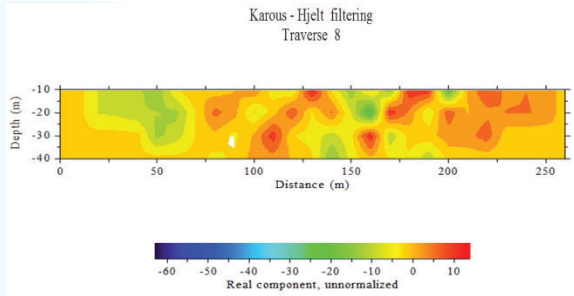

Figure 6. Traverse eight VLF-EM pseudo-section along the Northeast-Southwest Direction.

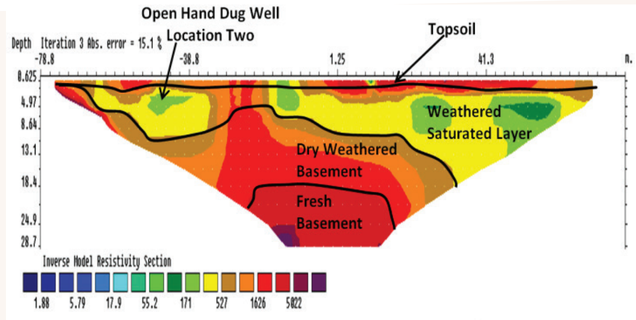

Figure 7. Traverse eight 2D ERT along the Northeast-Southwest Direction.

Table 1: The results of the inverted electrical resistivity tomography corroborated with hand dug wells within the area of investigation.

Depth	Resistivity	Geologic	Hand Dug Well One		Hand Dug Well Two	
(m)	(Ωm)	Interpretation	Depth (m)	Lithology	Depth (m)	Lithology
0 – 2.5	106 - 4818	Topsoil	0 – 1.5	Lateritic Sandy Clay	0 – 0.5	Lateritic Clay
2.5 – 7.5	90 - 370	Saturated Weathered Zone	1.5 – 3.8	Clayey Sand	0.5 – 1.8	Clayey Sand
7.5 – 10.8	1358 -5000	Dry Weathered Basement	3.8 – 8.2	Fine to medium Sand	1.8 – 4.7	fine Sand
Below 10.8	Above 5000	Fresh Basement				

Correlative analysis was carried out between the VLF-EM pseudo section and the electrical resistivity tomography (ERT). A high positive current density and low resistivity value was observed at the open hand dug well II situated along traverse one with the interval distances of 60 – 100 m and 190 – 230 m, while traverse three ranges from 60 - 90 m and 210 – 250 m, at thickness value varying from 3.5 – 15 m parallel to the geologic strike NW-SE. However in traverse eight, a negative current density and low resistivity was detected in the region of the open hand dug well I. This might be as a result of the VLF transmitting signal perpendicular to line of traverse NE-SW.

According to Lenkey et al. (2005) and Omosuyi (2010), borehole sited in a region of thick overburden weathered region denotes the tendency to produce high yield of groundwater. In the area of investigation, it was observed based on integration of the VLF-EM and electrical resistivity tomography (ERT) that the overburden thickness extends to the fresh basement at depth values ranging from 8 – 25m. Figure 3, 5 and 7 displayed that the overburden thickness (15 to 20 m) is reasonably thick along southwest and southeast direction, while the thickness (4 to 12 m) of the overburden is low at the direction of northeast and northwest. This results correlates well with the two open hand dug well which was affected by seasonal variation. Based on the correlated integrated approach, groundwater potential and location for optimal drilled well should be targeted towards the southeast, weathered saturated horizon of the investigated area.

Conclusions

An integrated technique was carried out to determine the subsurface structure and delineate groundwater potential at hard rock terrain of Ibadan, South-west, Nigeria. Two out of the eight profiles shows a favorable weathered saturated zone of interest for siting groundwater, which was observed from the low resistivity and positive Karous-Hjelt current density distribution. Drilling is recommended at traverse one which is at distance interval 190 – 230 m, and traverse three 210 – 250 m, with a depth ranging from 4 – 13m. This region shows an indication of high groundwater yield due to the thickness of overburden. Therefore, the use of integration geophysical technique in conjunction with geological investigation seems to be a vital tool for delineating groundwater bearing region.

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