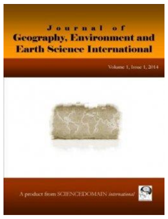

Journal of Geography, Environment and Earth Science International
2(1): 37-45, 2015; Article no.JGEESI.2015.004

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Gradio-magnetic and Resistivity Exploration for Groundwater in Wuro Yakubu Song Area, Hawal Basement Complex, Northeastern Nigeria

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Authors' contributions

This work was carried out in collaboration between both authors. Author BJ designed the study, wrote the protocol, and the first draft of the manuscript. Authors BJ and BNE, acquired data for this study, analyzed the data and managed the literature searches. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JGEESI/2015/15924
Editor(s):
(1) Wen-Cheng Liu, Department of Civil and Disaster Prevention Engineering, National United University, Taiwan and Taiwan Typhoon and Flood Research Institute, National United University, Taipei, Taiwan.
Reviewers:
(1) Anonymous, Jordan.
(2) Saad Bakkali, Earth Sciences Department, University A. Essaâdi, Morocco.
Complete Peer review History: http://www.sciencedomain.org/review-history.php?iid=938&id=42&aid=8152

Original Research Article

Received 26th December 2014
Accepted 30th January 2015
Published 16th February 2015

ABSTRACT

This research demonstrates the integrated use of magnetic-gradiometric and resistivity methods in mapping subsurface structural features to explore for ground water bearing zones in Wuro Yakubu area, Song Adamawa State in northeastern Nigeria. The research was carried out between March 2010 and December 2010. Acquisition of ground magnetic data was achieved using G-856-MagTM Proton Precision Magnetometer in the gradiometric mode, while resistivity measurements were done using ABEM SAS 1000c terrameter. Interpretation of ground magnetic and resistivity data were carried out using WinGlink and IX1D resistivity softwares respectively. Vertical magnetic gradient results in the study area revealed anomaly as high as 10 nT/m, while results of resistivity survey revealed three to four geo-electrical layers, with layer resistivity ranging from a minimum of 9.11 Ω-m to a maximum of 2329.6 Ω-m. Layer thickness ranges from 0.51 m to 35.62 m. Qualitative analysis of total magnetic intensity and the vertical gradient maps shows a prominent belt of anomalies striking in NW-SE direction and was interpreted to be due to the presence of fault,

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fracture or shear zones. Resistivity work across this zones shows that the third geo-electrical layer comprising of fractured/weathered basement with a resistivity range of 100.17-531.21 Ω-m, and thickness 27.29-35.62 m is a promising zone for ground water accumulation.

Keywords: Integrated survey; magnetic-gradiometric; resistivity; fault/shear zone; groundwater aquifer.

1. INTRODUCTION

The study area is in Song Local Government Headquarter in the present Adamawa state of Nigeria located along Yola-Gombi Road (Fig. 1). Geologically, the area is located in the southern part of the Hawal Basement Complex of northeastern Nigeria and is defined by the following coordinates: Longitudes 12°35' E-12°40' E and Latitude 9°45'N-9°52'N (Fig. 1).

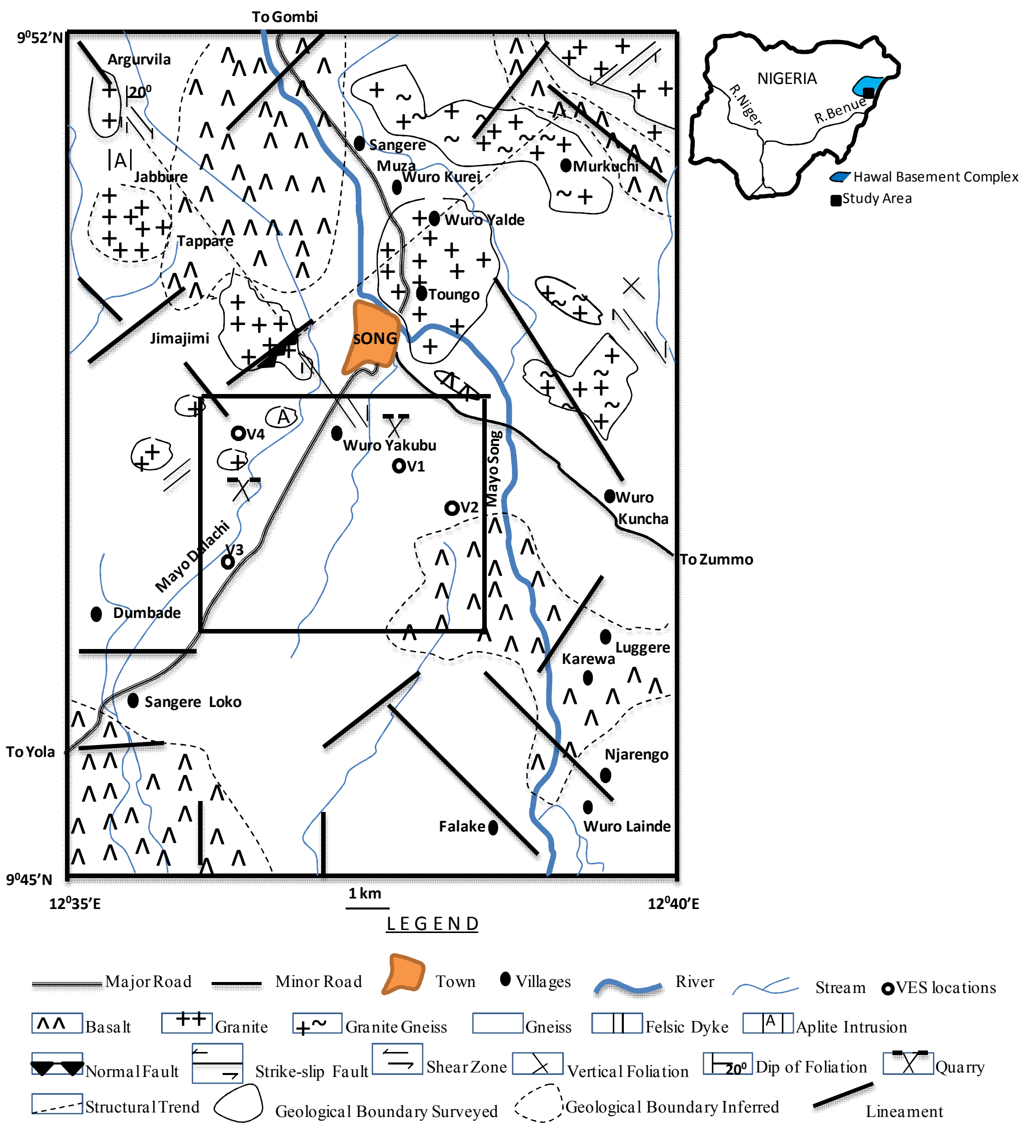

Fig. 1. Geological and structural map of song and environs after [1]
[Area in box is site for ground magnetic gradio-metric survey and VES locations]

The major group of rocks in the area includes gneiss, granite and basalt. Alluvial deposits are restricted to river channels. Structures in the area include dykes, veins shear zones and faults with a dominant trend in the N-S to NE-SW, and NW-SE. E-W trend is minor [2,3].

The area has tropical climatic condition which is found in other northern part of Nigeria. This is controlled by two main season's namely wet and dry seasons. The wet season commences from April to October, with July to September being the peak period of rainfall. The dry season starts from November to March with generally low temperatures and harmattan winds. However, high temperatures are recorded in March and April. The area is drained by River Song and other streams whose courses are controlled by N-S, NE-SW or NW-SE geologic structures [2].

This research work was conceived because of the persistent water shortage in the area especially at the peak of dry season. During interactions with some members of the community in the research area, March, 2010, the researchers found that water yields from most of the boreholes and hand dug wells in the study area and environs were poor, and some were not productive. 'Water' as an adage says is life therefore; increased population in an area is always marched by increased demand for water. The population data for Song area during the 2006 census was 192,697 when compared with 198,474 of 1991 census (source: National Bureau of Statistics Nigeria, 2012). This record shows a decrease in the population and this could possibly be related to the perennial water scarcity in this area among other factors. To help in alleviating the perennial water scarcity problem in the study area, as part of university community service this research was undertaken.

The research utilized a G-856-MagTM Proton Precision Magnetometer in gradiometric mode to map out subsurface structural features such as fault and shear zones on the basis of variations in magnetic susceptibilities of the underlying rocks. [4] did a similar work by using resistivity and ground magnetic investigation for ground water in Fobur area of Jos Plateau. It is known that faults, shear zones, etc. could act as impermeable barriers to groundwater flow, thus contributing to accumulation of bodies of water that could be exploited by boreholes [5]. Results from the magnetic survey paved way for electrical resistivity survey where the use of ABEM SAS 1000c terrameter was employed.

2. MATERIALS AND METHODS

2.1 Gradio-Magnetic Survey

The magnetic method was chosen because of a relatively flat topography in study area with near absence of metallic objects that could affect instrument readings. The area surveyed is approximately 4.5 km by 3 km (13.5 km^2). [6] suggested that, at low magnetic latitudes, (<15º), survey lines should always be in the magnetic north-south direction as anomaly are highly extended in the east-west direction. In this respect, the survey was carried out along north-south striking profiles these are nearly perpendicular to the NE-SW, NW-SE and E-W main tectonic trend of structures in the area. Six profiles each of length 3 km and a spacing of 0.9 km between profiles were covered, station spacing was 100 m along each profile and a total of 186 stations were surveyed. The traverse azimuths and distance between stations were located with the help of a geological compass and a Geko 101TM global positioning system (GPS). The vertical intensity of the total magnetic field was measured using G-856-MagTM Proton Precession Magnetometer in the gradiometer mode. This was achieved by using two vertically oriented sensors separated at two feet (0.6 m) interval, with the bottom sensor mounted on a tri-pod at 4 feet (1.2 m) above the ground.

The direct measurement of magnetic vertical gradient enhances the possibility of discriminating between neigbouring anomalies [7]. The vertical gradient of the total field is explained by the following mathematical formulation:

$$\partial F/\partial Z = (Z2 - Z1)/\partial Z. \qquad (1)$$

Where

∂F = change in total field,

Z2, Z1 = readings at lower and upper sensors respectively,

∂z = vertical interval between sensors.

The following procedure was observed during the survey exercise:

1. Measurements were taking in the morning between the hours of 7 am - 10 am to reduce the risk of magnetic storm.

2. At every station, the arrow on the upper sensor was aligned to the magnetic north before readings were taken.
3. At each station the magnetic field strength, station and profile numbers were recorded.
4. Since two sensors were used for the survey, magnetic readings were not corrected for diurnal variations.

The potential field data from both lower and upper sensors after computation of gradients were inputted into the WinGlink version 2.03.01 Geosystem software for gridding, and contouring.

2.2 Electrical Resistivity Survey

The ABEM Terrameter SAS 1000c with both current and potential electrodes made of non-polarizing copper electrodes was employed in this research work. Four vertical electrical sounding positions as shown on Fig. 1 were selected on the basis of suspected continuation of subsurface fault and shear zones (Fig. 1), and anomalous delineation by the gradio-magnetic survey. In the depth sounding mode, using the schlumberger electrode configuration, four VES data were acquired along the E-W traverses where series of measurements were made with increasing separation between the current electrodes from AB/2 of 1.5 m to a maximum of 100 m. The data obtained were interpreted using IX1D interpex software. This type of electrode configuration has been used worldwide with satisfactory results.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Gradio-magnetic result

The total magnetic intensity maps over the survey area as generated from the lower and upper sensors (Figs. 2 and 3) shows magnetic low of 32700 nT and magnetic highs as 34300 nT. Fig. 4 is a vertical magnetic gradient map computed from the formula shown in *equation 1.* It shows a vertical gradient anomaly ranging from 0-10 nT/m. These maps are interpreted qualitatively and the most prominent feature in Figs. 2, 3 and 4 is a NW-SE trending linear belt of anomaly (marked with dash line) with low magnetic values ranging from 33700 nT to 33900 nT (Fig. 2 and 3), and 0 nT/m to 3 nT/m (Fig. 4), which occurs to the northeast. A second belt of anomaly is found at the south east corner of Figs. 2, 3 and 4 where it runs northwest and continues west to the margin. Based on geological evidence (Fig. 1), these are attributed to faults, fractures or shear zones.

3.1.2 Resistivity result

The *IX1D interpex* software is computer interactive resistivity software which interprets resistivity sounding data in terms of layered depths. The results were presented graphically with apparent resistivity in ohm-metre (Ω-m) plotted against AB/2 in meters. Results of the interpreted data for all the VES stations occupied show all layers parameters which include layer resistivity, thickness, and depth (Fig. 5), models were considered acceptable at a fitting error of below 10%. Table 1 gives summary of interpreted results.

From the characteristics curves Fig. 5 and summary results of sounding on Table 1, three to four major geo-electrical layers were delineated within the study area. The top layer has resistivity value ranging from 20.82 Ω-m to 827.79 Ω-m and the layer thicknesses ranges from 0.51 m to 2.74 m. The second layer with resistivity range of 9.11 Ω-m to 350.25 Ω-m has thicknesses range of 4.58 m to 8.37 m. The third layer exhibits resistivity values of 100.17 Ω-m to 235.32 Ω-m and thickness of 27.29 m to 35.62 m. The fourth layer has a resistivity of up to 2329.6 Ω-m.

3.2 Discussion

The search for ground water in a semi-arid basement terrain requires a systematic approach. Though magnetic method is not commonly used as a geophysical method for the investigation of groundwater, this research has demonstrated that this method can be used to map out subsurface structural features such as fault and shear zones that could serve as avenues for ground water accumulation. Delineation of suspected fault and shear zones from the ground magnetic gradiometer survey data was done following criteria given by [8]. The author stated that in some fault and shear zones, magnetic minerals are altered to non-magnetic assemblages by meteoric water or by ore bearing fluids circulating through the faulted, sheared or crushed rocks and this is pronounced by series of closed low magnetic values on a contour map. This is applicable to present study area as seen in the northeastern and central parts of Fig. 2, 3 and 4 respectively. [9] also relates magnetic susceptibility contrast across a fracture zone due to oxidation of magnetite to haematite and filling of fracture planes by dyke-like bodies whose magnetic susceptibility is different from the host rock, such geological features which expresses geologic lineament may appear as thin elliptical closures on the magnetic map and this is evident from the magnetic map were the anomalous zones indicate low magnetic values when compared with the adjoining environment.

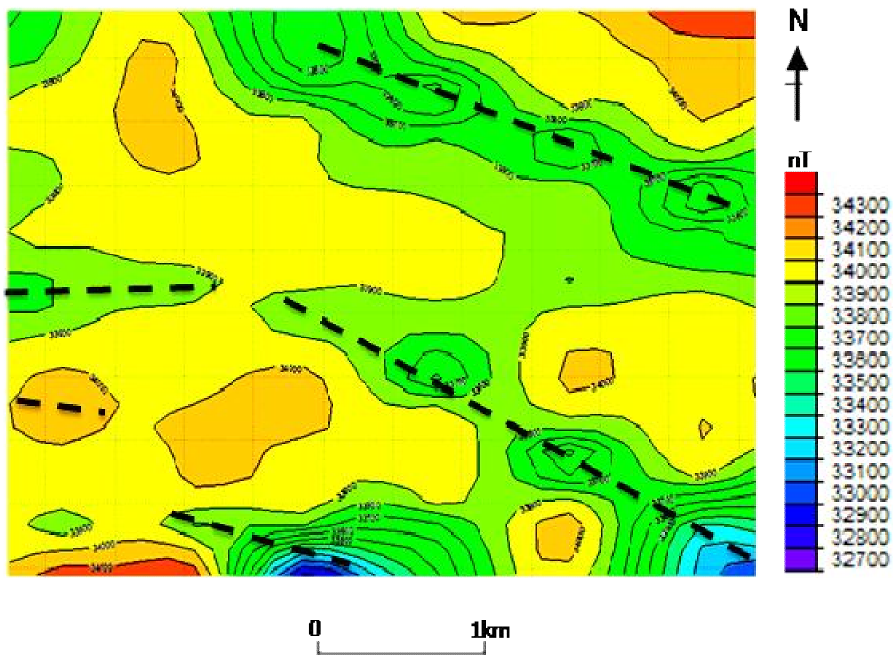

Fig. 2. Map of total magnetic intensity form the lower sensor

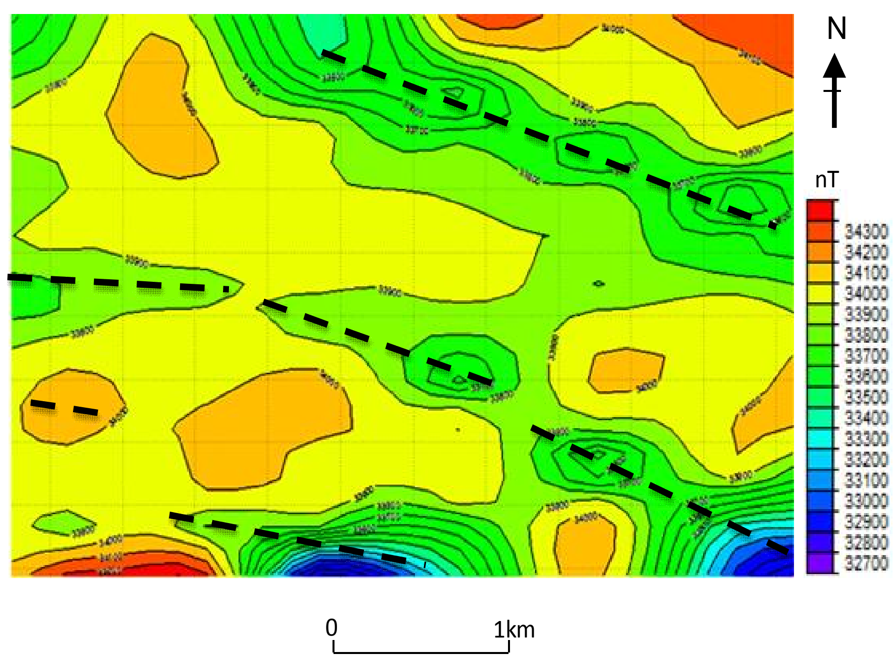

Fig. 3. Map of total magnetic intensity form the upper sensor

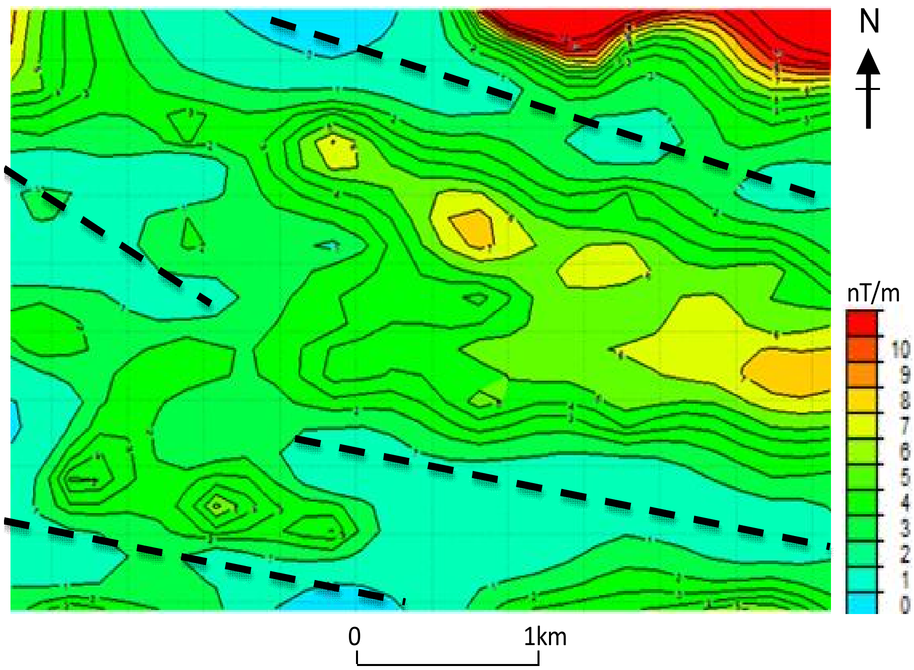

Fig. 4. Vertical magnetic Gradient map form the two sensors

Table 1. Results of Sounding in the study area

S/ No	VES point	Thickness of various layers (m)			Depth of soundin g(m)	Resistivity of layers (omh-m)				Fitting error (%)
		h_1	h_2	h_3		ρ_1	ρ_2	ρ_3	ρ_4	
1	VES 01	2.74	5.94	-	8.67	20.82	350.2	170.3	-	6.46
2	VES 02	0.51	4.58	27.29	32.38	143.76	9.11	100.17	256.98	3.13
3	VES 03	1.91	4.72	35.62	42.26	313.1	32.00	235.32	2329.60	7.66
4	VES 04	1.34	8.37	16.04	25.75	827.79	93.21	126.4	2215.00	6.11

From the geological map of Song (Fig. 1) there are several NE-SW lineaments, faults, shear zones and stream channels (from Argurvula at the NW corner of the map through Wuro Yakubu at the centre to Wuro Lainde at the SE corner. The NW-SE magnetic linear zone of Figs. 2, 3 and 4 is here interpreted as marking the subsurface continuation of the fault/shear zone that runs from Argurvila to Wuro Lainde. Other structures of diverse orientations/lineaments are also found in the area. By implication the area has experienced several episodes of tectonism including magmatim [2]. [5] suggested that in basement terrains, groundwater occurs in weathered mantle, fracture and fault zones within the bed rocks because of lack of primary porosity and permeability.

Results of the electrical resistivity sounding curves Fig. 5, commonly show a sequence comprising of three to four layers. Combining the data interpreted from the sounding results with information from available lithologic logs of boreholes already drilled in the area (Mallam Sadiq Abubakar-personal communication), the following conclusions were arrived at as shown in Fig. 6: The first geo-electrical layer with resistivity values ranging from 20.82 to 82.79 Ω-m and thickness ranging from 0.51 to 2.74 m is the top soil consisting mainly of soil, clay and laterite, the second geo-electrical layer with resistivity range of 9.11 to 350.2 Ω-m and thickness ranging from 4.58 to 8.37 m is the weathered and dry basement. The third geo-electric layer whose composition according to lithologic logs is mainly weathered and fractured basement rock and is likely to be the aquiferous zone has resistivity ranging between 100.17 Ω-m to 235.32 Ω-m and thickness of 27.29 m to 35.62 m. The fourth layer is the resistive fresh and unfractured basement complex rock and has resistivity of up to 2329.6 Ω-m. However, the recommended drilling depth in these areas from the resistivity survey is 30 to 40 m. Beyond this limit the ground water yield will be very poor because as [10] reported; the average yield for metamorphic and plutonic rocks decrease rapidly with depth. This is a consequence of lithostatic pressure increase with depth which seals up fractures thereby reducing rock permeability.

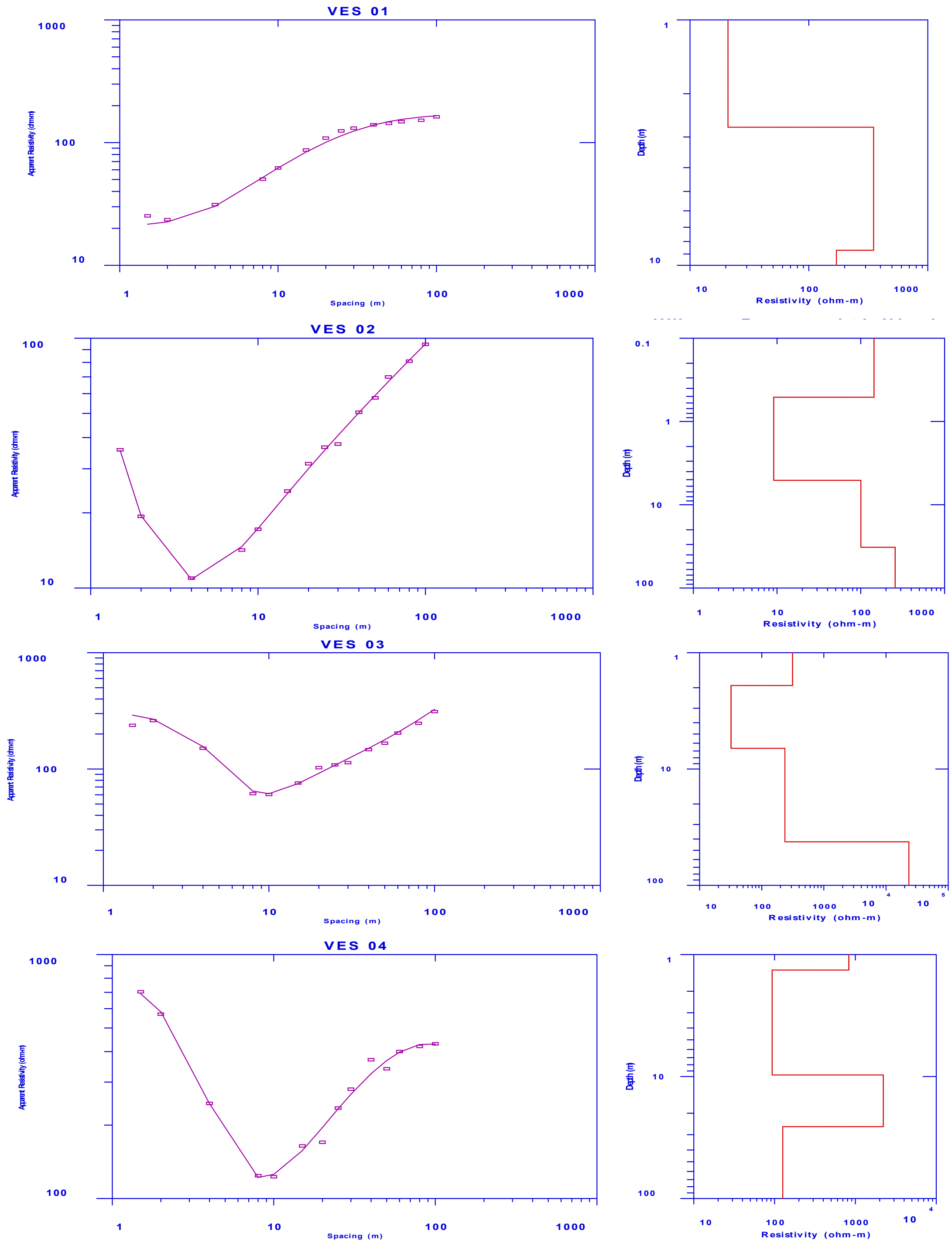

Fig. 5. VES curves (VES 01, VES 02, VES 03 and VES 04) from the study area

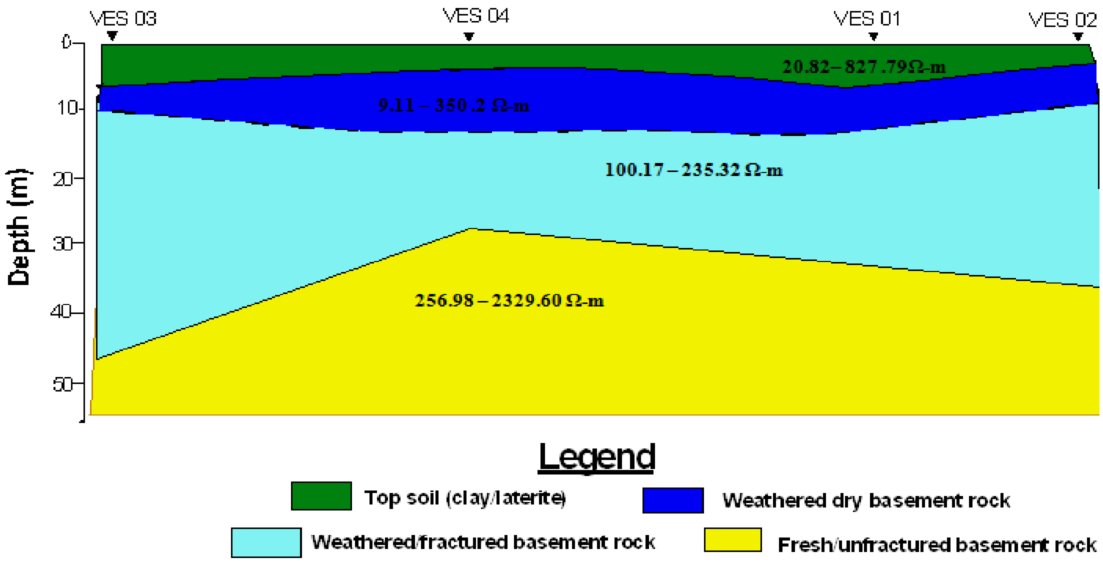

Fig. 6. Geo-electrical cross-section over the study area

4. CONCLUSION

Magnetic gradiometric survey has demarcated a linear zone of anomaly continuous with mapped fault/shear zone. Resistivity work across this zone gave three geo-electric layers. The third layer i.e. fractured basement/weathered basement with resistivity range of 100.17-235.32 Ω-m, and thickness 27.29-35.62 m is a promising zone for ground water accumulation. The recommended depth for drilling is 30-40 m.

Successful exploration/exploitation of groundwater in Basement Complex terrains requires proper understanding of the geo-hydrological characteristics of the area. Drilling without preliminary and appropriate geophysical investigations might result in abortive boreholes or boreholes with poor yield. The researchers recommend that integrated geophysical survey (magnetic, electromagnetic, seismic and resistivity) should be conducted to locate promising sites for drilling of productive boreholes in such difficult terrains. This work again demonstrates the beauty of joint magnetic and resistivity surveys for ground water exploration. Such integrated survey helps to reduce ambiguity in data interpretation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=938&id=42&aid=8152