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Research Paper

Geophysical Mapping of Groundwater Aquifers Beneath the Central Region of Ghana

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Abstract: Geophysical data were used to map groundwater aquifers beneath Beseadze and Nyamebekyere No. 2 of Central Region of Ghana. The geophysical data include electromagnetic (EM) profiling, electrical resistivity profiling and vertical electrical sounding (VES). The EM profiling were carried out using the Geonics EM43-3 ground conductivity meter and the data were processed and analysis using AEMINV inversion program. Both the electrical resistivity profiling and vertical electrical sounding were conducted using an ABEM Terrameter SAS 1000C and the Schlumberger electrode array. The resistivity profile data were processed and analysed using ProfileR inversion computer program and the VES data were analysed and interpreted using Zondip1D and Surfer 13. The results of this study revealed that, the surveyed areas are underlain by three to four layers. The depth to aquifer within the study area is between 0.48 to 7.42 m. The average aquifer thickness within the study area is about 14.78 m. The results of this study were used to determine the drilling locations for groundwater boreholes within the Beseadze and Nyamebekyere No. 2 of Central Region of Ghana.

Keywords: *Groundwater Aquifers, Central Region (Ghana), Electromagnetic data, Electrical Resistivity Data, Geophysical Mapping*

Introduction

Water is one of the basic natural resource necessary for the survival of human beings, animals, and plants. In many parts of the world, some towns and communities suffer with water related problems which include water shortage due to climate and environmental conditions and lack of clean water due to water contaminations through natural and artificial means.

In some communities, groundwater is preferable over surface water because groundwater (tends to be less polluted) is in general easier and cheaper to treat than the surface water (SDWF,2021). In some towns and communities, locating aquifers by using traditional methods or direct drilling led to failure and hence application of geophysical methods for aquifer delineation is necessary. For several decades, geophysical methods have been used successfully to delineate groundwater aquifers in any type of environment and geology (Boieroet al., 2010; Carrasquilla and Ulugergerli, 2007; Cull and Massie, 2002; Nascimento Da Silva et al., 2004; Sharma and Baranwal, 2005; Venkateswaran et al., 2014; Zohdy et al., 1990; Zohdy and Jackson, 1969). Geophysical methods continue to be among the successful methods of groundwater exploration.

This paper reports the use of electromagnetic profiling method, electrical resistivity profiling and sounding methods for delineating groundwater aquifers aimed at selecting points of high groundwater potentials for borehole site in two towns in the Central Region of Ghana. The towns were the beneficiaries of potable water supply project by the Community Water and Sanitation Agency (CSWA), Central Region.

Materials and Methods

Study Area

The study areas are Beseadze and Nyamebekyere No. 2 which are towns located within the Twifo – Hemang Lower Denkyira District of Central Region of Ghana. The towns are underlain by granitoids (Figure 1). The granitoids beneath these towns are classified as Cape Coast granite complex which is one of the three groups of granitoids in Ghana. The Cape Coast granite complex is associated with schists and gneisses and intrude the Lower Birimian meta – sediments. But most rocks in the study areas comprise of well-foliated, medium-grained, potash-rich muscovite-biotite granites, granodiorites and

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pegmatites (Kesse, 1985; Gyamera and Kuma 2014; Mohammed Nazifi and Gulen, 2019).
According to Ehinola et al., 2006, the aquifer systems within the crystalline basement rock in the region are fractured basement rocks and weathered basement rocks. These aquifers were formed because of secondary permeability and porosity developed by fracturing and / or weathering (Kesse, 1985; Gyamera and Kuma 2014; Mohammed Nazifi and Gulen, 2019).

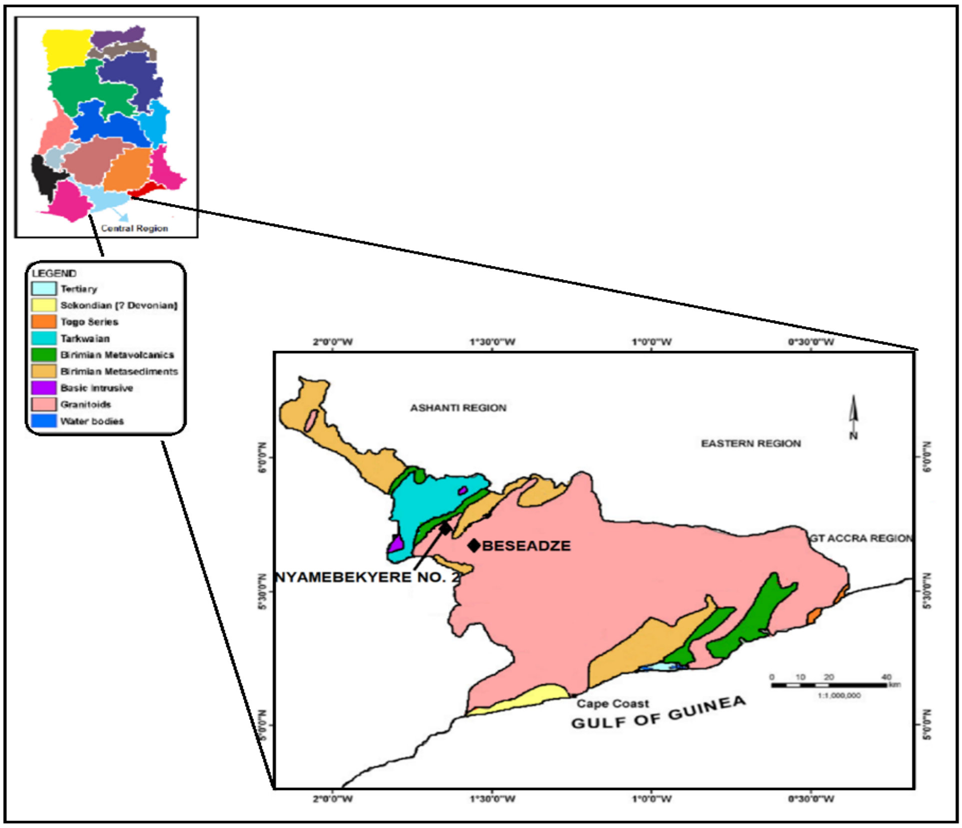

Figure 1. Geological map of Central Region showing the study areas (modified from Ewusi and Kuma, 2011).

Methods

Electromagnetic (EM) profiling and electrical resistivity (profiling and sounding) techniques was employed in data collections. The electromagnetic technique was used for reconnaissance purpose and it was aimed at detecting both narrow and large fracture zones as well as thick weathered zones (regolith), which are the two key controls on groundwater occurrence in crystalline rock. Short resistivity profiling measurements were conducted around the point where the EM profile displayed an anomaly (peaks). The short resistivity profiling was used to confirm or otherwise the conductive zones picked by the EM equipment. The VES method was used to estimate the depth to bedrock, the number of subsurface geological layers, and their corresponding resistivities.

Electromagnetic (EM) Profiling

The electromagnetic measurements were carried out using the Geonics EM43-3 ground conductivity meter. The equipment provides a direct reading of the apparent subsurface conductivity in the region of the measuring coil. This is achieved by generating a primary electromagnetic field from a transmitting coil, which subsequently induces a secondary magnetic field in the subsurface. A receiving coil detects the resultant electromagnetic field from both the primary and secondary fields. A 20 m separation coil was used for the profiling and EM readings taken at 10m intervals in Beseadze (for both traverses A and B) and traverse B in Nyamebekyere No. 2. For traverses A and C in Nyamebekyere No. 2 a 10 m separation coil was used for the profiling and EM readings taken at 5 m intervals. The EM profiling was aimed at primary exploration and hence shallow depth was targeted. Generally, 20 m intercoil separation was used but in areas such as around traverses A and C in in Nyamebekyere No. 2

where existing borehole depth information was available, 10 m intercoil separation was used. The 10 m intercoil separation has an exploration depth of 7.5 m for horizontal dipole (HD) mode and 15.0 m for vertical dipole (VD) mode, while the 20 m intercoil separation has an exploration depth of 15 m for horizontal dipole (HD) mode and 30.0 m for vertical dipole (VD) mode (Tsikudo Kwasi 2009; McNeill 1980). Measurements were taken in horizontal dipole (HD) and vertical dipole (VD) modes in both towns.

The EM profile data were processed and analysis using AEMINV inversion program. The detail of the description of the program and the principle used in developing the program is found in Pirttijärvi, 2014 and Mohammed Nazifi and Gulen 2019.

Short Resistivity Profiling

ABEM Terrameter SAS 1000C Resistivity equipment was used in short resistivity profiling data collection. The targeted depth of investigation was 19.0m. The survey was conducted with 6.0 m on both sides of the selected conductivity peaks. Profiling was carried out with relatively narrower separations of 2.0m with a primary motive to detect narrow fractures.

The resistivity profile data were processed and analysed using ProfileR inversion computer program (Binley 2003). ProfileR is an inverse solution for a 2-D resistivity distribution based on computation of 3-D current flow using a quadrilateral finite element mesh. According to Binley 2003, the inverse solution used in developing the program is based on a regularised objective function combined with weighted least squares (an 'Occams' type solution). The inversion program does not allow editing of the colour legend and that if one depend on the colour alone to make a judgment that would cause a big error, so the apparent resistivity values should be considered instead.

Vertical Electrical Sounding (VES)

VES measurements were confined to selected locations along the EM profiles and were carried out using an ABEM Terrameter SAS 1000C and the Schlumberger electrode array. To ensure reliable and consistent readings, measured results were plotted in the field during the measurements and inconsistent values were repeated to ensure uniformity in the readings.

The field data were analysed and interpreted using two geophysical programs namely, Zondip1D (a free product of Zond Geophysical Software) and Surfer 13 (a commercial product of Golden Software). The model outputs of the Zondip1D include the number of geological layers in the sub-surface, and their corresponding resistivity and thickness. The apparent resistivity values of the individual layers together with the GPS coordinates of the VES locations were organised and used in Surfer 13 program to generate a 2D contour maps of the subsurface beneath the areas.

Results and Discussions

EM data were collected from five (5) traverses in the two towns. Beseadze had two (2) traverse lines and Nyamebekyere No. 2 had three (3) traverse line. Only the vertical dipole (VD) modes data from the EM data were used in the EM inversion.

From the obtained EM profiling inversion results, the study areas within Beseadze is underlain by two layers as shown in Figures 2 and 3.

Generally, the thickness of layer 1 in the Beseadze range between 5 to 10 m although there on the traverse B the location under VES B240 extended to about 30 m. The second layer's thickness is interpreted as half space. Logarithmic scale was used in the inversion of the data and that the resistivity values layer 1 range from 2.5 – 3.5 Ωm and that of the layer 2 is between 4.5 – 6.0 Ωm. This means that the layer 1 is less resistive compared to the layer 2. In the absence of clay and metallic elements in an areas, high conductivity or low resistivity is associated with an area containing groundwater and hence from this assumption six location were recommended for further investigation using the resistivity method. The pointed recommended areas include, A94, A135, A196, B138, B240 and B318. From the EM inversion results points on the traverse B look more promising for finding groundwater.

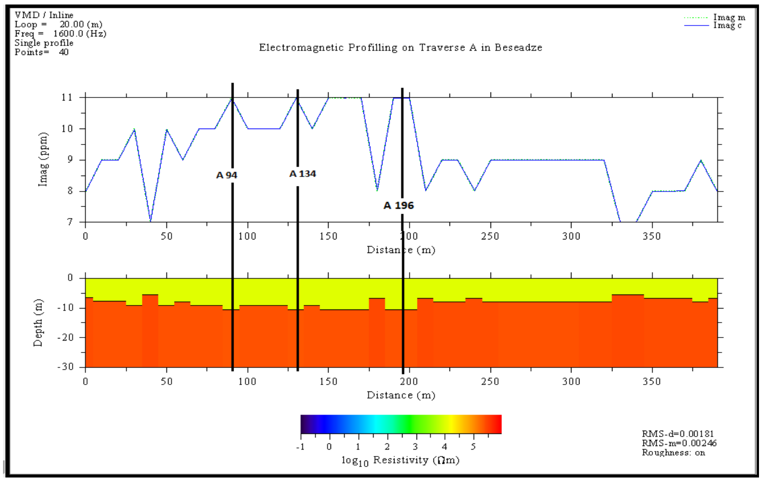

Figure 2. EM inversion result (VD mode) on traverse line A in Beseadze.

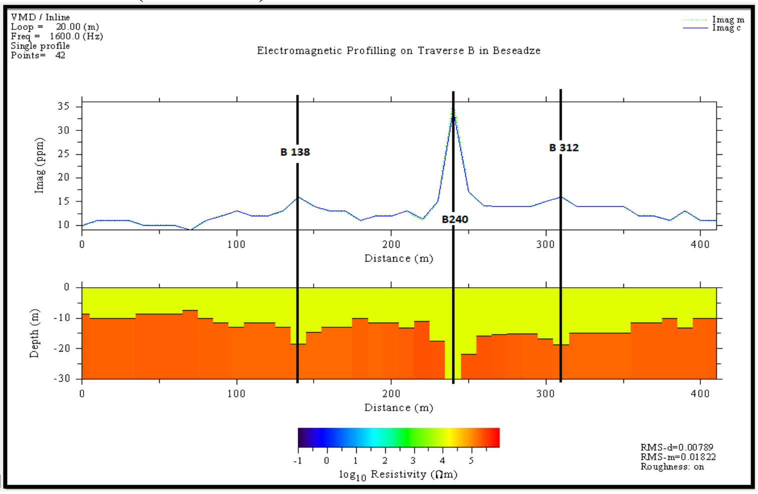

Figure 3. EM inversion result (VD mode) on traverse line B in Beseadze.

After the EM profiling, two short resistivity profiling were conducted in Beseadze. These were to virtualise the resistivity properties of the area surrounding the conductivity peaks revealed by the EM profiling. From the two short resistivity profiling inversion results (Figure 4 and 5), the resistivity values range from 143 – 450 Ωm. The results also revealed two resistivity layers in the study area in the Beseadze. In Figure 5, the anomaly (feature) between distance 85 – 57 m with resistivity values ranging between 198 - 233 ohm-m is interpreted as fault zone. There are good correlations between the resistivity profiling results and EM profiling results. Both revealed points on traverse A to have high groundwater potential than the traverse B. As stated in the method section when reading the inversion results in Figures 4 and 5 care should be given to the resistivity values rather than the contour colours.

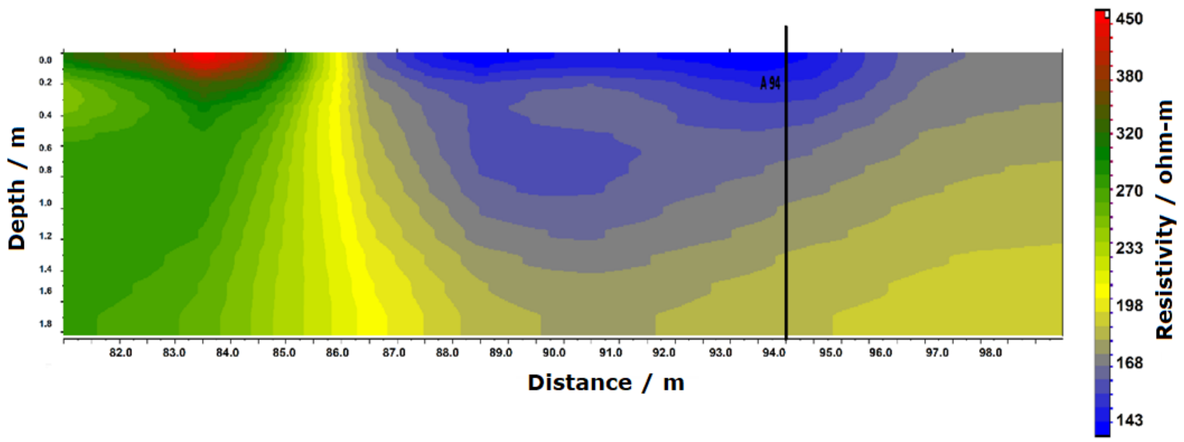

Figure 4. Short resistivity profiling inversion result around point A94 on traverse A in Beseadze.

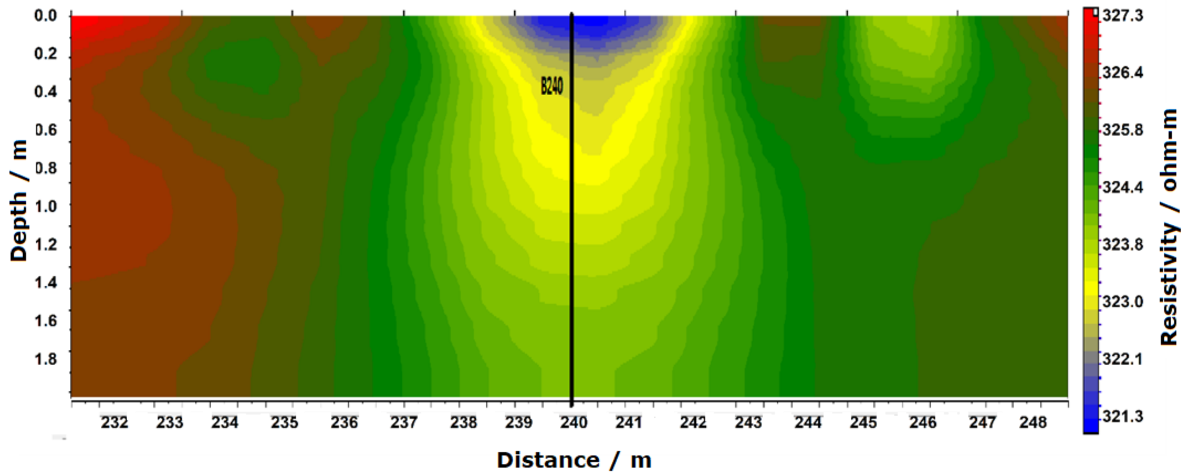

Figure 5. Short resistivity profiling inversion result around point B240 on traverse B in Beseadze.

In Nyamebekyere only two (traverse B and C) out of the three traverses were considered for groundwater investigation. The traverse A was excluded from the project because it was a short traverse and crosses the main high road that divided the town into two parts. The EM inversion results shows that the study areas within Nyamebekyere is underlain by two layers. The layer boundary beneath the traverse B (Figure 6) is not uniform but undulating with a lot of ups and downs. This traverse has a characteristic like that of the two traverses within the Beseadze. Like that of the Beseadze, the traverse B has resistivity values of layer 1 range from 2.5 – 3.5 Ωm and that of the layer 2 is between 4.5 – 6.0 Ωm. The thickness of layer 1 in of traverse B range between 1 to about 35 m although around 223 m and 327m the depth of the layer exceeds 40 m.

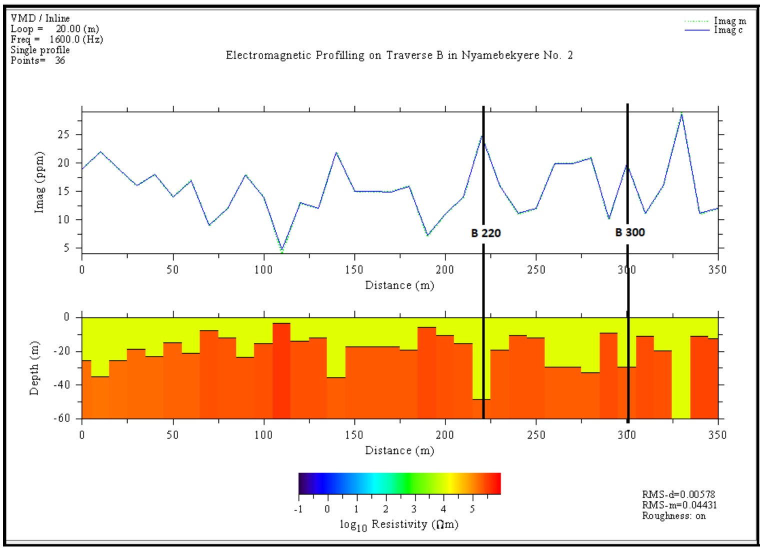

Figure 6. EM inversion result (VD mode) on traverse line B in Nyamebekyere No. 2.

The inversion of the data from traverse C reveal a three-layered model with high resistivity (3.0 – 4.0 Ωm) first layer, low resistivity (2.0 - 2.5 Ωm) second layer and moderate resistivity (2.5 - 3.5 Ωm) third layer (Figure 7). From the inversion values, it could be inferred that beneath traverse C would contain more groundwater than the rest of the traverses and point C60 might be the point with the highest potential of groundwater. Four (4) points were recommended for further investigation using the resistivity method. The recommended points include B220, B300, C10 and C60.

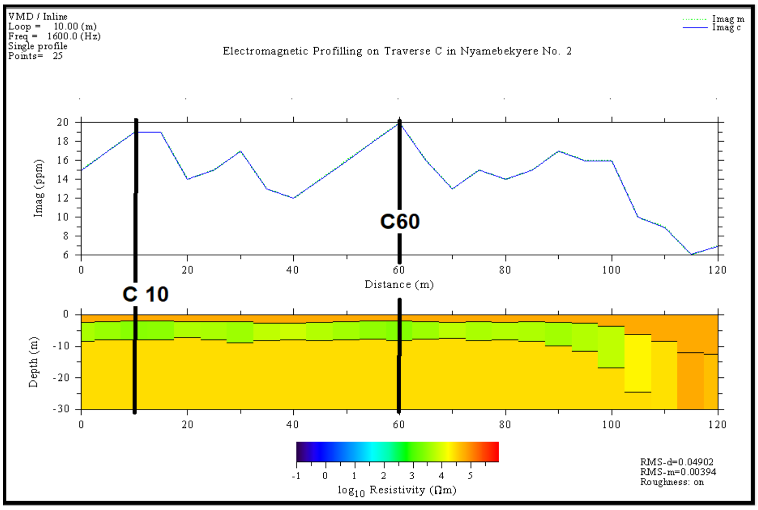

Figure 7. EM inversion result (VD mode) on traverse line C in Nyamebekyere No. 2.

A total of 10 points were recommended for further investigation using the electrical resistivity sounding method across the two towns. Six points in Beseadze and four points in Nyamebekyere No. 2. were investigated for the groundwater.

VES inversion results of the Beseadze data revealed a general 3 – layered structure, although one point revealed a 4 – layered structure. Some of the results from points investigated in this town are given in Figures 8 and 9. The layer 1 has thicknesses ranging from 0.48 – 7.42 m and resistivity values between 71.93 – 2399.70 Ωm. The layer 2 has thicknesses ranging between 4.22 – 20.87 m and resistivity values ranging between 41.96 – 1132.50 Ωm. The bedrock has resistivity values from 948.63 – 861250.57 Ωm.

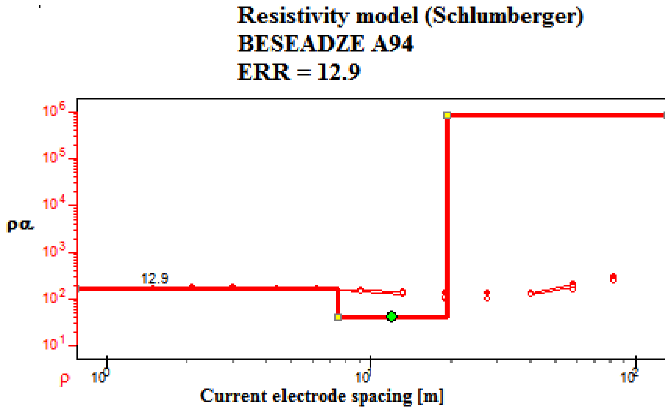

Figure 8. VES inversion results at point A94 on traverse A in Beseadze.

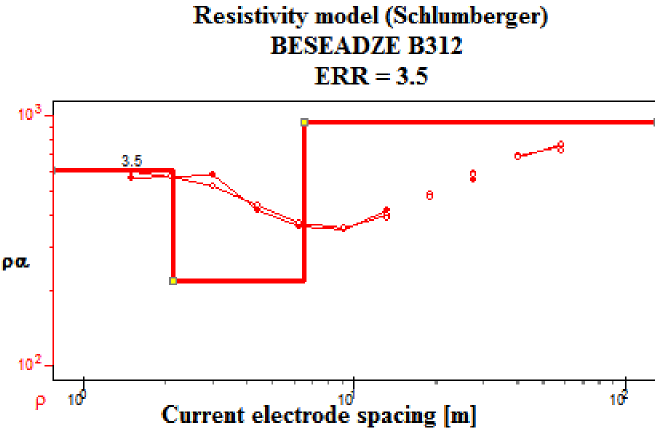

Figure 9. VES inversion results at point B312 on traverse B in Beseadze.

Table 1 and Figure 10 give the summary of the VES results in Beseadze. The ranking of the investigated points is also provided in the Table 1. It is inferred from the VES inversion results that the aquifer might intercept within the layer 2 for points A94, A196, B138, B240 and B312. The aquifer at point A134 might be within layer 3. The depth to the aquifer within this town is between 0.48 m to 7.42 m. The average thickness of the aquifer is about 12.85 m.

Table 1. Summary of VES inversion results from points in Beseadze

VES Point	Layer	ρ(Ω-m)	Thickness (m)	Depth (m)	Location (GPS)	Rank
A94	1 2 3	169.79 41.96 861250.57	7.42 11.90 -	0.00 7.42 19.33	5.65607N 1.56321W	1st
A196	1 2 3	2399.70 484.65 1021.67	0.48 20.87 -	0.00 0.48 21.35	5.65554N 1.56294W	2nd
A134	1 2 3 4	508.75 1132.50 508.93 2066.15	0.54 4.22 18.39 -	0.00 0.54 4.76 23.12	5.65586N 1.56316W	3rd
B240	1 2 3	71.93 522.62 2790.38	3.86 11.00 -	0.00 3.86 14.86	5.65768N 1.56323W	4th
B312	1 2 3	145.98 542.13 3868.06	0.56 10.59 -	0.00 0.56 11.15	5.65816N 1.56318W	5th
B138	1 2 3	609.40 219.24 948.63	2.15 4.35 -	0.00 2.15 6.50	5.65673N 1.56332W	6th

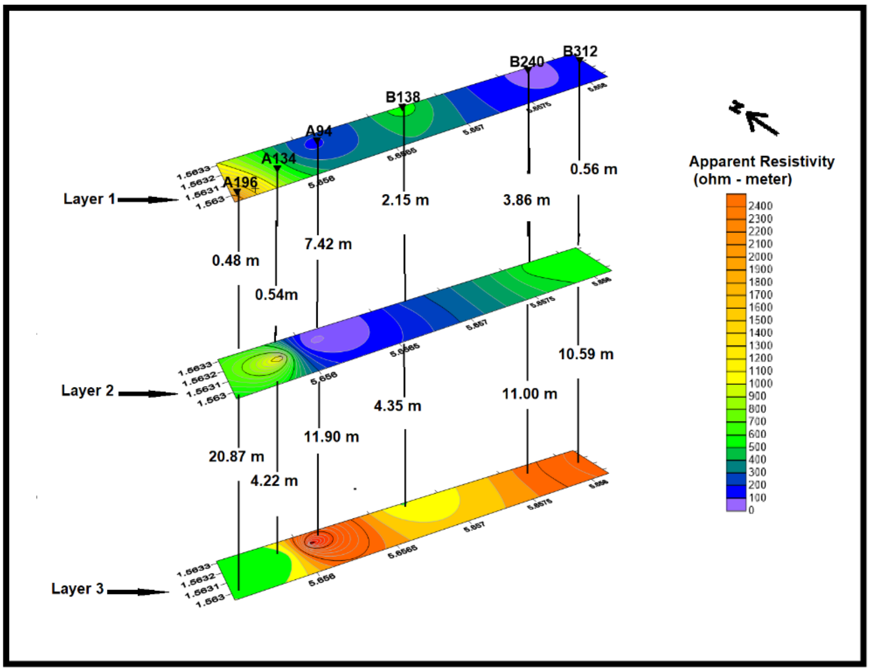

Figure 10. Summary of VES inversion results from points in Beseadze.

VES investigation results from Nyamebekyere No.2 revealed a general 4 – layered structure, although point C10 revealed a 3 – layered structure. Some of the VES inversion results from Nyamebekyere No. 2 are presented in Figures 11 and 12. The layer 1 has thicknesses ranging from 0.58 – 0.90 m and resistivity values between 282.26 – 907.32 Ωm. The layer 2 has thicknesses ranging between 1.77 – 19.97 m and resistivity values ranging between 119.42 – 1996.12 Ωm. The layer 3 has thicknesses ranging between 6.00 – 17.36 m and resistivity values ranging between 298.91 – 694.29

Ωm. The bedrock has resistivity values from 915.78 – 1854.60 Ωm.

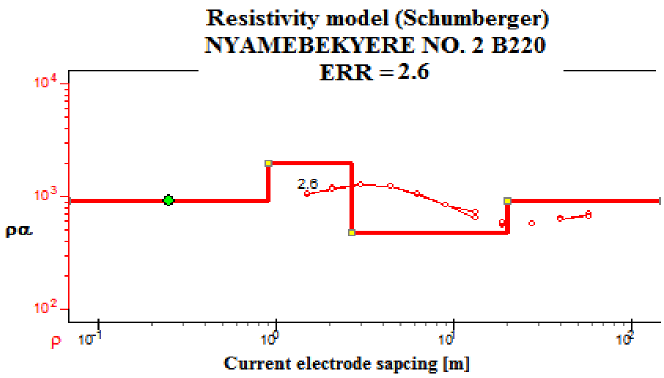

Figure 11. VES inversion results at point B220 on traverse B in Nyamebekyere No. 2.

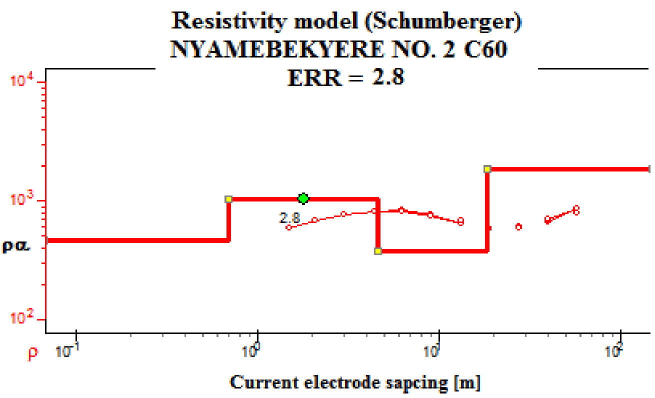

Figure 12. VES inversion results at point C60 on traverse C in Nyamebekyere No. 2.

Table 2 and Figure 13 present the summary of the VES results in Nyamebekyere No. 2. The ranking of the investigated points is also provided in the Table 2. The GPS coordinates of two points are absent and hence were not indicated on the resistivity map in Figure 13. Point S1 (which is a location of borehole within the area) was included in the resistivity map. Generally, from the VES inversion results the aquifer within this study area might intercept within layer 2 and 3. The depth to the aquifer within this town is between 0.58 m to 0.90 m. The average thickness of the aquifer is about 16.71 m.

Table 2. Summary of VES inversion results from points in Nyamebekyere No. 2.

VES Point	Layer	ρ (Ω-m)	Thickness (m)	Depth (m)	Location (GPS)	Rank
C60	1 2 3 4	458.08 1028.99 376.36 1854.60	0.69 3.93 13.80 -	0.00 0.69 4.63 18.43		1st
B220	1 2 3 4	907.32 1996.12 481.88 915.78	0.90 1.77 17.36 -	0.00 0.90 2.67 20.03	5.71982N 1.63311W	2nd
B300	1 2 3 4	282.26 119.42 298.91 1753.24	0.79 4.00 6.00 -	0.00 079 4.79 10.79	5.72037N 1.63356W	3rd
C10	1 2 3	621.40 694.29 1627.76	0.58 19.97 -	0.00 0.58 20.56		4th
S1	1 2 3 4	1334.00 755.95 173.65 8689.18	1.58 3.28 8.55 -	0.00 1.58 4.85 13.40	5.72046N 1.63331W	Drilled borehole

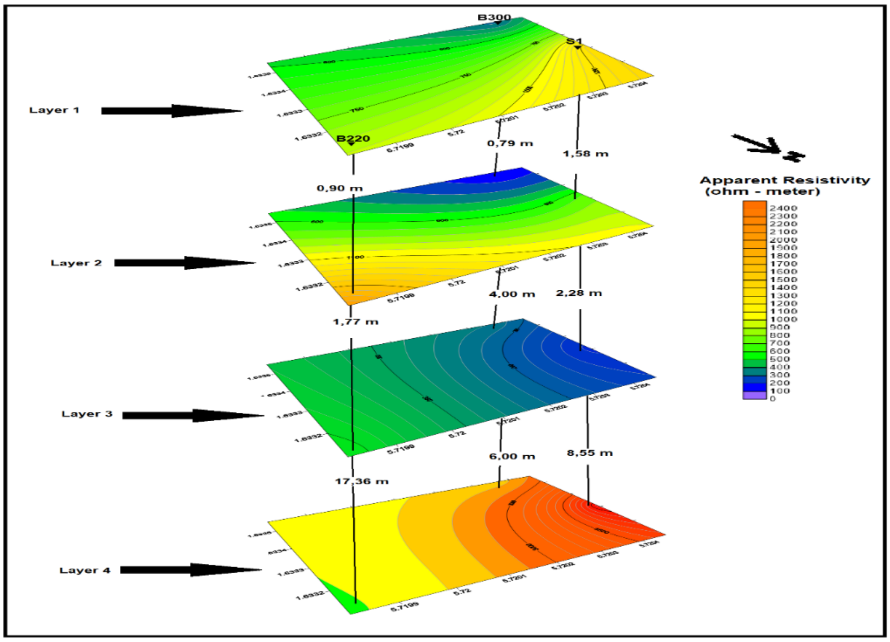

Figure 13. Summary of some VES inversion results from points in Nyamebekyere No. 2.

In this work, the EM profiling and the short resistivity profiling delineate the geological setting at shallow depth while the VES delineate the geological layers at a deeper depth than the two profiling methods. It was inferred that the layers revealed by the profiling results are the layer 1 and part of layer 2 of is revealed by the VES results. Both the EM profiling and the short resistivity profiling results perfectly correlated with the VES results.

Generally, the geophysical results from the different method correlated and they help in determining the points in the town that have high groundwater potential. It is recommended the ranking of the point is considered for borehole drilling.

Conclusion

This work reported a practical use of the inversion to process and interpret EM profiling data. The EM profiling results assisted in choosing points for further investigation using vertical electrical sounding technique. The use of multi-geophysical methods for groundwater exploration saves time and resources and reduce ambiguous interpretation of the results. In the absence of funds for 2D or 3D hydrogeological investigation, these two methods would be enough to prospect for groundwater.

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References

Binley, A, (2003) *ProfileR*. Lancaster, England: Lancaster Environment Centre, Lancaster University.

Boiero, D, Godio, A, Naldi, M,Yigit, E, (2010) Geophysical investigation of a mineral groundwater resource in Turkey. *Hydrogeology Journal*, *18*(5), 1219–1233. https://doi.org/10.1007/s10040-010-0604-2

Carrasquilla, AA, Gonçalves, C, Ulugergerli, E (2007) Evaluating the performance of difference geophysical methods for groundwater prospecting in Espirito Santo Basin - Southeast Brazil. *Tecnociencia*, *9*(2), 89–106.

Cull, JP, Massie, D, (2002) Aquifer Mapping and Groundwater Guality in Faults and Fractures. *Exploration Geophysics*, *33*(2), 122–126.

Ehinola, OA, Opoola, AO, Adesokan, HA, (2006) Empirical analysis of electromagnetic profiles for groundwater prospecting in rural areas of Ibadan, southwestern Nigeria. *Hydrogeology Journal*, *14*(4), 613–624. https://doi.org/10.1007/s10040-005-0468-z

Ewusi, A, Kuma, JS, (2011) Calibration of Shallow Borehole Drilling Sites Using theElectrical Resistivity Imaging Technique in the Granitoidsof Central Region, Ghana. *Natural Resources Research*, *20*(1), 57–63. https://doi.org/10.1007/s11053-010-9129-6

Gyamera, EA, Kuma, JS, (2014) *Hydrogeological studies on soils developed over granitic deposits*. *2*, 29–40. doi.org/10.33500/ijaar.2014.02.003

Kesse, GO, (1985) *The mineral and rock resources of Ghana*. Rotterdam, Netherlands: A. A. Balkema.

Mohammed Nazifi, H, Gülen, L, (2019) The use of electromagnetic and vertical electrical sounding methods in groundwater exploration, *Bulletin of the Mineral Research and Exploration*, *158*, 327–344. https://doi.org/10.19111/bulletinofmre.451557

McNeill, J, (1980) Electromagnetic Terrain Conductivity measurement at Low induction Number, Ontario, Canada. Available at: http://www.geonics.com/pdfs/technicalnotes/tn6.pdf.

Nascimento Da Silva, CC, De Medeiros, WE, De Sá, EFJ, Neto, PX, (2004) Resistivity and ground-penetrating radar images of fractures in a crystalline aquifer: A case study in Caiçara farm - NE Brazil. *Journal of Applied Geophysics*, *56*(4), 295–307. https://doi.org/10.1016/j.jappgeo.2004.08.001

Pirttijärvi, M, (2014) *AEMINV, Laterally constrained 1-D inversion of EM profile data*. Oulu, Finland.

SDWF, (2021) Groundwater fact sheet. Retrieved August 01, 2021 from *Safe Drinking Water Foundation Website*: https://www.safewater.org/fact-sheets-1/2017/1/23/groundwater#

Sharma, SP, Baranwal, VC (2005) Delineation of groundwater-bearing fracture zones in a hard rock area integrating very low frequency electromagnetic and resistivity data. *Journal of Applied Geophysics*, *57*(2), 155–166. https://doi.org/10.1016/j.jappgeo.2004.10.003

Tsikudo Kwasi, B, (2009) Geophysical investigation for groundwater in the Gushiegu-Karaga and Zabzugu-Tatale districts of the northern region of Ghana using the electromagnetic method. *Kwame Nkrumah University of Science and Technology, Kumasi(*unpublished*).*

Venkateswaran, S, Prabhu, MV, Karuppannan, S, (2014) Delineation of Groundwater Potential Zones Using Geophysical and GIS Techniques in the Sarabanga Sub Basin , Cauvery River , Tamil Nadu , India. *Int. J. Curr. Res. Aca. Rev.*, *2*(1), 58–75. doi=10.1.1.449.3797&rep=rep1&type=pdf

Zohdy, AAR, Eaton, GP, Mabey, DR, (1990) Application of Surface Geophysics to Ground-Water Investigations. In *Techniques of Water-Resources Investigations of the United States Geological Survey* (p. 116). Retrieved from http://pubs.usgs.gov/twri/twri2-d1/pdf/TWRI_2-D1.pdf

Zohdy, AAR, Jackson, DB, (1969) Application of Deep Electrical Sounding for Groundwater Exploration in Hawaii. *Geophysics*, *34*(4), 584–600. doi:https://doi.org/10.1190/1.1440033