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Vertical Electrical Sounding Survey for Groundwater Exploration for Rural Water Supply in Parts of Ketu South in the Volta Region of Ghana

Patrick Adadzi[1*], Harrison Coffie[2], Emmanuel Afetorgbor[1] and Mohammed Takase[3]

[1]*Department of Civil Engineering, Faculty of Engineering, Ho Technical University, Ho, Ghana*

[2]*Department of Building Technology, Faculty of Built Environment, Ho Technical University, Ho, Ghana*

[3]*Department of Environmental Science, School of Biological Sciences, University of Cape Coast, Cape Coast, Ghana*

[*]**Corresponding author:** P. Adadzi, Department of Civil Engineering, Faculty of Engineering, Ho Technical University, Ho, Ghana, Tel: +233245142414; E-mail address: pcadadzi@gmail.com

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Abstract

Hydrogeological investigations and geophysical surveys are important methods in many subsurface characterization studies. This work examines the importance of geophysical surveys in the construction and development of boreholes to provide portable drinking water to rural communities. The paper discusses the interpretation of subsurface features that can be used to assist in the evaluation of groundwater resources in a typical rural area. Lack of infrastructure in these areas is a constraint on borehole drilling due to limited subsurface data availability. Vertical Electrical Sounding (VES) stations were established to investigate the subsurface geology and aquifer potentials in the study area. VES technique was performed by measuring the resistivity change with depth. The resistivity measurements were conducted using ABEM SAS 100C Terrameter by using Schlumberger electrode configuration. The hydrogeological information obtained by the methods discussed in this paper can be used as estimates of the depth of groundwater, aquifer geology, and recharge and discharge zones. The objective of the study was to provide guidelines with sufficient data and information to evaluate borehole options and future borehole drilling and development campaigns in typical rural settings.

Keywords: Hydrogeology; Geophysics; Borehole drilling; Vertical electrical sounding

Introduction

The widespread development of groundwater is the only affordable and sustainable way of improving access to clean water and meeting the Millennium Development Goals for water supply. The reliance on groundwater is such that it is necessary to ensure that there are significant quantities of water and that the water is of a high quality. The use of geophysics for both groundwater exploration and for water quality evaluations has increased dramatically over the years due to the rapid advances in technology and associated numerical modelling solutions. Groundwater applications of near-surface geophysics include mapping the depth and thickness of aquifers, mapping aquitards or confining units, locating preferential fluid migration paths such as fractures and fault zones and mapping contamination to the groundwater such as that from saltwater intrusion.

Borehole drilling and development requires information on hydrogeological assessment and it is a big constraint in regions with little infrastructure and limited or no technical resources. Geophysical techniques enable the detection, monitoring and visualization of subsurface characteristics indirectly and non-invasively from the surface. The information obtained may relate to shallow conditions (e.g. in the active layer), or to material properties several tens to hundreds of meters below the surface. The methods rely on mathematical inversion of data measured at the surface to yield geophysical model parameters at greater depth, for instance, specific resistivity, seismic or electromagnetic wave velocity, or permittivity. Electrical resistivity tomography (ERT), also called electrical resistivity imaging, electromagnetic (EM) induction, ground-penetrating radar (GPR) and refraction seismics are the most common techniques.

According to Bridge et al [1], aquifer characterization should ideally involve the following steps: (1) analysis of borehole logs, cores, and hydraulic testing data to determine the sedimentological nature and origin of the strata, and their hydraulic properties; (2) stratigraphic correlation of boreholes logs and cores in order to assess the lateral continuity of distinctive sediment types (facies) between boreholes; (3) use of geophysical profiles to assess the orientation and structural continuity of sequences of strata, and to recognize distinctive geophysical patterns that can be related to distinctive sedimentary facies; (4) modelling of the geometry and distribution of sedimentary facies in the volume between boreholes, and (5) distribution of properties such as porosity and permeability as a function of sedimentary facies. The theoretical and practical background to geophysics has been extensively reviewed and can be studied in standard text on the subject, for example: Kearey & Brooks, Telford et al, Parasnis, Dobrin,Grant and West [2-6]. Basic outlines of geophysical methods are also given in standard hydrogeology text such as that by Fetter [7]. Groundwater and near surface investigations in particular have been specifically covered in some detailed in recent text by Reynolds, Milsom [8,9].

General methods of practice have been produced for geophysical techniques in groundwater exploration but as MacDonald et al. point out, situations with complex geology and hydrogeology do not lend themselves to the generic approach and require specific targeting of methods for particular problems [10,11]. Most geophysical techniques have been used for groundwater characterisation but once again it is with the electrical and electromagnetic methods that the greatest success has been shown in directly mapping and monitoring contaminated and clean groundwater.

The direct-current (DC) electrical resistivity method for conducting a vertical electrical sounding (VES) has proved very popular with groundwater studies due to the simplicity of the technique and the ruggedness of the instrumentation. An excellent example of the use of the technique was shown in a survey for a rural water supply in Ghana. The use of geophysics for groundwater studies has been stimulated in part by a desire to reduce the risk of drilling dry holes and also a desire to offset the costs associate with poor groundwater production. Today

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the geophysicist also provides useful parameters for hydrogeological modelling of both new groundwater supplies and for the evaluation of existing groundwater contamination.

Before the VES were used with a failure rate of over 82% recorded for boreholes. With the geophysics and a combination of geological and photogeological inspection this was dramatically reduced to less than 20% failure. Van Overmeeren showed the use of electrical measurements in mapping boundary conditions in an aquifer system in Yemen [12]. Beeson and Jones, Olayinka and Barker, Hazell et al., Barker et al., Carruthers and Smith all have demonstrated the use of electrical techniques for siting wells and boreholes in crystalline basement aquifers throughout sub-Saharan Africa [13-17]. Other similar examples are given by Wurmstich et al., Yang,Yang et al. [18-20]. Sauck and Zabik have demonstrated a development of the sounding technique by conducting azimuthal surveys [21]. This method was successfully used to assess the directional variation in hydraulic conductivity of glacial sediments in Switzerland. The vertical sounding techniques are typically limited in the near surface to exploration depths less than 50m due to the spacing of the electrodes and the strength of currents required [22].

Recent advances in technology have led to developments in electrical techniques that have opened up the possibility of conducting true 2D geo-electric cross-sections and more experimentally 3D volumes [16]. The 2D geo-electric methods are very effective at measuring sections down to 10m with some recent results shown from deeper penetration. Results for electrical surveys are usually presented as geo-electric, conductivity or resistivity sections, line profiles or maps and volumes. A good example of this for groundwater exploration is shown by Dahlin and Owen using 2D resistivity surveys with an ABEM Lund Imaging System together with ground penetrating radar in shallow alluvial aquifers in Zimbabwe [23].The results were used to build conceptual geological/hydrogeological models of the aquifers as a basis for guiding the drilling programme.

Most recent surveys tend not to rely on the electrical method alone for data but rather to integrate it with other geophysical techniques. Examples of the multi-technique approach using electrical and electromagnetic techniques include those by Beeson and Jones, Zonge et al., Bartel, Buselli et al., Hazell et al., Saksa and Paananen, Sorensen and Sondergaard, van Overmeeren et al.[12,13,15,24-30].

Materials and Methods

The direct-current (DC) electrical resistivity method for conducting a vertical electrical sounding (VES) has proved very popular with groundwater studies due to the simplicity of the technique and the ruggedness of the instrumentation. The geoelectrical survey was carried out using the following equipment acquired from the Geological Survey Department of Ghana. In the research work, the Schlumberger array was adopted. Terrameter SAS 100C, coiled wire, measuring tape, hammer, GPS, current and potential electrodes, and D.C. battery (12volts), were the equipment used for the survey is.

Study area

The study area is Eleme community located between Weta and Abor along the main Akatsi – Aflao trunk road. The topography is generally flat with topographic heights not exceeding 100m above sea level. The area falls under wet semi-equitorial climatic regions with double rainfall maxima [31]. Figure 1 below shows the study area with surveyed traverses.

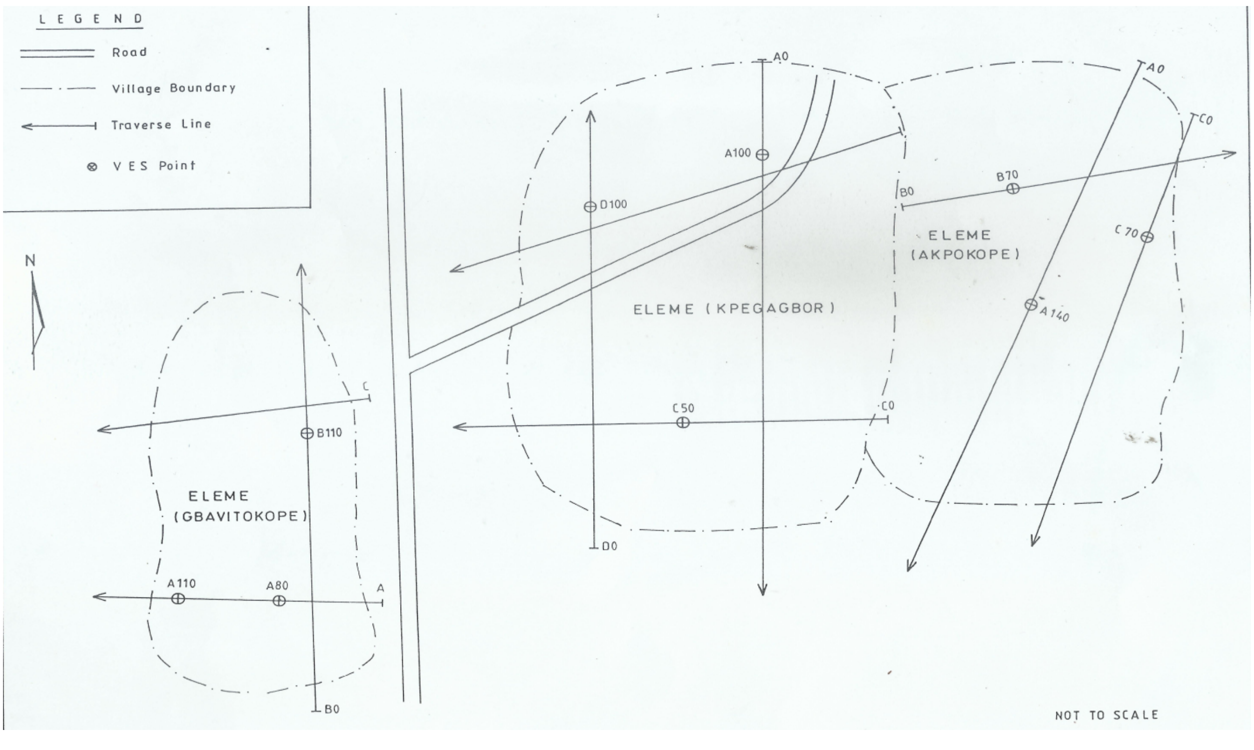

Figure 1: Layout of Eleme study area Community showing traverse lines and VES points

Field Investigations

Reconnaissance survey: The objective of the reconnaissance survey was to select suitable target areas for geophysical survey which was carried out with community leaders and other stake holders. The activities undertaken were:

- Verification of photo-lineaments in the field
- Geomorphological survey of areas identified on topographic maps, that have the potential of hydrogeological significance were observed
- Determination of direction of traverse lines for geophysical survey

Selection of traverse lines: A total of ten (10) traverse lines whose lengths ranged from 200m and 350m were cut in the community (Figure 1). Three (3) traverse each labeled A-C were cut in two of the suburbs, while four were cut in one on the suburbs. In Eleme Gbavitikope suburb, 3 traverses, labeled A-C totaling 950m were surveyed. At Akpokope suburb, 3 traverses totaling 950m were surveyed and at Kpegagbor a total traverse length of 1000m was surveyed on 4 different traverses. All the 10 traverses were chosen to run in the NE-SW and E-W directions. The rational was to intercept the expected trend of the predominating NW-SE lineaments of the area. At the end of the survey, metal pegs were placed at the beginning and end of each traverse line as well as all the points selected for VES. The VES points were identified by inscriptions (say, D150 to indicate that the VES was conducted on Traverse D, and at the point 150m on the traverse line).

Geophysical survey

The geophysical survey consisted of resistivity profiling and vertical electrical sounding (VES). The ABEM terrameter SAS 1000C which is more sensitive and has a relatively higher degree of accuracy was used for the resistivity measurements.

Resistivity profiling

Resistivity profiling was carried out along all the nine traverse lines using the Schlumberger configuration. Two depths of 19m and 40m were investigated, using electrode separation of (L/2, a/2) given by (19m, 0.5m) and (40m, 5m). The traverse lengths varied between 200-350m with total length of 2,900m. The electrode arrays (19m, 0.5m) and (40m,5m) were assumed to probe the weathered layer and bedrock respectively. The length and bearing of each traverse line at the three suburbs are indicated in table 1.

Area	Traverse	Length (m)	Bearing(o)
Gbavikope	A	350	180
	B	300	270
	C	300	180
		950	
Akpokope	A	350	180
	B	300	140
	C	300	220
		950	
Kpegagbor	A	300	130
	B	250	210
	C	200	030
	D	250	270
		1000	

Table 1: Resistivity profiling traverse lines.

Selection of VES points: The profiling results were plotted on a linear scale, and preliminary interpretation was carried out to select points for VES. The VES points were restricted to areas where relatively lower apparent resistivities were recorded on the horizontal profiles. In all 9 points were selected for VES in the study area. Three of them were selected in each of the three suburbs. For easy identification, the VES points were marked with metal pegs in the field.

Vertical electrical sounding (VES): Vertical electrical sounding (VES) was carried out with the aim of determining the formation resistivities and the depth to bedrock, as well as finding the possibility of obtaining fractures at depth at the sounding points. It was carried out using the Schlumberger electrode configuration and expanding procedure. Data control was ensured by plotting the VES results in the field as VES measurements were in progress. Values which appeared to be unreasonable, and registered high standard deviations greater that unity were rejected at the same spot several times until standard deviation was less than unity. The Schlumberger method that was uses the expansion procedure was adopted for the VES.

Results and Discussions

Geophysical Survey

The resistivity profiling result are shown in profiling response curves presented in Figure 1 below.

Resistivity Profiling

The interesting feature of resistivity profiling interpretation is the identification and selection of anomalous points or zones. These anomalous points or zones generally have resistivity values below the average resistivity values along a given profile. On the average, the measured apparent resistivity values for the (19m, 0.5m) and (40m, 5m) were high to medium. Values ranging between 9.0 ohm-m and 2,164.0 ohm-m, and averaging 78.0 ohm-m were recorded. The general medium resistivity values recorded in the community could indicate high overburden thickness and high weathering and fracture development conditions in the area. It could also signify a geological formation with high clay content. The groundwater potential in this community could be variable. It could be low if the low resistivity values are due to high clay content. On the other hand, the groundwater potential could be high if the medium to low apparent resistivity values in the area is due to fracture and weathering development.

Gbavitokope Area: Traverse A at Eleme-Gbavitokope had a total traverse length of 350m. The bearing was 180o. The measured apparent resistivity values ranged between 22.7 and 149.0 ohm-m with a mean of 69.7 ohm-m for the (19m, 0.5m) separation. For the (40m, 5m) separation, the measured apparent resistivity values were relatively lower, and ranged between 9.0 ohm-m and 78.7 ohm-m with a mean of 40.6 ohm-m. Lower resistivity values were recorded with the (40m, 5m) than the (19m, 0.5m) separation along the traverse, and this is an indication of high conductance with increasing depth. Considering the low to medium resistivity values along the entire traverse, two points, namely A(80m) and A(110m) were selected along the traverse for VES.

Traverse B at Eleme – Gbavitokope had a total traverse length of 300m, and was on the bearing of 270o. For the (19m, 0.5m) electrode separation, the measured apparent resistivity values ranged between 31.7 ohm-m and 155.3 ohm-m with a mean of 59.7 ohm-m. For the (40m, 5m) separation, the measured apparent resistivity values were relatively higher, and ranged between 29.20 ohm-m and 78.71 ohm-m with a mean of 42.40 ohm-m. One point, namely B(110m) was selected along the traverse line for further investigation.

Traverse C at Eleme-Gbavitokope had a total length of 300m, and was on the bearing 180o. Resistivity values recorded along this traverse were in the range of 376.3 ohm-m and 2,164.3 ohm-m with a mean of 1,200.0 ohm-m for the (19m, 0.5m) separation. For the (40m, 5m) electrode separation, the measured apparent resistivity values were slightly lower and ranged between 274.1 ohm-m and 549.2 ohm-m, with a mean of 537.9 ohm-m. As a result of the relatively high resistivity values recorded on this traverse, no point was selected on this traverse for VES. The resistivity response curves are all shown in figure 2.

Figure 2: Resistivity Response Curve of Traverses at Eleme-Gbavitokope.

Akpokope area: Traverse A at Eleme-Akpokope had a total traverse length of 350m and the bearing was 180o. The measured apparent resistivity values were low to medium and ranged between 17.0 and 105.4 ohm-m with a mean of 62.1 ohm-m for the (19m, 0.5m) electrode separation. For the (40m, 5m) electrode separation, the measured apparent resistivity values were relatively lower and uniform. Resistivity values ranged between 26.7 ohm-m and 74.2 ohm-m with a mean of 41.6 ohm-m. Lower resistivity values indicating high conductance at depth were recorded with the (40m, 5m) than the (19m, 0.5m) separation along the traverse. Considering the low medium resistivity values along the entire traverse, one point, namely A (140m) was selected along the traverse for VES.

Traverse B at Eleme-Akpokope had a total traverse length of 300m, and was on a bearing of 140o. The measured apparent resistivity values ranged between 22.7 ohm-m and 91.8 ohm-m with a mean of 48.5 ohm-m for the (19m, 0.5m) electrode separation. For the (40m, 5m) electrode separation however, the measured apparent resistivity values were relatively lower, and ranged between 28.7 ohm-m and 78.2 ohm-m with a mean of 41.9 ohm-m. The point B(70m) that indicated the lowest resistivity value was selected for VES.

Traverse C at Eleme-Akpokope had a total length of 300m with a bearing of 220o. Resistivity values recorded were medium and uniform. Recorded resistivity values ranged between 39.7 ohm-m and 194.9 ohm-m with a mean of 64.8 ohm-m for the (19m, 0.5m) electrode separation. For the (40m, 5m) electrode separation, the measured apparent resistivity values were slightly lower and ranged between 32.2 ohm-m and 73.7 ohm-m, with a mean of 51.6 ohm-m. One point, namely C (70m) was selected from this traverse for VES. The resistivity response curves are all shown in figure 3.

Figure 3: Resistivity Response Curve of Traverses at Eleme-Akpokope.

Kpegagbor area: Traverse A at Eleme-Kpegagbor has a total traverse length of 300m. The bearing of this traverse was 130o. The measured apparent resistivity values ranged between 24.9 ohm-m and 408.0 ohm-m with a mean of 87.9 ohm-m for the (19m, 0.5) electrode separation. For the (40m, 5m) electrode separation, the measured apparent resistivity values were relatively lower, and ranged between 29.7 ohm-m and 108.9 ohm-m with a mean of 56.6 ohm-m. Lower resistivity values were recorded with the (40m, 5m) that the (19m, 0.5m) electrode separation, and this is an indication of high conductance at depth. Considering the low to medium resistivity values along the entire traverse, one point, namely A(100m) was selected along the traverse for further investigation by VES.

Traverse B at Eleme-Kpegagbor has a total traverse length of 250m, and was on the bearing of 210o. The measured apparent resistivity values ranged between 37.1 ohm-m and 146.2 ohm-m with a mean of 84.3 ohm-m for the (19m, 0.5m) electrode separation. With the (40m, 5m) electrode separation however, the measured apparent resistivity values were relatively lower, and ranged between 29.7 ohm-m and 75.2 ohm-m with a mean of 57.5 ohm-m. No point was selected for this traverse for VES.

Traverse C at Eleme-Kpegagbor was on the bearing of 030o and had a total traverse length of 200m. Recorded apparent resistivity values were medium to low, and were in the range of 39.7 ohm-m and 183.6 ohm-m with a mean of 62.6 ohm-m for the (19m, 0.5m) electrode separation. With the (40m, 5m) electrode separation, the measured apparent resistivity values were lower and ranged from 27.2 ohm-m to 75.2 ohm-m, with a mean of 49.4 ohm-m. As a result of the relatively lower resistivity values along this traverse than the others, one point, namely C(50m) was selected for VES.

Traverse D at Eleme-Kpegagbor has a total traverse length of 250m and was on the bearing of 270o. The measured apparent resistivity values ranged between 30.6 ohm-m and 143.9 ohm-m with a mean of 84.5 ohm-m for the (19m, 0.5m) electrode separation. The (40m, 5m) electrode separation had measured apparent resistivity values relatively lower, ranging between 22.3 ohm-m and 85.1 ohm-m with a mean of 42.7 ohm-m. Lower resistivity values were recorded with the (40m, 5m) than the (19m, 0.5m) electrode separation and this in an indication of high conductance at depth. Considering the low to medium resistivity values along the entire traverse, and especially for the (40m, 5m) separation, one point, namely D(100m) was selected for VES. The resistivity response curves are all shown in figure 4.

Vertical Electrical Sounding (VES)

On the basis of the the interpretation of resistivity profiling results, the points A(80m), A(110m), and B(110m) were selected for VES for Eleme – Gbavikope. The points A(140m), B(70m) and C(70m) were selected for VES for Eleme – Akpokope, while at Eleme – Kpegagbor, the points A(100m), C(50m) and D(100m) were selected for VES. The VES results of the nine (9) selected points were analyzed using SONDEL computer analysis and ranked are presented in table below.

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Figure 4: Resistivity Response Curve of Traverses at Eleme-Kpegagbor.

Selection of potential drilling points: The selection of points for test drilling was done by taking into consideration the thickness of the various layers on the subsurface structure, their corresponding apparent resistivity from the analysis of VES results as well as accessibility of the sites to accommodate the drilling rig and its accessories. The ranking of the VES points in order of preference for drilling is presented in table 2 below.

LOCATION	RANK	VES POINT	LAYER	DEPTH (m)	APPARENT RESISTIVITY (ohm-m)
Eleme - Gbavitikope	1		1	1.7	107
			2	3.2	239
			3	36	26
			4	-	363
	2		1	2.3	2741
			2	16.7	62
			3	42.7	14
			4	-	289
	3		1	2.0	847
			2	14.3	65
			3	68.0	25
			4	-	87
Eleme - Akpokope	1		1	2.1	120
			2	14.8	67

			3	46.1	23
			4	-	115
	2		1	1.7	103
			2	17.2	58
			3	67.2	38
			4	-	32
	3		1	1.2	45
			2	2.0	9
			3	53.1	25
			4	-	223
Eleme - Kpegagbor	1		1	3.4	218
			2	27.7	72
			3	59	16
			4	-	116
	2		1	4.4	372
			2	6.2	100
			3	-	56
	3		1	3.6	115
			2	46.8	35
			3		91

Table 2: Rank list of VES points for drilling.

Based on the results of the computer analyses, the study area is underlain predominantly by three sub-surface geological formations. The first layer is predominantly made up of sandy clay with clay formation. It has a mean thickness of 4.1m (3.4-4.4m). The resistivity of this layer varies between 115.0 ohm-m and 372.0 ohm-m. The second layer is a relatively lower resistivity soil formation whose resistivity values lies between 35.0 ohm-m and 100.0 ohm-m. The thickness of the second layer ranged between 6.2m and 46.8m. It is presumed to be completely weathered formation comprising of clay and minor sand. The third layer is the highly weathered and fractured schist and gneiss rock formation which lies beyond and average depth of 27.0m below ground level. The resistivity of this layer is relatively low, and ranged between 16.0 ohm-m and 91.0 ohm-m. The fourth layer is the slightly weathered gneiss formation with medium resistivity value up to 363.0 ohm-m. The medium to low resistivity values of the bedrock indicates that the layer has the potential of yielding additional groundwater to the other layers.

Conclusions and Recommendations

Based on the analysis of the entire results, and in line with the objectives of the study, the following conclusions were drawn:

- Eleme community is underlain basically by Dahomeyan gneisses and Schists with thick clay and sand overburden
- The thickness of the clay/land overburden is estimated to be about 30m
- The formation has undergone varying degrees of weathering which control groundwater occurrence and accumulation
- Groundwater potential could be medium.
- Based on the studies, the following recommendations were made:
- One point should be drilled at each suburb to confirm the existence of aquifer system at the area. At Gbavitikope suburb, the point B(110m) should be drilled, with the point A(110m) as the alternative drilling point. At Akpokope suburb, drilling should be done at the point A(140m) with point C(70m) as the alternative drilling point. At Kpegagbor area, the point A(100m) should be drilled and point D(100m) as the alternative.
- Borehole depth in this community should be between 55 and 65m below ground level.
- Due to recorded low resistivity values with increasing depth, mud-drilling technique is recommended.

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