The Use of Electrical Resistivity Survey for Groundwater Exploration in Ga West Municipality, Greater Accra Region, Ghana

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Abstract: ***In Ga West Municipal Assembly of Ghana, lack of potable water in both urban and rural communities necessitated the need for groundwater exploration in 11 communities. For this purpose, 1-dimensional electrical resistivity profiling and vertical electrical sounding were carried out in these communities using ABEM Terrameter SAS 300C.The Schlumberger electrode array was used for both electrical resistivity profiling and vertical electrical sounding.While the electrical resistivity profiling led to the identification of 31 anomalous pointsfor vertical electrical sounding, the modeled results of the 31 anomalous point led to identification of 3, 4 and 5-layer subsurface structures characterized by A, H, K, AA, KH, QH and HKH- types resistivity curves. The H-type is the most dominant and occurred mostly in areas underlain by granite of the Birimian Granitites whileK-type is associated withOfankor Market, underlain by Togo Structural Units.Analyzed results showed that apparent resistivity for first layer values varied from 38.8 Ω m at Ebenezer (A 4) to 1624.6 Ω m at Dedeiman (A 80); intermediate layers had apparent resistivities that changed from 10.0 Ω m (A 35, Adom) to 2494.4 Ω m (A 80, Dedeiman) while bedrock apparent resistivity values varied from 50.4 Ω m (A 28, Dedeiman) to 1613.4 Ω m (A 43, Ntafrafra). Thickness of intermediate layersexceeding 9.1 m indicate conductive zone for groundwater occurrence while low(50.5 Ω m)to moderate (813.1 Ω m)bedrock apparent resistivities indicates thepresence of fracture systems within the bedrock and therefore such points were considered suitable for exploitation. While all anomalous points identified at Adom, Ofankor market and Dedeiman are suitable for the construction of tube wells, other suitable points that can be considered for construction of boreholes are B 53 at Saapeiman, B 15 at Ayikai Dobro, either A 30 or A 55 at Tetteh Asofaha, A 120 at Gatsikope, B 25 at Ntafrafra, B 62 at Adjeiman Kpalafia, A 18 at Ebenezer, and A 36 at Atsiato. Anomalous points that may not support the exploitation of groundwater include A 4 at Ebenezer and A 19 at Atsiato, A 169 at Gatsikope, A 59 at Ayikai Dobro, A 30 at Ntafrafra, and A 43 at AdjeimanKpalafia. Thus, there exist at least a point in each community suitable for the construction of boreholes.***

Keywords: Anomalous Point, Vertical Electrical Sounding, Bedrock Apparent Resistivity, fractured bedrock.

1. Introduction

Over the past two decades or so, groundwater has become the most cost-effective means of providing potable water to a large portion of the Ghanaian population living in both rural and urban areas. In Ga West Municipal, city dwellers in new settlement areas most often lack water to meet their domestic water supply. The dire need of water by people living in these areas is due to population growth, rapid construction of houses, inability of government to extend existing pipelines to these areas, high capital cost involvedin the construction of new pipelines among others. In order to provide water for some residents, electrical resistivity was conducted in 11 communities to determine the presence of water-bearing zones within the he basement rocks underlying the communities.

2. Study Area

The study area lies within the Ga West Municipal Assembly which is bounded by longitudes 0˚10.00'W and 0˚24.00'W and latitude 05˚35.00'N and 05 ˚29.00'N and covers an area of approximately 315.4 Km^2.Adom, Ofankor(Asofa) Market, Saapeiman, Dedeiman, AyikaiDoblo, Tetteh Asofaha, Gatsikope, Ebenezer, Ntafrafra, AdjeimanKpalafia, and Atsiatoare the list of eleven communities (Fig.1.0).The vegetation in the study area is Guinea Savanna Grassland. Two wet seasons and one dry season are experienced in the area. The major wet season starts in March and ends in July with peak rain in June. Mean annual rainfall is about 115mm.The minor rainy season starts in late August and ends in early October.The dry season also starts in late September or early October and ends in February.Mean Annual Temperature in the area varied from 28˚C to 31˚C. The hottest month is February while the coolest month is August. Within the dry season, the area experiences a strong northeast trade wind known as Harmattan which affects the entire country (Dickson and Benneh, 1980). Geologically, the area is underlain by the Birimian Supergroup, the Kwahu overlain by the Togo Structural Unit at the eastern and northeastern fringes.The Birimian Supergroup is part of the Eburnean Plutonic Suite of the PaleoproterozoicEra and is made up granitoids as its main rock. The Kwahu Group is made of Kwahu sandstone and theTogo Structural Unit belongs to Neoproterozoic Era with principal rocks mainly made up of sandstones, quartzites, quartzitic sandstone, schist, and shale (Ghana Geological Survey Authority, 2009; Kesse, 1985; Ahmed et al, 1977). The perennial Densu River is the main dendritic drainage system in the area with Adaisu, Honi, Ntafrafra, Tsetsebula, Dobro, Adwenebu, Obabome and Nsaki as the main tributaries.Several existing boreholes within the area have depth not exceeding 100mand yields that varied from0.6 m^3/h to 16.8 m^3/h. Few boreholes within the Birimian Granitoids have depths up to 300m but yieldsrarely exceed 3.0 m^3/h.

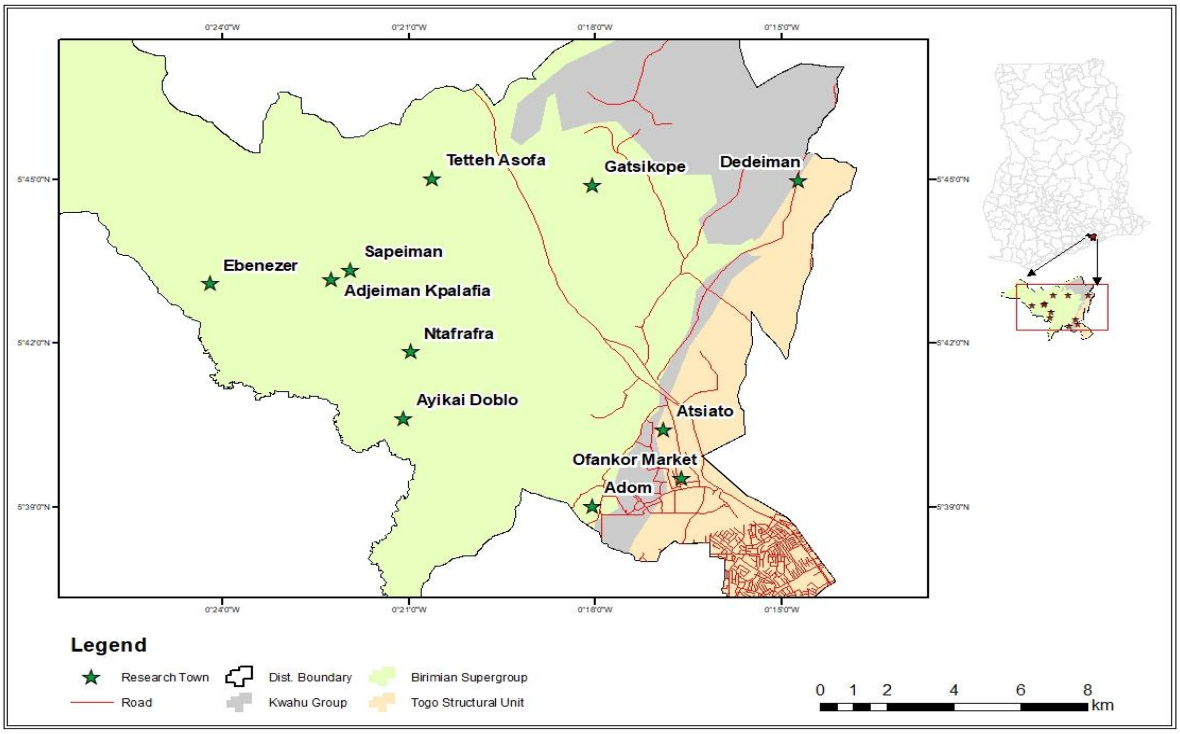

Figure 1: Map Ga West Municipal indicating research communities

3. Method and Material

Electrical resistivity method survey is one the near surface geophysical methods for subsurface investigation (e.g. Telford et al, 1994; Sharma, 2000). It had been used extensively for groundwater exploration (Patil et al, 2015; Gupta et al, 2014; Ahilan and Kumar, 2011; George et al, 2011; Nwankwo et al, 2011; Armada et al, 2009; Oyolabi et al, 2009; Reddy and Raju, 1997; Hazel et al, 1992; Caruthers and Smiths,1992; Giddo et al, 1992; Barker et al, 1981), it had been used for determining groundwater potential (Alabi et al, 2016; Joshua et al, 2011; Nejad, 2009). It has also been used to determine salinity (Holdlur, 2010; Van Overmeeren, 1989), characterize interface between saline water and freshwater (Gupta et al, 2014), and characterize aquifers (Quadif et al, 2012;Majumdar, et all 2011; Tizro et al, 2010; Onu, 2003; Urish and Frohlich, 1990).

In Ghana, it had been used for groundwater exploration (e.g. Ewusi and Kumah, 2011) and is considered the most popular method for groundwater exploration. In this study, the method was used because of it is simple, cost associated with its usage is low and had successfully been used in all geological formation in Ghana for exploring groundwater for most communities that used boreholes as source of potable water.To determine water-bearing zones within the underlying rocks in our study area, electrical resistivity surveys was carried in each of the communities using Schlumberger Electrode Arrays (Sharma 2000; Nath et al, 2000; Lowrie, 1997; Telford et al 1994) with electrode separations given as (AB, MN): (40m, 5m) for electrical resistivity profiling. The essence of using the electrode array: (40m, 5m), was to investigatethe basement rocks of the communities. The ABEM Terrameter SAS 300Cwas used for electrical resistivity profiling and Vertical Electrical Sounding (VES). The Schlumberger electrode arrays were used for both electrical resistivity profiling and vertical electrical sounding to obtain the true resistivity values. Electrical resistivity profiling was carried out at 10 m, 5 m, or 2 m interval depending on the size of public land available in communities. Once anomalous point has been identifiedas anomalous point(s), another electrical resistivity profiling at 2m interval were carried out across the identified point(s) for final selection of point(s) for Vertical Electrical Soundings (VES) for 5 m and 10 m interval profiles. To obtain apparent resistivity for profiling and of VES, the multiplying factors for each electrode spread was used.For vertical electrical soundings, the Schlumberger array with expanding electrode procedure was used. Minimum current electrode spread for vertical electrical soundings for anomalous points varied from 1.5 m to 83 m. Potential electrode spread also changed from 0.5 m to 5 m.Resistivity values were plotted as VES was in progress to obtain the best line of fit so as to obtain the resistivity boundaries of the subsurface conditions.Accuracy of resistivity profilingdata were confirmed by VES data by ensuring that there was no much variation between profiling results at anomalous pointsand corresponding sounding results for the (40 m, 5m) Schlumberger electrode arrays. The final VES apparent resistivity values for each sounding points were imported into Resist Software Program (Vander Velpen, 1988) for modeling. Iterations and curve smoothening of the raw data were done to ensure minimum root mean square (r.m.s)errors were obtained. The Resist software has a limiting value 2.5% as its lowest root mean square error below which it was not possible for further iterations to be carried out on the data sets. Thus, in the process of modeling,iteration was stopped when the r.m.s value was close to 2.5%. In study,a minimum root means square errors2.45 % wasobtained. The modeled results gave quantitative values of apparent resistivities (R) values with corresponding layers (L) and depths (D) or thickness(T) of the various layers as well as the apparent resistivity of the bedrock are interpreted to determine conductive zones and is used to determine water-bearing zonesin the communities.

4. Results and Discussion

Table 1.0 providessummary statistics of profiling results in the study area. Length of traverses varied from 18 m to 190 m depending on the available space identified in the communities. Minimum standard deviation of 4.28 Ω m occurred at Adom while maximum of 483.81 Ω m occurred at Dedeiman. The wide spectrum of standard deviation within the study area is an indication of the heterogeneous nature of the underlying rocks. With the exception of Dedeiman and Ofankor market, profiling results in most communities have low standard deviations. Dedeiman and Ofankor Market are underlain by the Togo Structural Units while the remaining communities are underlain by the Birimian Supergroup. The wide variation of rock types: quartzites, quarzitic sandstone, shale, schists and phyllite, multiple lineaments, contacts between the rock types (Kesse. 1985) as well as variation in modal compositions of the minerals within the rocks may account for the high standard deviations of measured resistivity within the Togo Structural Unit. The estimated low standard deviation associated with the remaining communities may be due to granite as a single rock underlying these areas with possible low variation in its modal composition.

Table 1: Summary statistics of profiling results in communities

Communities	Traverse	Traverse Length(m)	Minimum (Ωm)	Maximum (Ωm)	Mean (Ωm)	Median (Ωm)	Standard Deviation(Ωm)
Adom	A	110	37.62	54.45	47.00	48.01	4.28
Ofankor Market	A	60	184.14	468.27	287.70	266.81	87.30
	B	65	210.37	369.27	260.97	255.66	43.72
Saapeiman	A	85	39.60	62.86	50.21	50.49	6.45
	B	50	47.02	95.04	67.77	68.31	16.09
Dedeiman	A	150	476.68	1782.00	1051.65	1074.15	366.49
	B	120	302.44	1955.25	880.33	869.22	483.81
AyikaiDoblo	A	100	141.57	193.54	167.4	164.83	19.15
	B	85	116.82	165.82	137.63	130.18	16.26
Tetteh Asofaha	A	80	64.35	83.65	71.95	69.79	6.40
	B	60	35.10	67.32	52.27	49.99	9.50
Gatsikope	A	190	74.25	140.08	110.70	114.09	18.57
	B	85	79.69	418.27	134.55	104.44	83.04
Ebenezer	A	18	87.61	110.38	97.59	98.01	5.80
Ntafrafra	A	90	105.93	149.98	127.56	124.74	13.5
	B	110	82.66	169.29	111.06	104.19	26.97
AdjeimanKpalafia	A	85	56.43	92.07	72.71	72.27	10.95
	B	100	73.75	131.67	95.04	90.09	18.58
Atsiato	A	40	148.99	205.42	176.39	174.73	15.21

The total length for resistivity profiling at 10 m,5 m, and 2 m intervals was 1683m. A total of 31 VES points was identified as anomalous points within the communities. Four anomalous points were identified at Adom, Gatsikope and AdjeimanKpalafia, two anomalous points were selected at Tetteh Asofaha and Ebenezer each while three points were obtained at each of the remaining 6 communities.

The modeled results indicated the existence of 3, 4- and 5-layer structures (Table 2.0) within the area. The 3-layer structures are A, H and K. The H is most dominant compared to the A and K and are most often located in areas underlain by the Birimian Supergroup. Typical 4-layer structures include AA, KH, QH while HKH, and KHQ constitute 5-layers. Adom is underlain by a single Birimian Supergroup and has 3, 4 and 5-layers which suggest fracture systems within the area especially for A 35 and A 65. Point A65 has least bedrock apparent resistivity at Adom and is therefore possible for the existence of fractures within the bedrock at this location. At Ofankor Market, A 50 and B 30 depict similar resistivity curve with closely related bedrock apparent resistivities. However, almost the same bedrock apparent resistivity exists as third layer at B55. Thus, if low bedrock resistivity values at A 50 and B 30 are indications of fracture systems capable of producing water, then third layer at B 33 are also conductive zone capable of producing groundwater. For this reason, all three points are potential points for exploitation of groundwater. At Saapeiman, H-type resistivity curves occurred at all 3 locations. However, apparent resistivities of bedrock varied substantially. High bedrock apparent resistivity at A 20 suggests a smaller number of fracture or conductive zone at increasing depth compared to the other 2 (A 39 and B 53). On the basis of intermediate layer and the bedrock apparentresistivity, B 53 can be considered the prime point followed by A39 and then A 20. At Dedeiman, wide bedrock apparent resistivities varied from 50.4 Ω m to 1095.6 Ω m, intermediate layers had apparent resistivity that changed from 39.1 Ω m to 2494.4 Ω m with varying thickness of 2.9 m to 35.6 m. At a glance, one may consider A 28 as the best point due to low bedrock apparent resistivity and thick most conductive intermediate third layer. However, the writer is of the view that the area is underlain by Togo Structural Unit which has shale as one of the rock types with low apparent resistivity compared to sandstone with high apparent resistivity. Shale generally has low groundwater potential than sandstone. It is on that basis that B 38 can be considered as the best point followed by A 28 as alternate and then A 80.On the basis of bedrock apparent resistivities, the apparent resistivities of intermediate layers and their corresponding thicknesses, B 65 is the prime point followed by B15 and then A 59 for Ayikai Dobro. At Tetteh Asofaha, both points: A 30 and A

55 are equally good for groundwater exploitation. The only difference was that A 55 has lower bedrock apparent resistivity compared to A 30 and provided the same rock type exist at both points, we expect better fracture system at A 55 than at A 30.

Table 2: Modeled results of anomalous points selected within research communities

Community	VES Point	Modeled Results L	R	T	r.m.s value (%)	Curve Types	Comments/GPS
Adom	A35	1	57.3	1.3	2.51	QH	Conductive zones exist at depth
		2	50.1	1.0			beyond 2.3m approximately.
		3	10.0	8.6			05˚39.044’N, 00˚18.016’W, 87.6m
		4	330.4				
	A65	1	204.2	1.0	2.49	HKH	Conductive zone at shallow depth
		2	23.6	12.0			exceeding 1.0m approximately.
		3	91.8	24.7			05˚39.030’N, 00˚18.0224’W, 91.8m
		4	74.1	16.8			
		5	106.8				
	A95	1	684.9	1.0	2.74	H	A conductive zone of 20.6m
		2	27.1	20.6			thickness encountered at the point.
		3	433.8				05˚39.017’N, 00˚18.034’W, 88.2m
OfankorMarkket	A50	1	64.6	0.9	2.50	K	Conductive zones suspected to be
		2	784.5	8.1			beyond 9m.
		3	117.0				05˚39.558’N, 00˚16.578’W, 81m
	B30	1	61.0	1.1	2.90	K	Shallow conductive zone at depth
		2	569.8	10.1			exceeding 11.2m.
		3	105.9				05˚39.530’N, 00˚16.602’W, 81m
	B55	1	99.6	1.0	3.04	KH	Conductive zone of 27.7m
		2	424.0	14.1			encountered beyond 15.1m.
		3	105.6	27.7			05˚39.563’N, 00˚16.610’W, 81m
		4	400.3				
Saapeiman	A20	1	67.1	2.4	3.26	H	Conductive zone encountered
		2	19.4	12.3			beyond 2.4m.
		3	1037.2				05˚43.331’N, 00˚21.921’W, 84.6m
	A39	1	43.1	1.6	2.58	H	Conductive zone at 9.4m
		2	18.7	15.8			
		3	718.4				05˚43.331’N, 00˚21.921’W, 91.2m
	B53	1	117.8	2.1	2.54	H	Conductive zone at 12.5m
		2	15.8	10.9			
		3	300.1				05˚43.34.3’N, 00˚21.921’W, 84.6m
Dedeiman	A28	1	1230.1	1.4	2.49	QH	Conductive zone encountered at
		2	191.9	10.8			shallow depth beyond 13.2 m
		3	39.1	26.3			05˚44.984’N, 0˚14.711’W, 291m
		4	50.4				
	A80	1	1624.6	1.6	2.48	KH	Conductive zone encountered at
		2	2494.4	3.6			depth between 5.2 m to 38.5 m.
		3	703.1	33.3			05˚44.969’N, 0˚14.684’W, 262.2m
		4	1095.6				
	B38	1	849.9	1.5	2.29	KH	Conductive zone inferred at depth
		2	1185.0	2.9			between 4.5m to 40.1m.
		3	549.7	35.6			05˚44.899’N, 0˚14.751’W, 234m
		4	627.0				
Ayikai Dobro	A59	1	126.0	1.6	2.51	H	Shallow conductive zone
		2	34.8	6.3			encountered possibly beyond at 3.9m
		3	413.1				05˚40.618’N, 0˚21.075’W, 70m
	B15	1	388.6	1.1	2.52	H	Thick conductive zone encountered
		2	42.8	9.5			just beyond 5.3m
		3	460.5				05˚40.661’N, 0˚21.139’W, 68m

Table 2: Continued

Community	VES Point	Modeled Results L	R	T	r.m.s value (%)	CurveType	Comments/GPS
Ayikai Dobro	B65	1	274.4	1.1	2.46	KH	Conductive zone at shallow depth of
		2	355.1	1.7			approximately 15m
		3	43.8	11.1			05˚40.641’N, 0˚21.115’W, 79m
		4	467.3				
	A30	1	168.2	1.9	2.55	H	Thick conductive zone encountered
		2	30.8	15.0			at shallow depth.

Tetteh Asofaha		3 296.6			05°45.018’N, 0°20.607’W, 110m
	A55	1 303.9 1.5	2.20	H	Thick conductive zone encountered
		2 33.9 8.9			at shallow depth.
		3 135.0			05°45.027’N, 0°20.579’W, 101m
Gatsikope	A120	1 137.8 0.7	2.63	H	Shallow conductive zone
		2 61.2 12.9			encountered at about 14m
		3 376.2			05°44.898’N, 0°18.028’W, 141m
	A169	1 438.7 1.0	2.53	H	Shallow conductive zone
		2 30.1 6.7			encountered at 7.7m approximately.
		3 364.2			05°44.890’N, 0°18.001’W, 130m
	B70	1 111.0 1.1	2.34	H	Shallow conductive zone
		2 24.9 5.3			encountered at 7m approximately.
		3 231.6			05°47.414’N, 0°09.064’W, 139m
Ntafrafra	A30	1 113.8 1.1	2.48	H	Small conductive zone at depth
		2 30.6 3.2			of 4m approximately.
		3 352.4			05°41.851’N, 0°20.975’W, 89m
	B25	1 293.1 1.5	2.51	H	Moderate conductive zone at depth
		2 22.4 9.1			of 10m approximately.
		3 419.6			05°41.845’N, 0°20.962’W, 79m
	B97	1 223.8 1.8	2.54	H	Moderate conductive zone at depth
		2 34.0 10.9			of 12m approximately.
		3 796.2			05°40.149’N, 0°15.144’W, 87m
AdjeimanKpalafia	A43	1 274.6 1.3	2.95	H	Small conductive zone at 8m depth
		2 10.6 7.0			approximately.
		31613.4			05°43.118’N, 0°22.2239’W, 88m
	A70	1 119.9 0.6	2.79	H	Shallow conductive zone at depth
		2 22.0 8.7			of 9m approximately.
		3 904.1			05°43.126’N, 0°22.223’W, 85m
	B10	1 100.2 1.9	3.60	H	Moderate conductive zone at depth
		2 25.3 10.6			of 12m approximately.
		3 813.1			05°43.170’N, 0°22.242’W, 92m
	B62	1 238.3 1.3	2.79	H	Shallow conductive zone at depth
		2 18.6 8.4			of 9.7 m approximately.
		3 371.1			05°43.145’N, 0°22.229’W, 92m
Ebenezer	A18	1 85.3 1.6	2.50	H	Thick conductive zone at depth of
		2 66.4 22.6			2m to 24m approximately.
		3 576.3			05°43.093’N, 0°24.178’W, 105m
	A4	1 38.8 1.3	2.45	A	Shallow conductive zone at depth
		2 90.7 10.9			of 1.3m approximately.
		3 411.9			05°40.425’N, 0°16.866’W, 196m
Atsiato	A19	1 43.6 1.7	2.73	AA	Shallow conductive zone at depth
		2 177.2 23.3			of 9m approximately.
		3 194.9 11.7			05°40.420’N, 0°16.866’W, 194m
		4 373.7			

Table 2.0: Continued.

Community	VES Point	Modeled Results L R T	r.m.s value (%)	CurveType	Comments/GPS
Atsiato	A36	1 68.1 1.7	2.63	H	Thick conductive zone between
		2 13.4 28.4			2m and 30.1m approximately.
		3 83.9			05°40.414’N, 0°16.879’W, 205m

At Gatsikope, A 120 is good as prime point for exploitation, B 70 may be considered as another point because of the low bedrock apparent resistivity, while A 169 may not support the construction of borehole. At Ntafrafra, B 25 can be considered as the best followed by B 97 while A 30 is not likely to support the drilling of borehole. On the basis of bedrock apparent resistivities values, the apparent resistivities of intermediate layers and their corresponding thicknesses at AdjeimanKpalafia, B 62 is considered the prime point followed by B 10, A 70 and lastly A 43 which may not support the construction of a tubewell. At Ebenezer, A 4 may not support the construction of borehole because the modeled apparent resistivity data displayed increasing apparent resistivity with increasing depth, a phenomenon suggesting barren ground within the depth of investigation. However, A 18 may support the construction of a borehole at Ebenezer.At Atsiato, A 19 may not support the construction of borehole but A 36 can support the construction of tube well. In general, high apparent resistivities are associated with areas underlain by the Togo Structural Unit while comparatively lower apparent resistivities are associated within the granites of the Birimian Supergroup for the same electrode spread.

5. Conclusions

Electrical resistivity survey for groundwater exploration in 11 communities in Ga West Municipality suggest the existence of 3, 4 and 5-layer subsurface structures. Typical resistivity curves are A, H, K, KH, AA, QH, HKH, and KHQ. The 3-layer H-type resistivity curve is the most dominant and occurred most often in areas underlain by granite of the Birimian Supergroup. There exist conductive zones with varied apparent resistivities and thickness within intermediate layers and the existence of possible fractures within bedrocks of some anomalous points identified. These scenarios are indications of the existence of groundwater at anomalous points identified. Prime points that can support the construction of tubewells are A 95 at Adom, A50 at Ofankor Market, B 53 at Saapeiman, B 28 at Dedeiman, B 15 at Ayikai Dobro, either A 30 or A 55 at Tetteh Asofaha, A 120 at Gatsikope, B 25 at Ntafrafra, B 62 at AdjeimanKpalafia, A 18 at Ebenezer, and A 36 at Atsiato. Typical anomalous points that may not support the exploitation of groundwater include A 4 at Ebenezer and A 19 at Atsiato, A 169 at Gatsikope, A 59 at Ayikai Dobro, A 30 at Ntafrafra, and A 43 at Adjeiman Kpalafia, These wide spectrum of anomalous points some of which can support the construction of tubewells whiles others cannot suggest wide variation in groundwater potential in the area. Thus, there exist a point as water-bearing zone that can be exploited for the construction of a well in each community.

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