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Groundwater investigations in Ghana using electromagnetic and electrical resistivity methods

Hafiz Mohammed Nazifi[*1], Levent Gülen[2], Can Karavul[3]

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ABSTRACT

The electromagnetic profiling and Vertical Electrical Sounding (VES) data were acquired from some communities in the Twifo – Hemang Lower Denkyira District of the Central region of Ghana, in order to determine zones of high groundwater potentials and to recommend suitable sites to drill boreholes for community water supply. The research reported here covered three communities namely; Esukese Ekyire, Kwanyarko. First the electromagnetic measurements were carried out, qualitative interpretations of the data were carried out and weathered rock zones were identified. Then the VES measurements using Schlumberger array were conducted at points on the electromagnetic traverse that displayed weathered zones. ZONDIP1D software was used in creating 1D sounding curve models of geological subsurface structures beneath the sounding points. Results of the modelling suggest that the communities are underlain by three to four geological layers. Interpretations of the 1D inversion of the VES data provide the resistivities and thicknesses of subsurface layers. On the basis of resistivity values and thicknesses of the layers in the 1D models, sites were recommended to drill boreholes for community water supply.

Keywords: groundwater exploration, EM profiling, vertical electrical sounding, Ghana, weathered zone

Gana'da bazı topluluklarında elektromanyetik ve elektrik rezistivite yöntemlerle kullunılarak yeraltı su kaynakları araştırması

ÖZ

Gana' nın merkez bölgesinde bulunan Twifo – Hemang Lower Denkyira ilçesindeki bazı topluluklardan yüksek yeraltı su potansiyeline sahip bölgeleri belirlemek ve belirlenen bu yerler doğrultusunda toplulukların su ihtiyacını karşılayabilecek uygun sondaj yerleri önermek için Elektromanyetik (EM) Profili ve Düşey Elektrik Sondajı (DES) verileri alınmıştır. Bu çalışmada, sırasıyla Esukese Ekyire, Kwanyarko ve Nyameyeadom kasabalarına ait etüd sonuçları tartışılacaktır. İlk olarak, EM ölçülerin alımı gerçekleştirilmiştir. Daha sonra EM verileri nitelik olarak yorumlanmış ve bunun sonucunda çatlak ve/veya kırık zonları tespit edilmiştir. Schlumberger elektrot dizilimi kullanılarak DES ölçümleri kayaç bozunması gözlenen noktalarda elektromanyetik ölçüm alınan yerlerde yapılmıştır. ZONDIP1D yazılımı, sondaj noktaları altındaki jeolojik yeraltı yapılarının 1D sondaj eğri modellerinin üretilmesinde kullanılmıştır. Modellemenin sonuçları bölgede üç veya dört jeolojik zon bulunduğunu göstermiştir. DES verilerinin 1D ters çözümü yorumlamaları katmanlarının özdirenç ve kalınlık değerlerini vermektedir. Su temini için gerekli olan sondaj kuyu yerleri 1D sondaj eğrisi modeli ve yeraltı katmanlarının kalınlıklarına göre önerilmiştir.

Anahtar Kelimeler: yeraltı suyu araştırması, EM etüdü, düşey elektrik sondaj, Gana, bozunmuş kayaç zonu

[*] Corresponding Author
[1] Sakarya University, Department of Geophysics Engineering, Sakarya, Turkey – mohammednazifi@gmail.com
[2] Sakarya University, Department of Geophysics Engineering, Sakarya, Turkey – lgulen @sakarya.edu.tr
[3] Sakarya University, Department of Geophysics Engineering, Sakarya, Turkey – karavul@sakarya.edu.tr

1. INTRODUCTION

Locating groundwater zones and knowing their quantity and in some instants the quality of the groundwater is a problem for most part of Africa and Ghana in particular. If not, how come the African Continent which has an immense supply of rainfall, with an annual average of 744 mm; has low withdrawals of groundwater for its major water sectors namely, community water supply, agriculture and industry[1,2].

In many world regions, particularly in the developing regions like Africa, availability and access of freshwater largely determines patters of economic growth and social development[2]. In Ghana, a sub – African country, many people in districts like Twifo – Hemang Lower Denkyira Districts and rural communities are battling with the problems of inadequate availability of potable water for their daily activities. These communities are mostly depending on surface water as sources of water for household activities. These water sources are prone to pollutions due to the activities of some farmers and some small mining companies. The continued use of water directly from these sources may lead to water borne diseases like cyclosporiasis, amoebiasis, hepatitis A, cholera, diarrhoea, bilharzias among others. Furthermore, women and children spend a lot of time and effort everyday going to the stream and river sites to fetch water. These practices affect the productivity of these women and children and the district at large. Sometimes children waste precious school hours outside classrooms in search of water at the expense of their education.

The main methods use for groundwater investigations in Ghana include; the review of archival reports, interpretations of topographical, geological and structural maps, survey of existing boreholes and other water sources and discussions with residents of the communities. These methods would not be the best but that are some of the methods widely used in Ghana [3]. The use of geophysical techniques are not much popular in Ghana, but there is some improvement in recent years. The important roles in the use of geophysical methods for groundwater investigations are being realized in the current decade. The main geophysical methods used in groundwater investigation and aquifer characterization are the electrical and electromagnetic methods.

The paper explains how electromagnetic profiling method and Vertical Electrical Sounding (VES) were used in exploring for groundwater in some communities in Ghana. The electromagnetic method was used for reconnaissance survey. Points on the electromagnetic profiles that show adequate conductivity were considered for electrical resistivity sounding. Geonics EM 34-3 Ground Conducting meter and ABEM Terrameter SAS 1000C equipment were used for electromagnetic profiling and vertical electrical sounding respectively. The theories and field procedures of both the electromagnetic method and the vertical electrical sounding were explained in standard texts such as [4]–[9] and that much of it would not be presented here.

2. METHODOLOGY

2.1. Geological Setting

The study area consist of three communities namely; Esukese Ekyire, Kwanyarko and Nyameyeadom. They are located within the Twifo – Hemag Lower Denkyira District (Figure 1), which is located between latitudes 5°50'N and 5°51'N and longitudes 1°50'W and 1°10'W. The district is located to the northwestern part of the Central Region of Ghana and it is bounded in the north by the Upper Denkyira East Municipality, to the south by the Abura Asebu Kwamankese district, Cape Coast Metropolis and Komenda-Edina-Eguafo-Abirem Municipality, to the west by the Wassa Mpohor East District and to the East by Assin North Municipal and Assin South District.

The study area falls within the Granite formation (Figure 1). The main rock types include granite and granodiorite with some gneiss. These rocks are strongly folded, foliated and jointed. Intense weathering along fractures and veins had permitted water percolation to form groundwater reservoirs. Aquifers are therefore located where secondary porosity has been developed. The two main aquifer types are (i) the weathered zone which develops on the crystalline basement rocks, and (ii) fracture zones within the bedrock [10]. According to Gyamera & Kuma [11] basic granitic intrusives and granites underlie almost all the study area. Major rock types comprise well - foliated, medium - grained, potash-rich muscovite-biotite granites, granodiorites and pegmatites. Granites found in the study area are post Tarkwaian and can be divided into three groups: Bongo Granites, Dixcove Granite Complex and Cape Coast Granite complex. The Cape Coast granites are often associated with schists and gneisses, and they intrude the lower Birimian meta-sediments. One characteristic of the granite is that it is not inherently permeable, but secondary permeability and porosity have developed as a result of fracturing and weathering. Groundwater occurs mainly in fractured portions of the bedrock. However, some amount of water may be obtained from the overburden and at the interface between the overburden and the bedrock.

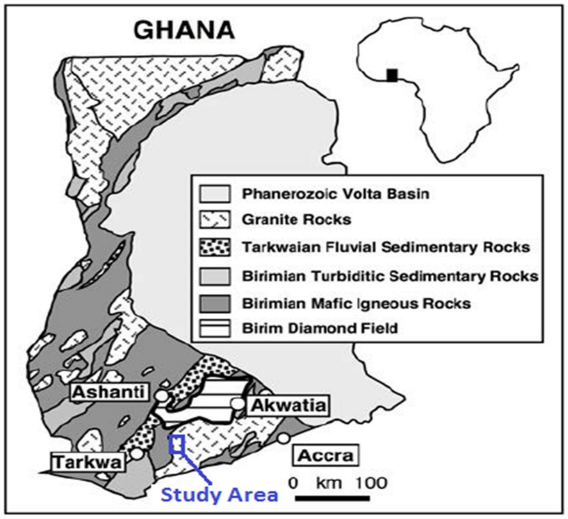


Figure 1. Simplified geological map of Ghana [12]

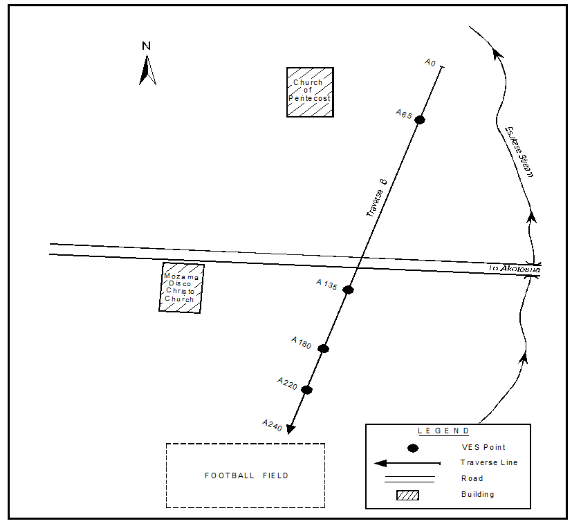


Figure 2. Schematic layout of Esukese Ekyire Community (not to scale)[13]

3. RESULTS

3.1. Electromagnetic Data

The EM data were collected along eight (8) traverses, whose lengths vary between 200 m and 280 m (Table 1). Out of the eight traverses, one traverse was conducted in Esukese Ekyire Community on a profile length of 240 m and on a bearing of 205° from the True North (Figure 2). In Kwanyarko Community four traverses were completed; Traverse A was carried out on a profile length of 260 m on a bearing of 032° from the True North; traverse B was carried out on profile length of 220 m and on a bearing 034° from the True North; the traverse C has a profile length of 240 m and was carried out on a bearing of 187° from the True North and lastly the traverse D was carried out on a bearing of 148° from the True North and on a profile length of 200 m (Figure 3). In Nyameyeadom Community three traverses were carried out; traverse A was carried out on a profile length of 240 m on a bearing of 058° from the True North; traverse B was carried out on a bearing of 075° from the True North and on a profile length of 250 m long and lastly traverse C was carried out on a bearing of 085° from the True North and on a profile length of 280 m (Figure 4).

Both the Horizontal Dipole mode (HD) graph and Vertical Dipole mode (VD) graph of the electromagnetic data were presented together on the same graph as apparent conductivity [m mhos / m] against stations [m]. Some results EM profiles from the study are shown in Figures 5 and 6.

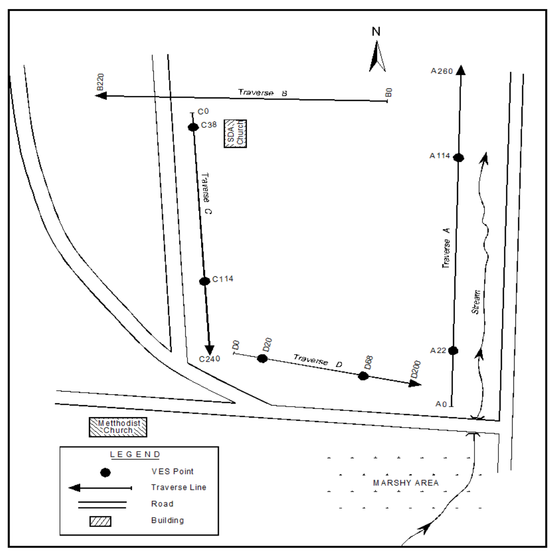


Figure 3. Schematic layout of Kwanyarko Community (not to scale)[14].

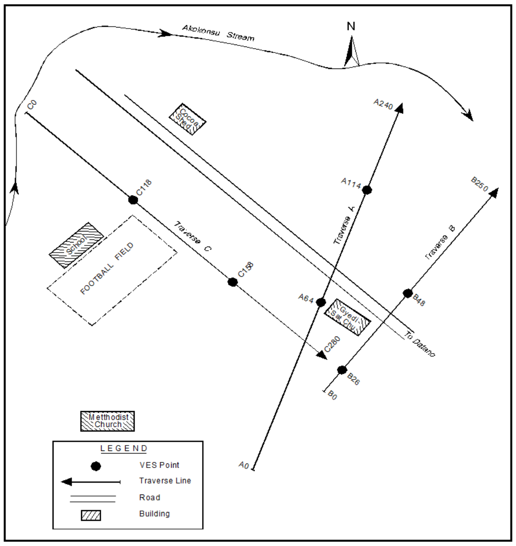


Figure 4. Schematic Layout of Nyameyeadom Community (not to scale)[15]

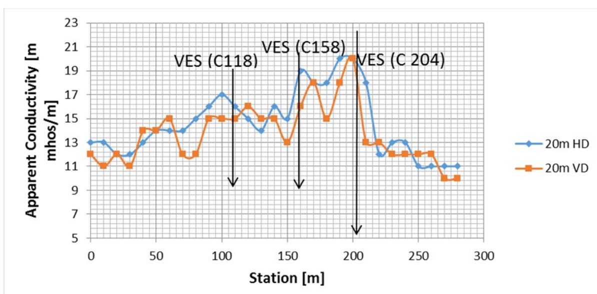


Figure 5. EM terrain conductivity measurements along a profile C at Nyameyeadom Community

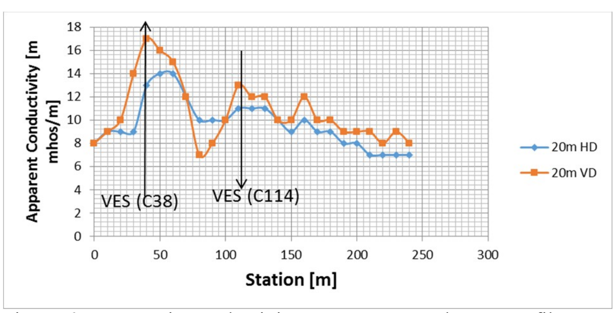


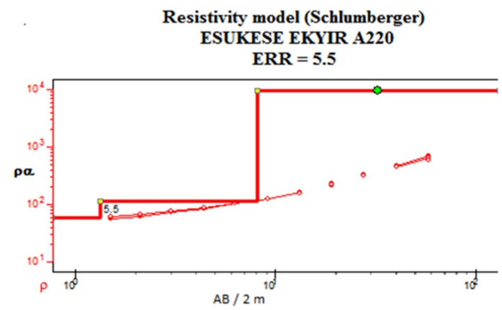
Figure 6. EM terrain conductivity measurements along a profile C at Kwanyarko Community

Table 1. Summary of the EM Profiling

Community	No. of EM traverses	Maximum apparent conductivity value (m mhos/ m)	Minimum apparent conductivity value (m mhos/ m)	length of traverse lines (m)		Coil spacing	
				Longest	Shortest	10 m	20 m
Esukese Ekyir	1	67	-20	240	-	ALL	-
Kwanyarko	4	23	6	260	200	-	ALL
Nyameyeadom	3	29	10	280	240	-	ALL

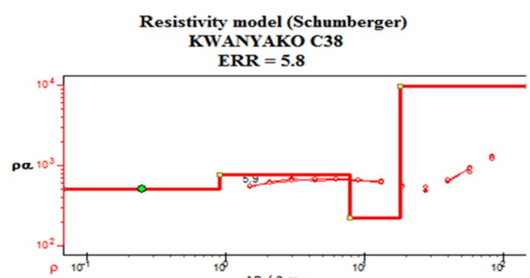
3.2. Sounding Curves

The VES data were interpreted both qualitatively and quantitatively. The results from the VES data are presented as sounding curves. The sounding curves consist of log – log plots of resistivity values as a function of AB/2 spacing of the Schlumberger array. The models provide information on the number of layers, their thicknesses, depths, resistivity values and the error margin (Err) between the measured and the calculated resistivity values. In all, a total of 16 VES were conducted in the three communities. 4 VES in Esukese Ekyir, 6 VES in Kwanyarko and another 6 VES in Nyameyeadom. Figures 7 to 9 show some of the VES curves and their one dimensional resistivity inversions. Table 2 displayed the summary of VES results in the study area.



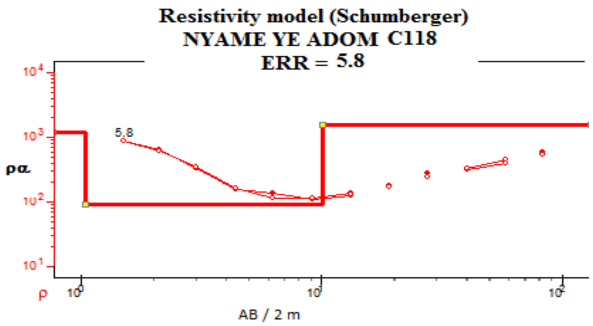
N	ρ	h	z
1	58.63	1.33	0/0
2	113.43	6.76	1.33
3	9374		8.09

Figure 7 .VES model curve at station A220 m, Esukese Ekyir Community.



N	ρ	h	z
1	512.55	0.90	0/0
2	756.31	6.90	0.90
3	222.92	10.40	7.80
4	9644.30		18.20

Figure 8. VES model curve model at station C38 m, Kwanyarko Community



N	ρ	h	z
1	1184.67	1.04	0/0
2	93.04	9.03	1.04
3	1543.85		10.07

Figure 9. VES model curve at station C118 m, Nyameyeadom Community.

Table 2. Summary of the Sounding Curve model

Community	No. of VES Stations	No. of layers 3 - layers	4 - layers	5 - layers	Sounding Curve Type(s)	Expected Water-bearing layer(s)
Esukese Ekyir	4	3	1	-	KH, A & H	2nd
Kwanyarko	6	5	1	-	KH & H	1st & 2nd
Nyameyeadom	6	2	4	-	KH & H	2nd & 3rd

4. DISCUSSIONS

The shapes of the EM curves varied depending on the nature of the subsurface. Some curves are erratic in nature while others are smooth. The erratic ones are interpreted as having complex geological structures beneath the earth surface. Points with high anomalies were of interest and they were inferred to be conductive and that they are related to weathering or fractured subsurface which are capable of being saturated with groundwater. Anomalous zones were considered for VES investigation. Not all the high anomalies on the EM curves are related to the conductivity of the subsurface. Some of the anomalies are due to interference of roofing and waste dump and they were not considered for further investigations. On the EM graphs when the Vertical Dipole mode (VD) curves has a higher apparent conductivity along the profile than that of the Horizontal Dipole mode (HD), the interpretation is that; the deeper subsurface is more fractured or weathered than the shallow subsurface but when the opposite happened then the shallow subsurface is interpreted to be more fractures or weathered than the deeper subsurface. Points on the EM graphs with higher terrain conductivities and crossover points were considered and the best points were selected for further investigations. All points selected on the EM profiles were proven by the VES investigation to be weathered or fractured as inferred by the EM profiling.

In Esukese Ekyir Community, results of three of the VES stations indicated 3 – layer earth model (H & A Types) and one VES station displayed 4 – layered earth model (KH – Type). Figure 7 shows a sounding curve in Esukese Ekyir Community. Generally, the Esukese Ekyir Community is underlain by three layered structure. The first layer has resistivity values between 58.63 Ωm and 208.00 Ωm; and can be intercepted at a mean thickness of 2.22 m. The second layer has thickness range of 2.24 – 10.81 m and a mean apparent resistivity value of 535.52 Ωm while the bedrock has apparent resistivity value range between 82.44 Ωm and 14827 Ωm. The first two layers are expected to be water – bearing layers in this community (see Table 2). It is inferred that the groundwater might be present even before the 1.5 m mark. The Esukese stream (from which the community had it name) flows from south to north in the eastern part of the community and this stream might be the main source of recharge for groundwater within this community. The Table 3 shows the list of the VES points, their GPS locations and the ranking of the VES points for the purposes of borehole drilling in Esukese Ekyir Community. All VES points except VES A220 are recommended for borehole drilling.

Table 3. Ranked VES points hand-dug well development at Esukese Ekyir Community

VES Points	**No. of layers**	**Rank**	**Location of VES Points (GPS)**
A65	4	1^{st}	5.38711N 1.51240W
A180	3	1^{st}	5.38620N 1.51293W
A135	3	3^{rd}	5.38647N 1.51257W
A220	3	4^{th}	5.38587N 1.51298W

In Kwanyarko Community five VES stations suggested a 3 – layered model (H – Type) and only one station displayed 4 – layerd subsurface (KH – Type (Figure 8)). Analyses of the VES curves suggested that the Kwanyako is underlain by three geological substrata. Generally first and third layer have higher resistivity values than second layer. First layer has resistivity values ranging from 363.97 – 1306.28 Ωm, and it can be intercepted at a mean depth of 1.91 m. The second layer which is expected to be the water – bearing has a thickness range of 3.50 – 9.74 m and a mean apparent resistivity value of 197.33 Ωm. The third layer has apparent resistivity value ranging from 1434.39 -2715.98 Ωm. All the VES points investigated were recommended for borehole drilling. Table 4 displays the list of the VES points, their GPS locations and the ranking of the VES points for the purposes of borehole drilling in the Kwanyarko Community.

In the last community considered in this work is the Nyameyeadom Community. In this community two VES stations displayed 3 – layered model (H – Type, Figure 9) and the remaining four VES stations displayed a 4 – layered model (KH - Type). From the interpretations of the curves, all the VES points were recommended for borehole drilling. Table 5 shows the list of the VES points, their GPS locations and their rankings for the purposes of borehole drilling in the Nyameyeadom Community. The VES stations conducted within this community suggest that Nyameyeadom Community is underlain by three – four geological layers. The first layer has apparent resistivity values ranging from 55.11 - 1184.67 Ωm and a mean depth of 0.98 m. The second layer has thicknesses ranging from 1.50 – 9.03 m and a mean apparent resistivity value of 136.29 Ωm. The third layer also has a mean apparent resistivity value of 51.76 Ωm and thicknesses ranging from 5.10 – 9.54 m. The fourth layer has apparent resistivity values ranging from 3773.48 – 17574.20 Ωm. From the qualitative and quantitative interpretations of data from this community, the groundwater beneath the study sites are of high amount and there is less risk for drilling at any point investigated in this community and that all would yield high quantity of groundwater.

The dominant curve types in the study are the H – Type and KH – Type (see Table 2) which Okafor & Mamah [16] cited Omosuyi [17] saying; these curves types (H and KH) are often associated with groundwater possibilities. Worthington [18] in [16] state that, field curves or sounding curves often mirror image geo – electrical nature of the successive lithology sequence in an area and hence they can be used to assess the groundwater potential of an area qualitatively.

Table 4. Ranked VES points for borehole drilling at Kwanyako Community

VES Points	**No. of layers**	**Rank**	**Location of VES Points (GPS)**
D68	3	1ST	5.54435N 1.55359W
D20	3	2ND	5.54460N 1.55392W
A22	3	3RD	5.54451N 1.55346W
A114	3	4TH	5.54534N 1.55312W
C38	4	5TH	5.54576N 1.55384W
C114	3	5TH	5.54515N 1.55401W

Table 5. Ranked VES points for borehole drilling at Nyameyeadom Community

VES Points	No. of layers	Rank	Location of VES Points (GPS)
C204	4	1ST	5.51728N 1.60225W
C158	4	2ND	5.51752N 1.60235W
A64	4	3RD	5.51755N 1.60197W
B26	4	3RD	5.51731N 1.60178W
B48	3	5TH	5.51741N 1.60152W
C118	3	6TH	5.51776N 1.60258W

5. CONCLUSION

Electromagnetic (EM) Profiling and Vertical Electrical Sounding (VES) were successfully used for groundwater investigations in Ghana. The EM profiling was used for reconnaissance purposes while the VES was used for detailed investigation. The VES data were interpreted by the traditional one dimensional sounding curve model. It helps in identification of zones, thicknesses and depths of groundwater accumulation beneath the study area.

Generally, the study areas have 3 or 4 resistivity layers. The Esukese Ekyir and Kwanyarko Communities predominantly consist of 3 layers while Nyameyeadom Community has 4 layer earth structure. The resistivity values of the first layers in all the communities range approximately from 55-1306 Ωm, the second layers have an average approximation of 289 Ωm. The resistivity values of the third layers in all the communities range approximately from 51-14827 Ωm and that of the fourth layer ranges from 3773-17574 Ωm. The Nyameyeadom Community has the highest probability of finding high amount of groundwater than other communities. This community is followed in rank by Kwanyarko Community and lastly Esukese Ekyir Community.

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