American Academic Scientific Research Journal for Engineering, Technology, and Sciences
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402
http://asrjetsjournal.org/

Geo-Electrical Investigation for Groundwater Resources in a Part of Butembo Area (North Kivu Province; Democratic Republic of Congo)

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Abstract

This paper presents the results of the groundwater research undertaken in Butembo area, Eastern part of the Democratic Republic of Congo. By the geophysical survey undertaken in this campaign, the expected result was to find out aquifers through the geological exploration and geophysical survey. The geological exploration has revealed that the geology of Butembo is built by crystalline rocks covered by a lateritic top soil. The geophysical investigation was focuses on the electrical method of resistivity using the Schlumberger configuration spreading the current electrodes from 1.5 to 280m with depth penetration capability of 93.3m. The field data was acquired using the allied Ohmega resistivity meter and the computer plot using the WinResist software after being subjected to manual plotting. The analyses of sounding curves of data over the areas have brought out three to four subsurface geo-electric patterns. The geophysical curves suggest that aquifers are made by fractured crystalline bedrock. The aquifer level is overlain by more than 20 m of saprolite and a thick slightly weathered basement. This sandy clay saprolite can constitute an aquifer but it lower transmissivity and the hygienic conditions made it unusable. By this research, we have got ideas relatively to the underground water of the region so that we may evaluate the possibility of their domestic use by drilling.

Keywords: geo electrical; groundwater; Schlumberger methods; crystalline rocks .

1. Introduction

The access to potable water is nowadays a governmental priority and is supposed to be among the main facts of development in the entire world. It’s evident that investing in water is to provide human health and the economic growth. Even though seventy two percent of the Earth surface is occupied by water [19] less than five percent is potable.

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It's known that either iceberg water in the polar region, the ground water is one of the principal continental fresh water but it's no easy to reach this precious material. Civilizations have typically obtained water from natural and constructed surface-water resources throughout most of human history. Only during the last 50–70 years has a significant quantity of water for humans been obtained through pumping from wells [8]. During this short time, alarming levels of groundwater depletion have been observed in many regions, especially in semi-arid and arid areas that rely heavily on groundwater pumping from clastic sedimentary basins [13]. Groundwater has commonly been a source of high-quality freshwater and an important safeguard against uncertain inter-annual and inter-decadal shortfalls in precipitation and surface-water supplies [5, 8]. However, overdraft of this important resource has only accelerated during the twenty-first century [18] and is further threatened by future climate uncertainty [10]. Despite continued unsustainable groundwater abstraction in many areas, water policy efforts continue to respond to near-term crises and fail to anticipate long-term future conditions [8]. Groundwater is a crucial water resource in areas where surface water is scarce or difficult to access. Besides, sustainable development relies not only on the availability of surface water but also on sustainable exploitation of aquifers [2]. Dependence on intensive groundwater abstraction to supply domestic water is expected to increase substantially in towns and cities such as Addis Ababa in Ethiopia, Dakar in Senegal, Lusaka in Zambia, Nairobi in Kenya, and Dodoma in Tanzania [6]as the urban population of Sub-Saharan Africa is projected to triple between 2000 and 2050 [19]. The scarce of potable water is a huge problem in sub-Saharan villages and cities although it water potential. Located in the eastern part of the Democratic Republic of Congo, Butembo is among the biggest cities of the North-Kivu province and the population is growing up every day. This situation is followed by the increase of the water demands and has posed a great problem to the society. It is necessary to have a clear view that the surface water is not sufficient for the population use; the exploration of underground water is an urgent necessity and presents itself as a great challenge to be overcome because people are exposed to problems due to hydric diseases, Ebola and corona viruses. Therefore, the objective of this study was to identify potential well site locations and to know the overall groundwater conditions of the study area using surface geophysical survey. In the last years the electrical resistivity method has been applied around the world in the groundwater exploration, geo-electric and hydrogeological characterization of water resources and in the study of underground water contamination. Several arrays can be employed, depending on the complexity and purpose of the survey. These procedures are related with the position of the electrodes on field and offer great versatility to the method. The main arrays applied are: dipole-dipole, Wenner and Schlumberger [9]. This study was focuses on the Schlumberger configuration in ten chosen points and was interpreted using geological approaches.

2. Materials and methods

2.1 Description of the study area

2.1.1 Geographic background

The study area is located in the Eastern part of the Democratic Republic of Congo; it's among the biggest city of the North Kivu province. The city is built in the Kibarian Mountains of the Kivu region and is crossed by the national road N5 which facilitate traffic with Goma town in the south and Beni city in the North of the province.

The soil of this region is lateritic. It is a result of the weathering of the crystalline basement and depends on the equatorial climate which is characterized by a long rainy season. In a city of more than a billion of people more than seventy percent lives from commercials activities; the agriculture is done in the behinds villages. The river flow is dictated by the geomorphology which is made by a succession of mountains and valleys. The important of domestic water of Butembo come from mountains behind the city and their catchment is done by the national office of water. However, Butembo’s rivers are not powerful and the scarcity of drinking water is continuously observed in the major part of the city. The works undertaken during this campaign was dictated by the geographic and geological conditions. This study is focuses on ten sites as reported below:

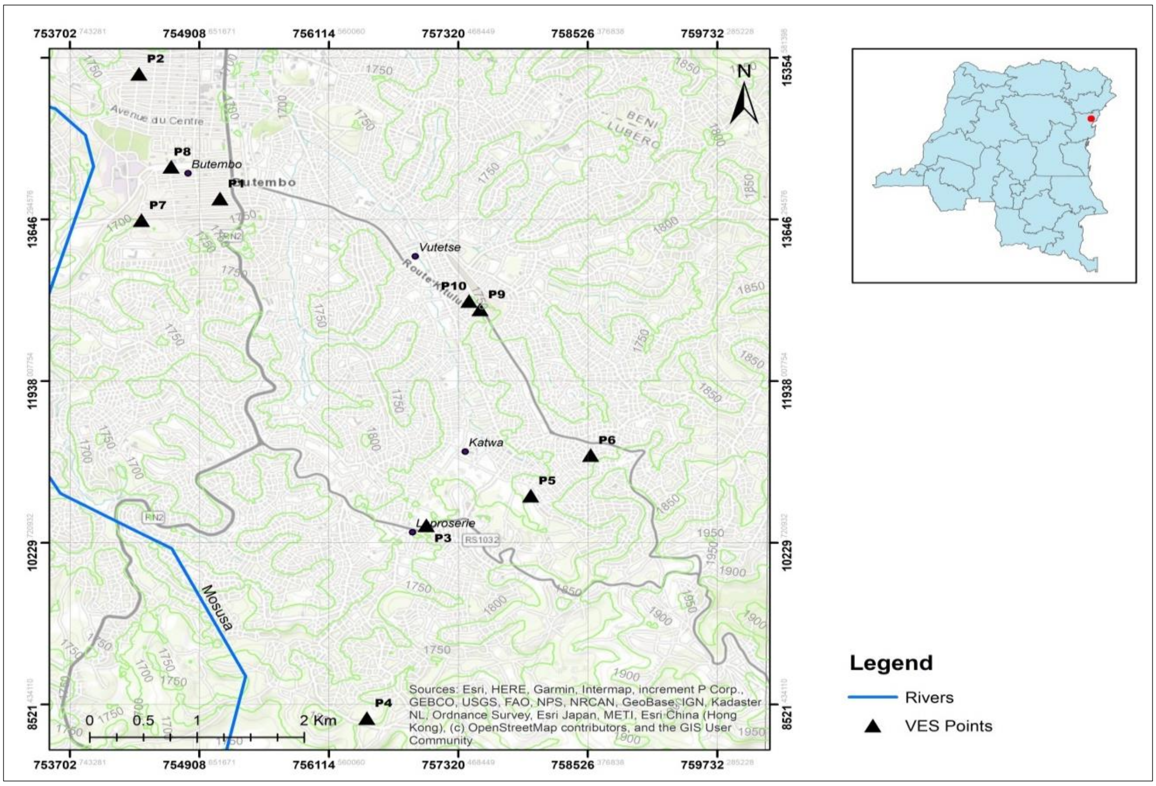

Figure 1: location of Vertical electrical soundings.

2.1.2 Geology and hydrology

Since the memorable geological campaign of F. Delhaye et A. Salée, 1921 – 1923 and 1926-1927; A. Salée, N. Boutakoff and J. DE LA Vallee Poussin, 1929-1932 ; Boutakoff, 1939 ; Villeneuve, 2006 ; Dewael, 2010 ; it is known that the geology of Kivu is made by Precambrian metamorphic rocks and granite. Butembo is a part of Kivu; it is built on crystalline rocks [15]. The granite, gneiss and dolerite are the most wide spread rocks unit in the area, covering over half of the area occurring as intrusive, low-lying outcrops. The water research undertaken was focuses on either fractures location weathered materials which, in this kind of terrain, are water containers. Weathered crystalline bedrock aquifer systems underlie approximately 40% of Sub-Saharan Africa and provide a vital source of water to over a quarter of a billion people [5]. For decades, these aquifer systems have sustained low-intensity groundwater abstraction (up to 1 L s^{-}) from wells, typically via hand pumps [6]. More intensive groundwater abstraction (>1 L s^{-1} per well), using electrical submersible pumps, increased over the second half of the twentieth century, primarily in order to supply rapidly growing towns and cities with a low-cost source of safe domestic water [8]. Butembo is therefore built on a basement terrain covered by a thick overburden layered materials. The dolerite outcrops were located in the eastern part of the city; in Vighole village. The study was aimed to understand the nature, number and type of aquifers within the study area so as to identify the potential well sites that could balance the water demand and supply. The below map is a synthesis of the major geological formations of the study area:

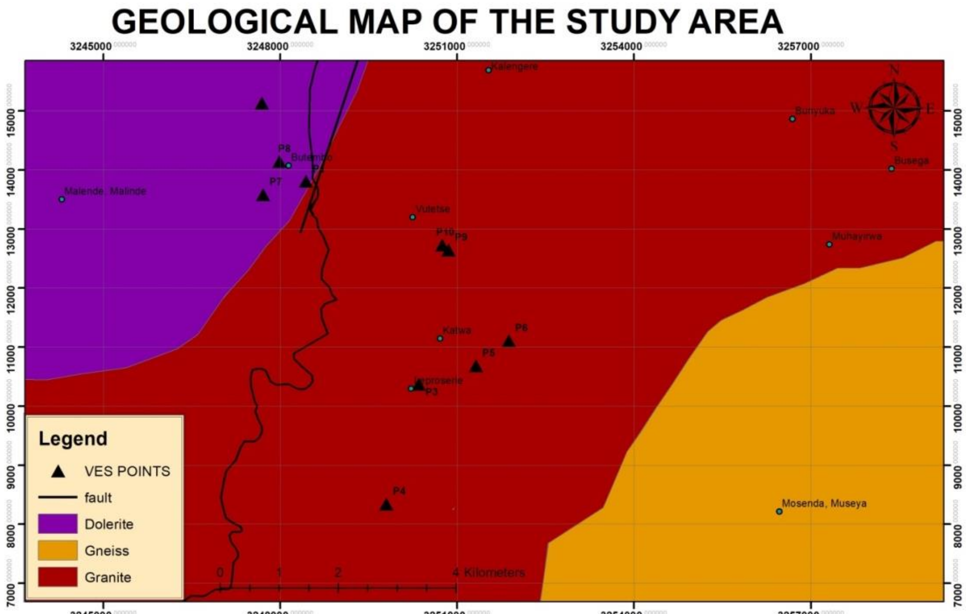

Figure 2: geological map of the study area (modified map of Lepersonne; 2005).

2.2 Methods

Before the geophysical investigation, hydrogeological indications were located. The hydrogeological investigation includes the observation of local geological setup and the Hydrogeological properties of rocks such as recharge rate, well yielding capacity, behavior of wells, attitude of rock formations, thickness of overburden and so on[3]. By this step we have selected some high water potential points. Geophysical investigation was carried out using the electrical resistivity method. The electrical resistivity method has a long history in applied geophysics, including the pioneering work in 1912 by Conrad Schlumberger of France, a few years early than that, Swedish explorationists had experimented with locating conductive bodies by moving around a first pair of potential electrodes while keeping a second pair of current electrodes in a fixed location [11]. The technic has enjoyed a resurgence in popularity since 1990 [10] due to rapid and impressive advancement in data acquisition, forward modeling and inversion capabilities. This technique is best adapted to determine depth and resistivity for flat-lying layered rock structures, such as sedimentary beds, or the depth to the water table. In this method a series of potential differences are acquired at successively greater electrode spacing while maintaining a fixed central reference point [1]. The Schlumberger configuration is most commonly used for vertical electrical sounding investigations. The goal is to observe the variation of resistivity with depth. Some of the common sedimentary rocks being more porous possess higher water content; hence they normally have lower resistivity values. Wet and clayey soils normally have a lower resistivity than sandy soils. Resistivity of each rock type depends on certain characters such as porosity, degree of water saturation and concentration of dissolved salts [9]. The usual configuration is formed by a set of four electrodes, called A, B, M and N. The pair of electrodes AB is used to inject the electric current in the subsoil while the pair MN is used to measure the electrical potential difference generated as a result of the current flow. The equipment used for Vertical Electrical Sounding was “the allied Ohmega resistivity meter”.

3. Results

The geophysical investigation method used for this research was the geo-electric resistivity technique employing the Schlumberger array with current electrode spreading from 1.5-280m with depth penetration capability of 93.3m. The field data was acquired using Allied Omega Resistivity meter. The obtained readings in the field (as reported bellow in the table) were manually plotted in the semi-logarithmic graph sheet before the computer plotting, and the geo-electric field curves were interpreted correlatively with the variation of resistivity and geological approaches. The software used was the WinResists program.

Table 1: Field data presentation.

Distance AB/2	**RESISTIVITY (Ohm meter)**									
	P1	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**	**P8**	**P9**	**P10**
1.5	46.47	53.75	150.34	168.43	133.64	251.7	37.57	131.629	577.72	130.25
2	37	49.558	109.25	194.4	126.85	294.74	47.45	129.344	484.63	128.5
2.6	36.83	49.816	81.13	211.82	139.387	298.77	51.57	116.299	464.6	133.2
3.4	41.78	55.95	78.455	228.9	155.49	254.25	57.44	118.464	430.97	113.4
4.5	47.77	63.61	91.663	174.8	173.45	246.55	61.42	110.528	327.8	103.5
6	48.7	69.177	111.98	184.6	161.17	228.42	74.79	130.152	250.43	76.5
8	52	80.2	140.04	220.8	154.76	221	105.6	162.38	231.6	66.4
10.5	51	86.5	147.33	309	144.76	219.64	156.39	184.106	190.99	65.55
10.5	70.224	52.14	129.8	296.296	107.18	297.26	202.2	168.3	152.27	75.03
14	54.52	86.1	138.49	230.39	162.36	226.32	248.46	199.57	181.63	88.6
14	81.328	81.68	126.24	243.21	109.73	276.84	315.48	181.25	142.73	111.2
18	78.53	69.44	115.08	235.3	137.56	283.64	355.88	195.02	85.3	136
24	79.239	43.24	92.14	239.79	153.82	346.45	302.58	221.63	84.4	167.99
32	81.31	38.31	124.67	273.2	217.46	398.15	247.88	228.6	116.22	232.45
42	86.067	40.08	163.02	344.27	181.72	426.95	232.66	210.334	188.6	311.25
42	75.486	43.68	150.97	292.58	132.594	372.4	253.7	203.98	239.98	381.2

55	97.425	48.55	201.09	423.44	155.56	429.53	208.2	215.91	172.83	232.67
55	88.252	51.814	193.37	351.265	121.98	414.12	196.5	211.248	235.85	264.4
72.5	107.522	56.8	263.89	376.697	133.7	482.26	281.73	264.288	289.7	320.35
95	131.803	73.3	338.72	657.51	164.9	467.28	406.31	229.813	346.85	451.9
125	166.599	104.3	421.428	506.19	216.38	471.598	577.82	260.365	474.02	640.1
165	223.614	153.5	562.004	657.51	284.09	519.16	702.96	260.64	563.58	909
165	214.279	126.59	418.75	482.32	292.85	328.08	736.8	317.031	581.6	715.87
215	302.118	147.36	703.5	928.59	400.31	619.51	825.6	434.162	567.6	1320.096
215	303.07	151.5	550.61	720.04	381.31	371.19	966.27	389.204	602.4	1844.47
280	418.175	247.25	739.17	1078.4	501.81	424.3	1023.6	439.675	643.78	1737.2

Typical field curves generated from the interpretations of the VES data using WinResist software are shown from figures 3 to 13 and the geological mining in tables.

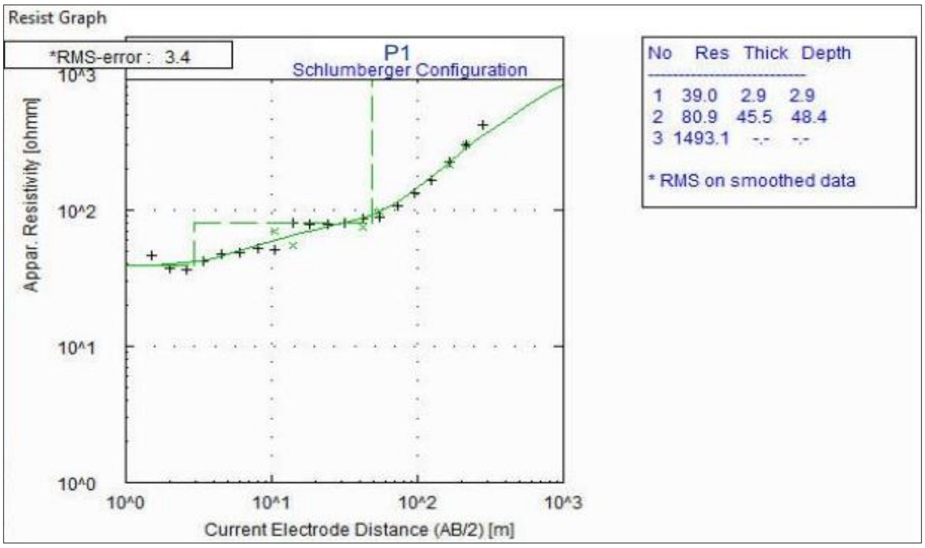

Figure 3 : curve No P1.

Table 2: Geophysical sounding No. P1

Layer	Depth (m)	Resistivity (Ohm-m)	Inferred lithostrata	Remarks
1	0-2.9	39.0	Topsoil	
2	2.9-48.8	80.9	Weathered basement/fractured basement	Possibly aquifer
3	48.8-??	1493.1	Fresh basement	

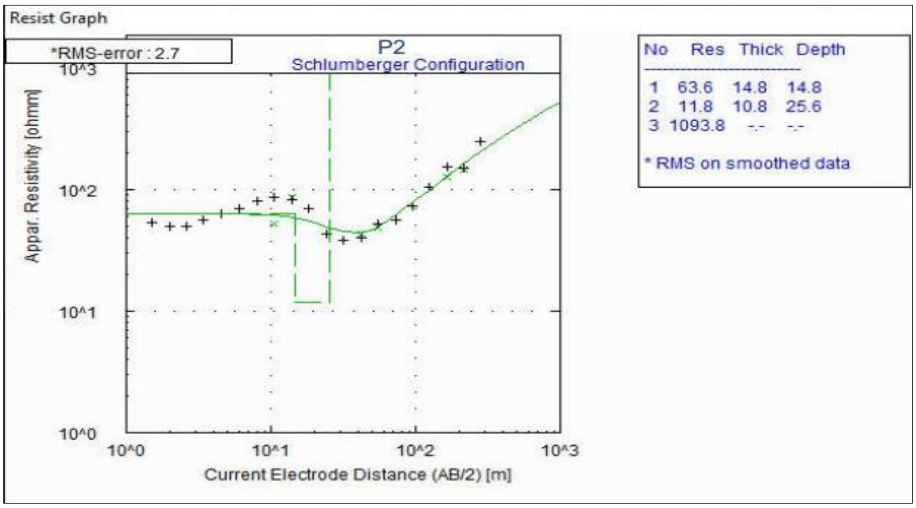

Figure 4: curve No. P2.

Table 3: Geophysical sounding No. P2.

Layer	Depth (m)	Resistivity (Ohm-m)	Inferred lithostrata	Remarks
1	0-14.8	63.6	Weathered basement	
2	14.8-25.8	11.8	Fractured basement	Possibly aquifer
3	25.8-??	547	Fresh basement	

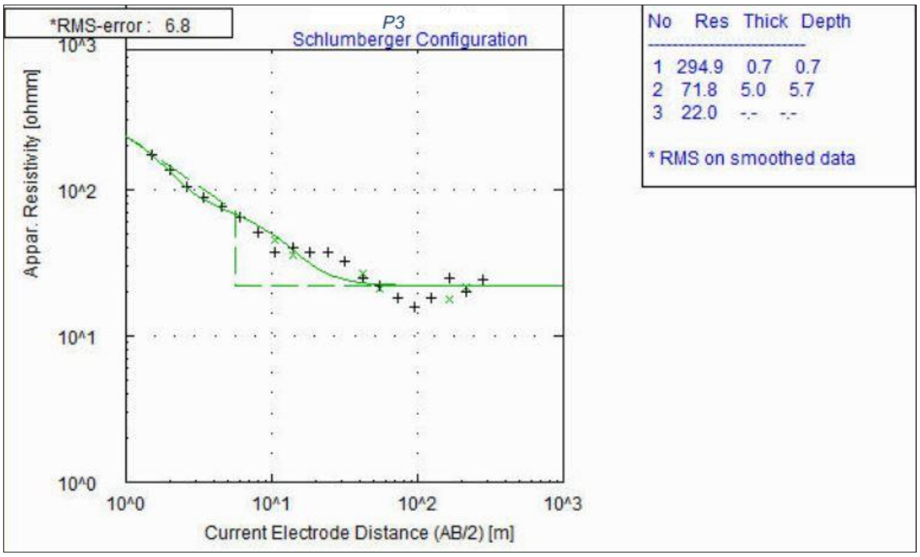

Figure 5: curve No P3.

Table 4: Geophysical sounding No. P3.

Layer	Depth (m)	Resistivity (Ohm-m)	Inferred lithostrata	Remarks
1	0-0.7	294.9	Topsoil	
2	0.7-5.7	71.8	Weathered basement	Possibly aquifer
3	5.7-??	547	Fractured basement	

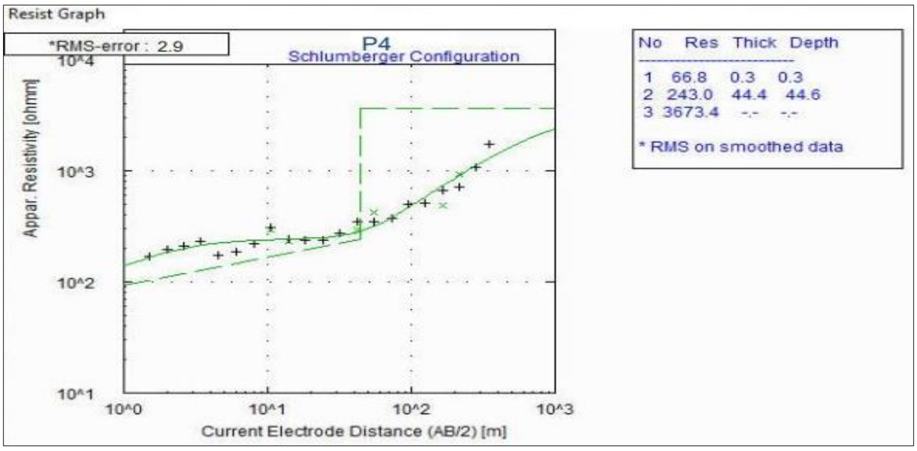

Figure 6: curve No P4.

Table 5: Geophysical sounding No. P4.

Layer	Depth (m)	Resistivity (Ohm-m)	Inferred lithostrata	Remarks
1	0-0.3	66.8	Topsoil	
2	0.3-44.6	263	Weathered basement/ Fractured basement	Possibly aquifer
3	44.6-??	3673.4	Fresh basement	

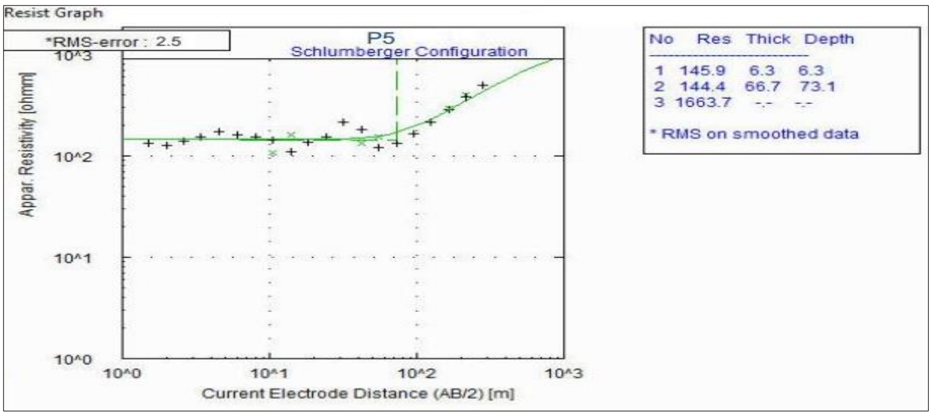

Figure 7: curve No P5.

Table 6: Geophysical sounding No. P5.

Layer	Depth (m)	Resistivity (Ohm-m)	Inferred lithostrata	Remarks
1	0-6.3	145.9	Topsoil	
2	6.3-73.1	144.4	Weathered basement	Possibly aquifer
3	4.7-18.2	547	Fresh basement	

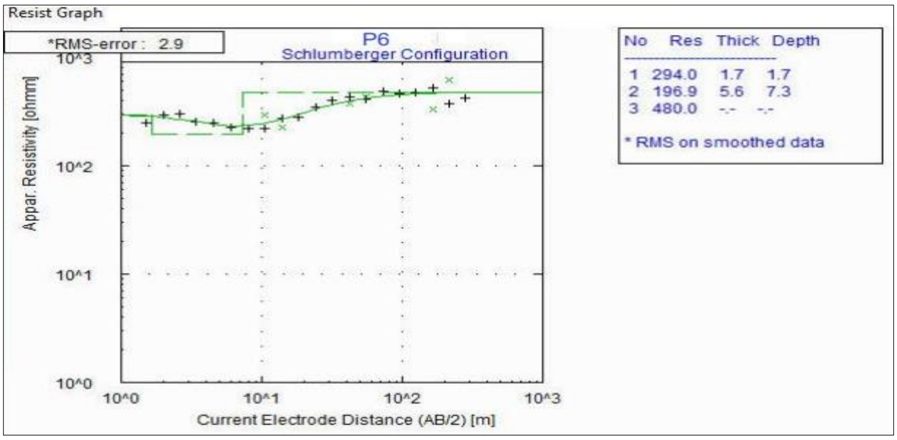

Figure 8: curve No P6.

Table 7: Geophysical sounding No. P6.

Layer	Depth (m)	Resistivity (Ohm-m)	Inferred lithostrata	Remarks
1	0-1.7	294	Topsoil	
2	1.7-7.3	196.9	Weathered basement	
3	7.3-??	547	Slightly fractured basement	Possibly aquifer

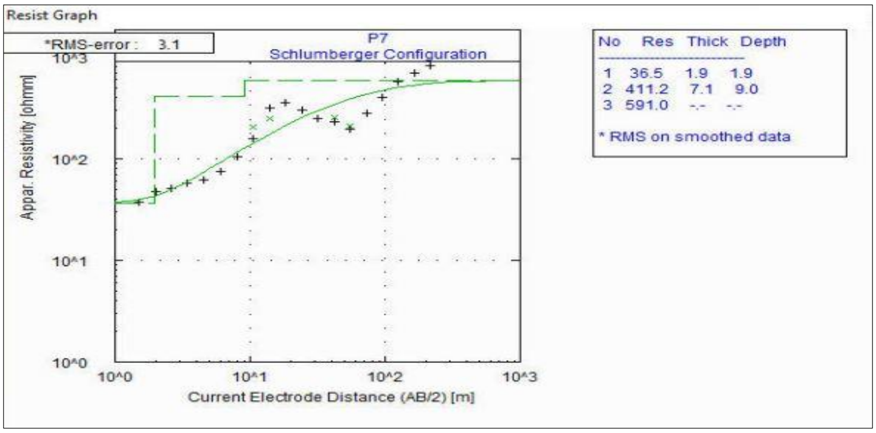

Figure 9: curve No P7.

Table 8: Geophysical sounding No. P7.

Layer	Depth (m)	Resistivity (Ohm-m)	Inferred lithostrata	Remarks
1	0-1.9	35.8	Topsoil	
2	1.9-9.0	144.4	Weathered basement	
3	9.0-??	547	Slightly fractured basement	Possibly aquifer

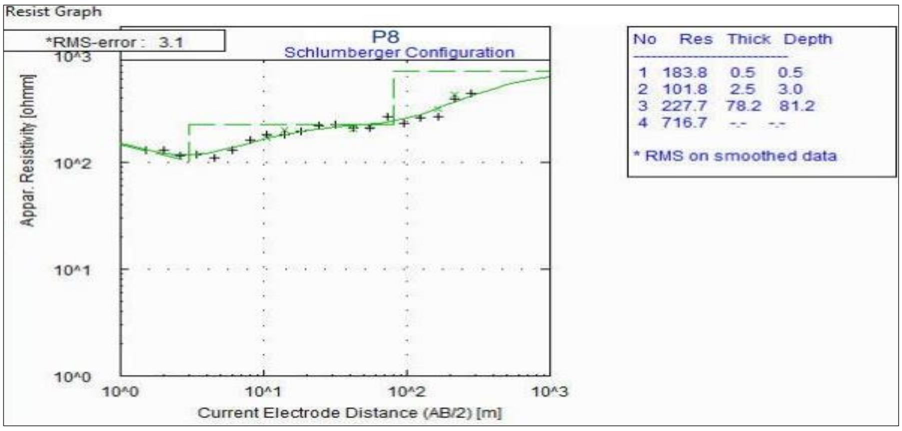

Figure 10: curve No P8.

Table 9: Geophysical sounding No. P9.

Layer	Depth (m)	Resistivity (Ohm-m)	Inferred lithostrata	Remarks
1	0-0.5	183.8	Topsoil	
2	0.5-3.0	108.1	Weathered basement	
3	3.0-81.2	227.7	Weathered basement/ Fractured basement	Possibly aquifer
4	81.2-??	79	Slightly Fractured basement	Possibly aquifer

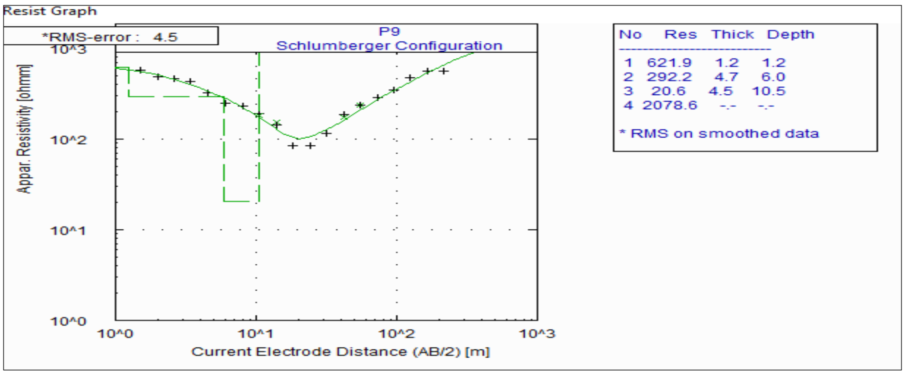

Figure 11: curve No P9.

Table 10: Geophysical sounding No. P9.

Layer	Depth (m)	Resistivity (Ohm-m)	Inferred lithostrata	Remarks
1	0-1.2	621.9	Topsoil	
2	1.2-6.0	292.2	Weathered basement	
3	6.0-10.5	20.6	Fractured basement	Possibly aquifer
4	10.5-??	2078.6	Slightly fractured basement	Possibly aquifer

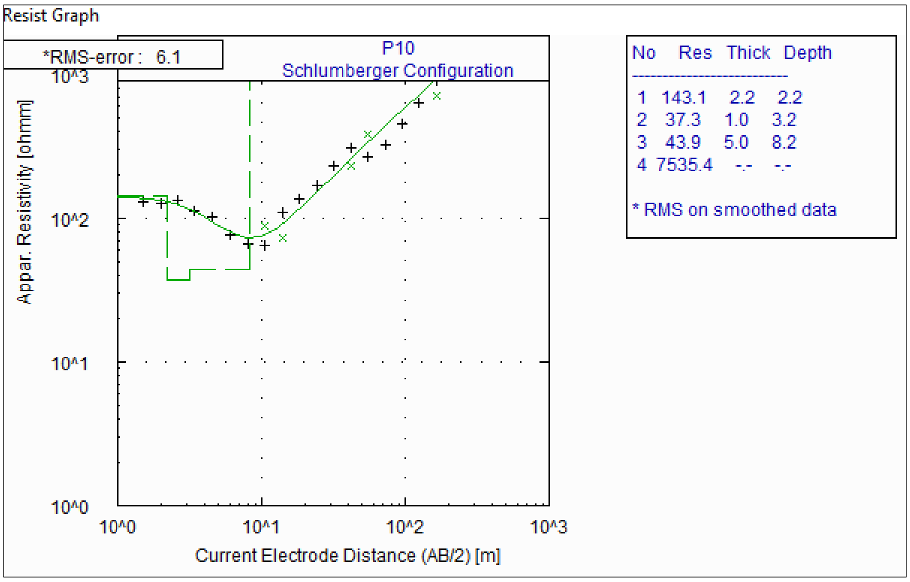

Figure 12: curve No P10.

Table 11: Geophysical sounding No. P10**.**

Layer	Depth (m)	Resistivity (Ohm-m)	Inferred lithostrata	Remarks
1	0-2.2	143.1	Topsoil	
2	2.2-3.2	37.3	Weathered basement	
3	3.2-8.2	43.9	Weathered basement	Possibly aquifer
4	8.2-??	7535.4	Fresh basement	

4. Discussions

The resistivity of geological materials can vary within an extensive range. Igneous rocks, for example, present high resistivity values, sedimentary rocks are more conductive and metamorphic rocks present intermediate resistivity values. The definition of electrical resistivity is given by Ohm's laws. Physically, electrical resistance represents the difficulty of establishing an electric current in a given conductor. In geology, the classification of the types of conductivity is given from the mechanisms of propagation of electric current [16]. A simple interpretative law which strictly applies only under ideal geological conditions has been suggested by MacDonald [6]. A different approach for interpreting geo-electrical measurements in terms of aquifer properties was suggested by Soupios and his colleagues [12] who combined information from wells with 1-D inversions of Schlumberger vertical electric sounding data acquired at a number of the site on the island of crete. The principle is focuses to the Archie's law. The interpretation of the resistivity section is based on geological outcrop and stratigraphy from boreholes [20]. The upper layer of Butembo is strongly heterogeneous reflecting the unorganized spatial distribution of the constituent concrete and brick debris; the upper layer is more resistive than the underlying natural soil; this is justified by the atmospheric conditions it is exposed to. The analyses of sounding curves obtained from geophysical survey data over the area have brought out three to four subsurface geo-electric patterns. The geophysical curves suggest that aquifers are made by fractured crystalline bedrock. The aquifer level is overlain by more than 20 m of saprolite and a thick slightly weathered basement. This sandy clay saprolite can constitute an aquifer but it lower transmissivity and the hygienic conditions made it unusable. Saprolite-saprock aquifer systems have highly variable but generally low transmissivities (< 10 m^2 per day: [13], [17] and low storage (1–2%), though few reliable measures of the latter exist. Sustained low-intensity abstraction from saprock aquifers occurs in many areas of the world and has long been thought to depend on leakage from the overlying, more porous saprolite [7,14]. The aquifer of the area is made by different levels of fractured basement alternating with a fresh bed rock. It means that Butembo is built on a fractured crystalline bed rock and the origin of fractures is supposed to be caused by the tectonic movement due to the kibara erogenous more than one billion of years ago. In this condition, boreholes must be deeper; from 70 to 100m. A borehole made under 50m can be realized unless a hand pump is provided and this for a small community.

5. Conclusion

In order to resolves the problem due to the scarcity of water; the underground research is nowadays a quick and durable solution. Several methods are used for that but the electrical resistivity method was used because it is rapid and cheaper. The geophysical survey undertaken through this research was aimed to explore the water potential of the area and propose the solution to the scarcity of water and reduce hydric diseases, Ebola and corona viruses. The geological survey done in the area has revealed that Butembo city is built on a crystalline bed rock covered by a thick overburden material. The principal formation of the area is granite gneiss. Groundwater occurrence, circulation and storage properties of the area are determined greatly by the type of geology, geological contacts, geomorphology and rainfall patterns. The main aquifer systems in the area are made by weathered and fractured basement which is characterized by high-moderate to low productivities. The drilling project can be done in order to respond on the scarcity of water but must take care of the hygienic conditions because of the high demographic aspect. This is a preliminary research and can be completed by drilling approaches in order to highlight the water characteristics in the area.

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