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The Application of Vertical Electrical Sounding (VES) for the hydrogeological and Geophysical Investigations in Kibumba Area, DR Congo

Byamungu Mayange[1-3], Ngenzebuhoro Claver[2], Kiro Kubuya[3], and Shungu Lama[4]

[1]College of Life and Environmental Sciences, Daegu University, South Korea

[2]Faculty of Sciences, Department of Earth Sciences, University of Burundi, Burundi

[3]Centre d'Expertise et d'Etude Géologique, CEEG, RD Congo

[4]Faculty of Sciences, Department of Geology, University of Goma, RD Congo

ABSTRACT: A natural and instantaneous geophysical method for groundwater investigation in volcanic formations of Kibumba area has been developed. A geophysical evaluation using Electrical Resistivity method for groundwater investigation was carried out which involved the utilization of Vertical Electrical Sounding (VES) technique with Schlumberger array system. The study area is located within the igneous rocks, sedimentary, and metamorphic. The data acquired from twelve (12) VES stations using ABEM terrameter (SAS 1000) was tabulated in a table which shows the resistivity, the thicknesses and the number of layers for each VES station. The data was analysed using computer inversion software called INTERPEX1D, which yield an automatic interpretation of the apparent resistivity. The VES results revealed heterogeneous nature of the subsurface geological sequence. The geological profile sequence in the study area includes the topsoil (clay and fragments rocks and/or boulders formations of basalt), weathered layer (and/or fractured basalt) and fresh basement. The value for topsoil ranges from 10 Ωm to 1500 Ωm with thickness varies from 0.3 m to 10 m. The weathered layer (and/or fractured basalt) resistivity ranges from 100 Ωm to 2000 Ωm and thickness of 3 m to 20 m. The fresh basalt or bedrock basement ranges in value from 30 Ωm to 3000 Ωm with an unknown thickness due to the volcanic formation in the study area. However, the bedrock depth of all the VES stations from the earth's surface could range from 1 m to 34 m. Based on the result of VES data, the proper area for making boreholes would be VES Kibumba 2, VES Kibumba 5 and VES Kibumba 9.

KEYWORDS: Vertical Electrical Sounding (VES), Groundwater potential aquifers, topsoil, weathered layer, fractured basalt layer, fresh basalt.

1 INTRODUCTION

Groundwater exploration is becoming increasingly important for D.R.Congo due to an ever-increasing demand for water; especially in areas like Kibumba with absent or inadequate surface water supplies. Already, ten percent of the world's population is affected by chronic water scarcity and this is likely to rise to one-third by about 2025 (WHO, 1996).

The problem of gaining an adequate supply of quality water is generally becoming more severe effect due to ever increasing of population, irrigation and industrialization. Due to this situation, surface water cannot be dependable throughout the year; hence another alternative is needed in order to supplement for surface water. (Fadele et al., 2013). The first alternative opened to man is ground water, which may be defined as "water in the zone of saturation and from which wells, springs and underground runoff are supplied". This water is trapped by geological formations (Palacky et al., 1981).

The groundwater can be in the sedimentary terrain where it is less difficult to exploit or in the basement complex terrain in which it can be a bit difficult to locate especially in areas underlined by crystalline rocks (Fadele et al., 2013).

Hence, a systematic and scientific approach to the problem is therefore essential for the study area in order to overcome these problems. The quantity and disposition of ground water depends on the geological characteristics of the host rock formation. The search for ground water is faced with lots of uncertainties; to minimize or avoid failures altogether, it is pertinent that the right exploration techniques are utilized in the delineation of subsurface water-bearing formations (Coker et al., 2009).

Nowadays the used of geophysical techniques for groundwater exploration and water quality evaluations has increases due to rapid advances in computer software and other numerical modelling techniques. The use of Vertical Electrical Sounding has become very popular with groundwater prospecting due to simplicity of the technique. The purpose of electrical geophysical survey method is to detect the surface effects that produce by the flow of electric current inside the earth. This technique have been used in a wide range of geophysical investigations such as mineral exploration, archaeological investigation, engineering studies, geothermal exploration, permafrost mapping and geological mapping (Fadele et al., 2013).

This present research use the Electrical Resistivity Surveys with an instrument called ABEM (SAS 1000) terrameter which were taken using Schlumberger array. Hardianshah et al. (2013) carried out similar experiment to investigate the subsurface geology and aquifer potentials in the area of Dent Group sedimentary rock. 40 Vertical Electrical Sounding stations technique were performed by measuring the resistivity change with depth. The resistivity measurements were conducted using ABEM SAS 300C Terrameter by using Schlumberger electrode configuration with maximum current electrode separation of 500m. Interpreted VES data in the Sebahat formation produces three to four geo-electrical resistivity layers. Musa G. et al. (2014) also used vertical electrical sounding groundwater exploration in the crystalline rocks of Tudun Wada Kano State, Nigeria. Their study used Schlumberger arrangement in six (6) VES stations and the resultant data was analyzed using computer software (IPI2win) which gives an automatic interpretation of the apparent resistivity. Vertical Electrical Sounding has been put to effective use in many earlier groundwater studies and found to be extremely successful. In the present study, the Vertical Electrical Sounding using Schlumberger array were carried out at six (12) VES stations. The study used current electrode spacing of 1/2AB = 40 m, in which the potential electrode separation MN has maintain its order of increment. The research was carried out to study the subsurface geology condition, the hydrogeological condition and the Geophysical condition of the Kibumba region with the following objectives: To identify the thickness, resistivity value of sub-surface layers; to determine the hydrological conditions of the area and to characterize the location and configuration of weathered basaltic bedrock units in hope to reach a formation which contains an aquifer with the chances of high yielding boreholes. This site is located in northern Goma town, along the second National Road (RN2), at almost 30 km from Goma town.

2 STUDY AREA

The study area located in Nyiragongo territory (Kibumba Region), North Kivu, Democratic Republic of Congo (DRC) or located at 1°29'50.2" S latitude and 29°20'38.4" E longitude. This territory covers a total area of 333 Km^2 with a population of 38,689 as for 2004 census and a density of 237 in Hab. /Km^2. The area experiences a tropical climate having rainy and dry seasons. A short dry season: from January to February; a great rainy season: from March to May; a great dry season: from June to August; and a short rainy season: from September to December. In spite of the alternation of these four seasons, the territory of Nyiragongo sometimes knew an irregularity of seasons. This situation was explained by its very high altitude, which made the rainy season extend more than 8 months a year. The mean annual rainfall is 1000 mm with a relative humidity ranges from 25-75% and the mean annual temperature varies from 21°C to 30°C.

This area is a mountainous region whose mountains would have risen to the tertiary as a result of a tectonic break giving rise to the horsts and Graben of the East African rift, its altitude varies between 1461 m in the South and 2000 m in the North. Nyiragongo territory belongs to the Virunga volcanic province. One of the particularities of the Virunga Volcanic Province is the NNE trend of. The rift in this province is most probably a half-graben with a marked normal fault on the western side and no clear normal bounding fault on the eastern side, with a series of 10-to 20-km-long high angle normal fault within a 10 to 15 Km wide zone (Ebinger, 1989). The Mio-Pliocene Virunga lava flow took place after an important tectonic phase responsible of many new structures; these flows are from passed by faults (Ilunga, 1991). The basement of Nyiragongo territory is Mesoproterozoic formations (kibaran belt) covered by the recent volcanic formations due to the activity of the Virunga Volcanic Province (VVP).

3 MATERIALS AND METHODS

The layout of a geo-electrical sounding setup showing the depth of investigation as a function of the geometry of the setup. Geophysical prospection comprises several techniques used in subsurface investigations. Among these techniques, geo-electrical sounding (resistivity method) is the most commonly used method in groundwater investigations. Geo-electrical prospection, which consists of injecting the electric current into the subsoil by two electrodes, enables to detect less and most conductive layers. The resistivity of a geological material decreases substantially when the latter is impregnated with an electrically conductive fluid such as water. These electrically conductive areas are a priori more permeable: in an aquifer, there is a good correlation between the two parameters namely electrical properties and hydrodynamic parameters (Meylan, P., Favre, A.-C. and Musy, 2005). This method, therefore, allows determining quantitatively the distribution of thickness of layers of different electrical properties directly below a point and is implemented through four electrodes that the Geologist pushes into the ground with a hammer. The method consists of sending an electric current of known intensity into the ground through two current-injection electrodes, A and B, and to measure the difference of potential generated by the current intensity using two measuring electrodes M and N (Chouteau. & Giroux, 2008)

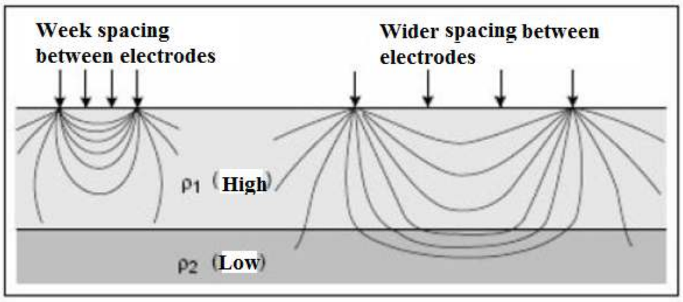


Fig. 1. Layout of a geo-electrical sounding setup showing the depth of investigation as a function of the geometry of the setup

There are 3 main types of setting up potential electrodes M, N and current electrodes A, B in geo-electrical survey, which give rise to three main types of configuration of the geophysical exploration setup by resistivity method. These configurations are: Schlumberger array, Wenner array and Dipole-Dipole array. This present research has used the SCHLUMBERGER array which is illustrated in the following figure:

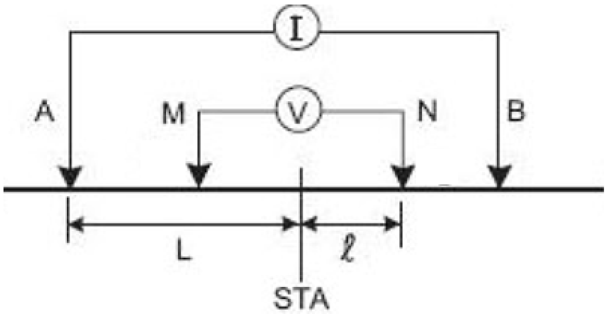


Fig. 2. Schlumberger array

AB: current electrodes

MN: potential electrodes

L= AB/2 et l = MN/2

$$\rho a = \pi \frac{\left(L^2 - l^2\right)}{2l} \frac{V}{I}$$

Where ρ_a = apparent resistivity, V= difference of potential and I= intensity of injected electrical current.

Given the fact that subsurface layers are generally heterogeneous, the measured resistivity is an apparent resistivity which is actually a sort of average of the resistivity of the different layers encountered within the volume of subsurface material practically concerned by the distribution of electrical current. Two interpretative models of the vertical electrical sounding data show H-type sounding curves (Reynolds, 1997) which reveal 3 geo-electricals layers of which the middle one is the least resistant (Wenner array). The presence of a layer of low resistivity sandwiched between two layers of high resistivity indicates the presence of clay to sandy clay layer which partially confines the aquifer. The interpretation of geo-electrical soundings is done in comparison to different values of resistivity typical of main types of rocks (Table 1).

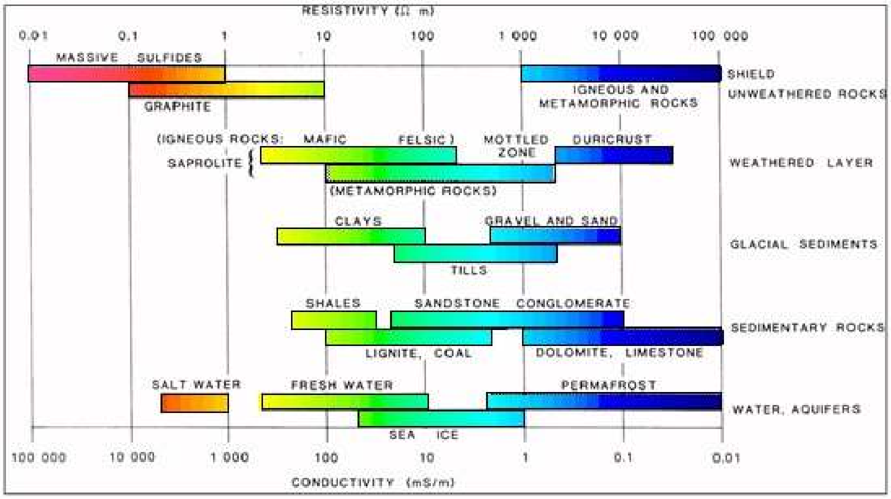


Table 1. Typical resistivity values of main rocks

4 RESULTS AND DISCUSSION

The geometric factor, K, was first calculated for all the electrode spacing using the relation; K= π (L2/2b – b/2), for Schlumberger configuration in which MN=2b and AB⁄=L. The results obtained were multiplied with the resistance values to obtain the apparent resistivity, ρa values. By the use of computer inversion software called INTERPEX1D in the present study, the result of apparent resistivity and electrode spacing was plotted in a log-log scale to obtain VES sounding curve.

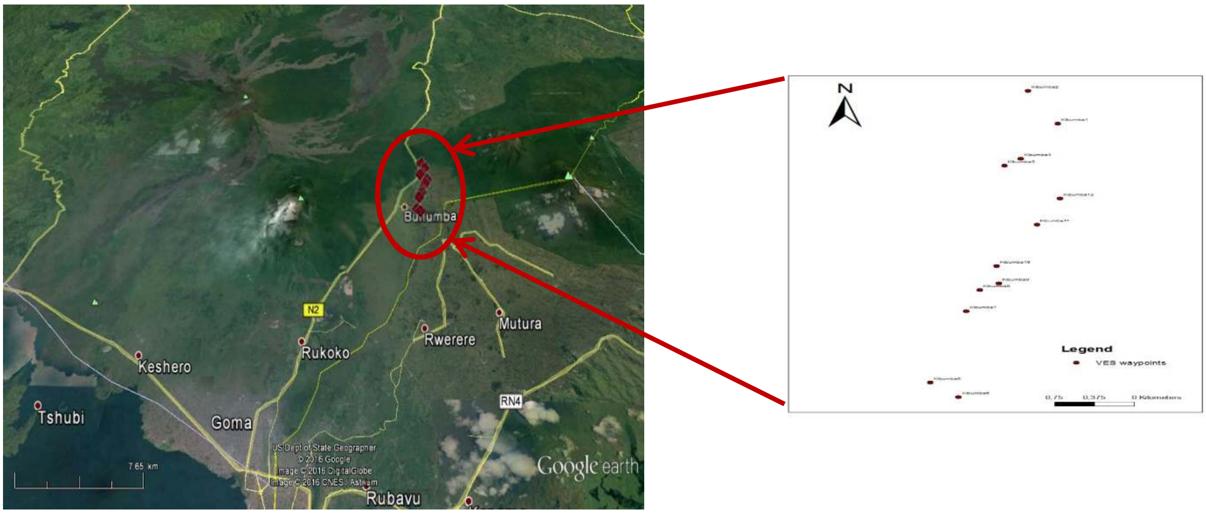


Fig. 3. Map showing the location of the VES surveys in Kibumba

All the sounding curves and their models are showing in Figure 6. The VES survey data collected from different sites are presented graphically and interpreted with their possible geological meanings and the apparent resistivity value in the Table 2, layer thickness and depth tabulated as follows:

The first layer or topsoil, composed of clay, fragments rocks and/or boulders formations of basalt and its value ranges from 10 Ωm to 1500 Ωm with thickness varies from 0.3 m to 10 m. The weathered layer and fractured basalt resistivity ranges from

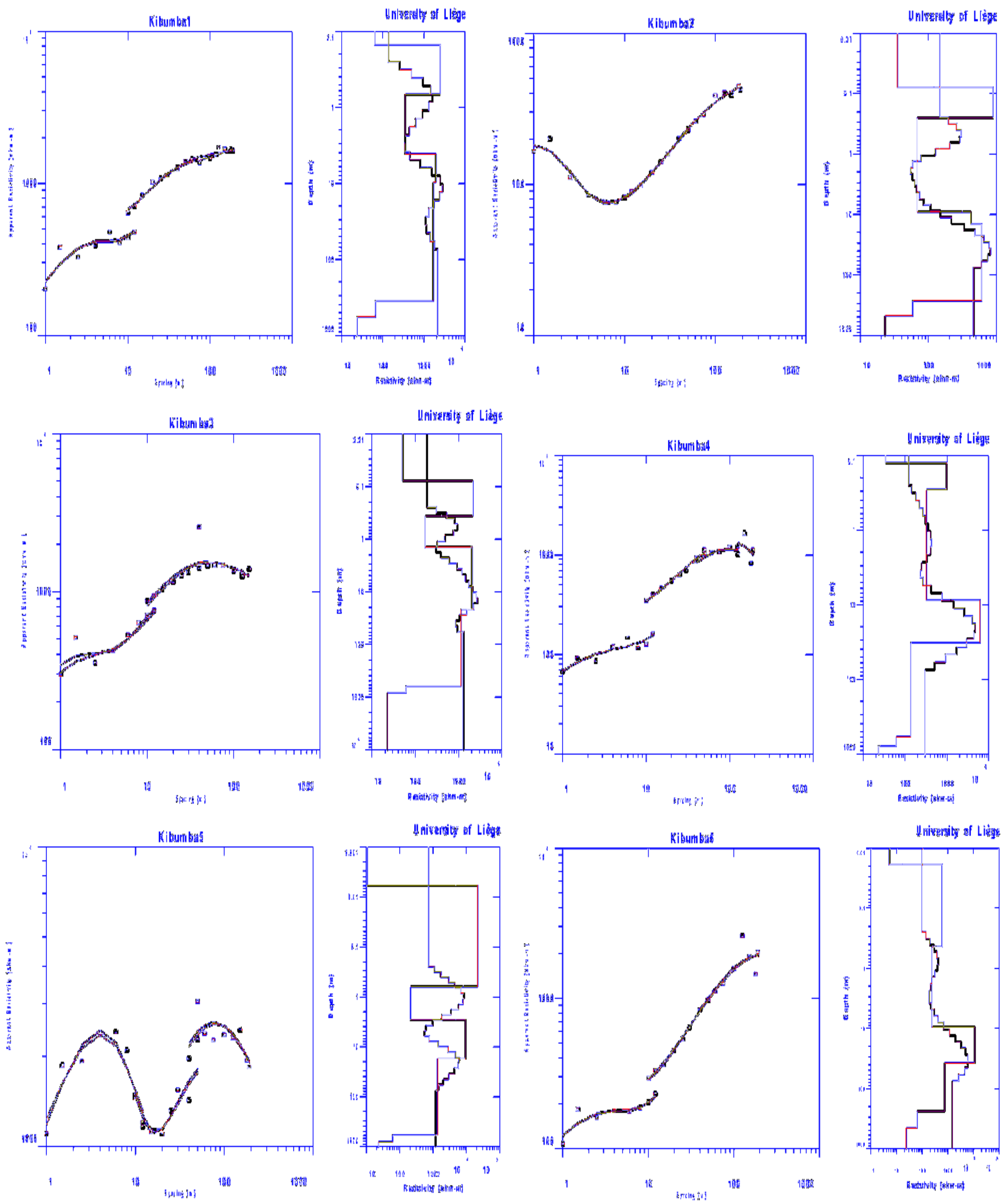
100 Ωm to 2000 Ωm and thickness of 3 m to 20 m. The fresh basalt or bedrock basement ranges in value from 30 Ωm to 3000 Ωm with an unknown thickness due to the volcanic formation in the region.

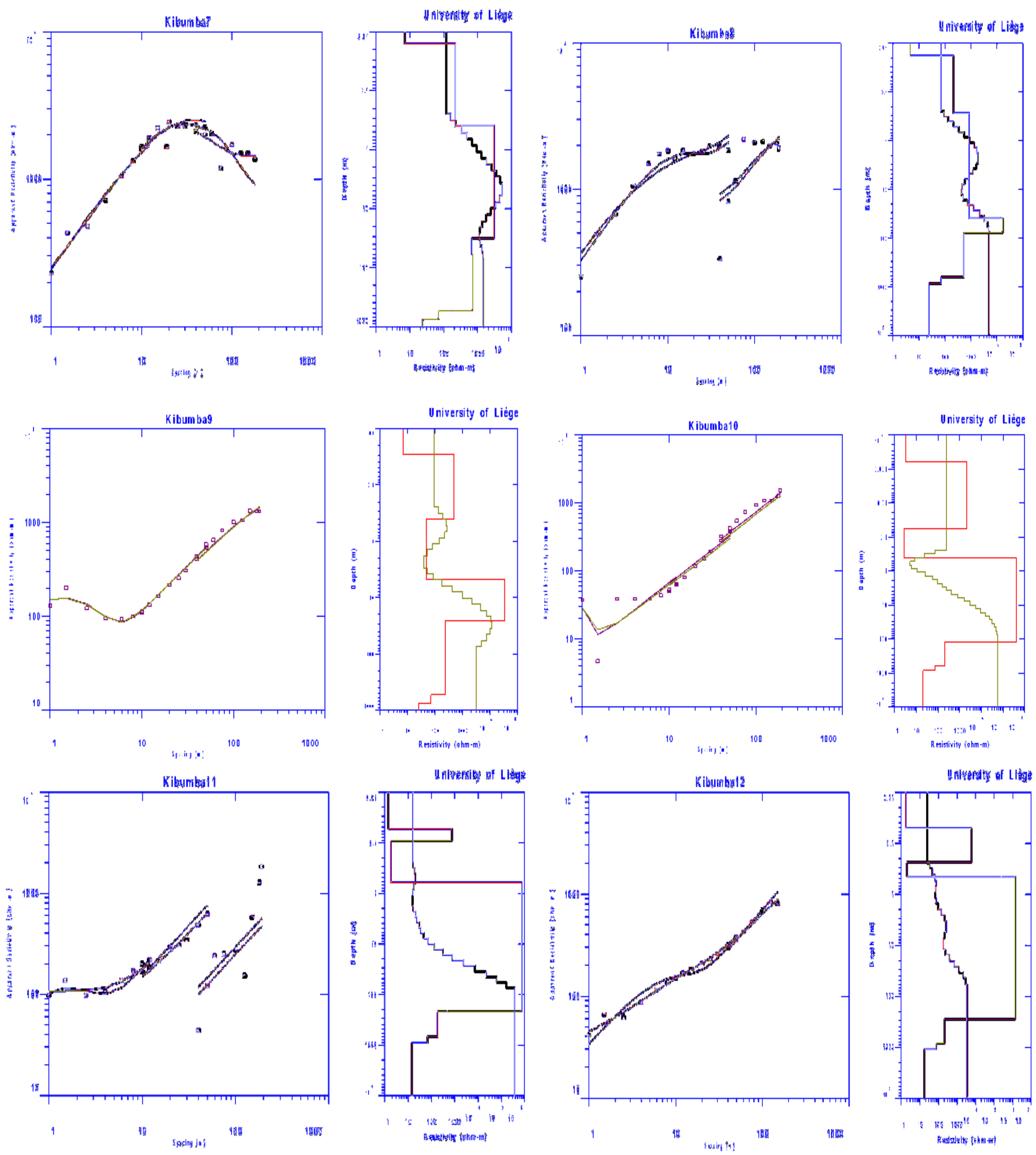
However, the bedrock depth of all the VES stations from the earth's surface could be range from 1 m to 34 m with a resistivity which move down infinitely.

Table 2. The results of the interpreted VES stations (1 to 12) of the study area are shown in the table below

VES stations	Layer Resistivity (Ωm)	Depth (m)	Number of layers and some explanation of the unknown layers
VES Kibumba 1:	30 to 3000 Ωm 3000 to 300 Ωm 300 and 2000 Ωm	0.8 m 4.2m unknown	3
VES Kibumba 2:	15 to 900 Ωm 900 to 70 Ωm 70 and 600 Ωm	0, 3 m 14.7 m unknown	3
VES Kibumba 3:	25 to 1500 Ωm 1500 to 1000 Ωm unknown	2 m Unknown Unknown	2
VES Kibumba 4:	20 to 300 Ωm 300 to 800 Ωm Unknown	10 m 20 m unknown	3
VES Kibumba 5:	0 to 20000 Ωm 20000 to 100 Ωm 1000 and 3000 Ωm	1 m 3 m unknown	3
VES Kibumba 6:	10 to 300 Ωm 300 to 3000 Ωm Unknown	10 m 20 m Unknown	3
VES Kibumba 7:	10 to 100 Ωm 100 to 2000 Ωm Unknown	0.5 m 20 m Unknown	3
VES Kibumbu 8:	it's very difficult to confirm the number of layers	Unknown	The points are scattered, which means that there is no result that can be interpreted to characterize the underground, there has been what is called noise (figure 6. VES Kibumbu 8)
VES Kibumba 9:	10 to 200 Ωm 200 to 30 Ωm 30 and 3000 Ωm	0.4 m 6.6 m unknown	3
VES Kibumba 10:	It shows that the sounding didn't reach a depth over 1 m		The explanation can be found in the figure 2 which shows the resistivity variation as a function of depth, called reverse model or inversion.
VES Kibumba 11:	Its shows a lot of noises since 40 m of spacing AB/2. The depth the sounding had reach is minus 1 m		sounding issues during the experiment
VES Kibumba 12:	The resistivity increases from the surface to depth but this depth investigated did not exceed 1 m.		Same as VES Kibumba 10

Fig. 4. The sounding curves and their models





5 CONCLUSION

The hydrogeological and geophysical investigations using electrical resistivity method were carried out with twelve (12) VES stations in Kibumba and have revealed that, seven (7) VES stations (VES Kibumba 1,2,4,5,6,7,9) have three layers mostly in the study area, while one (1) VES station (VES Kibumba 3) have two (2) layers, but the VES Kibumba 10 shows that the sounding didn't reach a depth over 1 m, the VES Kibumba 11 shows a lot of noises after 40 m of spacing AB/2 and the depth sounding had reach minus 1 m. Finally, on the VES Kibumba 12, the resistivity increases from the surface to depth but this depth investigated did not exceed 1 m. The geological sequence beneath the study area is composed of topsoil (clay, fragments rocks and/or boulders formations of basalt), weathered layer (and/or fractured basalt) and fresh basement. The fresh basalt or bedrock basement ranges in value from 30 Ωm to 3000 Ωm with an unknown thickness due to the volcanic formation in the study area. Based on the qualitative interpretation of the VES data, It has seen that the most likely stations to drill were VES Kibumba 2 in the north, VES Kibumba 5 in the south and VES Kibumba 9 in the central part of the study area, with appreciable thicknesses of the subsoil and characterized by structural features such as fractures which improve the permeability and storage of groundwater. The analysis of this study was completed using also information about the local and regional geology and give an understanding of subsurface electrical properties of the region.

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