Characterization of Geothermal Reservoir in Cibitoke and Rumonge Provinces of Burundi

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Abstract: The geothermal energy sector in Burundi has not yet had any particular attention in term of developing this renewable resource which has the potential as a source for electricity generation and direct use applications. The country has more than 13 geothermal springs spread over different regions. This research is focused on the characterization of geothermal reservoir of Mugara and Ruhwa sites. Geophysical and geochemical methods have been used to collect the data. Thus, geological, electrical resistivity data based to Schlumberger method and chemical elements were analysed in order to investigate the geological structures and the quality of these geothermal reservoirs. The results showed that in Mugara site, the geothermal reservoir is located geologically in the spongoliths, coarse cemented sands, clay-sandstone spongoliths whereas the Ruhwa site is found in the white quartzites with intercalations of phyllite rocks with the presence of schites, psammoshistose, sandstone-silty quartzites. The aquifer in Mugara site is a semi-confined aquifer and the Ruhwa geothermal reservoir is a confined aquifer due to its roof, which is composed of clay. The highest temperature in Ruhwa site is 68°c and underground source temperatures are postulated to be as high as 110-120°c based on the quartz geothermometer in the hot springs from the porous sediments. The chemical analysis results of water from Ruhwa and Mugara indicated that 3 elements which are Fe, Mg and K have a high content of 21.5 mg/l, 10mg/l and 76mg/l respectively.

Keywords: *Geothermal Reservoir, Burundi, Resistivity, Geology, Ruhwa, Mugara.*

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I. INTRODUCTION

In Burundi, geothermal energy belongs to a sector that has not yet had any particular attention in the direction of electricity production, whereas it can be a significant source of power (Sinzinkayo et al, 2015). Geothermal power is normally derived from geothermal reservoir hot waters or steam being brought to the surface through drills holes or percolating through natural vents. Studies indicate that the whole Burundi produces an average of 245.97GWh from different hydroelectric power plants (Sinzinkayo et al., 2015). More than 42.4% of the total electricity in the country (16.3MW) is imported from Ruzizi I &II in Republic Democratic of Congo. That total electricity production can be increased by constructing other hydroelectric power plants. Burundi also has potential to develop solar and wind energy (Sinzinkayo et al., 2015). Unfortunately, geothermal power production is yet to be explored and exploited.

Surface manifestations do exist in form of hot springs in at least 13 different areas located in different physical and geological environments in the country. These thermal waters of Burundi, like so many other thermal waters encountered in different countries of the world have the potential to promote use of geothermal reservoirs, once in-depth studies are carried out especially those relating to the production of electricity from these ground waters (Grant & Bixley, 2011). Although these thermal waters are distributed in different regions of the country, the majority of the springs are located in the western belt of the country, in the province of Cibitoke in the northwest and in Rumonge province, to the southwest (Mpawenayo et al, 2005).

Previous studies related to thermal waters in Burundi have been carried out by several workers (Belgique, 2004; Mpawenayo et al., 2005; Ndyamuhaki et al, 2021, Sinzinkayo et al., 2015). These studies mainly focused on exploration and localization of the different springs through

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carrying out chemical analysis. However, none of these researches has investigated or characterized geothermal energy potential of the hot springs, especially those of Ruhwa and Mugara in the western region. Our present work assesses the possibility of the promotion of a geothermal applications in Burundi by characterizing the geothermal reservoirs of Mugara and Ruhwa springs.

II. GEOLOGICAL CHARACTERIZATION OF STUDY AREA

Burundi is a landlocked country located between East and central of Africa. It stretches between 2°45' and 4°28' of latitude south and between 28°50' and 30°50' of longitude east and has an area of about 27,834 km^2. It shares its borders with Tanzania to the East and South, Democratic Republic of Congo (DRC) to the West, and Rwanda to the North (Bakundukize, 2012). Our study area is located in two regions, one in Rumonge province in south-west and the other in Cibitoke province in north-west of the country. The Rumonge province thermal waters site, is located in at Mugara part of Rumonge commune in a concave place, in the junction of the 3 different hills (Figure 1). The second part of the thermal water site, which interested our research is in the commune Rugombo of the province Cibitoke. This site is located close to the border of Burundi and the Democratic Republic of Congo and also at a few km from the border with Rwanda near Ruhwa river (Figure 1).

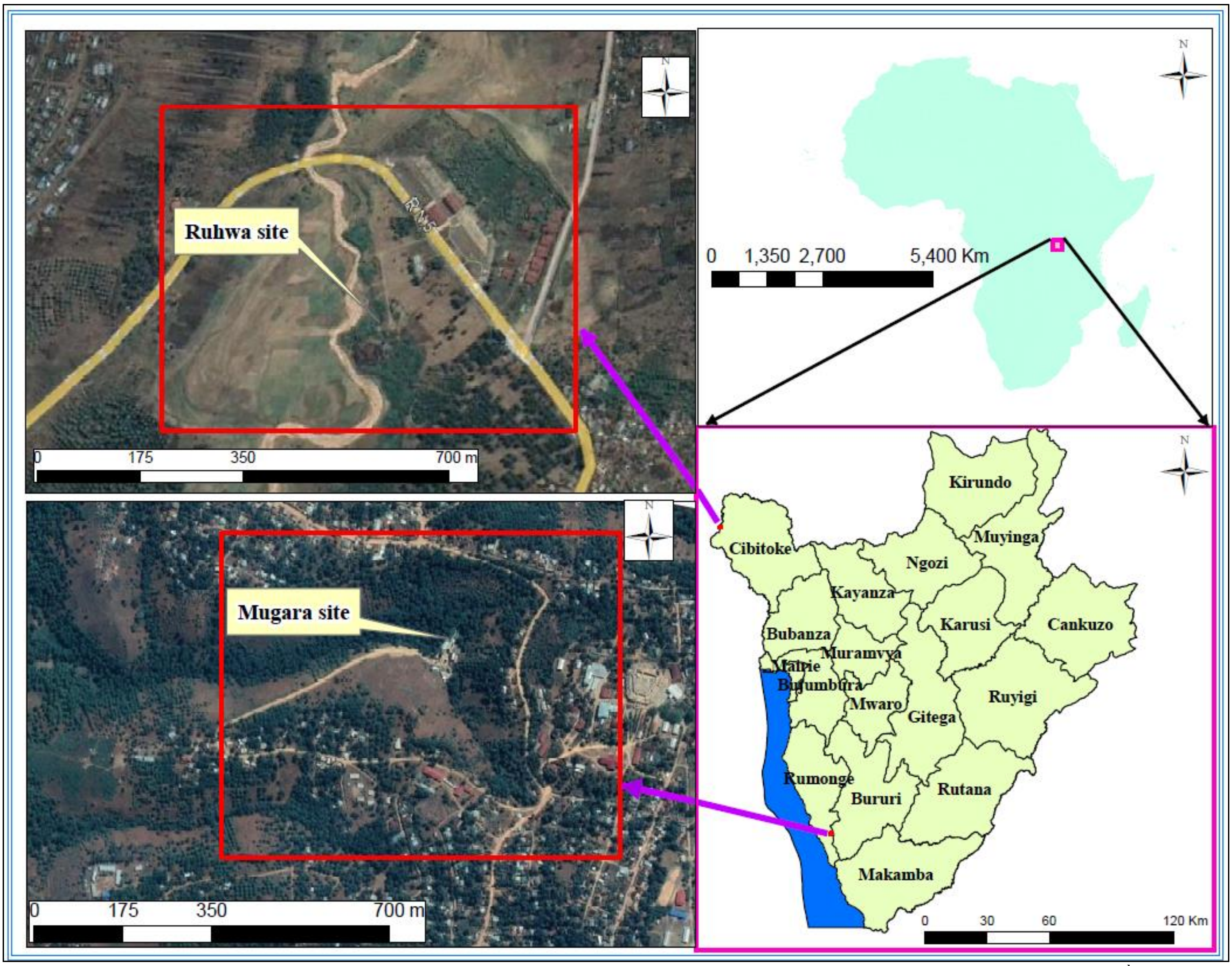

Fig 1: Location of Mugara and Ruhwa Studied Sites (Modified Image from Google Earth. Accessed on October 10th 2021)

Geologically, the study area of Mugara site is located in different geological formations, namely the ancient lake formation, the Vyanda complex, the alluvium at the bottom of the valleys and low terraces (Tack, 1995). Granite rocks exist in the northwestern part of this thermal water site (Figure 2). The old lacustrine formations, comprising of spongoliths, coarse cemented sands, clay-sandstone spongoliths have been identified.

The Vyanda complex observed near the study area is monotonous and consists of alternating metaquartzites and similar phyllites, evoking a stratigraphic repetition due to tectonic deformation. The metaquartzites are observed in some places as lenses of very reduced dimensions and are of a particular mineral association interpreted as relics of a tufa rock.

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These metaquartzites are generally white to beige, gray and sometimes pink, its grains are very fine in some levels and coarser elsewhere. They locally contain muscovite, tourmaline, and quite often garnet. The mylonitic texture, consistent with the sedimentary bedding, is very pronounced in reduced levels and is never penetrative. These mylonitic quartzites are produced in sheets. Metapellites are often observed which alternate with these quartzites locally occupying extensive regions and are reduced to less thick levels. They are all banded, gray in color, dark to light altering in red tones.

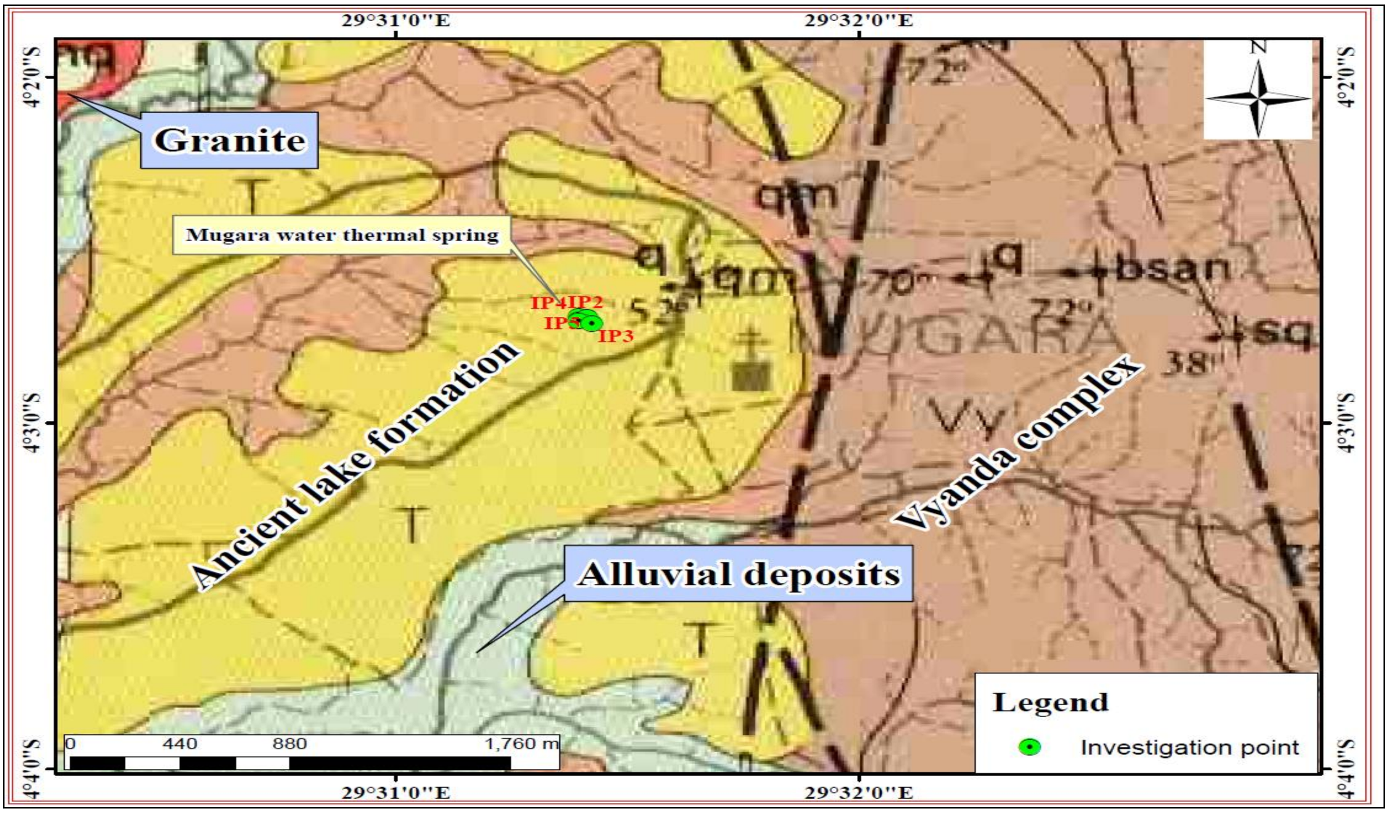

Fig 2: Geologic Map of Mugara Site (Modified from the Geological Map of Burundi)

The site of Ruhwa in the province of Cibitoke is alsogeologically located in different formations, especially the rugendo-mabayi-sagahanga formation and there are magmatic rocks of basic and/or intermediate composition(Tack, 1995), the Masango-Butara complex as well as the Butahana-Murwi formation around the formation that contains our Ruhwa hot spring (Figure 3).

Indeed, the Rugendo-Mabayi-sagahanga formation is made up of well-stratified white quartzites with intercalations of phyllite rocks (Bignall et al., 2010). Lenses of dark gray quartzites and coarse conglomerates rich in iron oxides are observed with highly altered light gray-green phyllites. In this geological formation, there are schites, psammoshistose levels and misclassified, sandstone-silty quartzites containing gravelly levels associated with red schists. The sagahanga facies is particularly made up of feldspathic quartzites and sandstones, white feldspathic and tuffaceous shales.

For the Masango-Butara complex, there are gray to grey-green phyllites, quartzo-phyllites and traces of volcanic rocks (amphiboles, amphibolo-chloritoschists, tuffs). There is also an alternation of beds of feldspathic quartzites, psammoschists and schists and local intercalations of amphiboles. Additionally, in the Butahana-Murwi-Ngozi Formation, there are dark, banded gray and gray-green metapelites with graphitic horizons. Carbonate rocks, dolomitic limestones and some rare quartzites are observed with volcanic rocks presenting amygdalar lavas, volcanosediments as well as amphibolitic rocks. The shales encountered in this formation are essentially pelitic with passages of sandstone-pelitic. These shales are sometimes dark and light gray, banded or homogeneous, altered in red with rare levels of amphibolites.

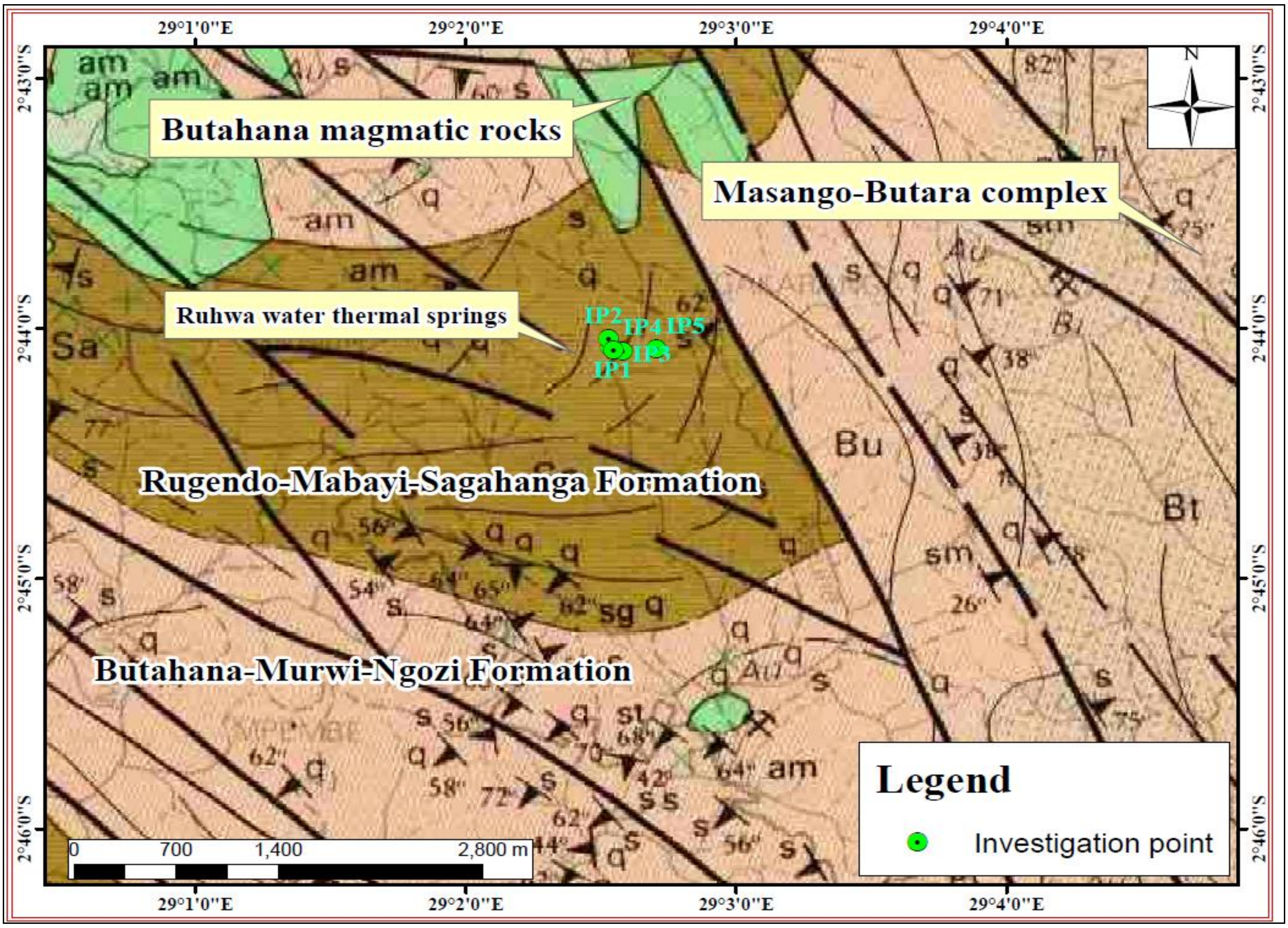

Fig 3: Geologic Map of Ruhwa Site (Modified from the Geological Map of Burundi)

III. MATERIALS AND METHODS

Geophysics has implemented techniques such as the spontaneous polarization method and the resistivity method (electrical investigation) to analyze the variation of layers deep in the subsoil (Patterson et al, 2020). Among these methods, the resistivity method is currently the most widely used in the prospection of groundwater zones due to its simplicity and its fairly controllable results (Castañeda et al., 2009). Spontaneous polarization is applied by measuring the potential of naturally generated materials while electrical probing is based on measurements of the electrical potential generated by the injection of direct current into the soil (Domra et al, 2015). The geo-electric prospecting, consists of injecting electric current into the subsoil, which makes it possible to detect the least conductive and the most conductive areas of electric current, whether by horizontal exploration or by vertical exploration of a point of investigation (Ochieng, 2013). The variations in resistivity obtained by adjusting a geometry factor and the resistance recorded by a resistivity-meter for a geological material are many and depend on impurities and crystals (El-Qady, 2006; Feng el al, 2020).

The vertical resistivity method of a point of investigation provides geophysicists with information on the succession and thicknesses of geological layers at depth (Aydin & Temizel, 2022). Its implementation is possible due to four electrodes; two electrodes A and B to inject an electric current of known intensity into the soil and two electrodes M and N to measure the potential generated by the current.

In our research, the Schlumberger method was used due to its availability, portability and ease of use (Figure 4). A GPS and a thermometer were used at the sites to get the location and temperature of the springs, respectively.

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Fig 4: The Geophysical Equipment used in the Investigations

The DC resistivity sounding system of Schlumberger is a geophysical survey based on measurement of different VES stations using an electrode spacing system starting from AB/2=2m up to 1000m, in a consecutive steps (El-Qady, 2006). The investigation points (IP) were selected according to the accessibility and applicability of the Schlumberger method. Five IPs were chosen for Mugara water thermal spring (Figure 5) and five other IPs for Ruhwa site (Figure 6).

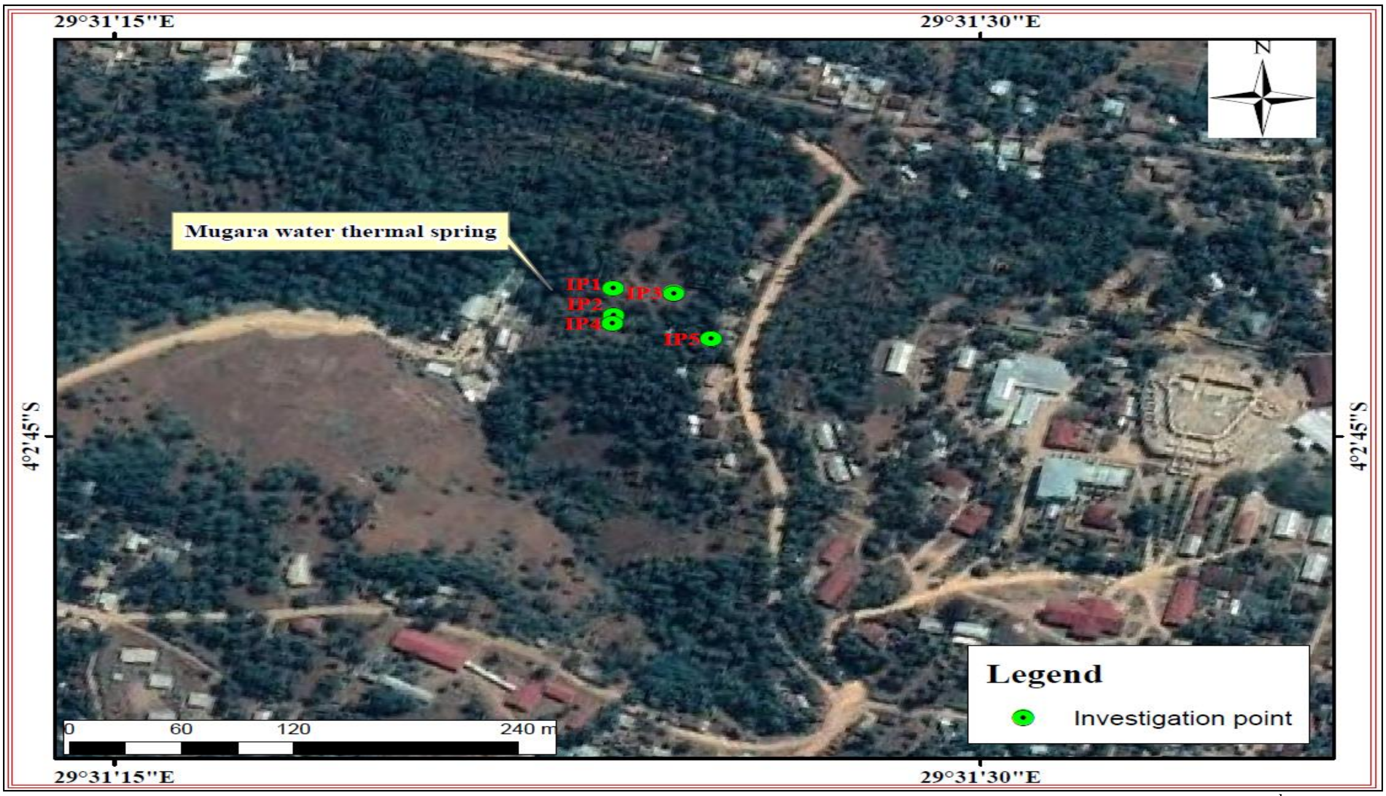

Fig 5: Investigation Points of Mugara Water Thermal Spring (Modified from Google Earth. Accessed on October 10th 2021)

In both sites, the Schlumberger line was kept parallel to the profile direction in order to obtain the adequate information about the properties of our prospective geothermal springs. However, the found resistivities are in reality the apparent resistivities because the ground is heterogeneous and its resistivity will no longer be alone from the ground but a complex average (Björnsson, 2005) of all the resistivities of the medium where the measuring devices are located. These apparent resistivities were analysed and interpreted by using 1X1D software.

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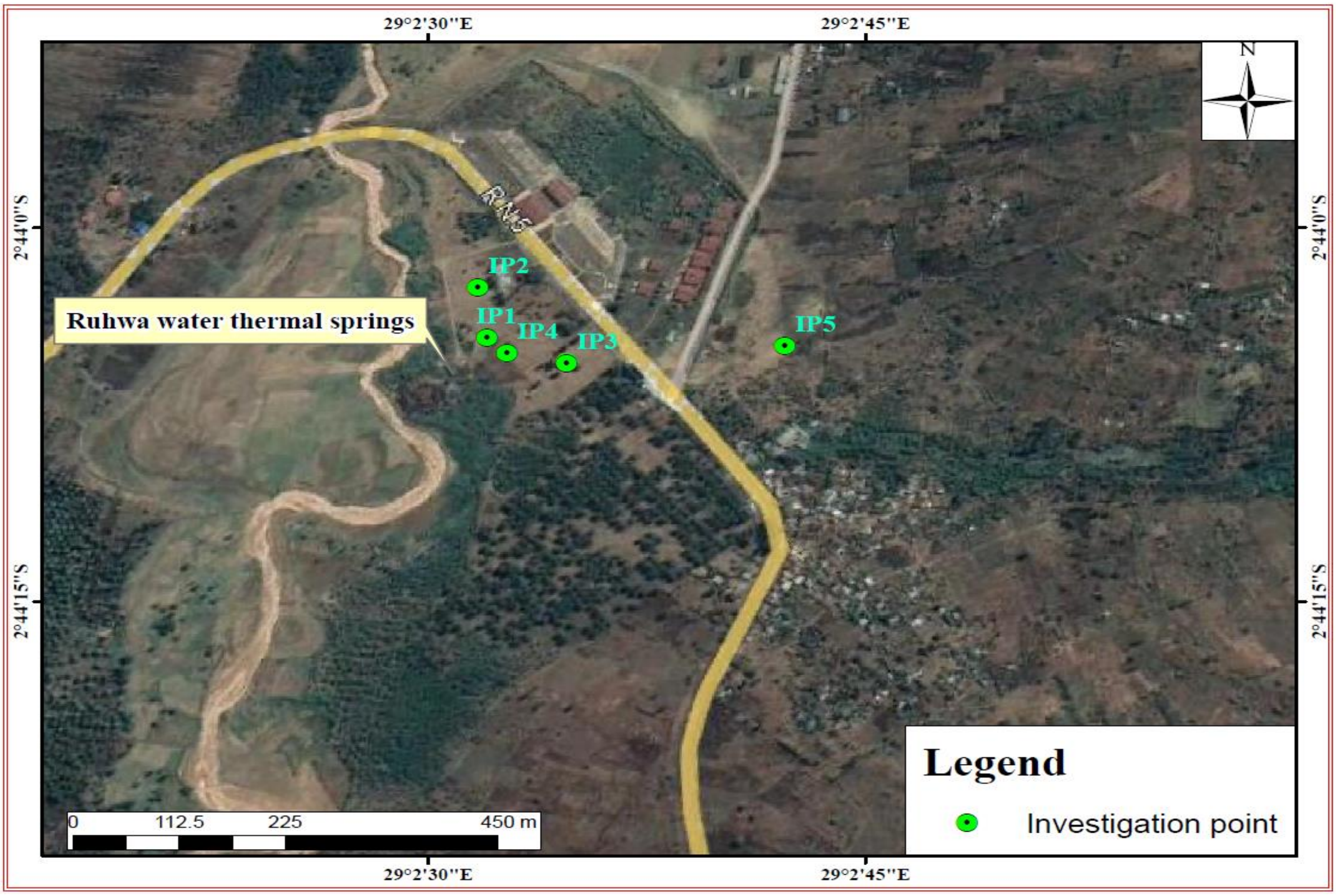

Fig 6: Investigation points of Ruhwa water thermal spring (modified from Google Earth. Accessed on October 10th 2021)

In the two sites where geophysical investigations carried out, the temperatures and flows of the thermal waters were also measured. At the Mugara thermal water site (southern part of the country) a temperature of 64°C was measures flow rate of 14.2 l/s while in the Ruhwa site, the highest temperature was 68°C with a global flow of 3 l/s. Thus, there was a difference of about 4°C between the Ruhwa spring and Mugara spring, located in the two opposite parts of the country. Previous studies by Frau et al, 2020 and Fournier & Rowe, 1966, using quartz geothermometer, suggested a reservoir temperatures of between 110 and 120°C for the Ruhwa site, which indicating a gradient of 42-52°C between the surface spring water and the underground spring water. Thus, the spring water in underground from the site of Mugara site may reach 106-116°C.

IV. RESULTS AND DISCUSSION

A. Mugara Site

The apparent resistivities recorded in the 5 investigation points on the Mugara site are in the range of 100 to 10000 ohm-m. Figure7-a shows an apparent resistivity between 100 and 1000 ohm-m while Figure 7-b shows an apparent resistivity between 400 and 4000 ohm-m with a concave appearance. Figures 7-c and 7-d show relatively high resistivities ranging from 1500 to 7000 ohm-m and Figure 7-e shows an increasing resistivity from 420 up to 3000 ohm-m.

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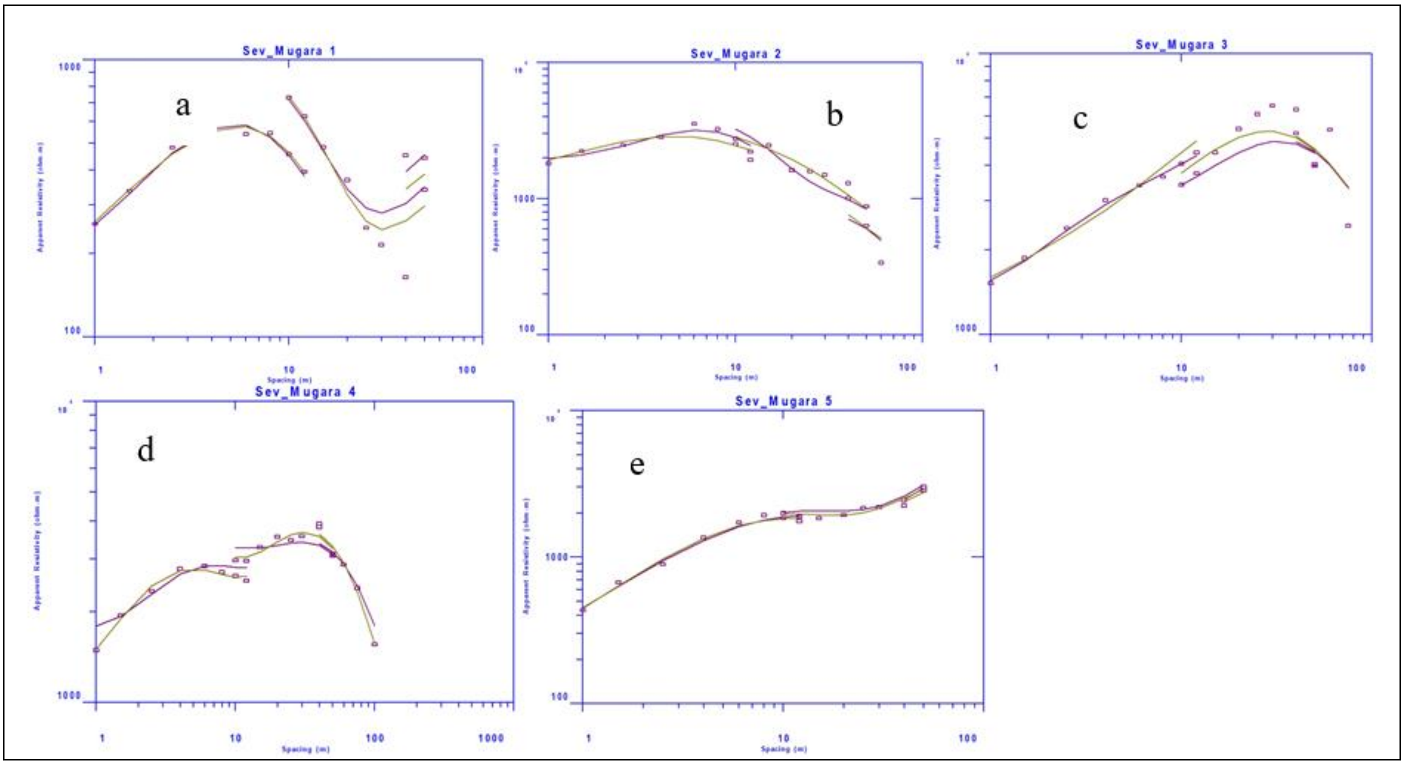

Fig 7: Apparent Resistivity as a Function of spacing at Mugara Site. (a) Investigation Point at 7m from Source, (b) Investigation Point at 15m from Source, (c) Investigation Point at 20m from Source, (d) Investigation Point at 30mfrom Source, (e) Investigation Point at 60m from Source

Depending on the depth, the resistivities interpreted in 1X1D software show a remarkable variation (Figure 8) in the different geological layers. The first point of investigation and the third each show the presence of 4 geological layers extending respectively to 30m and 29m (Figure 8-a and Figure 8-c) while Figure 8-b, Figure 8-d, Figure 8-e and Table 1 indicate a possible presence of 5 layers down to depths of 21m, 35m and 24m respectively.

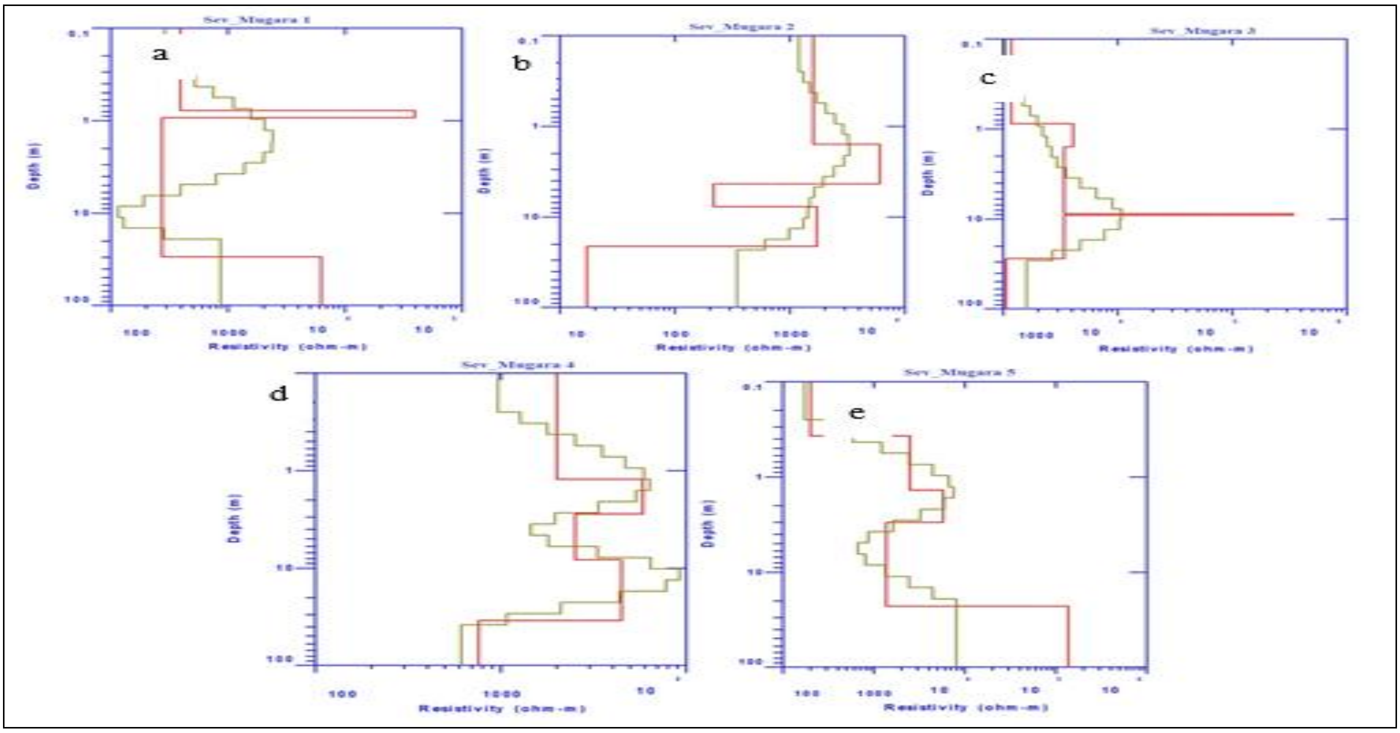

Fig 8: Resistivity (ohm-m) as a Function of Depth (m) at Mugara Site. (a) Investigation Point at 7 m from Source, (b) Investigation Point at 15 m from Source, (c) Investigation Point at 20 m from Source, (d) Investigation Point at 30 m from Source, (e) Investigation Point at 60 m from Source

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B. Ruhwa Site

As in the case of the Mugara site, the 5 points of investigation were conducted in the Ruhwa site and the apparent resistivities recorded are in the range of 0.1 to 1000 ohm-m. Figure 9-a and Figure 9-b show the apparent resistivities between 0.1 and 1000 ohm-m while Figure 9-c, Figure 9-d and Figure 9-e show the apparent resistivities between 1 and 100 ohm-m.

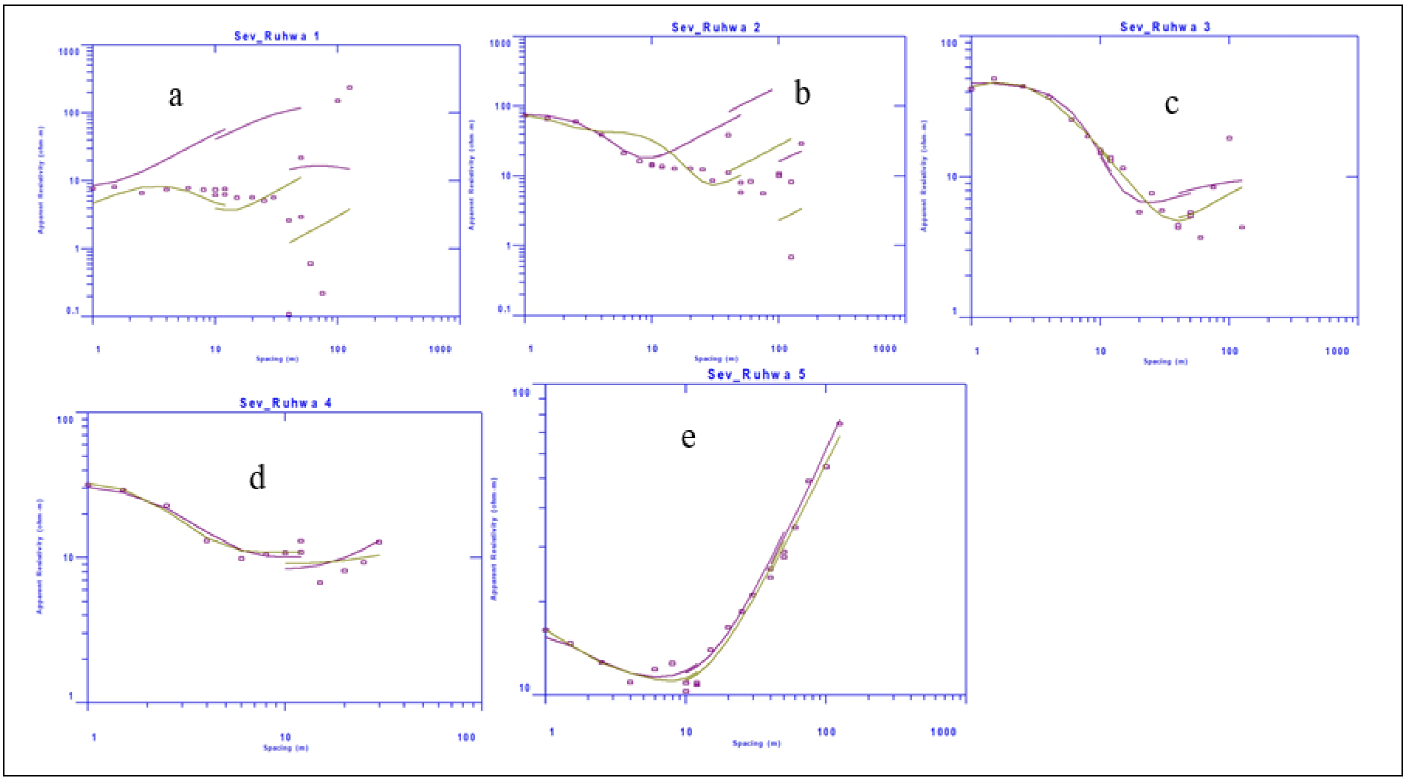

Fig 9: Apparent Resistivity as a Function of Spacing at Ruhwa Site. (a) Investigation Point at 4m from Source, (b) Investigation Point at 7 m from Source, (c) Investigation Point at 12 m from Source, (d) Investigation Point at 30 from Source, (e) Investigation Point at 200 m from Source

From Figure 10, Tables 1 and 2, the resistivities recorded in the Ruhwa site show the existence of the different layers depending on the depth. It is noted that the first four points of investigation (IP1, IP2, IP3 and IP4) show the presence of 3 layers up to around 20 m deep while IP5 shows the fourth layer at 40 m deep and this layer has very high resistivity of about 6500 ohm-m (Table 2). This layer therefore may constitute a hard rock and hence considered as the base of the aquifer of the Ruhwa site. In this site, the reservoir is considered to be under the clay layer and upper the hard rock, it is in that side where the fresh water is found.

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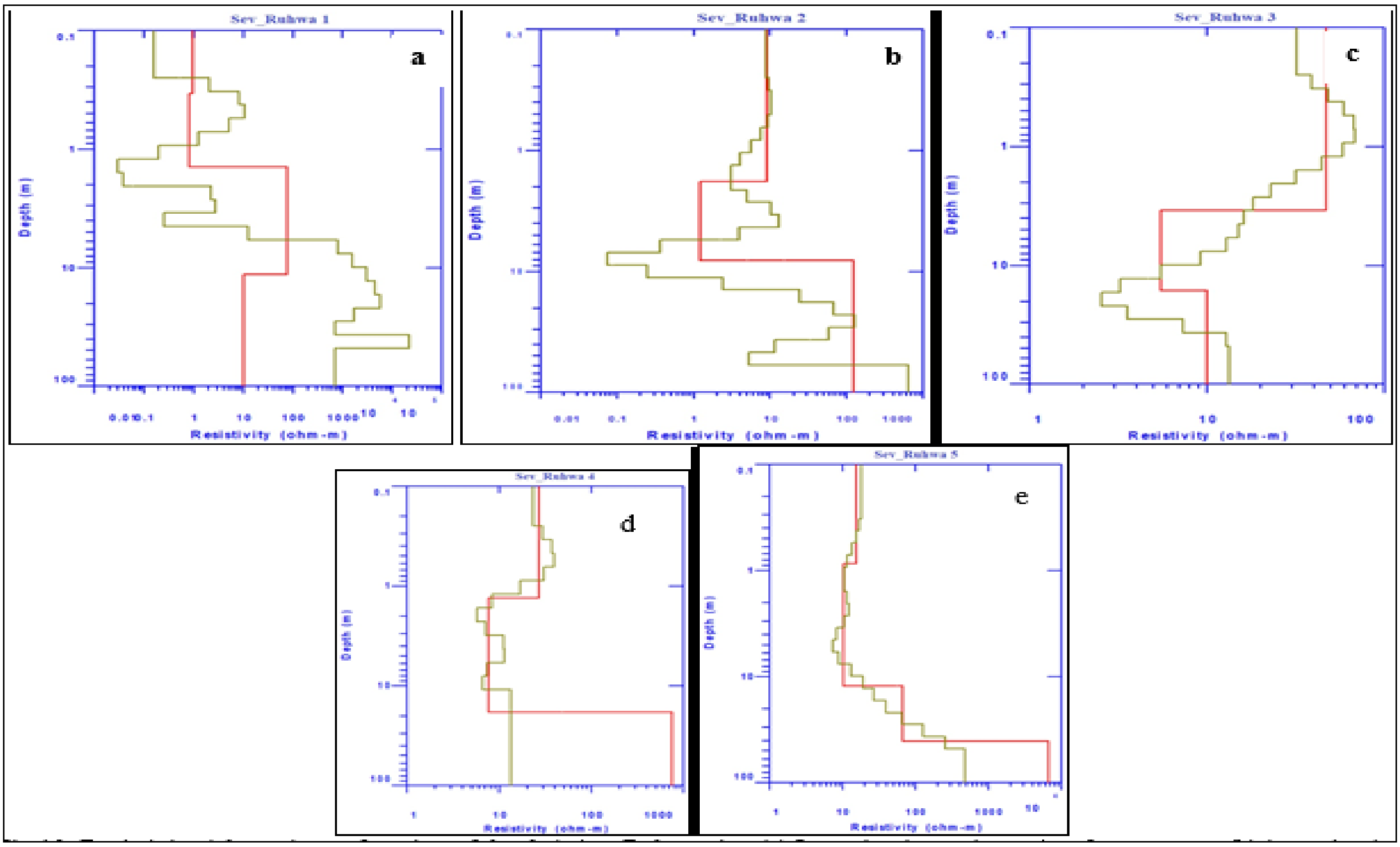

Fig 10: Resistivity (ohm-m) as a Function of Depth (m) at Ruhwa Site. (a) Investigation Point at 4 m from Source, (b) Investigation Point at 7 m from Source, (c) Investigation Point at 12 m from Source, (d) Investigation Point at 30 m from Source, (e) Investigation Point at 200m from Source.

Table 1: Depth of different Layers (m)

	Mugara site					Ruhwa site			
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 1	Layer 2	Layer 3	Layer 4
IP1	0.1-0.7	0.7-1	1-30	30-	-	0.1-1.6	1.6-12	12-	-
IP2	0.1-1.5	1.5-4	4-7.5	7.5-21	21-	0.1-2	2-9	9-	-
IP3	0.1-0.9	0.9-9.5	10-29	29-	-	0.1-3	3-19	19-	-
IP4	0.1-1.4	1.4-3	3-10	10-35	35-	0.1-1.4	1.4-20	20-	-
IP5	0.1-0.4	0.4-1.5	1.5-3	3-24	24-	0.1-0.9	0.9-13	13-40	40-

Table 2: Resistivity of Different Layers (ohm-m)

	Mugara site					Ruhwa site			
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 1	Layer 2	Layer 3	Layer 4
IP1	400	500000	150	6000	-	2.5	60	10	-
IP2	2000	55000	200	2000	9.5	10	2	110	-
IP3	1050	3500	3500	1000	-	45	6.5	10	-
IP4	1500	5000	2000	4500	750	25	8	750	-
IP5	200	3000	6000	1500	150000	25	10	70	6500

It was noted that for the site of Mugara the first point of investigation had fresh water, eruptive metamorphic rocks, conglomerates and sandstones. Using results obtained from different studies conducted in order to determine the resistivities of rock and minerals (Brace & Orange, 1968; Caldwell et al, 1986; Hersir et al, 2009; Keller, 2017; Keller, 1988; Parkhomenko, 1982) this analysis shows also that even the others points of investigation on the Mugara site could consist mainly of conglomerates and sandstones except that there are sands and gravels on the roof and the base of the aquifer in certain places (Table 3). Therefore, it is postulated that the aquifer of the Mugara site is made up of conglomerates but the eruptive metamorphic rocks constitute its basement, making it a semi-confined aquifer. For the Ruhwa site, the aquifer is also made up of conglomerates and sandstone but its roof is generally made up of clay (Table 3). Thus, this aquifer may not be a confined aquifer. The geothermal reservoirs in Mugara and Ruhwa sites are found these mentioned aquifers.

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Table 3: Identification of different Layers of Mugara and Ruhwa Geothermal Reservoirs

	Mugara site					Ruhwa site			
	Layer 1	Layer 2	Layer 3	Layer 4	Layer 5	Layer 1	Layer 2	Layer 3	Layer 4
IP1	Fresh water	Eruptive and metamorphic rocks	Sands and gravels	Conglomerate and sandstone	-	Clay	Sands and gravels	Clay	-
IP2	Sands and gravels	Permafrost	Fresh water	Conglomerate and sandstone	Fresh water	Clay	Clay	Fresh water	-
IP3	Sands and gravels	Sands and gravels	Conglomerate and sandstone	Sands and gravels	-	Clay	Fresh water	Fresh water	-
IP4	Sands and gravels	Conglomerate and sandstone	Conglomerate and sandstone	Conglomerate and sandstone	Conglomerate and sandstone	Clay	Fresh water	Conglomerate and sandstone	-
IP5	Fresh water	Conglomerate and sandstone	Conglomerate and sandstone	Conglomerate and sandstone	Permafrost	Clay	Fresh water	Fresh water	Conglomerate and sandstone

C. Chemical Analysis

The analysis of water from Mugara and Ruhwa was carried out by sampling the waters and analyzing them for Fe, Cl, Zn, Mg and K content. Table 4 and Figure 11 show the results of the analysis which indicate that chlorides distributions are high in water from Mugara than the one from Ruhwa but other chemical element (Fe, Zn, Mg, K) contents are less than the one from Ruhwa.

Table 4: Chemical Analysis Results

	Cl(mg/l)	Fe(mg/l)	Zn(mg/l)	Mg(mg/l)	K(mg/l)
Mugara site	0.32	0.1	0.07	0.001	4.1
Ruhwa site	0.04	21.5	0.12	10	76

The comparison of the results (Figure 11) indicates that 3 chemical elements (Fe, Mg and K) have the high concentrations of 21.5 mg/l, 10.0 mg/l and 76.0 mg/l, respectively. Some of these contents are unlikely over the allowable concentration in drinking water. For example the high limit permissible content of Fe in drinking water according to WHO is 0.1mg/l (Kumar & Puri, 2012). Thus, the water from Ruhwa is not permitted to drink.

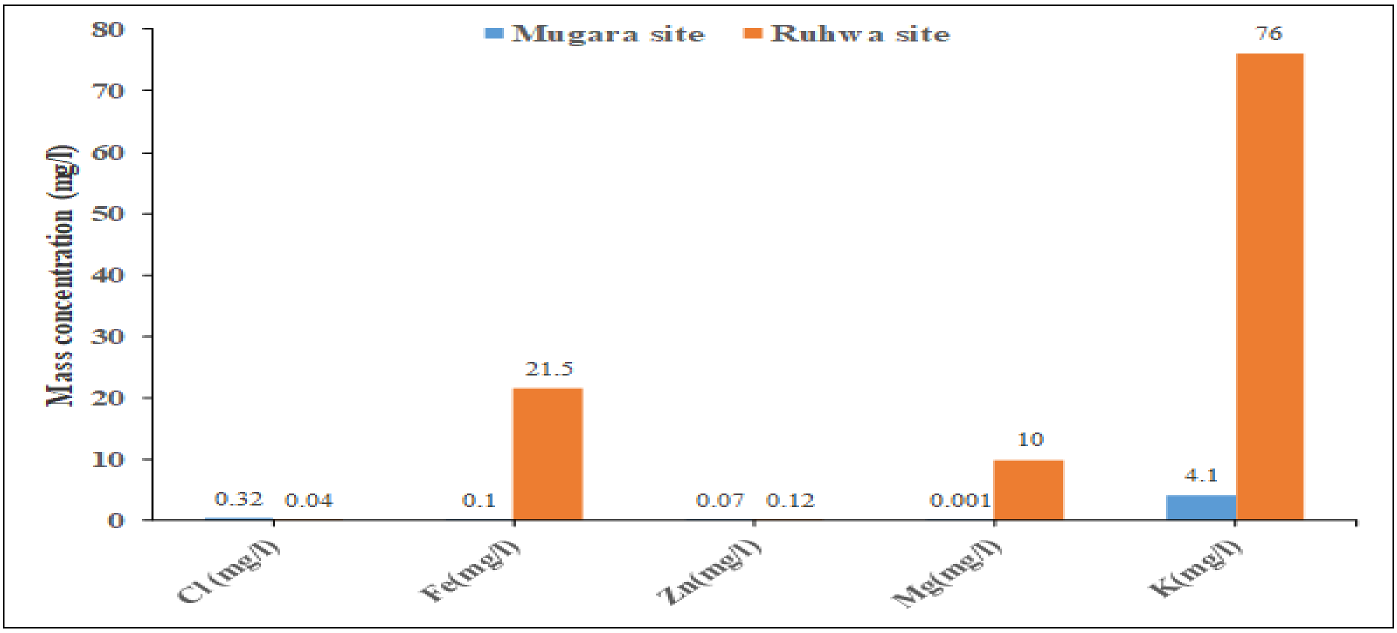

Fig 11: Comparison of Chemical Results of Water from Mugara and Ruhwa Sites

V. CONCLUSION

Our research is mainly based on the characterization of geothermal reservoir of Mugara and Ruhwa sites. In Mugara site, the geothermal reservoir is located geologically in the ancient lake formation composed by spongoliths, coarse cemented sands, clay-sandstone spongoliths whereas the Ruhwa site is found in Rugendo-Mabayi-sagahanga Formation, which is composed by white quartzites with intercalations of phyllite rocks. There are also the dark gray quartzites and coarse conglomerates rich in iron oxides but highly altered in gray-green phyllites. The schites, psammoshistose, sandstone-silty quartzites with red schists are also observed in this geological formation. Thus, in all the two sites, the basement of the aquifer is the metamorphic and eruptive rocks, and in igneous rocks, resistivities are high if the rock isn't fractured, porous and does not contain much fluids which circulate therein, they will be very resistant. Therefore, the fractures of the rock reduce its resistivity. We noticed that in sediments, the resistivity is generally low, which means that the water content is the determining factor of the resistivity**.**

The geothermal reservoir of Mugara site consist mainly of conglomerates and sandstones but on the roof of the reservoir, there are sands and gravels, which indicate that the aquifer in Mugara is a semi-confined aquifer. For the Ruhwa site, the geothermal reservoir is a confined aquifer due to its roof which is composed by clay. The highest temperature in Ruhwa site is 68°c and underground source temperatures is approximatively as high as 110-120°c according to quartz geothermometer in the hot springs from the porous sediments. Thus, the hot spring of Ruhwa is postulated to originate from a sedimentary terrain. Based to different investigation point, Mugara geothermal reservoir has a deep of 35m while Ruhwa geothermal reservoir has a deep of 40m.

The results of the water analysis showed that 3 chemical elements which are Fe, Mg and K have the high content of 21.5 mg/l, 10mg/l and 76mg/l respectively and some of them such as Fe are unlikely over to the allowable concentration in drinking water according to the requirements of WHO. Thus, the water from these geothermal reservoirs are not permitted to drink. The investigation depths for Mugara and Ruhwa are 20m and 25m respectively

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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