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Detection of Vadose Zones by the Electrical Method; Case of Tanganyika Province, Kongolo Territory, Baluba Sector

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ABSTRACT
This study focuses on the detection of vadose zones by the electrical method in the province of Tanganyika, territory of Kongolo, sector of Baluba, specifically in the villages of Léya 1, Léya 2 and Léya 3. In this context marked by recurring difficulties in accessing drinking water, geophysical prospecting appears as a relevant tool to identify geological formations favorable or unfavorable to the installation of boreholes.

The method used is based on measuring the apparent electrical resistivity of the subsoil using the Schlumberger array, with an IRIS SYSCAL type georesistivity meter. The data analyzed come from vertical electrical soundings and resistivity profiles carried out at several points in the three villages studied. The interpretation of the results made it possible to distinguish different geoelectric layers corresponding in particular to sandy clays, clays, weathered material, fractured zones of the granite bedrock, and sound bedrock.

The results show that unsaturated zones (vadose zones) are located at varying depths depending on the site. At Léya 1, they generally extend between 0 and 9.36 m, 0 and 17 m, and 0 and 31 m, according to the boreholes. At Léya 2, they are located between 0 and 10 m and 0 and 17 m. At Léya 3, they are identified between 0 and 11 m, 0 and 22 m, and 0 and 15 m. The potentially aquifer horizons are mainly associated with weathered rocks and fractured zones of the basement, and sometimes with alluvium.

The study thus confirms that the electrical resistivity method is an effective way to characterize unsaturated surface layers, locate potentially aquiferous zones, and guide the selection of drilling sites. Consequently, siting recommendations have been proposed, including a preferential drilling depth of 40 m at Léya 2 and 30 m at Léya 3, subject to confirmation by the geological conditions observed during the drilling.

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KEYWORDS: *Detection, aquifer, wave, method, drilling, zone, vadose.*

I. INTRODUCTION

Geophysics, or Earth physics, aims to study the physical properties of the Earth. The main objective of geophysics is to deduce the physical properties and composition of the Earth from the physical phenomena associated with them, for example, the geomagnetic field, heat flow, seismic wave propagation, the force of gravity, etc.

Electrical prospecting is one of the geophysical methods that

It is essentially based on the interpretation of the electrical resistance of the ground. The value of the resistance is obtained by measuring a potential difference on the one hand and an intensity on the other.

Water is an essential resource for human life, economic development, and the preservation of ecosystems. However, in several rural areas of the Democratic Republic of Congo, particularly in Tanganyika Province, access to drinking water remains a major challenge. The populations of the villages of Léya 1, Léya 2, and Léya 3 regularly experience difficulties in obtaining water, which affects their health, their agricultural activities, and their quality of life.
Faced with this situation

Tanganyika province faces numerous difficulties related to
to the supply of drinking water, particularly in rural areas where surface water resources are insufficient or seasonal. Despite the probable existence of groundwater reserves, their location often remains poorly known, leading to failures during drilling and increased operating costs.

Faced with this situation, applied geophysics, particularly electrical resistivity surveys, is an effective tool for exploring the subsurface and identifying areas conducive to groundwater accumulation. However, the effectiveness of this method in detecting contiguous zones (areas unfavorable to the presence of aquifers) in Tanganyika Province warrants further investigation.

Our research will be based on the following questions:
Therefore, a central question arises:

- To what extent does the electrical measurement method allow for the precise identification of these areas unfavorable to the implantation of boreholes?
- Are there any adjacent areas within the study area that are not unfavorable to groundwater accumulation?

We assume that the province of Tanganyika contains geological formations with geo-electrical characteristics favorable to the presence of groundwater.

Thus, the application of the electrical resistivity measurement method will highlight variations in subsurface resistivity, identify areas likely to constitute aquifers, and suggest suitable sites for water intake structures. The use of the electrical resistivity method (direct current), based on measuring the apparent resistivity of the soil, allows differentiation between clay formations (conductive) and sandy or fractured formations (potentially aquifers). It is assumed that a combined interpretation of electrical soundings and resistivity profiles will identify areas of high hydraulic conductivity and those of low electrical conductivity. We hypothesize that the villages of Léya 1, Léya 2, and Léya possess geological formations with electrical resistivities characteristic of aquifer zones.

Applying the electrical measurement method would make it possible to identify these formations and to locate areas suitable for the installation of groundwater capture structures.

This research aims to:

- Detect unfavorable areas with a lack of groundwater in the villages of Léya 1, Léya 2 and Léya 3 using the electrical measurement method.
- Conduct a geophysical study in the villages concerned;
- determine the apparent electrical resistivity of the different layers of the subsoil;
- identify geological structures likely to contain aquifers;
- map areas unfavorable to groundwater exploitation;
- to provide recommendations for the location of future drilling sites.

To achieve the established objectives, the following methodological approach will be adopted: literature review, fieldwork, and map development, incorporating observation, geophysical, and interpretation techniques. The data obtained will be analyzed using geophysical processing techniques to determine resistivity variations and interpret the nature of the geological formations.

II. Theoretical Framework

2.1. Aquifers

An aquifer is an underground water reservoir, sufficiently porous and permeable to be considered a resource usable by humans. It contains a layer of freshwater. The aquifer is therefore the container, and the layer is the contents. In other words, an aquifer is an underground geological formation composed of rocks or soils capable of holding and transmitting water. This groundwater generally originates from rainwater that infiltrates the soil. Aquifers constitute an important reserve of freshwater used for human consumption, agriculture, and industrial activities. Aquifers are found at various depths below the Earth's surface and often supply wells, springs, and some rivers.

2.2. Importance of aquifers

Aquifers play a vital role in human life and the environment.

- Source of drinking water: They provide a large part of the water consumed by the population through wells and boreholes;

- use : aquifers are used for crop irrigation, especially during periods of drought.

The diagram below shows the different boundaries of an aquifer. Generally speaking, we distinguish:

Figure 1. Water infiltration into the soil

2.3. Groundwater reservoirs

Basement formations encompass all crystalline and crystalline rocks, as well as ancient sedimentary rocks with comparable hydrogeological behavior. These rocks are characterized by their compact nature and low water retention capacity, and by the presence of permeable horizons that sometimes develop as a result of weathering processes and tectonic phenomena. The generally differentiated geological units are granites, gneisses and migmatites, schists, and quartzitic sandstones. Basement aquifers are represented by three types of reservoirs:

- The reservoir of weathered material which corresponds to the sandy-clayey arenas;
- the crack reservoir located above the sound rock which indicates a partially altered zone containing numerous cracks and joints generally filled with weathering products;
- and the network of major fractures that affect the parent rock. Numerous studies show that these reservoirs constitute a single aquifer whose storage function is ensured by the weathered rock and whose conductive function is ensured by the fissured and fractured zones.

III. Acquisition of data and materials used

The data used in this work were collected by Bienvenu Manzuma Mpukuta and Beauval Senzele, researchers at the Kinshasa Geological and Mining Research Center. (Bienvenu Manzuma Mpukuta et al., 2016)

3.1. Description of equipment

Apparent resistivity measurements were carried out according to the resistivity method with the geometric SCHLUMBERGER device.

The prospecting device used is an IRIS brand georesistivity meter, model SYSCAL, with its accessories consisting of:

- 2 reels of electrical cables, each 300 m long, for injecting current between electrodes A and B;
- 2 reels of electrical cables, each 200 m long, for measuring the potential difference between electrodes M and N;
- 1 x 12V external battery
- 4 stainless steel electrodes.

***Figure 2:* resistivity meter**

IV. Data Analysis

4.1. Survey implementation points

Table 1. Survey completion points

No.	Village	Survey	GPS coordinates of the survey point		
			Longitude (x)	Latitude (y)	Altitude (z)
1	LEYA 1	SE1	26.74286°	-5.55659°	676 m
		SE2	26.74388°	-5.55678°	670 m
		SE3	26.74517°	-5.55708°	667 m
2	LEYA 2	SE1	26.72095°	-5.56482°	668 m
		SE2	26.72215°	-5.56459°	675 m
3	LEYA 3	SE1	26.71895°	-5.56750°	669 m
		SE2	26.71910°	-5.56682°	671 m
		SE3	26.71856°	-5.56887°	674m

4.2. Procedure for conducting surveys

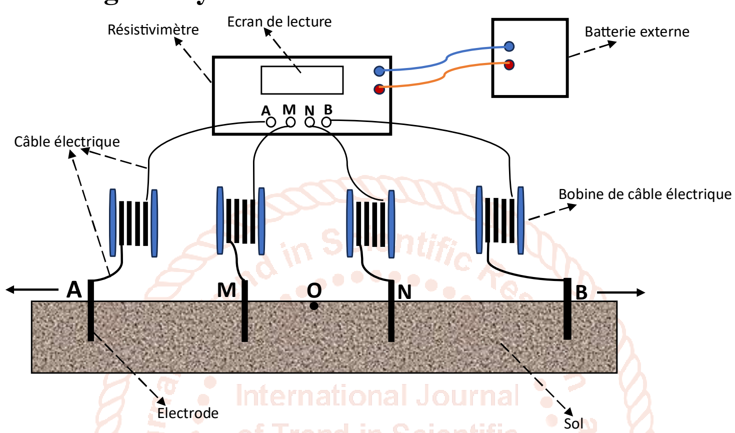


Figure 3. Schematic representation of the complete installation for electrical sounding

For each sampling point O, after all the components of the device are installed (Figure I.02), the steps of the procedure are as follows:

1. Determination of the coordinates of the sounding point O using GPS,
2. Place a decameter (along the alignment of points A, M, O, N, B) to allow the measurement of linear distances along the decameter,
3. Initialize the resistivity meter : Assign a number to the file that will contain the data to be collected from the point in question and define the distancing mode (Manual or automatic),
4. Vary the position of electrodes M and N along the decameter so that MO = ON = MN/2. For each position MN, enter (enter) the measurement of the distance MN into the resistivity meter, then:

- Move electrodes A and B a number of times along the decameter, moving them symmetrically away from point O so that AO = OB = AB/2 is always maintained.
- For each movement of electrodes A and B, record the measurement AB/2 in the resistivity meter, which then displays the potential difference $\boldsymbol{\Delta V}$, current intensity $\boldsymbol{I}$, and apparent resistivity, $\boldsymbol{\rho}$all automatically determined. These values are recorded on the *acquisition sheet for an electrical sounding* (Figure I.03). The sheet shows the columns intended to record the measured ΔV and I values. The geometric factor is pre-calculated for different MNs, allowing the apparent resistivity value to be calculated directly in the field, thus verifying the consistency of the measurements.

Note: The variation in the distance between the electrodes is facilitated by the unwinding of the electrical cables on the coils.

SURVEY NO.:………………… CONTACT INFORMATION:……………………………………………

DATE:… ……………………………………………

AB/2	MN = 2	MN = 6	MN = 20	MN = 40	ΔV	I	ρ_a
3	12,566						
4	23,562						
5	37,699						
6	54,978						
7	75,398						
10		47,647					
15		113.1					
20		204.73					
30		466.53					
35		636.7					

Figure 4. Acquisition sheet for an electrical sounding

The values recorded on the acquisition sheet for an electrical sounding are also automatically saved by the resistivity meter in the file corresponding to the sounding point. This file must be processed by appropriate software on a computer.

A. LEYA Village 1

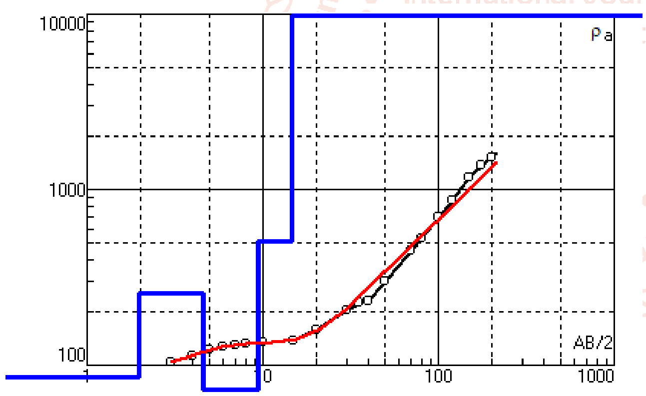
The aquifers are linked to weathered rocks and to the fractured part of the bedrock (Granite).

Two resistivity profiles were produced at AB = 80 m and MN = 20 m.

NB: the measurement step being maintained at 10 m; number of measurements: TE1 = 18; the total length of the profile is 180 m; TE2 = 16 measurements, the total length of the TE2 profile is 160 m.

Vertical electrical soundings were implanted on conductive anomalies of the streaks representing the lowest values of apparent resistivities.

SEV1



N	ρ	h	d	Alt
1	85.2	1.96	1.96	674
2	257	2.63	4.6	671.4
3	47.3	4.76	9.36	666.6
4	508	5.2	14.6	661.4
5	41594	85.4	100	576
6	41594			

RMS: 7.42%

Interpretation of the results

The details of the geo-electrical cross-section are as follows:

0 to 2 m: a conductive level of 85 ohm .m of resistivity corresponding to clays ;

2 to 4.6 m: a conductive level of 257 ohm .m of resistivity corresponding to sandy clays ;

4.6 to 9.36 m: a conductive level of 47 ohm.m resistivity corresponding to clays

m : a conductive level of 508 ohm.m corresponding to weathering and/or fracturing of the granite bedrock

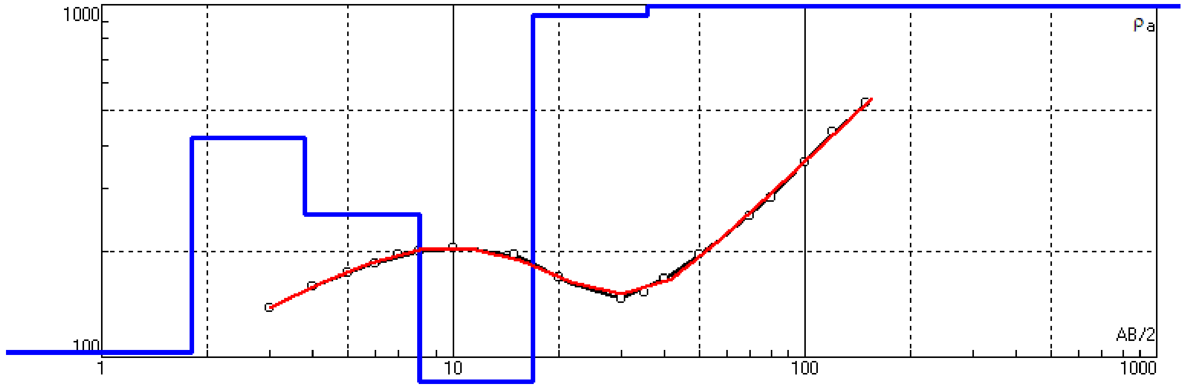
14.6 at 100 m: a very resistant level of 41594 ohm.m resistivity, corresponding to the sound granite bedrock

Beyond 100 m: a very resistant level of 41594 ohm .m of resistivity, corresponding to the sound base.

The geo-electrical cross-section above indicates that the unsaturated zone of the well would then correspond to the land above, approximately from the surface down to 9.36 m.

SEV2

Electrical sounding SE2 was installed at station point x= -120 m of electrical trail TE1.



N	ρ	h	d	Alt
1	103.5	1.8	1.8	668.2
2	419.9	1.995	3.795	666.2
3	254.7	4.207	8.002	662
4	44.2	8.869	16.87	653.13
5	932.6	18.7	35.57	634.43
6	2133	39.43	75	595
7	17170			

RMS: 1.56%

Interpretation of the results

The details of the geo-electrical cross-section are as follows:

0 to 8 m: a conductive level of 103 to 419.9 ohm .m of resistivity corresponding to sandy clays ;

8 to 17 m: a conductive level of 44 ohm .m of resistivity corresponding to clays ;

17 to 36 m: a conductive level of 933 ohm .m of resistivity corresponding to the alteration of the base;

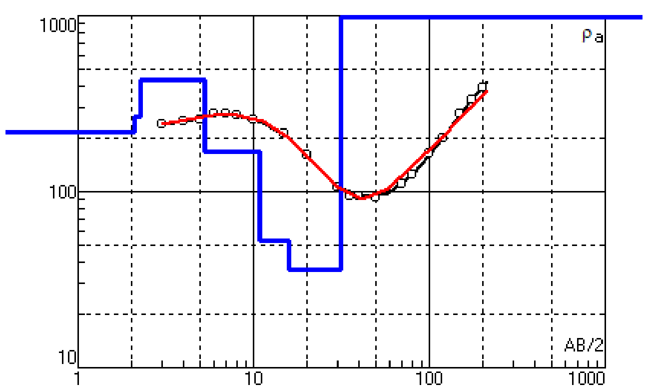
36 to 75 m: a resistance level of 2133 ohm.m of resistivity, corresponding to the cracking of the base;

Beyond 75 m: a very resistant level of 17170 ohm .m, corresponding to the sound base.

Considering this geoelectric cross-section, the unsaturated part (vadose zone) of the borehole is found between 0 and 17 m.

SEV3

The SE3 electrical sounding was installed at station point x= 20 m of the TE electrical trail.



N	ρ	h	d	Alt
1	220	2.08	2.08	664.9
2	265	0.216	2.3	664.7
3	432	3	5.29	661.7
4	169	5.64	10.9	656.1
5	53	4.8	15.7	651.3
6	36	15.4	31.2	635.8
7	7464	25.2	56.3	610.7
8	74643			

RMS: 5.36%

Interpretation of the results

The details of the geo-electrical cross-section are as follows:

0 to 11 m: a conductive level of 169 to 432 ohm .m of resistivity corresponding to sandy clays ;

11 to 31 m: a conductive level of 36 to 53 ohm .m of resistivity corresponding to weathering;

31 to 53 m: a resistance level of 7464 ohm .m of resistivity corresponding to the cracking of the base;

Beyond 53 m: a very resistant level of 74643 ohm .m of resistivity, corresponding to the sound base.

Considering this geoelectric cross-section, the vadose zone of the borehole is located from 0 to 31 m.

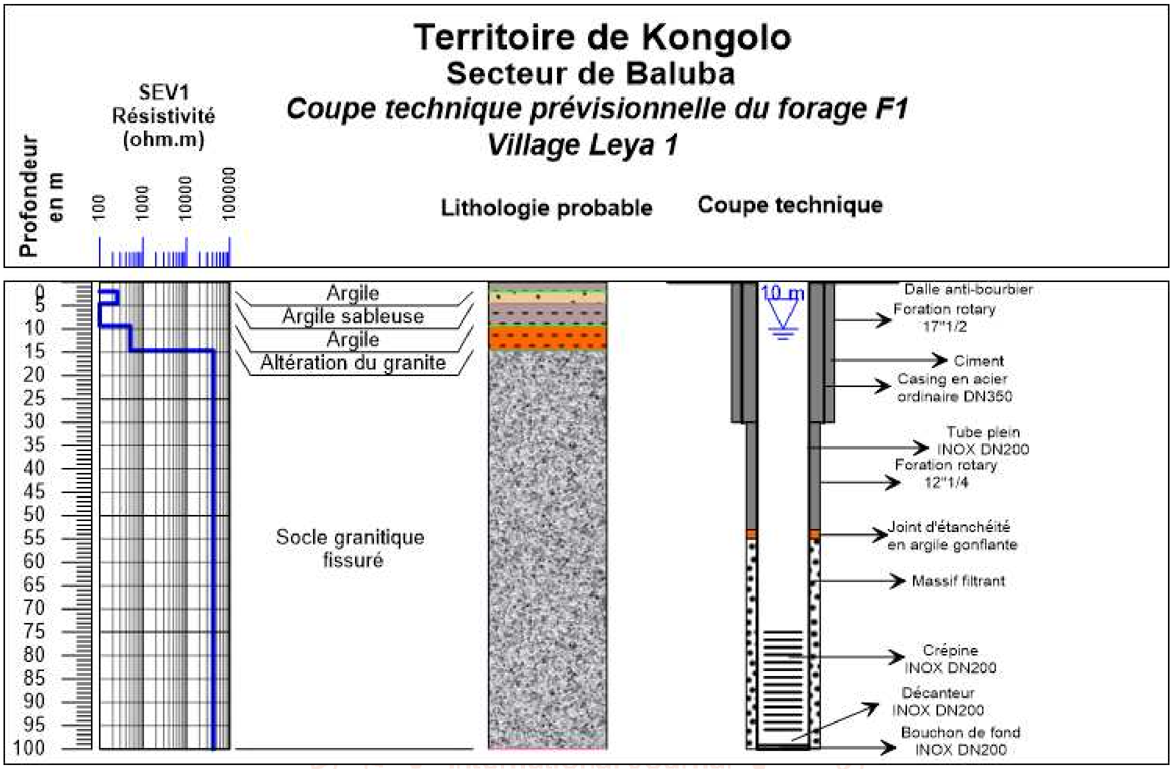


Figure 4. Preliminary technical cross-section of drilling f 1 / leya 1

B. LEYA Village 2

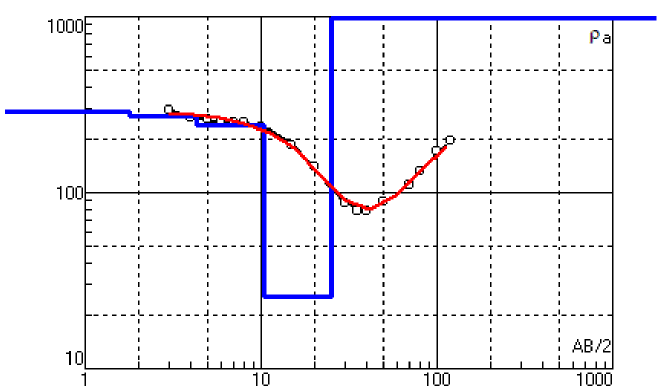
The aquifers are linked to weathered rock and the fractured part of the bedrock. A resistivity profile was carried out at AB = 80 m and MN = 20 m.

NB: the measurement interval is maintained at 10 m; number of measurements: 28; the total length of the profiles is 280 m.

Vertical electrical soundings were implanted on conductive anomalies of the streaks representing the lowest values of apparent resistivities.

Three vertical electrical soundings were carried out in the village of Leya 2.

SEV1



N	ρ	h	d	Alt
1	290	1.8	1.8	666.2
2	270	2.53	4.33	663.7
3	241	6.07	10.4	657.6
4	25.9	14.6	25	643
5	18548			

RMS: 2.77%

Interpretation of the results

The details of the geo-electrical cross-section are as follows:

0 to 10 m: a conductive level of 241 to 290 ohm .m of resistivity corresponding to sandy clays ;

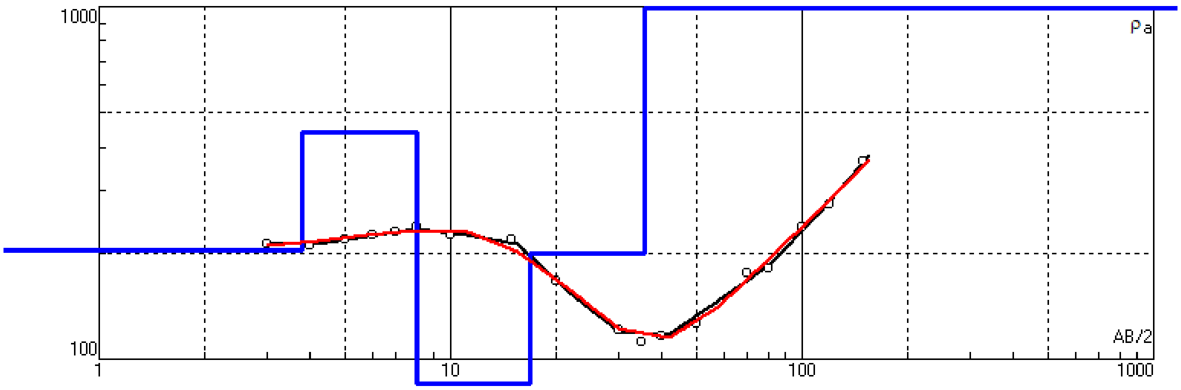
10 to 25 m: a conductive level of 25.9 ohm .m of resistivity corresponding to clayey alterations ;

Beyond 25 m: a very resistant level of 18548 ohm .m of resistivity, corresponding to the sound base.

Considering this geoelectric cross-section, the depth of the unsaturated zone of the borehole is between 0 and 10 m.

SEV2

The SE2 electrical sounding was installed at station point x= -120 m of the TE electrical trail.



N	ρ	h	d	Alt
1	203	3.8	3.8	671.2
2	442	4.21	8	667
3	29.7	8.87	16.9	658.1
4	201	18.7	35.6	639.4
5	71758			

RMS: 2.67%

Interpretation of the results

The details of the geo-electrical cross-section are as follows:

0 to 8 m: a conductive level of 203 to 442 ohm .m of resistivity corresponding to sandy clays ;

8 to 17 m: a conductive level of 29.7 ohm .m of resistivity corresponding to clays ;

17 to 35.6 m: a conductive level of 201 ohm.m resistivity corresponding to the alteration and/ or cracking of the base

Beyond 35.6 m: a very resistant level of 71758 ohm .m of resistivity, corresponding to the sound base.

Considering this geo-electrical cross-section, the depth of the unsaturated zone of the well is fixed from 0 to 17 m.

Recommendation

We therefore propose a borehole with a depth of 40 m, preferably located at the SE3 borehole site. SE2 is the backup location in case drilling at SE3 encounters technical difficulties or proves unsatisfactory. The drilling conditions at SE2 remain the same as those at SE3, with the same planned depth. However, the final depth will depend solely on the geological conditions encountered during the drilling process.

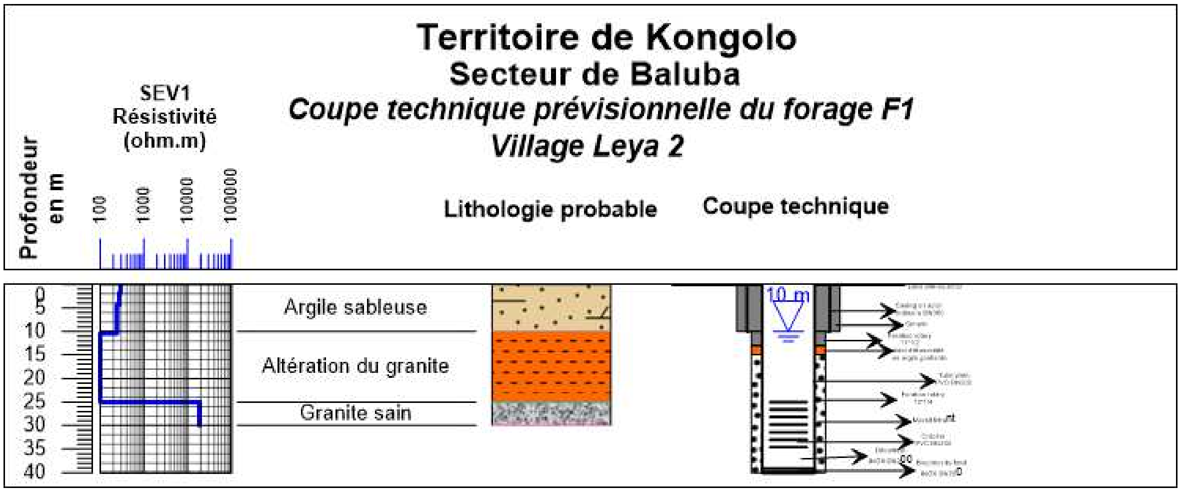


Figure 5. Preliminary technical cross-section of drilling f 1 / leya 2

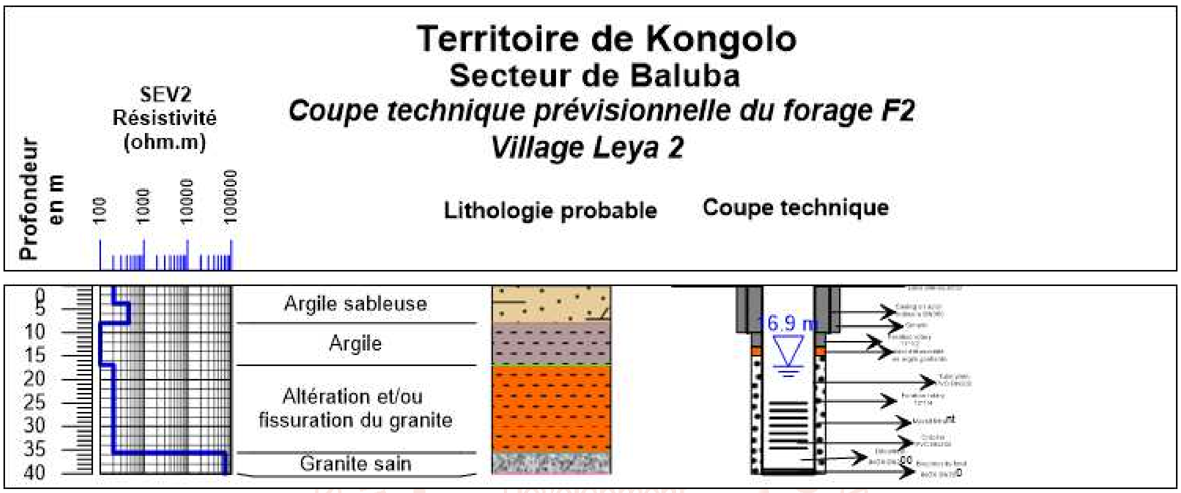


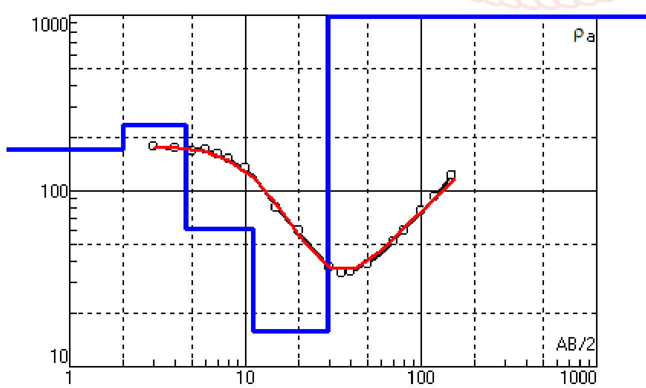
Figure 6. Preliminary technical cross-section of drilling f 2 / leya 2

C. Village LEYA 3

The aquifers are linked to alluvium, weathered material and the fractured part of the bedrock.

Three electrical surveys were carried out in the village of Leya3

SEV1



N	ρ	h	d	Alt
1	171	2.02	2.02	667
2	237	2.59	4.61	664.4
3	60.8	6.46	11.1	657.9
4	15.9	18.5	29.6	639.4
5	7289			

RMS: 3.4%

Interpretation of the results

The details of the geo-electrical cross-section are as follows:

0 to 4.61 m: a resistance level of 171 to 237 ohm .m of resistivity corresponding to sandy clays ;

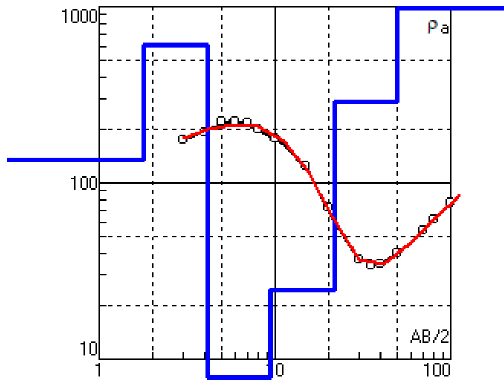
4.61 at 11 m: a conductive level of 60.8 ohm .m of resistivity corresponding to clays;

11 to 30 m: a very conductive level of 15.9 ohm .m of resistivity corresponding to weathering and/or cracking of the base;

Beyond 30 m: a conductive level of 7289 ohm .m of resistivity, corresponding to sound granites.

Considering this geoelectric cross-section, the depth of the unsaturated zone of the borehole is set at approximately 11.00 m.

<u>SEV2</u>



N	ρ	h	d	Alt
1	136	1.8	1.8	669.2
2	609	2.33	4.13	666.9
3	7.83	5.35	9.49	661.5
4	24.8	12.3	21.8	649.2
5	286	28.2	50	621
6	5111			

RMS: 2.14%

Interpretation of the results

The details of the geo-electrical cross-section are as follows:

0 to 4 m: a conductive level of 136 to 609 ohm .m of resistivity corresponding to sandy clays ;

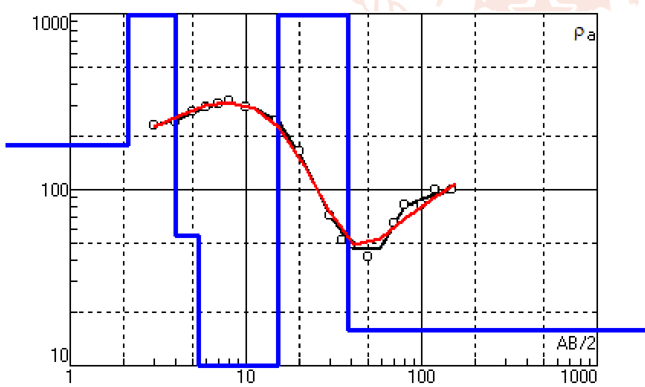
4 to 22 m: a very conductive level of 7.83 to 24.8 ohm .m of resistivity corresponding to clays;

22 to 50 m: a conductive level of 286 ohm .m of resistivity, corresponding to the alteration and/or cracking of the base;

Beyond 50 m: a resistance level of 5111 ohm .m of resistivity, corresponding to sound granites.

Considering this geoelectric cross-section, the depth of the unsaturated zone of the well is fixed from 0 to 22 m.

SEV3



N	ρ	h	d	Alt
1	178	2.14	2.14	671.9
2	1362	1.88	4.02	670
3	54.4	1.33	5.35	668.6
4	9.95	9.97	15.3	658.7
5	1795	22.7	38	636
6	15.9			

RMS: 6.69%

Interpretation of the results

The details of the geo-electrical cross-section are as follows:

0 to 2 m: a resistance level of 178 ohm .m of resistivity corresponding to sandy clays ;

2 to 4 m: a resistance level of 1362 ohm.m of resistivity corresponding to sandy clays with rocky blocks;

4 to 15 m: a resistance level of 9.95 to 54.4 ohm .m of resistivity corresponding to clays;

15 to 38 m: a resistance level of 1795 ohm.m of resistivity corresponding to alteration and/or cracking of the granite;

Beyond 38 m: a very conductive level of 15.9 ohm .m of resistivity, corresponding to weathering.

Considering this geoelectric cross-section, the depth of the unsaturated zone of the borehole is found to be between 0 and 15 m.

Recommendation

We therefore propose a borehole with a depth of 30 m, preferably located at the SE2 borehole site. SE1 is the backup location in case drilling at SE2 encounters technical difficulties or proves unsatisfactory. The drilling conditions at SE1 remain the same as those at SE2, with the same planned depth. However, the final depth will depend solely on the geological conditions encountered during the drilling process.

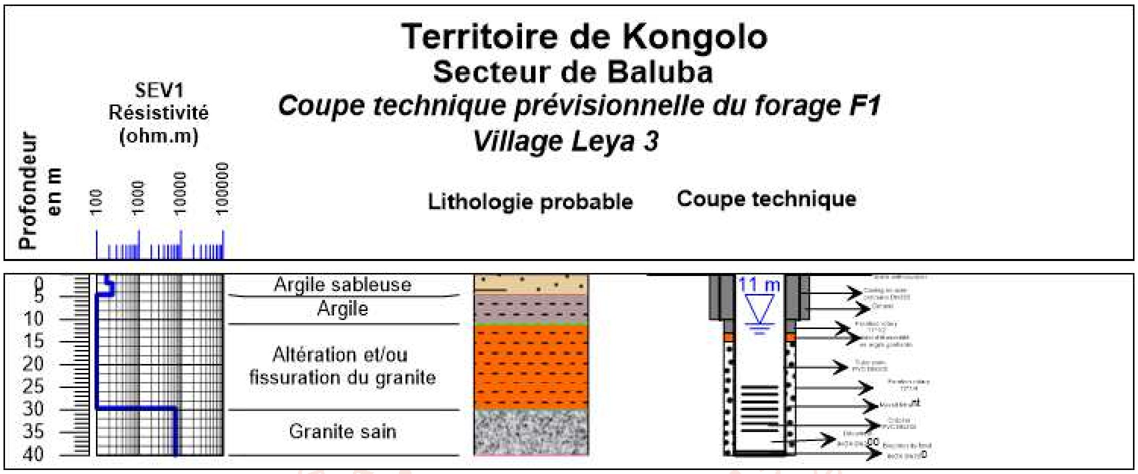


Figure 7. Preliminary technical cross-section of drilling f 1 / leya 3

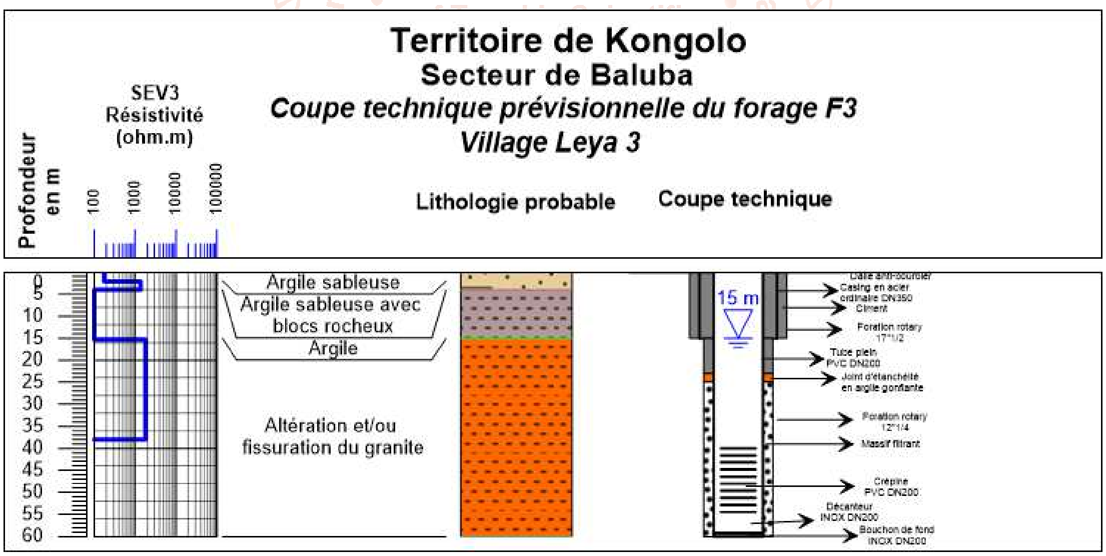


Figure 8. Preliminary technical cross-section of drilling f 3 / leya 3

Conclusion

This study, dedicated to the detection of vadose zones using electrical resistivity in the villages of Léya 1, Léya 2, and Léya 3, concludes that electrical resistivity surveying is an effective geophysical tool for exploring groundwater in basement rock. Analysis of vertical electrical soundings revealed variations in subsurface resistivity and identified the main geological formations encountered, including sandy clays, clays, weathered material, fractured zones in granite, and the undisturbed basement rock.

The results show that the vadose zones, corresponding to unsaturated ground, have varying depths depending on the sites studied. These depths were determined with satisfactory accuracy using geoelectrical interpretation. Furthermore, the study revealed that the levels most favorable to groundwater accumulation and circulation are generally associated with weathered rock and bedrock fracturing, while clayey layers appear to be less suitable for aquifer exploitation.

Thus, the initial hypothesis that the electrical method would allow for the identification of areas favorable and unfavorable for drilling is largely confirmed. This approach has led to the proposal of drilling sites and projected drilling depths adapted to local geological conditions.

In conclusion, this research highlights the importance of applied geophysics in the sustainable management of groundwater resources in rural areas of Tanganyika Province. It represents a valuable contribution to improving access to drinking water for local populations. However, it would be advisable to supplement these results with drilling, pumping tests, and hydrogeological analyses to confirm the actual potential of the identified aquifers.

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