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Geophysical Contribution for the Determination of Aquifer Properties in Memve Ele, South Cameroon

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ABSTRACT

This article aims to localise aquifer and to estimate hydraulic parameters such as transmissivity and tranverse resistance in the Memve Ele dam site (26.35 km²) in South-Cameroon region, using audiomagnetotelluric (AMT) method. For this purpose, resistivity data are collected at twenty-two measurement stations distributed along two perpendicular profiles in the study area. The sounding curves of phase and impedance are modelled and interpreted. The geological models and geoelectrical sections are also provided. The transverse resistivity and transmissivity field maps are plotted. The audiomagnetotellurics insights have been compared with boreholes. All these results allow us to localise the area which may be suitable to set up monitoring wells.

Keywords: Hydraulic Parameters; Aquifer; Audio-Magnetotelluric Method; Sounding Curves; Memve Ele

1. Introduction

Construction of great structures as dams implies delocalization of populations from the targeted area. This is the case of the Memve-Ele dam site project. The Choice of the rehousing zones depends both on the qualitative and the quantitative availability of water. Conventionally, these parameters are estimated through pumping tests carried out on water wells. Few boreholes are available and carrying out pumping tests at several sites may be costly and time consuming. The application of geophysical methods presents a cost-effective and efficient alternative to estimate aquifer parameters [1]. This paper discusses the results obtained from twenty-two soundings carried out through two perpendicular profiles using the audiomagnetotelluric (AMT) method. The survey consists of a quite fast and versatile geophysical investigation (AMT) technique applied to environmental studies focused on groundwater, along with correlated mechanical drillings [2]. The study was conducted in the Memve Ele dam site area. The main objectives of these geophysical surveys were to characterize aquifer lithology and main hydraulic parameters, to describe the aquifer nature, characterize the optimal drilling zone and the potential pollution risk zone.

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2. Geology

The Memve Ele site, in the lower reaches of the Ntem basin, is located between latitudes N02˚15' and N02˚30', E10˚15' and E10˚30'. Its catchment area is 26,350 km^2. At this site the Memve Ele waterfalls with about 35 m head offer favourite site for a hydroelectric power plant development. The geologic background suggests that the formations encountered are widely composed of pyroxene hornblende. These are essentially gneisseses and granitic gneisses that come from metamorphosed precambrian sedimentary rocks [3]. The geological map of the dam site is shown in **Figure 1**. The site's geological feature is characterized by the development and distribution of faults and schiscosity in the same direction [4]. The result of seismicity analysis shows that only three events had affected the site during past some 300 years [3]. The area's earthquaque coefficient (k) for the return period of 100 years is given by k = 0.001 G. There is no geological evidence regarding the active faults that results from investigations.

3. Methodology

3.1. Data Acquisition

The acquisition of data is based on the magnetotelluric method principle [5] which mainly measures the apparent

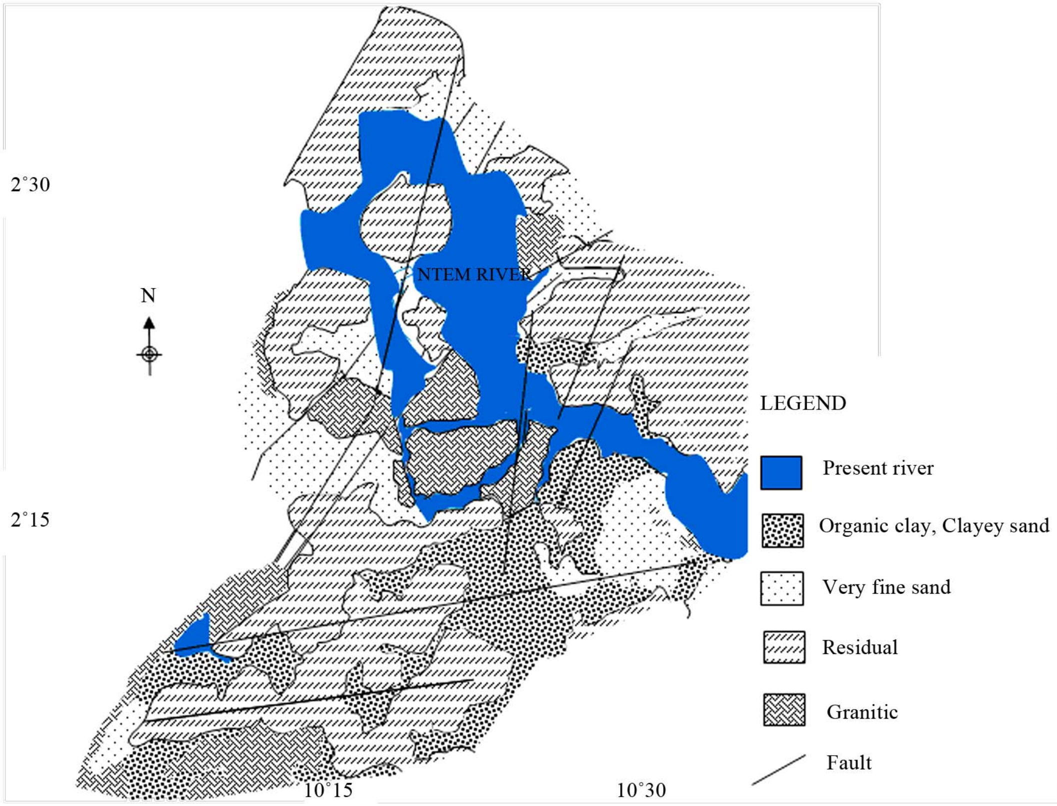

Figure 1. Geologic map of Menvele-Ele area [3], modified.

resistivity of physical environments through its fundamental relationship (1):

$$\rho_a = 0.2T\left|\frac{E}{H}\right|^2 \quad (1)$$

The equipment used is a resistivity-meter ECA 540. This resistivity-meter is a scalar type composed of two identical selective measuring outlets, associated to an acquisition and calculation system that uses a microprocessor. The data sets were collected into two perpendicular directions (N-S and E-W) with a resistivity-meter measuring the apparent resistivity $\rho\perp$ and $\rho||$ following respectively N-S and E-W directions. The apparent resistivity obtained in each direction has permitted to calculate the mean apparent resistivity (ρ_a) or impedance defined by (2)

$$\rho_a = \sqrt{(\rho\perp \times \rho||)} \quad (2)$$

This constitutes the analytic data. The value of phase (φ) have been determined by (3), [2,6]

$$\varphi = \frac{\pi}{2} - \frac{\pi}{4}\left[1 + \frac{\mathrm{d}ln\rho_a}{\mathrm{d}lnT}\right] \quad (3)$$

where, ρ and T are respectively the apparent resistivity and period.

Resistivity and phase values were inversed and modelled with the program developed by [1].

3.2. Hydraulic Parameters

In stratified conductors' theories, some parameters are fundamentally important both in the interpretation and understanding of the geoelectrical model. These parameters are related to different combinations of the thickness and resistivity of each geoelectrical layer in the model.

For a sequence of n horizontal, homogeneous and isotropic layers of resistivity ρ_i and thickness h_i, the Dar-Zarouck parameters (4) et (5) (longitudinal conductance S and transverse resistance T) are defined respectively [7,8] on a purely empirical basis:

$$S_i = \sum_i^n \frac{h_i}{\rho_i} \text{ in (Siemens)} \quad (4)$$

and

$$T_i = \sum_i^n \rho_i * h_i \text{ in (ohm·m}^2\text{)} \quad (5)$$

It can also be admitted that the transmissivity of an aquifer is directly proportional to its transverse resistance. By the other way, the protective capacity of the overburden could be considered as being proportional to the longitudinal Conductance. The hydraulic parameters are shown in **Table 1**.

4. Results and Discussion

4.1. Sounding Curves

The curves resulting from the whole soundings presented a five layered earth's model whose ranges of values led us to a three group's classification according to the covering resistivity values' ranges and drillings results. The low covering resistivity values (100 - 200 Ω·m) have been obtained at stations A1 and A4, the middle covering values of resistivity (200 - 300 Ω·m) have been obtained at A2, A3, A5, B1 and B2 while the high resistivity values (300 - 1000 Ω·m) have been obtained at stations B3, B4 and B5 (**Figures 2** to **4** and **Table 2**).

4.2. Geoelectrical Sections

Gathering the sounding curves, we delineate four resistivity values' ranges suggesting a four layered earth model. Moreover, a strong gradient of resistivity has been observed between the third and the fourth layer. These layers have been assumed by comparing resistivity values' ranges with data in **Table 3**. From the observation of

Table 1. Hydraulic parameters.

Profile	Station	Aquifer Deep (m)	Aquifer Resistivity	Aquifer Thickness	Longitudinal Conductance	Transverse Resistance
	A1	51	38	9	0.24	342
	A2	52	50	13	0.26	650
A	A3	51	62	20	0.32	1240
	A4	52	43	15	0.35	645
	A5	44	58	15	0.26	870
	B1	53	52	13	0.25	676
	B2	49	60	17	0.28	1020
B	B3	54	52	12	0.23	624
	B4	46	79	19	0.24	1501
	B5	54	60	14	0.23	840

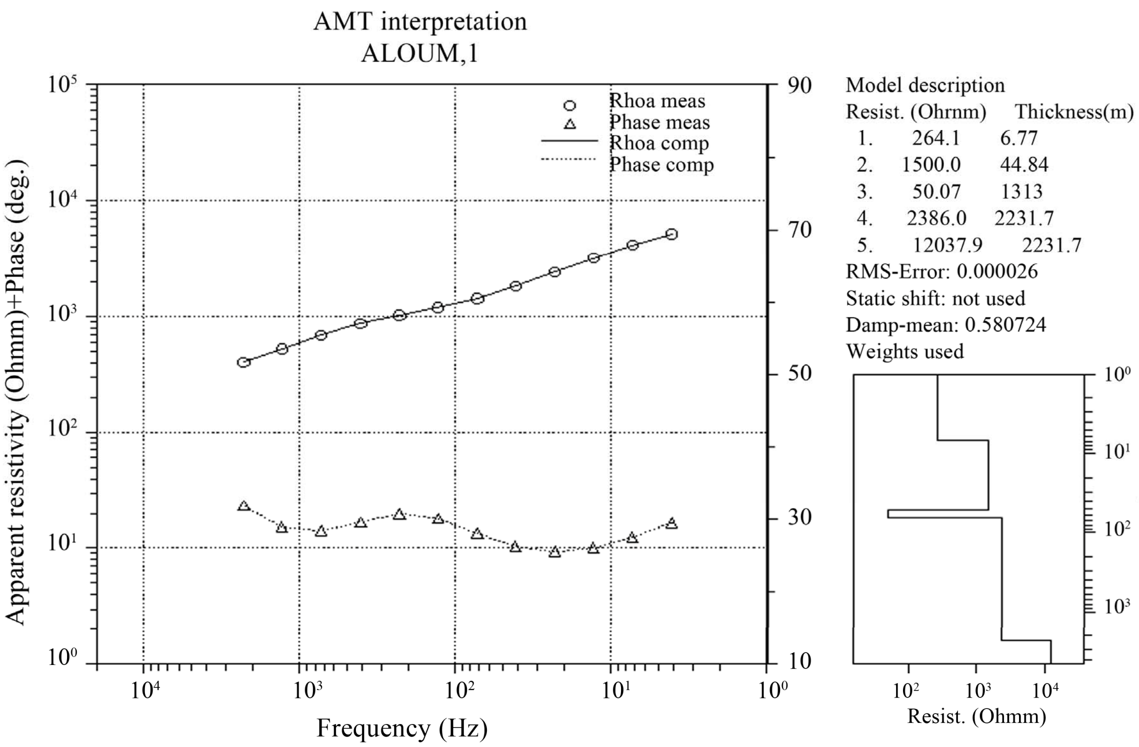

Figure 2. A2 sounding curves (Aloum 1).

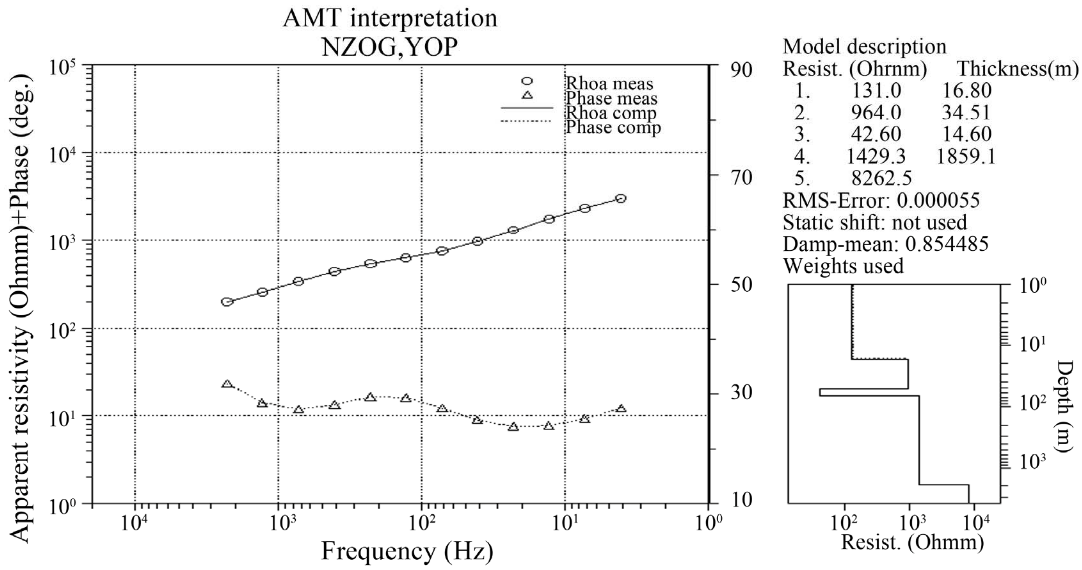

Figure 3. A4 sounding curves (Nzog Yop).

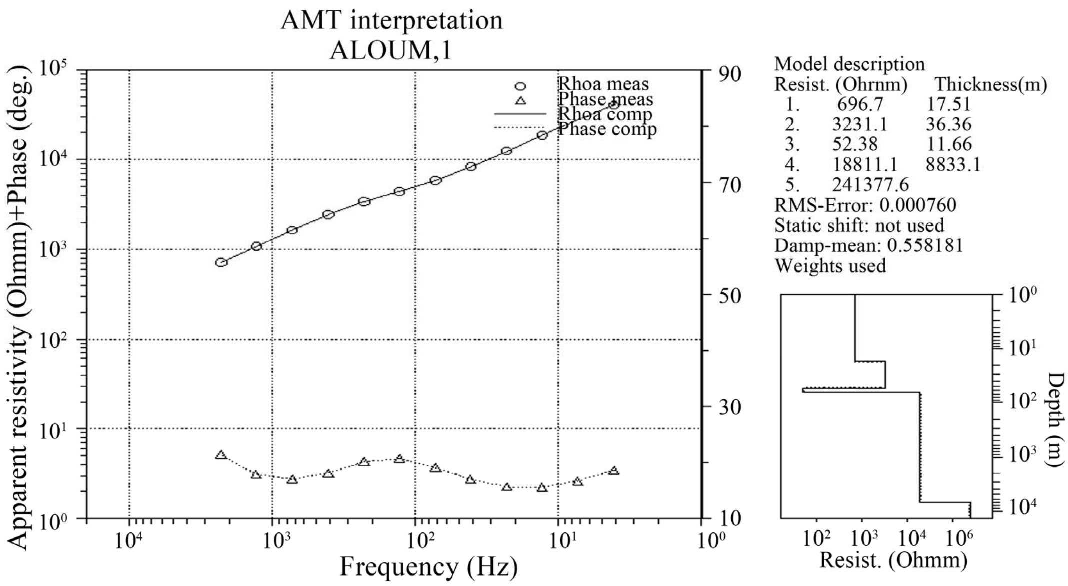

Figure 4. B5 sounding curves (E. P. Nnemeyong).

Table 2. Thicknesses and resistivity's values resulting from soundings curves.

Layer	A1		A2		A3		A4		A5	
	ρ	*h*	*ρ*	*h*	*ρ*	*h*	*ρ*	*h*	*ρ*	*h*
1	164	8	264	7	213	7	131	17	259	8
2	2079	43	1500	45	2267	44	984	35	1639	36
3	38	9	50	13	62	20	43	15	58	15
4	2955	4821	2386	2232	2761	2372	2429	1859	2956	4138

Layer	B1		B2		B3		B4		B5	
	ρ	*h*	*ρ*	*h*	*ρ*	*h*	*ρ*	*h*	*ρ*	*h*
1	246	16	246	21	696	18	461	19	350	7
2	2539	37	2181	28	3231	36	5867	27	3325	47
3	52	13	60	17	52	12	79	19	60	14
4	2014	4157	2901	3106	2833	6833	2751	5499	2281	2508

Table 3. Geoelectrical model.

Lithology (prevalence)	Resistivity (Ω·m)
Captive aquifer	40 - 100 (Ω·m)
Lateritic clay	100 - 200 (Ω·m)
Organic deposit	200 - 300 (Ω·m)
Weathered granite-gneiss	300 - 1000 (Ω·m)
Granite-gneiss	1000 - 10,000 (Ω·m)

sounding curves obtained and mechanical drillings carried out in the study area, we obtained the following geoelectrical models (**Figure 5**) which are similar to those proposed by [9,10].

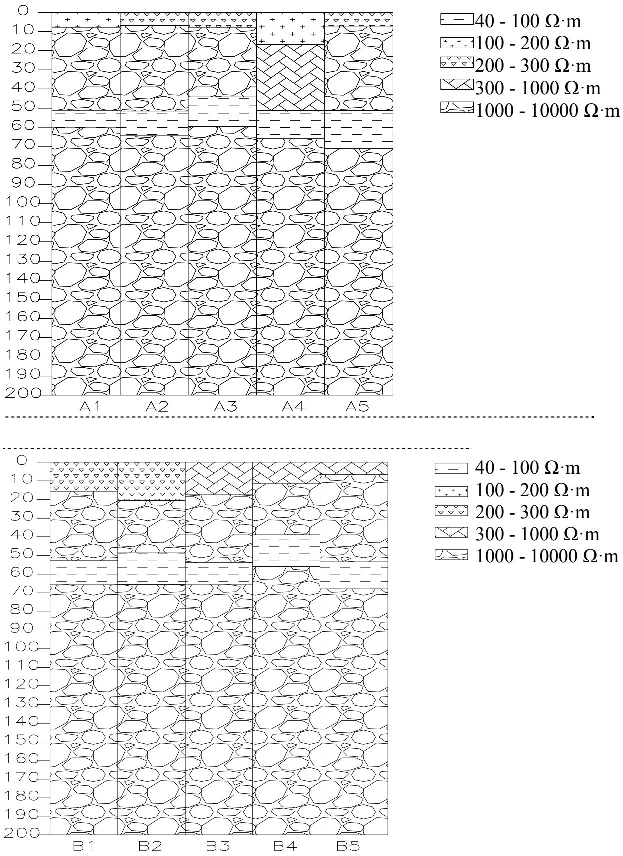

Figure 5. Geoelectrical sections.

5. Structural Analysis

5.1. Aquifer Nature

It arises that the lithology of the area is not homogeneous for the first two layers, due to old seismic movements. This is materialized by the in subsurface uplift of deep granite-gneisses in stations A3 and A5 for the first profile, and between B2 and B5 for the second profile (**Table 1**). This near surface presence of deep granite-gneisses suggests that the area underwent intense tectonics after which the aquifer layer has been set up [10,11]. We assumed that the probable captive potable aquifer, which correspond to the third layer regarding its resistivity range (49 - 100 Ω·m) observed, was formed before seismic events. Moreover, the geological map highlights the presence of obvious faults at these places [3,4] because seismic movements are noticeable on surface.

5.2. Optimal Drilling Zone

The analysis of the transmissivity field (**Figure 7**) estimated from transverse resistance (**Figure 6**) highlights the significant space variability of this parameter. The transmissive zones are located in the north-eastern part of the study area, between stations B3 and B5 where the geological map (**Figure 1**) shows a significant network of transverse faults; furthermore, these zones are marked by old seismic activities evidenced by the appearance of deep gneiss-granites at near subsurface. In addition, the average depth for both profiles can be accessed around 50 meters and the optimal drilling zone is not set in the future flooded zone.

5.3. Aquifer protection

Observation of conductivity's variation maps resulting from precedent data shows a weak variation (0.23 to 0.35 Siemens) of the ground water's conductivity in the area, inferring the quasi similar properties of the aquifer in this area. In addition, the samples collected by the KOEI Company did not present any physicochemical risk; this implies the inexistence of risky zones in this area.

6. Conclusion

The geophysical survey allowed us to obtain lithological identification and to characterize the conditions of the underground flow of the studied area. One ground w-terunit was identified. A map of the transverse unit resistance illustrates the aquifer. In this map, the tendencies of

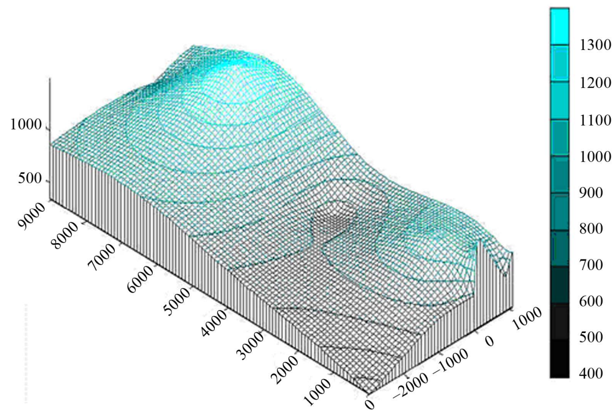

Figure 6. Transverse resistivity.

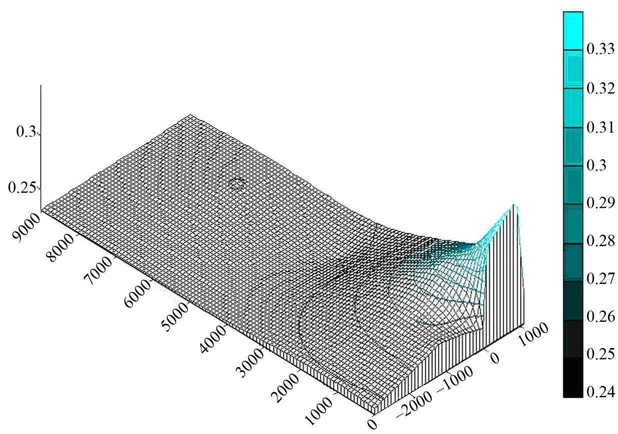

Figure 7. Transmissivity field map.

high values of Transverse resistance can be associated with high transmissivity zones; hence, these zones are suggested for the installation of monitoring wells for the unconfined aquifer. The map of longitudinal conductance associated to hydrochemical result illustrates that, in the studied area, an eventual contamination risk zone was not identified.

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