Joint use of MRS and TDEM for characterizing sedimentary aquifers in peri-urban area in tropical climate – Case study in the neighbourhood of Douala city (Cameroon)

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SUMMARY

The "Geoscientists Without Borders" (GWB) program aims to train students to innovative geophysical technics for solving an humanitarian issue. In this framework, we applied MRS and TDEM for characterizing the sedimentary aquifer of Doula city in order to propose solution for the problem of cholera.

Six sites were investigated for sampling both the shallow and the deep aquifer of Douala. Four MR soundings and six TDEM soundings of good quality were obtained despite difficult field conditions (tropical peri-urban context). Our results suggest that the shallow aquifer is vulnerable to surface pollution (high permeability) but the deep aquifer seems like a good water resource in term of quantity and quality (absence of saltwater). However these preliminary results should be confirmed by additional measurements for a better representativeness.

Key words: training, environmental issue, difficult field conditions.

INTRODUCTION

Douala city suffers from a recurring problem of cholera (e.g. 4000 cases and 77 deaths in 2011). This problem is related to poor access to safe water. The goal of the GWB program (Geoscientists without Borders) is to provide funding for projects that gather international multidisciplinary partnerships in order to train student to innovative geophysical methods that allow solving humanitarian issue. In this framework, our project aimed to characterise the groundwater of Douala by using geophysical and hydro-geochemical methods, and to establish a capacity building. Thus, the sedimentary basin of Douala was investigated by MRS, TDEM and hydro-geochemical measurements with 7 graduate students from Africa, Europe and North America. The objective was to train these students in the aim they become autonomous with these methods. This study also offered the possibility to present a demonstration for 22 master students of the Catholic St Jerome University of Douala. Our field results are of direct interest for humanitarian needs since they allow bringing new lightening on groundwater resources that could prevent future cholera outbreaks.

STUDY AREA

The study area is located around Douala city, economic capital of Cameroon, ~2 millions inhabitants (Fig 1.). The climate is humid tropical with an average annual rainfall of 4200 mm and ~220 days of rain per years, mainly between March and December (Feumba, 2014). The average annual temperature is high (27 °C) and facilitates the evapo-transpiration (AET ~1400 mm/year in the 1998-2007 period; Feumba et al. 2011).

The study area is located in the "Doula-Kirbi-Campo" sedimentary basin. This ~7000-km^2 basin (Njiké Ngaha, 1984) borders the Gulf of Guinea and lies on the metamorphic basement which forms the eastern boundary of the basin (Fig 1.). The western boundary is formed by the volcanic formation of Mount Cameroon. The sedimentary sequence consists of (from top to bottom):

1) Quaternary alluvium and Mio-Pliocene sand-clay alternations with gravel levels.
2) Eocene clay-marl-schist sediments.
3) Palaeocene continental sand and marine clay.
4) Secondary sediments (not investigated in our study).

Six sites were selected for geophysical and geochemical prospecting (Fig 1.). These sites were chosen in order to characterize both the shallow aquifer (Quaternary and Mio-Pliocene formation) and the deep Palaeocene aquifer of Douala city. For characterizing the deep aquifer, two sites (Ngombe and Bongo) are selected where the Palaeocene formation outcrops. These sites are located 20-30 km east of Douala. Due to the impossibility to perform MRS and TDEM measurements in urban area, the shallow aquifer was also investigated outside the city, in 4 sites west of Douala that is less urbanized than east.

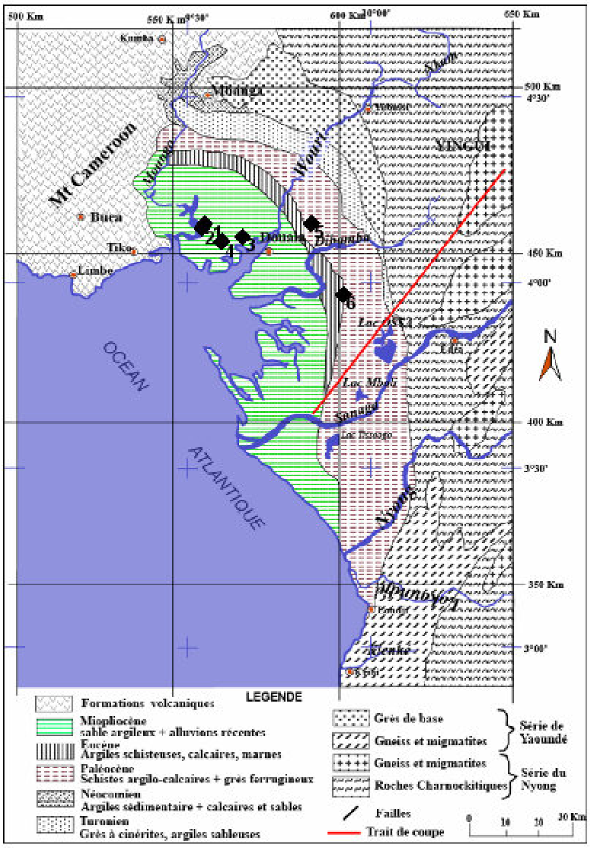

Figure 1. Location of investigated sites on simplified geological map (modified after Njiké Ngaha, 1984). Sites: 1. Moungo; 2. Tiko Moungo; 3. Towo; 4. Tiko; 5.Ngombe; 6. Bongo.

FIELD SET-UP

The field campaign took place in 2015 from January 18 to 30 (during dry season for practical reasons) with 6 days of effective fieldworks. Other days were spent for logistical preparation, courses, data compiling and wrap-up meeting.

For optimizing the capacity building, only the GWB team participated to the 3 first fieldwork days. The 22 other students from St Jerome University of Douala arrived the 4th day in small groups (7-8 students per day). The GWB students explained to students from St Jerome University the principle of the different technics we used (under the supervision of GWB teachers, of course).

MRS

MRS measurements were performed with Numis Plus equipment from IRIS-Instruments and Numrun software. Field conditions were difficult for many reasons:

1) High entropic noise due to peri-urban context. This issue was amplified by the Larmor frequency (1407-1412 Hz) close to a 50 Hz harmonic which limits the possibility of filtering.
2) High natural noise in tropical area because of frequent storms.
3) Difficult access to sites because of traffic in Douala (several hours can be wasted in traffic jams).
4) Management of many students on the field.

In order to overcome these difficulties, we spent one day for selecting favourable sites far from entropic source of noise. Eight-shape loops (with two 50-m-size square) allowed decreasing both entropic and natural noise. The use of spike correction also showed its efficiency for treating the natural noise (Fig.2). In the aim of avoiding both the increase of noise in the afternoon (often observed in tropical area) and traffic jams, we went in the field early in the morning (6 A.M). Despite these efforts, we did not manage to realize MR sounding in Towo site which was too close to urban area. So, only TDEM sounding and geochemical analyses were performed on this site. Moungo site was investigated the same day, but MRS was neither executed there due to lack of time.

As a compromise between data quality and saving time, we realized 10 pulse moments per MR sounding with 100 to 170 stacks. Thus, the duration of soundings ranged from 2h10 and 3h35 without loop installation and tidying (~2h and ~45min respectively) For other acquisition parameters (e.g. time sequences), default values were used for simplifying the explanations to students.

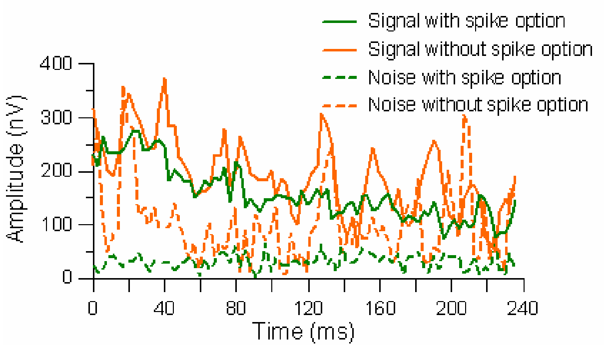

Figure 2. Efficiency of the spike correction for diminishing mean noise and improving the shape of signal. Example computed with Numpro software on Bongo site (pulse moment 2800 A.ms.)

TDEM

The aim of TDEM measurements was to rapidly assess the vertical distribution of electrical resistivity down to 200 m deep in order:

1) To evaluate the water quality (check if there is seawater in depth or mot);
2) To improve the inversion of MRS data.

TDEM measurements were acquired with the very light TEMFAST device (2 Kg) from AEMR Technology. The same cables as for MRS measurements were employed but in 100 × 100 m^2 square configuration (coincident transmitter and receiver array). After few tests all soundings were realized with the maximum possible intensity (3.6 A), the maximum time recording (9 in arbitrary unit of temfast software) and maximum number of stack (20 in arbitrary unit of temfast software). With these parameters the duration of TDEM soundings does not exceed 15 minutes plus ~45 minutes for changing the loop array after MRS measurements.

Hydrogeology and geochemistry

Water levels were measured in wells and borehole in the vicinity of geophysics-investigated sites. The altitude of these wells and borehole plus the altitude of neighbouring water surface if present (river, swamp or spring) were estimated with GPS and compared with the altitude of MRS/TDEM loop. In addition, the temperature and electrical conductivity of both groundwater and surface water were measured.

GEOPHYSICAL DATA INVERSION

MRS

All MRS raw data were first reprocessed with Numpro software in order to optimize the spike correction. After this process, signal-to-noise ratio ranges from 4.3 to 6.8. Then, MRS data were inversed with Samovar 11.62 software, taking into account the vertical distribution of electrical resistivity and the frequency shift. As the study site is located in tropical area, we assumed that the variation of Larmor frequency was caused by temporal variation of geomagnetic field. The inversion was realized in blocky mode (1 or 2 layers) using complex signal amplitude. The phase was used qualitatively to check the validity of the inversion.

TDEM

TDEM soundings were inversed with one-dimensional layered models using TEMRES software. On two sites (Moungo and Bongo), induced polarisation (IP) effects are clearly observed (negative values of resistivity for long times). These effects were taken into account. Sensitivity tests showed that although the parameters characterizing these IP effects are poorly defined, the distribution of electrical resistivity remains quite robust during the inversion. On two other sites (Tiko Moungo and Tiko), we suspect magnetic viscosity (SPM) effects. If there is no SPM effect on these sites, a conductive layer (~30 Ω.m) in depth (~180 m) is required for fitting well the data. The use of a central array (separated transmitter and receiver loops) would have allowed checking the presence or not of SPM effects.

RESULTS

Consistency of results

All geophysical results are presented in Figure 3. One can see a good agreement between MRS and TDEM results but also with water level. Indeed, if we consider the uncertainty due to the equivalence issue in the inversion of both MRS and TDEM data, the variation of water content occurs more or less at the same depth as the variation of electrical resistivity. In addition, water level (either from groundwater or surface water) always corresponds to an increase in MRS water content.

By using the electrical conductivity of groundwater (or surface water when no wells was found in the field), the factor formation (F) of the Archie's law (ratio between resistivity of rock and resistivity of water) was calculated and compared with MRS water content (Fig. 4). A good correlation is observed between F and the MRS water content, whereas Archie's law indicates an anti-correlation between F and the porosity. A possible explanation is that the resistivity of the rocks is influenced by the presence of clay: clay decreases both the electrical resistivity of the rock and the MRS water content. This hypothesis is strengthened by the absence of MRS-detected water in the layers where TDEM resistivity is lower than 10 Ω.m (Ngombe at ~100 m depth and Bongo between 5 and 25 m).

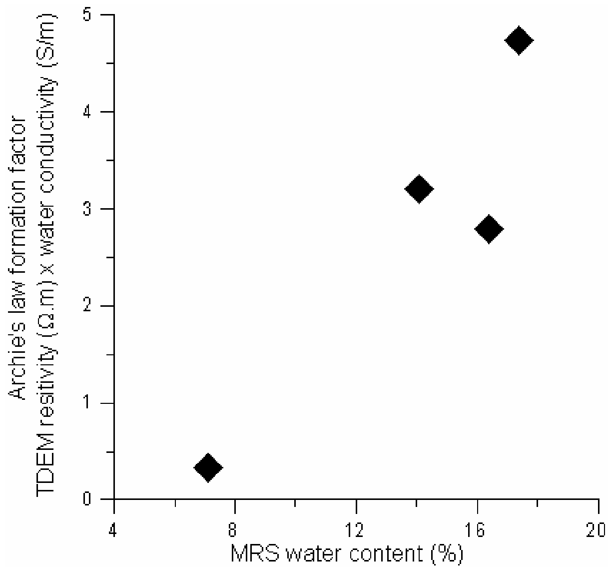

Figure 4. Comparison of the formation factor of the Archie's law and MRS water content. (Coefficient of correlation = 92 %).

Aquifer characterisation

MRS and TDEM show a high variability of behaviour depending on sites. However, as general rules, it can be said that both the Quaternary-Miopliocene aquifer (Tiko Moungo and Tiko) and the Palaeocene aquifer are characterized by relatively high MRS water content (7 to19 %) and by long decay time (> 200 ms) typical of coarse sand. Excepted on Moungo site, TDEM does not show very low resistivity (< 5 Ω.m) that could indicate the presence of a salt water wedge. This means that the shallow aquifer is probably vulnerable to surface pollution and the deep aquifer seems like a good water resource. For Mongo, the absence of MRS data prevents the possibility to solve if the ~3 Ω.m layer is due to salt water or clay.

CONCLUSIONS

The GWB program allowed training 7 graduate students to MRS and TDEM methods. They are now able to acquire and interpret data.

The data we collected during this formation are good quality despite difficult field conditions. They allow improving our knowledge about the sedimentary aquifers of Douala city (high MRS water content and decay time; no saltwater detected by TDEM down to 200 m deep). However, additional MRS and TDEM soundings are required to obtain a more representative data set.

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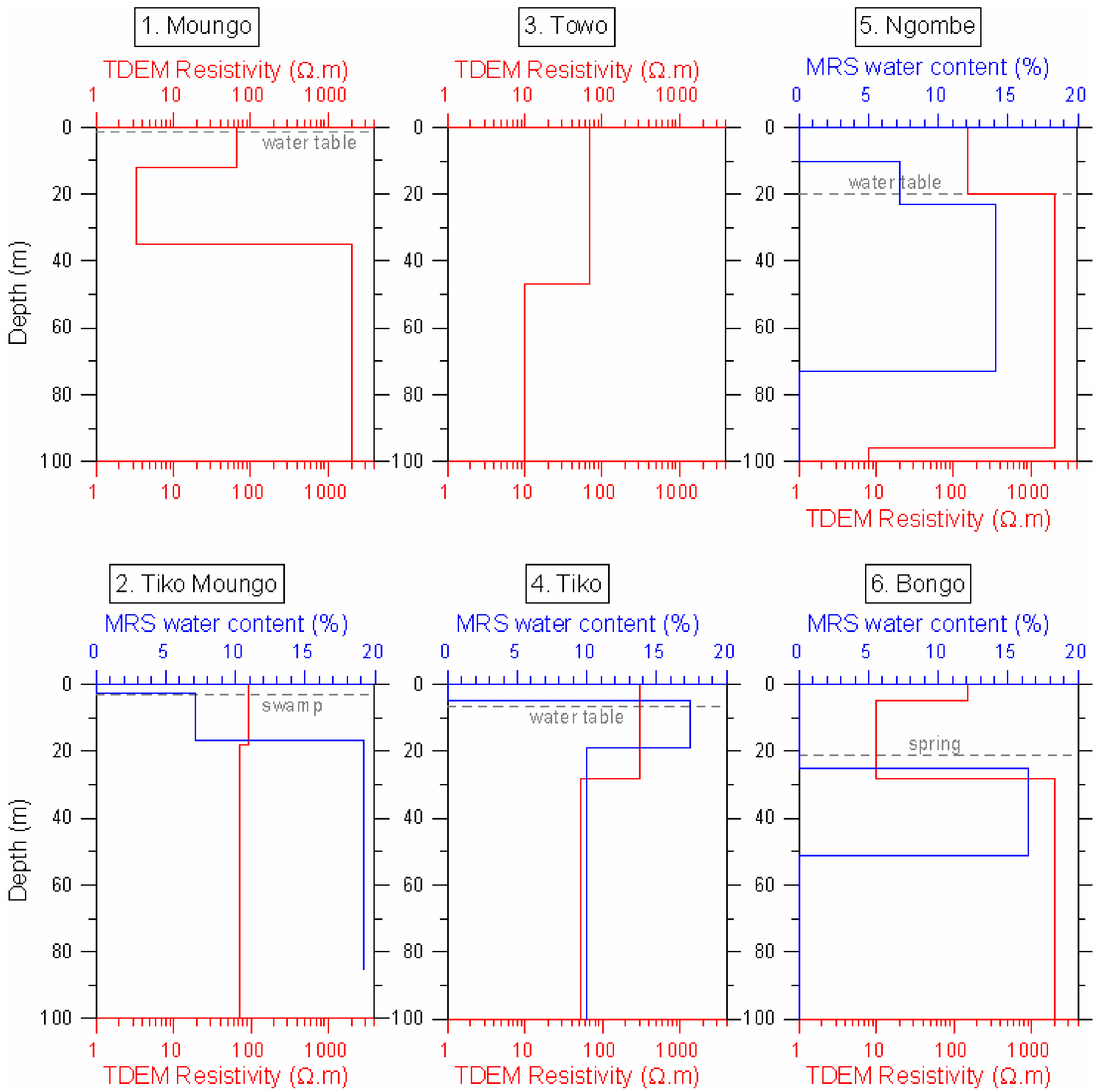

Figure 3. MRS and TDEM results and comparison with the groundwater level or surface water if no well nor borehole is present. TDEM results are presented down to 100 m for improving the readability of the figure, but TDEM investigation depth is ~200 m. For all TDEM sounding excepted in Ngombe, the resistivity between 100 and 200 m is the same as at 100 m deep. In Ngombe, we observed a resistive layer (2000 Ω.m) beneath ~140 m.