Final Report

Project Title: Development of Fresh Groundwater Use in Douala, Cameroon

Grant number: GWB #201310011

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1. Introduction

The present report summarizes our three years of activities of Geoscientists Without Borders program in Douala, Cameroon (GWB-Cameroon) from 2014 to 2017. The GWB-Cameroon program aims to explore a better aquifer system for prevention of cholera outbreaks and to enhance technical capacity of geophysical survey in local communities including universities and non-profit organizations. We performed two geophysical field campaigns in 2015 and 2016, and trained thirteen graduate students (including one postdoc) from Cameroon, Nigeria, Niger, Chad, and Benin. We also had more than thirty undergraduate students from the St. Jerome Catholic of Douala and three students from the Institute of Fish and Biology. We published four peer reviewed conference proceedings at international conferences and have been actively promoting the GWB program through various media sources.

1.1 Cholera outbreaks in Cameroon

The World Health Organization (WHO, 2012) reported the worst cholera outbreaks in Cameroon in the last decade. The recent outbreak started in the Extreme North region in the beginning of September 2009 (Figure 1). The case fatality rate was high and more than 60% of the deaths occurred in that region. At the end of August 2010, the affected regions was extended to the Extreme North and North where less than 25% of the population has access to potable water and less than 5% of the population uses latrines. The epidemic continued by spreading towards the South, in which cases were confirmed in Douala in September 2010. The most affected regions were the Extreme North and Littoral, followed by North, West, Center, and South West (Table 1).

Douala, the economic capital of Cameroon with a population of about two millions, has experienced repeated cholera epidemics in the past decade. Since 2004, Cameroon had experienced large cholera outbreaks with over 8000 reported cases in the Littoral and West regions (Figure 1). Repeated epidemics continued to occur especially between 2009 and 2012. According to the WHO (2012), the outbreak started in Bepanda, an urban slum in the northwest of Douala and spread rapidly to the entire city. While the population is fast growing with urban sprawl, the city infrastructure of drinking water, sanitation, and sewage system is highly limited for local people. As only less than 10% of city population had access to public water, the majority of residents obtained water from household wells, from which contaminated groundwater became the major source of cholera disease. Feumba (2015) showed that the leachate from household sewage system contaminated shallow groundwater in a local well, of which water depth is often 1-5m (Figure 2).

The major pathogen of cholera disease in Douala is Vibrio Cholerae. According to Guevart et al. (2006), Douala has habitable environmental factors for Vibrio: 1) the location of the city in estuary environments with brackish water of Atlantic Ocean, 2) sandy clay soil, 3) shallow polluted groundwater, 4) drainage/ditches infested with algae, and 5) high temperature with low rainfall during a dry season in January and February when the cholera occurrence is peak.
1.2 Project Objectives

The major goal of the project is to characterize the sedimentary basin in Douala by using two geophysical techniques – time domain electromagnetic sounding (TDEM) and magnetic resonance sounding (MRS) for better understanding of aquifer systems, which may provide a solution for developing fresh and clean groundwater resources in the region. Our project also aimed at knowledge transfer of geophysical techniques to enable local communities to improve drilling success as a decisive aid for decision-making, and hence accelerate better groundwater development in this region. The specific objectives are:

- To investigate the potentiality of groundwater well field development by using TDEM and MRS
- To establish capacity building for continuous and effective use of geophysical techniques for the sustainable development of groundwater resources
- To meet humanitarian needs to acquire clean and fresh water from the under-utilized groundwater resource and prevent future cholera outbreaks
Figure 1. A map of cholera incidence rate in Cameroon (UNICEF, 2014). The yellow circle shows a study area of Douala.
Table 1. Total cholera cases with population in each region in 2011. Douala is located in the Littoral region.

<table>
<thead>
<tr>
<th>Region</th>
<th>Population</th>
<th>Total cholera cases 2011</th>
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<tr>
<td></td>
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<tr>
<td>Adamaoua</td>
<td>1,048,004</td>
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<tr>
<td>Centre</td>
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<td>Far North</td>
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<td>Littoral</td>
<td>2,951,722</td>
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<td>North</td>
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<td>West</td>
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<td>South</td>
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<td>Southwest</td>
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<td>Total</td>
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</table>

Figure 2. Common septic systems with groundwater wells in Douala (modified from Feumba (2015))

2. GWB Cameroon Program in General

The GWB Cameroon program had two geophysical field campaigns in 2015 and 2016. Each field campaign consisted of three components: short course training, field survey, and student presentations. The short course training is to offer basic understanding of general hydrogeology, geophysical techniques, and geology of Douala (Figure 3). We invited not only the selected graduate students, but also undergraduate students from St. Jerome Catholic University. Following the intensive course work, students learned basic operation techniques of
each geophysical instrument and GPS unit. The site selection was made by the graduate students under the guidance of mentors using Google Earth and GPS as part of training. On the following day, we split students into two groups to investigate the field conditions of potential sites and determine which sites to survey.

![Figure 3](image)

**Figure 3.** (a) Group picture of participants, (b) orientation and short lecture, (c) orientation by Lee, (d) lecture by Boucher

Each field campaign had different goals and interests. The first field campaign was to set up timely efficient logistics under local conditions such as traffic and site accessibility, and to have basic understanding of aquifer system in Douala. During the first year field campaign, we characterized the basic aquifer conditions by identifying a potential depth and thickness of the deeper aquifer using MRS and TDEM. MRS and TDEM proved to be effective and complementary geophysical techniques to explore deeper aquifers in the urban settings, and could possibly help local stakeholders and engineers find a better drinking water source to prevent cholera disease. The GWB Cameroon team had following questions though after the first year experience. Is there any effect of saltwater intrusion in
the location of groundwater table and water quality? Can we map the change of shallow water bodies by using a geophysical method? Do the findings from the geophysical surveys support geochemical conditions of water? Can we have more involvement of the City and other stakeholders in the geophysical survey? The GWB Cameroon team decided to address above questions in the second field campaign occurred in 2016. During the second field campaign, we employed TDEM and EM31 instead of MRS as it was under technical service. We also collected over 30 groundwater samples for geochemical analysis.

At the end of the program, each graduate student gave a presentation to mentors with their preliminary results and own interpretation (Appendix IV). The basic data processing and analysis were made by themselves under supervision of mentors. During the presentation, mentors provided critical questions for students to enhance their scientific understanding, and at the same time, to improve their oral communication skills.

3. Geophysical Methods

We adopted three geophysical methods including MRS, TDEM and electromagnetic (EM) mapping using EM31. We also performed basic groundwater survey at nearby wells and geochemical analysis to verify and supplement the geophysical results.

3.1 Magnetic Resonance Sounding (MRS)

MRS is an emerging geophysical technique for characterizing groundwater aquifer and estimation of water content in porous materials (Legchenko et al. 2004). The MRS is based on exciting the nuclei of the hydrogen atoms in groundwater molecules, i.e. protons, and measuring the magnetic resonance signal that is generated by nuclei after the stimulating signal is terminated. In the field, a wire loop is laid out on the ground in order to generate the exciting signal and to record the resulting magnetic resonance signal. The diameter of the loop (D) is set between 10 to 150 m depending on the depth of the target, knowing that a cube with size 1.5D is the approximate maximum investigated volume. This investigated volume has the same order of magnitude as the radius of influence of wells making the MRS method particularly suited to groundwater prospecting for improving drilling success. The geophysical parameters recorded in the field by the MRS are the MRS-determined water content and signal decay time constants versus depth. The MRS-determined water content is generally close to the free water content (i.e. the portion of water that contributes to the flow and solute transport). MRS decay time constant is sensitive to pore size and is often used for estimating hydraulic conductivity and/or transmissivity with an empirical formulation. Numis Plus equipment from IRIS-Instruments and Numrun software were adopted for the MRS survey. Field conditions in Douala have two major difficulties: 1) high entropic noise due to peri-urban context, 2) high natural noise because of frequent tropical storms. Therefore, the sites had to be chosen far from entropic source of noise. Eight-shape loops (with two 50-m-size square) allowed decreasing both entropic and natural noise. For effective field performance, we chose 10 pulse moments per MR sounding with 100 to 170 stacks.
3.2 Time Domain Electromagnetic Sounding (TDEM)

TDEM is a controlled-source electromagnetic method that uses transient electromagnetic field diffusion. TDEM allows estimating electrical resistivity, which is a key parameter because it depends on parameters such as clay content, total porosity (i.e. water content), groundwater electrical conductivity and, for unsaturated soils, percentage of water filling the pores. The principle of TDEM method is based on electromagnetic induction and the field setup appears very similar to that of MRS method. The main advantages of TDEM compared to other methods are: (1) good sensitivity to electrically conductive formations such as clayey formations or salty groundwater; (2) investigation depth generally larger than the transmitter side length (100–150 m or more); (3) good lateral and vertical resolution; (4) ease of use without galvanic contact with the ground. The disadvantages are primarily poor sensitivity to resistive formations (above 300 ohm.m) and limited shallow surface resolution (the first 5–10 m are generally not well resolved).

In various contexts, the joint use of MRS and TDEM has shown its efficiency to answer the fundamental questions of hydrogeologists implementing boreholes, that is: "Where is the groundwater?", "What could be the expected yield of a drilled borehole?" and "What is the water quality?". We employed the very light TEM-FAST device (2 Kg) from AEMR Technology for the TDEM survey. The same cables for the MRS survey were used, but in $100 \times 100$ m² square configuration (coincident transmitter and receiver array). All soundings were recorded with the maximum possible current intensity (3.6 A), the maximum recording time (9 in arbitrary unit of TEM-FAST software) and maximum number of stacks (20 in arbitrary units of TEM-FAST software). TDEM soundings were inversed with one-dimensional layered models using TEMRES software.
3.3. Electromagnetic Mapping

Electromagnetic mapping is one of the most widely used geophysical methods in environmental and engineering applications. We employed Geonics EM31 (Figure 6) to measure apparent electrical conductivity under a gridded space. EM31 has two coils – a transmitter coil and a receiver coil with a fixed distance of 3.66 m parallel on the surface. If conductive material exists, the magnetic field from EM31 induces eddy currents in the conductor, which generates secondary magnetic fields to be detected by the receiver. The target depth is about 6 m and its operation is fairly easy.
3.4. Geochemical analysis for water quality

Geochemistry of groundwater is a description of the principal reactions or processes that have taken place during recharge and subsurface flow. This can give an insight into the relationship between rainfall, surface water and groundwater of a region. At each site we carried out measurement of physical parameters such as temperature, pH, EC, TDS, DO, etc. Collected water samples were sent to the LMI Picass’eau facilities in Montpellier (IRD) for the measurement of major cations and anions, minor ions, trace elements, stable isotope ($\delta^2$H and $\delta^{18}$O) and carbon-14 using appropriate equipment (ICP-OES, ICP-MS, AAS, flame photometry, X-Ray fluorescence, etc.).

Figure 7. Geochemical data collection. Left: students measure basic water quality parameters and collect water samples for chemical analysis. Right: students measure a groundwater level and collect water samples.

4. Results

4.1 Site Description

The study area lies on the “Doula-Kirbi-Campo” sedimentary basin. This basin borders the Gulf of Guinea with the metamorphic basement formation on the east, and the volcanic formation of Mount Cameroon on the west (Figure 8). This sedimentary basin consists of an alternation of aquifer and aquiclude formations. The climate is humid tropical with an average annual rainfall of 4200 mm during the rainy season from March to December (Feumba, 2014). The average annual temperature is about 27°C and the evapotranspiration rate is about ~1400 mm per year (Feumba et al. 2011).

Geophysical soundings were performed on 9 sites (Figure 8). Piezometric surveys and geochemical samplings were also performed on these sites and 2 additional sites at various distances from the bay shore. The objectives were to study the Quaternary/ Mio-Pliocene aquifer; to capture the geophysical and geochemical signatures of this aquifer with or without saline groundwater intrusions; to characterize the deeper Paleocene characteristics by prospecting two more inland sites (sites 7 & 8, Figure 8).
Figure 8: Localization of prospected sites on geological map modified after Njiké Ngaha (1984). The yellow line shows the position of profile presented in Figure 10.

4.2. Results

Figure 9 shows the results of MRS and TDEM at four sites. The water content distribution from MRS and the resistivity distribution from TDEM are plotted with the measured water level together to find accuracy of the geophysical estimation. All three datasets show good agreement. The change of water content occurs at the depth where the change of electrical
resistivity is observed. In addition, the measured water level from groundwater or spring water corresponds to the depth increase in the MRS water content. It is observed that both the Quaternary-Miocene aquifer (Tiko-Moungo and Tiko) and the Palaeocene deep aquifer are characterized by relatively high MRS water content and by long decay time typical of coarse sand. Except Moungo, TDEM does not show low resistivity (< 5 Ω.m), which could indicate the presence of a saltwater wedge. This preliminary observation indicates that the shallow aquifer is probably vulnerable to the surface pollution and the deep aquifer could be a good alternative water resource.

Figure 9. The results of TDEM and MRS at four survey sites.
Quaternary / Mio-Pliocene aquifer

Heterogeneities within the quaternary aquifer estimated using geophysical and geochemical approaches are summarized in Figure 10. MRS surveys indicate relatively high porosities (7 to 20 %) and permeabilities (MRS relaxation time of between 200 and 400 ms). These aquifer characteristics suggest that the superficial aquifer is strongly sensitive to surface contamination. This natural vulnerability is enhanced by mostly shallow water table depths (~ few meters). However, TDEM measurements and EC groundwater indicate that the saline intrusion is limited in space from the bay shoreline.

Figure 10. Hydrogeophysical profile in the vicinity of Douala (see location in Figure 8)

Paleocene aquifer

MRS and TDEM soundings performed on outcropping Paleocene formations (Figure 11) show relatively high water content and relaxation times (200-300 ms), together with strong electrical resistivities. These characteristics suggest highly permeable matrix, with limited clay content consistent with the geological log from a borehole 300 m away from site 7. This aquifer, at depth within the Douala urban city limits but with recharge areas north of the city, could therefore represent a good target to provide fresh domestic groundwater. Its relatively small aquifer thickness however could also represent a natural limit to extended exploitation.
Saline intrusion

Apparent electrical conductivity (AEC) surveys made on a sand beach, within the ocean tidal range, indicates a lowering of the AEC values at distance, and a lowering of the apparent resistivity (AER) between 6 and 15 m at depth (Figure 12). These measurements allow to estimate the saline intrusion AER value of between 2 and 17 $\Omega$.m and suggest a steep fresh water / saline interface, probably in response to the rainy equatorial climate and high recharge rates.
Geochemical Analysis

In the Douala aquifer region, samples of water from surface and groundwaters at different distances from the sea shore were collected for analyses. During the sampling program GPS was used to locate sampling point (borehole, tube well, wash bore, dug well). Collected water samples were initially sent to the analytical laboratory of LAGRES at the Yaounde 1 University. Due to delays in access to the facilities and shortage of reactives, in November 2017, samples were to be shipped to Grenoble University in France for the measurement of major cations and anions, minor ions, trace elements, and stable isotopes (δ²H and δ¹⁸O). The analyses showed influence of sea water intrusion at distances lower than 500 m but also some sewage contamination (nitrates, O-18/D, Na and Br/Cl ratio) at shallow (<10 m) depths, suggesting deep aquifer layers recognized by geophysics to be more suitable for long-term supply of domestic fresh water.

5. Broader impacts for humanitarian needs

The capacity building component of the GWB project was successfully achieved by training thirteen African graduate students to master the MRS, TDEM and EM techniques. The involvement of undergraduate students from the St. Jerome Catholic University of Douala also broadened the capacity of geophysical applications in the city of Douala with hands-on experience during the field campaign. In the beginning of the survey, the GWB mentors visited the water service sector of Douala city to promote the GWB project and how the project would benefit the water conservation and development in the city (Figure 13 (a)). The city arranged the field survey to the Mabanda school, one of the major K-12 schools in the city, experiencing a toxic groundwater issue (Figure 13 (b)). Dr. Roger Feumba, the additional mentor in the second field campaign, applied to the GWB-Cameroon when he was a Ph.D student, and joined our team as a postdoctoral fellow in the first year field campaign. As the hydrogeology of Douala is his major Ph.D thesis subject, his extensive knowledge of Douala geology and site conditions were beneficial to the entire program. After the first year field trip, Dr. Feumba joined the non-profit organization named ERA in Yaounde, Cameroon, to promote the geophysical methods for environmental applications in Cameroon. His efforts has continued in the region and we are planning to develop a new project to investigate the effect of salt water intrusion in the aquifer system using geophysical methods.
Figure 13. (a) Visit to the water service sector of Douala, (b) the Mabanda school site.

6. Dissemination

Student presentations

All graduate students presented their own analysis of TDEM and MRS data during the final wrap-up meeting. Each student had 20 minutes of presentation and 10 minutes of Q&A session. After the wrap-up meeting, mentors gave additional feedback to each student for better understanding of their results and presentation skills. The presentation slides are attached in Appendix IV.

Academic conferences

The team published four peer-reviewed conferences proceedings with oral presentations.

7. Lessons learned

The GWB Cameroon project provided great insight of how geophysical techniques could help people in Douala find a better source of clean water with effective training and simple practice. Below are the lessons we learned from the project.

1) TDEM, MRS, and EM are effective and complimentary to find aquifers in the urban settings under the high entropic noise from urban structures and the high natural noise from tropical conditions. The team was concerned if the urban settings and surface conditions from tropical environments would affect the quality of electromagnetic data. Although we had to make extra consideration in setting the sites, the data quality was good enough to provide meaningful results to answer the questions.

2) Geophysics is a field that requires extensive coursework and skill training to understand physical principles with geologic media and to master the operation of instruments and data analysis. We provided one-day intensive short course training to both graduate and undergraduate geology major students with few days of field practice. Students were able to manage all the necessary steps from the instrumental operation to data analysis and interpretation within few days. Such an effective training scheme will make geophysical applications more feasible and effective options for local people to adopt.

3) The students from St. Jerome Catholic University of Douala were very interested in the subject of geophysical exploration and the university was willing to provide the knowledge and techniques for students, but lacked the necessary instruments. Most of the studies were made only through textbooks without any field practice. This is actually a very common situation in many universities in developing and under developed countries. Even though the student participants learned how to use various geophysical techniques through this GWB-Cameroon program, we doubt they would be able to continue geophysical surveys without any instruments. If we can connect or develop any instrument adoption program by having old instruments from engineering companies, local people would have benefits to develop their own capacity for geophysical applications.
References


## Appendix I: List of Participants

### Mentors

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<tr>
<th>Name</th>
<th>Affiliation</th>
<th>Role</th>
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<tbody>
<tr>
<td>Jejung Lee</td>
<td>University of Missouri – Kansas City, USA</td>
<td>Managed overall project. Organized short course training. Led EM31 application.</td>
</tr>
<tr>
<td>Guillaume Favreau</td>
<td>Research Institute for Development, France</td>
<td>Managed international partnerships. Led hydrogeologic field survey and characterization.</td>
</tr>
<tr>
<td>Marie Boucher</td>
<td>Research Institute for Development, France</td>
<td>Led MRS and TDEM applications.</td>
</tr>
<tr>
<td>Benjamin Ngounou Ngatcha</td>
<td>University of Ngaoundere, Cameroon</td>
<td>Organized logistics. Led hydrogeologic field surveys and lab analysis.</td>
</tr>
<tr>
<td>Ibrahim Goni</td>
<td>University of Maiduguri, Nigeria</td>
<td>Organized field survey. Led hydrogeologic field surveys and lab analysis.</td>
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### Graduate Student Participants

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<td>Romuald Kopessi</td>
<td>Benin</td>
<td>MS, National University of Benin, Benin</td>
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<tr>
<td>Fleurine Matchuenkam</td>
<td>Cameroon</td>
<td>MS, University of Ngaoundere, Cameroon</td>
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<tr>
<td>Josiane Laure Pafeng Tchuindjang</td>
<td>Cameroon</td>
<td>Ph.D, University of Wyoming, USA</td>
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<tr>
<td>Roger Feumba</td>
<td>Cameroon</td>
<td>Post PhD, University of Yaoundé, Cameroon</td>
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<tr>
<td>Mvondo Valentin</td>
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<td>Kemgang Simon</td>
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<td>Melanie Ndedje Allah</td>
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<td>Benoît Viguier</td>
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<td>Oumou Kaltoum Hama Garba</td>
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<td>Mohammad Nur</td>
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<td>Musa Malham Aji</td>
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<tr>
<td>Mohammed Alh Kolo</td>
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<tr>
<td>Baba Musami Sheriff</td>
<td>Nigeria</td>
<td>MS</td>
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Appendix II: Details of Field Campaign

1. The 1st field campaign

The first field campaign took place from January 18th, 2015 to January 31st, 2015 for two weeks in Douala. Five scientists (mentors) led the campaign with eight African graduate students and twenty-two undergraduate students from the St. Jerome University of Douala. This team composition with African students promoted effective capacity building of geophysical applications as the mentors trained the African graduate students, who in turn guided the undergraduate students from the St. Jerome to learn geophysical techniques under the supervision of mentors.

Table 1. Detailed schedule

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<td>Tue</td>
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<tr>
<td>1/21/15</td>
<td>Wed, Site Check &amp; GW data collection</td>
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<td>1/22/15</td>
<td>Thu, Orientation, Short Course &amp; Operation Training</td>
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<td>Fri, Field Work Day 1</td>
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<td>Wed, Field Work Day 6</td>
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<td>1/29/15</td>
<td>Thu, Data compiling and Wrap-up meeting</td>
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<td>1/30/15</td>
<td>Fri, Departure</td>
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*Initially each team was supposed to arrive on January 18th, but due to flight cancellation, change, and visa issues, the entire team was finally gathered on January 20th.

Orientation and short course

The orientation and short courses were offered on January 21st for eight graduate students and twenty-two undergraduate students from the St. Jerome Catholic University. The short courses include general hydrogeology, geophysical techniques (TDEM and MRS), and geology of Douala, Cameroon.

2. The 2nd field campaign

The second field campaign took place from May 15th, 2016 to May 27th, 2016 for two weeks in Douala. In addition to the five mentors who proposed the project, the team recruited Dr. Roger Feumba as a new mentor who had joined the first year field campaign as a postdoc. After the first year field trip, Dr. Feumba joined the non-profit organization named ERA in Yaounde, Cameroon, to promote the geophysical activities for environmental applications in Cameroon. His experience and knowledge were crucial for the success of the second year project. This time, we had five graduate students from Cameroon, Nigeria, and Benin. We also had seven undergraduate students from the St. Jerome University of Douala and three graduate students from the Institute of Fish and Biology.
Table 2. Detailed schedule

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<td>Site check/water quality testing</td>
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<td>Short course training</td>
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<td>TDEM/EM Survey &amp; geochemical sampling</td>
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<tr>
<td>5/25/16</td>
<td>Wed</td>
<td>Data compiling &amp; presentation preparation/Optional field date</td>
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<td>5/26/16</td>
<td>Thu</td>
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<tr>
<td>5/27/16</td>
<td>Fri</td>
<td>Departure</td>
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</table>

Short course training
The orientation and short courses were offered on May 20th for five graduate students and seven undergraduate students from the St. Jerome Catholic University. The short courses include general hydrogeology, geophysical techniques (TDEM and EM), and geology of Douala, Cameroon.
Appendix III: Proceeding Manuscripts
Toward the prevention of cholera outbreak in Douala, Cameroon: Exploration of fresh groundwater using MRS and TDEM

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Douala, Cameroon has been experiencing repeated cholera epidemics due to contaminated groundwater. The present study is to characterize the sedimentary aquifer system of Douala using time domain electromagnetic sounding (TDEM) and magnetic resonance sounding (MRS) for better understanding of the aquifer system to explore cleaner groundwater resources in the region. The TDEM and MRS results show good agreement of aquifer structure with the observed water tables from nearby wells and spring water. The existence of a deeper aquifer from the survey may provide a solution to develop a new fresh groundwater well field for the prevention of future cholera outbreaks in the region. As part of the Geoscientists Without Borders project, the present study also emphasizes capacity building of geophysical applications in the region. The project successfully trained eight African graduate students to master the TDEM and MRS techniques with involvement of undergraduate students from the St. Jerome Catholic University of Douala.

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Toward the prevention of cholera outbreak in Douala, Cameroon: Exploration of fresh groundwater using MRS and TDEM

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Summary

Douala, Cameroon has been experiencing repeated cholera epidemics due to contaminated groundwater. The present study is to characterize the sedimentary aquifer system of Douala using time domain electromagnetic sounding (TDEM) and magnetic resonance sounding (MRS) for better understanding of the aquifer system to explore cleaner groundwater resources in the region. The TDEM and MRS results show good agreement of aquifer structure with the observed water tables from nearby wells and spring water. The existence of a deeper aquifer from the survey may provide a solution to develop a new fresh groundwater well field for the prevention of future cholera outbreaks in the region. As part of the Geoscientists Without Borders project, the present study also emphasizes capacity building of geophysical applications in the region. The project successfully trained eight African graduate students to master the TDEM and MRS techniques with involvement of undergraduate students from the St. Jerome Catholic University of Douala.

Introduction

Douala is the economic capital of Cameroon with a population of about 2 million. In 2004, Cameroon experienced a large cholera outbreak with over 8000 reported cases in the Littoral and West regions. According to the WHO (2012), the outbreak started in Bepanda in the northwest of Douala and spread rapidly to the entire city of Douala. Repeated epidemics continued to occur in Douala especially between 2009 and 2012. Contaminated groundwater is the major source of cholera disease in Douala as residents use groundwater for drinking and daily activities. It is observed that the leachate from household sewage system contaminates shallow groundwater in a local well, of which water depth is around 5-10 m.

The major goal of the present study is to characterize the sedimentary basin in Douala by using two geophysical techniques – time domain electromagnetic sounding (TDEM) and magnetic resonance sounding (MRS) for better understanding of aquifer systems, which may provide a solution for developing fresh and clean groundwater resources in the future. The present study is the very first results of the Geoscientist Without Borders (GWB) project with a team of scientists and students from the US, France, Nigeria, Niger, Chad, and the hometown Cameroon. To meet the goals of GWB, the study emphasized not only the scientific findings, but also capacity building to meet humanitarian needs in the region. The first field campaign took place from January 18th, 2015 to January 31st, 2015 for two weeks in Douala. Five scientists (mentors) led the campaign with eight African graduate students and twenty-two undergraduate students from the St. Jerome University of Douala. This team composition with African students promoted effective capacity building of geophysical applications as the mentors trained the African graduate students, who in turn guided the undergraduate students from the St. Jerome to learn geophysical techniques under the supervision of mentors.

The study area lies on the “Doula-Kirbi-Campo” sedimentary basin. This basin borders the Gulf of Guinea with the metamorphic basement formation on the east, and the volcanic formation of Mount Cameroon on the west (Figure 1). This sedimentary basin consists of four major formations (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, and 4. the secondary sediments. The climate is humid tropical with an average annual rainfall of 4200 mm during the rainy season from March to December (Fuemba, 2014). The average annual temperature is about 27°C and the evapotranspiration rate is about ~1400 mm per year (Fuemba et al. 2011).
Exploration of groundwater in Cameroon

Figure 1 shows six sites selected for MRS and TDEM surveys. These sites were chosen in order to characterize both the shallow aquifer (Quaternary and Mio-Pliocene formation) and the deep Palaeocene aquifer. Ngombe and Bongo, having the Palaeocene formation outcrops, were selected for characterization of the deep aquifer. These sites are located 20-30 km east of Douala. The other four sites were selected in the west of Douala for characterization of the shallow aquifer.

Method

We performed an MRS survey to characterize the aquifers by estimating water content in porous materials. The MRS-determined water content is generally close to the free water content (i.e. the portion of water that contributes to the flow and solute transport). MRS decay time constant is sensitive to pore size and is often used for estimating hydraulic conductivity and/or transmissivity with an empirical formulation. Numis Plus equipment from IRIS-Instruments and Numrun software were adopted for the MRS survey. Field conditions in Douala have two major difficulties: 1) high entropic noise due to peri-urban context, 2) high natural noise because of frequent tropical storms. Therefore, the sites had to be chosen far from entropic source of noise. Eight-shape loops (with two 50-m-size square) allowed decreasing both entropic and natural noise. For effective field performance, we chose 10 pulse moments per MR sounding with 100 to 170 stacks. Due to the closeness to the urban environments and limited accessibility, we could not run the MRS survey in Towo and Moungo.
Exploration of groundwater in Cameroon

We also performed the TDEM survey in all six sites. The advantages of the TDEM survey in addition to the MRS survey for the study area are: 1) to rapidly estimate the vertical distribution of electrical resistivity down to 200 m deep with potential detection of saltwater intrusion into the aquifer, and 2) to improve the inversion of MRS data. We employed the very light TEM-FAST device (2 Kg) from AEMR Technology for the TDEM survey. The same cables for the MRS survey were used, but in 100 × 100 m^2 square configuration (coincident transmitter and receiver array). All soundings were recorded with the maximum possible current intensity (3.6 A), the maximum recording time (9 in arbitrary unit of TEM-FAST software) and maximum number of stacks (20 in arbitrary units of TEM-FAST software).

All raw data were reprocessed for inverse modelling. The MRS data were inverted with Samovar 11.62 software, taking into account the vertical distribution of electrical resistivity and the frequency shift. As the study area is located in a tropical area, we assumed that the variation of Larmor frequency was caused by temporal variation of the geomagnetic field. The MRS inversion was performed in a blocky mode (1 or 2 layers) using complex signal amplitude. TDEM soundings were inverted with one-dimensional layered models using TEMRES software. During the TDEM inversion process, induced polarisation effects were taken into account for Moungo and Bongo.

Water levels were measured in nearby wells and springs at each site. The altitude of these wells and the altitude of neighbouring water bodies such as river, swamp, and spring were recorded with GPS and compared with the altitude of the MRS/TDEM loop.

Results

Figure 2 shows the results of MRS and TDEM at six sites. The water content distribution from MRS and the resistivity distribution from TDEM are plotted with the measured water level together to find accuracy of the geophysical estimation. All three datasets show good agreement. The change of water content occurs at the depth where the change of electrical resistivity is observed. In addition, the measured water level from groundwater or spring water corresponds to the depth increase in the MRS water content. It is observed that both the Quaternary-Miocene aquifer (Tiko Mouno and Tiko) and the Palaeocene deep aquifer are characterized by relatively high MRS water content (7 to 19 %) and by long decay time (> 200 ms) typical of coarse sand. Except Mouno, TDEM does not show low resistivity (< 5 Ω.m) which could indicate the presence of a saltwater wedge. This preliminary observation indicates that the shallow aquifer is probably vulnerable to the surface pollution and the deep aquifer could be a good alternative water resource.

Conclusions

The MRS and TDEM results show good agreement in depth and thickness of aquifers with the observed water bodies at six different locations around Douala. The aquifers in general have high MRS water content and decay time, but no indication of saltwater by TDEM. The existence of a deep aquifer may provide a good solution to develop a new well field for cleaner drinking water and to prevent future cholera outbreaks. The present results will be a good step for the second year of the GWB project which will investigate a more detailed understanding of aquifer structures and potentiality of new well field development around the city of Douala.

The capacity building component of the GWB project was successfully achieved by training eight African graduate students to master the MRS and TDEM techniques. The involvement of undergraduate students from the St. Jerome Catholic University of Douala also broadened the capacity of geophysical applications in the city of Douala with hands-on experience during the surveys.

Acknowledgments

The present study was supported by the Geoscientists Without Borders program of the Society of Exploration Geophysicists. Authors would like to acknowledge the IRD in Cameroon for facilitating the logistics, and the St Jerome Catholic University of Douala for their active participation in the geophysical fieldwork during the field campaign. We also thank M. Descloitres and A. Legchenko (IRD, LTHE) for their help in TDEM inversion and MRS data processing.
Exploration of groundwater in Cameroon

Figure 2. The results of TDEM and MRS at six survey sites.
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 innovate geophysical techniques for solving humanitarian issue. In this framework, we applied MRS and TDEM for characterizing the sedimentary aquifer of Douala 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-km² 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.
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.

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 not);
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 $100 \times 100$ 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 to 19 %) 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.

ACKNOWLEDGMENTS

The GWB program is supported by the Society of Exploration Geophysicists. Authors would like to acknowledge the IRD in Cameroon for having facilitated the logistics, and the Catholic St Jerome University of Douala for its interest in this GWB program through the coming of students both in courses and in the field. We also thank M. Descloires and A. Legchenko (IRD, LTHE) for their advices in TDEM inversion and MRS data processing respectively.
REFERENCES


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.
ÉTUDE HYDROGÉOPHYSIQUE D’UN AQUIFERE SEDIMENTAIRE COTIER EN CONTEXTE TROPICAL PERI-URBAIN: CAS DE DOUALA

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RÉSUMÉ
La ville de Douala (Cameroun) souffre de problème de contamination des eaux souterraines. Deux campagnes de mesures géophysiques et hydrogéochimiques dans cet environnement urbain à péri-urbain tropical, particulièrement difficile, ont permis de caractériser le système aquifère sous-jacent. Des recommandations sur l’approvisionnement en eau potable de la ville ont pu être formulées, tout en s’attachant au transfert de compétence.

Mots clés : Ressource en eau, Time Domain Electromagnétisme (TDEM), Résonance Magnétique des Protons (RMP), cartographie électromagnétique (EM), hydrogéochimie.

ABSTRACT

HYDROGEOPHYSICAL STUDY OF A COSTAL SEDIMENTARY AQUIFER IN PERI-URBAN TROPICAL CONTEXT: CASE OF DOUALA

Groundwater contamination problems affect Douala city (Cameroon). Two geophysical and hydro-geochemical field campaigns in this challenging urban / peri-urban tropical environment allow us characterizing the underlying aquifer system. Recommendations on drinking water supply for the city were made while focusing on the capacity building.

Key words: Water resources, Time Domain Electromagnetism (TDEM), Magnetic Resonance Sounding (MRS), Electromagnetic (EM) mapping, hydrochemistry.

1.1 INTRODUCTION

Dans le cadre du programme « Geoscientists Without Borders » (financé par la fondation SEG), deux écoles de terrain hydrogéophysiques ont été menées en 2015 et 2016 dans la région de Douala (capitale économique du Cameroun). En plus de l’objectif pédagogique, il s’agissait de caractériser le système aquifère sur
lequel repose la ville de Douala afin de trouver des solutions face aux problèmes d’accès à l’eau potable qui induisent des épidémies de choléra. Le déploiement de technique géophysique dans ce type de contexte tropical péri-urbain est un défi à cause de difficultés spécifiques (perturbation anthropique, bruit électromagnétique naturel, manque de place, etc.). Cette étude de cas à Douala est donc un exemple méthodologique qui pourrait être appliqué dans d’autres cas en contexte similaire, fréquent en Afrique.

2 SITE D’ETUDE ET TRAVAUX REALISES

Le site d’étude se situe sur le bassin sédimentaire de “Doula-Kirbi-Campo” qui comprend une alternance de formations aquifères et aquicludes (Fig. 1). Le climat est tropical humide avec une température moyenne de 27°C et 4200 mm/an de pluviométrie (Feumba et al. 2011).

Des mesures géophysiques (Tab 1.) ont été réalisées sur 9 sites (Fig. 1). Elles ont été complétées par des mesures de niveau piézométrique et conductivité électrique de l’eau. Trois sous-objectifs ont guidé le choix des sites : l’étude de l’aquifère quaternaire superficiel (sites 2 à 6) ; la prospection de l’aquifère profond du paléocène (sites 7 et 8) ; la signature géophysique du biseau salé (sites 1 et 9).

Fig. 1 – Localisation des sites de mesures sur fond géologique modifié d’après Njiké Ngaha, 1984 (En jaune : position du profil de la Fig. 3)

Tab. 1 – Méthodes géophysiques utilisées

<table>
<thead>
<tr>
<th>Equipement</th>
<th>Dispositifs de mesure</th>
<th>Traitement</th>
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<tr>
<td>TDEM</td>
<td>TEM-FAST</td>
<td>Coincident 40x40 ou 100x100 m et parfois Central</td>
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<tr>
<td>RMP</td>
<td>Numis plus</td>
<td>Huit carré de 50x50 m ou Carré simple 100x100 m</td>
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<tr>
<td>Carte EM</td>
<td>EM31 &amp; GPS</td>
<td>Espace entre mesure : 2 à 10 m</td>
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Surfer
.3 RESULTATS

3.1. Réponse géophysique du biseau salé
La carte EM réalisée sur la plage (Fig. 2 gauche) indique une diminution de la conductivité électrique lorsqu’on s’éloigne de l’Océan et les sondages TDEM (Fig. 2 droite) une baisse de résistivité entre 10 et 15 m de profondeur. Ces mesures permettent d’estimer la résistivité électrique du biseau salé entre 2 et 17 Ω.m et suggèrent que ce biseau s’approfondit rapidement probablement à cause de la forte pluviométrie dans la région.

Fig. 2 – Carte EM et sondages TDEM réalisés sur la plage

3.2. Aquifère quaternaire de Douala

Fig. 3 – Profil hydrogéophysique en bordure de Douala
La Fig. 3 résume les résultats obtenus sur l’aquifère quaternaire superficiel et révèle des hétérogénéités. Les mesures RMP indiquent des porosités (7 à 20 %) et perméabilités (temps de relaxation RMP 200 à 400 ms) assez élevées qui rendent l’aquifère superficiel vulnérable aux pollutions de surface. Cette vulnérabilité est accentuée par des niveaux piézométriques très peu profonds. En revanche, les mesures TDEM et de conductivité de l’eau montrent que l’intrusion saline reste limitée latéralement.

3.3. Aquifère paléocène
Les sondages RMP et TDEM réalisés là où la formation paléocène affleure (Fig. 4) montrent des teneurs en eau et des temps de relaxation (200-300 ms) relativement élevés, associé à de forte résistivité électrique. Cela suggère une formation perméable sans argile. Cette formation en profondeur au niveau de Douala pourrait donc être une bonne alternative pour l’alimentation en eau de la ville. A noter toutefois que sa faible épaisseur pourrait être un facteur limitant

CONCLUSION
Malgré des conditions de mesures particulièrement difficiles, nous avons réussi à acquérir des données de bonnes qualités, tout en formant de jeunes doctorants. Les différentes méthodes mises en œuvre montrent une cohérence et une complémentarité entre elles. Les résultats ainsi obtenus permettent de donner des recommandations sur l’utilisation des ressources en eau pour la ville de Douala.

REFERENCES BIBLIOGRAPHIQUES
USE OF GEOPHYSICAL TECHNIQUES FOR PREVENTION OF CHOLERA OUTBREAKS IN DOUALA, CAMEROON

Marie Boucher, IRD, Cotonou, Benin
Benjamin Ngounou Ngatcha, University of Ngaoundere, Ngaoundere, Cameroon
Guillaume Favreau, IRD, Marseille, France
Jejung Lee, University of Missouri, Kansas City, USA
Ibrahim Baba Goni, University of Maiduguri, Maiduguri, Nigeria
Roger Feumba, University of Yaoundé, Yaoundé, Cameroon

Abstract

Douala, the economic capital of Cameroon with a population of about 2 million, has experienced repeated cholera epidemics in the past decade. Contaminated groundwater is the major source of cholera disease as residents use groundwater as major source of water for drinking and daily activities. Previous works showed that the leachate from household sewage system contaminated shallow groundwater in a local well, of which water depth is around 5-10 m. The major goal of the present study is to characterize the aquifer system in Douala by using geophysical techniques including time domain electromagnetic sounding (TDEM), magnetic resonance sounding (MRS), and electromagnetic method (EM) for better understanding of aquifer systems and developing safe groundwater resources in the region. As funded by the Geoscientist Without Borders (GWB) program, the study emphasized not only the scientific findings, but also capacity building to meet humanitarian needs in the region. The TDEM, MRS, and EM results show good agreement in depth and thickness of aquifers with the observed water bodies at nine different locations around Douala. The deeper aquifers in general have high MRS water content and decay time, but no indication of saltwater by TDEM. The existence of a deep aquifer may provide a good solution to develop a new well field for cleaner drinking water and to prevent future cholera outbreaks. The present complementary approach of geophysical techniques can be applicable to other similar urban settings in Africa as it produces good quality data under difficult urban settings with anthropogenic disturbance and natural electromagnetic noise.

Study area and field survey

The study area lies on the “Doula-Kirbi-Campo” sedimentary basin. This basin borders the Gulf of Guinea with the metamorphic basement formation on the east, and the volcanic formation of Mount Cameroon on the west (Figure 1). This sedimentary basin consists of an alternation of aquifer and aquiclude formations. The climate is humid tropical with an average annual rainfall of 4200 mm during the rainy season from March to December (Feumba, 2014). The average annual temperature is about 27°C and the evapotranspiration rate is about ~1400 mm per year (Feumba et al. 2011).

Geophysical soundings (Table 1) were performed on 9 sites (Figure 1). Piezometric surveys and geochemical samplings were also performed on these sites and 2 additional sites at various distances from the bay shore. The objectives were to study the Quaternary/ Mio-Pliocene aquifer; to capture the geophysical and geochemical signatures of this aquifer with or without saline groundwater intrusions; to characterize the deeper Paleocene characteristics by prospecting two more inland sites (sites 7 & 8, Figure 1).
Figure 1: Localization of prospected sites on geological map modified after Njiké Ngaha, 1984 (Yellow line: position of profile presented in Figure 3)

Table 1: Example of a Sample Table and the Table Caption

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Array</th>
<th>Inversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>TDEM</td>
<td>TEM-FAST</td>
<td>40x40 or 100x100 m coincident (+ sometime central)</td>
</tr>
<tr>
<td>MRS</td>
<td>NUMIS plus</td>
<td>50x50 m eight-square or 100x100 m simple square</td>
</tr>
<tr>
<td>EM map</td>
<td>EM31 &amp; GPS</td>
<td>2 to 10 m spacing</td>
</tr>
</tbody>
</table>
Saline intrusion

Apparent electrical conductivity (AEC) surveys made on a sand beach, within the ocean tidal range, indicates a lowering of the AEC values at distance, and a lowering of the apparent resistivity (AER) between 6 and 15 m at depth (Figure 2). These measurements allow to estimate the saline intrusion AER value of between 2 and 17 Ω.m and suggest a steep fresh water / saline interface, probably in response to the rainy equatorial climate and high recharge rates.

Figure 2: EM map and TDEM soundings close to the Ocean

Quaternary / Mio-Pliocene aquifer

Heterogeneities within the quaternary aquifer estimated using geophysical and geochemical approaches are summarized in Figure 43. MR surveys indicate relatively high porosities (7 à 20 %) and permeabilities (MRS relaxation time of between 200 and 400 ms). These aquifer characteristics suggest that the superficial aquifer is strongly sensitive to surface contamination. This natural vulnerability is enhanced by mostly shallow water table depths (~ few meters). However, TDEM measurements and EC groundwater indicate that the saline intrusion is limited in space from the bay shoreline.

Figure 3: Hydrogeophysical profile in the vicinity of Douala (see location in Figure1)
Paleocene aquifer

MR and TDEM soundings performed on outcropping Paleocene formations (Figure 4) show relatively high water content and relaxation times (200-300 ms), together with strong electrical resistivities. These characteristics suggest highly permeable matrix, with limited clay content consistent with the geological log from a borehole 300 m away from site 7. This aquifer, at depth within the Douala urban city limits but with recharge areas north of the city, could therefore represent a good target to provide fresh domestic groundwater. Its relatively small aquifer thickness however could also represent a natural limit to extended exploitation.

![Site 7 and Site 8](image)

Figure 4: MRS and TDEM results in the Paleocene formation.

Conclusions

Good quality geophysical data were obtained in the Douala urban community aquifer formations, despite noisy EM conditions and field access. Various methods were applied to show consistently that (i) groundwaters are at risk of contamination from the sub-surface (ii) saline intrusion is currently limited in space and (iii) deeper aquifer could represent a good alternative fresh water resource for domestic supply of Douala city.

References


Acknowledgements

The present work was funded by the Geosciences Without Borders program, sponsored by the Society of Exploration Geophysicists.
Appendix IV: Student Presentations
AQUIFER CHARACTERIZATION USING MRS, TDEM AND WATER QUALITY AROUND TIKOMONGO-DUOALA

Site Description: Tikomongo
- Vegetation

- Topography
- Geology
- Hydrogeology

Methods used
MRS
TDEM
WATER QUALITY

MRS: MAGNETIC RESONANCE SOUNDING
Sites Selection
Sources of disturbances should be avoided:
- Generators
- Pipes
- Electric cables
- Metal fence
- Antenna
- etc

Prior Measurement and Considerations
- Selection of loop type
- Alignment and connections; tighten & in box
- Configuring of the capacitors - earth magnetic field - working frequency

Check tuning
Capacitor configuration used for setting capacitors
Other calibrations in the Programme window include:
- Select type of loop
- Loop size
- Stacking
- Pulse moment - Default
- Duration of pulse - 40ms
- Number of pulse - 1 or 2
- Save data - yes

Press OK - Result of the communication window will appear
- Name of data file - in one line
- After this, NUMIS data acquisition window will appear, then the equipment will be ready to acquire data

DATA INTERPRETATION

- Once the data has been acquired it is possible to make the inversion of the same model in 1D.

- Before the inversion, the following processes should be followed:
Inversion configuration window

Representation and inversion data process

TDEM: TIME DOMAIN ELECTROMAGNETIC METHOD

TDEM RESULTS

TDEM MODEL

PHYSICO-CHEMICAL PARAMETERS

<table>
<thead>
<tr>
<th>S/N</th>
<th>Location</th>
<th>Lat</th>
<th>Long</th>
<th>DTW</th>
<th>Temp</th>
<th>pH</th>
<th>EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tiko Mongo (swamp 1)</td>
<td>055 86</td>
<td>045 75</td>
<td>37</td>
<td>26</td>
<td>6.55</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>Tiko Mongo (swamp 2)</td>
<td>055 86</td>
<td>045 77</td>
<td>39</td>
<td>28</td>
<td>7.02</td>
<td>36</td>
</tr>
<tr>
<td>3</td>
<td>Tiko Mongo (Dug well)</td>
<td>055 79</td>
<td>045 87</td>
<td>00</td>
<td>5.6</td>
<td>27.9</td>
<td>5.6</td>
</tr>
</tbody>
</table>
**General geology of Douala Basin**

* Deposits: coastal sand, black vases from the Mangrove and fluvial alluviums of great thickness in continuity with the present Pliocene deposits.
* Continental and marine sediments deposited on a metamorphic basement.
* Quaternary alluviums: Wouri formation dating from the Plio-Pleistocene. Thickness ~30 m by the river’s estuary and decreases as we move away.
* Non-consolidated sand layers with interbedded silts, clay and loam unconformably laying on top of all the previous formations.
* Three main levels (top to bottom): Coarse, gravel and sandy clay matrix more or less kaolinitic.

**Hydrogeology of Douala Basin**

* Deep aquifer system:
  * Red sandstones
  * Paleocene sands
* Superficial aquifer system:
  * Mio-pliocene formations
  * Quaternary alluviums

**Quaternary alluviums aquifer**
- Phreatic table
- Captive water table
- Perched water tables in interbedded sandy-clay layers.
- Perched water tables:
  - Thickness: 50-60 m.
  - Used by people and industries via wells and boreholes.

**Superficial aquifer system**
- Mio-pliocene formations
- Quaternary alluviums

**Potential study sites**

**Site 1: Tiko (palm grove)**

* UTM 32N: 564523E - 453848N. Altitude 13±2 m.
* Geology:
  * Yellow sandy clay (non-saturated zone).
  * Sandstones in the saturated zone.
* Well 1:
  - UTM 32N: 564523E - 453848N
  - Altitude: 4m.
  - Depth of well:
  - Phreatic Head:
  - Temperature:
  - EC:
  - PH Value:
Well 2:
- UTM 32N: 564490E – 453804N
- Elevation: 8m.
- Depth of well: 7.84m
- Piezometric Head: 2.03m
- Temperature: 27.4°C
- EC: 42microS
- PH Value: 7.03

Well 3:
- UTM 32N: 564380E – 453829N
- Elevation: 8m.
- Depth of well: 6.86m
- Piezometric Head: 3.37m
- Temperature: 27.4°C
- EC: 105microS
- PH Value: 7.05

Well 4:
- UTM 32N: 564309E – 453866N
- Elevation: 11m.
- Depth of well: 7.90m
- Piezometric Head: 4.47m
- Temperature: 27.2°C
- EC: 25microS
- PH Value: 7.04

Well 5:
- UTM 32N: 564216E – 453851N
- Elevation: 6m.
- Depth of well: 6.56m
- Piezometric Head: 0.94m
- Temperature: 27.0°C
- EC: 665microS
- PH Value: 7.04

Well 6:
- UTM 32N: 564109E – 453872N
- Elevation: 6m.
- Depth of well: 6.03m
- Piezometric Head: 1.5m
- Temperature: 27.0°C
- EC: 665microS
- PH Value: 7.04

Well 7:
- UTM 32N: 564819E – 453265N
- Elevation: 11m.
- Depth of well: 7.10m
- Piezometric Head: 4.65m
- Temperature: 27.06°C
- EC: 23microS
- PH Value: 5.25
River 8:
- UTM 32N: 564951E – 453532N
- Elevation: 1m.
- Depth of well: 4.65m
- Piezometric Head: 4.65m
- Temperature: 27.71°C
- EC: 84 microS
- PH Value: 5.44

*MODEL

*T2 pore size
GWB PROJECT
DOUALA-CAMEROON

Josiane Laure Fateng Tchuindjang

Day 4: 01/27/15

Outline

• Studied area
• Site 1: Grand Towo
• Site 2: Moungo
• Conclusions

Site 1: Grand Towo

• Location
  o 570866E
  o 455236N

• Geologic setting
  o Sands (quartz) at the surface
  o Loamy-clay soils towards swamp.

Site 1: TDEM

• Recording setting
  o 100 m square loop
  o Current 3.7A
  o Frequency 50 Hz
  o 9 recording times and stack of ~20

Data
Inversion results

Hydrologic measurements

- **Swamp**: 570947E - 455322N. Altitude: 7+3 m.
- **Water characteristics**
  - Piesometric level: 7m
  - T: 29.4 C
  - Conductivity: 170 microS/cm

- **Stream**: 570958E - 455292N. Altitude: 7+3 m
- **Water characteristics**
  - Piesometric level: 7m
  - T: 28.2 C
  - Conductivity: 190 microS/cm

Site 2: Moungo

- **Location**
  - 559384E
  - 459223N

- **Geologic setting**
  - Sands (quartz) at the surface.
  - Loamy-clay soils towards swamp.

Site 2: TDEM

- **Recording setting 1**
  - 100 m square loop
  - Current 1A
  - Frequency 50 Hz
  - 5 recording times and stack of ~20

- **Recording setting 2**
  - 100 m square loop
  - Current 3.7 A
  - Frequency 50 Hz
  - 9 recording times and stack of ~20

Data

Red: 1A
Green: 4A
**Hydrologic measurements**

- **Well**: 559425E - 459324N.  
  Altitude 11+-3 m.

- **Well characteristics**
  - Rim at ground level.
  - Well depth: 2 m

- **Water characteristics**
  - Static level: 1.55 m
  - Piesometric level: 9.45 m
  - T: 27.5°C
  - Conductivity: 210 microS/cm

- **Stream**: 570938E - 455292N.  
  Altitude: 7+-3 m

- **Water characteristics**
  - Piesometric level: 7m
  - T: 30.7°C
  - Conductivity: 140 microS/cm

**Conclusions**

- Grand Towo: Conductive layers below ~50 m
- Moungo: less salty water. Possibility of drinkable water.

- Need MRS data for more information.
Présentation du site Bongo PK 30

Date : 26 janvier 2015
Coordonnées gpx : WGS 84 UTM zone 32 N
X 601126 E ; Y 4379146 Z = 46 m

Source

WGS84 UTM zone 32 N : 601307 m E ; 438264 m N
Z (gpx) : 25 ± 3 m
T°C : 26,6
CE (microS/cm) : 14
Résistivité (Ohm.m) : 714
Croûte latéritique en surface et élément sablo-limoneux à argilo-limoneux entre les nodules latéritiques

Basses eaux

Hautes eaux

RMP

Profil de résistivité utilisé :
0 à 5 m : 80 Ω.m
5 à 23 m : 8 Ω.m
23 à 75 m : 2000 Ω.m

Interprétation

Ω.m

nappe perchée (sud ou déplin sablo-limoneux sur les latérites)
horizon argileux saturé ou cuirasse latéritique à composante argileuse (eau libre null !)
horizon sablonneux saturé ou grande concentration fractures ouvertes saturées (eau libre++)
Horizon à éléments poreux fin (sable fin / limon) eaux libre - +

Horizon à éléments poreux fin (sable fin / limon) eaux libre - +
Bilan :

⇒ Utilisation du mpm dans la compréhension de la distribution verticale des horizons saturée à «large » porosité.

⇒ Le recoupement avec les observations de terrains semblent être nécessaire à obligatoire.

⇒ Un seul modèle hydrogéologique (hors contraste) ne peut être retenu.

⇒ Nécessité de recouper les informations géophysiques.

⇒ La nécessité d'une étude géologique de terrain à l'échelle de la zone d'étude semble pouvoir apporter de nombreux indices sur le modèle hydrogéologique.
Geophysical survey on Ngombe
Oumou Kaltoum Hama Garba

Site de Ngombe

Position UTM
(32N):
Est de Douala
4,00638°N
9,85502°E

Altitude moyenne:
40 m +/- 3 m

Caractéristiques du site

Relief:
Dénivelée de 22-24m +/- 5m

Végétation: Forêt arbustive (défrichée)

Caractéristique Hydro-géochimie

<table>
<thead>
<tr>
<th>Cord</th>
<th>Point de mesures Hydro-geoch.</th>
<th>Altitudes (m)</th>
<th>N (ph)</th>
<th>T°C</th>
<th>Conductivité µS</th>
</tr>
</thead>
<tbody>
<tr>
<td>551269</td>
<td>source-Ngombe</td>
<td>36</td>
<td>36</td>
<td>26.2</td>
<td>11</td>
</tr>
<tr>
<td>551270</td>
<td>route-Ngombe</td>
<td>33</td>
<td>33</td>
<td>26.3</td>
<td>9</td>
</tr>
<tr>
<td>553090</td>
<td>Forage-Ngombe</td>
<td>31</td>
<td>31</td>
<td>29.6</td>
<td>16</td>
</tr>
<tr>
<td>550224</td>
<td>stagnant au sud-Ngombe</td>
<td>40</td>
<td>40</td>
<td>26.8</td>
<td>26.8</td>
</tr>
</tbody>
</table>

Caractéristique Hydro-géochimie

Climat (Fumba, 2015)
P = 3 600 mm/an
ETP = 1200 mm
T entre 27 et 32°C
Humidité = 85 %
Infiltration = 9 % de la lame d’eau

Géologie-Hydrogéologie:
- Bassin sédimentaire : roche sédimentaire (alternance de sable et d’argile avec des passages de graviers (Fumba, 2015)
- Sable limoneux de couleur jaune
- Circul.Souter.: Ouest-Est
Géophysique

- Méthodes et Paramètres utilisée
  - RMP:
    - Loop: eight
    - Size: 50m
    - Noise limite: 18000
    - Pulse: 10
    - Freq. Mag.: Très élevée ordre de 35-39000 nT (hypothèse: utilisation des engrains chimiques contenant 3,5% d’oxyde de magnésium)

Géophysique

- TDEM:
  - Loop: Square
  - Size: 100m
  - Courant inj.: 4A
  - Freq: 50 Hz
  - Stack: 20
  - Profondeur: 230m

Géophysique

Résultat

- TDEM:
  - 4 couches
  - 0-20m: 150 Ohm.m
  - 20-96m: 2000 Ohm.m
  - 96-140m: 8 Ohm.m
  - 140-200m: 2000 Ohm.m

Résultat

- RMP:
  - Inversion: lisse
  - 40 couches
  - Données bruités
  - Stack: 10 dont 9 acceptables
Plan

Aim

Methodology

Hydrogeochemistry

Geophysical soundings

Aim

- Detect front between saline water (Sea water) and fresh groundwater.
- Form students in the using of geophysical methods and interpretation of results.
- Improve their capacities (manners) on fieldwork.

Methodology

- Hydrogeochemistry
  - WTW equipments
  - Hanna equipments
  - Sampling bottles
- Geophysical soundings
  - EM 31
  - TDEM

Hydrogeochemistry

<table>
<thead>
<tr>
<th>pH</th>
<th>T (°C)</th>
<th>EC (µS/cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.02 – 7.01</td>
<td>27.49 – 30.80</td>
<td>2082 – 2663</td>
</tr>
</tbody>
</table>

We were not able to do spatial mapping of these data because they were insufficient (04 measures) for the area.

We can only say that conductivities increase from Besseke to Mabanda.
Geophysical soundings (2)

THANK YOU FOR YOUR KIND ATTENTION
THE EXPLORATION OF FRESH GROUND WATER AROUND LIMBE AREA IN SOUTH-WESTERN PART OF CAMEROON.

BY
MOHAMMED ALH KOLO

INTRODUCTION

- Douala - Population over 2million people
- 2004 cholera outbreak
- 2011, 3972 cases and 77 deaths reported in Douala
- 2012, the outbreak started in Bepanda in the northwest of Douala and spread rapidly.
- Ground water contamination
- GWB 2015

AIMS AND OBJECTIVE

- To investigate the potentiality of groundwater well field development by using TDEM.
- To detect any saltwater intrusion into the aquifer system of the study area.
- To assess the water quality of the study area.

OUTLINE

- INTRODUCTION
- AIM AND OBJECTIVE
- FIELD WORK
- RESULTS
- CONCLUSION

Fig. 1. Geological map of Douala, Cameroon (modified after Njiké Ngaha, 1984).

Field work
Field work con.
Water sampling
- GPS
- Plastic containers
- Physico-chemical parameter measurement field kits. Etc.

RESULTS FOR PHYSICO-CHEMICAL

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Batoke Beach</th>
<th>IRAD BH Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>8.04</td>
<td>6.91</td>
</tr>
<tr>
<td>Ec (us/cm)</td>
<td>4982.0</td>
<td>299.0</td>
</tr>
<tr>
<td>Temp (°C)</td>
<td>31.4</td>
<td>28.7</td>
</tr>
<tr>
<td>TDS (mg/l)</td>
<td>24.91</td>
<td>149.0</td>
</tr>
<tr>
<td>Salinity (mg/l)</td>
<td>32.4</td>
<td>0.14</td>
</tr>
<tr>
<td>Eh (Mv)</td>
<td>86.1</td>
<td>18.7</td>
</tr>
<tr>
<td>Do (%)</td>
<td>3.7</td>
<td>3.92</td>
</tr>
<tr>
<td>Elevation (m)</td>
<td>--</td>
<td>43.0</td>
</tr>
</tbody>
</table>

Conclusion
The resistivity result from the TDEM shows that it is low.
The deep aquifer is likely to an alternative source of water supply.
The results of field data shows that the water collected at the borehole is free from salinisation.

THANK YOU
INTRODUCTION
• Les eaux souterraines sont dans la plupart des cas, de meilleure qualité que les eaux de surface, car moins exposées aux pollutions.
• Cependant, on observe parfois dans les zones côtières le phénomène d'intrusion saline qui modifie la qualité de l'eau et rend sa consommation difficile.
• Il est donc important d'associer de plus en plus les techniques géophysiques dans les projets et campagnes d'approvisionnement en eau potable.
• C'est dans ce souci que le projet GWB s'est incrusté depuis quelques années et avec pour d'étude Douala.

CADRE D'ÉTUDE
• Le pays s'étend entre le Nigéria, le Tchad, la Guinée Équatoriale, la RCA, le Congo (Brazzaville) et le Gabon.
• Superficie : 475 442 km²
• Population :
• Pluviométrie : 4400 mm
• Capitale politique : Yaoundé
• Capitale Economique : Douala

ACQUISITION DES DONNÉES
• EM 31
  • L'EM31 permet de mesurer la conductivité électrique d'un terrain afin d'établir une cartographie de surface du sous sol
  • Il permet de distinguer les différences de nature géologique de terrains
  • Il peut être aussi employé pour la détermination d'objets métalliques divers enfouis dans le sous sol.

ACQUISITION DE DONNÉES
• La méthode TDEM est une méthode électromagnétique de sondage géophysique. Elle permet de sander le sous-sol grâce à l'induction électromagnétique produite par la coupure brusque d'un champ magnétique statique établi en surface grâce à une boucle de câble déployée à la surface dans laquelle on a fait circuler un courant électrique.
ACQUISITION DES DONNEES

- Mesure de quelques paramètres: pH, T°C, Salinité, potentiel redox, oxygène dissous, etc...
- Echantillons d’eau

RESULTATS OBTENUS/ TDEM

RESULTATS OBTENUS

Valeurs mesurées dans les ouvrages d’eau

<table>
<thead>
<tr>
<th>NOUS</th>
<th>X</th>
<th>Y</th>
<th>pH</th>
<th>T°C</th>
<th>Salz</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>6080</td>
<td>3407</td>
<td>5.25</td>
<td>28.40</td>
<td>199</td>
</tr>
<tr>
<td>F1</td>
<td>6079</td>
<td>3407</td>
<td>5.53</td>
<td>26.40</td>
<td>59</td>
</tr>
<tr>
<td>P2</td>
<td>6082</td>
<td>3406</td>
<td>6.31</td>
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<td>F2</td>
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<td>3400</td>
<td>5.76</td>
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<td>61</td>
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</table>

RESULTATS OBTENUS/ EM31

<table>
<thead>
<tr>
<th>EM 31</th>
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<tbody>
<tr>
<td>X</td>
</tr>
<tr>
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CONCLUSION

- Les données issues de cette campagne nous ont permis d’observer à certains niveau la limite entre l’eau douce et l’eau salée.
- La campagne de collecte de données et l’utilisation des appareils de géophysique ainsi que ceux de mesure des paramètres physico-chimiques a permis d’acquérir plus de connaissance et une très bonne expérience.
A REPORT PRESENTED TO
GEOSCIENTISTS WITHOUT BORDERS
(GWB)
ON EXPLORING FOR FRESH
GROUNDWATER AND SALT WATER
INTRUSION USING TDEM ALONG LONDJI
SITE 2, DOUALA, CAMEROON

BY
BABAMUSAMISHERIFF

5TH May, 2016.

Presentation Outline
✓ Introduction
✓ Location and accessibility
✓ Geology of Londgi site
✓ Methodology
✓ Sample collected
✓ Results
✓ Conclusion

INTRODUCTION
• Geoscientists Without Borders (GWB) project was initiated in Douala, Cameroon in 2014 to promote the use of geophysical techniques for better understanding of groundwater for humanitarian needs.
• EM31 and TDEM techniques were used to find a better understanding and solution for the cholera outbreaks in Douala, Cameroon.

LOCATION AND ACCESSIBILITY

Fig. 1: Map showing accessible road to Longdi (Google map).

Fig. 2: Geological map of Douala, Cameroon (modified after Njioki Ngaha, 1984).

Fig. 3: Some selected pictures of Londji site 2.
METHODOLOGY

Fig. 4: TEM-FAST device

Fig. 5: Sketch of Londgi site (2) showing the loop

Fig. 6: Map of Londgi site (2) using Map source

RESULTS

Fig. 7: Results of the TDEM

SOUNDING USED USING TDEM AT LONDGI SITE 2

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SAMPLE COLLECTED

- Physical parameters taken from a swamp
- Coordinates: N 607733 E 343756
- Conductivity: 103µs/cm
- Temp: 28.14°C
- pH: 5.28
- Redox: 74.8mV
- DO: 0.97 mg/l = 12.7%
- Resistivity: 9730 Ωcm
- TDS: 51
- Salinity: 0.05

SAMPLE! COLLECTED!
CONCLUSION

• TDEM shows low resistivity and perhaps the existence of a deep aquifer may provide a good solution to develop a new well.

• The results is good for second year of the GWB project in investigating and understanding of the aquifer structures and potentiality of new well field around the city of Douala.
GWB PROJET: Result of Ngombe site

KEMG

PLAN:
- SITE LOCATION
- METHOD AND FIELD WORK
- RESULT

FIELD WORK
- Equipement : EM 31
- Square of ~ 60 x 60 m
- 290 measurements
- Spacing : 3 x 3 m
- EM31 Max depth = 6m

- Equipement : TEM–FAST 48
- Square loop of 40 m for the transmitter/ receiver
- Square loop of 40 m for the transmitter and 10m receiver

RESULT
- Conductivity map at Ngombe site
  - Variogram: Linear
  - Interpolation method: krigging
  - Conductivity ranged from 0.05 to 2 μs/cm

INTERPRETATIONS
- High resistivity
- No free ground water in 6m depth
- MRS GWB(2015) shown 0% of free water for the first 10m depth
- TDEM resistivity values are far from the EM31

SITE LOCATION
- Geological map of study area
- Paleocene formations:
  - clayed -calcareous Schist and gres ferrugineux
- Rainfall of 4200 mm March to December
- Temperature of 27°C/yr

GEOPHYSICAL METHOD:
- Electromagnetic
- Equipment : EM 31
- Shallow investigation
- For mapping
- Equipment : TEM–FAST 48
- Sensitive to conductive layer
- Deeper information

EM 31 RESULT
- Square of ~ 60 x 60 m

TDEM RESULT
- Square loop of 40 m for the transmitter and 10m receiver
- Square loop of 40 m for the transmmitter/ receiver
- TDEM31 Max depth = 2× Loop size = 80

THANKS FOR YOUR KIND ATTENTION
THANK GWB PROJET