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MRS contribution for better understanding the quaternary aquifer of Lake Chad basin in Cameroon

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SUMMARY

In the Far north of Cameroon, the main source of drinking water is the Quaternary sedimentary aquifer. In this semi-arid region, with high population growth, the groundwater resource is affected by climate and land-use changes but also by the impact of Lake Chad level variation. For better quantifying the role of each of these processes, it is necessary to improve our knowledge about aquifer characteristics. Thus, 13 MR soundings were performed in 2012 and 2103 for characterizing hydrodynamic properties of aquifer in the vicinity of the Limani-Yagoua sand-ridge which is considered by many authors as the limit of the Mega-Lake Chad during the last humid period of Holocene (~-6000 years BP).

Despite of difficult conditions of measurement (high natural electromagnetic noise in the afternoon and low Lamor frequency), data of acceptable quality were obtained with a fairly efficient velocity of execution (1 sounding per day). MRS results are in good agreement with available geological logs and with the water levels measured in neighboring wells. They also show high heterogeneity of aquifer characteristics: the water content ranges from less than 2% to 25.5 %, the thickness from 4 to 25 meters and the transmissivity (calibrated with available data in literature) varies from 6×10^{-5} to 1×10^{-4} m^2/s. No water was found within the first 30 m of the Limani-Yagoua sand ridge, confirming the absence of water storage in this formation laid on the regional quaternary aquifer.

During this study, the main limitation for MRS was the depth of investigation (~ 30 meters) with the equipment we employed (Numis Lite). Thus a new field survey is scheduled in March 2015 with more powerful equipment (Numis Plus).

Key words: Sedimentary aquifer, hydrodynamic properties, semi-arid climate, Lake Chad Basin, Far north Cameroon

INTRODUCTION

In semiarid and arid areas, groundwater reserves represent the unique source of drinking water and the main source for human activities. The Sahelian belt is characterized by high demographic pressure and extreme poverty of the population. The economic activities are based on agriculture and livestock farming which increase water needs. Therefore the population exploits groundwater through boreholes and wells.

MacDonald et al. (2012) shown that in Africa, hydrogeological field surveys are rare and sustainable exploitation of the aquifers requires urgent knowledge of available groundwater resources and recharge estimates., Millennium development goals reveal that more than 70% of population in the far north region of Cameroon has no access to potable water (MINEPAT, 2010). Previous works in the area (e.g. Tillement 1970, Ngounou Ngatcha 1993) allowed describing the two main hydrogeological units and their functioning. However, for a quantitative estimate of groundwater flows, more information are required about hydrodynamic properties of the quaternary aquifer. In addition, the hydraulic role of the Limani-yagoua sand ridge that separates the two hydrogeological units is not obvious.

In our study, 13 sites were investigated with MRS for estimating their hydrodynamic properties. MRS results are compared with independent data to check their consistency. Then, the mapping of hydrodynamic properties allows confirming the functioning of the quaternary aquifers and the range of these properties could be used for groundwater modeling.

STUDY AREA

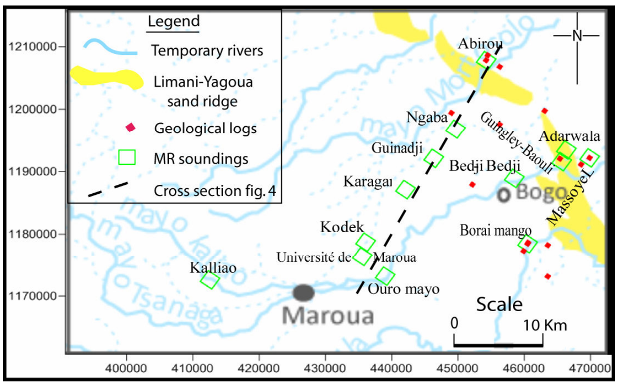

Figure 1: Study area and soundings location.

General settings

The study area (fig.1) is located in the far north region of Cameroon near Maroua City. The topography is characterized by a low slope from south to the sand ridge (0.2%). More in the North, the plain is very flat. This smooth geomorphology is occasionally disturbed by bedrock outcrops called "inselberg". The semi-arid climate is characterized by a long dry season from October to May and a ~5-month rainy season from May to September/October. The annual rainfall is ~900 mm and temperature range from 26 to 35°C.

Hydrogeology

Based on geological logs, previous studies (Tillement, 1970; Ngounou Ngatcha, 1993) evidenced that the quaternary aquifer is composed of two hydrogeological units (Piedmont plain aquifer in SW and Yaéré aquifer in NE). These two units are separated by the so-called "Limani-Yagoua" mega sand ridge. The quaternary formation consists of heterogeneous sequence of sand, clayey sand and sporadically gravel-sands. Aquifer can be impregnated with clay over all its thickness (Pias, 1970). Thus the quaternary aquifer includes several shallow groundwater lenses and a deeper regional aquifer.

Schwoerer et al. (1965) showed that any groundwater exists in; the Limani-Yagoua sand ridge. However the hydraulic function of this geomorphological unit did not found general agreement in scientific community: Biscaldi (1970) considered it like a hydraulic barrier, while, according to Ngounou Ngatcha et al. (2001), it is a permeable formation which allows deeper groundwater recharge.

The recharge of the quaternary aquifer mainly occurs from percolation from surface water and slightly from infiltration of effective rainfall during intensive rain (Tillement, 1970; Ngounou Ngatcha et al. 2007). The major source of discharge is, the evapotranspiration, the human groundwater withdrawal remaining low in the area.

MATERIAL AND METHOD

MRS field set-up

MRS surveys were realized in August 2012 and January 2013 with Numis ^{Lite} equipment from Iris Instruments and NumRun software. The Lamor frequency ranged from 1460 to 1476 Hz, limiting the pulse moment to 3000 A.ms with our equipment (UDC max of 110 V). The ambient electromagnetic noise varied from 200 to 10,000 nV with a 3200 m^2 loop. It was mainly related to natural source (far storm) but also to man-made source on few sites (motors of maize or millet mills and power lines). It is important to note that the electromagnetic noise increased naturally in the afternoon and made MRS measurements impossible after ~2 PM. For minimizing the noise, we used an eight- shape loop composed of two 40-m-side squares. The number of stacks (120 to 280) and pulses moment (10 as first-line) was chosen for optimizing both data quality and duration of acquisition (one sounding per day). Finally, we implemented a total of 13 MR soundings.

MRS inversion and interpretations

The inversion of MRS data was realized with the Samovar software V11.6. It consists of 1) a smooth inversion for getting a general idea of the water content distribution, and 2) a block inversion (1 or 2 layers) for estimating the water table level, the average water content and the transmissivity of aquifer. For this last, we used the usual empirical equation:

$$T_{MRS} = Cp.\Theta_{MRS}.(T_i)^2.\Delta z$$

with T_{MRS} the MRS transmissivity, Ti the decay time (T_1 or T_2*), θ_{MRS} the MRS water content, Δz the thickness of the saturated layer, and Cp a parametric factor which is calculated by comparing T_{MRS} with a pumping test transmissivity. In our case, we chose to use T_2* because the signal was low and do not allow accurately measuring T_1 (such as Vouillamoz et al. 2014). Cp was calculated on two sites where short pumping tests were available in the literature (transmissivity and thickness).

Data were inversed using complex amplitude taking into account the vertical distribution of electrical resistivity and the time variation of geomagnetic field. On Abirou site, we tested if the deep aquifer below a shallow one like suggested by geological log could be resolved with our MRS data. Results (Figure 2) show that neither amplitude nor phase allowed accurately characterizing the deep aquifer.

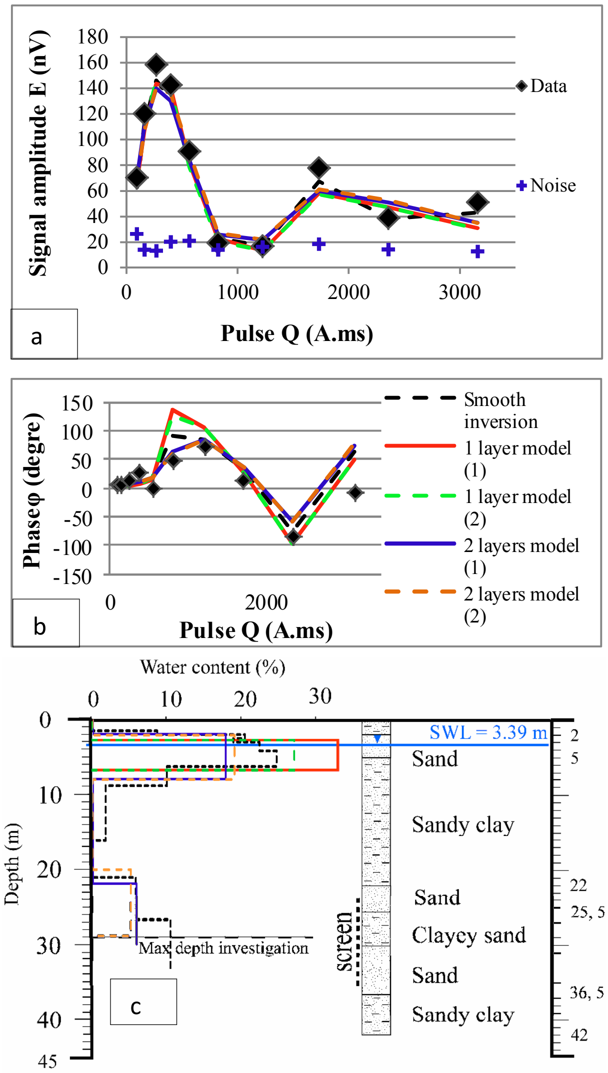

Figure 2: Measured and modeled signal amplitude (a) and phase (b) as a function of pulse on Abirou site (c) Vertical water distribution corresponding to model in (a) and (b) compared to geological log. All models fit data with RMS lower than average noise.

Complementary data

MRS data were compared with geologic logs available in literature and with static water level we measured in wells close to MRS sites. The vertical distribution of electrical resistivity was assessed with the time domain electromagnetic (TDEM) method. Due to the structure of the aquifer with alternation of clayey and sandy layers, TDEM was not able to discriminate each thin layer as shown by geological log and only gave a mean value of resistivity. Descloitres et al. (2013) described similar observation in the eastern part of Lake Chad basin in Niger. Nevertheless, to take in account one equivalent model of resistivity is sufficient for enhancing MRS results (Legchencko et al. 2008).

RESULT AND DSCUSSION

Data quality

Despite difficult measurement conditions, we manage to drop the noise down to 14 nV in average. However due to low signal only 5 among the 13 MR soundings have signal to noise ratio (S/N) higher than 1.5 (S/N ranges from 3.6 to 0.8). The hydrodynamic properties were estimated for soundings with SN > 1.5 and for the others soundings, we computed the maximum possible water content (table 1).

The main limitation of MRS is the pulse moment that could not exceed 3000 A.ms thus reducing the depth investigation to ~30 meters in our field condition. Thus, the bottom of aquifer cannot be well estimated for most of the sites.

Comparison of MRS results with water levels in wells

The top of aquifer estimated by MRS are generally in good agreement with the static water level (SWL) measured in wells (Fig. 3). In two sites the MRS top of aquifer is slightly shallower than SWL in wells which could be explained by presence of capillary water above SWL that is detected by MRS (Vouillamoz et al 2014).

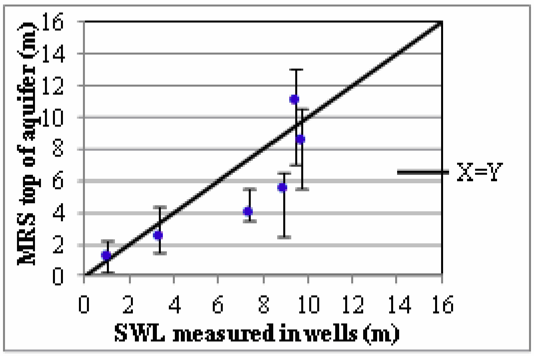

Figure 3: MRS top of aquifer versus static water level.

In addition, the dry wells in the field correspond to soundings with very low MRS signal (Ngaba θ_{MRS} <2%; Kalliao θ_{MRS} <5%).

Characterization of spatial heterogeneity

Water content ranged from less than 2 to 25.5%. These ranges of values are comparable to those obtained by Boucher et al. (2012) and Descloitres et al. (2013) in Kadzell plain and and in Komadugu valley (eastern part of Lake Chad basin). The highest MRS water contents are recorded near the seasonal river (Aboirou and Ouro-mayo). The lowest water content are observed (1) in sites where geological information suggested a more clay impregnation in certain part of piedmont plain (eg. Ngaba), (2) and no shallow groundwater in the Limani-Yagoua sand ridge (e.g. Guingley-Baouli). Both lateral and vertical heterogeneities in the distribution of water content against depth are observed (fig. 4).

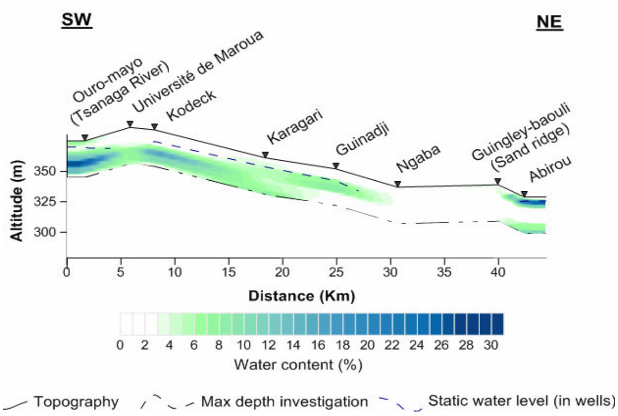

Figure 4: MRS water content cross-section.

The thickness of aquifer ranges from 4 to 26 m and the transmissivity varies from 2×10^{-5} to $1 \times10^{-4} m^2/s$ (5 sites). These parameters are also contrasted and confirm the heterogeneity of the sedimentary quaternary aquifer already shown by Ngounou Ngatcha (1993). These values are comparable to those obtained in Kadzell plain and Nigerien part of Komadugu valley of Lake Chad basin by Boucher et al. (2012) and Descloitres et al. (2013).

Note that the calibration factor we used for the estimate of transmissivity ($Cp = 9.7\times10^{-10}$) need to be better calibrated because it was obtained with only two very short pumping tests (< 6 hours) that gives different results (table 1).

Consequence on the aquifer functioning

The distribution of MRS water content (fig. 4) confirms the existence of shallow groundwater of local importance such as described by Tillement (1970). These shallow aquifers are separated by clay impregnation, like near Ngaba where the barren zone was already described by Tillement (1970).

Low values of water content are sometimes observed in the vicinity of seasonal rivers (e.g. Ngaba, Boraï-mango, and Guingley-baouli). These evidences that rivers do not always communicate with groundwater along its whole course such as often mentioned in hydrogeological models in semi-arid sedimentary context.

The two MRS soundings located on Limani-Yagoua sand ridge (Guingley-baouli and Adarwala) did not show any groundwater for our investigation depth (around 30 m). This confirms previous observations (e.g. Schwoerer et al. 1965), but does not allow determining the role of the sand ridge formation. To know if it is a hydraulic barrier as assumed by Biscali (1970) or a permeable zone with deep infiltration as mentioned by Ngounou Ngatcha et al. (2001), MR soundings with deeper investigation zone are required.

CONCLUSION AND OUTLOOKS

In the far North Cameroon, MRS data of acceptable quality (mean noise ~14 nV corresponding to 2% of water content) were obtained although measurement conditions in tropical area are difficult. The results are in good agreement with independent data and allow:
1) determining the range of hydraulic parameters: Water content ranged from less than 2 to 25.5%; Thickness ranged from 4 to 25m; Transmissivity ranged from 2×10^{-5} to 1×10^{-4} m^2/s; (2) confirming the existence of shallow groundwater of local extension; (3) showing that rivers are often a recharge area for groundwater but not always as frequently assumed in hydrogeological models in semi-arid sedimentary context; (4) confirming the absence of groundwater within the 30 first meters of Limani-yagoua sand ridge

Based on these promising results, additional measurements will be carried out 1) to investigate the aquifer more in depth (more powerful equipment) and in a larger area (including Yaéré aquifer) 2) to better calibrate the MRS transmissivity (long pumping tests).

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MRS location	S/N	θ_{MRS} (%)	SWL (m)	MRS SWL (m)	Noise (nV)	Thickness (m)	Cp	T_{MRS} (m^2/s)
Abirou	3.67	33	3.39	2.39	13.4	4	/	6.7E-05
Ouro mayo	2.31	13.5	5.12	1.2	12.9	21.2	/	1.3E-05
Massoyel	1.27	9.5	6.75	28	11.7	/	/	
Borai mango	1.03	< 2.5	13.49	dry	14.2	/	/	
Kalliao école	0.87	< 5	dry	dry	33.2	/	/	
Kodek école	1.52	9	9.49	11	12.9	17.6	1.7E-10	2 E-05
Université de Maroua	1.34	13	/	17.1	11.4	11	/	/
Karagari	2.55	5.4	7.46	4	10.3	25.9	/	6.3E-05
Guinadji	1.75	6.7	9.75	8.5	12.4	15.6	5.4E-09	6.9E-05
Ngaba	1.27	< 2.3	sec	dry	13.5	/	/	
Darwala	1.13	<4.5	19.05	dry	14.2	/	/	
Guinley-Baouli	0.99	< 2	/	dry	15	/	/	
Bedji-bedji	1.81	4.4	8.9	5.5	14.8	24.6	/	1 E-04

Table 1. MRS results and static water levels from field measurements.