Quantifying groundwater storage in African hard rock aquifers:
comparison of the first results obtained in Benin, Burkina Faso and Uganda

Vouillamoz, J.M.[(1)]; Lawson, F.M.A.[(1)(2)]; Yalo, N.[(2)]; Koita, M.[(3)]; Owor, M.[(4)], Okullo, J.[(4)]; Tindimungaya, C.[(5)]

[(1)] IRD/UJF-Grenoble-1/CNRS/G-INP – UMR LTHE; [(2)] Université d'Abomey-Calavi/Institut National de l'Eau, Benin; [(3)] Fondation 2iE, Burkina Faso; [(4)] Makerere University, Uganda; [(5)] Water Resources Management Directorate, Uganda

Introduction

➔ **Groundwater plays a major role in supplying domestic water** to millions of people in Africa. In future, the ability to increase reliable water supplies for domestic and possibly irrigation purposes will depend on groundwater development.

➔ **Groundwater storage is a key property** because it controls the buffering behaviour of an aquifer: the greater the groundwater storage, the higher the buffering capacity of the aquifer (other variables being constant) and the slower the impact of changes caused by variation in pumping, recharge or evapotranspiration.

➔ **Quantitative knowledge of groundwater storage in Africa is very limited** (MacDonald et al., 2012). This lack of knowledge is a major concern in hard rocks, which cover about 40% of the surface area of Africa.

➔ Groundwater storage in unconfined aquifers is calculated by **multiplying the saturated thickness with the specific yield**. Data regarding saturated thickness are available from numerous boreholes drilled in Africa during recent decades (e.g. Courtois et al., 2010; Vouillamoz et al., this conference). However, **reliable quantification of specific yield is rarely, if ever, carried out for routine work in Africa** because it requires the drilling of several boreholes and the setup of long-duration pumping experiments.

➔ This poster presents **the first results of the application of the Magnetic Resonance Sounding** (MRS) geophysical method for assessing groundwater storage in different types of hard rocks in 3 African countries.

Materials and Methods

➔ The major advantage of MRS as compared to other geophysical methods is that MRS is **a direct measurement of groundwater** (Legchenko and Valla, 2002). In this study, we used the NumisPlus® apparatus from Iris Instruments (Fig. 1) with a transmitter/receiver loop of large surface area (i.e. a square shape of 100m length per side on average), thus **investigating a large aquifer volume** of about 130m x 130m of surface area times 70m in depth. The total duration of a sounding usually lasted two (2) to three (3) days.

➔ New development in the application of the MRS method makes it possible to **estimate specific yield from MRS results** with an uncertainty of about 20% (Vouillamoz et al., 2012; 2014). Groundwater storage can thus be calculated as the product of **specific yield and saturated thickness derived from MRS results** (Vouillamoz et al., 2015).

➔ To quantify specific yield and groundwater storage, **MRS results have first to be parameterized**. Thus, we setup 6 experimental sites in Benin, 4 in Burkina Faso and 1 in Uganda where long duration pumping experiments and MRS have been carried out (Fig. 2). From the comparison of pumping tests and MRS results, conversion equations between MRS output parameters and hydrogeological properties will be defined (Vouillamoz et al., 2014).

➔ Subsequently, we carried out a total of **72 MRS in several hard rocks group** in Benin, Burkina Faso and Uganda (Fig. 3). At every location, groundwater storage will be calculated using the conversion equation obtained at the experimental sites.

Figure 1: MRS measurement in Benin

Figure 2 : Pumping test experiments in Benin

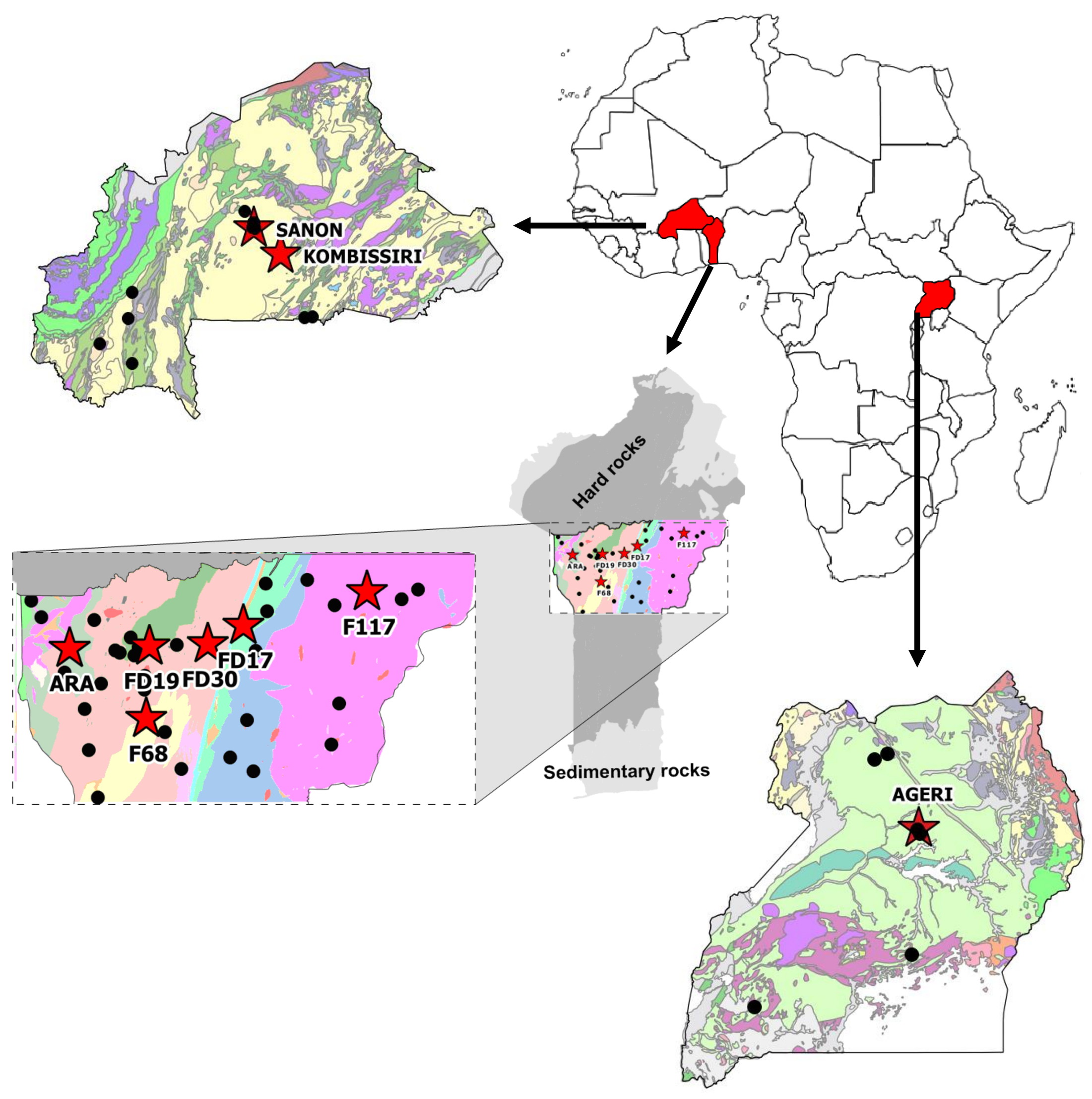

Figure 3: Location of study areas for experiments and simplified geological maps (colors are the different hard rock groups)

Results and discussion

➔ Firstly, we compare unparameterized groundwater storage calculated in gneisses/migmatites rocks, granitoids and volcano-sedimentary rocks respectively (Fig. 4). **Gravitational water is differentiated from undrainable water** based on the properties of the MRS signal (Vouillamoz et al., 2015). The results are similar in the three countries: storage in gneisses/migmatites is on the higher end (50% of the values range within 650 and 1,400 mm) whereas storage in granitoids is on the lower end (50% of the values range within 140 and 270 mm). Although water is present in the volcano-sedimentary rocks, the storage is about zero since most of the groundwater is probably undrainable.

➔ The drainable groundwater storage is only quantified in Benin since parameterization of the MRS signal has not yet been completed in Burkina Faso and Uganda (Fig. 5). Our findings show that **the median storage is 540 mm and 380 mm** in gneisses/migmatites and granitoid, respectively. We also confirm that **the storage in volcano-sedimentary rocks is almost null** (Vouillamoz et al., 2015).

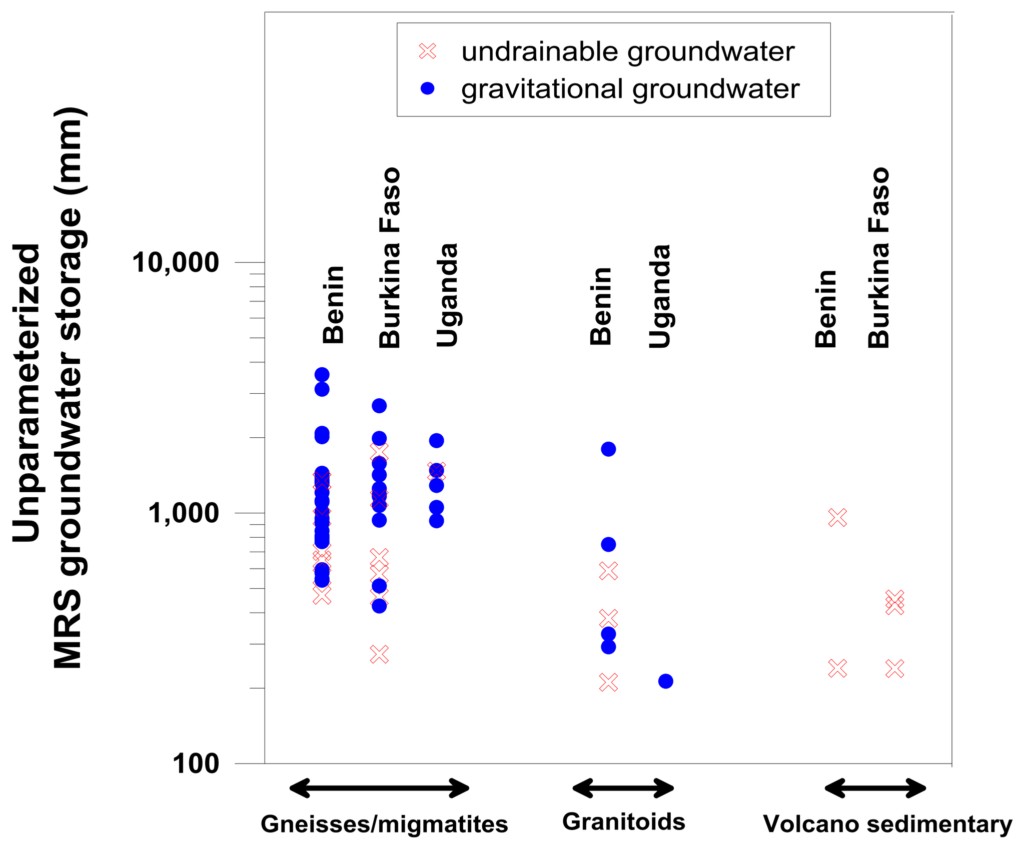

Figure 4 : Unparameterized MRS groundwater storage

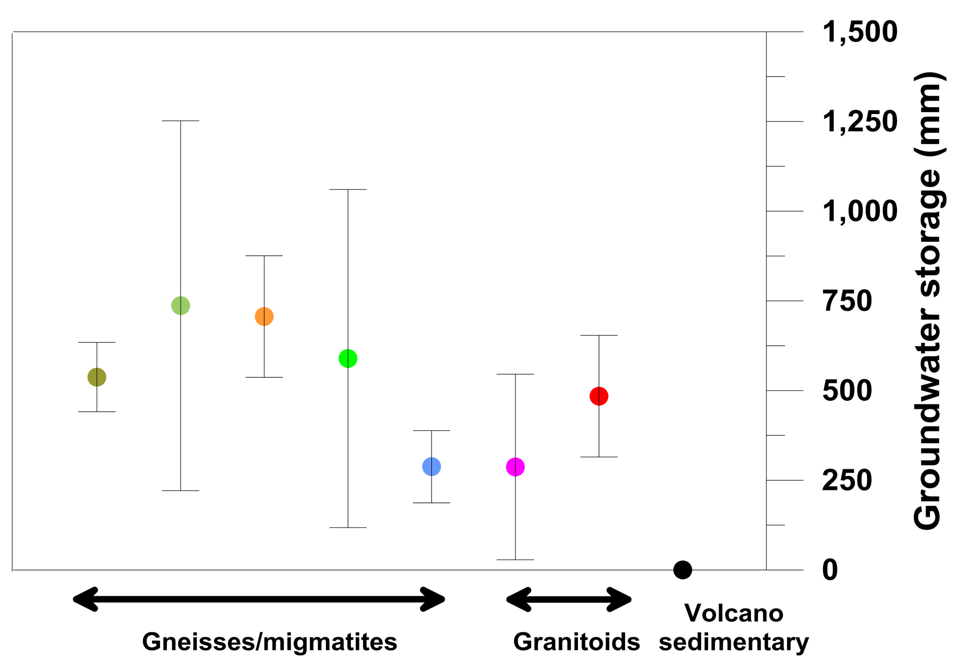

Figure 5 : Drainable groundwater storage in Benin vs geological units (modified from Vouillamoz et al, 2015)

Conclusion and perspectives

➔ Parameterization will be completed in Burkina Faso and Uganda, and **conversion functions found in the three countries will be compared**.

➔ **MRS has proven its interest for quantifying drainable groundwater storage** in deep weathered hard rocks.

➔ The same approach will be used for assessing how **MRS can quantify transmissivity of hard rock aquifers**.

References

Courtois, N., Lachassagne, P., Wyns, R., Blanchin, R., Bougaïré, F.D., Somé, S., Tapsoba, A., 2010. Large-scale mapping of hard-rock aquifer properties applied to Burkina Faso. Ground Water 48, 269–283.

Legchenko, A., Valla, P., 2002. A review of the basic principles for proton magnetic resonance sounding measurements. J. Appl. Geophys. 50, 3–19.

MacDonald, A.M., Bonsor, H.C., Dochartaigh, B.É.Ó., Taylor, R.G., 2012. Quantitative maps of groundwater resources in Africa. Environ. Res. Lett. 7, 024009.

Vouillamoz, J.M., Sokheng, S., Bruyere, O., Caron, D., Arnout, L., 2012. Towards a better estimate of storage properties of aquifer with magnetic resonance sounding. Journal of Hydrology 458–459, 51–58. doi:10.1016/j.jhydrol.2012.06.044.

Vouillamoz, J.M., Lawson, F.M.A., Yalo, N., Descloitres, M., 2015. Groundwater in hard rocks of Benin: Regional storage and buffer capacity in the face of change. J. Hydrol. 520, 379–386. doi:10.1016/j.jhydrol.2014.11.024

Vouillamoz, J.M., Lawson, F.M.A., Yalo, N., Descloitres, M., 2014. The use of magnetic resonance sounding for quantifying specific yield and transmissivity in hard rock aquifers: The example of Benin. J. Appl. Geophys. 107, 16–24.

Vouillamoz, J.M., Tossa, A.Y.A., Chatenoux, B., Kpegli, K.A.R., 2015. Propriétés des aquifères de socle du Bénin: analyse multi-variables et multi-échelles des paramètres de contrôle. « Aquifères de socle : le point sur les concepts et les applications opérationnelles » La Roche-sur-Yon, juin 2015.

Acknowledgments

This work was conducted within the framework of the GRIBA project (Groundwater Resources In Basement rocks of Africa) funded by The African Union, The European Union, and the Institut de Recherche pour le Développement (grant AURG/098/2012). The content of this paper is the sole responsibility of the authors and can under no circumstances be regarded as reflecting the position of The European Union or The African Union. This work also benefited from the occasional support of the AQUI BENIN JEAI project.

Vingtièmes journées techniques du Comité Français d'Hydrogéologie de l'Association Internationale des Hydrogéologues.
« Aquifères de socle : le point sur les concepts et les applications opérationnelles » La Roche-sur-Yon, juin 2015