Geochemical footprints in groundwaters of Uganda: a national-scale analysis

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Rationale

- groundwater represents a vital source of freshwater to meet distributed, rapidly rising demands for safe drinking water, irrigation and industry in low-income countries across the tropics;
- intrinsic quality of groundwater derived from natural processes can act as a major impediment to the use and adoption of groundwater as a source of freshwater on both health and aesthetic grounds;
- here, we characterize observed relationships between shallow (<20 mbgl) groundwater chemistry from 3721 sites (selected from a database of >30,000) and mapped lithologies of main aquifer environments to identify predominant water-rock interactions determining baseline groundwater quality;
Geology of Uganda grouped into 7 broad categories:

A - Meta-sediments;
B - Volcanics;
C - Cataclasites;
D - Granites;
E - Metamorphics;
F - Meta-igneous;
G - Sediments;

+ hydrochemical sample location
• sampled groundwaters are mostly shallow (69% of samples from depths of <20 mbgl);

**colour codes refer to mapped geological environment (majority are E: metamorphic)**

(a) depth (mbgl) to bedrock  
(b) static water levels (mbgl) on well completion
• generally low well yields (82% <3.6 m$^3$·h$^{-1}$), <1.8 m$^3$·h$^{-1}$ in crystalline basement in Africa, MacDonald et al. (2012); specific capacity (84% <5 m$^2$·d$^{-1}$);
• inferred low $T$ and storage serve to regulate naturally groundwater withdrawals, inhibiting overdevelopment;

(a) estimated yield (m$^3$·h$^{-1}$) from groundwater sources 
(b) estimated specific capacity (m$^2$·d$^{-1}$) on well completion
• predominance bicarbonate (HCO$_3^-$) anionic facies in 95% of samples;
• \( \text{SO}_4 \)-rich and \( \text{Cl} \)-rich anionic facies associated with mineralized intrusions, volcanic eruptions, geothermal waters and wetlands (Lake Victoria Management Zone);
- extended Durov plots of groundwater samples indicate importance of cation-exchange processes where Na$^+$ replaces Ca$^{2+}$ and Mg$^{2+}$;

pH commonly (6-8) and EC <1000 µS·cm$^{-1}$;
Gibbs (1970) plots of all groundwater samples show the dominance of water-rock interactions as controlling factors over evaporation and precipitation;

(a) TDS vs. Na\(^+\)/(Na\(^+\) + Ca\(^{2+}\));  (b) TDS vs. Cl\(^-\)/(Cl\(^-\) + HCO\(_3\)^-)
groundwater chemistry dominated by silicate weathering - leading to problems of excessive Fe and Mn where weatherable minerals (e.g. micas) bearing these elements occur;
Summary

- At the time of drilling groundwater across Uganda is generally fresh with TDS <8% threshold exceedance of WHO (2011); pH is commonly neutral (6-8) and EC <1000 µS·cm⁻¹;

- Dominance of HCO₃ facies in groundwaters across all lithological categories (95%) reflecting localized flow conditions commonly found in these discontinuous aquifers;

- Key hydrogeochemical controls include cation exchange and to a lesser extent evaporation and precipitation of salts;

- Natural groundwater chemistry at well completion can be expected to support rising freshwater demand for irrigation, safe major chemical drinking water and industry;

- Need to assess how human activity (e.g. land-use change) and effluent (e.g. faecal waste) impact on groundwater quality.
Thank you