

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

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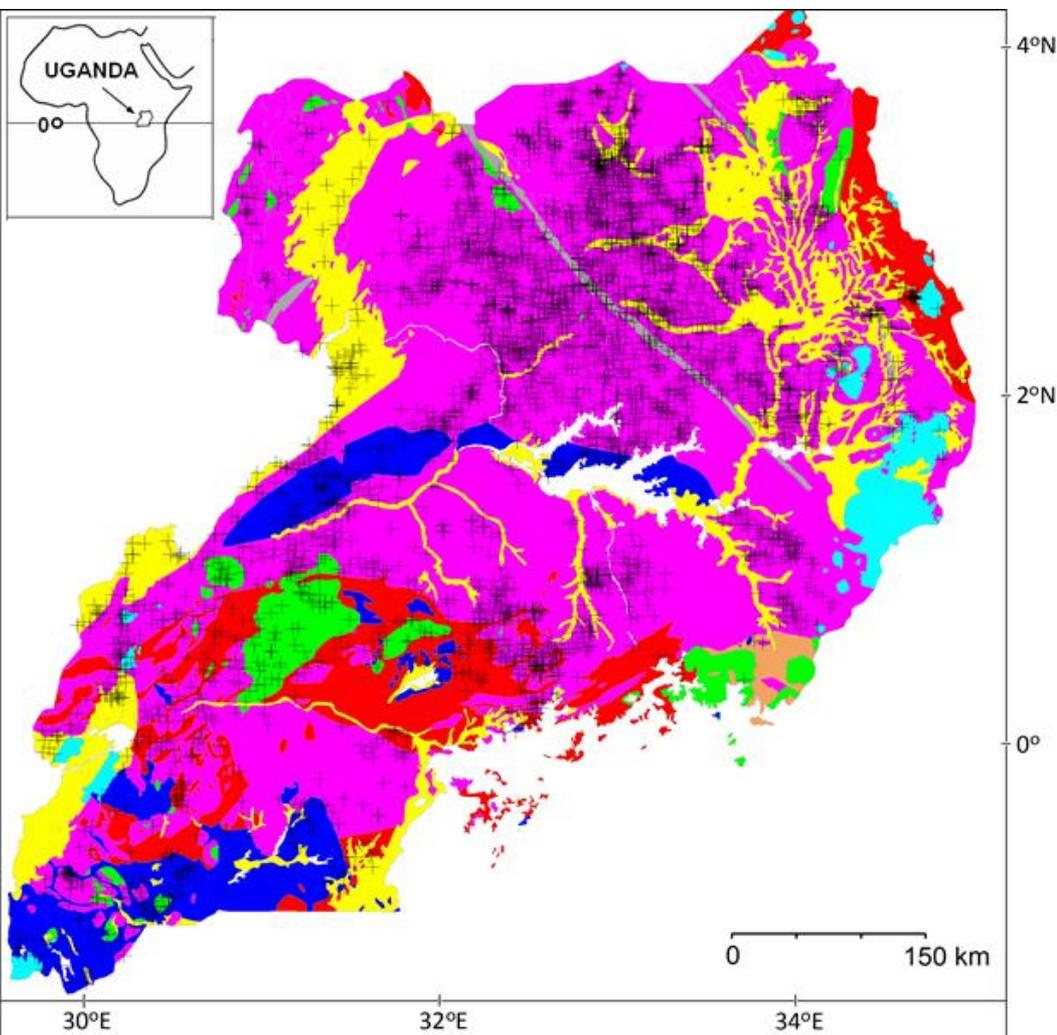
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# Rationale

- 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:

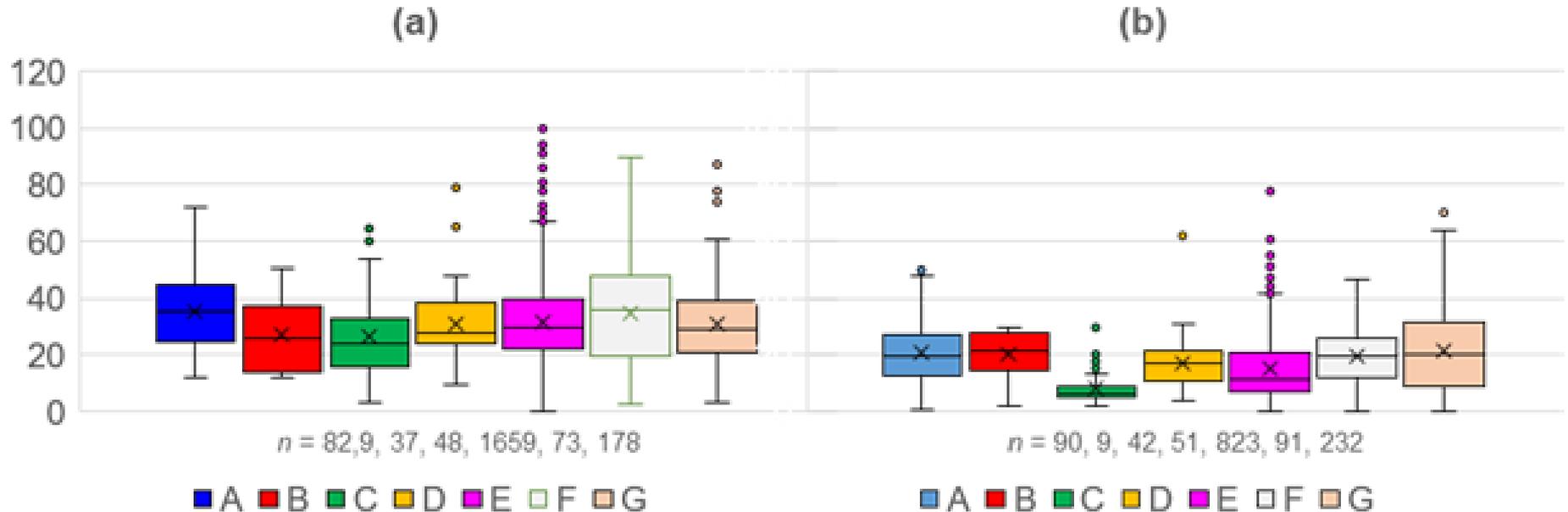
- A - Meta-sediments;
- B - Volcanics;
- C - Cataclasites;
- D - Granites;
- E - Metamorphics;
- F - Meta-igneous;
- G - Sediments;

+ hydrochemical sample location

- A:** K-A: Argillites & arenites with some basal metacalcareous rocks; S: Conglomerates, sandstones & subordinate shale; M-B: Sandstones, arkoses, conglomerates & silified rocks; KR: Shales; B-K: Shales, arkoses & quartzites; NZ: Metavolcanics, banded ironstones, cherty quartzites & greywackes;
- B:** TC: Carbonatite & syenite; P11: Volcanic rocks; T: Volcanic rocks & associated sediments;
- C:** CM: Cataclasites;
- D:** GZ: Granitoid & highly granitized rocks; G: Mobilized & intrusive granites;
- E:** A: Banded gneisses; W: Granulites facies, charnokites, enderbites & retrograded derivatives; MR: Mirian gneisses; GC: Undifferentiated gneisses & granulite facies;
- F:** KS: Acid gneisses, amphibolites, quartzites, marbles & granulite facies; BT: Phyllites & schists with basal quartzites & amphibolites; M: Schists, quartzites, marbles & gneisses;
- G:** P1R: Rift valley Sediments; P12: Sediments, alluvium, black soils & moraines;

- sampled groundwaters are mostly shallow (69% of samples from depths of <20 mbgl);

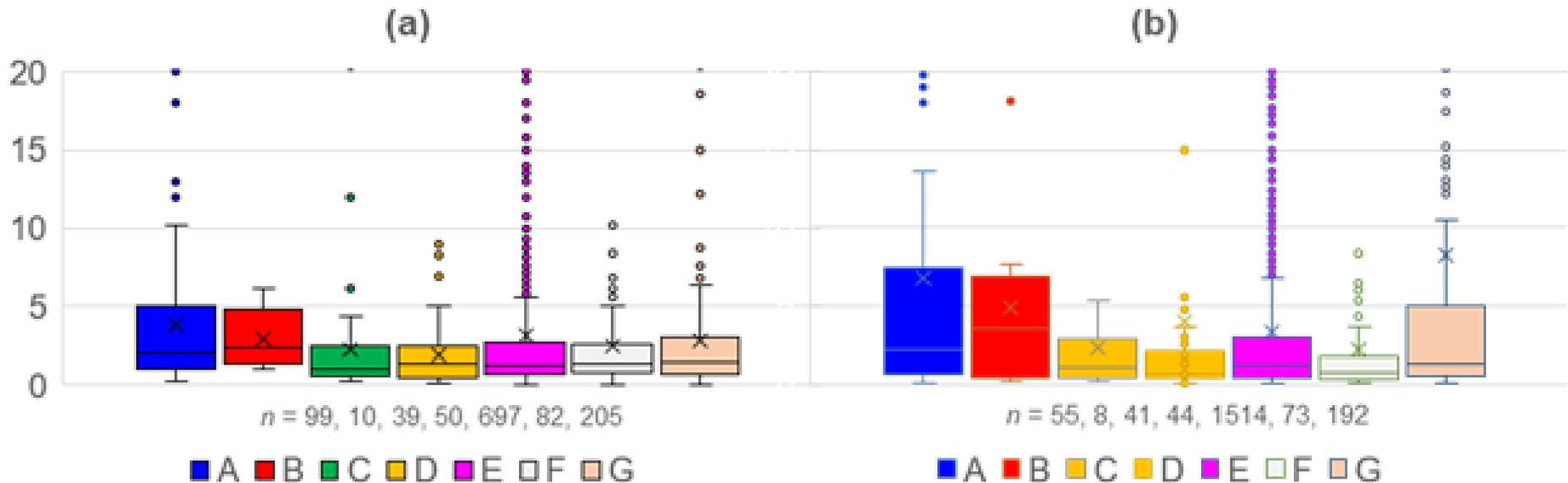
***colour codes refer to mapped geological environment (majority are E: metamorphic)***



(a) depth (mbgl) to bedrock

(b) static water levels (mbgl) on well completion

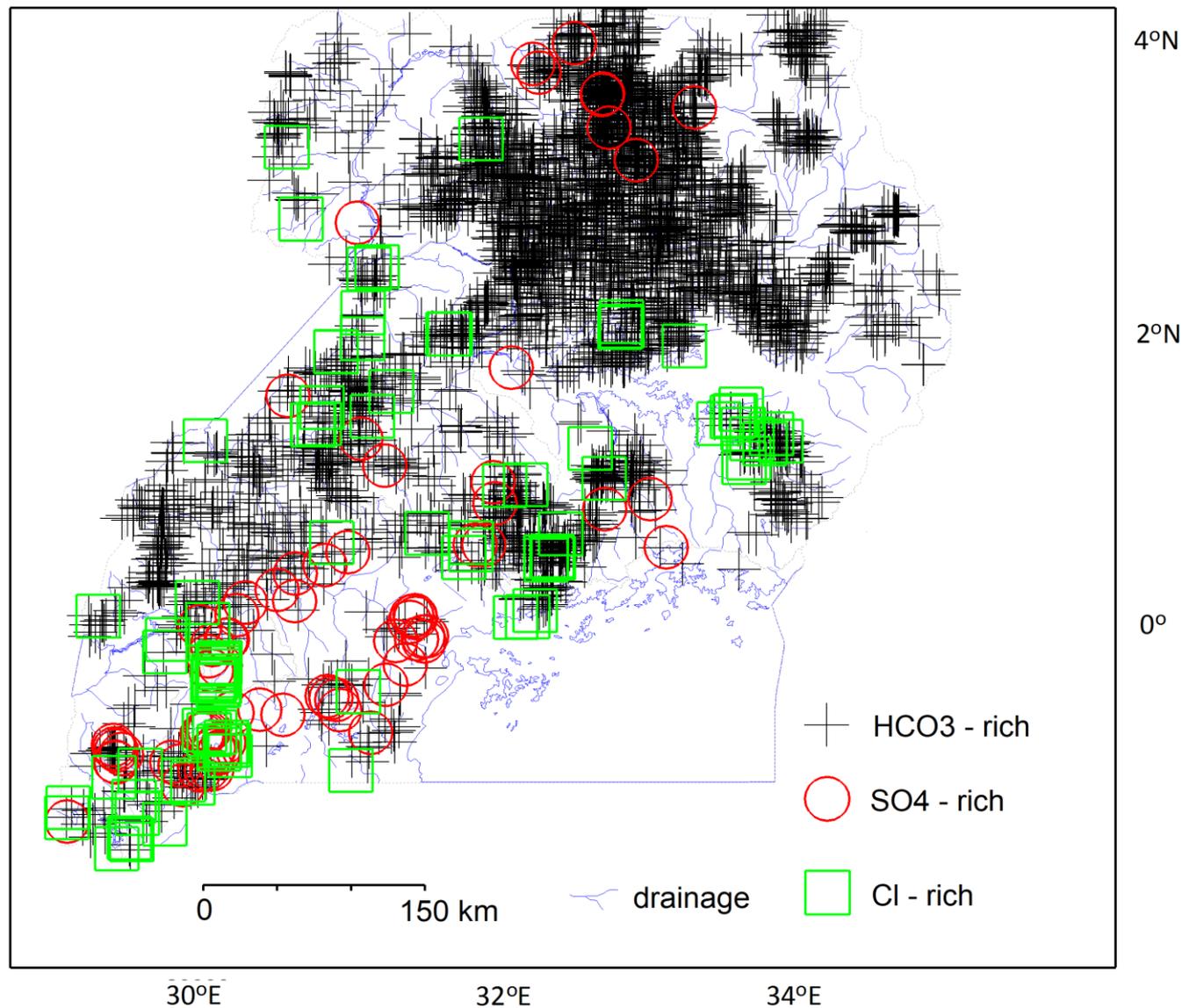
- generally low well yields ( $82\% < 3.6 \text{ m}^3 \cdot \text{h}^{-1}$ ),  $< 1.8 \text{ m}^3 \cdot \text{h}^{-1}$  in crystalline basement in Africa, MacDonald *et al.* (2012);
- specific capacity ( $84\% < 5 \text{ m}^2 \cdot \text{d}^{-1}$ );
- inferred low  $T$  and storage serve to regulate naturally groundwater withdrawals, inhibiting overdevelopment;



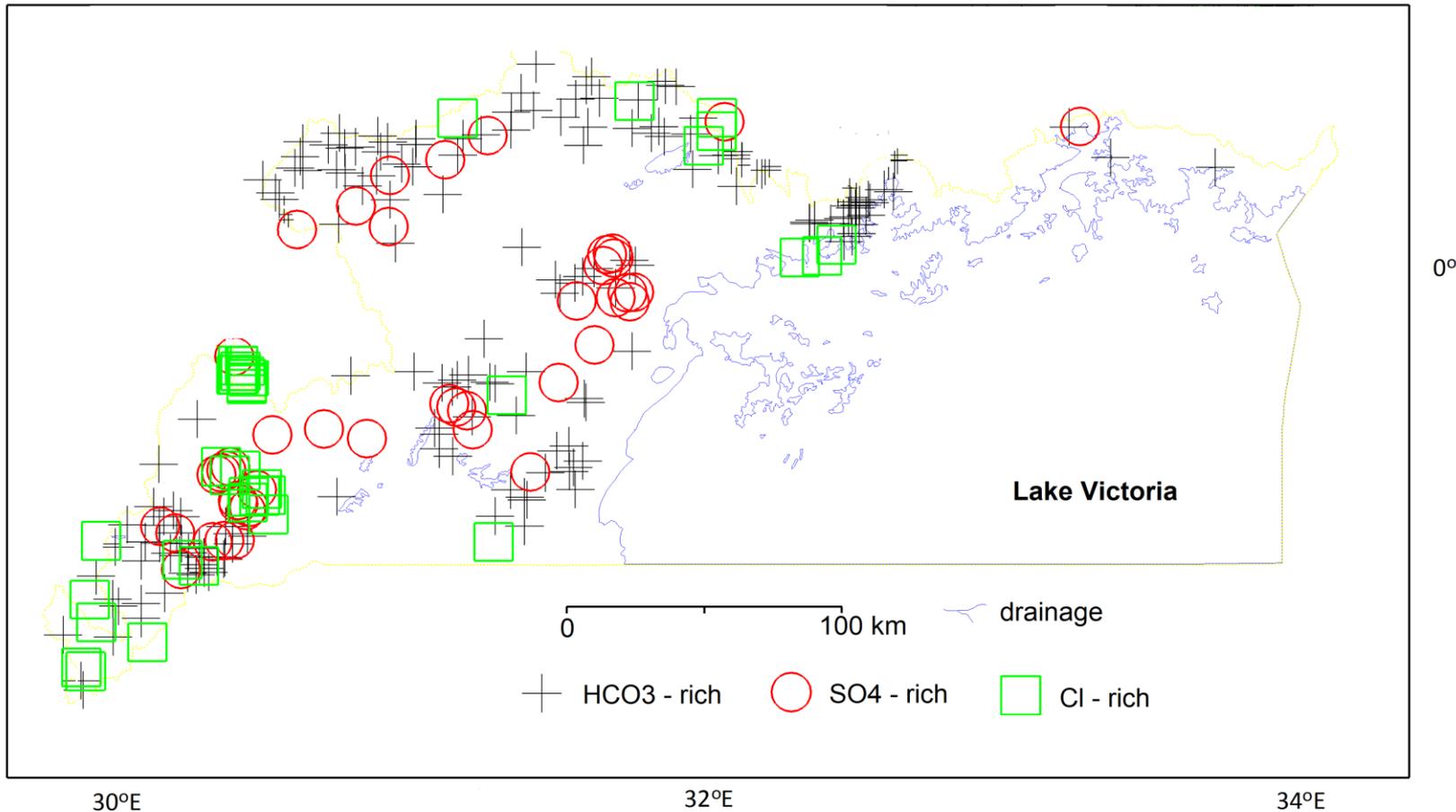
(a) estimated yield ( $\text{m}^3 \cdot \text{h}^{-1}$ ) from groundwater sources

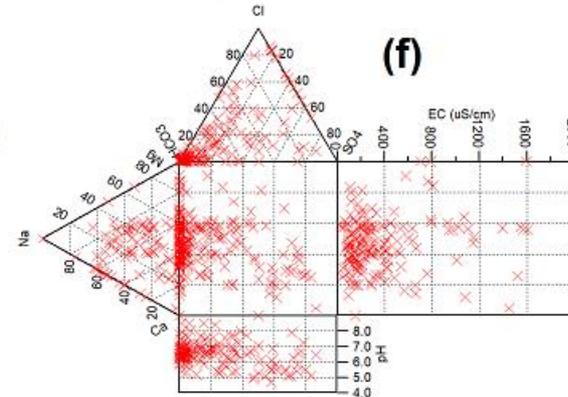
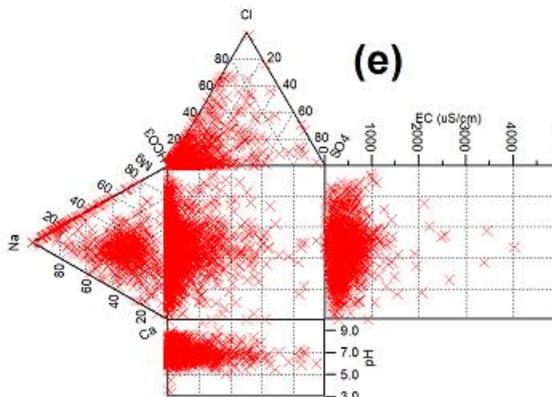
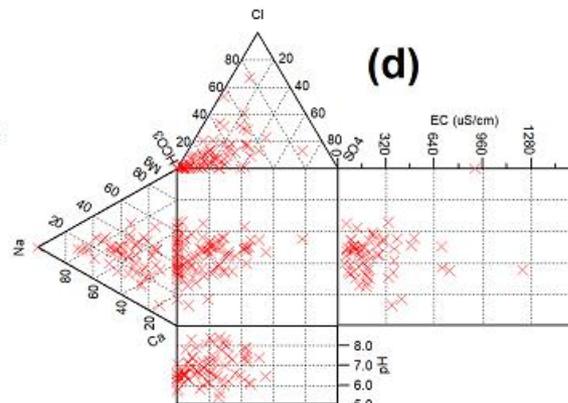
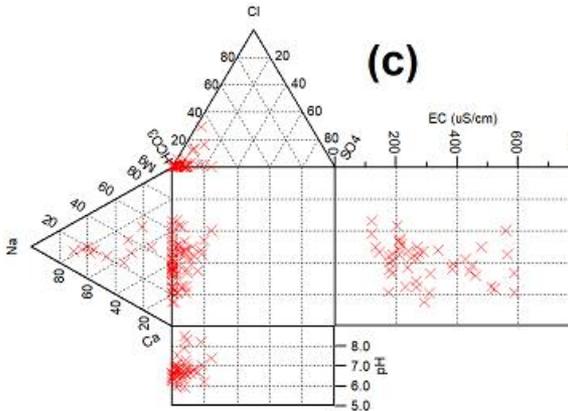
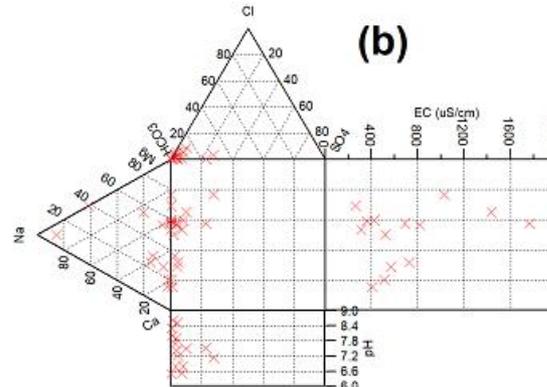
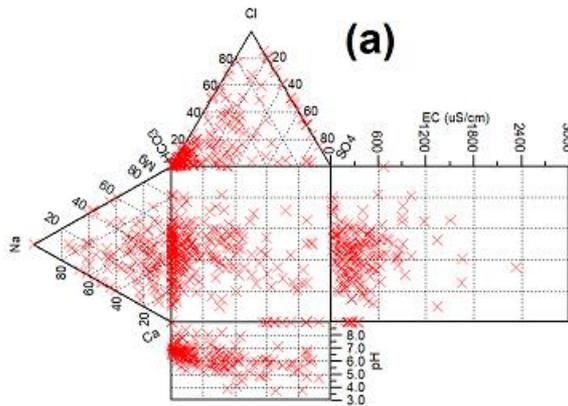
(b) estimated specific capacity ( $\text{m}^2 \cdot \text{d}^{-1}$ ) on well completion

- predominance bicarbonate ( $\text{HCO}_3^-$ ) anionic facies in 95% of samples;



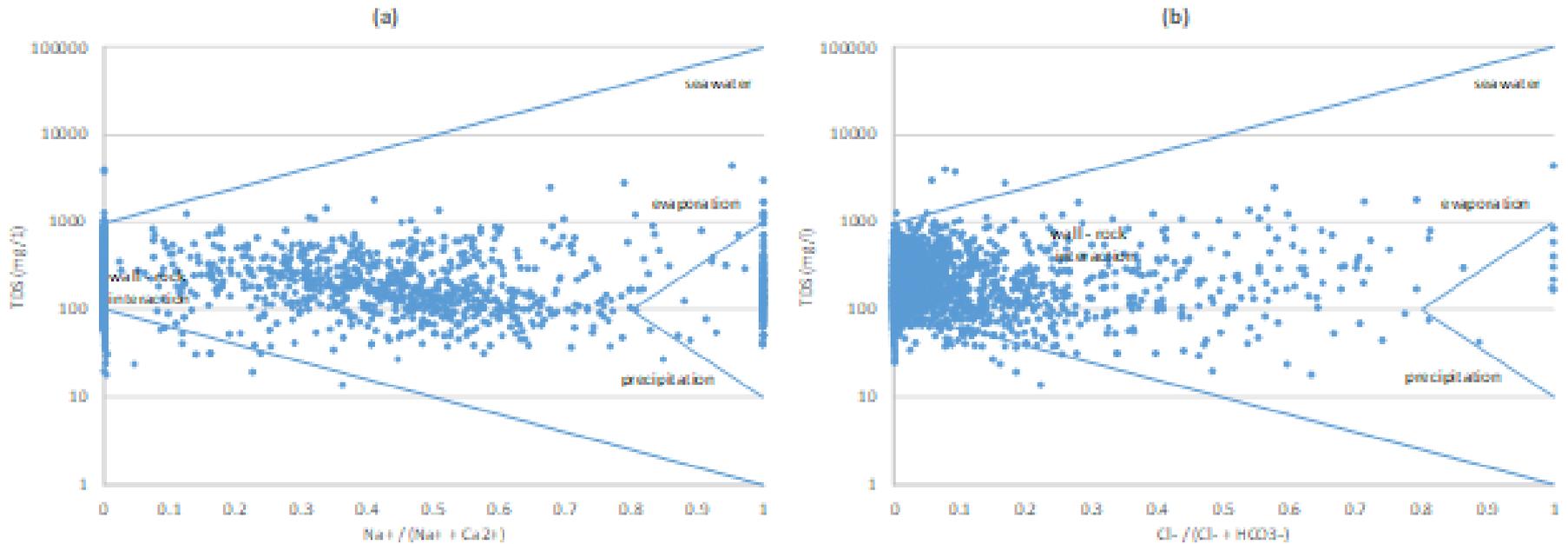
- $\text{SO}_4$ -rich and Cl-rich anionic facies associated with mineralized intrusions, volcanic eruptions, geothermal waters and wetlands (Lake Victoria Management Zone);



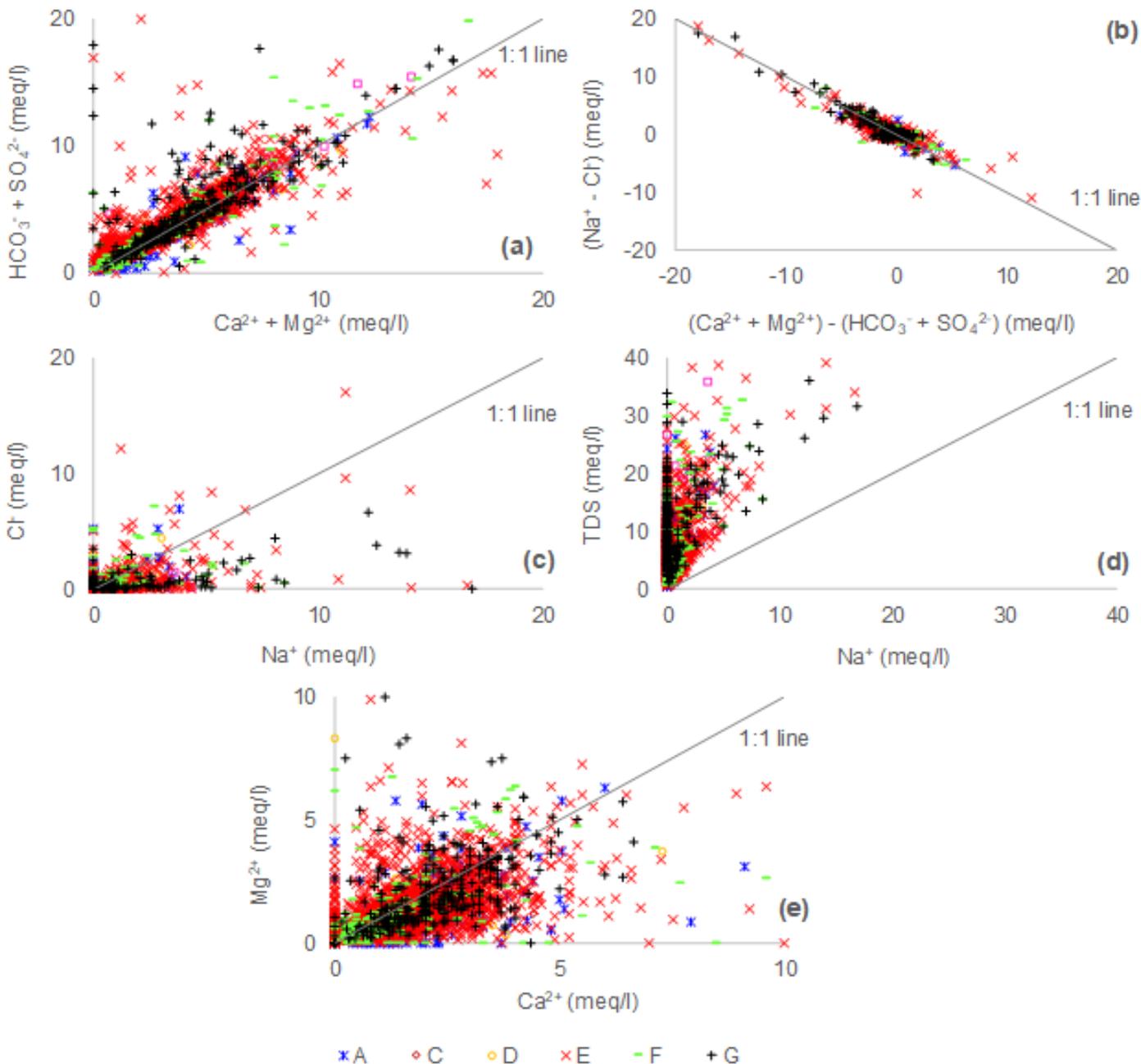


- extended Durov plots of groundwater samples indicate importance of cation-exchange processes where  $\text{Na}^+$  replaces  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ;
- pH commonly (6-8) and EC  $< 1000 \mu\text{S}\cdot\text{cm}^{-1}$ ;

Gibbs (1970) plots of all groundwater samples show the dominance of water-rock interactions as controlling factors over evaporation and precipitation;



(a) TDS vs.  $\text{Na}^+ / (\text{Na}^+ + \text{Ca}^{2+})$ ; (b) TDS vs.  $\text{Cl}^- / (\text{Cl}^- + \text{HCO}_3^-)$



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  $\mu\text{S}\cdot\text{cm}^{-1}$ ;
- dominance of  $\text{HCO}_3$  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**

