Hydrogeochemical characterization of the southern sector of the Guarani Aquifer System

Insights into Flow Dynamics and Mixing Processes

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INTRODUCTION

Transboundary aquifers hold critical importance in the realm of global water security and sustainable development. The Guarani Aquifer System (SAG) spans across Brazil, Argentina, Paraguay, and Uruguay, and is used as water supply for more than 15 million people. It exhibits a complex architecture influenced by basin framework and geological structures that segment the aquifer into four large compartments. The conceptual model depicts a regional flow from north to south (LEBAC, 2008).

The Southern compartment is characterized by greater influence of geological structures and marked stratigraphic heterogeneities, compared to the outcrop in the northern areas. Shallower hydraulic heads in Brazilian territory represent greater hydraulic connectivity, while in Argentina the SAG is almost fully confined (Fig. 1).

Vertical mixing with overlaying and underlying aquifers leads to the increase in SO_4, F^-, Fe and Mg concentrations in the SAG. Despite this process has been widely characterized (Gonçalves *et al.* 2020; Teramoto *et al.* 2020), the quantification of mixing proportions is restricted.

This study aims to characterize geochemically and isotopically the southern sector of the SAG in Brazil and Argentina, quantifying the vertical mixing proportions.

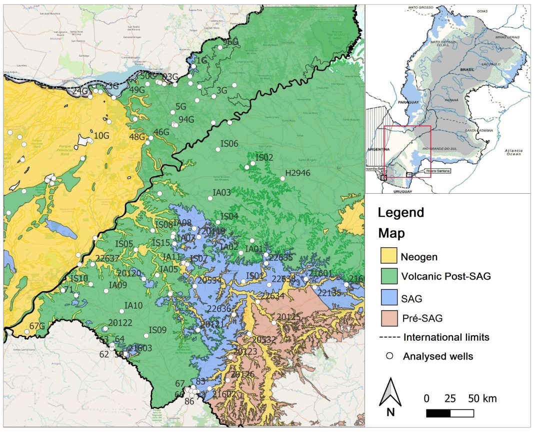

Figure 1. Study area with the analysed wells.

METHODS

- Hydrochemical and isotopic characterization of the Southern compartment of the SAG through traditional diagrams (Piper and stable isotope plotting), using a large database with a total of 157 analyses.
- Quantification of mixtures through End Member Mixing Analysis (EMMA).

RESULTS

Waters are generally low mineralized, with calcium carbonate facies being the most abundant (80%). The presence of sulfate and chloride facies indicates mixing with older formations.

The comparison with stable isotopes end members identified by Ortega *et al.* (2022) reveals a good agreement with well characteristics and relative geographic positions (Fig. 2)

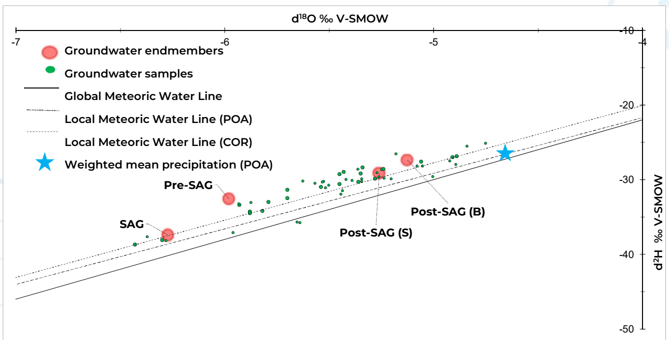

Figure 2. Stable isotope plot and end-members defined by Ortega *et al.* (2020).

Principal component analysis identified four eigenvectors (EVs) that explain 85% of the total variance, linking them to four distinct water types. EV1 represents highly saline groundwater from deep wells, enriched in sulfates. This end-member is represented by a deep well (1050 m) overpassing the SAG lithology, contributing to sulfate enrichment. EV3 represents the typical evolved SAG water (Facies E), characterized by relatively depleted $\delta^{18}O$, high alkalinity, marked pH values, and a geochemical evolution towards the Na-HCO3 facies. EV2 and EV4 are associated with low-mineralized waters. EV2 presents the chemical contribution from the volcanic post-SAG formation, marked by Ca-Mg loading. EV4 represents the less evolved SAG waters (Facies R), with chemical and isotopic signature indicating recent recharge. Both end-members have $\delta^{18}O$ signatures close to recent precipitation.

The PCA eigenvalues were projected into the space defined by the EVs to select end-members and define mixing trends (Fig. 3).

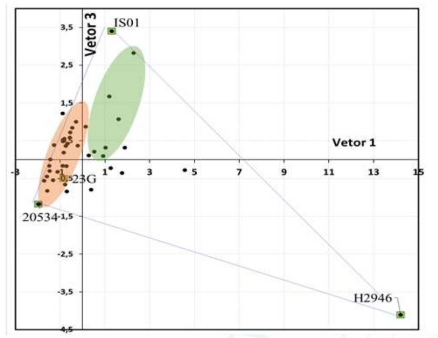

Figure 3. Groundwater mixing trends. RED: binary mixture of recente and more evolved SAG groundwaters. GREEN: ternary mixture with the Pre-SAG end-member.

CONCLUSIONS

Comparison with findings by Ortega *et al.* (2022) revealed similar isotopic signatures but less evolved water facies in Brazil, corroborating the flow model, with flow lines from the southern Brazil towards Argentina.

Water from the Pre-SAG contributes about 2% to the mixture within the analyzed wells. Despite its small proportions, it alters the hydrochemical properties of the SAG. The mixing proportions are influenced by topography and confinement conditions (Fig. 4).

It was identified two water facies from the SAG. The rock-water interactions generates distinct geochemical characteristics, depending on the lithology chareceristics. A recent update in the stratigraphy of the study area may lead to the need of a review in the operational SAG limits.

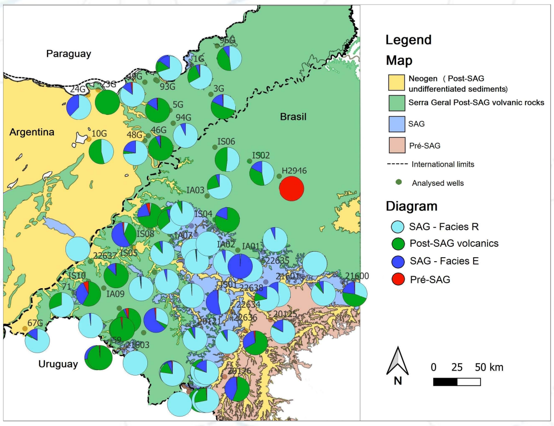

Figure 4. Mixing proportions spatial distribution.

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