

# Guarani Aquifer System: Water Quality, Hydrogeochemistry and Legal Implications: A Review

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**Abstract** — The Guarani aquifer system is the most important underground water resource in South America. Knowing in detail the characteristics of the aquifer facilitates the management of this resource. Therefore, this paper aims to review the literature on Guarani Aquifer System from the perspective of Water Quality, Hydrogeochemistry and Legal Implications.

**Keywords**— Guarani, Aquifer, Water Quality, Hydrogeochemistry, Legal Implications

## I. STATE OF ART

There are several large aquifer systems around the world. One of the most important is the Guarani Aquifer System (GAS), located in the Paraná sedimentary basin in South America with a surface area of 1.1 million Km<sup>2</sup> [1]. The geological and hydrogeological structure of the GAS is well known in Brazil, Paraguay, Uruguay and Argentina [2] as depicted in Fig. 1.

The Paraná sedimentary basin is intercratonic, where the sedimentary sequence covers since the Silurian–Devonian up to the Cretaceous periods [3]. The Guarani aquifer has an average thickness of 300–400m, and is composed of silty and shaly sandstones of fluvial–lacustrine origin and variegated quartzitic sandstones accumulated by eolian processes under desertic conditions [4].

Climatic classification for the region following Koeppen indicates a humid subtropical climate with summer rains, showing a variation to tropical climate with dry winter. The mean annual precipitation is about 1300–1400 mm, while the mean temperature in the region is 20.5°C [5].

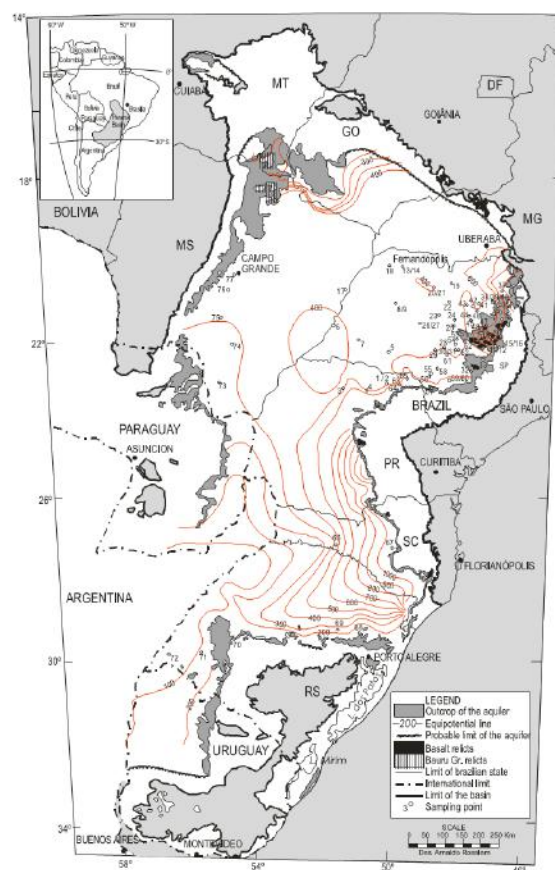


Fig. 1: The outcrop of the Guarani aquifer at the Paraná sedimentary basin [3, 6].

## II. WATER QUALITY, HYDROGEOCHEMISTRY AND LEGAL IMPLICATIONS

The main hydrochemical facies are sodium-(bi)carbonate, calcium-(bi)carbonate, potassium-

(bi)carbonate, sodium/calcium/magnesium/potassium-(bi)carbonate, sodium-(bi)carbonate/chloride/ sulfate, sodium chloride, and sodium-sulfate, as shown in Fig. 2 [8].

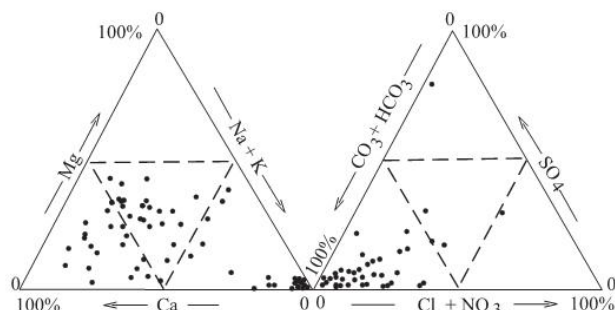


Fig. 2: The data for major cations and anions in groundwaters from Guarani aquifer plotted on a partial Piper diagram [3, 8].

Concentrations exceeding the maximum allowable for fluoride, sulfate, and sodium were identified in some wells, but their waters are not used for human consumption, only for recreation purposes [3].

The groundwaters show a hydrochemical evolution along the major flow paths from the recharge areas toward the confined zone in the center of Paraná Basin that progresses from Ca-HCO<sub>3</sub> water to Ca-HCO<sub>3</sub>-Cl-SO<sub>4</sub> water. Chloride and SO<sub>4</sub> in high concentrations are probably related to mixing of Guarani waters with groundwaters originating in underlying aquifers units, as supported by the ratios of Na<sup>+</sup>/Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup>/Cl<sup>-</sup> from the groundwaters of both units (GAS and underlying aquifers) [9].

The Guarani aquifer show a isotopic concentration of the natural dissolved radionuclides <sup>36</sup>Cl, <sup>40</sup>K, <sup>238</sup>U, <sup>234</sup>U, <sup>226</sup>Ra, <sup>222</sup>Rn, <sup>210</sup>Po, <sup>210</sup>Pb, <sup>232</sup>Th, <sup>228</sup>Th, and <sup>228</sup>Ra. Most of the gross alpha radioactivity values were below the critical level of detection corresponding to 1 mBq/L [10].

Atoms <sup>222</sup>Rn escape from the rocks and soils into the surrounding fluid phases, such as groundwater and air. <sup>222</sup>Rn decays to stable lead according to the sequence: <sup>222</sup>Rn (3.84 d, α) → <sup>218</sup>Po (3.05 min, α) → <sup>214</sup>Pb (26.8 min, β-) → <sup>214</sup>Bi (19.7 min, β-) / <sup>214</sup>Po (0.16 ms, α) → <sup>210</sup>Pb (22.3 a, β-) → <sup>210</sup>Bi (5 d, β-) → <sup>210</sup>Po (138.4 d, α) → <sup>206</sup>Pb (Fig. 3). Since <sup>222</sup>Rn data in marine environments are very promising for various applications, like groundwater discharge, earthquake brakes, rainfall, etc [3].

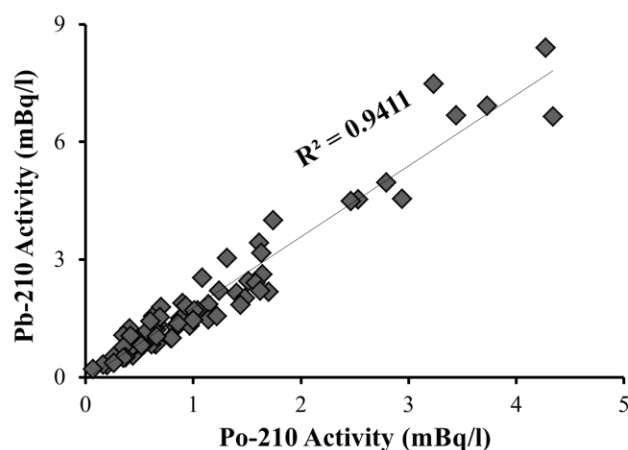


Fig. 3: Isotopic activity in groundwaters from Guarani aquifer plotted <sup>210</sup>Pb vs. <sup>210</sup>Po graph. Adapted from [4].

Much attention has been paid to Rn in waters, since it is considered a constituent that may be responsible for fatal cancers when continuously ingested in drinking water. Because it is a colorless, odorless, tasteless and chemically inert gas, its measurement is difficult, being mainly based on the detection of alpha particles emitted. The importance of Rn monitoring in water-supply systems has been recognized for most industrialized countries, whereas a similar situation has not been achieved in other parts of the world [11].

Another important radionuclide is <sup>36</sup>Cl (half-life of 301,000 years) produced naturally in the atmosphere and lithosphere via various reactions. In the atmosphere, production is predominantly by cosmic-ray spallation of argon, though detonation of thermonuclear devices in the marine environment in the 1950's and 1960's generated considerable quantities via neutron capture of stable <sup>35</sup>Cl in seawater [12]. The utilization of <sup>36</sup>Cl helps understanding groundwater dynamics such as for indicative of the water recharge (Tables 1 and 2).

Table 1 – Chloride ratios in the bulk composition of rainwater at the locations sampled in São Paulo State, Brazil [12].

Parameter unit	Distance to Rio Claro (km)	Na/Cl meq/l	K/Cl meq/l	Ca/C 1 meq/1	Mg/Cl meq/l
Rio Claro	0	1.05	0.21	1.78	0.32
São Pedro	50	1.14	0.97	4.45	1.11
Botucatu	140	0.87	0.61	3.59	0.80
Águas de Santa Bárbara	210	0.80	0.42	3.49	0.63
Assis	330	0.97	0.44	3.93	0.87
Presidente Prudente	440	0.85	0.22	3.05	0.81

Table 2 – Chloride ratios in the bulk composition of rainwater at the locations sampled in São Paulo State, Brazil [12].

Parameter unit	Distance to Rio Claro (km)	SO <sub>4</sub> /C l meq/l	HCO <sub>3</sub> /Cl meq/l	NO <sub>3</sub> /Cl meq/l	PO <sub>4</sub> /C l meq/l
Rio Claro	0	<0.03	1.35	0.04	<0.09
São Pedro	50	<0.04	4.60	0.08	<0.11
Botucatu	140	<0.10	3.14	<0.08	<0.30
Águas de Santa Bárbara	210	<0.03	2.71	0.08	<0.10
Assis	330	<0.13	4.30	0.11	<0.41
Presidente Prudente	440	<0.06	1.00	0.09	<0.19

### III. CONCLUSION

Based on the data presented, it is considered necessary to effectively manage subsurface water resources of the Guarani aquifer system, especially the public bodies. It is possible to state that water will be available for future generations, if used in a sustainable way.

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