Origin of groundwater salinity and implications for groundwater management of the Emborê Aquifer, Rio de Janeiro State, Brazil

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ABSTRACT

The population of northern coastal area of Rio de Janeiro State (Brazil) relies on coastal groundwater resources as its main source of water supply. However, the increasing demand for groundwater resources in the last decade has increased the risk of aquifers' overexploitation and salinization. The Emborê aquifer is the most important aquifer in Rio de Janeiro State and the main source of freshwater for the region but still very little investigated. The aim of the present study is to investigate the water quality of the aquifer, to determine the origins of groundwater salinity and to identify early warning signs of seawater intrusion in order to prevent it. A detailed hydrochemical (major and some minor elements) and isotopic (^{2}H and ^{18}O) study of groundwater quality was carried out and allowed for: (1) the identification of distinct areas within the aquifer with different hydrochemical properties; (2) the identification of main patterns of hydrochemical evolution; and, (3) the identification of principal geochemical processes occurring in the aquifer. Regionally, the groundwater presents distinct geochemical signatures depending on its stratigraphic setting within the aquifer, the proximity to the coastline and the presence/ absence of palaeochannels. Distinct salinity distribution patterns were identified within the Emborê aquifer but seem to reflect the impact of local phenomena more than modern saline intrusion. Results indicate that groundwater infiltration and movement occurred without pronounced evaporative effects and that increasing salinities in the Emborê aquifer are mostly related to mixing with higher salinity waters flowing in interlayered aquifer levels with lower permeabilities and longer residence times.

INTRODUCTION

Brazil has large reserves of oil and groundwater resources in sedimentary basins along the coast. The Campos sedimentary basin is located in the northeast part of the Rio de Janeiro State, close to the delta of Paraíba do Sul river, with a total area of 115,000 km^2 (and an area of just 2000 km^2 onshore). Its oil reserves are one of the most important in the Southern Atlantic domain (Contreras, 2011). The Emborê Formation, which is part of the Campos sedimentary basin, is indeed the most important aquifer in Rio de Janeiro State and the main source of fresh water resources for a region, which includes the municipalities of Campos dos Goytacazes, São Francisco de Itabapoana, São João da Barra and Quissamã (Barreto et al., 2001). Other aquifer formations in the region include the Barreiras Formation and the Fluvial-Deltaic and Alluvial-Lacustrine Formations (Figure 1).

The increasing demand for groundwater resources in this region of the Rio de Janeiro State has increased the risk of aquifers' overexploitation and groundwater quality deterioration. The main aim of the present study is then to investigate the water quality of the Emborê

aquifer, to determine the origins of groundwater salinity and to identify early warning signs of seawater intrusion in order to prevent it.

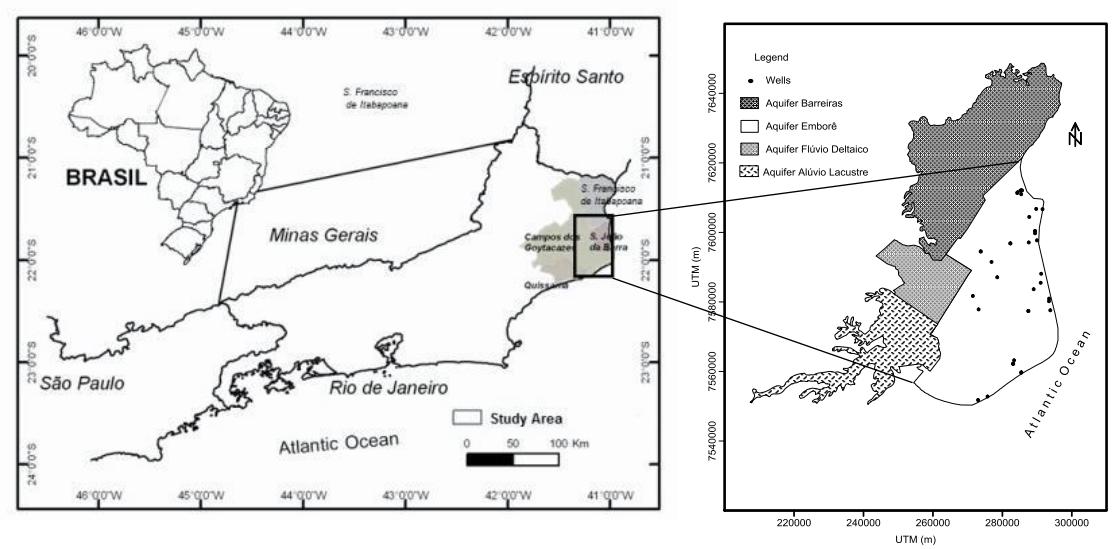

Figure 1. Map of the study area indicating the main aquifers in Campos sedimentary basin and the location of groundwater sampling wells in Emborê aquifer.

HYDROGEOLOGY

The depositional conditions varied within the Campos basin and in the Emborê Formation, sediments of marine influence alternate with predominant detrital infilling of continental origin. The Emborê Formation is composed of poorly calibrated sandstone deposits with conglomeratic and fossiliferous bands, sandy coquinas, calcarenites and organic sandy clays with traces of pyrite and the total thicknesses may vary from 100 to 2,000 m thick.

From the hydrogeological point of view, the Emborê Formation is a multilayer confined aquifer that underlies Quaternary fluvial-deltaic and alluvial-lacustrine aquifer formations. Permeability values change in depth and spatially according to the geology and the impact of local tectonics. Groundwater recharge occurs mainly through preferential flow along palaeochannels and from Paraíba do Sul River. Average transmissivity values for the aquifer vary from 150 to 250 m^2/day and storage coefficient values are typical of a confined aquifer (10^{-5} to 10^{-4}). Most boreholes drilled in the aquifer for water supply are at most 250 m deep.

METHODS

A detailed hydrogeochemical study was carried out in the Emborê aquifer to characterize the groundwater geochemical evolution. 28 groundwater samples were collected for major and some minor elements analysis and isotopic composition determination (^{2}H and ^{18}O). Field parameters (pH, temperature, electrical conductivity) were also determined.

RESULTS AND DISCUSSION

Regionally, the groundwater presents two distinct hydrochemical facies depending on its stratigraphic setting within the aquifer, the proximity to the coastline and the presence/

absence of palaeochannels where preferential flows may occur (Figure 2). In the southern portion of the study area, all the samples collected correspond to calcium-bicarbonate type groundwaters with electrical conductivity (EC) values that range from 307-640 μS/cm and chloride concentrations varying from 10 to 102 mg/L. In the northern part, EC is generally higher than 640 μS/cm, reaching a maximum value of 1627 μS/cm, and groundwaters are mainly of sodium-chloride or sodium-bicarbonate type. The lower salinity values observed and the predominance of calcium-bicarbonate type waters in the southern most part is probably due to the mixing with the continental freshwaters recharged along the palaeochannels.

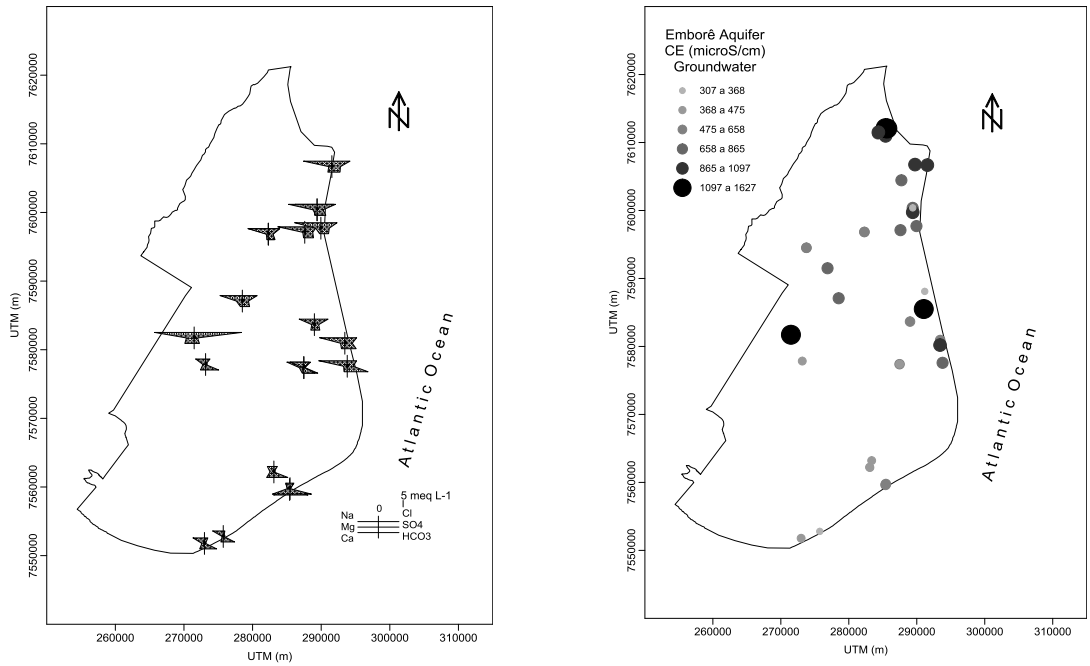

Figure 2. Distribution of the principal hydrochemical facies and electrical conductivity in the Emborê aquifer.

Ionic molar ratios (Cl/Br, Na/Cl and Na/Ca) were calculated to infer salinization or freshening patterns of groundwater evolution (Figure 3). Groundwater Br/Cl ratios aline with seawater mixing line regardless of groundwater salinity and Na/Cl and Na/Ca indicate an enrichment of Na to Ca or Cl, indicating groundwater freshening patterns and discarding brine dissolution.

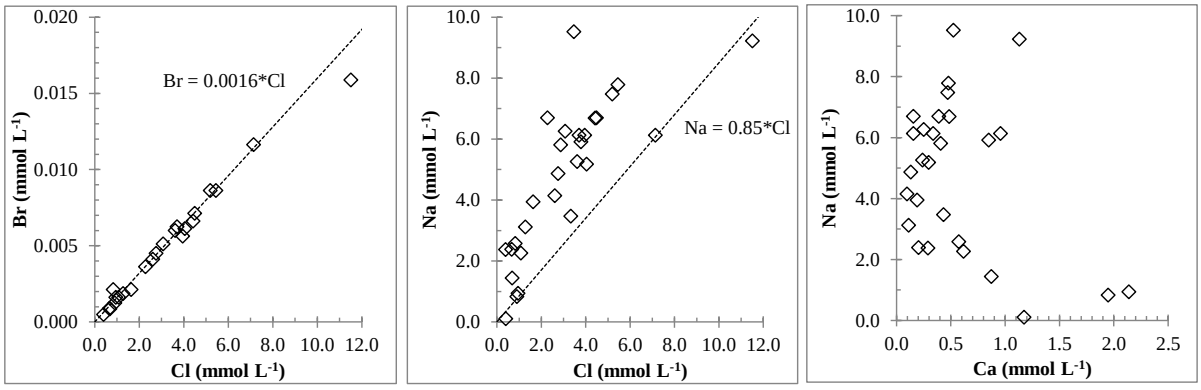

Figure 3. Calculation of some ionic rations (Br/Cl, Na/Cl and Na/Ca) to infer salinization or freshening patterns of groundwater evolution.

Stable isotopic composition of groundwaters in the Emborê aquifer (oxygen-18 and deuterium) plot on the Local Meteoric Water Line (LMWL) discarding the hypothesis that some of the higher salinity groundwaters could be related to pronounced evaporative effects during recharge processes (Figure 4). Most groundwaters of calcium-bicarbonate facies and showing lower salinities are more depleted in ^{18}O and ^{2}H when compared to the rest of the aquifer.

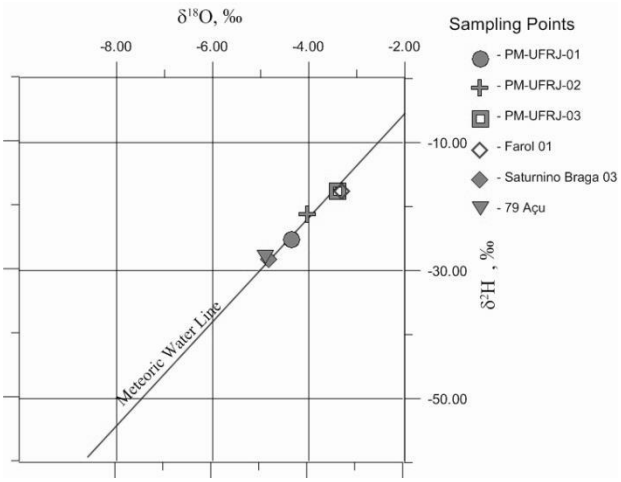

Figure 4. Relationship between $\delta^{2}H$ and $\delta^{18}O$ contents in groundwater samples.

CONCLUSIONS

The results show that increasing salinities in the north and central part of the aquifer are related to mixing processes with seawater (either modern or old seawater trapped in the sediments) but patterns of groundwater quality still indicate predominant freshening processes. Influence of evaporative effects during recharge or brine dissolution in the increasing salinities were discarded based on the isotopic composition and ionic molar ratios.

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