Coastal aquifers of Barra de Maricá, Brazil: contamination and saline wedge behavior

A. Peralta Tapia[1], G. M. de Almeida[2] , **G. da Silva Jr**.[2] and M. Waterloo[1]

[1] Faculty of Earth and Life Sciences, VU University, Amsterdam, The Netherlands
[2] Departamento de Geologia, Universidade Federal do Rio de Janeiro, Rio de Janeiro, RJ, Brazil

ABSTRACT

The Barra of Maricá along the southeastern coast of the state of Rio de Janeiro, Brazil, shares the challenge of understanding and managing the aquifer that supplies fresh water to the population, which is common problem in many locations around the world. In areas where fresh water aquifers get in close contact with marine waters, water stress due to salinization of fresh coastal aquifers has become a major issue. The population growth causes a direct increase in the number of wells and the volume of water pumped from the aquifer. This study aims at evaluating the current situation of the groundwater resources in the Barra of Maricá area, both in hydrodynamic and hydrogeochemical sense, as well as seawater influence on groundwater head fluctuations. A number of techniques were used to assess aquifer properties and saline wedge behavior. Seventeen existing domestic wells and six piezometers were monitored for hydrogeological and hydrogeochemical characteristics (Peralta 2009). Methods included hydrochemical analyses, geophysical methods such as Vertical Electrical Soundings (VES), hydraulic head measurements and automatic logging of the water table, temperature and salinity. Sediment samples from boreholes were analyzed for hydrogeological properties (Carrier 2003). Results show that more than 38% of the water samples, taken from wells used mainly for domestic consumptive and non-consumptive purposes, presented a chloride concentration above the Brazilian regulation for drinking water use. Nitrate concentrations higher than recommended were detected in 61% of the samples. Additionally, we observed a lowering of 0.3 m of the phreatic level over a 21 days period during the summer.

INTRODUCTION

The Barra de Maricá area is located on the Rio de Janeiro State eastern shore, 50 km from the city of Rio de Janeiro, belonging to the Rio de Janeiro Metropolitan Area. Throughout the last decades there was a significant population growth, due mainly to tourism activities and construction of summer residences. This has placed significant pressure on groundwater resources, the only local permanent water source. The geology and land use at Barra de Maricá are representative for that of the southeastern Brazilian coastline (Silva Jr. and Pizani 2003).

Background

The Barra of Maricá (22°56' S; 22°45' W) is a coastal sand barrier with an approximate length and width of 11 km and 1 km, respectively. The natural boundaries of the area are the southwestern Atlantic Ocean on the southern part and three brackish lakes on the northern part of the Barra, locally called the “Região dos Lagos” complex. This lagoon system was formed during the late Pleistocene and early Holocene (Cruz and Silva Jr. 2006) and is resting on crystalline metamorphic and igneous basement rock.

METHODS

In the field, Electrical Conductivity (EC), temperature, pH, nitrate and alkalinity, were measured and water sampling was taken in order to study them in the laboratory. Six observation boreholes were made and monitored, together with seventeen existing wells. In the laboratory at Vrije Universiteit, anions (filtered samples with 45 μm Whatman filters) cations (samples acidified to pH lower than 2 to preserve them) and $\delta^{18}O$ and $\delta^{2}H$ isotopes ratios were measured. Data analyses included Piper plots, Stiff diagrams, plots of cations vs. chloride, and isotopic ratio plots. Saturation Index (SI) for Calcite, Dolomite and Gypsum were calculated for a better understanding of the geochemical processes in the reservoir. Mixing line deviations were obtained, also known as ionic deltas (Appelo and Postma 2005; Pulido-Leboeuf 2004). Several vertical electrical soundings were made in the area in order to build a North-South lithological and salinity transect of the sand barrier.

RESULTS

More than 38% of the water samples, taken from wells used mainly for domestic consumptive and non-consumptive purposes, had a Cl^- concentration above the Brazilian regulation for drinking water use (250 mg/L Cl^-). More than 61 % of the samples had NO_3^- concentrations above the limit of 10 mg/L according to Brazilian law and the highest concentration observed was 149 mg/L. Groundwater temperature showed a small increase from 25.5 ºC to 25.7 ºC during the study period.

A relation between EC and concentration was obtained from the groundwater samples studied with a linear regression $y = 0.2629x - 100.77$ and $R^2 = 0.9992$, where *x* is EC in and *y* is Cl^{-1} concentration in mg/L .

By combining the data from boreholes and the VES we obtained a lithological and aquifer salinity profile for the North-South cross section of the aquifer in the middle sector of the Barra (Figure 1).

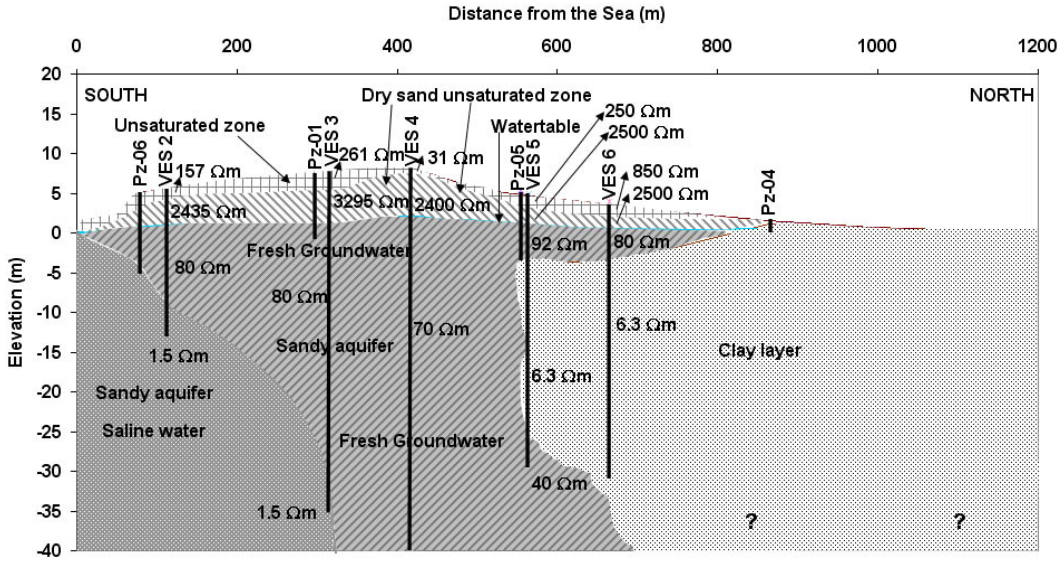

Figure 1. Maricá sand barrier N-S lithological transect profile.

Phreatic level in piezometer 6 (Pz-06 in Figure 1) showed a decrease of 0.3 m throughout the 21 days period of study in summer, presumably due to pumping from the aquifer.

DISCUSSION AND CONCLUSIONS

The salinization distribution observed for our study period supports the findings of Almeida (2009). A comparison with results from previous studies in the area (Almeida and Silva Jr. 2007) suggests an increase in salinization of the aquifer. The high concentrations of nitrate can be attributed to installation of septic tanks and inadequate sewage disposal from the beach residences and suggest the aquifer is being contaminated.

Pulido-Leboeuf (2004) studied a similar coastal system in Castell de Ferro, Spain. Due to the particular geological situation, those authors had easy access to fresh groundwater that to serve as an end member in their Piper plot. In our study the fresh water end member plotted much more towards the center of the Piper plot. This fresh sample helped Pulido-Leboeuf (2004) to create a more accurate mixing line for saline and fresh waters in their system. As the water table in our aquifer has a small gradient and is completely surrounded by salt water or clay substrate, the only source of fresh water is rainfall. Water with a composition more representative of a fresh water end member can only be found more inland on the crystalline basement. In our case, the closest approximation to a fresh water end member was collected at a short distance from the beach houses, but in the vicinity of a septic tank and in the well closest to the ocean. Hence, it is well possible that there are locations on the Barra where water with a lower dissolved salt content is present. The results of the hydrochemical analysis did show a salinization in different degrees, as well as local contamination with nitrate.

We observe that after nine years of sampling by the ACOST-RIO project (Almeida and Silva Jr. 2007), the proportion of samples that presented a nitrate concentration above the limit recommended for human consumption increased from 11% to 61%. The maximum NO_3^- concentration obtained increased from 42 mg/L to 149 mg/L.

Comparing the cross-section profile obtained in this project with previous studies, we can say that even when it is a new approach to the study of the Barra of Maricá, it completely agrees with the geological description available and also agrees with the typical behaviour of the saline cone in coastal aquifers (Domenico and Schwartz 1990). The depth and shape of the clay layer was our interpretation of the VES data available. Nevertheless, some uncertainty remains about these results. It is possible that the clay layer is underlain by crystalline hardrock. This situation was observed on profiles from the ACOST-RIO project for the sand barrier of Itaipuaçu (Monteiro 2000), the area to the West of our study area. There the crystalline hardrock was present under the complete width of the sand bar at approximately 30 m depth.

The cross section profile obtained was an initial approach to visualize the shape of the aquifer all along the Barra. The lowering of the phreatic level was significant throughout the period, and this could be part of a natural process. However, with the data available is not possible to know that yet.

The western portion of the aquifer is more affected by the effects of marine intrusion than the eastern, although there are large seasonal variations in salinity. Lithological characteristics of the aquifer might facilitate aquifer freshening, if there is a balance in the groundwater exploitation in the future. Aquifer should be studied in other seasons as well, since tourists visit mainly in summer season.

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Contact Information: Andrés Peralta Tapia, Vrije Universiteit, E-336 Earth Sciences Department, De Boelelaan 1085, 1081 HV Amsterdam, Noord Holland, The Netherlands, Phone: +58-212-2430672, Fax: +58-212-9063590, Email: a.peralta.tapia@gmail.com