Investigation of seawater intrusion in Recife coastal plain (Pernambuco, Brazil)

Suzana M.G.L. Montenegro[1], Anderson L.R. de Paiva[1], Jaime J.J.S.P Cabral[1], Giancarlo L. Cavalcanti[2] and Eduardo Scalia[1]

[1] Department of Civil Engineer, Federal University of Pernambuco (UFPE), Recife, PE, BRAZIL
[2] Sanitation Company of Pernambuco (COMPESA), Recife, PE, BRAZIL

ABSTRACT

Recife, capital of Pernambuco State located in northeastern Brazil, has been undergoing an accelerated urbanization process osince the 1970's, especially in its coast. Therefore, the demand for fresh water has increased severely and in order to satisfy this need groundwater is one of the most exploited resources. The risk of salinization in the regional aquifers by saltwater intrusion has also increased. The coastal region of Recife is a plain area, its southern area lies next to an estuarine zone and it has high population density together with high concentration of wells. The high water pumping rates combined with the reduction of recharge rates make this area vulnerable to salinization problems. These problems may be caused by both by saltwater intrusion and wells construction problems verified in previous studies. For this research, an analysis was performed with hydrogeological and hydrochemical data acquired from various past government projects and scientific studies. A study was carried out using ionic ratios and mathematical modeling of flow and salt transport with Modflow combined with the Seawat software. Modeling results are at a preliminary stage. The existence of potenciometric drawdown was verified mainly due to the high pumping rates above the limits allowed by the state agency responsible for managing water resources. Moreover, the results of the ionic ratios analysis show that several wells have been under the process of salinization, but still occurring in a spatially heterogeneous way. The modeling indicated possible saltwater intrusion.

INTRODUCTION

Groundwater has been historically used in the Recife Metropolitan Region - RMR (northeast coast of Brazil) as a complementary source of water. However, a shortage on water supply, due to droughts in the late 1990's, besides problems related to losses in the water supply system, has led part of the population to look for guaranty on water supply, drilling private wells. Thus, the over-exploitation of groundwater in the last years and the difficulties in recharging the aquifers in the highly urbanized areas of the RMR has severely depleted the potenciometric levels of the aquifers in the last 20 years and increased their vulnerability to seawater intrusion. Many wells have been abandoned in Recife and others neighbor towns. The main problems are excessive drawdowns in piezometric levels and increasing groundwater salinity. Many academic and technical studies have been undertaken aiming to issue elements for groundwater management in the area. This paper shows an analysis of seawater intrusion in the south region of Recife Coastal Plain through ionic ratios and mathematical modeling both aiming to investigate the salinization process.

DESCRIPTION OF STUDY AREA

Pernambuco State is situated in the northeast from Brazil, the poorest region in the country in terms of water. Recife city has over than 1,5 millions of inhabitants (IBGE, 2009). It is located on a low plain with an average of 2,0m meters above the sea level surrounded by small hills. The precipitation reaches 2458 mm/year and the average temperature is of 25,5° C. The area of study is located at the south portion of Recife coastal plain.

The aquifers in the RMR are classified according to the geomorphological domain in: 1) Basement rocks plain (fractured aquifer); 2) Northern Sedimentary and Recife Coastal plains (porous aquifer). The Cabo aquifer occurs in the Recife coastal plain, and comprises sandstones, siltstones and mudstones, with average thickness of 90m. Cabo aquifer is a semi-confined formation and is most exploited. The Boa Viagem aquifer, an unconfined formation, overlies Cabo aquifer and comprises sand, silt and clay, with an average thickness of 40m. The Boa Viagem aquifer is upper and the most vulnerable formation in terms of water quality because of sewage septic tanks leakage, and due to connection to mangroves and rivers estuaries. Since the area is highly urbanized, recharge from rainfall is decreasing throughout the years.

Population growth and deficiencies in the public water supply system have led to an intensively exploitation of groundwater. The use of groundwater without control, mainly in the Cabo aquifer, has led to an over-exploitation situation. The number of production wells has increased dramatically with the urbanization process. This over-exploitation has changed potentiometric gradients between the upper and the lower aquifers and between the sea and the lower aquifer. Now, in some places, head gradients produce flow from the sea towards the continent, with high risk of seawater intrusion and in some places from upper to lower aquifer (Costa, 2002). This makes the Cabo aquifer vulnerable to diffuse contamination. Recently, Government agencies started controlling the drilling and exploitation of groundwater by private wells. In addition, the technical information about the wells is, in general, not satisfactory. Seawater intrusion and hydraulic interconnection to mangroves and estuarine areas have been pointed out as the possible causes for the increasing salinity in this intensively exploited coastal aquifer system.

IONIC RATIOS

The evaluation of ionic ratios considered 107 wells scattered throughout the region. This study shows the salinization effect that has been occurring in the region and that is already referred in previous studies. The data of the hydrochemical analysis was obtained through the State's Water Resources Secretary and it portrays the conditions of the aquifers in the last decade. The ionic ratios obtained were compared to the standard values of sea water to determine whether sea water influences the aquifers. The values that are considered to be sea water standard are shown in the table 1 along with the percentage of wells with seawater patterns relative to the total number of analysed wells. Some results as the relation between (rK+rNa+rMg)corrected and $(rCl/2)^{0.5}$ have served as a strong indication of the influence of sea water on the aquifer. It was observed that most wells with salinization indicatives lie near a zone of higher potenciometric levels drawdowns of the aquifer, which is consistent with what was observed in the mathematical simulations. On the other hand, the $rCa/(rHCO_3 + rSO_4)$, rK/rNa and $rCl/rHCO_3$ ratios exhibited that a small amount of wells indicated this influence. It should be noted that the wells registered at the State's Water Resources Secretary don't represent the worst problems of salinization, because some times people don't apply for registration if after drilling brackish water is found.

Table 1. Seawater standards ionic ratios.

Ionic ratio	Sea water Standard	Percentage of wells with seawater patterns (%)
rMg/rCa	< 1.00	56.72
rK/rNa	0.02 – 0.025	2.63
$rCl/rHCO_3$	20 - 50	6.67
rNa/rCl	< 0.86	64.30
$rCa/ (r HCO_3 + rSO_4)$	> 1.00	14.29
Relation between $(rK+rNa+rMg)_{corrected}$ and $(rCl/2)^{0.5}$	$(rCl/2)^{0.5}$>(rK+rNa+rMg)	80.00

MODELLING

The modeling was accomplished through the Visual Modflow software, which incorporates the SEAWAT code. The conceptual model consists of three layers: the first layer from the bottom represents the phreatic Boa Viagem aquifer; the second layer represents the discontinuous aquitard; and, the third layer represents the confined Cabo aquifer. The study area is limited by the UTM 283.000m to 302.500 E and 9.098.000m to 9.107.000 N coordinates. A grid where all cells have the same dimensions of 500 x 500 m for all three layers was considered.

The hydrogeological parameters were obtained by analysis of the information from Monteiro (2000) and Costa (2002). The first (upper) layer has hydraulic conductivity (m/s) of $9.0x10^{-4}$, the third layer of $4.0x10^{-5}$, and for the second layer $1x10^{-9}$ where some cells have values of $1.0x10^{-8}$, because there are some areas observed by Monteiro (2000) in which the semi-confining layer is more permeable. The specific storage is of $2.0x10^{-6}$ m^{-1}, the effective porosity of 0.1 and the storage coefficient of 0.1. In the region 1580 wells were considered (Costa, 2002). Even thought this study does not represent all the wells in this area it is the best existing source in the region. Regarding the boundary conditions, the North and south limits were considered conditions with null flow. In the western borders lie recharge areas of the aquifers. In the eastern boundary lies the Atlantic Ocean which has constant hydraulic head. The recharge values were estimated in certain zones, considering impermeable zones. The conceptual model also considered with: cells representing rivers and wetlands, since it is an estuarine zone; constant concentration for the sea and rivers. The initial condition for the simulation was established in 1970, and final time simulation in 1999. Calibration was not performed.

High potenciometric drawdown was verified, especially in the most urbanized areas. Drawdowns over 35 meters in Cabo aquifer were verified. Salinization by saltwater intrusion was verified in coastal zone (Figure 1). The salt concentration reached the value upper than 5000 mg/L in some parts of the region.

DISCUSSION AND CONCLUSIONS

Even though the results reveal areas where the salinity is high, the occurrence of seawater intrusion has not been clearly identified, as in previous works in the area.. The results suggest that a mixing between fresh groundwater with saline waters is occurring in some wells in the studied area. So far it is not possible to precise what type of saline water is mixing with fresh groundwater. It could be an effect of seawater intrusion, a mixing with brackish water (estuarine

and mangrove waters) through hydraulic interconnection between both upper and lower aquifers, which would confirm that deficiencies in well construction, or a mixing with paleo saline waters. This is observed in deep and also in shallow wells confirming salinization processes in both aquifer systems. The high pumping rates pose the system under the threat of deterioration both in terms of quantity and quality.

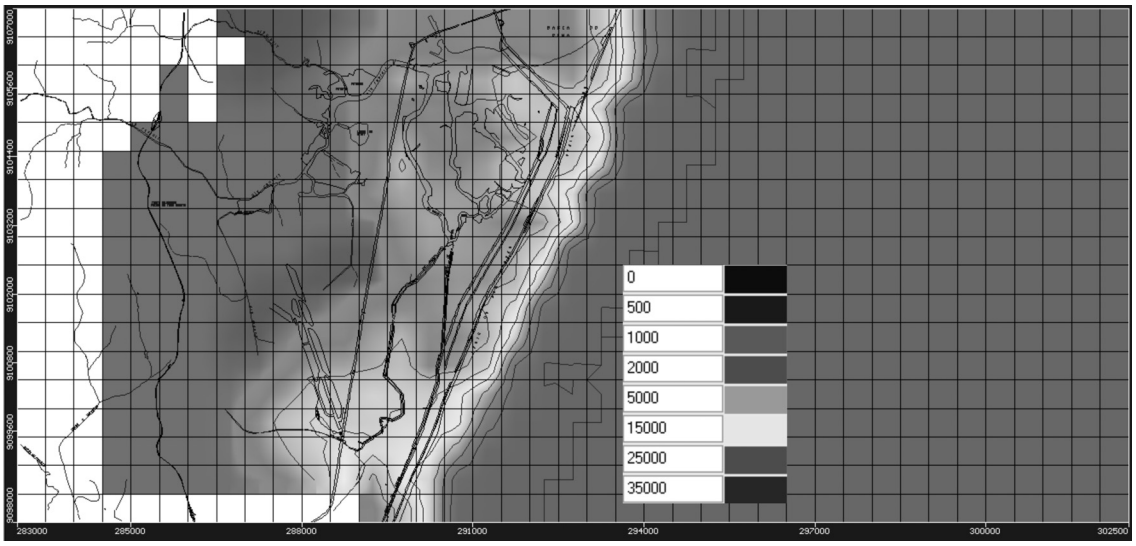

Figure 1. Concentration of salt (mg/L) in Cabo aquifer.

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Contact Information: Suzana M. G. L. Montenegro, Federal University of Pernambuco (UFPE), Civil Engineer Department, Av. Prof. Acadêmico Hélio Ramos, sn, Cidade Universitária, Recife/PE, 50740-530, BRA, Phone: +55-81-2126-7216, Fax: +55-81-3454-0482, Email: suzanam@ufpe.br