Groundwater indicators as a tool to improve coastal aquifer management: case studies in South America.

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ABSTRACT

Groundwater indicators have been used mainly to evaluate the current situation and trends of degradation, both quantitative and qualitatively. In this context, the situation of the Recife Coastal Plain, Brazil, facing problems with the public water supply, and Mar del Plata, Argentina, where a population of 600,000 inhabitants triples during the summer, are highlighted. In Recife, groundwater has been intensely exploited in the region and in the last years with consumption peaks due to eventual droughts, as in 1998/99. In Mar del Plata, water for urban, agricultural and industrial uses is exclusively supplied by groundwater resources. This paper applies environmental indicators in three main lines of approach to make an analysis of the coastal aquifers: pressure, state and response. In order to assess adequately coastal environmental processes by decision-makers, indicators were applied to both cities to analyze and compare their situations. This study suggests that the use of indicators has proven to be of great value for proposing protection guidelines aimed at economical, social and environmental sustainability of the coastal region.

INTRODUCTION

Recife, the capital of Pernambuco State in the northeast from Brazil, has about 1,5 millions inhabitants. In Recife, groundwater has been historically used as a complementary source of water. However, there is an increasing water supply by drilling private wells. Thus, the intensive exploitation of groundwater and the difficulties in recharging the aquifers in the highly urbanized areas of Recife has severely depleted the potentiometric levels in the last 20 years and changed groundwater gradients between the upper and the lower aquifers, as well as between the sea and the lower aquifer. High risk of seawater intrusion has risen in some places, from the upper to the lower aquifer (Montenegro *et al*., 2006). Many wells have been abandoned in Recife and others neighbor towns. The main problems are excessive drawdown in piezometric levels and increasing groundwater salinity.

Mar del Plata is the capital of General Pueyrredon District, on the southeast coast of Buenos Aires Province, and constitutes the main seaside resort of Argentina. Its permanent population is about 600,000 inhabitants, but it triples during the summer. Until the early 1950s its main economic activity was fishing. Urban growth has led to an increase in population density, industrial activity and tourism in the central area. The periurban areas were occupied by

clandestine landfills, undesirable industries and precarious shantytowns in areas under flood risk. Water supply is exclusively satisfied by groundwater, and currently there are serious concerns in terms of quality. The intensive exploitation brought about the intrusion of seawater in a wide belt of the downtown area. The most commonly occurring environmental problems related to water resources are: high urban expansion, seawater intrusion, agricultural pollution of groundwater, inadequate waste management, and recurrent or rare flash floods in urban and surrounding areas (Bocanegra *et al*., 2006). This paper applies selected groundwater indicators for analyzing the problems in these two cities aiming to improve coastal aquifer management.

HYDROGEOLOGICAL FEATURES OF RECIFE AND MAR DEL PLATA

The porous aquifers in Recife coastal plain are Boa Viagem, Beberibe and Cabo. The Boa Viagem aquifer, unconfined, composed basically by sand, silt and clay, is the most vulnerable, because of the urban concentration in the areas where it occurs, associated with the lack of an adequate sewage system. Both Beberibe and Cabo aquifers are semi-confined. They are composed basically by sandstone, with intercalations of mudstone. The Beberibe is the most important, due to the high exploited volumes from the water company, the main user. The Cabo aquifer is the most intensively exploited, due to the high concentration of particularly owned wells and the deficit of recharge.

Mar del Plata is located on the northeastern side of the Tandilia range that has a maximum altitude of about 40 m a.s.l. In the study area, the range consists of lower Palaeozoic quartzites, grouped under the name of Balcarce Formation (Bocanegra *et al*., 2006). The quartzite bedrock is overlain by a sedimentary cover of Upper Tertiary and Quaternary silts and silty-to-sandy sediments. Miocene clayey-to-sandy sediments are found at a depth of 60 m in the grabens. The Quaternary deposits are called “pampean sediments” or “loess-like sediments”. From a hydrogeological viewpoint they constitute the most important sequence. They are a multi-layered Water table aquifer. Table 01 shows the summary of the hydrogeological features of the mentioned formations.

Table 01. Hydrogeological features of the studied aquifers.

City	Aquifer	Type	Thickness (m)	T[1] (m²/s)	K (m/s)	m (%)	S
Recife	Boa Viagem	Water table	40	0.007	0.00017	0.1	-
	Cabo	semi-confined	90	0.00086	0.00001	0.07	0.0001
	Beberibe	semi-confined	100	0.0022	0.000022	0.1	0.0002
Mar del Plata	Pampean Sediments (urban)	Water table multilayered	70-100	0.007 - 0.009	0.0001	0.15	0.001
	Pampean Sediments (rural)	Water table multilayered	70-100	0.011 - 0.016	0.0001	0.15	0.001

[1] T = Transmissivity; K = permeability (hydraulic conductivity); m = effective porosity; S = storage coefficient

METHODOLOGICAL FRAMEWORK

The use of indicators provides conditions of consistent analyses for the decision process. Their application can contribute for a more decentralized and participative management. Groundwater indicators have been used mainly to evaluate the current situation and trends of

degradation, both quantitatively and qualitatively. Bocanegra *et al*. (2006) listed several indicators that were applied to analyse the coastal aquifer in Mar del Plata, Argentina, and in order to define the coastal environmental processes related to groundwater resources. Some of these indicators, devised for decision makers, are discussed in the case of the two selected coastal cities (Recife and Mar del Plata). A set of indicators for pressure, state and response were selected taking into account their relevance and data availability (Tables 02 – 04). The year 2000 was used for comparison.

Table 02 - Pressure indicators in 2000 for the two study areas.

Indicators	Mar del Plata	Recife
Population (10^3)	564.1	1422.9
Urban area (km^2)	150	219.5
Population density (inhab/km^2)	3384	6483
Urban population (%)	90	100
Annual exploited volume (10^6 m^3)	97.6	104.6
Summer exploited volume (%)	37	n.a.
Daily water supply (L/inhab)	539	305
Population lacking water supply (%)	20.8	12*
Population lacking sewage (%)	27.1	70
Irrigated areas (km^2)	141	n.a.
Official urban damping (km^2)	1.2	n.a.
Annual waste weight (10^3 ton)	255.5	n.a.

n.a.: data not available. * Groundwater is a complementary resource.

Table 03 - State indicators in 2000 for the two study areas.

Indicators	Mar del Plata	Recife
Annual recharge (mm)	198*	515**
Water level in wells <0 m a.s.l. (%)	14	n.a.
Maximum drawdown reached (m a.s.l.)	-27.1 (year 1970)	-70 (last 20 years)
Wells with Cl > 200 mg/L (%)	3	n.a.
Max. chloride conc. (mg/L)	366	n.a.
Wells with NO3 > 45 mg/L (%)	18	n.a.
Bacteriologically polluted wells (%)	> 83	n.a.

* mean annual value, in the period 1930–2005.

**total calculated recharge divided equally over the area of the Recife plain (112 km^2) /

n.a.: data not available.

RESULTS AND DISCUSSION FOR THE STUDY AREAS

The analysis and comparison of the pressure indicators (Table 02) shows that the situation in Recife is considerably worse than in Mar del Plata: the population is about 2.5 times higher, the population density is two times higher, the whole population is urban and the annual exploited volumes are almost the same. Besides, the daily water supply (*per capita*) in Recife represents only 56.5% in relation to Mar del Plata. The risk of groundwater contamination is significantly higher in Recife as well. Analyzing the state indicators (Table 03), comparing recharge with exploitation volumes, in both cases they are inadequate, resulting in the high observed drawdowns. In Recife, due to the aquifer confination in some points the drawdown reached -70 m in the last 20 years. In terms of quality, in the case of Mar del Plata, nitrates and the biological pollution are more significant than chlorides. The percentage of wells hit by bacteriological pollution has been determined considering the bacteriological data from water samples taken from each of the wells. On the other hand, in Recife the lack of quality data did not allow to determine these indicators. Response indicators (Table 04) show some remarkable differences

considering the ratio of working wells to groundwater supply, the cost of running-water systems and the environmental regulations that have been applied. The present jurisdictional framework is also different: in Recife the State is responsible and in Mar del Plata is the Municipality.

Table 04 - Response indicators in 2000 for the two study areas.

Indicators	Mar del Plata	Recife
Total wells *	310	11,259
Working wells	255	≈11,259
Abandoned wells	55	n.a.
Jurisdictional organization	Municipal	State Company
Annual budget (US$/inhabitant)	30	n.a.
Cost of water systems (US$/$m^3$)	0.10	≈ 0.45
Staffing (employers/1000 inhabitants)	1.2	n.a.
Environmental regulations	Provincial Laws Local regulation on cesspools; Register of well constructors; Mechanisms of control. Master Plan 2006–2016	A State law (1997) establishes the Water Resources Management Policy and the groundwater law: regulation of ownership, well drilling and groundwater use, artificial recharge, and groundwater protection.

* Private and domestic wells are included in the case of Recife; n.a.: data not available.

CONCLUSIONS AND FINAL CONSIDERATIONS

The use of indicators of pressure, state and response to analyse groundwater conditions allows us identify several differences between the Recife and Mar del Plata areas. The situation of the Recife plain is serious and actions must taken by the decision-makers, in order to effectively implement the Groundwater Management Policy. In general, the technical information about the wells is not satisfactory and new surveys must be undertaken in order to generate new data, including quality data, so that other indicators can be applied to confirm the trends and improve the analyses, generating refined conclusions. In Mar del Plata, uncontrolled urban expansion led to saline intrusion and pollution of groundwater. The results show that the use of indicators has proven to be of great value for the economical, social and environmental sustainability of the coastal region. There, some state indicators should constitute requisites of special value, since they show whether water is drinkable or not.

REFERENCES

Bocanegra, E. M., Massone, H. E., Cionchi, J. L., Martinez, D. E. 2006. *Integrated management of the coastal aquifer in Mar del Plata, Argentina.* Proceedings 1st SWIM-SWICA Joint Saltwater Intrusion Conference, Cagliari, Italy - September 24-29, 2006, 1:129 – 134.

Montenegro SMGL, Montenegro AA de A, Cabral JJSP, Cavalcanti G. 2006. *Intensive exploitation and groundwater salinity in Recife coastal plain (Brasil): monitoring and management perspectives*. Proceedings. 1st SWIM-SWICA Joint Salt Water Intrusion Conf., Cagliari, Italy - September 24-29, 2006 1:79-85.

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