HYDROLOGICAL CHARACTERIZATION OF THE BRACKISH - FRESH WATER RELATIONSHIP IN DIFFERENT MORPHOLOGICAL ENVIRONMENTS OF THE PROVINCE OF BUENOS AIRES, ARGENTINA

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Abstract

Various morphological environments in Argentina with different brackish-fresh water relationships are analyzed in this work. A great part of the Province of Buenos Aires is a flatland region with very subtle topographic slopes and where micro-morphologic features are important factors of the hydrological system. These features are related to the excess of water in the hydrologic balance, the distribution of permeable soils and the scarcity or lack of a drainage network. They control the infiltration and groundwater recharge processes. The hydrogeology, geomorphology and climate of the plain produce areal variations of the hydrodynamic and hydrochemical behavior. The following cases are included in this analysis: coastal dunes zone; shore zone; estuarine zone; coastal plains of major rivers (Paraná and Río de la Plata) and the continental dunes zone. The brackish-fresh water relationship in these environments involves complex phenomena, and their analysis and evaluation become important for the exploitation and management of groundwater resources. In most zones, groundwater is the only source of fresh water supply for human consumption.

Keywords: brackish-fresh water relationship, coastal dunes, continental dunes, shore zone, estuarine zone.

Introduction

The characteristics of the brackish-fresh water relationship are fundamental for the evaluation of groundwater reserves and groundwater management. This aspect acquires greater importance in regions where the fresh water resource is limited. A great part of the Province of Buenos Aires (Argentina) is a flatland region of very low topographic slope, where spatial and vertical hydrochemical variations in groundwater are significant. The hydrogeological, geomorphological and climatic characteristics of the

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plain cause difficulties for the estimation of the fresh water–brackish water-salt water interface, especially with those methodologies that are based on the differences of water densities.

The objective of this work is to describe the types of fresh water - salt water relationships in this plain.

General characteristics

In the Province of Buenos Aires the plain occupies about 300,000 km^2 (Figure 1). It is a very low slope plain that extends towards the Atlantic Ocean for about 300 km down to the continental shelf (200 meters below sea level). The hilly areas occupy less than 10 % of the surface and have low elevation (between 500 and 700 m.a.s.l.). The climate is template humid, with an average precipitation of approximately 900 mm/year. Dry and humid periods exist and modify this average value. The plain is regionally homogenous, presenting local morphological and hydrological characteristics with a significant influence in the hydrological behaviour. The greatest elevation of the plain is 150 m.a.s.l. in the northwest and drops towards the sea, with regional slopes between 10^{-3} and 10^{-4}. The area has a poorly developed fluvial network (densities of drainage between 0 and 0.16 m.km^{-1}).

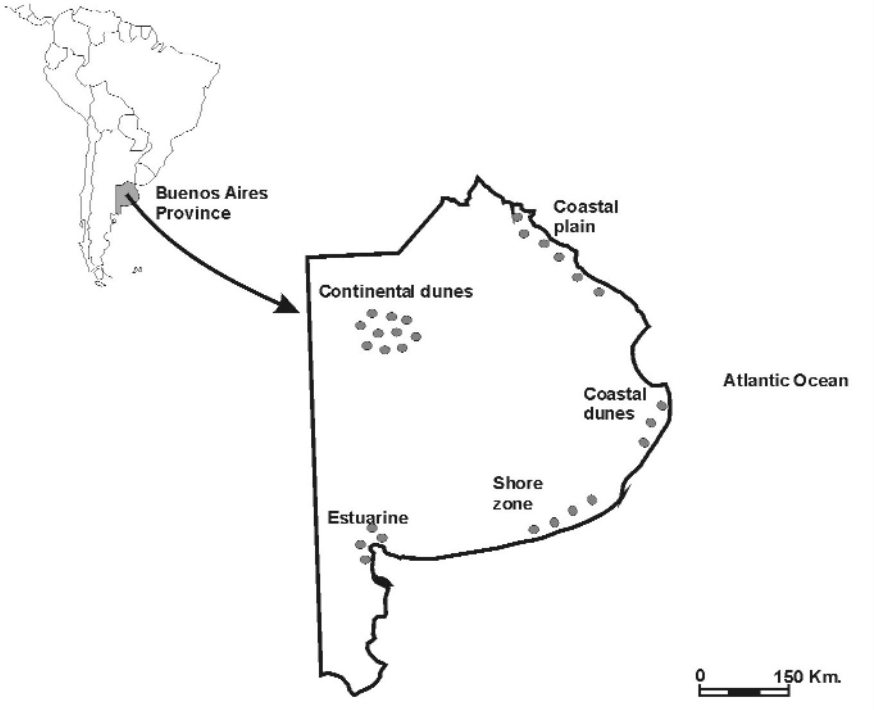

Figure 1. Location map.

The region is a plain formed by eolian processes. The sediments fill up a deep fault depression. The hydrogeologic basement (granitic rocks), which crops out in the hills, is located in the plain at depths that

can exceed 6000 m (Salado Basin). Over the hydrogeologic basement there are Mesozoic rocks of varied permeability.

The cropping out sediments in the surface are of continental origin and they belong to the upper Pleistocene and Holocene periods. They are called "loess" and are constituted of volcanic sands, ashes, silts and clays. Within this environment there is a mantle of sands and dunes. The regional faults affect the oldest rocks, but they do not prevent the existence of a regional groundwater flow. Groundwater is recharged by regional groundwater inflow and by precipitation. The regional groundwater flow discharges in the marine platform and the local groundwater flow discharges in water courses and lagoons (Sala et al., 1998). In general terms the regional groundwater flow contains waters of higher saline content, while the local groundwater flows contain waters of lower salinity.

The interrelation between the groundwater flows and waters of different saline contents depends on the geological characteristics and on the hydraulic heads of the aquifer units.

Types of fresh – saline interfaces

Coastal dunes environment

The coastal dunes zone forms a ridge parallel to the coast, whose width is approximately 5 km. This ridge is limited towards the west (continent) by low altitude areas, prone to be flooded. The sandy sediments of eolian origin (dunes) cover a semi-confined aquifer containing saline water (between 3 and 15 g/L). The permeability of the sandy sediments is greater than 10 m/day and the effective porosity is 0.15 (González Arzac et al., 1992). In this unit a phreatic aquifer of low salinity (between 400 and 1000 mg/L) is developed, limited by brackish water (phreatic continental aquifer and a semi-confined aquifer) and seawater (Figure 2). The sandy sediments of the surface facilitate the infiltration and transmission of water. The phreatic maps show a groundwater divide in coincidence with the greater heights of the coastal ridges. Continental water, marine water and dune water conform a complex interface. In this interface three hydraulic heads have influence: local groundwater flow (dunes); regional groundwater flow (continent); and ocean head (zero).

Continental dunes environment

The continental dunes zone is a typical environment of the Northwest of the Province. This area is a plain with a small regional topographic slope of about 10^{-3}. Minor topographic forms that are hydrologically important can be differentiated within the general morphology. There are slightly noticeable elevations alternating with depressions that give a relief of soft, somewhat aligned crinkles. They represent typical forms of paleo-dune environments. The region shows elongated ridges with a prevailingly southward direction (Kruse et al., 1993).

Recent permeable sediments, fine sandy and silty sediments forming the dunes, cover the region; several overlying eolian cycles have been recognized. In the interdune lows finer sediment with lower relative

permeability have been found. It is an arreic environment. Superficial sandy eolian sediments from a few centimeters up to 4 meters thick and permeability in the order of 20 m/d were found. They lie over silt with variable proportions of sand and clay, and usually calcareous materials.

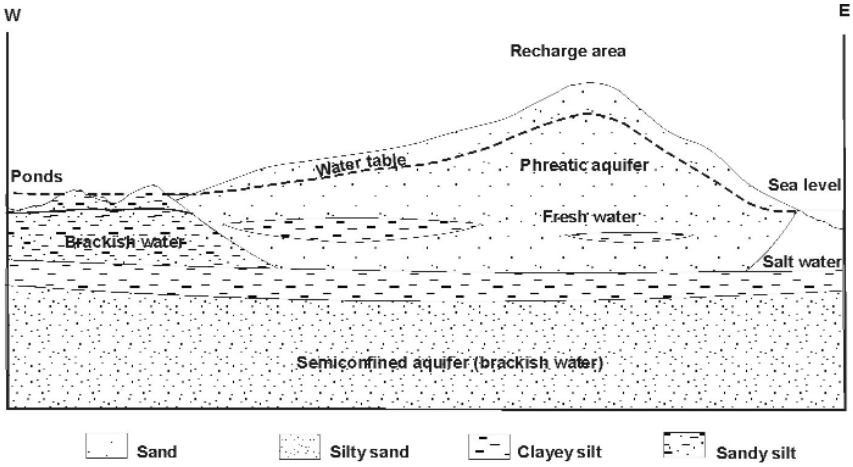

Figure 2. Illustrative scheme of the fresh – salt water relationship in the coastal dunes environment.

The dunes contain fresh water bodies (400 – 800 mg/L) conforming lenses (Figure 3) over high salinity groundwaters (2 – 10 g/L). A noticeable hydrochemical zonation of morphological character is recognized. The geomorphological and hydrogeological characteristics indicate the predominance of infiltration. The phreatic morphology is similar to the land surface, although with smaller gradients (Kruse, 1993). The local groundwater flow (fresh water) has a rapid flow and a short contact time with the sediments. The saline water is associated with a long time contact with the sediments in the regional groundwater flow, due to low hydraulic gradient and low permeability.

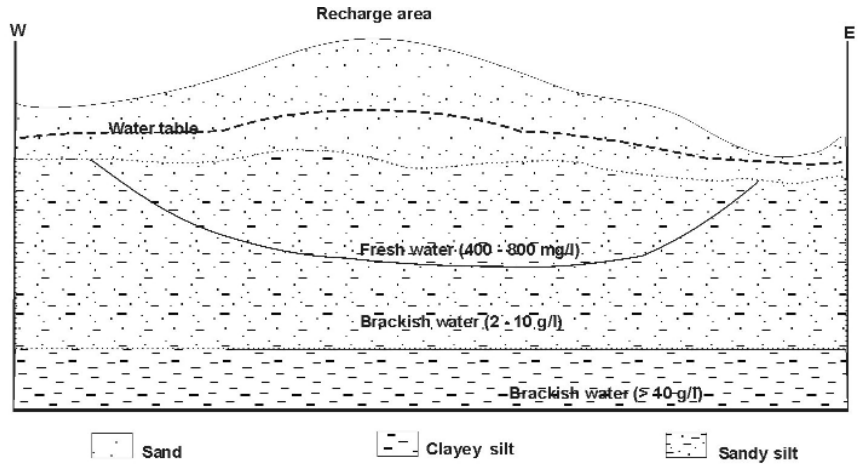

Figure 3. Illustrative scheme of the fresh – salt water relationship in the continental dunes environment.

Estuarine zone

This environment is situated in the south of the Province of Buenos Aires, close to Bahía Blanca. In this coastal zone the phreatic aquifer presents an abrupt increase in the water salinity, reaching values up to 50 g/L (Sala et al., 1985), which are higher than seawater.

The case study of the estuarine zone is a very low-sloped (2.10^{-3}) abrasion platform carried on Pleistocene formations. Near the coastal zone, fine sand and silt layers between 12 and 30 m thick are frequent. This unit overlies sandy silt and sandy clay cemented by calcium carbonate (Figure 4).

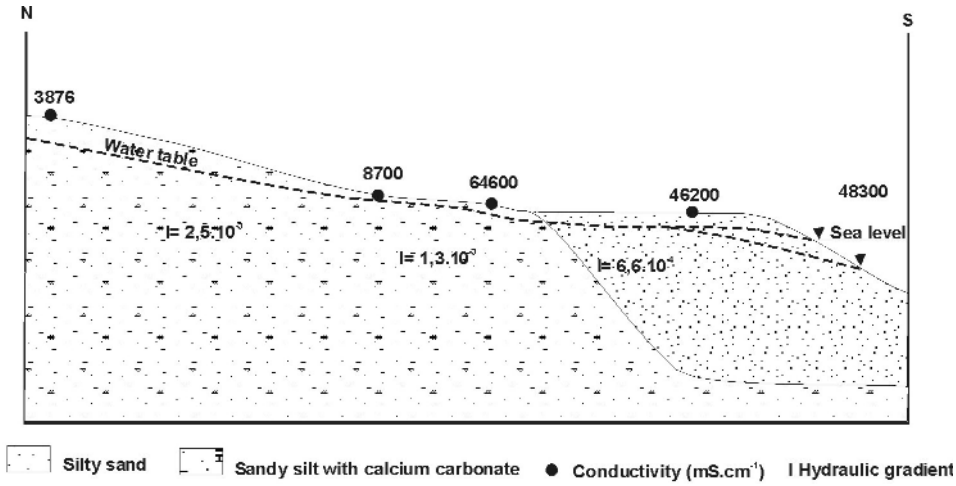

Figure 4. Illustrative scheme of the fresh – salt water relationship in the estuarine zone environment.

The phreatic maps indicate that local groundwater discharges into the sea and the depth of the water table is approximately 2 m or less.

The phreatic aquifer contains fresh water near the area, but at a few kilometres from the coast, an abrupt increment in the salinity is observed. The salinity of the phreatic water is higher than that of the deep aquifers. Groundwater with high salinity is not exploited.

The phenomenon of increase in salinity can be attributed to the dissolution of salts and to evaporation. The longer contact times between water and sediments, as a consequence of the decrease of groundwater flow velocity near the discharge areas, leads to more pronounced salinization of the phreatic water.

Coastal plain of major rivers (Paraná – La Plata River)

In this zone, a semiconfined aquifer of high productivity (Puelche) situated below a poor aquifer (Pampean) acquires importance. The Puelche sands (Pliocene) represent the most important aquifer of the Northeast

of the Province of Buenos Aires. It includes a quartz sand sequence topping marine green clays (Miocene). The Pampean sediments (Pleistocene) are mainly formed by silt with sands and clays presenting frequently calcareous concretions.

The Puelche and Pampean aquifers contain fresh water (approximately 1000 mg/L) and they present increasing salinity in groundwater when reaching the coastal plain, before discharging to the fluvial system (Ainchil and Kruse, 2002). In the discharge area, water in the Pampean aquifer present 5 g/L and in the Puelche aquifer about 30 g/L. A vertical and an areal geological zonation are recognized. A saline enrichment in each aquifer (Puelche and Pampean) exists. Water salinity increases towards the discharge area in the Paraná and La Plata rivers. It could be related to the increment of the contact time between water and sediments, due to the diminution of the groundwater flow velocity and to the presence of marine and estuarine sediments (silty clay and clay) deposited during a higher sea level stage (7000 to 2700 years before present).

Intensive groundwater exploitation has produced depression cones and the encroachment of the brackish water from the coastal plain (La Plata River). An example is the groundwater exploited in La Plata, which back in 1885 was used to meet the demands of the population. The intense exploitation imposed a regime characterized by depression cones in continuous expansion, which produced the modification of the natural hydraulic gradients. Thus, the original groundwater flows from La Plata towards the La Plata River, modified the flow direction giving origin to saltwater intrusion. As a result, in 1945, some exploited wells began to show the presence of salinization (salinity of about 5 g/L), which forced them to be abandoned. When pumping ceased, the hydraulic heads recovered and stopped the displacement of the salt water intrusion. Presently, there is an over-exploitation of the Puelches aquifer further away from the coastal plain. This has modified the hydraulic conditions and, collaterally, it affects the hydrochemical characteristics, caused by contamination from human wastes.

Shore zone

The zone developed in the area surrounding Mar del Plata city is a piedmont plain. The typical interface of fresh water–sea water is recognized in this case. The quartzite bedrock is overlain by a sedimentary cover of Upper Tertiary and Quaternary silts and silty-sandy sediments. These sediments are the most important sequence from a hydrogeological point of view. They constitute a multilayered phreatic aquifer, 70 to 100 m thick. Its hydraulic conductivity is 10-15 m/day. Its transmissivity is about 1000 m^2/day and the porosity is 0.20 (Bocanegra et al., 2002).

The recharge of the aquifer system is due to rainfall infiltration in the surface of the area. The natural discharge is towards the sea; artificial discharge takes place due to pumping. According to historical information, at the beginning of the century groundwater flow was seawards, with piezometric contours parallel to the coast. The overexploitation of groundwater produced the intrusion of salt water in a wide belt of the urban area, and an important piezometric decline in the northern and southern zones (Bocanegra et al., 2002).

The exploitation was stopped in 1970 in the area affected by salt water intrusion. Also, the advance of the saline front halted (Bocanegra et al., 1993) and, at present, the piezometric levels in the urban area reach

5 m.a.s.l. A reorganization of pumping wells has allowed the modification of the hydraulic gradients and the arrest of the saline front displacement.

Conclusions

The interface brackish water–fresh water or salt water–fresh water is an important phenomenon in the evaluation and management of groundwater in different environments of Buenos Aires Province (Argentina).

A complex interface, influenced by hydraulic heads, conformed by a regional flow of brackish water (phreatic continental aquifer and semi-confined aquifer), fresh water flow from local recharge, and salt water flow from the sea, is recognized in the coastal dunes.

Freshwater lenses over brackish water are characteristic of the continental dunes zone. The high salinity in the regional groundwater flow is associated with a long contact time with the sediments.

In the estuarine zone the phreatic water that discharges into the sea shows salinity greater than that of the sea (50 g/L). This high salinity originates from the salt dissolution by longer contact time between water and sediments and by evaporation.

In the coastal plain zone the aquifers increase the salinity content when reaching the discharge zone into the fluvial system of the major rivers (Paraná – La Plata). The presence of estuarine and marine sediments in the area has influence the increment of groundwater salinity. Intensive groundwater exploitation in the interior plain has prodin in ed depression cones and the encroachment of brackish water from the coastal plain.

A typical fresh water–sea water interface is recognized in part of the shore zone. The exploitation of groundwater produced the intrusion of sea water. The arrest of the exploitation and a reorganization of pumping wells have allowed the modification of the hydraulic gradients and the halting of the saline front displacement.

References

AINCHIL, J. and KRUSE, E. (2002). Características hidrogeológicas de la Planicie Costera en el Noreste de La Plata, Buenos Aires, Argentina. *Proc. of the XXXII IAH Congress Groundwater and Human Development*, Mar del Plata (Argentina): 606-612.

BOCANEGRA, E. (1993). Modelación hidrogeoquímica de los procesos de salinización del acuífero de Mar del Plata. In: BOCANEGRA E. and A. RAPACCINI (Eds.), *I Seminario Hispano Argentino sobre Temas Actuales de la Hidrología Subterránea*, Mar del Plata: 349-360.

BOCANEGRA, E., MARTÍNEZ, D., MASSONE, H. and BENAVENTE, M. (2002). Quantitative studies in coastal hydrogeology in Mar del Plata, Argentina. *Proc. of the XXXII IAH Congress Groundwater and Human Development*, Mar del Plata (Argentina): 2004-2011.

GONZÁLEZ ARZAC;, R.; VIZCAINO, A. and CAMPOS ALFONSO, F. (1992). Acuíferos costeros de la Provincia de Buenos

Aires. Consejo Federal de Inversiones, Serie: *Investigaciones Aplicadas, Colección Hidrología Subterránea* Nº 4; Buenos Aires.

KRUSE, E.;, AIELLO, J.L. and FORTE LAY, J.A., (1993). Aspectos hidrológicos en el Oeste de la Provincia de Buenos Aires y Este de La Pampa. República Argentina. *Anais I Simposio de Recursos Hídricos del Cono Sur.*, Gramado (Brasil). 2: 545-551.

KRUSE, E. (1993). Técnicas de estudio en llanuras. Caso: Noroeste de la Provincia de Buenos Aires. *I Seminario Hispano Argentino. Temas Actuales de la Hidrología Subterránea,* Mar del Plata: 287-298.

SALA, J.M., KRUSE, E. and ROJO, A. (1998). Relación aguas en superficie – aguas subterráneas en la Pampasia Bonaerense – Argentina. Actas *X Congreso Latinoamericano de Geología*, Buenos Aires, III: 335-339.

SALA, J.M., BONORINO, A. and CARRICA, J. (1985). Aspectos hidroquímicos del acuífero libre de los alrededores de Ingeniero White, Provincia de Buenos Aires. Actas *I Jornadas Geológicas Bonaerenses*, Buenos Aires: 505-524.