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Estimating the freshwater-lens reserve in the coastal plain of the middle Río de la Plata Estuary (Argentina)

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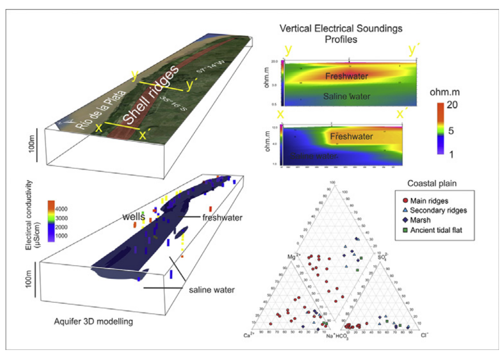
HIGHLIGHTS

- Freshwater source in the Río de la Plata littoral is stored into groundwater lenses.
- Freshwater lenses distribution is linked to the litho-morpho-stratigraphic setting.
- First information is provided to set a preliminary groundwater management plan.

GRAPHICAL ABSTRACT



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ABSTRACT

Drinking-water supply is one of the main issues that populations face in many coastlands. Shallow coastal aquifers are often characterized by the presence of lens-shaped freshwater floating on the saline groundwater plume of marine origin. These groundwater lenses are commonly associated with landforms, such as littoral ridges and dunes and in many cases they represent the main source of water supply in remote coastal areas. At the right side of the middle Río de la Plata estuary (Argentina) the aquifer system is generally saline. Elongated and thin sandy beach ridge systems emerging from the general flat morphology of the marsh-flood plain are capable of storing precipitations forming freshwater lenses, which to date are the main freshwater supply for inhabitants. The aim of this study is to identify and delimitate the presence of such valuable freshwater reserves in order to provide the first necessary guidelines for the water management plan in this area, which has never been implemented since, to the Authors' knowledge, no specific investigation had been carried out before this study. To achieve this goal, Vertical Electrical Sounding, groundwater electrical conductivity measurements, water balances and groundwater chemical analyses were performed and interpreted together. The whole dataset was processed to define the electro-stratigraphic model of the study area and to produce the map of the electrical conductivity of the shallow aquifer. In addition, a three-dimensional model of the fresh water reservoir has been implemented for a better understanding of the relationship between geomorphology and groundwater. Results point out that a total freshwater volume of 78,259,700 m^3 is stored into a continuous lens and the annual average recharge from precipitation amounts to 6,303,500 m^3. Although preliminary, this work provides the basic knowledge on the potential fresh groundwater lenses and provides important information for addressing a sustainable use of the freshwater resource.

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1. Introduction

The majority of the world's population living in coastal areas depends on groundwater for freshwater human consumption, irrigation, farming, industry, tourism and other economic activities. However, many coastal aquifers are severely impacted or threatened by various natural and human-induced processes, among all, saltwater contamination is the most common one (e.g., Pousa et al., 2007; Akinbinu, 2015; Sathish and Elango, 2016; Argamasilla et al., 2017). The distribution of fresh- and salt- groundwater in coastal aquifer systems has been shaped by natural processes acting at geological and continental time scale (e.g., Kooi et al., 2000). However, human activities, such as river diversions, water reclamations, lowland drainage, groundwater exploitation, urbanization and mining, have modified the natural relationship between continental and marine water exchanges leading to a global depletion of freshwater reserves (e.g., Oude Essink, 2001; Antonellini et al., 2008; Bobba, 2017).

Numerous studies document the occurrence of freshwater lenses floating on saltwater in coastal aquifers. Freshwater lenses in coastal aquifers and oceanic islands are the result of rainfall infiltration that accumulates above saline groundwater derived from the sea. In general, the Ghyben–Herzberg theory (Verruijt, 1968) describes the relationship between saltwater and freshwater bodies; it specifically states that the thickness of the freshwater lens is directly related to the elevation of the water table above sea level. Nevertheless, size and shape of the freshwater lenses are controlled by many factors, including subsoil architecture, ground elevation, vegetation covering, land use and groundwater exploitation and recharge. Since the peculiarity of the freshwater presence in atolls and barrier islands, many studies focus on such environments but coastal plains are also relatively well documented. Among such studies addressing atoll groundwater, the knowledge base on the occurrence of freshwater lenses has been consolidated by Werner et al. (2017) who summarized the key processes, investigation techniques and management approaches of atoll island groundwater systems by means of an up-to-date literature review. Regarding the freshwater lenses in coastal plain aquifers, Cozzolino et al. (2017) determined the presence of freshwater lenses below coastal dunes in the north Adriatic Sea (Italy) and highlighted natural and anthropogenic factors affecting groundwater resource such as land cover, local drainage network, and beach erosion. Vandenbohede and Lebbe (2012) studied the presence of freshwater lenses occurring in the central part of the Belgian coastal plain where land reclamation in the past caused freshwater recharge and displacement of the older saltwater. de Louw et al. (2011) investigated the south-western delta of the Netherlands where freshwater availability is limited to shallow rainwater lenses and performed a detailed measurement of the mixing zone between infiltrating fresh rainwater and saline groundwater.

The coastal plain located at the right margin of the Río de la Plata estuary, in the NE sector of the Buenos Aires Province (Argentina), is characterized by a flat morphology drawn by the Pleistocene and Holocene deposits (Cavallotto et al., 2004; Violante and Parker, 2004) in which the aquifer systems and related water quality are strictly linked to the stadial/interstadial sedimentary cycles and controlled by the physiographic setting (Carol et al., 2015a).

The littoral zone is dominated by low-permeability surface sediments associated with coastal plain and marsh environments. The water table is <2 m deep and the hydraulic gradients of both the surface water and groundwater are extremely low. In general, soils and groundwater in the coastland are highly salinized. Freshwater is scarce and stored into shell ridge deposits and thin sandy layers forming lenticular shape reservoirs. Its availability is strictly connected to the amount of local rainfall, which are the only source of aquifer recharge (Carol and Kruse, 2012; Carol et al., 2013). In addition, the freshwater reserve, as well as the wetland ecosystem, is severely compromised by the drainage of excessive water volumes through the system of canals, groundwater mismanagement and exploitations, shell ridge quarry (mining activities) and disposals of sewage (Carol et al., 2015a).

Punta Indio district encompasses a littoral zone extending about 30 km along the middle estuary of the Río de la Plata, 7 km of which are occupied by the homonymous town (Fig. 1). The population of Punta Indio town consists of less than 600 residents (INDEC, 2010). Such number is decreasing (Stratta Fernández and De los Ríos Carmenado I., 2010) because of transformations in the Pampas agriculture (Rabinovich and Torres, 2004) and probably due to the continuous reduction of inhabitants, no water supply network has been already set up and domestic wells are used to supply water for the local residents.

Over the last decades, tourism activities have been developed in the littoral of Punta Indio leading to an increase of 5000 people during summer and weekends (Punta Indio Tourism Authority, personal communication, September 12th, 2017). Consequently, the freshwater demand has increased and new wells were drilled without a specific exploitation planning to prevent the depletion and degradation of fresh water resources.

The aim of this work is to estimate the potentiality of the fresh groundwater reserve in Punta Indio littoral to cope with a sustainable economic development of this sector in the Buenos Aires Province. We used an integrated approach consisting of geophysical surveys, well measurements, geological and geomorphological characterization, and chemical analyses. This study was developed as follows: firstly, morpho-stratigraphic characterization; secondly, groundwater analysis; thirdly, water balance and finally, quantification of the fresh groundwater availability, achieved by a 3D model of the aquifer architecture. A discussion to meet a sustainable groundwater management and the summary of the results conclude our work.

2. Material and methods

The geological setting has been identified by 10 litho-stratigraphic logs obtained by boreholes drilled for water supply and their correlation with those reported in previous studies carried out near the study area (e.g., Cavallotto, 1995; Fucks et al., 2010; Richiano et al., 2012). Furthermore, 20 new exploration sediment cores, about 4-m depth, were taken in order to reach to a better characterization of the stratigraphic architecture of the shallow deposits. Geomorphological units have been identified by field reconnaissance and mapped by satellite images and aerial photographs available from Google Earth and Bing Imagery (Cellone et al., 2016). The regional digital elevation model (DEM) of the Instituto Geográfico Nacional (IGN) Argentino (http://ign.gob.ar/node/987), which consists in the Shuttle Radar Topography Mission (SRTM) data specifically updated for Argentina (IGN, 2016), was used to compute the elevation of the sandy ridges.

A regional groundwater monitoring network based on 29 mills and household wells between 8 and 30 m depth, selected from a census ad-hoc done within this study, has been setup. Hydrological data consists of electrical conductivity (EC) and water level (WL) measures carried out in the monitoring network using portable conductivity meters and water level sensors. Specifically, three groundwater monitoring campaigns have been carried out in September 2015, February 2016 and July 2016.

Additional chemical analyses have been done on 25 water samples taken in July 2016. Water sample collection, preservation and chemical analysis were carried out according to the standard methods proposed by the American Public Health Association (APHA, 1998). Carbonate (CO_3^{2-}), bicarbonate (HCO_3^-), calcium (Ca^{2+}), magnesium (Mg^{2+}) and chloride (Cl^-) were determined by volumetric methods, whereas sodium (Na^+) and potassium (K^+) were determined by flame photometry and sulphates (SO_4^{2-}) were measured by turbidimetry. The analytical error of the samples was, on average, below 4%. Chemical analysis of the major elements was conducted at the Centro de Investigaciones Geológicas (CIG).