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Review

Contribution of electrical resistivity tomography to the study of detrital aquifers affected by seawater intrusion–extrusion effects: The river Vélez delta (Vélez-Málaga, southern Spain)

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A B S T R A C T

The coastal aquifer of the Plio-Quaternary delta sediment deposits of the Vélez river (province of Málaga, Spain) presents a highly irregular basement morphology and widely varying fill thickness (10–80 m between neighbouring sectors). The basin, which is tectonically controlled, is filled with lutite facies alternating with channel-filling rudites. This detrital aquifer is affected by seasonal seawater intrusion–extrusion processes due to increasing withdrawal of groundwater for human consumption and irrigation during dry periods.
A study was performed to improve the hydrogeological knowledge of this coastal aquifer system. The study examined the morphology of the impervious substratum, the facies distribution and the position of the seawater wedge. For this purpose, an Electrical Resistivity Tomography (ERT) geophysical technique was used and the tomographic data were calibrated using geological observations and borehole studies. An analysis was carried out to compare the direct information obtained from the 35 boreholes with the indirect data corresponding to the four electrical tomography profiles. In the study, over 9660 resistivity data points were processed.
The ERT profiles perfectly corroborated the information derived from the boreholes. The profiles made it possible to detect thickness changes, lithological changes and the presence of faults. Moreover, from a hydrogeologic standpoint, this research technique is capable of detecting the position of the phreatic level and, in coastal aquifers such as the one examined in this study, the possible horizontal or vertical penetration of seawater intrusion. Therefore, the electrical geophysical prospecting based on ERT can be highly useful in areas lacking sufficient geological information and/or mechanical borehole data.

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1. Introduction

In studying the thickness and geometry of depositional systems, a common procedure is to make use of information from geological research, drilling and exploitation boreholes. However, these methods are expensive and time consuming, preventing their use on a large scale. Moreover, these types of data are spatially limited. In contrast, geophysical measurements can provide a less expensive way to improve the knowledge of a set of boreholes (Maillet et al., 2005). For this reason, in many cases, geophysical prospecting techniques can provide complementary data that enable geological correlation, even in sectors where there are no data from boreholes (Gourry et al., 2003; Colella et al., 2004; Maillet et al., 2005;

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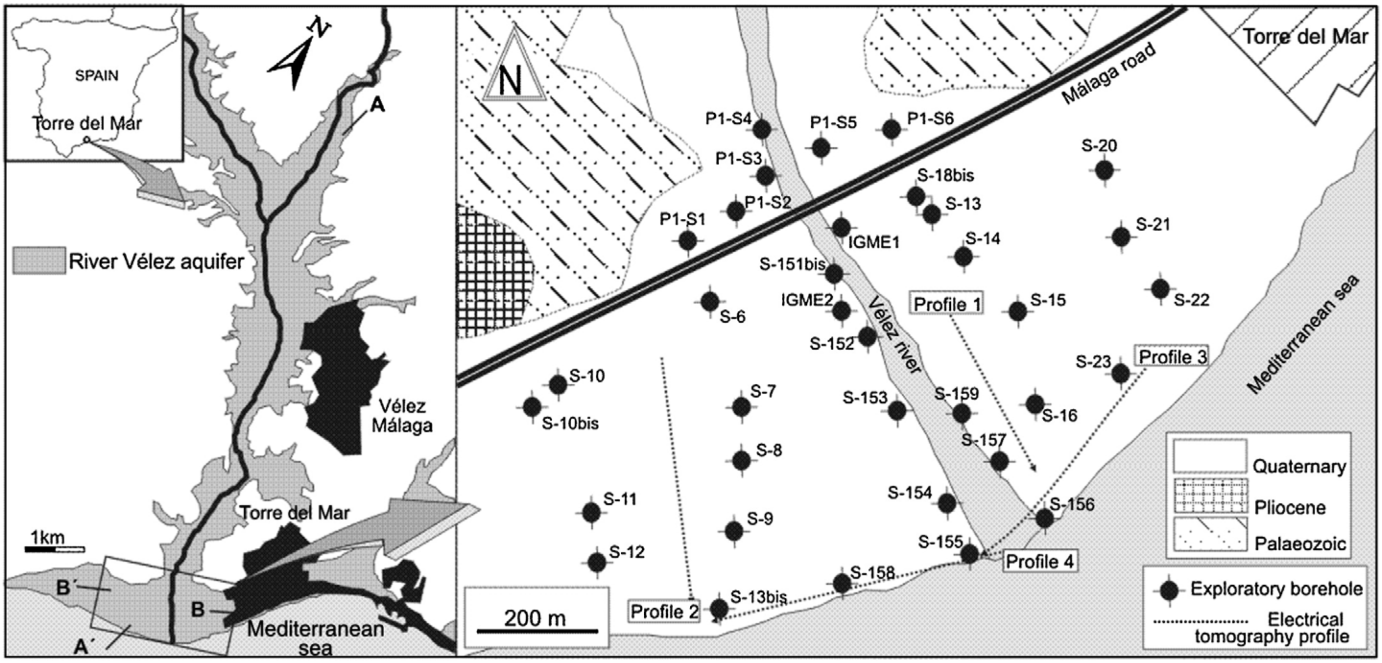

Fig. 1. Geographic situation of the Velez river aquifer and location of the studied deltaic sector. The position of the analysed mechanical boreholes and the spatial distribution of the four electrical tomography profiles are also included.

Sumanovac, 2006; Massey and Taylor, 2007; Naudet et al., 2008). Borehole can provide direct information about the subsoil, but is spatially localised. However, indirect geophysical methods generate continuous data throughout a given profile. Both aspects are of particular interest in this study because block tectonics give rise to significant lithological variations between nearby areas. An accurate determination of the fill geometry is important from a hydrogeological standpoint when assessing available water reserves. It also helps in the understanding of the spatial relations between fresh, brackish and salt water, which commonly coexist in coastal aquifers.

In the last decade, a renewed interest in the geoelectrical method has been observed due to the development of multi-electrode arrays, fast acquisition systems, and new inversion algorithms. As a consequence, this method has been re-applied to a wide spectrum of geological studies. However, relatively few electrical resistivity investigations have been performed in fluvial environments totally or partially saturated with salt or brackish water. Electrical Resistivity Tomography (ERT) has been applied in a sand-infilled paleochannel located in the Rhône Delta (Maillet et al., 2005). Massey and Taylor (2007) used ERT in a study of the coastline of South Devon, South-west England, which is believed to be subsiding rapidly. However, ERT has rarely been used for complex tectonic reconstruction and control of saline intrusions.

This study set out to determine the reliability of indirect data obtained by ERT. To do so, these data were compared with those obtained from a well-documented depositional system, for which information was available from both boreholes and indirect methods. The system in question is that of the delta sediments of the Vélez river, near the town of Torre del Mar (SE Spain) (Fig. 1). A comparison was made with data from the boreholes in the area, on some occasions complemented with piezometric, physical and chemical data on the groundwater, and information from electrical tomography profiles. The aim of this study was to test the efficiency of the ERT technique in determining the geometry of complex depositional systems affected by seawater intrusion while providing knowledge about the hydrogeological setting of the detrital aquifer of the Vélez river basin.

2. Geological and hydrogeological context

The Vélez river basin, with a surface area of 610 km^2, is located in the south-eastern part of the province of Málaga (Spain) on the Mediterranean coast (Fig. 1). The southern sector consists of alluvial deposits with an area of 20 km^2 which form a delta at the river mouth. The alluvial deposits are assumed to be related to the fluvial activity of the Vélez river and its tributaries. In lithological terms, these deposits are made up of gravel, sand and silt of varying thicknesses, which may exceed 80 m (Lario et al., 1995; García-Aróstegui, 1998).These fluvial-deltaic materials comprise a detrital coastal aquifer that is of great interest because of its high degree of permeability and relatively important volume of reserves. In the delta sector, the aquifer (like others on the Spain Mediterranean coast) has a dual-layer arrangement. The lower level is confined, while the upper one is phreatic. Between the two, there is a layer mainly made up of silt. The silt disappears upstream so that this dual-layer arrangement gives way to a single unconfined aquifer. The Palaeozoic substrate of the aquifer is constituted of metapelitic materials from the Alpujarride Complex (Internal Zones of the Betic Cordilleras) and the Benamocarra Unit (Elorza et al., 1981), forming a monotonous series of schists with bluish–grey toned staurolite. Sporadically, the substrate contains marine Mio-Pliocene materials, in which three facies can be distinguished: sands, marly clays and conglomerates. Fig. 2 contains stratigraphic columns elaborated from the borehole data.

The aquifer is located in an area with high water demand for agriculture and human consumption. The demand increases during the summer months because of tourism. Prior hydrogeological studies have been completed, and some have involved mechanical prospection boreholes and the application of geophysical techniques. Furthermore, pumped extraction of water from the aquifer during periods of scarce recharge has provoked an inland advance of several kilometres of the transition zone between fresh and salt water, leading to the salinisation of some wells in the delta sector; however, this process has been found to be reversible after episodes of significant

Fig. 2. Stratigraphic columns from mechanical boreholes located in Fig. 1. The basement consists of Palaeozoic metapelitic materials. The presence of the impervious silt and clay levels led to the identification of an upper unconfined and a lower confined aquifer.