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Recent and old groundwater in the Niebla-Posadas regional aquifer (southern Spain): Implications for its management

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SUMMARY

The Niebla-Posadas (NP) aquifer in southern Spain is one of the main groundwater sources for the lower Guadalquivir Valley, a semiarid region supporting an important population, agriculture and industry. To contribute to the understanding of this aquifer the assessment of sustainable use of groundwater, the residence time of groundwater in the NP aquifer has been estimated using ^{3}H, ^{14}C and ^{36}Cl. Along the flow paths, recharged groundwater mixes with NaCl-type waters and undergoes calcite dissolution and is further modified by cation exchange (Ca–Na). Consequently, the water loses most of its calcium and the residual $\delta^{13}C_{DIC}$ in the groundwater is isotopically enriched. Further modifications take place along the flow path in deeper zones, where depleted $\delta^{13}C_{DIC}$ values are overprinted due to SO_4^{2-} and iron oxide reduction, triggered by the presence of organic matter. Dating with ^{3}H, ^{14}C and ^{36}Cl has allowed the differentiation of several zones: recharge zone (<0.06 ky), intermediate zone (0.06–20 ky), deep zone 1 (20–30 ky), and deep zone 2 (>30 ky). An apparent link between the tectonic structure and the groundwater residence time zonation can be established. Regional faults clearly separates deep zone 1 from the distinctly older age (>30 ky) deep zone 2. From the estimated residence times, two groundwater areas of different behavior can be differentiated within the aquifer.

1. Introduction

With a surface of 60,000 km^2, the Guadalquivir basin is a major geological and hydrological unit in southern Spain, sustaining a population of more than 4 million. It is a semiarid region where the distribution of water resources between human use and the environment is a challenge (CHG, 2012). The Niebla-Posadas (NP) aquifer is one of the main groundwater resources of the lower Guadalquivir basin. It supports traditional agriculture and is a drinking water reserve for many localities, including Seville. Further competition for water resources in recent years in the area has arisen from the expansion of irrigation agriculture, with an increase of 64% of irrigated crop area in the 2000–2011 period (CHG, 2012), gas explorations and the opening of two major open-pit mines. The Cobre Las Cruces (CLC) and Aznalcollar mines (now in the process of reopening after a serious environmental incident about 15 years ago) exploit ore bodies located in contact with the base of the Niebla-Posadas (NP) aquifer. The CLC mining complex is one of the largest open pit mining in Europe. To drain the open pit, a world-class Drainage and Reinjection System (DRS) has been implemented. The DRS is formed by two rings of perimetral wells, one of drainage wells and the other of reinjection wells. The function of this system is to prevent groundwater head drawdown and pollution of the NP aquifer outside the mining project. Farther to the south, the deeper NP sands below the Doñana National Park (>2000 m depth) host gas reserves and the feasibility of temporary CO_2 storage in the sands has been studied.

In NP aquifer, groundwater salinity increases with depth following a characteristic pattern discussed by Tóth (1999), common in many aquifers worldwide (e.g.: Frengstad et al., 2001; Wen et al., 2005; Cloutier et al., 2006; Su et al., 2013; and many others). Furthermore, the complex regional geological structure complicates the identification of flow paths and the assessment of tracer travel

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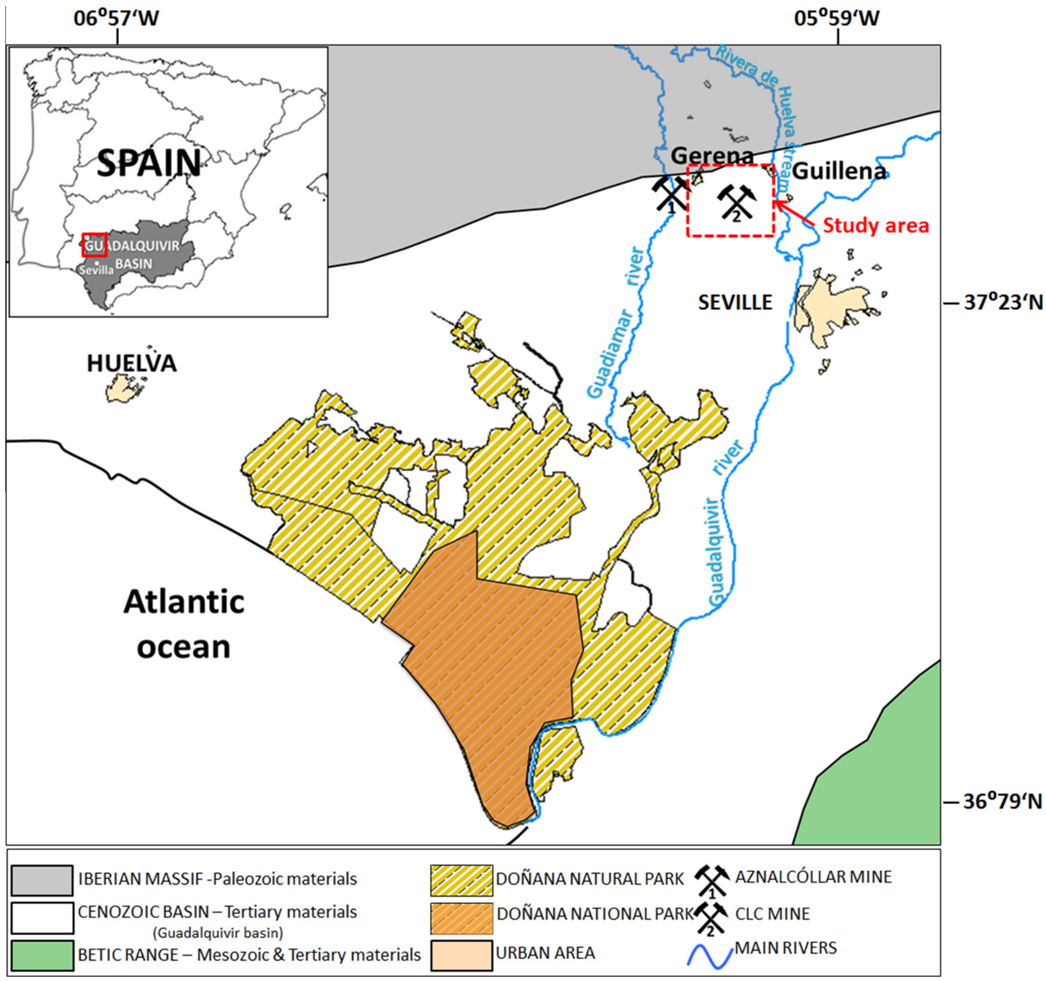

Fig. 1. Regional map with major catchments boundaries and detail of main regional relief units.

times. The consequence is a multiple hydraulic and hydrochemical zonation. All these considerations result in a highly complex hydrogeochemical zonation of the NP aquifer. This generates groundwater management uncertainties that include key issues such as the definition of uses, reserves estimation, water quality degradation induced by mixing and pumping, etc. In summary, the increasing demand for mining and agriculture and the rising public opinion concerns require a clearer assessment of groundwater.

Despite the described setting, no scientifically based assessment of water reserves is available. To respond to these questions, a hydraulic and hydrogeochemical conceptual model is needed. The objective of the present work is to define a methodology based on a combination of hydrogeochemical and isotopic techniques to identify which part of the aquifer contains groundwater that can be regarded as a renewable resource and which part is mostly composed of fossil groundwater. This will enhance the understanding of the groundwater system dynamics and become a support for sustainable management and protection of groundwater resources, which likely can be generalized to other similar studies.

To achieve the defined objective, a hydrogeochemical and groundwater dating study has been carried out. The use of hydrochemistry and environmental isotopes is an effective method to differentiate water–rock interactions and define the origin of groundwater, in order to construct a conceptual model of transfer processes between different aquifer waters (Dogramaci and Herczeg, 2002; Edmunds et al., 2002; Andre et al., 2005; Edmunds, 2009; Cartwright et al., 2010; among many others). Moreover, residence time estimation will be used, employing radioisotopes such as ^{3}H, ^{14}C, ^{36}Cl. This will be crucial to identify the volumes of non-renewable groundwater. A number of studies have used radioisotopes (^{3}H, ^{14}C, ^{36}Cl) to identify ancient and modern recharge and to estimate time scales of groundwater renewal (Bentley et al., 1986; Guendouz and Michelot, 2006; Cartwright et al., 2012; Meredith et al., 2012; Plummer et al., 2012; Cendón et al., 2014).

Some recent works also combine hydrogeochemical and isotopic techniques to estimate recharge sources and residence times to assess the sustainability of regional aquifer water resources development (Bouchaou et al., 2008; Mahlknecht et al., 2006; Sukhija et al., 2006; Douglas et al., 2007; Cresswell et al., 2001; Wallin et al., 2005; Currell et al., 2013; Atkinson et al., 2013). The recent proliferation of mining activities foreseeably makes these techniques the most likely immediate application of the methodology and conclusions of the present paper.

2. Hydrogeological setting

The Guadalquivir depression was formed during the Neogene due to the compression of Africa against Eurasia. It constitutes a foreland basin located between an active edge, the Betic Range, and the passive edge of the old Iberian (Hesperian) Massif (Fig. 1). The northern margin of the Guadalquivir Basin is in contact with