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Isotopic features of Emilia-Romagna region (North Italy) groundwaters: Environmental and climatological implications

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SUMMARY

$^{18}O/^{16}O$, D/H, tritium and carbon isotopes were analysed together with the main geochemical parameters of selected wells of groundwaters in the Emilia-Romagna region. The isotope data collected in a three-year monitoring program of surface waters allowed a subdivision of the studied region within the main feeding areas of the Po and Apennine Rivers. The isotopic investigation demonstrated the existence of palaeowaters hosted in deep aquifers in the plains and their overexploitation, which induced land subsidence phenomena. Groundwater stable isotopes have been utilized as a proxy for temperature and have shown significant atmospheric temperature variations over the past 30,000 years.

1. Introduction

The Emilia-Romagna region has a surface area of 22,123 km^2 and is situated geographically in the southern part of the Po valley. It is bounded by the Northern Apennines to the South and by the Adriatic Sea to the East. The Po valley sedimentary basin has been subsident during the Neogene, allowing the fulfillment by sediments coming from Apennines and the Alps. Sediments coming from Apennines and Alps generated aquifers characterized by hydrogeological features previously summarized by Idroser (1977), by Antonelli et al. (1981) and by the Regione Emilia Romagna, ENI-AGIP (1998).

The region's population in excess of 3 million inhabitants uses large amounts of water for public, industrial and agricultural purposes, with over 60% of the supplies drawn from about 100,000 wells whose depths range between 10 and 700 m. Most of the wells lie in the foothills of the Apennine chain in aquifers of a non-confined, semi-confined and confined type in areas of conoid generated by the course of the rivers of Apennine origin. A large number of wells is also situated in the low and medium plain areas to the south of the Po river that draw water from confined aquifers. The high consumption levels (736 million m^3/year, Bonsignore et al., 2008) have generated land subsidence phenomena of 10–40 mm/year in main towns along with a deterioration in the quality of the underground waters (Carminati and Martinelli, 2002). During 2009 and 2010 a detailed survey on a network composed by 52 phreatic wells network was carried out by ARPA Emilia Romagna (Chahoud et al., 2011). Phreatic aquifer is characterized by a depth to water in the range 1–7.5 m while the average yearly excursion is around 1.2 m. Monitoring surveys allowed to establish that recharge of phreatic aquifer is mainly due to local rainfalls while rivers and a dense channels network drain phreatic aquifer. Isotopic analysis carried out on groundwaters sampled in selected phreatic wells by Olive (1977), Venturini et al. (1990), Dadomo and Martinelli (2005), Barbieri and Martinelli (2007), Rapti-Caputo and Martinelli (2009), Mollema et al. (2013) and this study evidenced an average value of −7.95 $^{18}O/^{16}O$ (see Supplementary data, sheet 1) and −53.4 D/H in plain areas, very similar to the average isotopic values reported by Longinelli and Selmo (2003) for local precipitations (e.g. −7.50 $^{18}O/^{16}O$, −48.8 D/H, in Bologna) in plain areas.

Shallow groundwaters are insulated from deep aquifers by clay lenses in all the medium and low plain and previous studies did

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not evidence significant recharge contributions to deep aquifers in all the plain area not characterized by Apenninic derived alluvial fans (Dadomo and Martinelli, 2005; Regione Emilia-Romagna-ARPA, 2006; Chahoud et al., 2009).

A comparison of piezometric levels (Fig. 1) and precipitation data does not evidence important recent natural water recharge at depths > 100 m in the southern part and at depths > 50 m in the central and northern parts of the plain (Albarello and Martinelli, 1994) and a groundwater deficit of at least $24 * 10^6\ m^3$ was recognized (Regione Emilia-Romagna-ARPA, 2006). Higher deficit values were recently estimated by Chahoud et al. (2009). This findings have made it even more important to gain a better knowledge of the processes for feeding and recharging the Emilia-Romagna aquifer by means of isotopic techniques. Geochemical and isotopic values measured in groundwaters were previously reviewed by Martinelli et al. (1998), Conti et al. (2000) and Dadomo and Martinelli (2005) and considered in Regione Emilia-Romagna-ARPA (2006). Previous investigations oriented to a preliminary description of palaeoclimatic trends in the Po valley by isotopic data (Gorgoni et al., 1982; Zuppi and Sacchi, 2004; Pilla et al., 2006) evidenced that underground waters may act as a natural archive of recent and past palaeoclimatological trends. A detailed isotopic investigation was carried out in order to better investigate the environmental consequences of groundwater overexploitation of main deep aquifers located in the plain area (11,500 km^2) and past and present climatological features from groundwater archives.

2. Geological and hydrogeological setting

The Quaternary sediments (Fig. 2) are mainly continental and gravels correspond to the Apennine alluvial fans while sandy-clay layers have been mainly transported by the Po river. Gravels are mostly constituted by arenaceous and calcareous sandstones while clays are prevalently illitich and chloritic. Sands deriving by Apenninic sources are mainly composed by quartz and feldspars while sands deriving by Alpine sources are composed by quartz, feldspars, micas and femic minerals. The grain size of the sediments is frequently dependent on the eustatic–climatic oscillations at the scale of 20–40 kyrs. These sediments lie on a pre-Holocene substratum constituted by impermeable marine formations of the Calabrian-Pliocene age (Regione Emilia Romagna ENI-AGIP, 1998). In the upper plain thickness of the alluvial deposits varies from 50 to 200 m. It reaches 400–500 m east of Parma while, south of the Reno river, gravel fans are less extensive and they dip under the Adriatic Sea near Rimini. The middle part of the plain is mainly characterized by clay and clay sandy sediments, which separate Apennine derived coarse sediments by Po river-derived fine sediments. The thickness of the Quaternary alluvial cover is over 700 m in this area. In the northern part of the plain (low plain) alluvial deposits derived from the Po river occur. These deposits consist of alpine thick interbedded sandy and clayey layers (Antonelli et al., 1981; Ori, 1993). The upper part (0–30 m) of aquifer is in phreatic conditions while confined conditions prevail at depth. The Emilia Romagna plain lies on a series of fold-faulted Apenninic terrains dipping northward in a tectonic regime characterized by an NE compression (Baldi et al., 2011 and references therein).

These marine terrains partially emerged during the Pliocene period (Ghielmi et al., 2010) originating a significant Na–Cl contamination of local aquifers (Fig. 5). Brackish waters follow the topography of Pliocenic formations and are characterized by TDS in the range 3–25 g/L (see also ENI, 1972; Antonelli et al., 1981; AGIP, 1994; Regione Emilia Romagna ENI-Agip, 1998) (Fig. 2 and Fig. 5). The thickness of the Quaternary sediments is limited to < 100 m in the Mirandola area, north of Modena (Figs. 2 and 5).

In alluvial Apenninic fans hydraulic gradients are relatively high up to 10‰ due to topographic differences and to the presence of coarse sediments while in the Apenninic plain are in the range of 1–2‰. In the Po river plain area hydraulic gradients are very low (0.2–0.3‰) due to low topographic differences and to the presence of fine sediments like sands and clays (Figs. 1 and 2). Groundwater velocity can reach 2–4 m per day in high recharge areas of alluvial apenninic fans while velocities are strongly reduced in the plain area up to 0 m per day (Regione Emilia-Romagna-ARPA, 2006).

3. Parameters analyzed and methods

Two prospecting campaigns were carried out. The first one was performed in July 2001 (208 samples) and the second in February 2002 (208 samples) (Fig. 3). Water temperature, Electric Conductivity, pH and Eh were measured on site.

The following chemical parameters were determined in the laboratory: HCO_3^-, Cl^-, SO_4^{2-}, Ca^{2+}, Mg^{2+}, Na^+, K^+, Si, NO_3^-, NH_4^+. The following stable isotope ratios were analyzed: $^{18}O/^{16}O$, D/H. Tritium, carbon 13 and carbon 14 were determined in selected samples.

Fig. 1. Piezometric levels of groundwaters in Emilia-Romagna region (Regione Emilia-Romagna-ARPA, 2006, updated).