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The impact of river infiltration on the chemistry of shallow groundwater in a reclaimed water irrigation area

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ABSTRACT

Reclaimed water reuse is an effective method of alleviating agricultural water shortages, which entails some potential risks for groundwater. In this study, the impacts of wastewater reuse on groundwater were evaluated by combination of groundwater chemistry and isotopes. In reclaimed water infiltration, salt composition was affected not only by ion exchange and dissolution equilibrium but also by carbonic acid equilibrium. The dissolution and precipitation of calcites and dolomites as well as exchange and adsorption between Na and Ca/Mg were simultaneous, leading to significant changes in Na/Cl, (Ca + Mg)/Cl, electrical conductivity (EC) and sodium adsorption ratio (SAR). The reclaimed water was of the Na-Mg-Ca-HCO_3-Cl type, and groundwater recharged by reclaimed water was of the Na-Mg-HCO_3 and Mg-Na-HCO_3 types. The hydrogeological conditions characterized by sand-clay alternation led to both total nitrogen (TN) and total phosphorus (TP) removal efficiencies >95%, and there was no significant difference in those contents between aquifers recharged by precipitation and reclamation water. >40 years of long-term infiltration and recharge from sewage and reclaimed water did not cause groundwater contamination by nitrogen, phosphorus and heavy metals. These results indicate that characteristics of the study area, such as the lithologic structure with sand-clay alternation, relatively thick clay layer, and relatively large groundwater depth have a significant role in the high vulnerability.

1. Introduction

Water shortages in arid and semiarid regions become increasingly prominent, which promotes wastewater irrigation worldwide (Bouri et al., 2008; USEPA, 2012; Chopra and Pathak, 2015). Agricultural wastewater reuse reduces the use of chemical fertilizers (Rosenqvist and Dawson, 2005; Teklehaimanot et al., 2015) and increases production (Xu et al., 2010; Wu et al., 2010). But, wastewater reclamation could potentially increase the risk of surface water and groundwater contamination (McArthur et al., 2012; Zhang et al., 2013; Teklehaimanot et al., 2015).

Sewage has a relatively high sodium adsorption ratio (SAR), and exchange between sodium and calcium ions may increase salinity during infiltration (Jain et al., 2005; Kass et al., 2005; Candela et al., 2007; Bouri et al., 2008). The infiltration of sewage irrigation may cause groundwater contamination by nitrogen (Jiang et al., 1997; Mitra and Gupta, 2000; Kass et al., 2005; Yin et al., 2012) and heavy metals (Weng and Chen, 2000a, 2000b; Rattan et al., 2005). However, other studies have presented opposite results, indicating that irrigation with sewage containing high concentrations of heavy metals does not pollute groundwater (Mooers and Alexander, 1994; Stuart and MILNE, 2001; Yadav et al., 2002; Domínguez-Mariani et al., 2004). Scholars have stated that groundwater contamination by sewage irrigation depends on groundwater vulnerability (Liu et al., 2006; Quayle et al., 2010), and groundwater pollution risk is assessed by matching land use using DRASTIC model (Shirazi et al., 2013). The stable isotope method was used for quantitative evaluation of groundwater recharge sources in a sewage irrigation district (Domínguez-Mariani et al., 2004; Kass et al., 2005; Chen et al., 2006; Li et al., 2012). There are few in situ investigations focusing on the impacts of long-term continuous infiltration of river water on groundwater chemistry in reclaimed water irrigation districts.

The main objectives of this study were as follows: (1) to evaluate recharge sources of different aquifers under reclaimed water infiltration by stable hydrogen and oxygen isotopes; (2) to identify the impacts of reclaimed water infiltration on water quality of different aquifers, including of salinity, nitrogen and heavy metals; (3) to investigate

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groundwater vulnerability and removal efficiency of major types of pollutants such as nitrogen, phosphorus and heavy metals, in sand-clay alternating hydrogeological conditions.

2. Materials and methods

The study area is located at Nanhongmen reclaimed water irrigation area (NRWIA), Daxing District, which is 13,300 ha. Quaternary sediment of the study area consists of an aquifer with a sand-clay alternating multilayer structure. The aquifer is recharged by precipitation infiltration and the leakage of river, canal and farmland irrigation. Groundwater discharge is mainly evapotranspiration and lateral outflow. Annual average rainfall in the area is 504 mm, and annual average evaporation is 979 mm. NRWIA began to use urban sewage to irrigate farmlands in 1969 and reclaimed water for that purpose in 2003, representing a sewage irrigation history of 40 years. Currently, 90 million m^3 of reclaimed water with secondary treatment at the Xiaohongmen sewage treatment plant is used annually, and a total of 2 billion m^3 of sewage and reclaimed water have been used since 1969. The Fenghe River (FHR) is a major canal for water transportation and drainage in NRWIA, and its infiltration rate is 1.2 cm/d. It flows into Hebei Province in the Anci District of Langfang City. The annual runoff of FHR is 10,000,000 m^3, including 80% of reclaimed water. Research wells are located on the river's left bank. Groundwater is at depths 7–12 m, with flow direction from northwest to southeast (Fig. 1).

2.1. Research wells and sampling

Fig. 1 shows that monitoring sites were north of the Fengheying gate, downstream of NRWIA. The three monitoring holes, WC, WM and WF, were drilled on the left bank of the river at respective distances of 5, 25 and 50 m from the bank. Nine groundwater-monitoring wells in the three monitoring holes were set up in different groundwater aquifer depths of 17–24 m (WC1, WM1 and WF1), 28–32 m (WC2, WM2 and WF2), 45–53 m (WC3, WM3) and 68–72 m (WF3), respectively. A 4-m permeable steel pipe with quartz sand as filter material was placed at the end of each well pipe, and the remainder of the pipe was placed with impermeable steel. The impermeable segments were sealed with clay balls to avoid groundwater connectivity between different aquifers. Locations of the nine monitoring wells are shown in Fig. 2.

During the study period (May 2010–September 2013), water chemicals for heavy metals and ions were sampled 20 times. Meanwhile D and ^{18}O isotopes were measured 11 times (July 2011–September 2013). A submersible pump was used to withdraw groundwater samples. Flow rate of the pump was 2 m^3/h, and it began pumping 30–45 min prior to each water sampling to ensure representativeness of

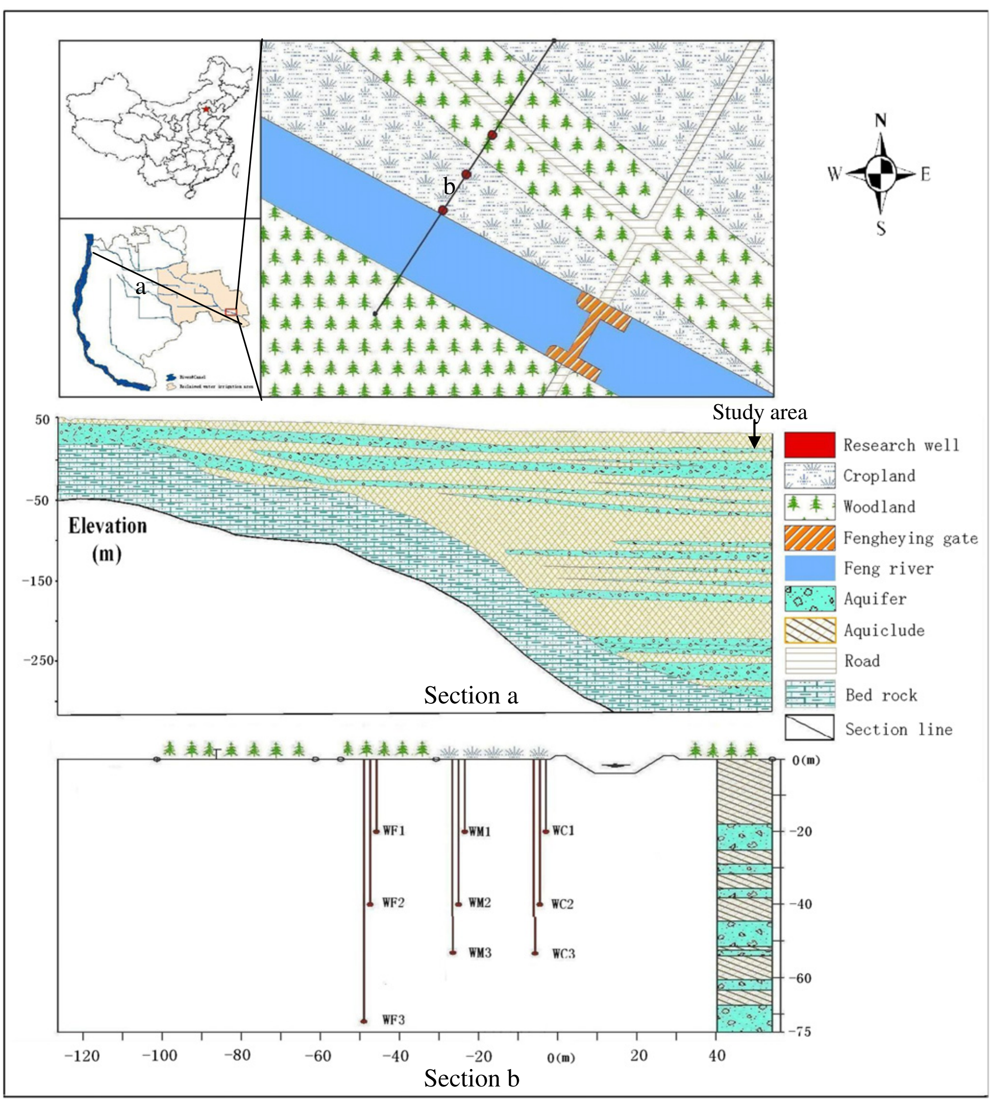

Fig. 1. Plan view, regional cross-sectional hydrogeological profile (section a) and location of research wells (section b) of study area.