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Multi-component transport and transformation in deep confined aquifer during groundwater artificial recharge

Wenjing Zhang [a, b, *], Ying Huan [b], Xipeng Yu [b], Dan Liu [b], Jingjing Zhou [b]

[a] College of Water Sciences, Beijing Normal University, Beijing 100875, China
[b] College of Environment and Resources, Jilin University, Changchun 130021, China

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ABSTRACT

Taking an artificial groundwater recharge site in Shanghai, China as an example, this study employed a combination of laboratory experiment and numerical modeling to investigate the transport and transformation of major solutes, as well as the mechanism of associated water-rock interactions in groundwater during artificial groundwater recharge. The results revealed that: (1) Major ions in groundwater were mainly affected by mixing, ion exchanging (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}), as well as dissolution of Calcite, Dolomite. Dissolution of carbonate minerals was not entirely dependent on the pattern of groundwater recharge, the reactivity of the source water itself as indicated by the sub-saturation with respect to the carbonate minerals is the primary factor. (2) Elemental dissolution of As, Cr and Fe occurred in aquifer was due to the transformation of subsurface environment from anaerobic to aerobic systems. Different to bank filtration recharge or pond recharge, the concentration of Fe near the recharge point was mainly controlled by oxidation dissolution of Siderite, which was followed by a release of As, Cr into groundwater. (3) Field modeling results revealed that the hydro chemical type of groundwater gradually changed from the initial $Cl{-}HCO_3{-}Na$ type to the $Cl{-}HCO_3{-}Na{-}Ca$ type during the recharge process, and its impact radius would reach roughly 800 m in one year. It indicated that the recharge pressure (approx. 0.45 Mpa) would enlarge the impact radius under deep well recharge conditions. According to different recharge modes, longer groundwater resident time will associate with minerals' fully reactions. Although the concentrations of major ions were changing during the artificial recharge process, it did not pose a negative impact on the environmental quality of groundwater. The result of trace elements indicated that controlling the environment factors (especially Eh, DO, flow rate) during the recharge was effective to reduce the potential threats to groundwater quality.

1. Introduction

Groundwater is an important natural resource with high economic value and social significance, which is considered as a readily available water source for domestic, agricultural and industrial uses. However, in many areas, the over-exploitation of groundwater has given rise to a continual decline of water table as well as frequent environmental-geological problems, such as land subsidence and cracking and seawater intrusion. Therefore, many areas have performed a series groundwater artificial recharge projects, which had played a significant role in controlling these problems. For example, in China Wu et al. (2009) carried out a series experimental research on artificial recharge in shallow aquifer to control land subsidence in Shanghai city. Zuurbier et al. (2011) applied the Aquifer Storage and Recovery (ASR) system in water supply and water reuse for irrigation. In 2013 Zuurbier et al. also implemented performance estimation to identify the potential sites for ASR in coastal areas. In order to manage seawater intrusion, some numerical models were adopted by Ward et al. (2008) to explain the importance of anisotropy and layered heterogeneity in saline aquifers occurred during ASR. Studies mentioned above were mainly focused on how to recharge the water into the aquifer, as well as how to control the related environmental-geological problems. However, it remains unclear whether the implementation of artificial recharge could pose negative impacts onto the groundwater quality.

In order to answer these questions, several studies have been

* Corresponding author. College of Water Sciences, Beijing Normal University, Beijing 100875, China.
E-mail address: zhangwenjing80@hotmail.com (W. Zhang).

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carried out and some research results have been published in the recent years (Tredoux et al., 2009; Goren et al., 2011). It was demonstrated that groundwater quality within 25 m radius of the recharge wells was mainly affected by the dissolution of carbonate (Andrew et al., 2004). Some results indicated that oxidation of pyrite and organic matter domination was the key reactions in a deep confined aquifer recharge. In addition, Price and Pichler (2006) revealed that groundwater recharge process could alter redox conditions in an aquifer, which would lead to variations in the stability of As-containing minerals, and would further result in As concentrations exceeding the standard for drinking water quality post-recharge. Massmann et al. (2006) indicated that during artificial recharge variable temperatures would affect the groundwater redox conditions, and variable redox conditions would further influence the behavior of a number of pharmaceutically active compounds. Obviously, it is a complex process including physics, chemistry even biological reactions occurred in the aquifer system. These previous findings have offered some useful mechanism to understand the water-rock interaction. But it is still hard to determine the impact scope and degree of the groundwater quality during these recharge process. Some quantitative evaluation based on these physics, chemistry even biological reactions should be further developed and discussed.

Therefore, on the basis of understanding of the geological, hydrogeological and hydro geochemical conditions of the test site, laboratory experiments and numerical modeling (model aquifer and field aquifer) were conducted in this study. It aims to give a quantitative evaluation on the transport and transformation of multi-component solutes in groundwater during a deep confined aquifer recharge process, as well as to reveal the associated water-rock interactions according to its specific subsurface condition and recharge method. Based on this research, some useful information could be offered to estimate the impact scope and degree of groundwater quality during the artificial recharge process, and that also could be used to conduct the further artificial recharge implementation.

2. Materials and methods

2.1. Field condition

The groundwater artificial recharge site situated in northern Shanghai, South East China (Fig. 1). The site was designed to prevent and control land subsidence through injecting surface water into the aquifer. Before performing this project, some questions should be answered, especially how is the groundwater quality going? In order to find the key, the related research has been implemented in this article.

The site is underlain by a sequence of Quaternary sediments, the widely distributed aquifer system of which consists of 5 aquifers from top to bottom, including: the Holocene unconfined aquifer, the first and second Late Pleistocene confined aquifers (I, II), the third Middle Pleistocene aquifer (III), and the fourth and fifth Early Pleistocene aquifers (IV, V) (Fig. 2). According to the water storage capability, Aquifer IV was chosen as the target aquifer. The lithology of Aquifer IV consists of gravel, medium coarse sand with fine sand, where the single borehole yield is around 3000–5000 m^3/d. The thickness of the target aquifer is approximately 50 m with 170 m depth. Hydraulic connections between Aquifer IV with Aquifer III and Aquifer IV have been cut off owing to the solid clay deposits above and beneath Aquifer IV. The flow direction of groundwater within this aquifer is from North to South with a hydraulic gradient at approximately 0.3‰. The velocity of groundwater runoff within this aquifer is relatively slow.

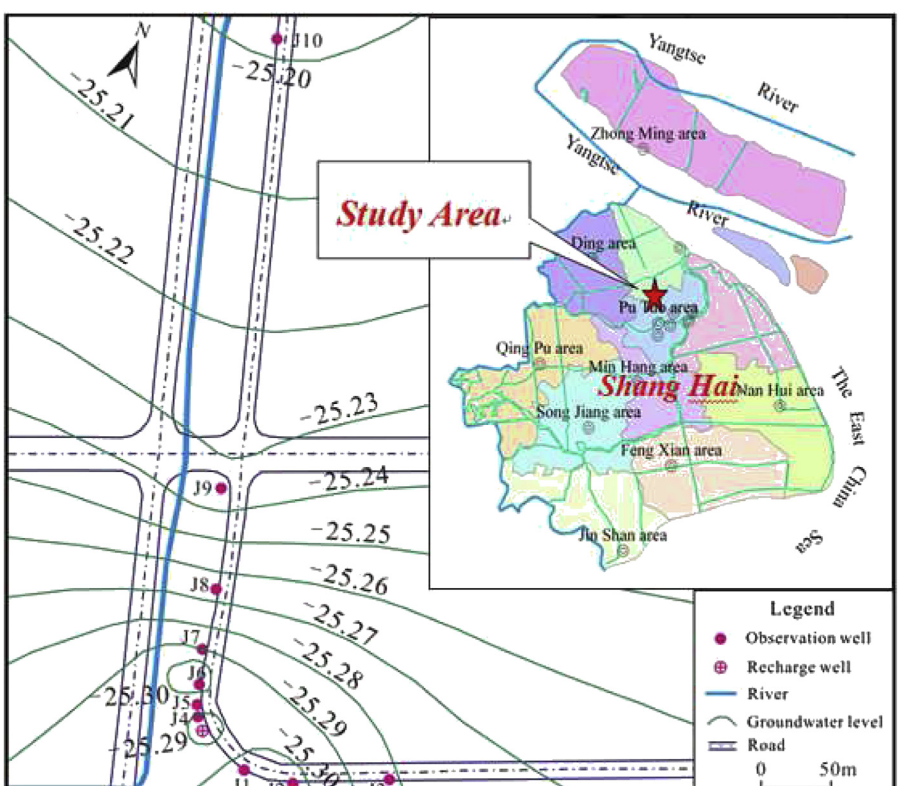

Fig. 1. Test site location and groundwater flow field of the Aquifer IV.