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Characteristics of change in water quality along reclaimed water intake area of the Chaobai River in Beijing, China

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ABSTRACT

To reveal the basic characteristics and controlling factors of water quality change in the project Wenyu to Chaobai reclaimed water diversion, the water quality in the study area was monitored for one year at seven monitoring sites. Inverse geochemical models of the statistical groups were developed using PHREEQC to elucidate the hydrochemistry characteristics of reclaimed water and the factors. The monitoring results indicated that nitrogen and phosphorus contents were significantly reduced along the river mainly caused by seasonal and location variation. The pH ranged from 7.44 to 9.81. Photosynthesis of algae and denitrification in anaerobic microenvironment ultimately led to a sudden pH increase after the Jian River and the Chaobai River confluence. Mg^{2+} and SO_4^{2-} levels dropped obviously in the summer and increased in winter seasons after intersection. Na^+ and Cl^- are relatively stable, and marked drop in the concentration only after the two rivers meet. And there is a decrease of Ca^{2+} and HCO_3^- and increase in CO_3^{2-} during monitoring period. As a whole, the primary ions and nutrient components, including nitrogen and phosphorus, had high levels in winter. Algae's photosynthesis and respiration were observed to have an impact on the river water quality; there was precipitation–dissolution of minerals and denitrification from upstream to downstream. Inverse geochemical PHREEQC modeling confirmed that there was precipitation of aragonite or calcite, and gypsum or anhydrite in summer, and dissolution in winter; as well as precipitation of dolomite in winter, and cationic exchange and denitrification along the river.

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Introduction

With the rapid increase of the population and deterioration of water resource in the world, it has made the reuse of reclaimed water even more important than ever, especially in China (Chiou et al., 2007; Yi et al., 2011). There were more than 3300 reclaimed water utilization projects, mainly distributed in Japan, United

States, Australia, and some other countries and regions in the Europe (Kim et al., 2012). Reclaimed water could be reused in river supply, industrial use, municipal use and groundwater recharge (Jamwal and Mittal, 2010; Jang et al., 2010; Yi et al., 2011). However, reclaimed water contained high salts, nitrogen (N), phosphorus (P) and a variety of trace toxic substances (toxic ions, organic pollutants, etc.) and pathogens, which could not be completely

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removed in wastewater treatment plants. And long-term reuse of reclaimed water may conceivably lead to ecological risk (Huang and Wang, 2009; Liu et al., 2005; Wang et al., 2010; Yan, 2009; Zou et al., 2002). Therefore, this study focused on the Wenyu to Chaobai reclaimed water diversion project, which was the most important reclaimed water utilization project in Beijing. On the base of a typical case study, to research on the water quality variation characteristics of rivers recharged by reclaimed water.

To ease the water supply shortage in Chaobai River, the Beijing Water Authority implemented the Utilization of Water Resources from Wenyu River in Shunyi New City project (shortened to Wenyu to Chaobai reclaimed water diversion project) in 2006 (Huang et al., 2010). In the project, reclaimed water was transported from the Wenyu River to the Chaobai River through the Jian River in Shunyi District. The transport capacity was designed to be 38,000,000 m³ each year. The project was completed in October 2007 (Wang et al., 2009), and enabled the introduction of water into the Chaobai River to be used as eco-environmental improvement and to recharge the groundwater. However, in the initial monitoring process, it was found that the water quality, in particular, the pH value, had changed from the replenishing outlet of the Jian River to the Chaobai River. He et al. (2009) showed that the maximum pH was very high in the study area. The change in the reclaimed water quality has an important impact on the ecological environment of the river and the surrounding groundwater environment. It was suggested that the basic principle, changing approaches, effects, and controlling factors on the watercourse ecological environment were most likely caused by the altered water quality, especially pH > 10 (Asano and Cotruvo, 2004). This had important and practical implications in terms of exploring effective ways of safe utilization of reclaimed water and proposing reasonable measures to avoid harming the river ecosystems.

The objective of this study is to understand the present water environment and the changes of the water quality after Wenyu River water from Shunyi New City was transported to the Chaobai River. The seasonal and spatial variations of water quality in the reclaimed water intake area were investigated based on one year monitoring data and the inverse geochemical modeling PHREEQC. Factors controlling the changes of water quality were discussed.

1. Materials and methods

1.1. Study area

The studied intake areas were the Jian River (north of the Beijing city) and downstream of the Chaobai River (from the intersection of the Jian River and Chaobai River to Xiangjiao Dam in Henan Village). The Jian River and the Chaobai River were wadies before Wenyu River water from Shunyi New City transporting into the Chaobai River in 2007. Stream of the Chaobai River between Xiangyang Brake and intersection with the Jian River had not yet been impounded during the monitoring period because there was an earth dam set near the intersection to avoid water flowing into this river reach (Fig. 1). And just the stream between Jian River and Xiangjiao Dam in Henan Village maintained a certain water surface about 2.5 m in average. Water supplement resources were just

rainfall and replenished reclaimed water. Seven water quality monitoring cross-sections were setup throughout the studied river reach, including (along river direction) the Jian river replenishing outlet (#1), Wolong Park north bridge (#2), west pavilion of Shuangxing (#3), Jian River (#4), intersection of the Chaobai river and the Jian river (#5), opposite of Binhe housing estate (#6), and Xiangjiao Dam of Henan Village (#7). The specific locations can be seen in Fig. 1.

1.2. Sampling and testing

There was obvious seasonal variation in river water quality in the study area, so the sampling time interval was 20–30 days, from August 2012 to July 2013, and would be adjusted according to the seasons over the course of one year. Water samples were collected and tested under the guidelines of the Regulation for Water Environmental Monitoring (SL219-98). Water samples were collected by polyethylene plastic bottles. At the first four monitoring points (#1–#4), water samples were collected at a depth of 0.5 m, while other three water samples (#5–#7) were collected at depths of 0.5, 1, and 1.5 m, respectively. The sample bottles were sealed with parafilm and shielded with black plastic bags. To ensure the stability of monitoring indicators, pH of the water samples used to test cations was adjusted with HNO₃, and pH of samples used to test the other indicators was adjusted to <2 with H₂SO₄.

Field environmental parameters, including water temperature, pH, redox potential, dissolved oxygen (DO), turbidity, electric conductivity (EC), and total dissolved solids (TDS). The inorganic ions detected were potassium (K⁺), sodium (Na⁺), calcium (Ca²⁺), magnesium (Mg²⁺), chloride (Cl[−]), sulfate (SO₄^{2−}), carbonate (CO₃^{2−}), and bicarbonate (HCO₃[−]). The nutrients monitored including total organic carbon (TOC), suspended solid (SS), nitrate-nitrogen (NO₃-N), nitrite-nitrogen (NO₂-N), and ammonia-nitrogen (NH₄-N). The monitoring indicator for algae was chlorophyll-*a*. Field environmental parameters were measured with a Multi-Parameter Water Quality Monitor (EUREKA, USA). Other water quality indicators were detected in accordance with Water and Wastewater Monitoring Analysis Method (Grady et al., 2002).

1.3. Establishment of PHREEQC modeling

PHREEQC is hydrogeochemistry simulation software developed by the United States Geological Survey. It is a computer program written in the C programming language, and is designed to perform a wide variety of low-temperature aqueous geochemical calculations (Parkhurst and Appelo, 1999). Inverse geochemical modeling in PHREEQC is used to deduce geochemical reactions that account for changes in the chemical composition of water along a flow path (Charlton et al., 1997). At least two chemical analyses of water are needed at different points along the flow path, as well as a set of phases that are potentially reactive along the flow path.

Based on the observed hydrochemical data, inverse geochemical modeling can extrapolate possible water-rock reactions, which could explain the observed hydrological data.

- (1) Simulation path and mineral facies. Because of hydrochemistry analysis results had obvious inconsistencies

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