JOURNAL OF ENVIRONMENTAL SCIENCES 45 (2016) 60–75

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JES JOURNAL OF ENVIRONMENTAL SCIENCES www.jesc.ac.cn

Field scale interaction and nutrient exchange between surface water and shallow groundwater in the Baiyang Lake region, North China Plain

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ARTICLE INFO

Article history:
Received 20 August 2015
Revised 29 October 2015
Accepted 2 November 2015
Available online 27 January 2016

Keywords:
Groundwater pollution
North China Plain
Surface water–groundwater interaction
Wheat–maize double cropping
Nitrogen
Anammox

ABSTRACT

Fertilizer input for agricultural food production, as well as the discharge of domestic and industrial water pollutants, increases pressures on locally scarce and vulnerable water resources in the North China Plain. In order to: (a) understand pollutant exchange between surface water and groundwater, (b) quantify nutrient loadings, and (c) identify major nutrient removal pathways by using qualitative and quantitative methods, including the geochemical model PHREEQC) a one-year study at a wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) double cropping system in the Baiyang Lake area in Hebei Province, China, was undertaken. The study showed a high influence of low-quality surface water on the shallow aquifer. Major inflowing pollutants into the aquifer were ammonium and nitrate via inflow from the adjacent Fu River (up to 29.8 mg/L NH_4-N and 6.8 mg/L NO_3-N), as well as nitrate via vertical transport from the field surface (up to 134.8 mg/L NO_3-N in soil water). Results from a conceptual model show an excess nitrogen input of about 320 kg/ha/a. Nevertheless, both nitrogen species were only detected at low concentrations in shallow groundwater, averaging at 3.6 mg/L NH_4-N and 1.8 mg/L NO_3-N. Measurement results supported by PHREEQC-modeling indicated cation exchange, denitrification, and anaerobic ammonium oxidation coupled with partial denitrification as major nitrogen removal pathways. Despite the current removal capacity, the excessive nitrogen fertilization may pose a future threat to groundwater quality. Surface water quality improvements are therefore recommended in conjunction with simultaneous monitoring of nitrate in the aquifer, and reduced agricultural N-inputs should be considered.

Introduction

Water pollution by nitrogen fertilizers has been recognized as a common environmental impact of agricultural activities in many regions (Costa et al., 2002; Rupert, 2008; Strebel et al., 1989; Zhang et al., 1996). However, as the world is facing demands for food that are estimated to increase by up to 70% by 2050 (Nelson, 2010), production – and therewith fertilization – must be kept high. To

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http://dx.doi.org/10.1016/j.jes.2015.11.021

protect the equally important water resources, concurrent environmental monitoring and management of the local surface waters and aquifers are crucial. Because pollution sources and pathways in agricultural systems can show large spatial variability, knowledge of regional features and field scale interactions is an important area of research that gives base for the development of appropriate monitoring strategies—and the necessary protection measures.

China is the largest producer of grain worldwide, and has undergone large agricultural yield improvements for the three main staple foods (wheat, maize, and rice) in recent decades. In this way, the government's explicit goal to keep at least close to self-reliant in food has been fulfilled, despite the fact that it has to feed 20% of the world's population while relying on only 8% of the world's arable land. One of the most important production areas in the country is the North China Plain (NCP), which encompasses the northeastern provinces of Beijing, Hebei, Shanxi, Shandong, and parts of Henan. The dominant agricultural production system in the NCP is a rotation of irrigated winter wheat (*T. aestivum* L.) and rainfed maize (*Z. mays* L.), of which the NCP produced 61% (wheat) and 39% (maize) of China's national output in 2012 (Zhao and Guo, 2013). Current enhancements in the productivity of the NCP have been driven by two major management changes: the expanded use of inorganic fertilizer since the 1970s, and the increase in irrigation (Li et al., 2011) that enables the harvest of two crops per year. However, the growth in production is taking a toll on the environment, and recent studies report overexploitation of local water resources with observed groundwater (GW) level declines of up to 1 m per year (Liu et al., 2008), as well as elevated nitrate concentrations in groundwaters exceeding 11.3 mg NO_3-N/L (50 mg NO_3/L), which is the World Health Organization's drinking water standard (Chen et al., 2005; Ju et al., 2006; Zhang et al., 1996).

In light of the increased water pollution, there is an urgent need to understand regional pollutant transport and removal, and to protect the local water resources in the NCP. In fact, numerous studies on best practices for crop management, irrigation management, and optimal fertilizer application have recently been published (Dikgwatlhe et al., 2014; Li et al., 2015; Sheldrick et al., 2003). Few studies also discussed the nutrient transport of polluted river water (RW) into wetland areas and lakes, and its potential impact on the ecosystem (Mao and Yang, 2011; Muqi et al., 1998; Wang et al., 2001). Others focused on nitrogen budgets (Liu et al., 2003; Zhao et al., 2006), or selected removal mechanisms such as anaerobic ammonium oxidation (anammox) (Zhu et al., 2013). However, little focus has been given to interactions and pollutant exchange between agriculture, RW, and GW, and to removal processes within the systems.

To fill this gap, the field study presented here was carried out on a typical wheat–maize field in the NCP near Baiyang Lake that is located directly adjacent to a passing stream (Fu River). Based on irrigation, crop management, and nutrient input, the objectives were to: (a) describe the local flow dynamics and solute transport between GW and RW, (b) assess temporal water quality changes in the GW regarding inorganic water chemistry and nitrogen, and (c) evaluate dominant geochemical processes, in particular nitrification/denitrification processes, by using qualitative and quantitative methods, including the geochemical modeling code PHREEQC. The insight and better understanding of the nitrogen sources, pathways, and removal processes in the RW-GW system enables us to develop a conceptual model for the nitrogen fluxes, and to reflect on

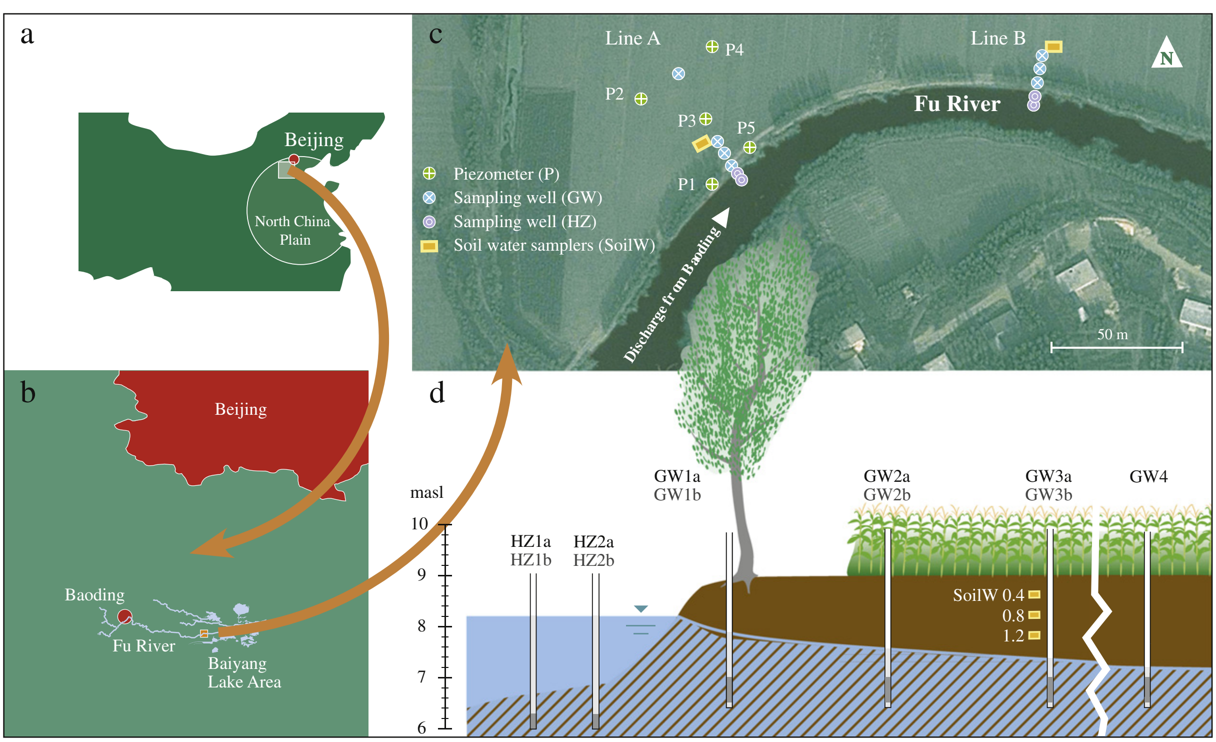

Fig. 1 – (a, b) Location of the field site, (c) aerial view of the sampling lines A and B, and (d) cross-section of the installed wells and soil water samplers (labeling for sampling lines A and B in black and in gray letters, respectively).