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# Temporal variation of groundwater level and arsenic concentration at Jianghan Plain, central China

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ABSTRACT

Elevated arsenic in groundwater affects some 60 thousand people in the Jianghan Plain, yet mitigation efforts are hindered by persistent uncertainty about the proximal source of As and mechanisms for its mobilization. Samples were collected every month from May 2012 to April 2014 in a set of 39 monitoring wells and two rivers in the field monitoring site, Jianghan Plain, to evaluate the temporal variation of groundwater level and chemical composition for As and other constituents. Results showed that groundwater tables fluctuated during the sampling period, with higher water levels during the rainy season and lower water levels during the dry season. Wells at 25 m and 50 m deep had lower water level than those of the wells at 10 m deep. Water levels of the wells located in the south of the field monitoring site were always 1 m higher than the wells in the north. Only five wells showed no significant changes in As concentrations during the monitoring period; 23 wells exhibited seasonal variations in groundwater As concentration that were consistent from year to year; the rest of the 11 wells not only showed seasonal variations but also exhibited increasing trends over the monitoring period. Seasonal As concentration changes in groundwater were positively correlated to groundwater level changes, with lower concentration corresponding to lower water level during dry season and vice versa during rainy season. The rise in As concentration during the rainy season could be attributed to enhanced reductive dissolution of iron oxyhydroxides and/or reductive desorption of As(V) as the conditions turn to be more reducing, while during the dry season more As could be scavenged onto fresh iron oxyhydroxides. Meanwhile, temporal variations showed compatible trends between As and Fe, Fe(II), $S^{2-}$, indicating that As variation would be related to Fe and S cycling in the aquifer systems. Additionally, the availability of labile organic carbon as a driver of microbial reduction may play an important role in controlling the spatial and temporal variation of groundwater As concentration in the Jianghan Plain.



## 1. Introduction

The presence of naturally elevated levels of arsenic in groundwater has been reported worldwide, including in Bangladesh, India, Cambodia, Vietnam, Argentina, the United States, Chile, and China, with the most serious waterborne endemic arsenic poisonings occurring in Bangladesh, India, and China (Nickson et al., 1998; Nordstrom, 2002; Smedley and Kinniburgh, 2002; Romero et al., 2003; Zheng et al., 2005; Harvey, 2008; Polizzotto et al., 2008; Deng et al., 2009; Fendorf et al., 2010; Saha et al., 2010; Xie et al., 2011; Li et al., 2012; Guo et al., 2013a). In terms of redox conditions favorable for As enrichment in the subsurface, high As groundwater has been more frequently found under reducing conditions (Smedley and Kinniburgh, 2002), and recent studies have shown that groundwater As concentration is highly variable at both local and regional scale in reducing aquifers from river deltas and inland basins (van Geen et al., 2003; Fendorf et al., 2010; Guo et al., 2012). The causes of the heterogenous As distribution include geologic setting, organic matter sources, water–rock interactions, groundwater flow, and anthropogenic influences (Harvey et al., 2002; McArthur et al., 2004; Stute et al., 2007; Kocar et al., 2008; Neumann et al., 2010; Guo et al., 2011; Freikowski et al., 2013). Such spatial variability naturally leads to the concern that groundwater As concentration may temporarily change as well.

Temporal change of As concentrations has been reported in Bangladesh (Cheng et al., 2005; Dhar et al., 2008), West Bengal of India (Savarimuthu et al., 2006; Farooq et al., 2011), Vietnam (Berg et al., 2001), Hetao basin and Yichuan Plain of China (Guo et al., 2012, 2013b; Han et al., 2012), Ganges Floodplain of Nepal (Brikowski et al., 2014), Duero River Basin of Spain (Mayorga et al., 2013), Nevada and Snohomish County of USA (Frost et al., 1993; Steinmaus et al., 2005;

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Thundiyil et al., 2007), Ouro Preto of Brazil (Goncalves et al., 2007), and Zimapán Valley of Mexico (Rodríguez et al., 2004). Temporal variations of As concentrations in different sites show different trends. Several studies have documented that As concentrations in some wells might vary dramatically by season (Frost et al., 1993; Savarimuthu et al., 2006; Goncalves et al., 2007; Farooq et al., 2011; Guo et al., 2012; Brikowski et al., 2014), while in other sites the temporal variation was inconsistent from year to year (Dhar et al., 2008), although some studies suggest absence of any significant change in As concentration (McArthur et al., 2004; Cheng et al., 2005; Steinmaus et al., 2005; Thundiyil et al., 2007). Anthropogenic or natural factors responsible for the observed groundwater As concentration changes include dilution by recharge of water with low As concentrations, seasonal changes in redox conditions, pumping rates, water table depths, or shifts in direction of hydraulic gradient (Tareq et al., 2003; Rodríguez et al., 2004; Cheng et al., 2005; Goncalves et al., 2007; Benner et al., 2008; Dhar et al., 2008; Kocar et al., 2008; Polizzotto et al., 2008; Guo et al., 2012; Brikowski et al., 2014).

Several studies have been conducted for revealing the high As groundwater in the Jianghan Plain since it was first noted in 2005. In May 2006, the Center for Endemic Disease Control of Xiantao and Hubei Province investigated 19 towns in Xiantao, where 60% of the 2538 $km^2$ fertile alluvial–lacustrine sediments deposited by rivers and lakes is farmland cultivated with rice, rape, cotton, and vegetables, and 24% is pond for aquariculture. The results showed that 863 wells in 12 towns (179 villages) had As levels exceeding China's National Drinking Water Standard of 10 μg/L. The hydrogeochemical characteristics of the shallow groundwater in the Jianghan Plain have been investigated by us (Zhou et al., 2013; Gan et al., 2014). Groundwater with high As was found in wells at depths of 10 to 45 m along rivers. The main potential mechanism for the release of As is the reductive dissolution of Fe and Mn oxides/hydroxides under reducing conditions, while microbial degradation of organic matter may also facilitate the release of As into groundwater (Gan et al., 2014). Elevated As in groundwater affects the health of some 60 thousand people in the Jianghan Plain (Wang and Zhao, 2007; Li et al., 2010), and it is crucial to characterize temporal variations in groundwater As concentration to understand the mechanisms of As cycling and to help to develop effective strategies for sustainable exploitation of groundwater resource.

The objectives of this study are to (1) fill a major gap in our understanding of the temporal variability in groundwater level and As concentration in the Jianghan Plain; (2) provide new insights into the mechanisms of As mobilization under reducing conditions in the study area; and (3) help us highlight the important implications of temporal variations in As concentration on the exposure and the precision of the health risk assessments.

## 2. Regional hydrogeology

Jianghan Plain is an alluvial plain formed by the Yangtze and Han rivers located in the Middle Reaches of the Yangtze River that includes the central and southern regions of Hubei Province (Fig. 1). It has a sub-tropical monsoonal climate and annual temperature ranges between 15 °C and 17 °C. The average annual precipitation in the region is 1269 mm, increasing from 800 mm in the northwest to 1500 mm or more in the southeast, 30–50% of which occurs in summer. The average annual evaporation is 1200 mm, which is almost equal to the total precipitation. The non-frost season is 200–290 days.

Jianghan Plain is a semi-closed Quaternary basin with a higher elevation in the north and a lower elevation in the south. The middle region in the plain is a low alluvial plain with elevations of 20–27 m in the southeast and 30–40 m in the northwest, while the outlying areas

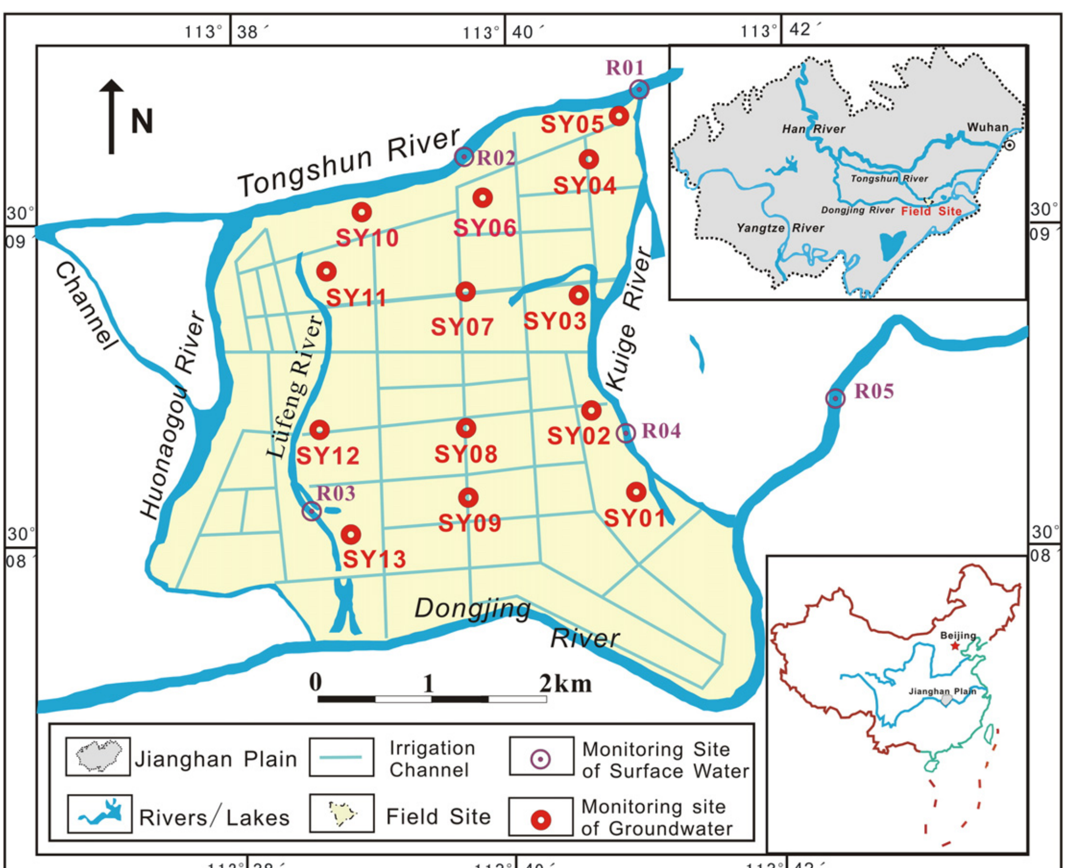


**Fig. 1.** Location of the Shahu field monitoring site and the monitoring wells.