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Review

# A review of high arsenic groundwater in Mainland and Taiwan, China: Distribution, characteristics and geochemical processes

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ABSTRACT

China is a typical high-As region, where 20 provinces have high As groundwaters among 34 provinces. These groundwaters usually occur in both arid–semiarid inland basins and river deltas. In the inland basins, mainly distributed in the northwest of China, shallow groundwaters usually have high As concentrations in alluvial lacustrine or lacustrine sediment aquifers, while high As groundwater mainly occurs in fluvial–marine sedimentary aquifers in the river deltas, which have been affected by transgression. In both the inland basins and the river deltas, high As groundwaters, mainly occurring in reducing conditions, are characterized by high Fe and Mn concentrations, high pH and $HCO_3^-$ concentration, and relatively low $NO_3^-$ and $SO_4^{2-}$ concentrations. Although As contents are well correlated to Fe/Mn contents in the aquifer sediments, groundwater As concentrations are generally independent of sediment As contents. Redox processes, microbe-related reduction, and desorption processes are the major geochemical processes for As enrichment in groundwaters. In reducing conditions, both reductive dissolution of Fe oxides and reductive desorption of As are believed to result in As mobilization, which would be catalyzed by indigenous microbes. Although decomposition of the low-molecular weight organic matter during microbe metabolization would also release the colloid-bound As into groundwater, the cycling of colloidal As still needs to be further investigated during redox processes. Besides, high pH and high $HCO_3^-$ lead to As desorption from adsorption sites in the aquifer systems. However, the contribution of competitive desorption to high As concentrations is still unknown and remains to be discovered, relative to reductive dissolution of Fe oxides, especially in the inland basins.



**Contents**



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## 1. Introduction

Arsenic is a ubiquitous element in the earth's crust, which has notoriously been known as a toxicant and carcinogen for the general population. It has been ranked among the top 20 most hazardous, high priority substances by the Agency for Toxic Substances and Disease Registry (ATSDR, 2005), which can cause acute and chronic health effects on human (Gray et al., 1989; WHO, 1996; Saha, 2003). Acute poisoning symptoms include gastrointestinal discomfort, vomiting, coma and even death, which usually occur within 30 min of ingestion, while the chronic effects commonly include skin diseases (pigmentation, dermal hyperkeratosis, and skin cancer), many other cardiovascular, neurological, hematological, renal and respiratory diseases, skin cancer, and other internal cancers (Morton and Dunette, 1994).

Elevated As levels of aqueous environment have resulted from both natural processes and anthropogenic activities (Bissen and Frimmel, 2003). Most As problems are the result of mobilization under natural conditions, including weathering reactions, biological activities and volcanic emissions (Smedley and Kinniburgh, 2002). Arsenic concentration in geothermal water is up to 50 mg/L (Ellis and Mahon, 1977), while natural groundwaters in As-rich provinces have high As concentration of 1500 μg/L (Guo et al., 2008a). Ingestion of high As drinking water is a major pathway for As to enter the human body, and therefore poses the significant treat to human health. High As concentrations have widely been found in potable groundwaters, which have received much concern from both governmental and scientific levels (Guo et al., 2007a). In order to protect public health, the World Health Organization has set a provisional guideline limit of 10 μg/L for As in drinking water (WHO, 1996), which has been subsequently adopted by the European Union (European Commission, 1998), the United States (EPA Office of Groundwater and Drinking Water, 2002), and China (Ministry of Health of PR China, 2006). However, although China is seeking to reduce its limit in line with the WHO guideline value, the guideline is still set to the 50 μg/L in rural areas because of lack of adequate testing facilities for lower concentrations and high cost of water treatment for As removal.

South and Southeast Asia is a typical high-As region, where the occurrence of As in the alluvial/lacustrine aquifers of many inland basins and deltaic systems has become a well-known tragedy (Winkel et al., 2008). Hundreds of millions of people are suffering from chronic As poisoning in Bangladesh, India, China, Pakistan, Nepal, Cambodia, and Vietnam (Bissen and Frimmel, 2003; Smedley and Kinniburgh, 2002). The groundwater As is of geogenic origin and considerably patchy on a local scale or a regional scale (Harvey et al., 2002; Ng et al., 2003; van Geen et al., 2003; McArthur et al., 2004; Guo et al., 2008a). Hydrogeological and biogeochemical studies showed that source of dissolved organic carbon, microbial diversity, sedimentation sequences and groundwater hydraulics are the major contributors for spatial and temporal variation in As concentrations (Harvey et al., 2002; van Geen et al., 2003; McArthur et al., 2004, 2011; Guo et al., 2012, 2013b; Fendorf et al., 2010).

Among these high As groundwater countries, China is one of the largest countries, where high As groundwaters have been found in both inland basins experiencing an arid/semiarid continental climate, and river deltas experiencing a humid tropical climate (Guo et al., 2008a; Chen, 1998). In the Mainland of China, high As groundwaters (>10 μg/L) have been found in 19 provinces. These provinces include Anhui, Beijing, Gansu, Guangdong, Hebei, Henan, Hubei, Inner Mongolia, Jilin, Jiangsu, Liaoning, Ningxia, Qinghai, Shandong, Shanxi, Shaanxi, Sichuan, Xinjiang, and Yunnan (Jin et al., 2003). Estimation based on a statistical risk model shows that 19.6 million residents are at risk of being affected by the consumption of high-As groundwater throughout China (Rodríguez-Lado et al., 2013). The number of residents at risk may be underestimated since the model mainly considers the alluvial sediment aquifers. According, the results must be confirmed with additional field investigations.

This paper summarizes distribution and chemical characteristics of high As groundwater, hydrogeological settings of high As groundwater aquifers, and systematically reviews geochemical processes controlling As distribution in typical areas of China.

## 2. Distribution of high As groundwater

High As groundwaters (>10 μg/L) have been widely found in China (Fig. 1). Generally, there are two types of areas where high As groundwater naturally occurs. One is the arid–semiarid inland basins. The other is the river deltas. The former mainly includes the Yinchuan basin, the Hetao basin, the Huhhot basin, the Datong basin, the Yuncheng basin, the Songnen basin, the Guide basin and the Dzungaria basin. The Yinchuan basin (7300 $km^2$), the Hetao basin (10,000 $km^2$), the Huhhot basin (4800 $km^2$), the Datong basin (7440 $km^2$), and the Yuncheng basin (4950 $km^2$) lies along the Yellow river from the west to the east. The Songnen basin is located in the west of Jilin province, and the Dzungaria basin in the north of Xinjiang province. The delta areas mainly include the Yangtze river delta, the Yellow river delta, and the Pearl river delta.