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Elevated arsenic and manganese in groundwaters of Murshidabad, West Bengal, India

M.S. Sankar [a], M.A. Vega [a], P.P. Defoe [b], M.G. Kibria [a], S. Ford [a], K. Telfeyan [c], A. Neal [d], T.J. Mohajerin [c], G.M. Hettiarachchi [b], S. Barua [a], C. Hobson [a], K. Johannesson [c], S. Datta [a,*]

[a] Department of Geology, Kansas State University, Manhattan, KS 66506, USA
[b] Department of Agronomy, Kansas State University, Manhattan, KS 66506, USA
[c] Department of Earth and Environmental Sciences, Tulane University, New Orleans 70118, USA
[d] Virginia Water Resources Research Center, Virginia Tech, VA 24061, USA

HIGHLIGHTS

- Identification of high occurrences of As in groundwaters of Eastern India.
- Identification of mechanisms of release of Mn in groundwaters.
- Both these occurrences are estimated east and west of NS flowing Bhagirathi river.
- We postulate processes that concentrate natural As, Mn in fluvio-deltaic settings.
- Concentrations of Mn and As are to some extent inversely related to each other.

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ABSTRACT

High levels of geogenic arsenic (As) and manganese (Mn) in drinking water has led to widespread health problems for the population of West Bengal, India. Here we delineate the extent of occurrences of As and Mn in Murshidabad, where the contaminated aquifers occur at shallow depths between 35 and 40 m and where access to safe drinking water is a critical issue for the local population.

A total of 78 well-water samples were taken in 4 blocks on either side of the river Bhagirathi: Nabagram and Kandi (west, Pleistocene sediments), Hariharpara and Beldanga (east, Holocene sediments). High As, total iron (Fe_T) and low Mn concentrations were found in waters from the Holocene gray sediment aquifers east of the river Bhagirathi, while the opposite was found in the Pleistocene reddish-brown aquifer west of the river Bhagirathi in Murshidabad. Speciation of As in water samples from Holocene sediments revealed the dominant species to be As(III), with ratios of As(III):As_T ranging from 0.55 to 0.98 (average 0.74). There were indications from saturation index estimations that Mn solubility is limited by the precipitation of $MnCO_3$. Tubewells from high As areas in proximity to anthropogenic waste influx sources showing high molar Cl/Br ratios, low SO_4^{2-} and low NO_3^- demonstrate relatively lower As concentrations, thereby reducing As pollution in those wells.

Analyses of core samples (2 in each of the blocks) drilled to a depth of 45 m indicate that there is no significant variation in bulk As (5–20 mg/kg) between the Holocene and Pleistocene sediments, indicating that favorable subsurface redox conditions conducive to mobilization are responsible for the release of As. The same applies to Mn, but concentrations vary more widely (20–2000 mg/kg). Sequential extraction of Holocene sediments showed As to be associated with 'specifically sorbed-phosphate-extractable' phases (10–15%) and with 'amorphous and well crystalline Fe-oxyhydroxide' phases (around 37%) at As-contaminated well depths, suggesting that the main As release mechanisms could be either competitive ion exchange with PO_4^{3-}, or the dissolution of Fe oxyhydroxides. In the Pleistocene sediments Mn is predominantly found in the easily exchangeable fraction.

1. Introduction

Large populations in the Bengal Basinal Delta system, roughly 43 million in West Bengal (Eastern India) and roughly 22 million in Bangladesh, are exposed to arsenic (As) poisoning by consumption of high arsenic (As) groundwaters (Bhattacharya et al., 1997; Nickson

* Corresponding author. Tel.: +1 785 532 2241.
E-mail address: sdatta@ksu.edu (S. Datta).

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et al., 1998; Smith et al., 2000; McArthur et al., 2001; Dowling et al., 2002; Roychowdhury et al., 2002; Ravenscroft et al., 2005; Acharyya and Shah, 2006; Datta et al., 2009; PHED, 2010 and references therein). Arsenic is extremely toxic and a Class-I carcinogen (Ghosh et al., 2013; Pandey et al., 2012; Datta et al., 2011; McArthur et al., 2012a,b) and the World Health Organization (WHO) guideline value for drinking water is 10 μg/L (WHO, 2011).

Elevated concentrations of manganese (Mn) are also found in the groundwaters of this region (McArthur et al., 2012a,b; Biswas et al., 2012). The ingestion of Mn is known to cause adverse health effects, and in excessive quantities it is a neurotoxin (McArthur et al., 2012a,b). The young and unborn are particularly at risk from Mn contamination (Hafeman et al., 2007). It has also been shown that maternal environmental exposure to Mn is associated with a reduced activity of the newborn's erythrocyte Ca-pump (Yazbeck et al., 2006). Moreover, Mn in drinking water is associated with neurotoxic effects in children, for example with a diminished intellectual function (Wasserman et al., 2006). The WHO guideline value for drinking water is set at <0.4 mg/L (WHO, 2011).

The predominant mechanisms by which sediment-bound arsenic is released into groundwater are thought to be through microbially mediated reductive dissolution of FeOOH(s) (McArthur et al., 2001, 2004; Dowling et al., 2002). Reducing conditions are also responsible for the release of manganese (Mn) through the reduction of Mn(III,IV) (hydr)oxides to soluble Mn(II) species. Manganese(III,IV) are reduced under less reducing conditions than Fe(III) (hydr)oxides (Morgan and Stumm, 1964). Thus elevated arsenic and manganese concentrations in chemically reduced groundwaters may be related. Farooq et al. (2011) found a mean Mn value of 0.9 mg/L from 35 sampled tubewells throughout Murshidabad, and numerous studies have found similar results in the neighboring regions of Bangladesh (Frisbie et al., 2002; Agusa et al., 2006., Van Geen et al., 2007; Hafeman et al., 2007). These studies have found, however, that Mn values frequently have little to no relationship with As.

In Murshidabad groundwater is the major drinking water source and 19 out of 26 blocks are at the risk of As contamination, making it one of the most densely affected districts in West Bengal (PHED, 2010). People utilize (hand pumped) shallow level tubewells drilled via local drilling companies. The contaminated aquifers occur at depths of ~35–40 m. Surface waters from Murshidabad are highly contaminated by anthropogenic pollutants, including enteric bacteria, due to overuse and additions of waste streams to the streams/channels as shown for Nadia, West Bengal (McArthur et al., 2012a,b). Health impacts associated with the use of As and Mn contaminated groundwaters for drinking, have been observed (McArthur et al., 2012a) and malnutrition, which is prevalent in the region (Deb et al., 2013; Mandal et al., 2012; Mondal et al., 2012; Arlappa et al., 2011) may aggravate the situation. The sustainable provision of water of sufficient quantity and

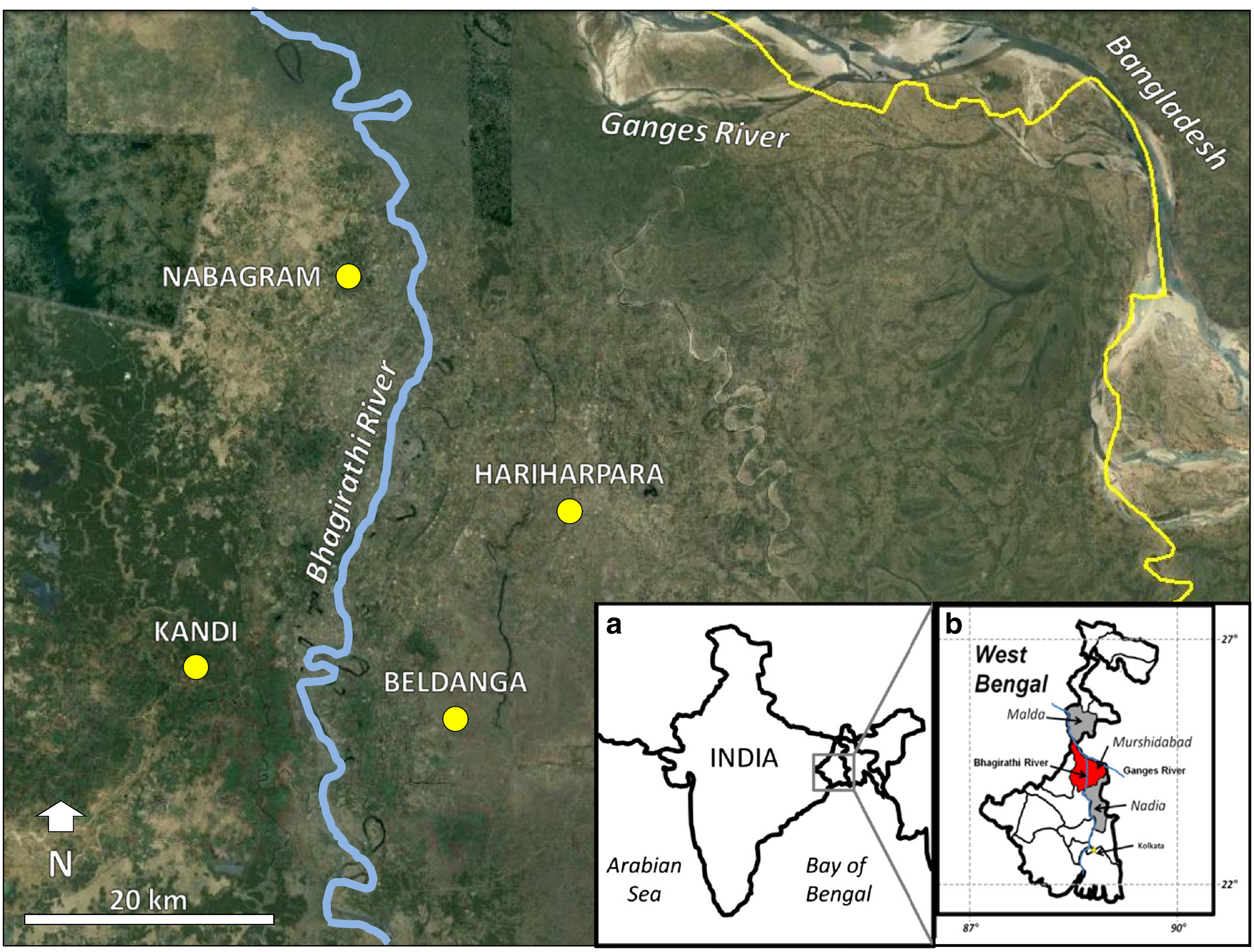

Fig. 1. Sites for arsenic: State of West Bengal, district of Murshidabad, 4 locations are chosen for the current study: Beldanga (BM), Hariharpara (HK) on the eastern side (high As and low Mn) and Nabagram (NB) and Kandi (KHN) on the western side (low As and high Mn) of the river Bhagirathi.
This figure is reproduced from Mohajerin et al., 2014.

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