Environ Chem Lett (2006) 4: 79–82
DOI 10.1007/s10311-006-0037-2

ORIGINAL PAPER

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Factors affecting arsenic concentration in groundwater in West Bengal

Received: 7 November 2005 / Accepted: 27 January 2006 / Published online: 4 May 2006

Abstract Groundwater is the major source of drinking water for the population in Malda district, West Bengal. Holocene sediments from Himalayas have contaminated those places through the river Ganges and arsenic was found a potential groundwater contaminant. Field and laboratory experiments were attempted to identify the relationship between arsenic versus Eh of groundwater and content specific elements (As, Co, Mn, Fe, C and S) in different types of Holocene sediments on a freshly constructed wells. Arsenic versus Eh of groundwater and Holocene clay over Holocene sand were found performing a major role in the aquifers of arsenic affected areas.

Keywords Bengal basin · Mahananda river · Dissolved arsenic · Redox potential

Introduction

Natural geologic environments in India affect human health in a variety of ways through interactions between geochemical, hydrologic, and biologic processes and human activities. Numerous national-scale cases serve as examples, fluorosis in semi arid Rajasthan and arsenicosis in West Bengal Ganges delta regions. The serious arsenicosis in parts of West Bengal state is related not only to the high arsenic content as high 16 μg/g (Stummeyer et al. 2002) in recent Ganges alluvium suspended sediment deposits but also to the semi-arid conditions on the desert in the sulphide mineral mining Rajasthan of the western part of India.

In the sediments of River Ganges, arsenic concentration in the clay show 10 μg/g arsenic and arsenic value in the sand show 4 μg/g. Chlorite-biotite separate from the sand sample analysed for arsenic shows 40 and 31 μg/g arsenic (Sengupta et al. 2004). The aquifer sediments of the delta region are constituted of material carried by the same rivers over the past thousands of years and are likely to store a large quantity of the element accumulated over the entire history of the fluvial regime.

Arsenic is, as manganese, a redox-sensitive element which can be transferred from As(V) (arsenate) to As(III) (arsenite) within a reducing sediment (e.g. Gault et al. 2005; Horneman et al. 2004; Stüben et al. 2003). Increasing evidence suggests that this is a microbiological phenomenon (e.g. Islam et al. 2004; Oremland and Stolz 2005). Arsenic is enriched even in the suspended matter under oxic conditions and in the sediment top under reducing conditions; obviously there is no cycling of arsenic in the water column or in the reducing sediments on the river mouth shelf in Bay of Bengal (Stummeyer et al. 2002). In both types of samples arsenic is found in the acid soluble and residual phase of the material. Linked tectonic, geochemical, and biologic processes lead to natural arsenic contamination of groundwater in Holocene alluvial aquifers, which are the main threat to human health around the Bengal delta (Saunders et al. 2005). These groundwaters are commonly found a long distance from their ultimate source of arsenic, where chemical weathering of arsenic bearing minerals occurs.

The current thinking about the genesis of the problem has many fronts—natural due to arsenic bearing minerals in the aquifer region or hinterland areas and anthropogenic due to the excess withdrawal of these arsenic waters thereby altering the basic controlling chemical regime of arsenic movement in the aquatic environment. While in the Indian state of West Bengal, extensive pipeline net work is being developed between the river Ganges and other adjoining rivers to supply surface water to all villages in between; hence number of wells being drilled here officially is small but local population continue to drill with indigenous technology for extracting subsurface water in many areas.

The main objective of this study is to provide an assessment of the level of natural arsenic presents in top to bottom sediments, from beginning to end freshly built tube wells between Ganges and Mahananda River in District of

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Malda. An additional objective is to provide an assessment of arsenic contaminant levels in the specific new well and its relation with other elements, such as Co, Mn, Fe, C and S were also looked. The goal of this study was to provide data, which will determine the distribution of sediment-bound arsenic contaminants and aid understanding sediment transport dynamics in the Ganges–Mahananda River, before it meet the River Brahamaputra.

Experimental

An intensive field survey was carried out in one of the arsenic affected district's Malda in Indian State of West Bengal for Eh, pH and Arsenic measurements during January–February 2002. Malda district has about 2 million population with a reported arsenic concentration levels, based on 222 samples of ground water ranging from 5 to 500 µg/l. In this area, subsurface water is being extracted from wells that are drilled with simple indigenous technology by local community. Using this technique, it was possible to obtain subsurface aquifer cross sections, for eight locations over a 35 km stretch between two rivers–the Ganges (24°N:87°E–24°N:89°E) and Mahananda (26°N:87°E–26°N:89°E) that joins the Ganges farther south.

Holocene clay and Holocene sand were found two major different types of sediments in the vertical profile as well in cross section between the rivers Ganges – Mahananda and shown in Fig. 1A. Groundwater samples were obtained from freshly built wells at a minimum depth of about 3 m near the Ganges River progressively increasing up to a maximum depth of about 20 m near the Mahananda River. The redox potential of groundwater was measured immediately from the fresh built well. Before analyzing redox potential, the platinum electrode was calibrated with Zobell's solution. Sediment (Holocene) core samples of each well at different depth were collected in a polyethylene bags brought to lab, air dried and digested in aqua regia. Core samples carbon and sulphur content were measured in a pre-calibrated Eltra Carbon & Sulphur analyzer. Digested core samples inorganic constituent's cobalt, manganese and iron were looked through Atomic Absorbance Spectrophotometer. Arsenic was determined in Atomic Absorbance Spectrophotometer combined with hydride generator. Merck standard solutions were used for instrument calibration. Finally, Table 1 was constructed for data analysis.

Results and discussion

The subsurface aquifer is potentially an important source of drinking water for the population in Malada district. Presently most of the water consumption in the area are derived from alluvial wells that yield water of insufficient quality. This causing concern regarding future utilisation of the aquifer in combination with the unavailability of treated surface water through municipal tap. The cross section of the aquifer reconstructed from the field data given in Fig. 1A show two meter of Holocene clay start on top

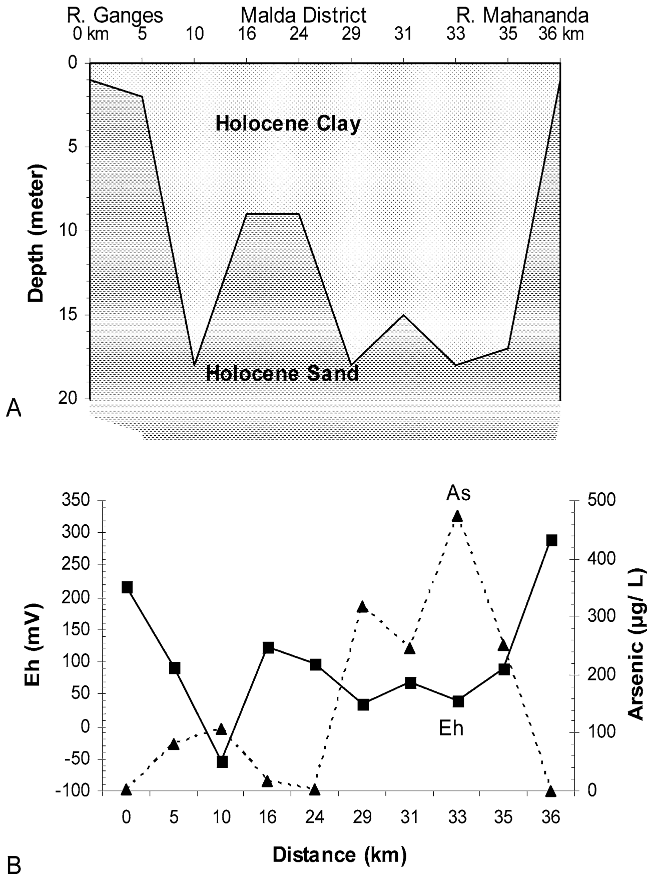

Fig. 1 Sampling location and cross section of fresh wells constructed in Malda district, West Bengal (A) and its relation to range of arsenic and Eh (B)

of a newly constructed well at Baishnager and its 5 km distance away from river Ganges. Maximum amount of Holocene clay (18 m) recovered from the following places: Monuvapathi, Malda South and Malda East. The distance from river Ganges to those individual places are 10, 29 and 33 km respectively.

Also shown in the Fig. 1B is the trend in arsenic and Eh values across this cross section. Arsenic values range from a low of around 3 µg/l to a high of around 473 µg/l in the same direction while the Eh in the same locations vary from a high of +290 mV near the River Mahananda to a low of +218 mV towards the River Ganges. The spatial distribution of groundwater arsenic and the redox potential (Eh) of the groundwater suggest that the two properties are related. In groundwater, less oxidized redox potential was found for the locations Baishnagar, Monuvapathi, southern and western side of Malda, northern and eastern side of Malda (−54–93 mV); whereas more oxidized redox potential (>97 mV) was observed for the places Sujapur and Kaliachak.

A trend between Holocene clay over Holocene sand and redox potential of groundwater show they are proportional to each other. If the Holocene clay over Holocene sand increases (15–18 m), in the freshly built wells between the rivers Ganges–Mahananda (breath of 35 km), the redox potential of groundwater show less oxidized. Whereas,

Table 1 Results of various inorganic constituents in freshly built wells between the rivers Ganges – Mahananda, Malda district, West Bengal

Location	Nature	*n*	Depth (m)	Eh (mV)	As (μg/g)	±	Co (μg/g)	±	Mn (μg/g)	±	Fe (%)	±	C (%)	S (%)
Baishnagar (5)[a]	Clay	1	0–2	–	15	–	21	–	564	–	5	–	0.8	0.003
Monuvapathi (10)	Clay	9	0–18	–	8	3	19	12	726	219	5	1	1.2	0.002
Sujapur (24)	Clay	2	0–9	–	4	1	21	5	601	5	5	0.1	1.0	0.001
Malda South (29)	Clay	5	0–18	–	5	2	11	4	422	246	4	1	0.3	0.004
Malda West (31)	Clay	5	0–15	–	9	7	22	20	341	263	5	1	0.1	0.000
Malda East (33)	Clay	4	0–18	–	9	6	16	3	557	90	6	2	0.1	0.000
Malda North (35)	Clay	4	0–17	–	5	2	17	3	1045	906	5	1	0.0	0.001
Baishnagar	Sand	4	2–11	–	5	3	11	12	279	87	2	1	0.6	0.002
Monuvapathi	Sand	1	18–21	–	7	–	8	–	314	–	1	–	0.2	0.001
Kaliachak	Sand	2	12–15	–	4	0.2	23	21	854	636	4	3	0.2	0.0003
Sujapur	Sand	7	9–23	–	2	1	10	6	403	152	2	1	0.2	0.0001
Malda South	Sand	5	18–34	–	5	1	5	4	455	203	1	0.4	0.2	0.000
Malda West	Sand	5	15–27	–	5	5	9	8	400	204	2	2	0.1	0.000
Malda East	Sand	4	18–30	–	4	2	18	16	600	252	3	1	0.8	0.0005
Malda North	Sand	5	17–30	–	2	1	5	4	314	30	2	1	0.0	0.002
			Clay[b]											
River Ganges	Water	1	0	218	3	–	–	–	–	–	–	–	–	–
Baishnagar	Water	1	2	93	82	–	–	–	–	–	–	–	–	–
Monuvapathi	Water	1	18	−54	108	–	–	–	–	–	–	–	–	–
Kaliachak	Water	1	9	124	17	–	–	–	–	–	–	–	–	–
Sujapur	Water	1	9	97	3	–	–	–	–	–	–	–	–	–
Malda South	Water	1	18	36	319	–	–	–	–	–	–	–	–	–
Malda West	Water	1	15	68	247	–	–	–	–	–	–	–	–	–
Malda East	Water	1	18	40	473	–	–	–	–	–	–	–	–	–
Malda North	Water	1	17	89	251	–	–	–	–	–	–	–	–	–
River Mahananda	Water	1	0	290	1	–	–	–	–	–	–	–	–	–

[a]Number in parenthesis, distance from river Ganges in km
[b]Thickness of clay in meters

Holocene clay over Holocene sand reduces 9–2 m in the freshly built wells, the redox potential of groundwater show more oxidized. The arsenic concentration for those less redox (<97 mV) groundwater samples show more arsenic and the measured arsenic concentrations were between 82 and 473 μg/l.

Relatively less arsenic concentration was observed for more oxidized samples and the measured arsenic concentrations were between 2 and 17 μg/l. Therefore, deep wells on Holocene clay over Holocene sand yield low redox potential groundwater as well more dissolved arsenic in groundwater which ultimately giving ill effect to human health. The relationship among groundwater arsenic versus thickness of Holocene clay over Holocene sand between the Rivers Ganges–Mahananda and the redox potential of groundwater show R-square value of 0.60 at an assigned p value <0.05 and shown in Fig. 2 (As in groundwater = 145.65 + 22.29 thickness of Holocene clay + 0.61 Eh). The identification of a threshold in redox conditions that prevents the release of arsenic to groundwater might help drillers target aquifers that are low in arsenic.

A relationship among Holocene sand arsenic concentration versus Holocene sand iron content and the redox potential of groundwater show R-square value of 0.52 at an assigned $p<0.05$ (As in Holocene sand = 5.23 + 0.02 Eh + 0.25 iron in Holocene sand). The formation of Fe(II)

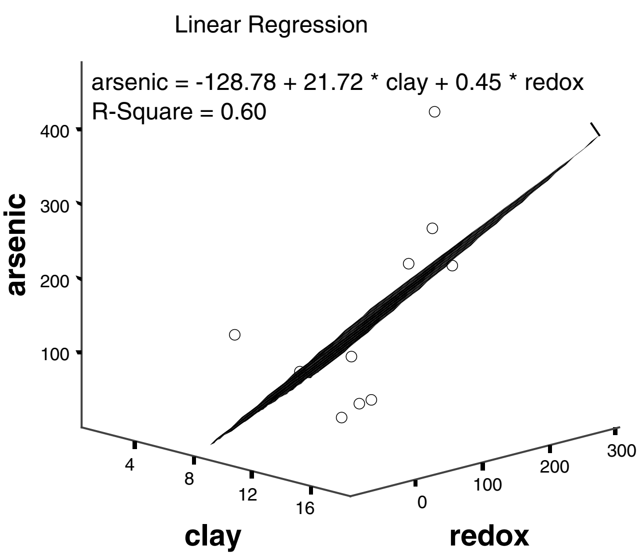

Fig. 2 Relationship between arsenic concentration in groundwater (μg/l) vs. thickness of Holocene clay (meters) and Eh (mV) of groundwater

or Fe(II/III) phases that leave arsenic in solution depending on redox potential of groundwater could help explain the significant scatter in the relationship between dissolved arsenic and Fe concentrations in Bengal groundwater (Horneman et al. 2004). The relationship among groundwater arsenic versus cobalt in Holocene clay and the amount of carbon presents in Holocene clay show R-square value of 0.77 at an assigned $p<0.05$ (As in groundwater $=$ $581.55 + 14.22$ Cobalt in Holocene clay $+$ 242.36 C in Holocene clay). Also, arsenic in groundwater versus carbon content in Holocene clay and carbon content in Holocene sand show R-square 0.80 at an assigned p value<0.05 (As in groundwater $=$ $283.41 + 204.27$ carbon in Holocene clay $+$ 274.90 carbon in Holocene sand).

Conclusion

The mobilisation of arsenic into the groundwater is an important process that eventually leads to arsenicosis in Malda district, West Bengal. Wells on deep Holocene clay over Holocene sand groundwater samples show less oxidized and are found more arsenic concentration between the rivers Ganges–Mahananda. Future research on reduction in groundwater and the release of arsenic concentration in aquifers of Holocene clay over Holocene sand and growing microorganisms may ultimately reveal an answer.

Acknowledgements The first author thanks CSIR, New Delhi for the Research Associate fellowship.

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