Groundwater Arsenic and Iron Contamination in the Gangetic Plains of India: Safe Drinking Water Option on Quaternary Stratigraphy

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Abstract

Late Quaternary stratigraphy, geomorphology, and sedimentation in the entrenched channels and floodplains of the upper, middle, and lower Ganga plains in the states of Uttar Pradesh, Bihar, Jharkhand, and West Bengal have control on groundwater arsenic contamination. Arsenic analysis was done through atomic absorption spectrometry, and Iron was analyzed by the use of UV spectro-photometer. Arsenic contamination in groundwater above 50 µg/L is reported in Unnao and Allahabad districts in the upper Ganga plain. In the middle Ganga plain, 66% of tubewells from Buxar, Ghazipur, Varanasi, and Mirzapur districts and 89% of tubewells from Vaishali, Patna, Bhojpur, and Ballia districts have arsenic > 10 µg/L (WHO guideline). Most of the arsenic-affected villages are located close to abandoned or present meander channels of the Ganga River. In contrast, tubewells located in Kanpur, Allahabad, Mirzapur, Chunar, Varanasi, Saidpur, Ghazipur, Muhammadabad, Ballia, Buxar, Ara, Chhapra, Patna, and Hazipur towns are arsenic-safe in groundwater because of their positions on the Pleistocene Older Alluvium upland surfaces. In the middle Ganga plain, 77% of tubewells are located in shallow depth (21–40 m). About 40% of tubewells have arsenic > 50 µg/L within the depth of 17–50 m. The iron content in tubewell water samples varies from 0.1 to 13 mg/L. In the lower Ganga plain, arsenic contaminated aquifers (arsenic >10 µg/L) are confined in the Holocene entrenched channels and floodplains of the Bhagirathi River.

Keywords

Arsenic • Tubewell water • Newer alluvium • Older alluvium • Fluvial geomorphology

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1 Introduction

Groundwater arsenic (As) pollution incidents were reported in different parts of the world such as Bangladesh, India, Pakistan, Nepal, China, Hungary, Vietnam, Thailand, Cambodia, Tiwan, Inner Mongolia, Ghana, Egypt, Japan, Argentina, Mexico, USA, and Chile (Mandal and Suzuki 2002; Ravenscroft et al. 2009). Drinking As-contaminated groundwater above 50 µg/L causes skin diseases, cardiovascular, renal, and respiratory diseases, as well as lung, bladder, liver, kidney, and prostate cancers (Smith et al. 1992). The upper permissible limit of As in drinking water is 10 µg/L (WHO 1993) which has been endorsed by the Bureau of Indian Standards (Bureau of Indian Standards 2003). Groundwater As contamination in the Gangetic plains in India (lower, middle and upper) has been reported by various workers (Chakraborti et al. 2003; Acharyya and Shah 2007; Central Ground Water Board 2010; Shah 2014).

Groundwater As in tubewells was tested from the Holocene Newer Alluvium aquifers and the Pleistocene Older Alluvium aquifers (Fig. 1). The main objective of the study is to investigate the distribution of groundwater As in entrenched channels and floodplains of the lower, middle, and upper Ganga plains and role of Quaternary stratigraphy for a safe drinking water option.

2 Geological Settings

The study areas in the lower, middle, and upper Ganga plains in the states of Uttar Pradesh, Bihar, and Jharkhand and West Bengal are shown in Fig. 1. The Varanasi Older Alluvium constitutes upland surfaces, which are occupying major parts of the Ganga plains. The Varanasi Older Alluvium consists of multiple sequence of sand, silt, and clay. The Pleistocene Older Alluvium sediments are recognized by yellow–brown colored sediments with profuse calcareous and ferruginous concretions (Kumar et al. 1996). The Ganga River Basin has

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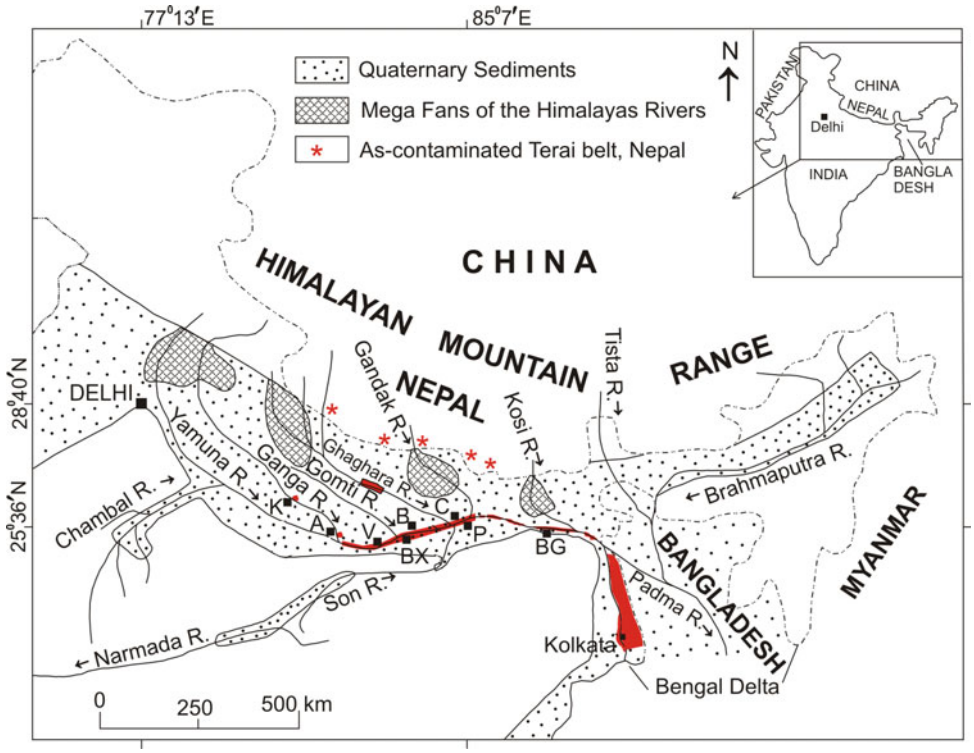

Fig. 1 Quaternary sediments in the Indo-Ganga foredeep and Bengal Basin. The study areas in the upper and middle Ganga plains, Ghaghara River plain and West Bengal delta plain. Abbreviations: K—Kanpur, A—Allahabad, V—Varanasi, BX—Buxar, B—Ballia, C—Chhapra, P—Patna and BG—Bhagalpur

low-lying floodplain areas which are constituted by the Newer Alluvium sediments. The Bengal delta covers most of Bangladesh and parts of the West Bengal, India**.**

3 Materials and Methods

Tubewell water samples (214) were stabilized in 10 ml pre-washed plastic bottles with 1 drop of dilute nitric acid (1:1) of analytical grade. The information of tubewell depth was acquired from the owner of the tubewell. Arsenic and iron were analyzed at the laboratory of the School of Environmental Studies, Jadavpur University. Arsenic analysis was done through flow injection hydride generation atomic absorption spectrometry (FI-HG-AAS) system of Perkin-Elmer Model 3100 (Samanta et al. 1999). Iron was analyzed by 1, 10 phenanthroline method by the use of UV spectro-photometer.

4 Results and Discussion

4.1 Groundwater Arsenic and Iron in the Gangetic Plains

Arsenic contamination in groundwater above 50 µg/L in the upper Ganga plain has been reported from the Unnao district of UP in the Suklaganj-Kanpur urban areas and Allahabad district in Uttar Pradesh (Chakraborti et al. 2009).

Tubewell water samples were analyzed from Buxar, Ghazipur, Varanasi, and Mirzapur districts the middle Ganga plain. It may be noted that 66% of tubewells have As concentrations above 10 µg/L (WHO guidelines), and 36% of tubewells have As above 50 µg/L. Maximum concentrations of As and Fe in tubewell water samples are 550 and 9.3 mg/L, respectively. About 77% of tubewels are installed in shallow depth, ranging from 21 to 40 m. Tubewells located on Buxar, Muhammadabad, Ghazipur, Saidpur, Varanasi, Chunar, and Mirzapur towns are As-safe in groundwater (<10 µg/L), because of their positions on the Older Alluvium upland surfaces (Shah 2014).

Tubewell water samples were analyzed from Vaishali, Patna, Bhojpur, and Ballia districts in the middle Ganga plain (Fig. 2). It was noted that 89% of tubewells have As concentrations above 10 µg/L, and 50% of tubewells have As above 50 µg/L. Maximum concentrations of As in tubewell water is 1300 µg/L at the Semariya Ojjhapatti village. Iron content in tubewell water varies from 0.1 to as much as 13 mg/L (Shah 2014). There is no good correlation between As and Fe, where the lower value of As corresponds with a higher value of Fe and vice versa. Tubewells in Ballia, Ara, Chhapra, Patna, and Hazipur towns are located on the Older Alluvium upland surfaces and are As-safe in groundwater.

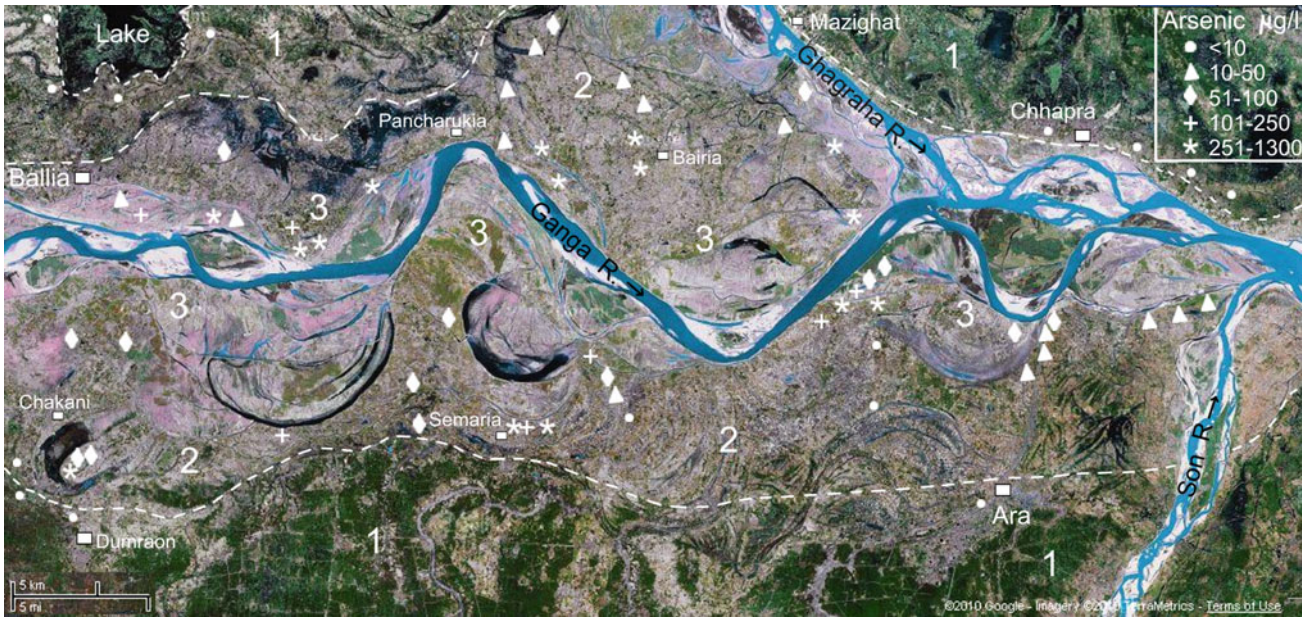

Fig. 2 Google satellite imagery shows spatial distribution of As-contaminated tubewells in entrenched channels and floodplains of the Ganga-Ghaghara River system

Apart from the above studies, groundwater As contamination has been reported from different parts of the middle Ganga plain. Currently, 57 blocks in 15 districts of Bihar are As-affected (>10 µg/L). The As-affected districts in Bihar are Buxar, Bhojpur, Patna, Saran, Vaishali, Begusarai, Samastipur, Lakhisarai, Purnea, Kathitar, Khagaria, Darbhanga, Bhagalpur, Kishanganj, and Munger (Chakraborti et al. 2003; Nickson et al. 2007; Central Ground Water Board 2010; Shah 2014).

The Bengal delta plain is extensively affected by groundwater As pollution, which affects mainly lower grounds comprising the Holocene deltaic sediments, whereas the Older Alluvial uplands and inter-fluve areas are generally unaffected. Currently, the groundwater of nine districts of West Bengal is As-contaminated. Arsenic contaminated aquifers are mainly confined in the Holocene entrenched channels and floodplains of the Bhagirathi River in the six districts (Malda, Murshidabad, Nadia, North 24-parganas, Kolkata, South 24-parganas) of West Bengal and mostly in the eastern parts of the Bhagirathi River (Chakraborti et al. 2003).

4.2 Sources and Release Mechanism of Arsenic

Groundwater arsenic mobilization in the Gangetic plains has similarity with the Bengal delta. Biomediated reductive dissolution of hydrated iron oxide (HFeO) that occurs mainly as coatings on sediment grains and corresponding oxidation of sedimentary organic matter is regarded as the main mechanism, which mobilizes As to groundwater from aquifer sediments (Kinniburgh and Smedley 2001). The anaerobic heterotrophic Fe^{3+} reducing bacteria (IRB) dissolve discrete phases of HFeO, with a consequent release of its sorbed As to groundwater (Islam et al. 2004).

5 Conclusions

The major parts of the Ganga plains consist of inter-fluve upland surfaces of the Pleistocene Older Alluvium. Shallow level As-contaminated aquifers of the Holocene age are extensive in the upper and middle Ganga plains and Bengal delta. The Pleistocene sediments caped by aquitardic paleosol and oxidized zone, and sediments beneath them are free of arsenic contamination. The Pleistocene uplands were dissected and entrenched by paleochannels, which were filled by organic rich Holocene sediments, and became prone to As pollution. The environment of the Pleistocene aquifers is not favorable to release sorbed As into groundwater and aquifers' groundwater is generally arsenic-safe. In As-contaminated areas, deeper tubewells in the Pleistocene Older Alluvium aquifers would be a better option for As-safe drinking water in the upper, middle, and lower Ganga plains.

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