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Quaternary shoreline shifting and hydrogeologic influence on the distribution of groundwater arsenic in aquifers of the Bengal Basin

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Abstract

Naturally occurring high arsenic concentration in groundwater of most alluvial aquifers in the Bengal Basin has been causing serious health problems in millions of people. Elevated dissolved arsenic concentrations are mostly confined within a shallow depth (<150 m) of the Middle Holocene aquifers of the GBM delta and the rapidly subsided Sylhet trough. Arsenic-rich zones in the Bengal Basin are located in the south-central parts of Bangladesh and northeastern parts of West Bengal, India, bounded by Chittagong Hills in the east and the Indian Craton to the west. Holocene sea level rise and development of reducing conditions at organic-rich swampy lands are directly linked to epicenters of arsenic distributions. Surface elevation and topographic slope seem to control the distribution of arsenic because higher levels of dissolved arsenic occur mainly within the present-day topographically low areas. Delta lobes that have experienced tidal influx in the recent past do not appear to have high arsenic concentrations in groundwaters. Groundwater quality data suggest that the sulfate-reducing condition in the coastal aquifers may limit the dissolved arsenic and iron concentrations in aquifers.

Keywords: Arsenic; Groundwater; Hydrogeology; Sea level change; Paleoshore; Bengal Basin

1. Introduction

Naturally occurring elevated arsenic (As) in groundwater of the Bengal Basin, including Bangladesh and West Bengal of India has been recognized as the worst case of groundwater contamination in the world. Millions of tubewells were installed in the Ganges–Brahmaputra–Meghna (GBM) delta complex in the last four decades to provide pathogen-free water for domestic and irrigation purposes in Bangladesh and West Bengal (Smith et al., 2000; BGS and DPHE, 2001). The major switch from polluted surface water to groundwater helped people avoid waterborne diseases, but detection of elevated dissolved arsenic in groundwater has panicked the people of Bangladesh and West Bengal, India (Nickson et al., 2000; BGS and DPHE, 2001). The first reported case of high arsenic in groundwater from the West Bengal of eastern India was recorded in 1978 (Acharyya et al., 2000). In 1993, the Department of Public Health Engineering (DPHE) first reported the existence of arsenic poisoning in the groundwater of Bangladesh in an area bordering West Bengal, but it was not until 1995 that the extensive occurrence of high arsenic was widely known (Dhar et al., 1997; WARPO, 2000; BGS and DPHE, 2001). The National Hydrochemical Survey of Bangladesh (NHS), which was carried out by DPHE and the British Geological Survey (BGS), and Mott MacDonald Ltd., in 1998 and 1999, found that nearly 35 million people were drinking groundwater containing As with a concentration of more than 50 $\mu g\ L^{-1}$ (Bangladesh standard), and about 57 million people consume water that exceeds 10 $\mu g\ L^{-1}$ As (World Health Organization standard), mostly extracted from alluvial aquifers located within 10–50 m of the ground surface (BGS and DPHE, 2001). In West Bengal, about 5 million people in nine districts in the southern deltaic region are found to be badly affected by arsenic poisoning in groundwater (Acharyya et al., 2000; SOES, 2006).

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Arsenic contamination of natural origin in groundwater has also been reported in many other parts of the world, including Argentina, Australia, China, Chile, Pakistan, Taiwan, Thailand, Mexico, Vietnam, and many parts of the United States (Smedley and Kinniburgh, 2002; Nickson et al., 2005; Liu et al., 2006). However, the human health-effects of groundwater arsenic in the Bengal Basin are the most widespread. The occurrence, origin, and mobility of arsenic in groundwater vary among the contaminated sites around the world (Ravenscroft et al., 2001). The mode of occurrence and mobility of arsenic in sedimentary aquifers is mainly influenced by local geology, geomorphology, hydrogeology, and geochemistry of sediments and water, as well as anthropogenic activities, such as, mining and land use (Bhattacharya et al., 1997; BGS and DPHE, 2001; Smedley and Kinniburgh, 2002). In the Bengal Basin, the occurrence of arsenic and its mobilization is associated with geochemically reducing subsurface environment. Several recent studies agree that biogenic reductive dissolution of Fe-oxyhydroxides is the primary release mechanism that puts arsenic into groundwater in Bengal Basin alluvial aquifers (Bhattacharya et al., 1997; Nickson et al., 1998; Zheng et al., 2004). A similar mechanism was proposed to explain arsenic contamination in Taiwan, Vietnam, and parts of the United States (Saunders et al., 2005; Liu et al., 2006). A study in the central Bangladesh by Harvey et al. (2002) suggested that arsenic mobilization may also be associated with recent inflow of carbon due to large-scale irrigation pumping. Saunders et al. (2005) tried to link the elevated arsenic occurrences in groundwater with the retreat of continental glaciation at the end of Pleistocene, which led to the rise of sea level during the Early to Middle Holocene, and deposition of alluvium and extensive marsh and peat and finer sediments in Bengal lowlands (Ravenscroft et al., 2001). During the Pleistocene the mechanical weathering of rocks in source areas (e.g., Himalayas, Indian Shield, and Indo-Burman Mountains) was enhanced due to mountain building activities and glaciation. The aquifer sands in the Bengal Basin were largely derived from physical weathering and erosion at a time of extended glaciation in the Himalayas, but the intensity of chemical weathering was limited by the low temperatures during erosion (McArthur et al., 2004). Close connection between groundwater arsenic and presence of glacial deposits was observed in many places in North America and Europe (Saunders et al., 2005).

Spatial distribution of high contents of As in groundwater contained in alluvial aquifers in Bangladesh and West Bengal is not random, rather it is controlled by regional hydrogeologic setting and geologic–geomorphic units of the country (Ahmed et al., 2004; Shamsudduha et al., 2006a). However, arsenic concentrations at shallow depths within the same aquifer and at similar depths are unpredictable (van Geen et al., 2003; Shamsudduha, 2004). High concentrations of groundwater arsenic, and the highest probability of exceeding Bangladesh standard of 50 $\mu g\ L^{-1}$, most often occur in tubewells screened within 50 m of the ground surface (Ravenscroft et al., 2001). Similar conditions exists in the western part of Bengal Basin, where the highest arsenic concentrations both in groundwater and aquifer sediments are found within a few meters to about 50 m below the ground surface (Pal et al., 2002).

This study examines the spatial and depth distribution of arsenic contamination in alluvial aquifers and relates this distribution to Quaternary sea level, hydrogeology and surface elevation in the Bengal Basin. Groundwater arsenic distributions in aquifers combining both Bangladesh and West Bengal are mapped using GIS techniques to understand the spatial distribution on a basinal scale. Formation of different delta lobes and shoreline changes within the Bengal Basin mostly during the Quaternary time and their controls over the geographic distributions of arsenic in groundwater are illustrated in this study.

2. Bengal Basin: an overview

The Bengal Basin, located in South Asia has been the major depocenter of sedimentary flux from the Himalayas and Indo-Burman ranges drained by the Ganges–Brahmaputra–Meghna, the largest river system in the world (Fig. 1). The basin is bounded by the Himalayas to the distant north, the Shillong Plateau, a Precambrian massif to the immediate north, the Indo-Burman ranges to the east, the Indian Craton to the west, and the Bay of Bengal to the south (Uddin and Lundberg, 1998). The basin includes one of the largest delta complexes (GBM delta) in the world, covering a vast portion of the basin filled with about $5 \times 10^5\ km^3$ of sediments (Johnson, 1994). Thick sedimentary deposits of the basin fill have been uplifted significantly along the north and eastern margins of the Sylhet trough in the northeast and along the Chittagong foldbelts of eastern Bangladesh (Uddin and Lundberg, 1998). The western part of the Bengal Basin, which covers the West Bengal of India, is mostly drained by the Bhagirathi–Hooghly river, a major distributary channel of the Ganges river (Fig. 1).

The alluvial plains of the GBM delta slope from north to south on a regional scale, but are interrupted locally by ridges and tectonically developed depressions, such as, Sylhet trough and Atrai depression. The Bengal Basin comprises of lowland floodplain and delta plain, and is surrounded by the Tertiary hills of various origins (Fig. 2; Goodbred and Kuehl, 2000; Ravenscroft et al., 2005). Within the eastern Bengal Basin, the Madhupur Tract and Barind Tract are uplifted alluvial deposits of Pleistocene age interrupt the regional surface gradient of the central basin (Morgan and McIntire, 1959). Neotectonically uplifted Lalmai Hills located to the southeast of Madhupur Tract are composed of highly oxidized clay and sand of Pleistocene age. Underneath the Pleistocene tracts, there is yellowish-brown colored sandy aquifer, formed within the Pliocene–Pleistocene Dupi Tila sand (Uddin and Lundberg, 1998).

The western part of the Bengal Basin is older than the eastern side and characterized by a sedimentary wedge of