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Dynamics of arsenic in agricultural soils irrigated with arsenic contaminated groundwater in Bangladesh

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Abstract

Arsenic (As) concentrations in the soil layers of 12 rice fields located in four As affected areas and two unaffected areas in Bangladesh were monitored during 2003. In the unaffected areas, where irrigation water contained little As (<1 μg/L), As concentrations of rice field soils ranged from 1.5 to 3.0 mg/kg and did not vary significantly with either depth or sampling time throughout the irrigation period. In the As affected areas where the irrigation water contained elevated As (79 to 436 μg/L), As concentrations of rice field soils were much higher compared to those in the unaffected areas and varied significantly with both depth and sampling time. For the top 0 to 150 mm of the soil, the As concentration increased significantly at the end of the irrigation season (May–June 2003). About 71% of the As that is applied to the rice field with irrigation water accumulates in the top 0 to 75 mm soil layer by the end of the irrigation season. After the wet season during which the rice fields were inundated with flood/rain water, the As concentrations in the soil layer decreased significantly and were reduced to levels comparable to those found in soil samples collected at the beginning of the irrigation period. The long-term As accumulation in agricultural soil appears to be counteracted by biogeochemical pathways leading to As removal from soil.

Keywords: Arsenic; Groundwater; Irrigation; Rice; Accumulation; Bangladesh

1. Introduction

In Bangladesh and neighboring West Bengal, India, the presence of elevated arsenic (As) (>50 μg/L) in shallow groundwater is a major public health concern. Out of the 465 upazilas (sub-districts) in Bangladesh, 270 have been affected with elevated concentrations of As, with the greatest contamination in the south and south-east regions (BGS and DPHE, 2001; Ahmed et al., 2004; BAMWSP, 2005). In Bangladesh, groundwater extracted from shallow aquifers with hand-tubewells is the primary source of drinking and cooking water for most of its population of over 140 million (World Development Report, 2006). An estimated 10 million domestic wells constitute the backbone of rural water supply of the country. According to BGS and DPHE (2001), 35 million Bangladeshi people are exposed to As concentrations in drinking water exceeding the national standard of 50 μg/L and 57 million people are exposed to concentrations exceeding the World Health Organization guideline value of 10 μg/L. Yu et al. (2003) estimated that the prevalence of arsenicosis in Bangladesh annually could be up to two million cases if consumption of contaminated water continues. For skin cancer it could be up to a million cases with an incidence of death from arsenic-induced cancer around 3000 cases.

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Besides domestic use, groundwater is widely used for irrigation during dry season (December to April), particularly for growing of the dry-season rice called *boro* which requires about 1 m of irrigation water each year (Hossain et al., 2003). A total of 925,152 shallow and 24,718 deep tubewells were used for irrigation during the 2004 dry season (BADC, 2005) and groundwater irrigation covered about 75% of the total irrigated area. *Boro* cultivation and irrigation have together increased since 1970, and from 1980 until present, the area under groundwater irrigation has increased by almost an order of magnitude (Harvey et al., 2005). During 2003 dry season, about 87% of the total irrigated area of about 4 million hectare (about 28% of the total area of the country) was under *boro* cultivation and *boro* accounted for about 49% of the total rice production (MoA, 2004). Thus, groundwater irrigation has greatly increased agricultural production in Bangladesh and the country's food security is heavily dependent on groundwater irrigation during the dry season.

Based on available information on the distribution of As concentration in groundwater (BGS and DPHE, 2001) and the area under shallow tubewell irrigation (BADC, 2005), Saha (2006) estimated that close to 1000 metric tons of As is cycled with irrigation water during the dry season of each year. The accumulation of As in rice field soil and its introduction into the food chain through uptake by the rice plant is of major concern. Rice production is reported to decrease by 10% at a concentration of 25 mg/kg As in soil (Xiong et al., 1987). Pot studies (Jahiruddin et al., 2004) showed that higher As concentration in irrigation water (0.1 to 2.0 mg/L) and soil (5 to 50 mg/kg) resulted in lower yield of a local rice variety (BR-29). In a greenhouse study, Abedin et al. (2002) also observed reduced yield of a local variety of rice (BR-11) irrigated with elevated As (0.2 to 8.0 mg/L) bearing water.

Due to its affinity for metal oxides/hydroxides in soil, the accumulation of As in irrigated surface soils is expected and a number of studies (e.g., Alam and Sattar, 2000; Meharg and Rahman, 2003; Ahmed, 2005; Farid et al., 2005; Islam et al., 2005; Jahiruddin et al., 2005) have reported elevated concentrations of As in rice field soils irrigated with As contaminated groundwater. However, limited data (Ali et al., 2003) suggest that As concentration in rice field soils irrigated with As contaminated groundwater varies significantly with both depth and time.

This research work focuses on developing a better understanding of the dynamics of As in rice field soils irrigated with As contaminated groundwater. Arsenic concentrations in top soil layers of 12 rice fields located in As affected and unaffected areas have been monitored in this study during 2003. This paper presents the variation of As concentration in the rice field soils as a function of depth of soil and sampling time. This paper also presents an estimate of the total amount of arsenic added to a rice field with irrigation water and the amount that is retained in the surface soil at the end of the irrigation season.

2. Methodology

2.1. Site selection

Arsenic concentration in the top (~ 450 mm) soil layers of *boro* rice fields was monitored during the 2003 dry season in 6 different areas of Bangladesh. These included four As affected areas in the central region and two unaffected areas in the north-western region of Bangladesh (Fig. 1). The As affected areas were: (i) Sreenagar in the Munshiganj district, (ii) Barura in the Comilla district, (iii) Nabinagar in the Brahmanbaria district, and (iv) Vanga in the Faridpur district. The unaffected areas were: (i) Bogra Sadar in the Bogra district, and (ii) Nazipur in the Noagaon district.

In each sampling area, the As concentration of irrigation water of six to eight rice fields was measured using a field kit (Hach) at the beginning of the irrigation season (February 2003). At each of the As affected areas, two fields with elevated As concentrations in irrigation water were selected for monitoring. In the two unaffected areas, the As concentration in the irrigation water of all the water samples was below the detection level (10 μg/L) of the Hach field kit. In each of the unaffected areas, two fields were selected for further monitoring. At each of the six sampling areas, two *boro* rice fields, irrigated by groundwater, were selected for monitoring of As concentrations in the top soil layers.

To estimate the total amount of As that is added to a particular rice field with irrigation water and the amount that is retained in the surface soil at the end of the irrigation season, the As concentration in irrigation water and the As concentration in the top (~ 450 mm) layers of soil in a *boro* rice field in Sreenagar, Munshiganj (identified here as "intensive" field site) was intensively monitored during the dry season of 2004.

2.2. Sample collection

2.2.1. Collection of water samples

Tubewell water used for irrigating each of the 12 *boro* rice fields at the six sampling areas was collected at two different times during the year: at the beginning of the