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Arsenic Linkage in the Irrigation Water-Soil-Rice Plant Systems

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Abstract. This investigation reports the levels of arsenic (As) in irrigation waters, soils and Boro (dry season) rice grain from 100 shallow tube well (STW) areas over the sadar upazila of Chapai Nawabganj. The As concentrations for all samples (soil, water and rice grain) varied widely between locations. The shallow tube well (STW) water As concentration ranged from 0.015-0.352 μg/ml with a mean of 0.075 μg/ml, the concentration being lower in shallow well depth, reaching to a maximum about at 25 m depth and then decreased with increasing depths. The levels of total As in soils over the locations ranged from 5.8-17.7 μg/g with a mean of 11.2 μg/g. Total As content in soils was positively correlated with irrigation water-As indicating a possibility of As build up in soil with time. The rice grain-As concentration was in the range of 0.24-1.30 μ/g g having a mean of 0.76 μg/g. 22% of the grain samples had As level <0.5 μg/g, 39% in the range of 0.50-0.75 μg/g, 36% in the range of 0.75-1.0 μg/g and the rest 12% more than 1.0 μg/g. The grain-As was poorly correlated with soil-As as well as irrigation water-As. 94% of the rice grain grown in Chapai Nawabganj irrigated with As contaminated water may lead to an intake of more than 100% maximum tolerable daily intake (MTDI) for an adult of 60 kg body weight.

Keywords: arsenic, shallow tube well water, soil, rice grain, rice straw

Introduction

Bangladesh is currently facing the challenge of high arsenic concentration in shallow aquifers (Nickson *et al.*, 1998). A large number of hand and shallow tube wells (STW) in some of the localities of 59 districts out of 64 districts have been identified to have As concentration above the Bangladesh standard of 0.05 As mg/l (Alam *et al.*, 2002). More than 80% of the population depends on agriculture for their livelihood. The agricultural sector employs about 90% of the rural males of the country (WDI, 1998). The use of groundwater for irrigation has increased markedly over the last three decades. About 86% of the total groundwater withdrawn is utilized in the agricultural sector (WRI, 2000). Irrigating the paddy fields with As contaminated groundwater may lead to result in increasing soil As status in Bangladesh (Meharg and Rahman, 2003). Irrigation with arsenic contaminated groundwater to rice increases its concentration, and eventually arsenic enters into food chains through crop uptake and poses long term risk to human health (Islam *et al.*, 2004a; Meharg and Rahman, 2003; Abedin *et al.*, 2002a; Marin *et al.*, 1992). Most of the hand and STWs in the Chapai Nawabganj sadar upazila are contaminated with arsenic (Islam *et al.*, 2004a; Chowdhury *et al.*, 1999). But reports on arsenic in irrigation water-soil-plant systems are limited in Bangladesh. Therefore, the aim of this study is to assess the linkage of As in irrigation water-soil-rice plant systems and also to determine the contribution of arsenic ingestion to an adult through the rice grown in Chapai Nawabganj sadar upazila.

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Materials and Methods

One hundred geo-referenced samples for each of irrigation water, soil and rice grain were collected from 100 STW command areas of Chapai Nawabganj sadar upazila, Bangladesh during dry season of 2003. Chapai Nawabganj is located on 24 ° 25′ N latitude and 88058′ and 88 ° 38′ E longitude. Water samples were collected from STW after 15 m of operation. 90 ml of water sample was filtered through 0.45μm membrane filter and kept in acid washed plastic bottles containing 10 ml of 2M HCl (ANALAR grade) to arrest the microbial growth and to prevent precipitation of metals. The water samples were brought to the laboratory and kept in the refrigerator until analysis by hydrid generation atomic absorption spectrophotometer (HG-AAS) (Unicam model 969).

Five soil samples (0-15 cm depth) were randomly collected from the adjacent field of STW after 15-20 days of transplanting of rice. During the sampling time, there was 2-3 cm water in the rice fields. Bamboo sticks were placed on the sampling site to identify the location for subsequent rice grain collection at harvesting stage. The soil samples were air dried, ground and passed through a 2 mm sieve, and finally stored in plastic pots.

Ten rice plants at maturity of the crop were collected from the rice field from the soil sampling sites. Rice grains were separated from the panicles by hand. The grain samples were stored in the polythene bags. Grains were dried for 72 h at 65 °C in oven. Husks were removed from the rice grains by grinding using a ceramic mortar. The samples were finely ground and stored for chemical analysis. For concentrations of total arsenic in rice grains, milled sub-samples (0.5 g) were weighed into glass digestion tubes, steeped in 5.0 ml of nitric acid and allowed to pre-digest/ stand overnight at room temperature. The samples were digested at 120 °C for 2 h and 2.5 ml H_2O_2 was added and digested until it became clear. In case of soil samples, a sub-sample of 1.0 g was taken and followed the same procedure to that of rice grain. Total As in the digest was determined followed by flow injection hydride generation atomic absorption spectrophotometer (HG-AAS) with Unicam model 969 and MHS-10 hydride generator assembly using matrix-matching standard (Welsch *et al.*, 1990).

Results and Discussion

Arsenic in STW water. The As levels in STW water showed a wide spatial variation in samples from different STW command areas (Table 1). The water As concentration ranged from 0.015-0.352 μg/ml with a mean of 0.075 μg/ml. Forty four percent of the samples had As level below 0.050 μg/ml, 33% of the samples had As level within 0.051- 0.100 μg/ml, 15% samples 0.101-0.200 μg/ml, 2% 0.201-0.300 μg/ml and the rest 6% had As level >0.3 μg/ml (Fig. 1). The As in STW water was lower in shallow well depth, reaching to a maximum at 25 m depth and then decreased with increase in depth of the wells (Fig. 2). It appears that increasing the depth of STW may partially overcome the inflow of As through the irrigation water into the rice fields.

Arsenic levels in soil. There was a wide variation in total As concentrations in the soil samples from different STW command areas of Chapai Nawabganj upazila. The levels of total As in soils over the locations ranged from 5.8-17.7 μg/g with a mean of 11.2 μg/g. Of the 100 samples, 32% of the soils had total As from 5.1-10.0 μg/g, 63% soils 10.1-15.0 μg/g, and the rest 5% soils 15.1-20.0 μg/g (Fig. 3). Jahiruddin *et al.* (2000) studied the As levels of 20 calcareous and 20 non-calcareous soils of Bangladesh and reported that the mean As level of calcareous soils was 17 μg/g while for non-calcareous soils was 7.65 μg/g. Total As content in soils was positively correlated with irrigation water As (Fig. 4) indicating a possibility of build up of arsenic in soils due to

Table 1. Arsenic concentration in water, soil, rice grain and straw samples (n =100)

Parameters	Range	Mean	Sd
Water As (μg/g)	0.015- 0.352	0.075	0.061
Soil As (μg/g)	5.8- 17.7	11.2	2.6
Grain As (μg/g)	0.24- 1.30	0.76	0.23
Straw As (μg/g)	1.48- 17.60	5.88	3.4

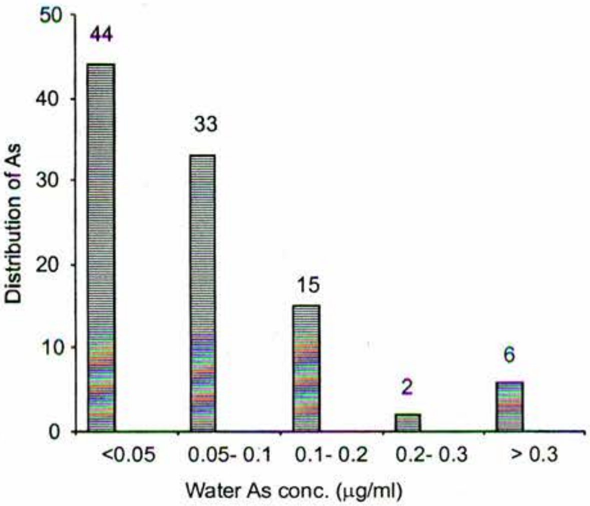

Fig. 1. Frequency distribution of water As (n = 199).

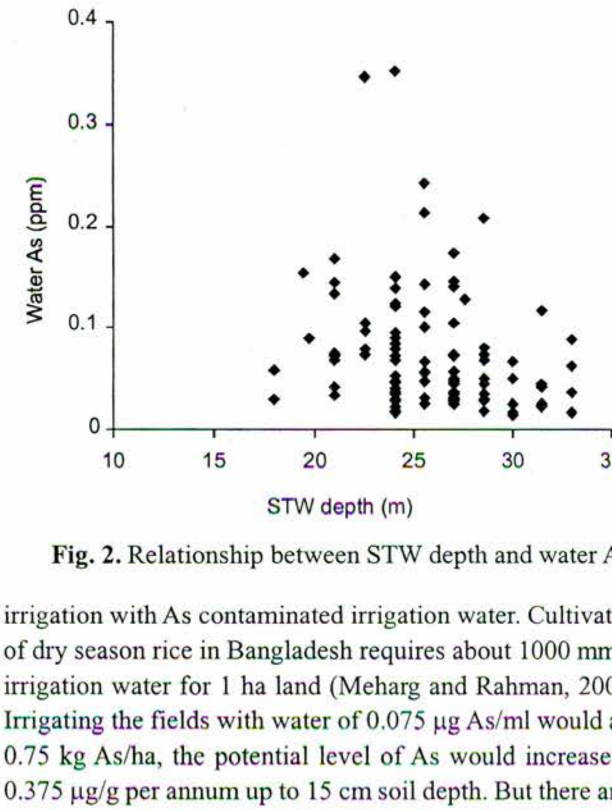

Fig. 2. Relationship between STW depth and water As.

irrigation with As contaminated irrigation water. Cultivation of dry season rice in Bangladesh requires about 1000 mm of irrigation water for 1 ha land (Meharg and Rahman, 2003). Irrigating the fields with water of 0.075 μg As/ml would add 0.75 kg As/ha, the potential level of As would increase by 0.375 μg/g per annum up to 15 cm soil depth. But there are a number of ways arsenic is lost from the soils. The average yields of Boro rice grain and straw in Bangladesh are 3.2 and 4.0/tha, respectively (BBS, 2003). The mean As concentrations of As in Boro rice grain and straw in this study are 0.76 and 5.88 μg/g, respectively. Arsenic is one of the least mobile elements in rice plants. Once arsenic is absorbed by the plants, the great majority portion is retained in roots, the lesser in rice straw and the least in rice grains. Therefore, the grain arsenic content is much lower than the rice straw. Arsenic concentration pattern in rice plant parts generally follow the

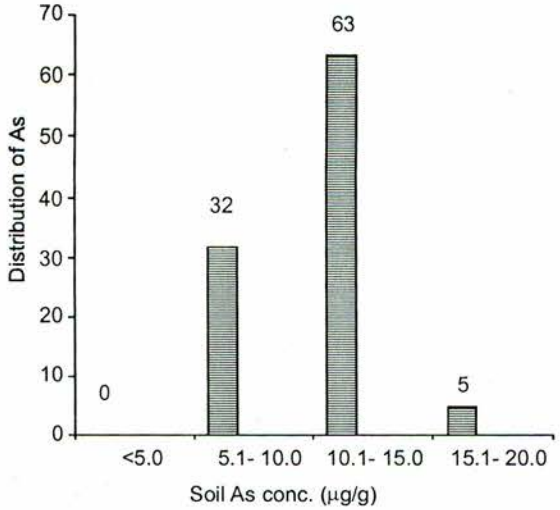

Fig. 3. Frequency distribution of soil As (n = 100).

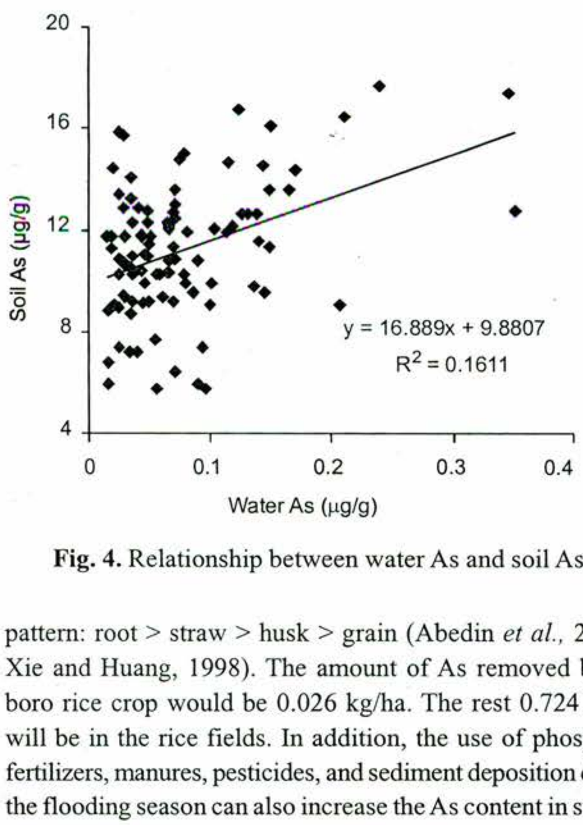

Fig. 4. Relationship between water As and soil As.

pattern: root > straw > husk > grain (Abedin *et al.*, 2002b; Xie and Huang, 1998). The amount of As removed by the boro rice crop would be 0.026 kg/ha. The rest 0.724 kg/ha will be in the rice fields. In addition, the use of phosphatic fertilizers, manures, pesticides, and sediment deposition during the flooding season can also increase the As content in surface soils. Data are not available about specific contribution of the above processes in the study area. When irrigation water comes in contact with air, the soluble ferrous iron is rapidly oxidised to ferric form precipitating arsenate present in water. Therefore, the level of arsenic in soils near the STW will be higher compared to those fields at far end of the command area (Jung *et al.*, 2002; Keegan *et al.*, 2002). During monsoon season, a good amount of arsenic may be lost from the soil with the horizontal flow of water and also through volatilisation as gaseous arsines under anaerobic condition by soil microbes (Turpeinen *et al.*, 1999; Cullen and Reimer, 1989). The percolation of irrigation water in paddy field is low, generally 1-2 cm a day (Brammer, 1996) due to the presence of a 3-4 cm hard plough plan common to rice fields of Bangladesh developed over the years due to continuous cultivation. Khan (2005), reported from a leaching study on four soils of Bangladesh that the amount of leaching loss through the undisturbed soil column ranged from 1-3% of the applied As through irrigation water. Besides, the upper 1-2 cm of a flooded paddy field is aerobic where As will be adsorbed by the soil particles. The As accumulated in the top layers may also be subject to losses through water erosion due to heavy monsoon rainfall. The cultivation of Aman (wet season) rice during the monsoon season will also uptake some of the As from the soil. The yield and concentration of As in T. Aman rice is lower compared to that of Boro rice (Islam *et al.*, 2004b; Duxbury *et al.*, 2003). Hence, the uptake of As by Aman rice will be lower compared to that of Boro rice. However, all these need to be taken into consideration before final quantification of building up of arsenic in paddy field soils. Build up of As in paddy soils through irrigating with As-contaminating irrigation water was also reported by some of the authors (Ali *et al.*, 2003; Meharg and Rahman, 2003; Roychowdhury *et al.*, 2002). The variation in soil As levels in different locations of Chapai Nawabganj may be due to variation of the amount of irrigation water having different levels of As used in different soils and also with the time period for irrigation with contaminated waters. Panaullah *et al.* (2003) reported that spatial variability for As contents was more prominent in case of soil compared to irrigation water and rice grain, however, it was not clear whether this variability of soil As depended on irrigation water or background As.

Arsenic levels in rice grain. The grain As concentration varied widely ranging from 0.24 to 1.30 μg/g with a mean value of 0.76 μg/g (Table 1). One percent of grain samples had As level below 0.25 μg/g, 12% samples within the range of 0.25-0.50 μg/g, 39% samples within the range 0.50-0.75 μg/g, 36% samples 0.75 -1.0 μg/g, and the rest 12% had As levels beyond 1.0 μg/g (Fig.5). Grain-As was poorly correlated with soil As and irrigation water As (Fig. 6 and Fig. 7) indicating that the amount of available As to plants is related to total soil and irrigation water As in a complex manner. The availability and uptake of As by plants may vary with the extent of As contamination of soil (Islam *et al.*, 2004a; Jahiruddin *et al.*, 2004; Duxbury *et al.*, 2003), the forms of As species (Abedin *et al.*, 2002a,b), phosphate level (Meharg and Macnair, 1994), season (Islam *et al.*, 2004b; Duxbury *et al.*, 2003), rice variety (Islam *et al.*, 2004b; Jahiruddin *et al.*, 2004; Meharg and Rahman, 2003). Meharg and Rahman (2003) tested grain As levels of nine Bangladesh rice genotypes of rice grown in BRRI farm (As-noncontaminated soil) and found that the As levels ranged from 0.043 to 0.206 µg/g while rice grain samples collected from As contaminated areas of Chapai Nawabganj and Naogaon were in the range of 1.747 to 1.835 µg/g. Duxbury *et al.* (2003) analysed 150 paddy rice samples from Barishal, Comilla, Dinajpur, Kaunia, and Rajshahi districts and also from the BRRI experimental station at Rajshahi in the boro (dry season) and Aman seasons (wet season) of 2000 and reported that mean concentration of As in unprocessed paddy rice ranged from 0.01 to 0.42 µg/g at 14% moisture content. Roychowdhury *et al.* (2002) reported that the mean As levels in rice grains from Jalangi and Domkal Blocks of West Bengal, India were 0.23 and 0.25 µg/g,

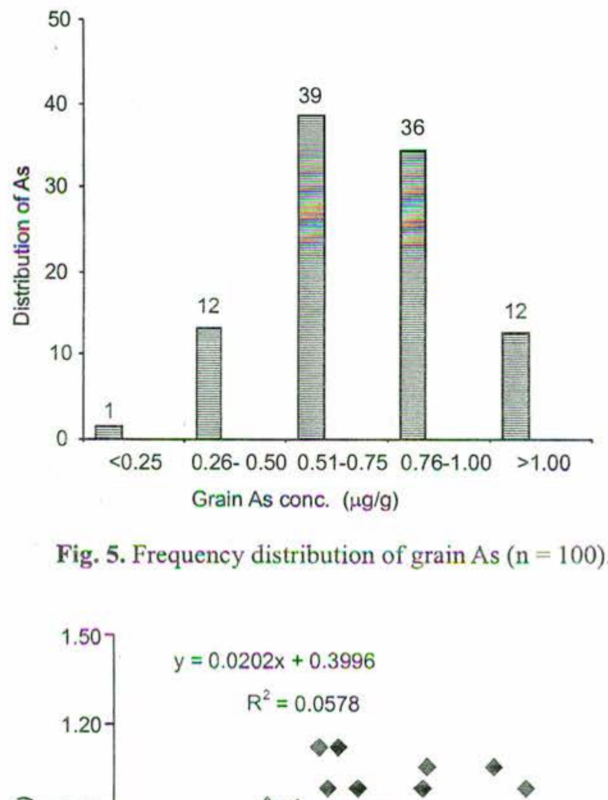

Fig. 5. Frequency distribution of grain As (n = 100).

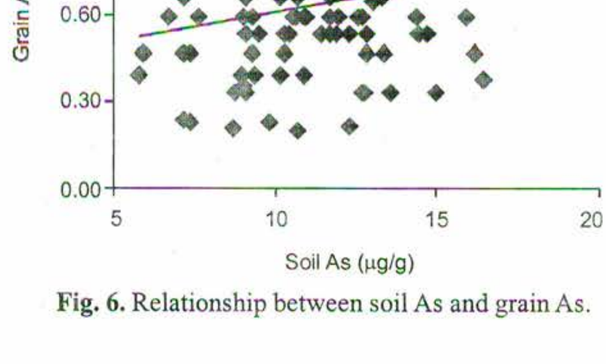

Fig. 6. Relationship between soil As and grain As.

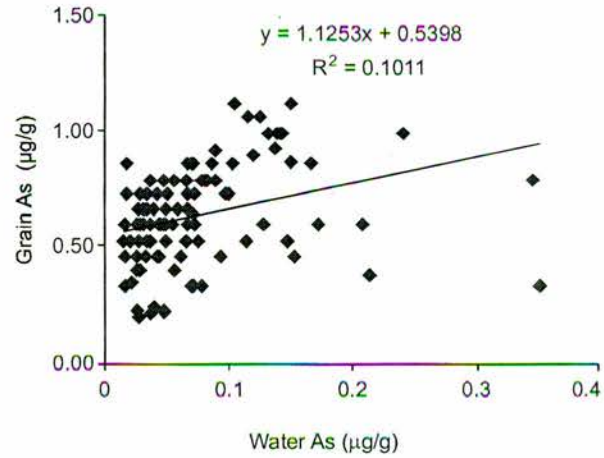

Fig. 7. Relationship between water As and grain As.

respectively. Islam *et al.* (2004a) reported that grain As concentration of samples collected from five districts of Ganges River floodplain of Bangladesh varied from 0-2.05 µg/g. Lin *et al.* (2004) analysed 407 rice samples from Taiwan and the mean As content was 0.08 µg/g.

Human exposure to arsenic via rice. Rice is the staple food for people of Bangladesh, who consume about 450 g of rice per day by an adult (CIMMYT, 2004). The total As content in Chapai Nawabganj sadar upazila ranges from 0.24-1.30 µg/g. Consuming 450 g rice from these samples will lead to an intake of total As ranging from 108-584 µg/day. Inorganic As in rice grains varies widely depending on varieties and countries of origin. Schoof *et al.* (1998) reported that the inorganic As in Taiwanese rice were 69-73% of the total arsenic whereas the inorganic arsenic in the United States rice were 24% (Schoof *et al.*, 1999) and 44% (Douglas *et al.*, 2001). The percentage of inorganic arsenic in Bangladesh rice varies from 70-90% depending on the varieties and growing conditions (William *et al.*, 2006). If we assume that 80% of the total arsenic in our studied samples is inorganic, an amount of 60-335 µg As/day will be ingested by an adult of 60 kg body weight. The maximum tolerable daily intake (MTDI) for an adult of 60 kg body weight is120 µg/kg/day. Results in Table 2 show the distribution of daily arsenic ingestion from the 100 rice samples from Chapai Nawabganj sadar upazila. Ninety four per cent of rice grain samples would lead to an intake of more than 100% MTDI for an adult. Besides, the people are also exposed to arsenic ingestion through other routes like drinking water and vegetables consumption. The As concentrations of the vegetables grown in these areas are quite high ranging from 0.312-0.812 µg/dry weight (Islam *et al.*, 2005). Most of the hand tube wells of these areas are also contaminated with As (Chowdhury *et al.*, 1999). Therefore, the dietary ingestion of As by the people in these areas will be very high.

Table 2. Comparison of total arsenic intake from rice samples (n = 100)

Rice samples (%)	Rice grain As concentration (μg/g)	Total As ingestion through rice (μg/day)	Inorganic As ingestion (μg/day)	% of MTDI
1	<0.25	108	86	66
12	0.251-0.50	172-206	138-165	115-138
39	0.501-0.75	240-333	192-266	160-222
36	0.751-1.00	343-450	275-360	229-300
12	>1.00	464-584	372-467	310-389

Conclusion

Arsenic status in soils of Chapai Nawabganj are below the maximum permissible limit of 20 μg/g (Kabata-Pendias and Pendis, 2001) but irrigating the rice crops with elevated As concentration may lead to the accumulation of As in soils as well as uptake by the crops. It may not be cost effective to remediate contaminated rice field soils. There may be a number of options for reduced inflow of arsenic in the rice fields. Results of this study show that the concentration of arsenic in water was lower in deeper aquifers compared to shallow aquifers. Therefore, pumping irrigation water from the greater depths might lead to an decrease in the arsenic load to the rice fields. Another option is the economic use of irrigation water by (i) reducing the depth of pounded water, (ii) keeping the soil just saturated or (iii) alternate wetting/drying (Guerra *et al.*, 1998). Water savings under saturated soil conditions were on average 23% with a yield reduction of only 6% (Bouman and Tuong, 2001). Rice varieties also differ in their ability to tolerate arsenic toxicity (Dasgupta *et al.*, 2004). Therefore, selecting or breeding rice varieties suitable for growing on arsenic contaminated soils might be also a good option to reduce the entry of arsenic in rice grain and ultimately food chain.

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