Arsenic in paddy soils of Bangladesh: levels, distribution and contribution of irrigation and sediments

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Introduction

Arsenic is widely distributed in nature. It is associated with igneous and sedimentary rocks, particularly with sulphide ores. Natural phenomena such as weathering, biological activity, and volcanic activity, together with anthropogenic inputs, are responsible for the emission of arsenic into the atmosphere, where from it is distributed on the earth's surface by rain and dry fall out. 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 arsenic (As) concentration above the Bangladesh standard of 0.05 As mg l^{-1} (Alam *et al*., 2002). To meet up the growing demand for food, the farmers had to cultivate high yielding varieties of Boro rice, which requires a large volume of irrigation water. Irrigation with arsenic contaminated groundwater to rice increases its concentration in soil (Jahiruddin *et al*., 2000; Meharg and Rahman, 2003; Ali *et al*., 2003), and eventually arsenic enters into food chains through crop uptake and poses long term risk to human health ((Duxbury *et al*., 2003; Islam *et al*. 2004a) But detailed study on the levels and distribution of arsenic in irrigated paddy soils, and contribution of different sources of arsenic on build up of soil arsenic levels are still lacking in Bangladesh. This paper presents the levels and distribution and also quantifies the contribution of different sources of As on build up of As in paddy soils of five upazilas of Bangladesh.

Materials and Methods

Four hundred fifty six geo-referenced samples for each of irrigation water, soil (0-15 cm depth), rice grain and rice straw were collected from 456 STW command areas of five upazila of Bangladesh during the boro season of 2002. The upazilas were B.Baria, Faridpur, Paba, Senbagh and Tala. The soils of B. Baria and Senbagh were developed by the sediments deposited by Old Meghna river while the soils of the rest three upazilas were developed by Ganges river borne sediments. The soils were analyzed for clay, organic matter, pH, available P, free iron oxide along with total arsenic, phosphate extractable and oxalate extractable arsenic. Soil, rice grain and straw samples were digested with concentrated HNO_3 and H_2O_2. Total As in the digest and water samples 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.

Results

There was a wide variation in total As concentration in the soil samples from different STW command areas of five upazilas (Table 1). The levels of total As in soils over the locations of the upazilas ranged from 1.0 –48.8 $\mu g\ g^{-1}$ with a mean of 12.3 $\mu g\ g^{-1}$. The soils of the Ganges river floodplain (Paba, Tala and Faridpur) had higher soil As levels compared to those of Meghna river floodplain (B. Baria and Senbagh). The mean total As levels of 4.7, 6.5, 7.2, 19.4 and 19.6 $\mu g\ g^{-1}$ were found in Senbagh, B.Baria, Paba, Tala and Faridpur upazila, respectively . Of the 456 samples, 53% of the soils had total As from 0-10.0 $\mu g\ g^{-1}$, 26% soils had 10.1 – 20.0 $\mu g\ g^{-1}$, 17% soils had 30.1-40.0 $\mu g\ g^{-1}$, and the rest 1% soils had arsenic level >40.0 $\mu g\ g^{-1}$ (Fig 1).

Table 1. Arsenic concentration in soil, water and grain samples of different upazilas of Bangladesh

Parameter	Statistical analysis	Upazila					All Upazila
		B. Baria (n=110)	Faridpur (n=100)	Paba (n=100)	Senbagh (n=41)	Tala (n=105)	All Upazila (n=456)
Soil total As ($\mu g\ g^{-1}$)	Range	1.0-38.6	9.9-48.3	3.0-23.6	2.5-7.7	5.2-48.8	1.0-48.8
	Mean±SD	6.5±6.9	19.6±6.7	7.2±2.9	4.7±1.5	19.4±7.3	12.3±8.8
Phosphate extractable As ($\mu g\ g^{-1}$	Range	0.12-10.6	1.0-20.8	0.4-4.5	0.3-2.1	0.8-14.8	0.1-20.8
	Mean±SD	1.9±2.1	4.7±3.5	1.2±0.6	0.8±0.4	4.3±2.3	2.8±2.7
Oxalate extractable As As ($\mu g\ g^{-1}$)	Range	0.5-32.5	3.4-28.9	0.9-9.5	0.8-5.2	2.7-24.8	0.6-28.9
	Mean±SD	4.8±5.1	9.4±4.5	2.6±1.6	2.5±0.9	11.5±5.3	6.6±5.4
Water-As ($\mu g\ ml^{-1}$)	Range	0.00-0.51	0-0.28	0-0.13	0.02-0.36	0.002-0.46	0-0.51
	Mean±SD	0.11±0.11	0.10±0.07	0.02±0.01	0.14±0.07	0.15±0.09	0.10±0.09
Grain-As As ($\mu g\ g^{-1}$)	Range	0.08-0.93	010-1.08	0-0.53	0.13-0.92	0.09-1.01	0-1.08
	Mean±SD	0.42±0.22	0.48±0.22	0.07±0.10	0.44±0.20	0.33±0.15	0.34±0.24

Total As content in soils was positively correlated with clay (r=0.52**) , soil pH (r=0.45**) and FeO (r=0.62**) (Figs. 2-4). The results indicated that heavy textured and high pH soils might have higher As contents compared to light textured soils. The soil As status was very weakly correlated with organic matter (r=0.10ns) indicating that organic matter does not contribute for As contents in soils (Fig. 5). A highly significant relationship between phosphate extractable As and oxalate extractable As (r=0.88**) indicated that both the extractants extracted a good amount of As from the same pool of soil (Fig. 6).

Cultivation of boro rice in Bangladesh requires about 1000 mm of irrigation water for 1 ha land. Irrigating the fields with water of 0.10 μg As ml^{-1} would add 1000 g As ha^{-1}. The addition of 2.0 t cow dung ha^{-1} to the rice fields would add 4.0 g As $ha^{-1}year^{-1}$. Sediment deposition is important for medium low to very lowland only. Our data showed that deposition of 2.53 t sediment $year^{-1}$ in Meghna river floodplain added 16.0 g As $ha^{-1}year^{-1}$. But sedimentation is very low in medium high and high lands where two rice crops are grown annually. Therefore, in medium high to high lands, the total inflow of As in rice field is 1004 g As $ha^{-1}year^{-1}$. The average yields of Boro and T.Aman rice are 3.2 and 2.5 t ha^{-1}, respectively. The mean As concentrations of As in Boro rice grain and straw in this study are 0.34 and 3.44 $\mu g\ g^{-1}$, respectively while the As concentrations of T. Aman rice grain and straw are about 0.25 and 2.0 $\mu g\ g^{-1}$, respectively (Islam *et al.*, 2004 b; Jahiruddin *et al.*, 2004). Total amount of As uptake by Boro and T. Aman crops is 23 g ha^{-1}. The remaining 981 g ha^{-1} if stays in the rice field, the potential level of soil As would increase by 0.50 $\mu g\ g^{-1}$ per annum. Vertical distribution of As in irrigated Boro fields and adjacent non-irrigated fields showed that the level of soil As was higher in the top soil compared to sub-soils of irrigated Boro fields while the reverse was found for non-irrigated fields indicating the contribuition of irrigation water As in building up the level of soil As in paddy soils. 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. The percolation of irrigation water in paddy field is low, generally 1-2 cm a day. Besides, the upper 1-2 cm of a flooded paddy field is aerobic where As will be adsorbed by the soil particles. Therefore, the leaching loss of As through the rice soil will be minimum. The As accumulated in the top layers may also be subject to losses through water erosion due to heavy monsoon rainfall.

Conclusion

At present 47% of the soils of the five upazilas have more than 10 $\mu g\ g^{-1}$ but irrigating the Boro rice with elevated As concentration will definitely increase the As status of soils as well as uptake by the crops. It may not be cost effective to remediate As-contaminated paddy soils. There may be a number of options for reduced inflow of arsenic in the rice fields. The concentration of As in STW water decreases with increasing well depth therefore, pumping irrigation water from the greater depths might lead to a decrease in the arsenic load to the rice fields. Another option is the economic use of irrigation water by reducing the depth of ponded water and by alternate wetting/drying practice for Boro rice cultivation.

Acknowledgement: We are grateful to the USAID for providing financial support to carry out this research.

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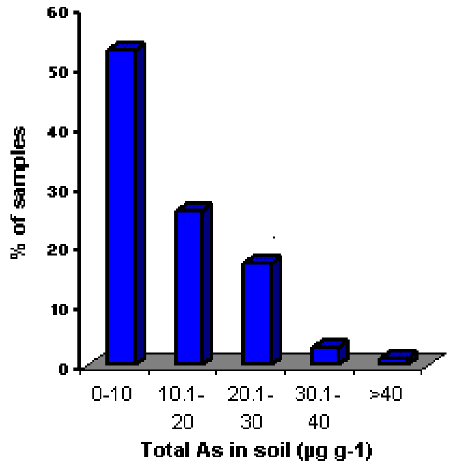

Fig. 1 Distribution of soil As

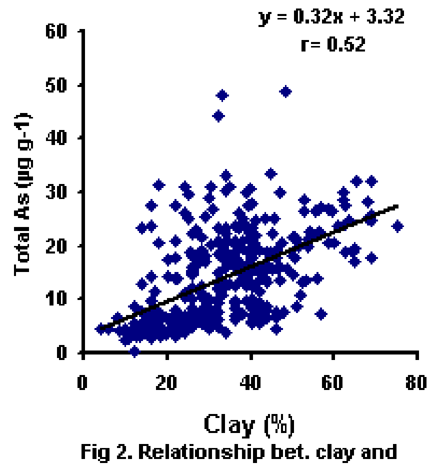

Fig 2. Relationship bet. clay and total As

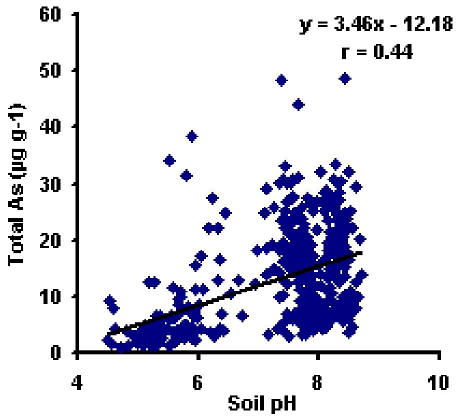

Fig 3 Relationship bet. soil pH and total As

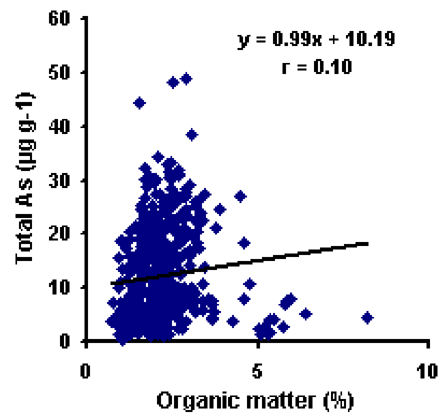

Fig 4 Relationship bet. OM and total As

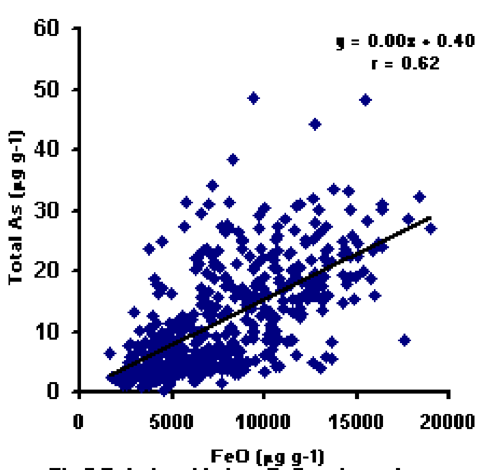

Fig 5 Relationship bet. FeO and total As

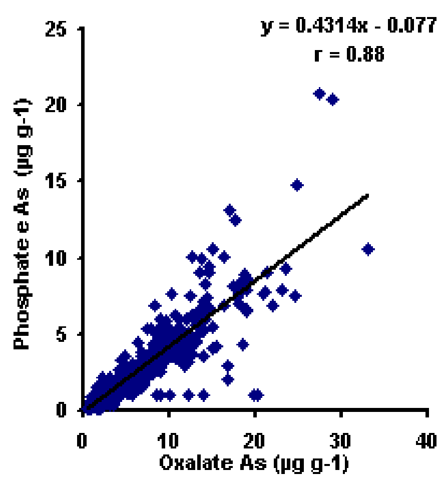

Fig. 6 Relationship bet. oxalate As and phosphate As