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Arsenic Incorporation into Garden Vegetables Irrigated with Contaminated Water

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ABSTRACT: Daily vegetable requirement are mostly fulfilled in Bangladesh through homestead garden production which are usually irrigated with arsenic-rich underground water. Garden vegetables grown in arsenic-tainted soil may uptake and accumulate significant amount of arsenic in their tissue. Mean, minimum and maximum arsenic content in some common garden vegetables, e.g. bean, bitter gourd, bottle gourd, brinjal, chilli, green papaya, mint, okra, palwal, potato, red amaranth, string bean and sweet gourd, from an arsenic-prone locality of Bangladesh have been assessed. The contribution of vegetable-arsenic in the daily diet was estimated. Correlation with the groundwater arsenic status and statistical significance of variations has been discussed. @ JASEM

The natural contamination of shallow hand tubewells in Bangladesh with arsenic has caused widespread human exposure to this toxic element through drinking water (Karim, 2000, Paul et al., 2000). Beside direct consumption for drinking, arsenic contaminated water is also used for irrigation and cooking purposes. Many previous reports demonstrated that foodstuffs collected from arsenic epidemic areas contain significant concentrations of arsenic. Roychowdhury et al. (2002) reported the arsenic concentrations in individual composites of cooked items, collected from an arsenic epidemic area of West Bengal, India, as rice (between 374.17 and 666.57 mg/kg), potato curry (186 mg/kg), leaf of vegetables (578 mg/kg), mixed vegetable (277.33 mg/kg), pulses (143 mg/kg). Das et al., (2004) reported arsenic concentrations exceeding the food safety limits in *Calocasia antiquorum* (between 0.09 and 3.99 mg/kg), potato (between 0.07 and 1.36 mg/kg), *Ipomoea reptoms* (between 0.1 and 1.53 mg/kg) collected from an arsenic epidemic area of Bangladesh. Thus, it is evident that not only 'soil–water–human' but also 'plant–human' may be a potential pathway of arsenic accumulation in human body, though arsenic contaminated drinking water is the major and direct source. Present study focused the extent of arsenic in groundwater as well as in some vegetables grown in the homestead gardens of *Mirsharai* and *Sitakunda* Upazila (an administrative block) of Bangladesh, irrigated with arsenic-contaminated groundwater. The intension is to assess the extent of arsenic poisoning in humans through the food chain pathway in that area.

MATERIAL AND METHODS

Study area

Water and vegetable samples were collected from *Mirsharai* and *Sitakunda* Upazila of *Chittagong* District, Bangladesh (Figure 1). The study area is in the south-west part of the county with an area of total 966.85 km^2, population of about 0.6 million, and 25.47% of the total inhabitants is in agricultural production (Anonymous, 2006a).

Sampling and arsenic analysis

Water: Randomly selected 50 groundwater samples from each of *Mirsharai* and *Sitakunda* Upazila, extracted from the shallow tubewells, were collected in pre-washed polyethylene bottles. 0.01% HNO_3 per litre of water was added as preservative and kept at 4°C before analysis. Ag-DDTC-Hexamethylenetetramine-Chloroform method, having detection limit 0.20 µg/mL of arsenic, was used to measure the total arsenic in the water samples (APHA, 1971, Sandhu and Nelson, 1979).

Plants: Fresh samples of 14 vegetable species were collected from the home gardens of the study area (Table 1) with replications. The edible parts of each plant were separated, carefully packed into polyethylene bags and weighed in situ for analysis. The samples were washed three times with distilled water and finally rinsed with de-ionized water to eliminate the pollutants, dried in an oven at 65°C for 24 h, re-weighed to determine water content, and then, for metal analysis, grinded using a ceramic-coated grinder.

Plant parts (10–25 g) were taken into a 100 mL microkjeldhal flask with a glass bead and 15 mL concentrated nitric acid. The flask was then placed on the digester and gently heated. The solution was removed and cooled after the initial brisk reaction. Concentrated sulfuric acid (4 mL) was then added carefully to the solution followed by the addition of 2 mL of 70% perchloric acid. Heating of the solution was continued till the formation of dense SO_3 fumes, repeating nitric acid addition, if necessary. The solution was then refluxed at 110-120°C. The residue was dissolved in distilled water and was filtered into 100 mL volumetric flask quantitatively and made up to the mark. The digested sample solutions were injected by an automatic sampler and analyzed by using air acetylene flame with combination as well as single element hollow cathode lamps into an atomic absorption spectrophotometer (Model-Shimadzu, AA-6401F), having detection limit of 0.002 mg/L of arsenic.

Statistical analysis

SPSS for Windows (version 11) was used for all statistical analyses. Statistical significance was considered valid only at 5% level.

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RESULT AND DISCUSSION

Total groundwater arsenic content analysis of *Mirsharai* and *Sitakunda* Upazila shows that □66% of the total samples have arsenic content above Bangladesh Guideline Standard (BGS) of 0.05 mg/L i.e. more than half of the screened tubewells have arsenic content above this guideline value (Figure 2). It becomes above 81% when WHO recommended guideline value of 0.01 mg/L is considered (Figure 2) and the highlight is □17% of total samples contain >0.10 mg/L arsenic i.e. 10 times higher than that approved by WHO. Arsenic content above BGS in □83% of the analysed samples was reported in a previous groundwater monitoring report for the same localities (Rahman, 2003). The variation may be due to the randomization in the sample collection and sample sizes. Groundwater arsenic concentrations as low as 0.005 mg/L and 0.022 mg/L, and as high as 0.283 mg/L and 0.326 mg/L have been observed for *Mirsharai* and *Sitakunda* Upazila, respectively, in the present study.

Most of the tube wells (85.4%) of the study area are in the depth below 25 m (Figure 3). A number of studies on groundwater arsenic-depth relation in different parts of Bangladesh showed that maximum arsenic concentration occur at depths between 15 and 50 m (BGS and DPHE, 2001, NRECA, 1997, Broms and Fogelstrom, 2001).

Age-dependent distribution of tubewells in the study area show that most are of 3 years or less (Figure 4). That is, the sample sources are relatively new compared to those included in the study of Rahman et al. (2003), and it may be the reason that made the present observation less frightening than that reported. Groundwater is the only available potable source in the study area and is also used for other household purposes and irrigation. Excessive pumping of groundwater for miscellaneous purposes results water table lowering and appears to trigger frequent arsenic mobilization into the groundwater as natural water recovery process is insufficient to cope with the withdrawal rate (Acharyya et al., 2000, Anawar et al., 2003, Bhattacharya et al., 1997, Dowling et al., 2002, Mallik and Rajagopal 1996, Mandal et al., 1996, McArthur et al., 2001, Nickson et al., 2000). Thus, the exploitation time (through tubewell) and the management pattern of a particular underground water-table are also to be considered as an important factor in the arsenic status assessment.

Though groundwater arsenic contamination exists and the residents of the *Mirsharai* and *Sitakunda* Upazila are in extreme health risks, any arsenicosis suffering patients are yet to be reported. Thus, it is important to assess the likely occurrence of water-soil-plant arsenic transfer as well as probable risks from arsenic laden diets-if any. Home gardening is a common practice in the locality and-as we observed during the field survey-the inhabitants find it convenient to irrigate their home garden with tubewell water. Arsenic concentrations in fourteen (14) different vegetable species were studied, the maximum was observed in the string bean (1.0695 □g/g Fresh Weight) and the minimum was in potato (0.0393 □g/g FW) while it was Below Detectable Limit (BDL) in okra, bottle gourd and palwal. An illustrated view of the average arsenic content in different vegetable species from the study area is shown in Figure 5, the samples with BDL arsenic content are ignored, though. As reported in literature, total arsenic contents in food products of vegetable origin ranged <0.004-0.303 □g/g FW (Dabeka et al., 1993, Schoof et al., 1999, Urieta et al., 1996, Ysart et al., 1999) which is within the range of values found in the present study. Average arsenic concentration in plants of the study area was 0.2770 □g/g FW (*Mirsharai* Upazila: 0.2535 □g/g FW, *Sitakunda* Upazila: 0.3866 □g/g FW) and it was higher than that of United Kingdom, 0.003 □g/g FW (MAFF, 1997) and Croatia, 0.0004 □g/g FW (Sapunar-Postruznik et al., 1996). However, string bean found to have highest mean arsenic content in both *Mirsharai* and *Sitakunda* Upazila.

Duncan's Multiple Range Test (DMRT) showed that the differences in arsenic concentrations among the plants was not statistically significant ($P>0.05$). Distribution of arsenic in different vegetable species without any momentous pattern has also been observed previously for *Samta* village of Bangladesh (Alam et al., 2003).

In light of legislation and health considerations, the vegetable products of *Mirsharai* and *Sitakunda* Upazila are safe to consume because the average arsenic concentrations in the vegetables is much lower than the country limit (1 mg/kg). It is also safe by other systems of legislation which permit similar or higher levels: 1 mg/kg in Guyana, Jamaica, Trinidad and Tobago, Kenya, Zambia, Malaysia, Singapore and the United Kingdom; 1.5 mg/kg in Papua New Guinea; and 0.5 mg/kg as set by Bulgaria, Czech Republic, Slovak Republic and Hungary (Anonymous, 1993). However-among the garden vegetable species- string bean has higher arsenic content than the country recommended value.

Chronic arsenic poisoning associated with groundwater contamination has been reported from many developing countries, where poor nutritional status is concomitantly found and it has been suggested that poor nutritional status affects the toxicity and metabolism of arsenic (Chen et al., 1988, Guha Mazumder et al., 1998, Maharjan et al., 2007, Mitra et al., 2004, Smith et al., 2000, Smith and Smith 2004). A case–control study conducted in Bangladesh showed that malnourished individuals are more often found among patients with arsenicosis than among the non-exposed population (Milton et al., 2004). During our survey, we have tried to amass the information regarding the financial condition and food habit of inhabitants of the study area to measure the dietary consumption pattern of vegetables. Our study shows that most of them are poor and rice and vegetables are their main food. They take fish once

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or twice in a month while meat is a dish of festival only. According to Hassan and Ahmad (1984), a Bangladeshi person, regardless of gender, consumes an average of 130 grams vegetables per day (leafy and non-leafy) and in the total diet, the proportion varied from 12 to 21 percent. Thus, the average dietary intake of total arsenic from vegetable origin by the inhabitants of the study area was estimated to be 36.0 □g/d (*Mirsharai* Upazila: 32.9 □g/d, *Sitakunda* Upazila: 50.3 □g/d) excluding the contribution of rice, pulses, meats, fishes and spices to dietary exposures. Rahman et al. (2007a) reported the average dietary-arsenic intake of the inhabitants of *Feni*-an adjacent locality-was 14.69 μg/d from vegetables which is lower than that estimated for *Mirsharai and Sitakunda*. Daily dietary intake of arsenic as estimated are also higher than that of Belgium: 12 □g/d (Buchet et al., 1983), Croatia: 11.7 □g/d (Sapunar-Postruznik et al., 1996) and Netherlands: 15 □g/d (De Vos et al., 1984) but lower than the Canada: 59.2 □g/d (Dabeka et al., 1993), Sweden: 60 □g/d (Jorhem et al., 1998), Japan: 160–280 □g/d (Tsuda et al., 1995) and Spain: 291 □g/d (Urieta et al., 1996). However, the recommended requirement of vegetables in daily diets is 200 g/person/d, though, the availability of vegetable is only about 1/5th of the suggested requisite in Bangladesh (Anonymous, 2006b). If we consider that every person is able to fulfill the recommended requirement of vegetables in their daily diets, than the estimated average daily dietary intake of vegetable-arsenic per person in the study area will be 55.4 □g/d (*Mirsharai* Upazila: 50.7 □g/d, *Sitakunda* Upazila: 77.3 □g/d). The average dietary intake comparison between the two blocks-*Mirsharai* Upazila and *Sitakunda* Upazila-of the study area showed that garden vegetables from *Mirsharai* Upazila is the safer source than that of *Sitakunda* Upazila.

Present study only includes the determination of total arsenic content without speciation in the vegetables. As found in the literature, inorganic arsenic species content in diets, so far, as follows: 40% (US EPA, 1988), 65% (Dabeka et al., 1993), 95-96% (Chowdhury et al., 2001) and 100% (Tao and Bolger, 1998). Based on those reports, we can assume that at least 50% of the total arsenic in the samples studied is inorganic. Then the daily dietary intake of inorganic arsenic from vegetables in area investigated is 18.0 □g or 27.7 □g. From the toxicological point of view, inorganic arsenic compounds are most toxic and according to WHO (1992), a daily intake of 2 μg of inorganic arsenic/kg body weight should not be exceeded to minimize the risk to humans. However, nutritional status of diets is also an important factor in such cases. People eating nutritious foods can tolerate arsenic up to certain range in spite of high dietary arsenic consumption (Harrington et al., 1978, US EPA 1988, Das et al., 1995). As surveyed, most of the locals of the *Mirsharai* and *Sitakunda* Upazila are poor and can hardly avail nutritious food. In the legislation point of view, consumption of the vegetables from the study area are proved safe but there may still be a definite health-risk for the inhabitants, if the present rate of dietary consumption pattern exists in combination of drinking arsenic-contaminated water for a long period of time.

Table 1. English, scientific and family name of the sampled vegetables (Anonymous, 2006b)

English Name	Scientific Name	Family
Bean	*Lablab niger*	Leguminoseae
Bitter gourd	*Momordica charantia*	Cucurbitaceae
Bottle gourd	*Lagenaria siceraria*	Cucurbitaceae
Brinjal	*Solanum melongena*	Solanaceae
Chilli	*Capsicum frutescens*	Solanaceae
Green papaya	*Carica papaya*	Caricaceae
Mint	*Mentha viridis*	Labiateae
Okra	*Abelmoschus esculentus*	Malvaceae
Palwal	*Trichosanthes dioica*	Cucurbitaceae
Potato	*Solanum tuberosum*	Solanaceae
Red amaranth	*Amaranthus gangeticus*	Amaranthaceae
String bean	*Vigna sesquipedalis*	Leguminoseae
Sweet gourd	*Cucurbita maxima*	Cucurbitaceae
Tomato	*Lycopersicon esculentum*	Solanaceae

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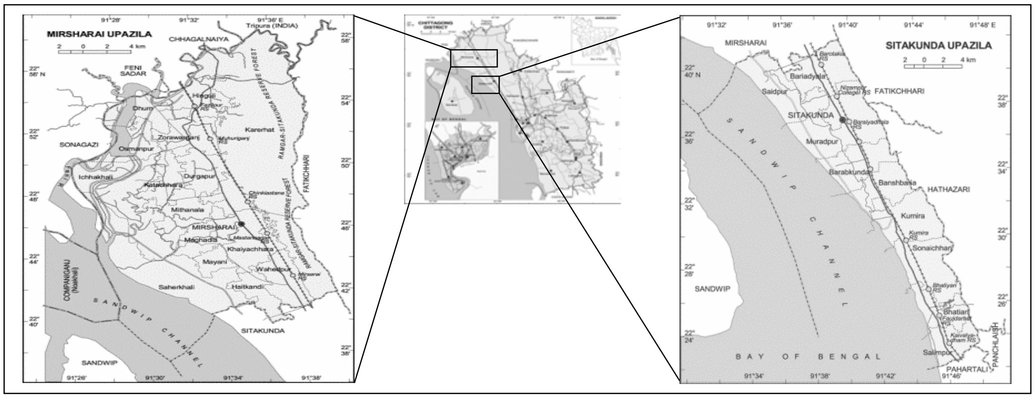

Figure 1. Map of the *Mirsharai* and *Sitakunda* Upazila (of *Chittagong* District, Bangladesh).

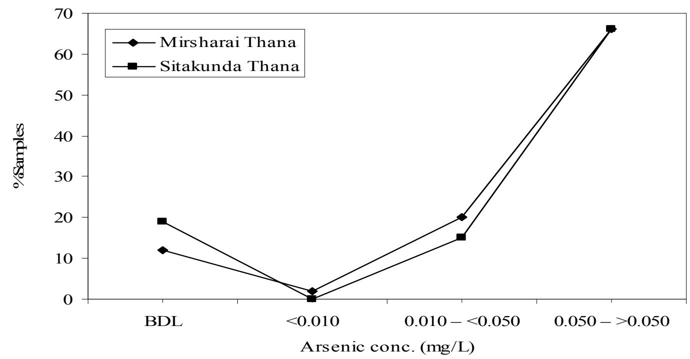

Figure 2: Groundwater arsenic status in *Mirsharai* and *Sitakunda* Upazila.

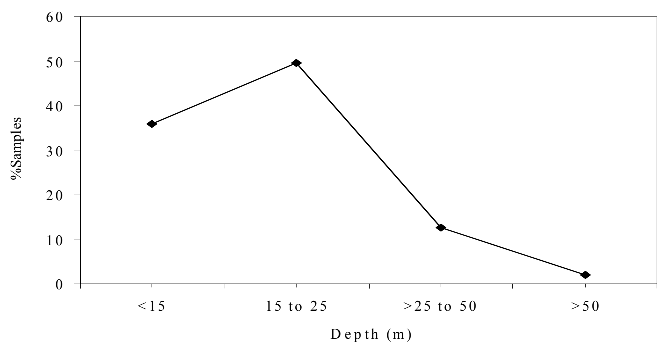

Figure 3: Tubewell depth-dependent distribution of groundwater samples.

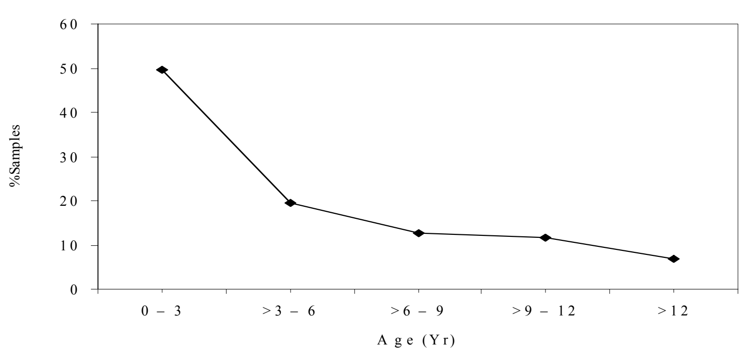

Figure 4: Tubewell age-dependent distribution of groundwater samples.

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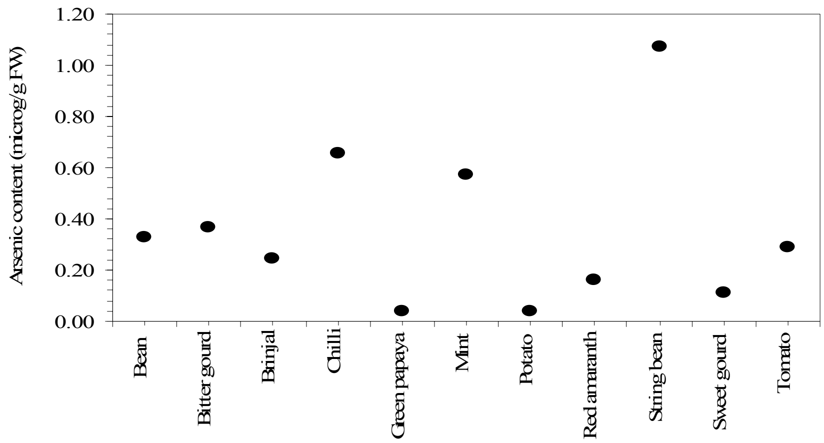

Figure 5: Average arsenic content in different vegetable species

FIGURE CAPTIONS:

Figure 1. Map of the *Mirsharai* and *Sitakunda* Upazila (of *Chittagong* District, Bangladesh).

Figure 2: Groundwater arsenic status in *Mirsharai* and *Sitakunda* Upazila.

Figure 3: Tubewell depth-dependent distribution of groundwater samples.

Figure 4: Tubewell age-dependent distribution of groundwater samples.

Figure 5: Average arsenic content in different vegetable species

CONCLUSION

Arsenic induced phytotoxicity to garden vegetables has been widely concerned because of wide use of arsenic contaminated groundwater for irrigation in the homestead gardens. Present study supports the phenomenon of soil-plant transfer. Average dietary intake pattern showed the risk of arsenic-related hazards for the residents of the study area. Excessive use of groundwater for crop irrigation could simulate a new dimension in existing risk from groundwater arsenic in Bangladesh. Moreover, when plants are exposed to excess arsenic either in soil or in solution culture, they exhibit toxicity symptoms such as inhibition of seed germination, reduction in chlorophyll content in leaf, decrease in plant height, reduction in root growth, decrease in shoot growth, lower fruit and grain yield and sometimes, lead to death (Rahman et al., 2007b). Further investigation is thus suggested to evaluate the effects of high soil arsenic content-resulted from the arsenic contaminated irrigated water-on germination, chlorophyll contents, growth and yield of the widely cultivated garden vegetable varieties in Bangladesh.

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