Arsenic in Plant-Soil Environment in Bangladesh

M. Ashraf Ali, A. B. M. Badruzzaman, M. A. Jalil, M. Delwar Hossain, M. Feroze Ahmed, Abdullah Al Masud, Md. Kamruzzaman and M. Azizur Rahman
Department of Civil Engineering
Bangladesh University of Engineering and Technology, Dhaka-1000, Bangladesh

INTRODUCTION

Arsenic in groundwater and its fate and transport in the environment have become matters of great concern in Bangladesh, India and several other countries. In Bangladesh, an estimated 268 upazillas out of 465 have been affected with significantly high concentrations of arsenic. In Bangladesh tubewell water extracted from shallow aquifers is the primary source of drinking/cooking water for most of its population. An estimated 7.5 to 8.0 million hand-tubewells constitute the backbone of the rural water supply in Bangladesh. Besides domestic use, huge quantities of water from shallow aquifer are also used for irrigation during the dry season. Since its detection in late 1993 in Bangladesh, much of the research works on arsenic have focused on its presence in and exposure through drinking/cooking water. However, widespread use of groundwater for irrigation suggests that ingestion of irrigated crops could be another major exposure route for arsenic. Besides, phytoxicity due to increased arsenic in soil/water and its long-term impact on agricultural yield is another major concern.

Limited studies (e.g., Meharg et al., 2001; Huq et al., 2001; Duxbury et al., 2002; Abedin et al., 2002) have been conducted to assess the presence of arsenic in food chain. However, more studies are needed to develop a reliable database on the presence of arsenic in irrigation water, irrigated soil and food samples, and to assess their interrelationships. The major objective of the present study is to evaluate the fate of arsenic (extracted from aquifer for irrigation and domestic purposes) in the environment. Specific objectives include: (i) Evaluation of arsenic profile in irrigated as well as non-irrigated agricultural lands, (ii) Evaluation of arsenic in selected edible crops, and (ii) Assessment of possible relationships between presence of arsenic in water, soil and food samples.

MATERIALS AND METHODS

In this study, two arsenic affected areas have been selected for detailed characterization of irrigation water, soil and crop/vegetables produced in the irrigated soils. These two locations are: (i) Sonargaon, Narayangonj and (ii) Srinagar, Munshiganj. Besides, water, soil and crop samples have also been collected from a less affected (i.e., with low levels of arsenic in shallow wells) area in the Dinajpur district in northern Bangladesh. For intensive sampling, one rice field (i.e., the whole area under the influence of one irrigation well) was selected at each of the two sampling locations (Sonargaon and Srinagar).

Collection of Water Soil and Crop Samples

Collection of Water Samples

At each of the two sites in Sonargaon and Srinagar, 10 irrigation wells were monitored over the entire irrigation season (about three months). During the first month of the irrigation season when the irrigation intensity was low (10 to 12 hours per day), groundwater samples from the irrigation wells were collected once every two weeks. Later in the season, when irrigation intensity increased (20 to 22 hours per day), water samples were collected every week. Besides, surface water samples were also collected from the ponds/canals, which are used for irrigating vegetable fields. At the Srinagar site, water samples were collected from two ponds used for irrigating potato fields. At the Sonargoon site, water samples were collected from two ponds and from three different sections of a canal used for irrigating vegetable fields. Water samples were also collected from a shallow hand-pump tubewell used for irrigating a vegetable (cauliflower) field. Besides Srinagar and Sonargaon, five groundwater samples were also collected from Dinajpur site. At each location, water samples were collected in two pre-washed plastic bottles. One bottle was acidified in the field with concentrated hydrochloric acid for analysis of metal ions.

Collection of Soil Samples

In a typical rice field, the area under the influence of a particular irrigation well is usually divided into a number of sub-areas (usually belonging to different owners). Groundwater from the irrigation well is carried to the different sub-areas through shallow irrigation canals. For intensive sampling, one rice field (i.e., the whole area under the influence of one irrigation well) was selected at each of the two sampling locations (Sonargaon and Srinagar). At the Srinagar site, the rice (BR-29 variety) field was about 3 hectares in size and it was divided into twenty one sub areas (see Fig. 1). At the Sonargaon site, the rice (BR-29 variety) field was about 4 hectares in size and was divided into 45 sub-areas (see Fig. 2). At each rice field site, soil samples were collected both from agricultural land (referred to as *field* samples) as well as the shallow irrigation canals (referred to as *canal* samples).

Soil samples were collected by inserting into the soil, a 37.5 mm diameter PVC pipe sampler, about 750 mm in height. A 3-pound hammer was used to insert the pipe sampler to required depth. After withdrawing the sampler along with the soil core, its both ends were sealed with tapes to reduce contact with air and transported to the environmental engineering laboratory of BUET. Besides paddy fields, soil samples were also collected (following the same method) from other agricultural fields growing vegetables. These fields did not receive irrigation water from shallow wells. However, these were irrigated by water from nearby surface water bodies (ponds/canals).

In Bangladesh, depending on location, dry season irrigation for rice commences between last week of December and first week of February and continues for a period of about three to three and a half months. At the Srinagar site, soil core samples were collected at three different times. The first sampling was carried out on 6th February 2002 (at the beginning of the 2001-2002 dry season), about one week after the commencement of irrigation at the site. During this time, a total of 29 soil core samples were collected. Among these, 11 are *field* samples, 12 are *canal* samples (see sampling locations in Fig. 1). The remaining 6 core samples were collected from four different potato fields at Srinagar. All these four fields were irrigated by water from ponds located close to the fields. The second sampling operation was carried out after the end of irrigation season and before the commencement of flood on 22nd June 2002. During this time, a total of five *field* samples were collected from the rice field site at Srinagar. The third and final sampling operation was carried out at the beginning of the 2002-2003 dry season. As a part of this sampling operation, 8 *field* core samples from the rice field and five core samples from potato fields were collected on 26th November 2002.

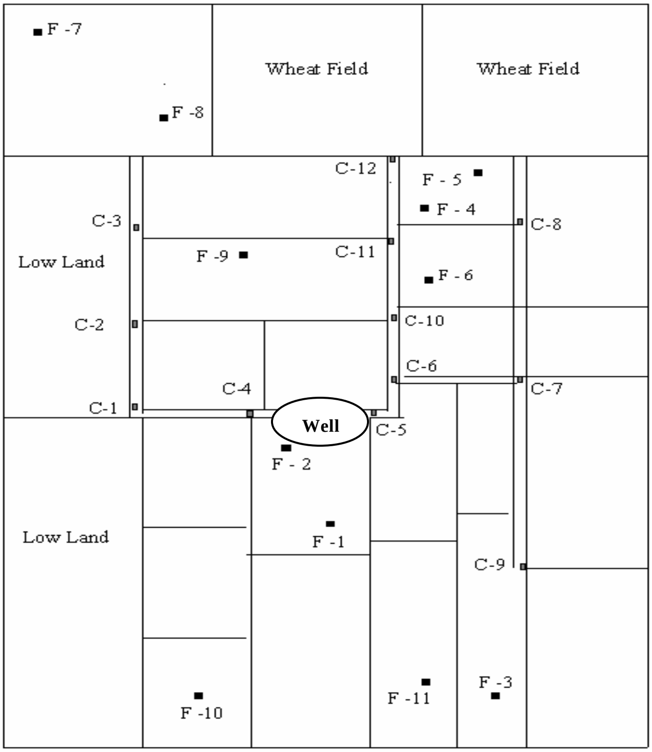

Figure 1: Schematic representation of Srinagar paddy field site along with sampling locations and identification numbers (F = Field Sample, C = Canal Sample)

At the Sonargaon site, the first sampling operation was carried out on 3rd March 2002 (at the beginning of 2001-2002 dry season), about 3 weeks after the commencement of irrigation at the site. During this time, a total of 42 soil core samples were collected. Out of these 42 samples, 14 are *field* samples, 16 are *canal* samples (see sampling locations in Fig. 2). The remaining 12 core samples were collected from 12 different vegetable fields. Among these, five were tomato fields, two *lalshak* fields, two *datashak* fields, two cabbage fields and one cauliflower field. Except for the cauliflower field, all vegetable fields were irrigated by pond or canal water located close to the fields. The cauliflower field was irrigated by water from a shallow hand-pump tubewell. The second and final sampling operation at the Sonargaon site was carried out at the beginning of the 2002-2003 dry irrigation season. As part of this sampling operation, 6 *field* core samples from the rice field and two core samples from vegetable fields were collected on 18th December 2002.

At the Dinajpur site, a total of ten soil core samples were collected from five different fields (two from each field). Four of the fields were growing *China Irri* variety of rice and one was growing *Chandina* variety of rice.

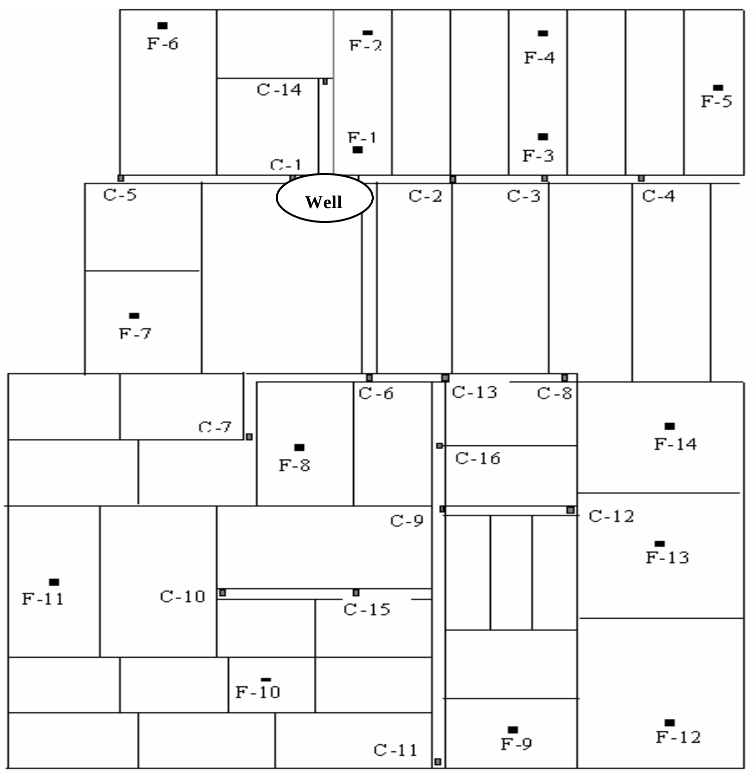

Figure 2: Schematic representation of Sonargaon paddy field site along with sampling locations and identification numbers (F = Field Sample, C = Canal Sample)

Collection of Crop and Vegetable Samples

Paddy samples were collected just before harvest time. Entire rice plants (including roots) were collected. Samples were collected from the different sub-areas under the same irrigation well. A total of 33 rice plant samples were collected, 12 from Srinagar site, 11 from the Sonargaon site, and 10 from the Dinajpur site. Besides rice, five tomato plant samples, two *lal shak* plant samples, two *data shak* plant samples, one cauliflower plant sample, and two cabbage plant samples were collected from the vegetable fields at Sonargaon site. These twelve samples were collected from twelve different vegetable fields at the Sonaraon site. Six potato plant samples (from four different fields) were collected from the Srinagar site.

Laboratory Analysis of Water, Soil and Plant Samples

Water and Soil Samples

Groundwater and surface water samples were analyzed for arsenic and a range of other water quality parameters. Arsenic analysis was carried out with an AAS (Shimadzu, AA6800) attached with a graphite furnace.

Before analysis, each *field* soil sample core was divided into four segments: the first segment consisting of the top 75 mm of soil, the second segment consisting of the next 75 mm, the third segment consisting of the next 150 mm, and the fourth segment consisting of the rest of the core. The *canal* samples were divided into two segments, top 150 mm and the next 150 mm. The soil samples collected from the vegetable fields were also divided into four segments (like the *field* samples) before analysis. Each segment of soil sample was analyzed for total arsenic after digestion.

Briefly, the soil digestion procedure consisted of the following steps: (i) oven-dry each segment of soil sample at 110^{o}C for 24 hours, (ii) take 5 gram oven-dried sample in a volumetric flask, add 2.5 ml concentrated nitric acid and 7.5 ml of concentrated hydrochloric acid to the soil sample and keep it overnight, (iii) heat the sample for 2 to 3 hours to boiling, then allow it to cool and adjust the volume to 500 ml by adding deionized water, and finally (iv) filter the sample and store it for analysis. Arsenic analysis was carried out with an AAS (Shimadzu, AA6800) attached with a graphite furnace.

Crop / Vegetable Samples

Before analysis, the rice plant samples were divided into five parts: (i) root, (ii) stem, (iii) leaf, (iv) grain, and (v) husk. Vegetable samples were divided into four parts: (i) root, (ii) stem, (iii) leaf, and (iv) edible part. For cabbage, the edible part was further divided into outer layer and inner layer.

For analysis of total arsenic, the different parts/segments of the rice and vegetable plant samples were digested. A number of similar but different digestion procedures are available in the literature (e.g., Bennett et al., 2000; Chen and Folt, 2000). At first three different digestion procedures were tested and compared (in term of extraction efficiency and reproducibility). The procedure reported in Shimadzu AAS Cookbook was found to be more satisfactory than the others and was selected for use in this study.

Briefly the digestion procedure consists of the following steps: (i) wash crop/vegetable samples with distilled water, (ii) divide the crop/vegetable sample into parts (as described above), (iii) take weight of each part of the sample, (iv) oven-dry the sample at 65^{o}C for 24 hours and take weight of the oven-dried sample, (v) take 2 grams of dry crop/vegetable sample in a volumetric flask and make it moist by adding a few milliliters of deionized water, then add 25 ml nitric acid to the flask and keep it overnight, (vi) heat the flask for two hours to boiling, then after cooling add 10 ml of perchloric acid to the flask and heat again (to boiling) for one hour, (vii) if color of the sample turns yellow, digestion is assumed to be complete, (viii) if color of the sample turns dark, add 2 to 3 ml of nitric acid to the flask and apply heat; repeat the process until the color turns yellow. Arsenic analysis of crop and vegetable samples were carried out with hydride generation atomic absorption spectrophotometry using an AAS (Shimadzu, AA6800).

RESULTS AND DISCUSSION

Arsenic in Irrigation Water

Arsenic concentration in groundwater samples from 10 irrigation wells (which were monitored) at Srinagar site varied from about 170 ppb to about 600 ppb. Arsenic concentration in the well water used for irrigating the rice field site at Srinagar varied from 220 to 537 ppb. At the Sonargaon site, arsenic concentrations in the 10 monitored irrigation wells varied from about 50 ppb to over 400 ppb. Arsenic concentration in the rice field irrigation water varied from about 83 ppb to 354 ppb. As both sites, arsenic concentrations of irrigation well water varied significantly with time. Arsenic concentrations in all groundwater samples from the Dinajpur district were below detection limit (i.e., below 1ppb).

Of the two pond water samples (used for irrigating potato fields) collected from the Srinagar site, arsenic concentration in one was 37 ppb and in the other it was 1 ppb (which is also the machine detection limit). Surface water usually contains relatively lower level of arsenic. During field visits it was observed that the pond with higher level (37 ppb) of arsenic is located about 300 ft from an irrigation well, whose arsenic concentration varied from 187 to 472 ppb). The higher level of arsenic in this pond water may result from overflow of groundwater from this nearby irrigation well containing high levels of arsenic.

At the Sonargaon site, concentration of arsenic was 2 ppb in one pond water sample and 10 ppb in the other. Concentrations of arsenic in three canal water samples were < 1 ppb, 8 ppb and 35 ppb. Arsenic concentration in the shallow hand-pump tubewell water used for irrigating a vegetable (cauliflower) field was 176 ppb.

Arsenic in Irrigated Soil

Arsenic in Irrigated Rice Field

Figures 3 and 4 show arsenic profiles of the eleven *field* and twelve *canal* soil core samples, respectively, collected from the Srinagar site one week after commencement of irrigation. This field was irrigated by groundwater from a shallow tubewell, whose arsenic concentration varied from 220 ppb to 537 ppb. Figures 5 and 6 show arsenic profiles of the twelve *field* and fifteen *canal* soil core samples, respectively, collected from the Sonargaon site about three weeks after commencement of irrigation. This field was irrigated by groundwater from a shallow tubewell, whose arsenic concentration varied from 83 ppb to 354 ppb. Figure 7 shows arsenic profiles of the ten soil core samples collected from the Dinajpur. These core samples were collected for rice fields irrigated with groundwater having arsenic concentration less than 1 ppb.

Arsenic profiles in the irrigated rice fields at the Srinagar and Sonargoan sites show accumulation of higher levels of arsenic primarily in the top layers (typically top 75 to 150 mm) of soil. In general, arsenic concentration in soil decreased with depth. Arsenic accumulation in the *canal* samples were relatively higher compared to the *field* samples. Among the *field* samples at the Srinagar site, arsenic concentration in the top soil layer (top 75 mm) varied from about 7 to 27.5 mg/kg. The mean arsenic concentration in the top layer (top 75 mm) was 14.5 mg/kg, while that in the layer (300 to 450 mm) was 4.9 mg/kg. As expected, arsenic concentration in the *canal* samples were relatively much higher compared to the *field* samples, with a mean arsenic concentration of 25.3 mg/kg in the top layer (top 150 mm) of canal samples.

At the Sonargaon site, arsenic concentration in the top soil layer varied from about 3.2 to 19 mg/kg. The mean arsenic concentration in the top soil layer (top 75 mm) was 8.9 mg/kg, while that at the bottom layer was 6.07 mg/kg. Like the Srinagar site, arsenic concentrations in the *canal* samples were much higher compared to the *field* samples. Mean arsenic concentration in the top (top 150 mm) layer of canal samples was found to be about 15.4 mg/kg. The higher arsenic concentration in the upper soil layers in the rice field samples appears to be due to irrigation with arsenicrich groundwater. The higher accumulation of arsenic at the Srinagar site (compared to the Sonargoan site) is probably partly related to higher arsenic concentration in the irrigation water at Srinagar site.

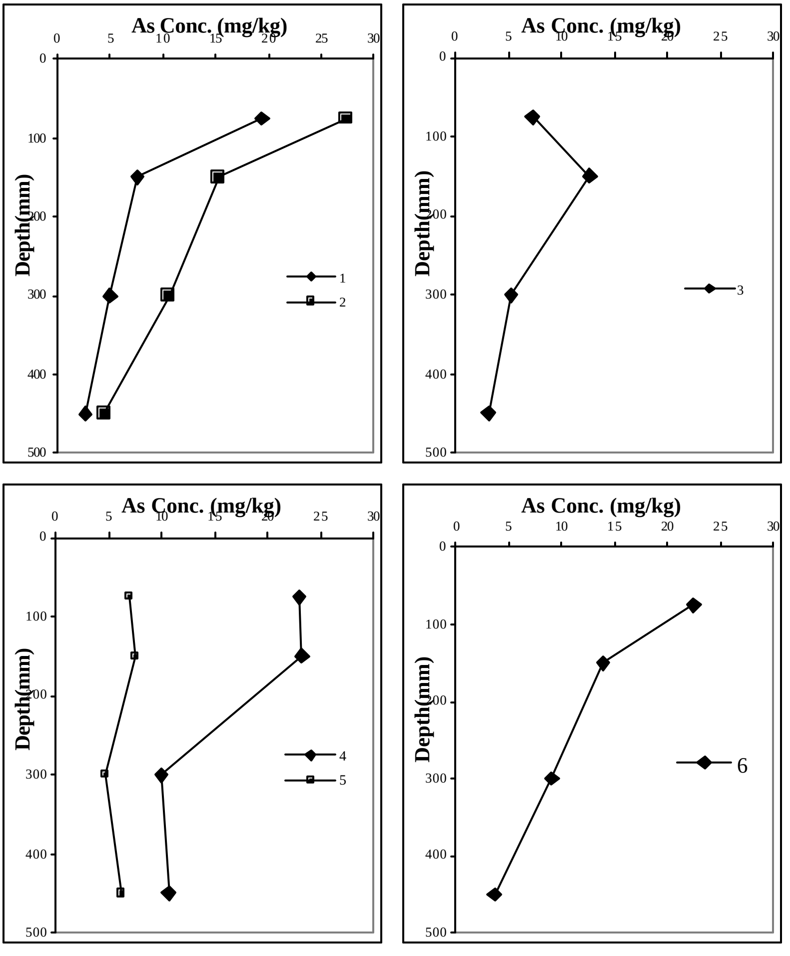

Figure 3 (a): Arsenic profiles of "field" samples collected from Srinagar site

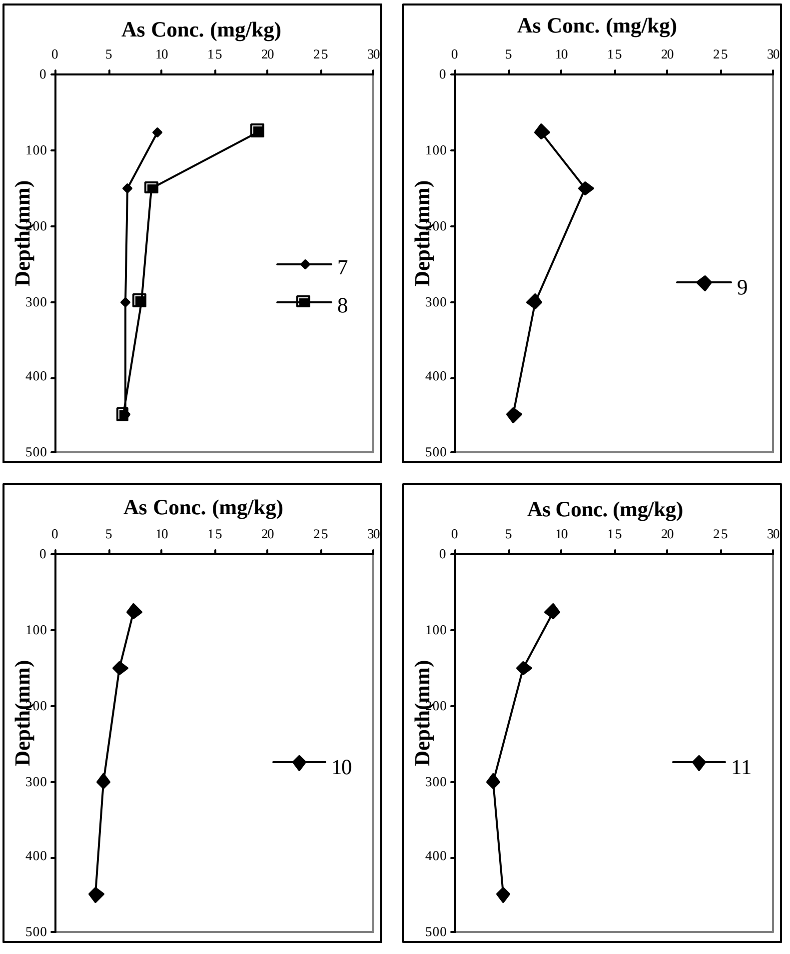

Figure 3 (b): Arsenic profiles of "field" samples collected from Srinagar

At the Dinajpur site where irrigation water contained arsenic at below detection level (i.e., less than 1 ppb), accumulation of arsenic in the soil core samples were insignificant compared to those at Srinagar and Sonargaon sites. The arsenic concentration in the top soil layers (top 75 mm) varied from 0.10 to 2.75 mg/kg. The mean arsenic concentration in the top soil layer (top 75 mm) was 1.04 mg/kg, and that for the bottom layer (300 to 450 mm) was 2.22 mg/kg. As can be seen from Fig. 7, unlike the Srinagar and Sonargaon sites, a slight increase of arsenic concentration with depth was observed for the samples from Dinajpur site. As discussed later, a similar trend was also observed for the soil core samples collected from vegetable fields at the Srinagar and Sonargaon sites that were not irrigated by arsenic contaminated well water.

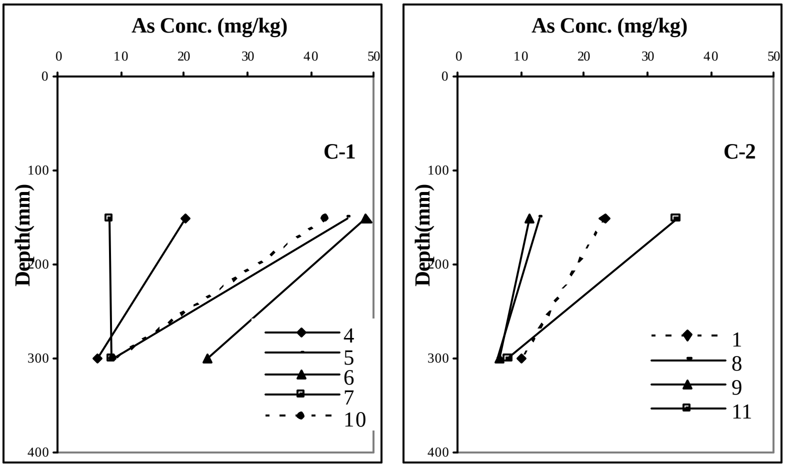

Figure 4: Arsenic profiles of some "canal" samples collected from Srinagar

Arsenic in Vegetable Fields

Figure 8 shows arsenic profile of six soil cores collected from potato fields in Srinagar. These fields were irrigated by surfacee water (from pond) with relatively low level of arsenic. Four of these six vegetable fields were irrigated by water from a pond with arsenic concentration of 37 ppb; and the rest two were irrigated by another pond water with arsenic concentration of 1 ppb. Figure 9 shows arsenic profiles of soil core samples collected from the vegetable fields from Sonargaon.

Compared to the rice field, arsenic concentrations in the soil samples collected from the vegetable fields were significantly lower. For example, mean arsenic concentration in the top soil layer (top 75 mm) at the Srinagar site was 7.8 mg/kg, compared to 14.5 mg/kg for rice field samples. For the Sonargoan site, the mean for the top layer (top 75 mm) of vegetable field samples was 3.5 mg/kg, compared to 8.9 mg/kg for the rice field samples.

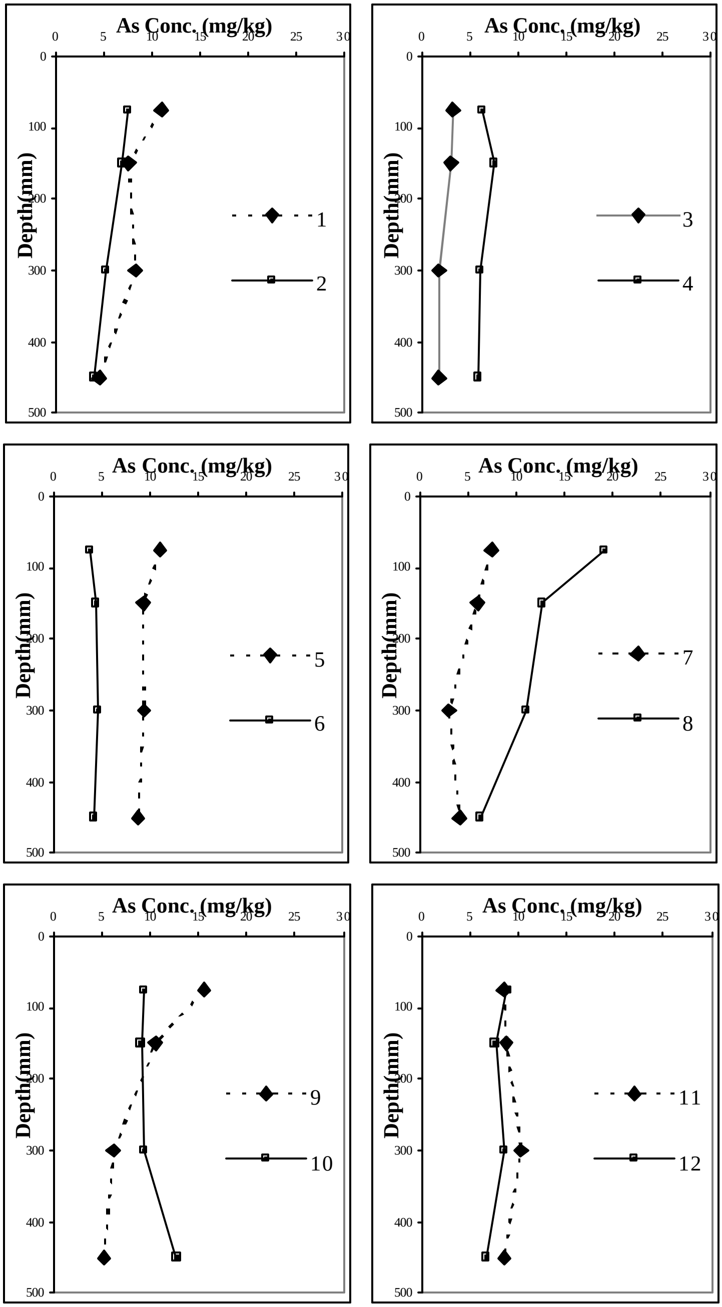

Figure 5: Arsenic profiles of "field" samples collected from Sonargaon

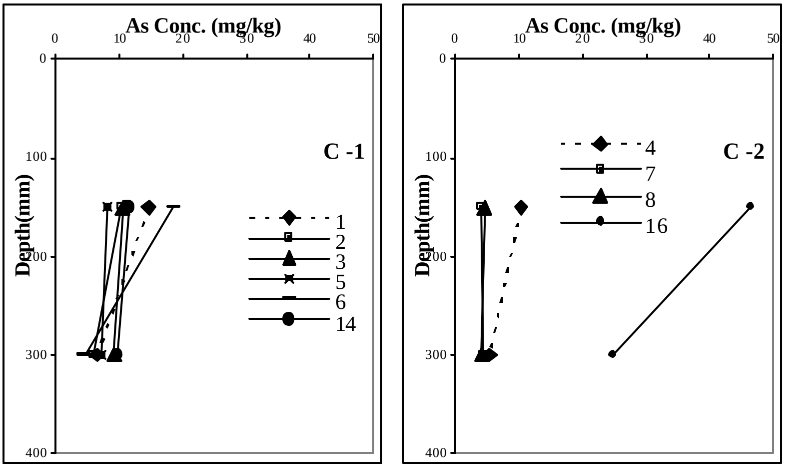

Figure 6: Arsenic profiles of some “canal” samples collected from Sonargaon

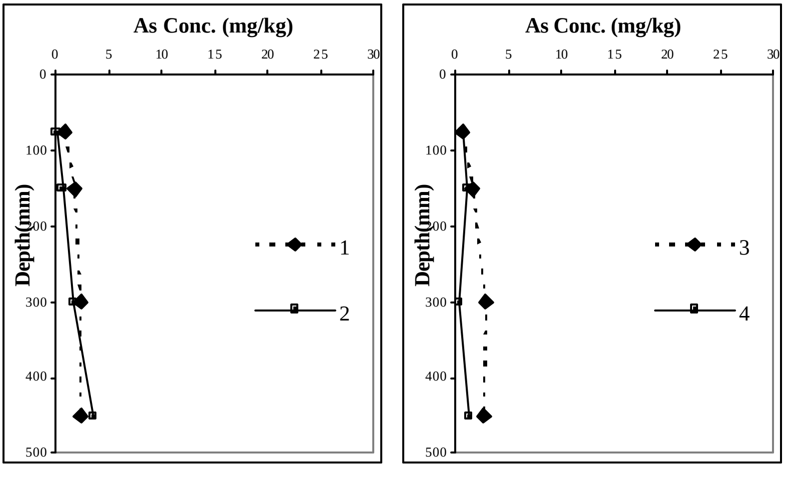

Figure 7(a): Arsenic profiles of soil samples collected from Dinajpur

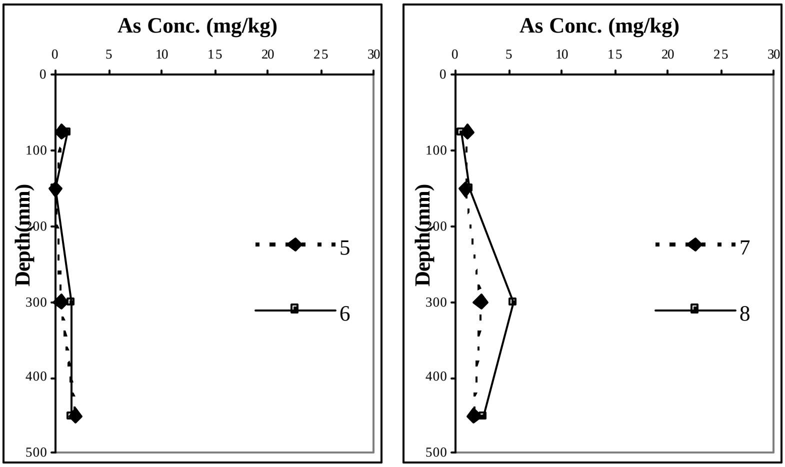

Figure 7(b): Arsenic profiles of soil samples collected from Dinajpur

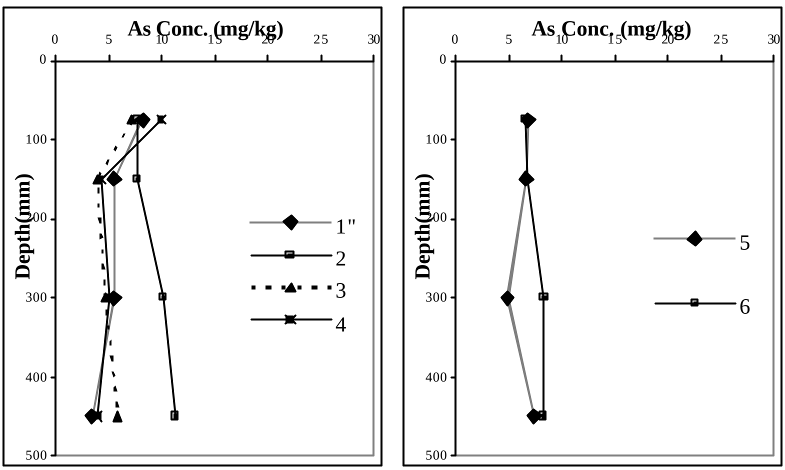

Figure 8: Arsenic profiles of potato field soil samples from Srinagar

It is apparent that the higher arsenic concentration in the rice field soil samples, both at Srinagar and Sonargoan sites, is due to the presence of high level of arsenic in the irrigation water. It is interesting to note that unlike the rice fields at Srinagar and Sonargaon, arsenic concentrations of soils in the vegetable fields in most cases either did not vary significantly with depth or increased slightly with depth. A similar trend was also observed for the rice field samples collected from Dinajpur where irrigation water contained very little arsenic.

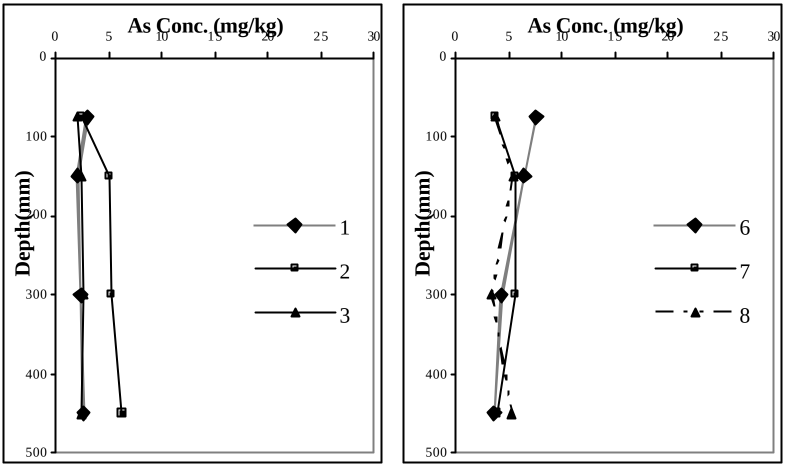

Figure 9: Arsenic profiles of some vegetable field soil samples collected from Sonargaon site

Accumulation of Arsenic in Soil Over Time

In order to assess the accumulation of arsenic in soil over time, soil core samples from rice and vegetable fields were collected at the end of the 2001-2002 irrigation season and also at the beginning of the 2002-2003 irrigation season. At the Srinagar site, core samples were first collected on the 6th February 2002 (at the beginning of the 2001-2002 dry season), about one week after the commencement of irrigation at the site. The second sampling operation was carried out on the 22nd June 2002, just before commencement of flood. During this time, five soil core samples were collected from five sub-areas of the rice field, from where core samples were also collected during the first sampling. The third and final sampling operation was carried out on the 26th November 2002 at the beginning of the 2002-2003 dry season. During this time core samples were collected from 8 sub-areas (including the five sub-areas covered during the second sampling) of the rice field. In addition, five core samples were also collected from potato fields, which were covered during the first sampling. Figure 10 shows arsenic profiles of some soil core samples collected from the Srinagar rice fields at three different times.

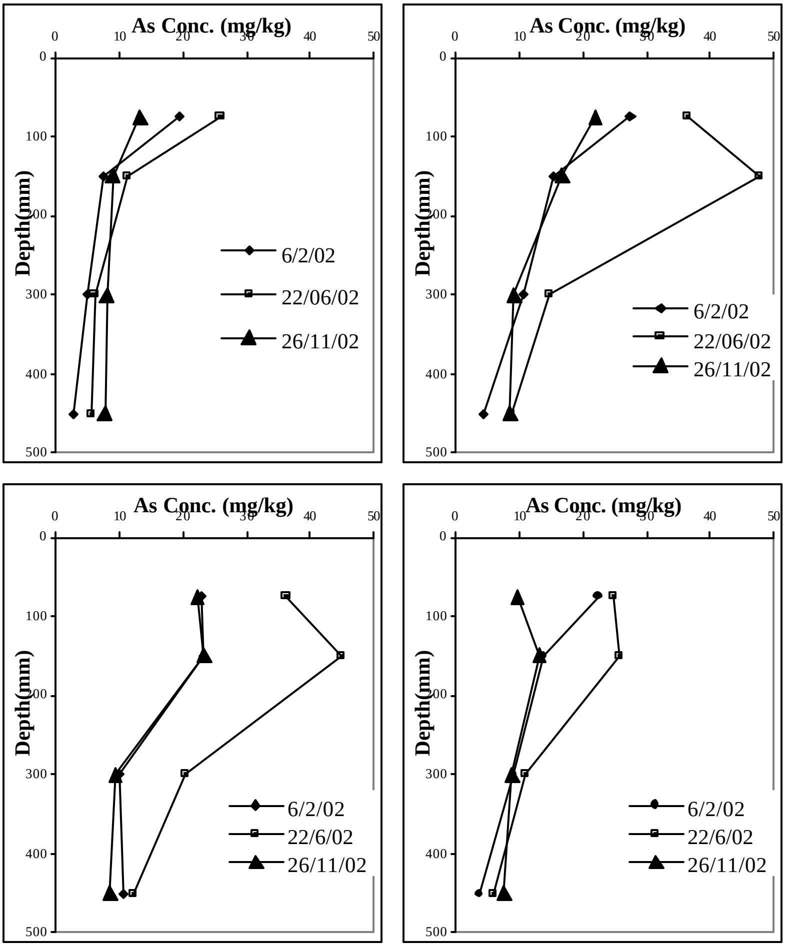

Figure 10: Arsenic profiles of some soil samples from Srinagar rice field at different times

Figure 10 shows that, in general, arsenic concentrations in soil were significantly higher at the end of the irrigation season, compared to concentrations at the beginning of the season. However, after the flood (during which the rice field at the Srinagar site was under floodwater for prolonged periods of time), arsenic concentration in soil came down to levels comparable to those at the beginning of the (2001-2002) irrigation season. The reduction in arsenic concentration in soil after the flood may result from bio-geochemical processes (e.g., bio-methylation, dissolution/ desorption) occurring in the rice fields. Thus it appears that over the monitoring period of about one year, arsenic concentration in the rice field at Srinagar did not increase significantly.

At the Sonargaon site, the first sampling operation was carried out on 3rd March 2002 (at the beginning of 2001-2002 dry season), about 3 weeks after the commencement of irrigation at the site. The second and final sampling operation at the Sonargaon site was carried out on 18th December 2002 at the beginning of the 2002-2003 dry irrigation season. During this time, six core samples from the rice field and 2 core samples from vegetable fields were collected. Core samples were also collected from these eight areas during the first sampling.

Figure 11 shows arsenic profiles of four sets of soil core samples collected from the Sonargaon rice fields at two different times. Of the six sets, three showed significant increase of arsenic concentration over the one-year monitoring period; while the other three sites did not show any significant increase in arsenic concentration. Unlike the Srinagar site, soil core samples were not collected from the Sonargaon site before the commencement of flood, and so it is not clear whether flood had any impact on arsenic profile at the Sonargoan site.

During field visits, it was gathered that *boro* rice cultivation with groundwater irrigation at the Srinagar field site started about 14 years ago. Before this time, this field was not used for agriculture. *Boro* cultivation using groundwater irrigation at the Sonargoan site began about 9 years back. Before that, the field was used only for *aman* (wet season rice) cultivation. In the absence of data, it is not clear whether the irrigation water at these sites contained arsenic in the past. So it is not possible to estimate how long it took for the arsenic in the soil to reach this level. From the limited results gathered in this study, it appears that the rate of accumulation of arsenic in soil at the Srinagar site is relatively slow. For the Sonargoan site, accumulation of arsenic appears to be significant for some plots of the rice field, while not so significant for the others. More studies are needed for better understanding of the processes leading to accumulation of arsenic in soil.

Figures 12 and 13 show arsenic profiles of soil core samples collected from the vegetable fields at Srinagar and Sonargoan sites, respectively, at two different times. These figures show little variation of arsenic concentration over the one-year monitoring period.

Arsenic in Plant Samples

Arsenic in Rice

Figures 14, 15 and 16 show arsenic concentrations in rice grains and different parts of rice plants collected from the Srinagar, Sonargoan, and

Dinajpur sites, respectively. These figures show the roots of rice plants accumulated the maximum level of arsenic, followed by leaf and stem. Rice grain and husk accumulated the least amount of arsenic. These trends are in agreement with those reported by Abedin et al. (2002) based on a greenhouse study.

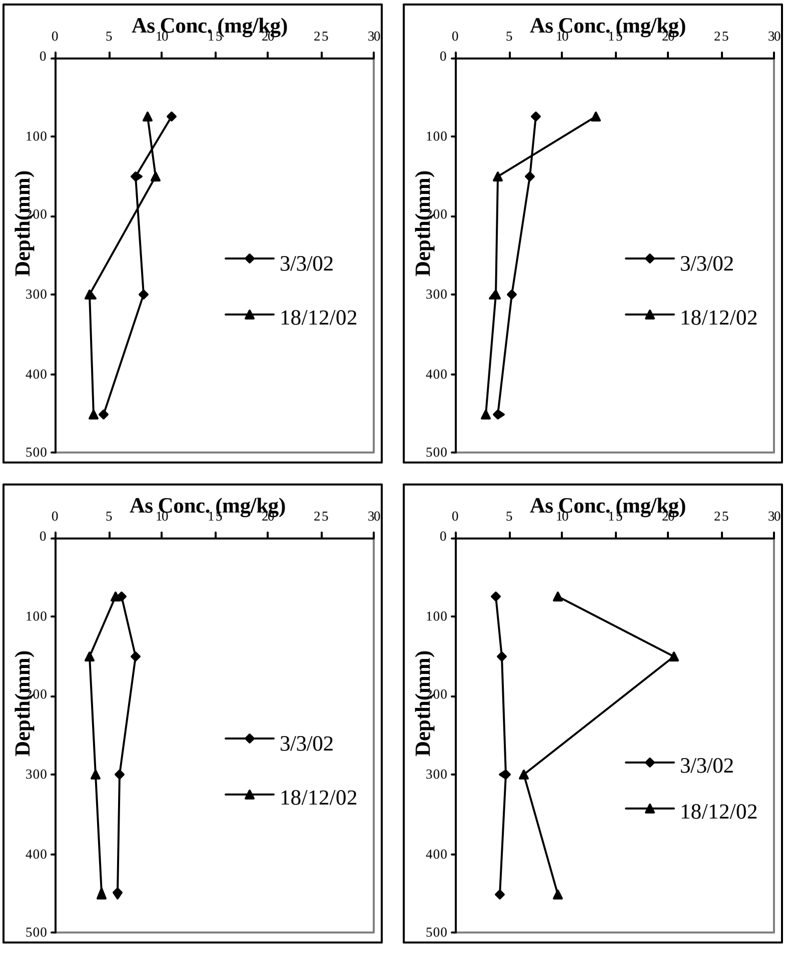

Figure 11: Arsenic profiles of some soil samples from Sonargaon rice field at different times

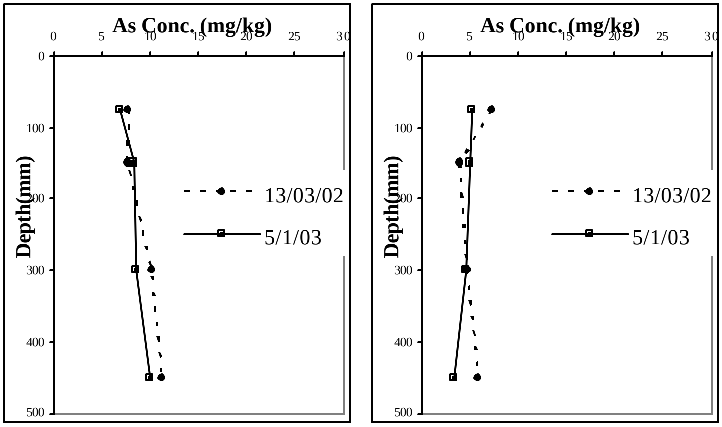

Figure 12: Arsenic profiles of soil samples collected from Srinagar vegetable fields at two different times

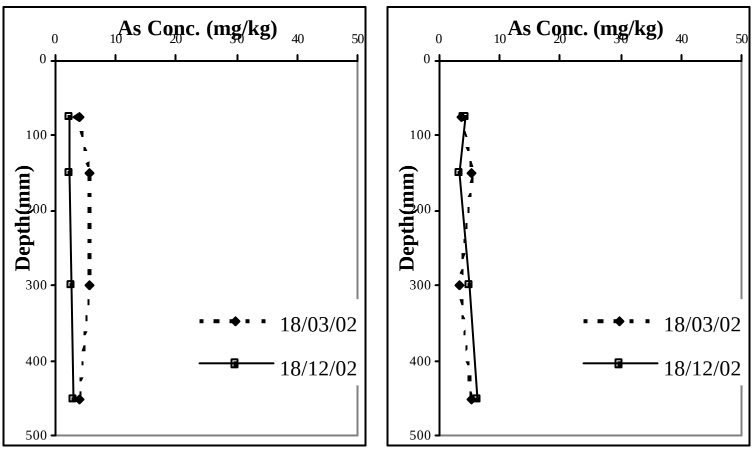

Figure 13: Arsenic profiles of soil samples collected from Sonargaon vegetable fields at two different times

Arsenic concentration in roots of rice plant samples collected from the Srinagar site varied from 2.81 to 16.8 mg/kg (with a mean of 8.9 mg/kg), while that in the rice grain varied from < 0.05 mg/kg (lowest detectable limit for this study) to 1.52 mg/kg (with a mean of 0.48 mg/kg). For the samples collected from the Sonargoan site, arsenic in root varied from 2.88 to 26.1 mg/kg (with a mean of 11.9 mg/kg), while that in the rice grain varied from < 0.05 mg/kg to 1.23 mg/kg (with a mean of 0.46 mg/kg). Two grain samples (out of nine) from Srinagar and only one (out of twelve) from Sonargaon exceeded the Australian food hygiene limit of 1.0 mg/kg.

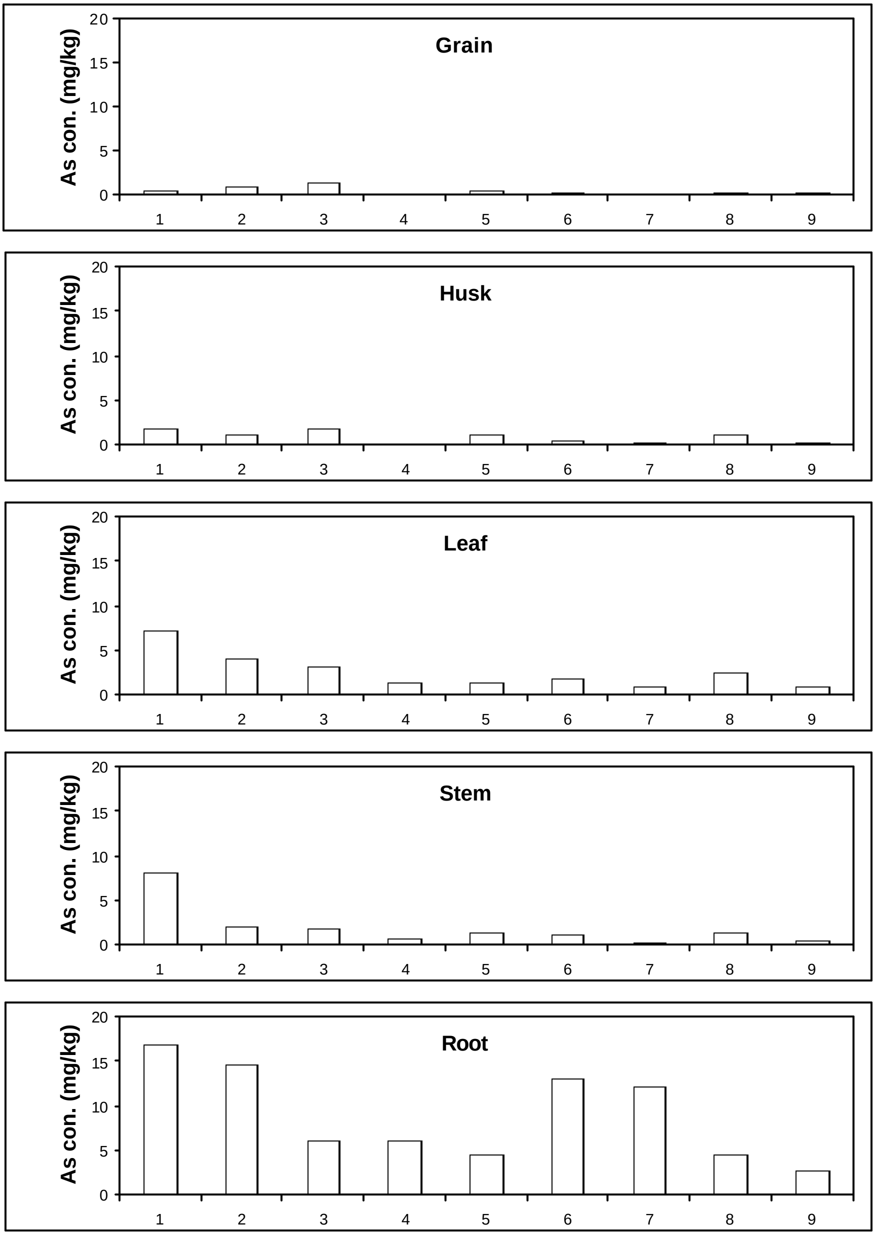

Figure 14: Arsenic concentrations in grain, husk, stem, leaf and root of rice plants collected from Srinagar site

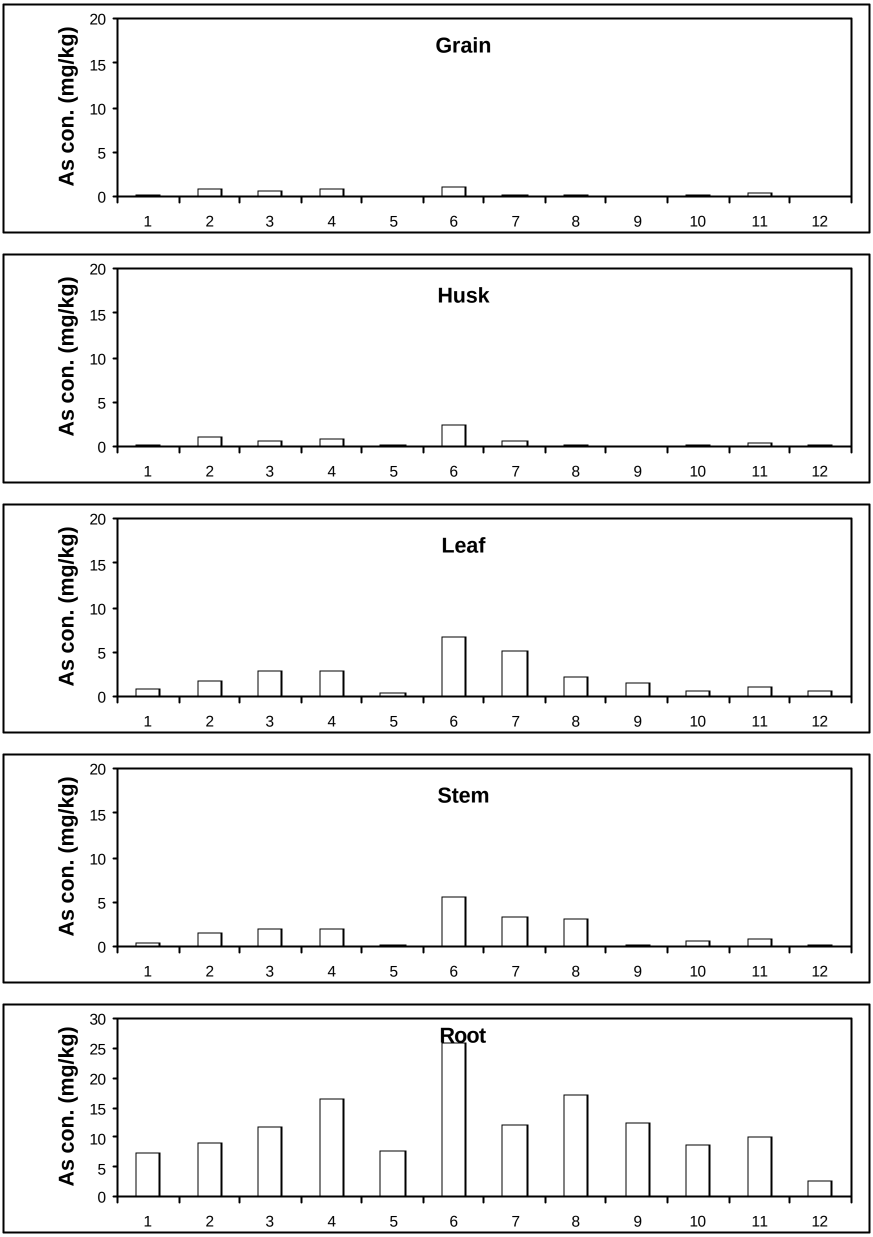

Figure 15: Arsenic concentrations in grain, husk, stem, leaf and root of rice plants collected from Sonargaon site

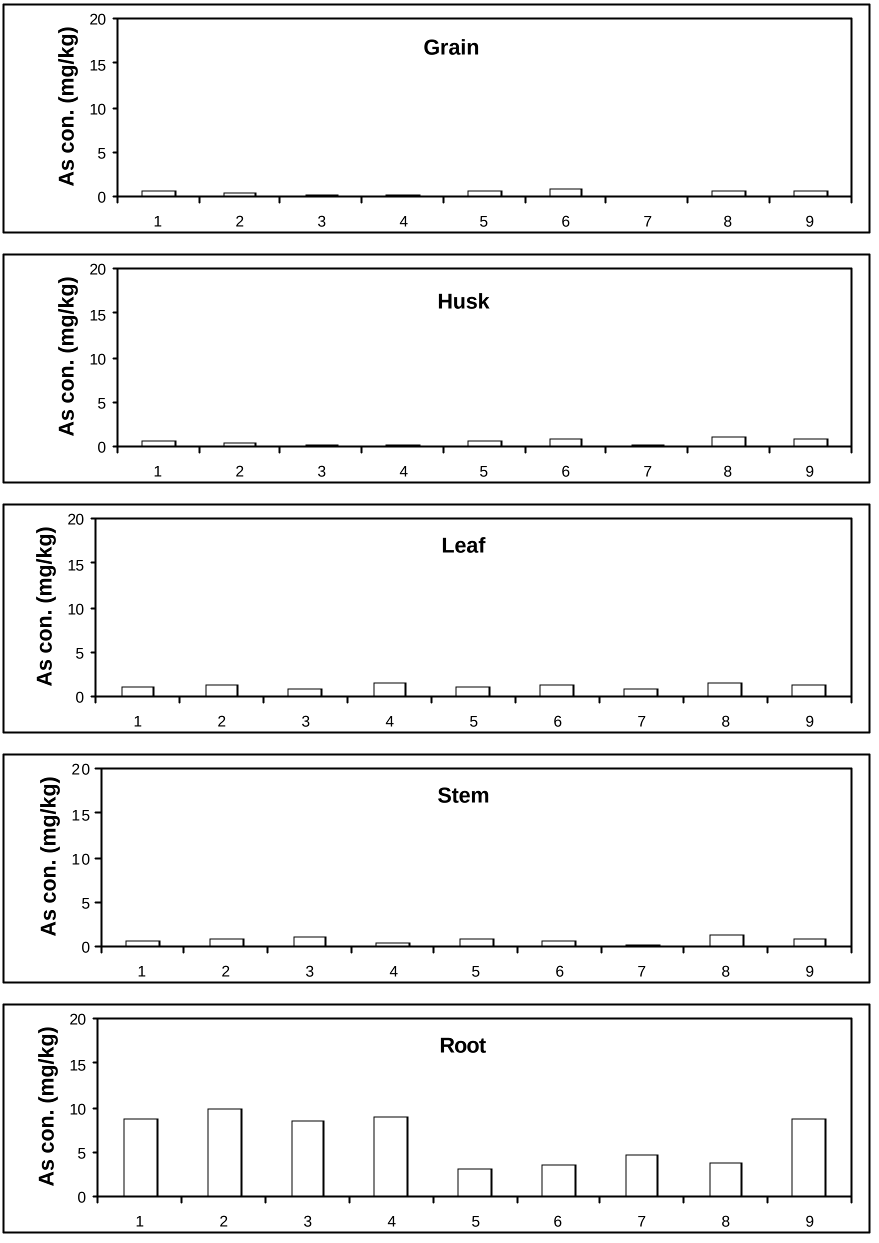

Figure 16: Arsenic concentrations in grain, husk, stem, leaf and root of rice plants collected from Dinajpur site

The level of arsenic in root, leaf and stem of the plant samples collected from Dinajpur (an arsenic-free area) were found to be significantly lower compared to those found in the samples collected from the Srinagar and Sonargoan sites. For example, average arsenic concentration in the root samples from Dinajpur was 6.76 mg/kg, compared to 8.9 and 11.9 mg/kg for the Srinagar and Sonargoan sites, respectively. Thus it appears that arsenic present in irrigation water and soil results in higher level of arsenic in rice plant root, leaf and stem. However, as shown in Fig. 17, no strong correlation could be observed (R^2=0.21) between the presence of arsenic in soil and rice plant root (as well as leaf and stem).

However, there was no significant difference in arsenic levels present in the rice grains and rice husks. In fact, the mean arsenic concentration in the rice grain samples from the Dinajpur site was found to be 0.54 mg/kg, slightly higher than those from the Srinagar and Sonargaon sites. Although none of the grain samples from Dinajpur exceeded the Australian food hygiene standard of 1.0 mg/kg. It should be noted, however that the rice cultivated at both Srinagar and Sonargaon site were of BR-29 variety, whereas those at Dinajpur site were of *China Irri* and *Chandina* varieties. As shown in Fig. 18, no correlation exists between the arsenic concentration in soil and in rice grains (R^2=0.017). Thus it appears that arsenic present in irrigation water and soil is not translocated to rice grain.

Figure 19 shows correlations between the arsenic present in grains and other parts of rice plants for the BR-29 variety of rice collected from Srinagar and Sonargaon sites. Relatively strong correlation was observed between arsenic in grains and husks (R^2=0.68); but correlations between arsenic in grains and arsenic in root, stem and leaf were poor.

Arsenic in Vegetable

Results of analysis of arsenic in different parts of potato and potato plant showed relatively lower level of accumulation. It should be noted that the potato fields were irrigated by pond water with relatively low levels of arsenic. Highest accumulation of arsenic was found in the root of potato plants (up to 2.9 mg/kg). However, these levels were significantly lower than those found in rice roots. Arsenic concentration in the edible parts varied from 0.12 to 0.85 mg/kg [dry (oven dried at 65°C) weight basis], all below the Australian food hygiene standard.

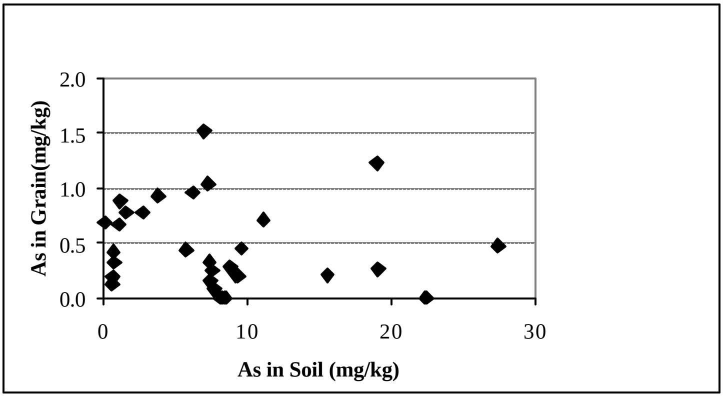

Figure 17: Arsenic concentrations in grain versus arsenic in top soil layer (all samples)

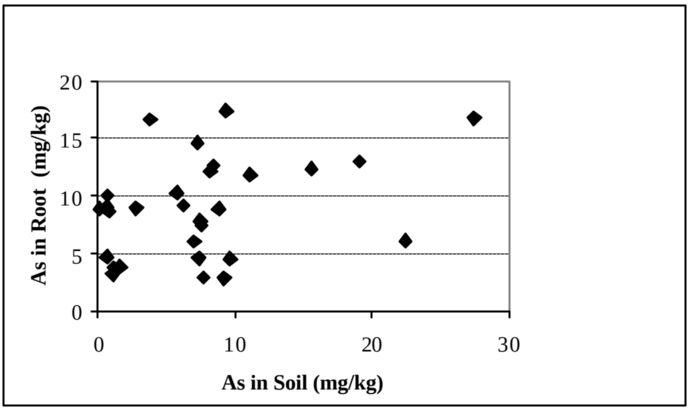

Figure 18: Arsenic concentrations in root versus arsenic in top soil layer (all samples)

Results of arsenic concentration in different parts of tomato, *lalshak*, *datashak*, cabbage and cauliflower samples collected from the Sonargoan site also showed relatively low level of accumulation. All these fields (except the cauliflower field) were irrigated by pond or canal water with relatively low levels of arsenic. Among the different parts, arsenic accumulation in roots was found to be the highest, although the levels (maximum 1.8 mg/kg) were very low compared to the rice roots. Arsenic concentration in edible parts of *lalshak* ranged from < 0.39 to 0.96 mg/kg; for *datashak* it ranged from 0.56 to 1.06 mg/kg, for cabbage 0.38 to 1.6 mg/kg and for cauliflower 0.35 mg/kg. Arsenic concentrations in the five tomato samples ranged from 0.18 to 1.33 mg/kg. However, since all the vegetable fields (except one) were irrigated by pond or canal water, effect of arsenic bearing irrigation water on these vegetables could not be assessed from these results alone.

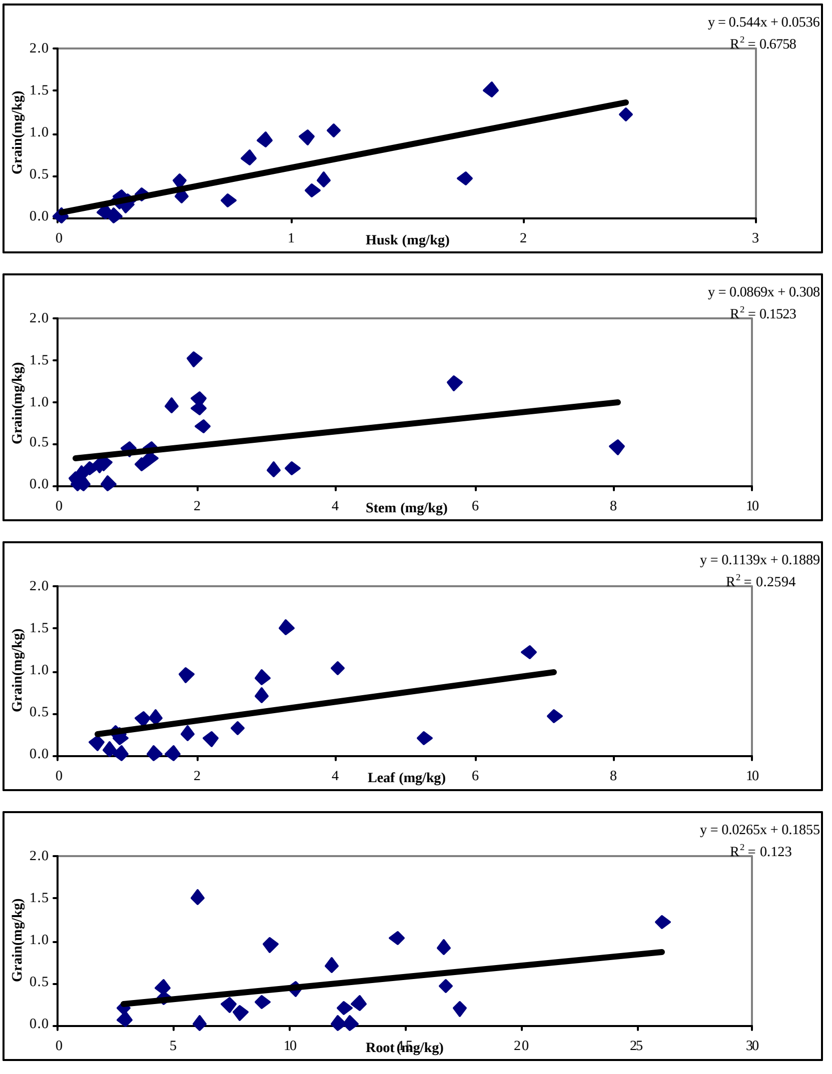

Figure 19: Correlations between arsenic in present grains and arsenic in other parts of rice plants (BR-29 variety) collected from Srinagar and Sonargaon

CONCLUSIONS

Results from this study suggest that presence of arsenic in irrigation water results in significant increase of arsenic concentration in the irrigated soil, particularly in the top layer (up to about 150 mm). At the Srinagar site, rate of accumulation of arsenic appears to be slow with significant reduction of arsenic concentration in soil after the flood. However, the situation was somewhat more complex in Sonargaon. More studies are needed to better understand the processes leading to accumulation of arsenic in soil. This is important because phytotoxicity (i.e., reduced growth/yield of plants), due to increased arsenic in irrigation water is another major concern. A number of studies have shown reduced growth of plants (including paddy) grown is soil containing high arsenic or when irrigated with water containing high concentration of arsenic (Abedin et al., 2002; Smith et al., 2001). Smith et al. (2001) have shown that yield of both tomato and silverbeet, grown in soil containing 100 – 200 mg/kg arsenic, were significantly reduced (5 to 10% of the control yield). Stunted growth of the plants was also observed in this study. Although arsenic concentration in soil of the rice fields covered in this study have not reached this level, it is important to know how the concentration is likely to change with time, and at what level it would have an impact on the crop productivity.

High arsenic in irrigation water and soil appears to result in higher concentration of arsenic in root, stem and leaf of rice plants. This result is in agreement with that reported by Abedin et al. (2002) based on a greenhouse study. This suggests that arsenic can be easily translocated to paddy shoot. Since rice straw is widely used as cattle feed in Bangladesh and India, high arsenic in rice stem and leaf (i.e., in straw) may result in adverse health impacts on cattle and increase human arsenic exposure via the plant-animal-human pathway.

In agreement with a number of other studies, arsenic concentration in rice grains was found to be relatively low. Among the 21 samples from Srinagar and Sonargaon, only three exceeded the Australian food hygiene limit of 1.0 mg/kg. There does not appear to be a strong correlation between the presence of arsenic in rice grain and husk with the presence of arsenic in irrigation water and soil. Similar results were also obtained by Meharg et al. (2001). However, it is not clear whether this result would hold for other varieties of rice. More data are needed to ascertain the findings of this study. The vegetable fields investigated in this study were irrigated by pond or canal water with relatively low level of arsenic. Hence the effect of arsenic bearing irrigation water on these vegetable could not be assessed from this study. Accumulation of arsenic in different parts of the vegetables (potato, tomato, lalshak, datashak, cabbage and cauliflower) was found relatively low.

It should be noted that very little is known about the chemical forms of arsenic (e.g., inorganic and organic) in crop/vegetable, which in turn is needed for estimating its toxicity. Some recent studies (Chakroborti et al., 2001; Magara et al., 2002) suggest that a significant portion of arsenic in rice and vegetable exist as As(V). Speciation of arsenic in rice straw (Abedin et al., 2002) revealed that the predominant species present in straw was arsenate followed by arsenite and dimethylarsinic acid (DMAA). However, in this study, speciation of arsenic present in food samples could not be performed due to analytical limitations.

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REFERENCES

Abedin, M. J., Cresser, M. S., Meharg, A. A., Feldmann, J. and Cotter-Howells, J. (2002), Arsenic Accumulation and Metabolism in Rice, *Env. Sci. Technol.,* 36(5), 962-968.

Bennett, J. P., Chiriboga, E., Coleman, J. and Waller, D. M. (2000), "Heavy metals in wild rice from northern wisconsin", *The Science of Total Environment*, 246(2000), 261-269.

Chakroborti, D., Rahman, M. M., Paul, K., et al. (2001), Groundwater arsenic contamination in south east Asia with special reference to Bangladesh and West Bengal-India, Arsenic in the Asia Pacific Region Workshop, Adelaide, Managing Arsenic for the Future: 1-4

Chen, C. Y. and Folt, C. L. (2000), "Bioaccumulation and diminution of arsenic and lead in a freshwater food web,", *Environ. Sci. Technol*., 34, 3878-3884.

Duxbury, J. M., Mayer, A. B., Lauren, J. G and Hassan, N. (2002), Arsenic Content of Rice in Bangladesh and Impacts on Rice Productivity, 4th Annual Conference on Arsenic Contamination in Groundwater in Bangladesh: Cause, Effect and Remedy, Dhaka,12 –13 January, 2002.

GoB (1998), National Minor Irrigation Project, National Minor Irrigation Census 1996/97, 1995-96 Irrigation Season, Government of

Bangladesh, Sir William Halcrow & Partners Ltd., DVH Consultants BV.

Huq, S.M.I., Ahmed, K.M., Suktana, N. and Naidu, R. (2001), Extensive Arsenic Contamination of Groundwater and Soils of Bangladesh, Arsenic in the Asia Pacific Region Workshop, Adelaide, Managing Arsenic for the Future: 94-96.

Magara, Y. (2002) Paper presented during panel discussion during the UNU-NIES International Workshop on Arsenic Contamination in Groundwater –Technical and Policy Dimensions, Tokyo, 18 February, 2002.

McLaren, R. G., Megharaj, M. and Naidu, R. (2001) Fate of Arsenic in the Soil Environment, Arsenic in the Asia Pacific Region Workshop, Adelaide, Managing Arsenic for the Future: 27-28.

Meharg, A.A., Abedin, M.. J., Rahman, Md. M., Feldmann, J., Cotter-Howells, J. and Cresser, M.S. (2001) Arsenic Uptake and Metabolism in Bangladesh Rice Varieties, Arsenic in the Asia Pacific Region Workshop, Adelaide, Managing Arsenic for the Future: 45-46.

Smith, L. H., Smith, J. and Naidu, R. (2001) Assessment of Soil-Plant Transfer of Arsenic from Agricultural Soils, Arsenic in the Asia Pacific Region Workshop, Adelaide, *Managing Arsenic for the Future*: 156-157.