Fate of Arsenic Extracted With Groundwater

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INTRODUCTION

Widespread presence of arsenic in groundwater at levels above the drinking water standard is a major concern in Bangladesh, India and several other countries. In Bangladesh, high levels of arsenic have been detected in 59 out of 64 administrative districts; the southern, south-western and north-eastern regions of the country are worst-affected. In Bangladesh tubewell water extracted from shallow aquifers is the primary source of drinking/cooking water for most of its population, particularly the rural 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. Although considerable work has been done on removal technologies of arsenic from contaminated groundwater and alternate water supply options, the presence of arsenic in irrigation water received relatively lesser attention. The dependency on groundwater for public water supplies and irrigation results in a huge quantity of arsenic being cycled through the environment each year with major implications on public health and environment. This paper presents an assessment of the use of groundwater for irrigation in Bangladesh and provides an assessment of the amount of arsenic that is extracted with groundwater used for irrigation as well as domestic purpose. This paper also provides an overview of the research needs for better understanding of the fate of arsenic in the environment.

GROUNDWATER IN IRRIGATION

In Bangladesh, in the absence of adequate surface water in the dry season, irrigation is heavily dependent on groundwater. Figure 1 shows increase in irrigated area in Bangladesh by different technologies during 1982-1997 (WARPO, 1999). As shown in Fig. 1, during the last fifteen years, the area under irrigation has been increased significantly to raise food production. Much of this increase has been accomplished through installation of shallow tubewell (STW). As can be seen from Fig. 1, the area under irrigation by surface water has remained more or less static since the early eighties; while the area under irrigation by shallow tubewells has increased by a factor of about five. During each irrigation season, an estimated 27209 Mm^3 of water [considering a discharge of 10 l/s and 1200 hours of irrigation per season] is extracted through shallow tubewells. This quantity is order of magnitude higher than the amount of groundwater extracted for domestic purpose throughout the year.

In Bangladesh irrigation season is divided into two periods – Rabi season and Kharif season. In the 1996/97 Rabi season, the total irrigated area was 3.8 million hectares, among which 2.63 million hectares irrigated using ground water and 1.17 million hectares irrigated using surface water. In the Kharif season a total of 0.2 million hectares was irrigated, among which 0.158 million hectares was irrigated using ground water and 0.042 million hectare using surface water.

In the Rabi 1996/97 season, STW irrigated 2.15 million hectares (63% of the total area under minor irrigation), among which *boro* field accounted for 1.68 million hectares, wheat field for 0.29 million hectare and other corps accounted for 0.18 million hectare. DTW irrigated 0.48 million hectare (14% of total area under minor irrigation), among which *boro* field accounted for 0.42 million hectare, wheat field accounted for 0.034 million hectare, and others accounted for 0.026 million hectare. In the Kharif 1996/97 season, STW irrigated 0.126 million hectare (66% of total area under minor irrigation), among which *aman* field accounted for 0.096 million hectare, and others accounted for 0.029 million hectare. DTW irrigated 0.032 million hectare (16% of total area under minor irrigation), among which *aman* field accounted for 0.029 million hectares and others accounted for 0.0027 million hectare.

According to a recent BADC survey (BADC, 2002), a total of 865213 shallow tubewells and 23182 deep tubewells were used for irrigation during the 2001 *boro* season. Shallow tubewells irrigated about 2.295 million hectares (about 61% of total area under irrigation) and deep tubewells accounted for about 0.538 hectare (about 14% of irrigated area). The contribution of surface and groundwater sources to total irrigated area has changed considerably over time. The contribution of groundwater to total irrigated area has increased from 41% in 1982/83 to 71% in 1996/97 and to over 75% in 2001. The contribution of surface water has, therefore, declined from 59% to less than 25% over this period.

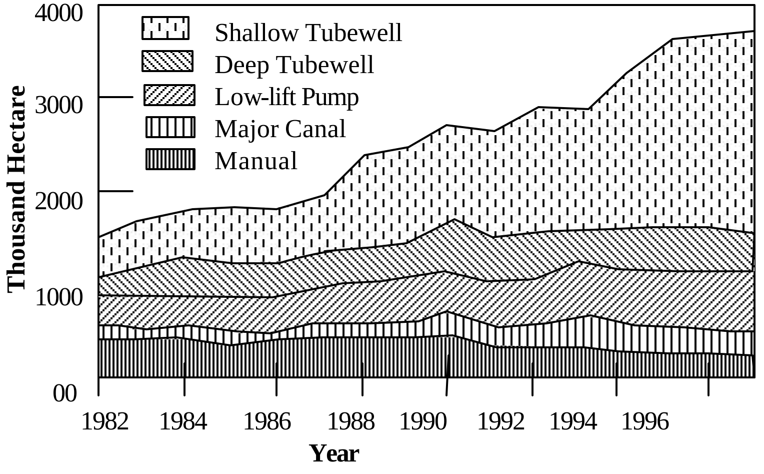

Figure 1: Increase in irrigated area in Bangladesh by different technology during 1982-1997 (WARPO, 1999)

In Bangladesh, *boro* rice (dry season rice) is the major recipient of irrigation water. Figure 2 shows total irrigation coverage as a function of time, along with contribution from FCDI (Flood Control, Drainage and Irrigation) coverage. It should be noted that in Bangladesh, total irrigation coverage accounts for over 60 percent of the net cultivable area. Figure 3 shows trends in growth of *boro* (dry season) rice production in Bangladesh. This figure shows that during 1973 – 94, *boro* registered a very high production growth, by a factor of over three. This rapid increase in *boro* production is mainly attributed to the increase in the area under irrigation (and also use of high yielding varieties of rice). In fact, growth in *boro* production (Fig. 3) and growth in area covered under irrigation (Fig. 2) are strongly correlated with a correlation coefficient of 0.98 (Chowdhury et al., 1997). Currently *boro* rice accounts for about 37% of the total rice production in Bangladesh. Besides *boro* rice, wheat and a range of other crops and vegetables cultivated during dry season also need irrigation.

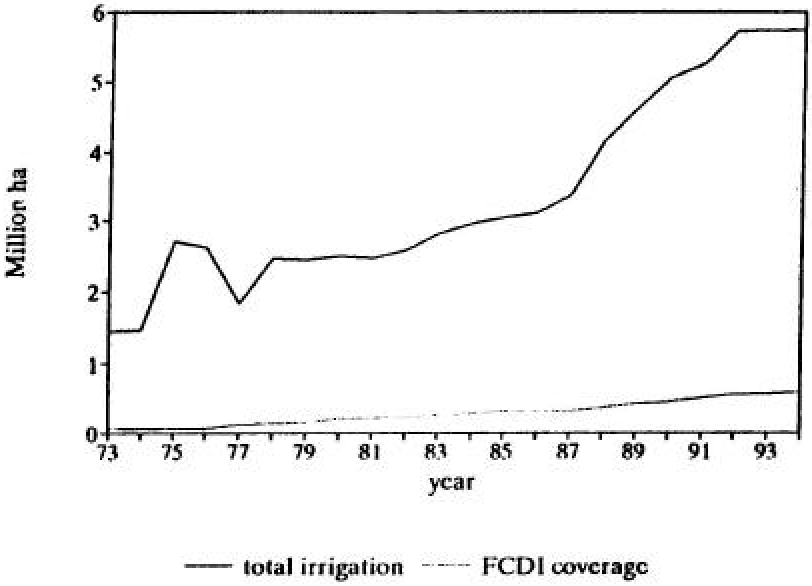

Figure 2: Growth in irrigation coverage in Bangladesh
(Source: Chowdhury et al., 1997)

Thus, for Bangladesh, attainment of self-sufficiency in food production is strongly related to its ability to produce food during the dry season with the help of irrigation. Since we are increasingly depending on shallow aquifer (a large part of which is arsenic contaminated) for irrigation water, a huge quantity of arsenic is being added in the agricultural fields each year with irrigation water. For example, if arsenic concentration in irrigation water is 100 ppb and if a total of 1000 mm of irrigation water is provided to the field over the dry season (e.g., for *boro* rice), then this adds 1 kg of arsenic per hectare of irrigated land each year. Therefore, concerns have been raised about possible introduction of arsenic in the food chain as well as long-term implications (e.g., reduced yield) of increased arsenic in the agricultural fields.

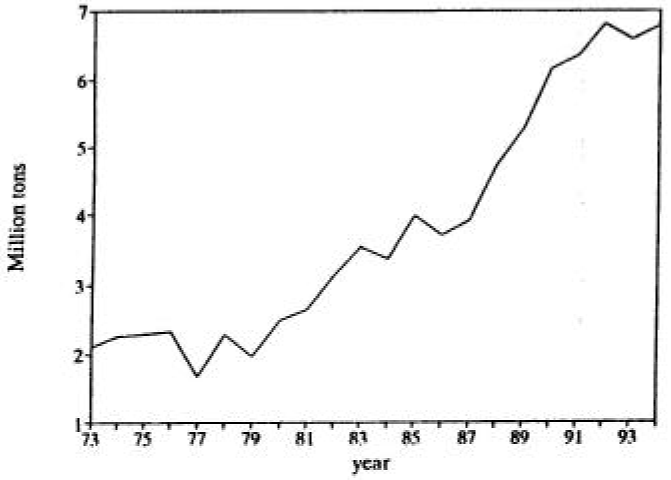

Figure 3: Growth in *boro* production in Bangladesh
(Source: Chowdhury et al., 1997)

AMOUNT OF ARSENIC EXTRACTED WITH GROUNDWATER

Arsenic Extracted with Irrigation Water

Figure 4 shows distribution (thana-wise) of shallow irrigation wells in Bangladesh. As shown in Fig. 4, high concentrations of shallow irrigation wells could be found in northern and north-western Bangladesh. It is interesting to note that the regions with heavy concentrations of irrigation wells (north and north-western region) are, in general, different from those with highest concentrations of arsenic in tubewell water (e.g., southern, central and north-eastern region).

A preliminary estimate of the quantity of arsenic extracted through irrigation water was made for each thana by assuming a discharge of 10 l/s for each irrigation well and 1200 hours of irrigation (each year) and taking arsenic concentration in the irrigation water as the average of the values reported for that thana in the arsenic-database developed by DPHE/BGS (2000). It should be noted that information on arsenic concentration, number of shallow irrigation wells and irrigated area were available for 394 *thanas* and only these information were used in this estimation process.

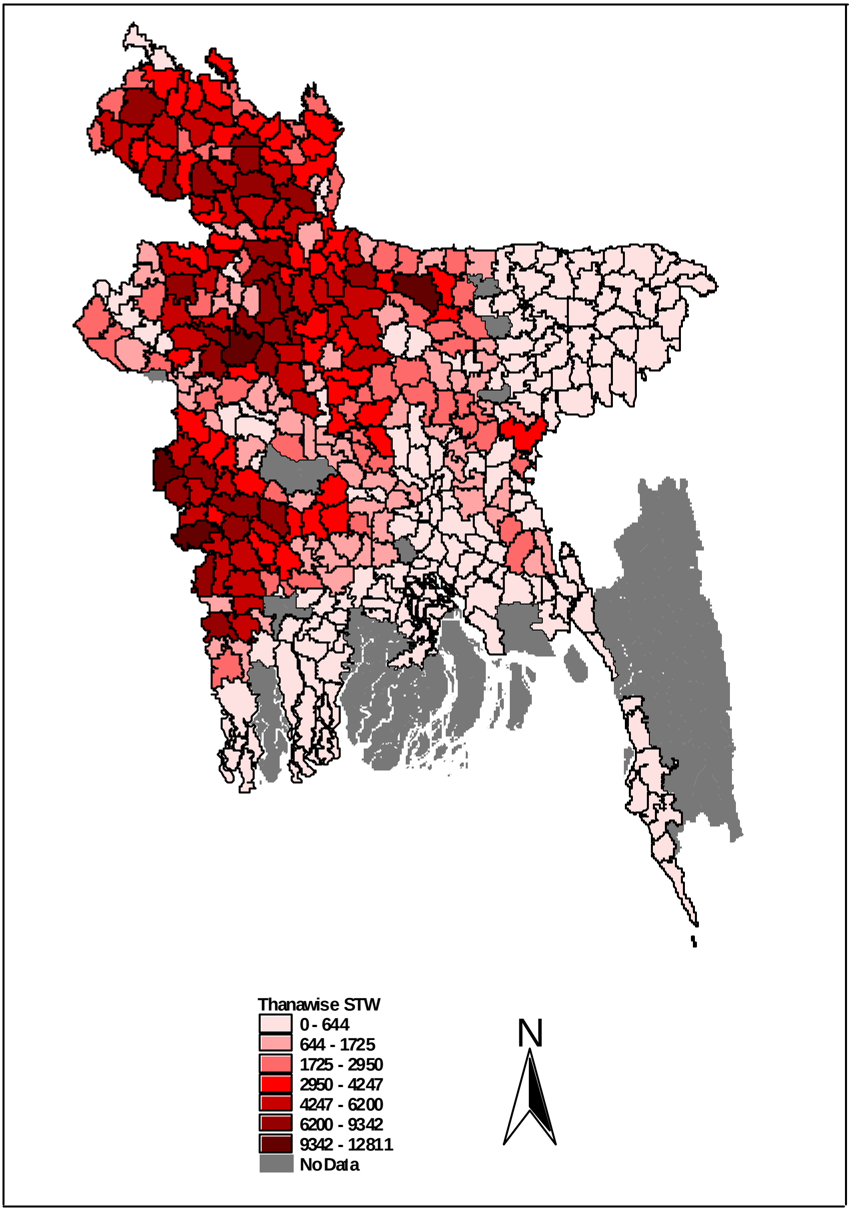

Figure 4: Distribution of shallow irrigation wells in Bangladesh (data from BADC, 2002)

Figure 5 shows amount of arsenic extracted through irrigation wells every year for all the *thanas* in Bangladesh. Thus if all irrigation wells run at full capacity, an estimated 1360 metric tons of arsenic would be extracted each year through irrigation water. The estimates are particularly high for south-western and south-central (excepting the hill districts) regions of Bangladesh, where both irrigation intensity and arsenic concentration in shallow wells are very high. Figure 5 shows that although the north-eastern region of Bangladesh is an area heavily affected by arsenic contamination, relatively lower quantity of arsenic is cycled through irrigation water in this region because of lower irrigation intensity (using groundwater). In fact, compared to the arsenic affected north-eastern region, more arsenic appears to be cycled through irrigation water in the relatively arsenic-free northern regions of Bangladesh where irrigation intensity is very high.

Figure 6 shows thana-wise estimates of the amount of arsenic deposited in agricultural land per hectare of irrigated area. This estimate was made by dividing the estimated total arsenic for each thana (presented in Fig. 5) by the irrigated area for that thana (BADC, 2002). According to this estimate, the districts with high deposition of arsenic include Chandpur, Munshigonj, Comilla, Gopalgonj, Faridpur, Madaripur, Jessore, Jhenaidah, Bagerhat, and Kushtia.

This preliminary estimate, which shows that a huge quantity of arsenic is cycled each year through irrigation water, further emphasizes the importance of understanding the fate of arsenic extracted through irrigation water and delivered to the agricultural lands. The districts and regions where arsenic deposition on agricultural lands appears to be higher may be targeted for additional studies.

Arsenic Extracted with Domestic Well Water

In this study, at attempt has been made to develop a gross estimate of arsenic extracted with groundwater from domestic wells. Arsenic extracted from domestic tubewells were estimated by combining estimates of total population of each *thana*, percentage of population using shallow wells for domestic purpose and per capita use of water. Only rural area was considered in this estimation. Besides shallow tubewell, a number of technologies are used in the rural water supply, which include deep tubewell (DTW), pond sand filter (PSF), and VSST/SST. Since a significant fraction of shallow tubewells is privately owned, there is no good record of actual number of shallow tubewells in the country. On the other hand, all the other technologies are almost entirely owned by the

Government and the statistics provided by the DPHE on these technologies can be considered to be reliable.

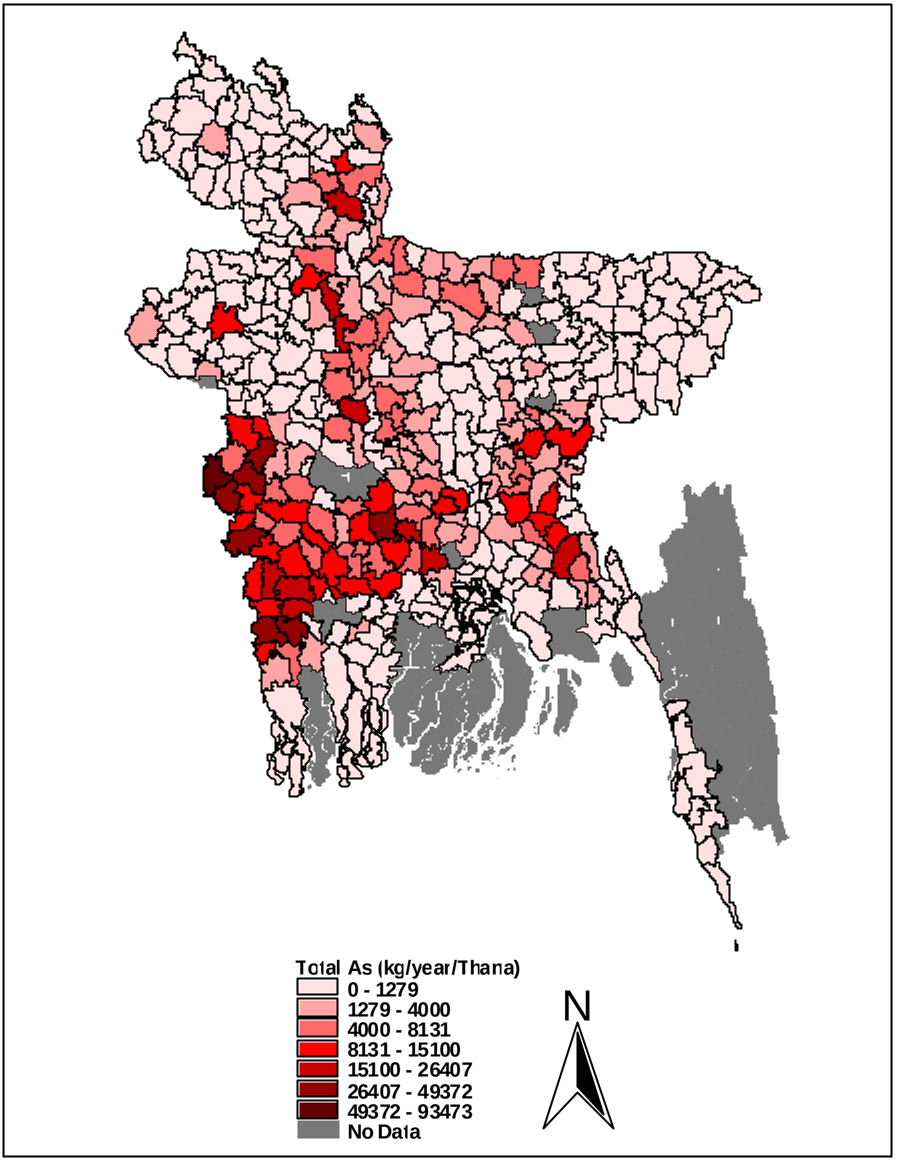

Figure 5: Estimates of arsenic extracted each year through shallow irrigation wells in Bangladesh

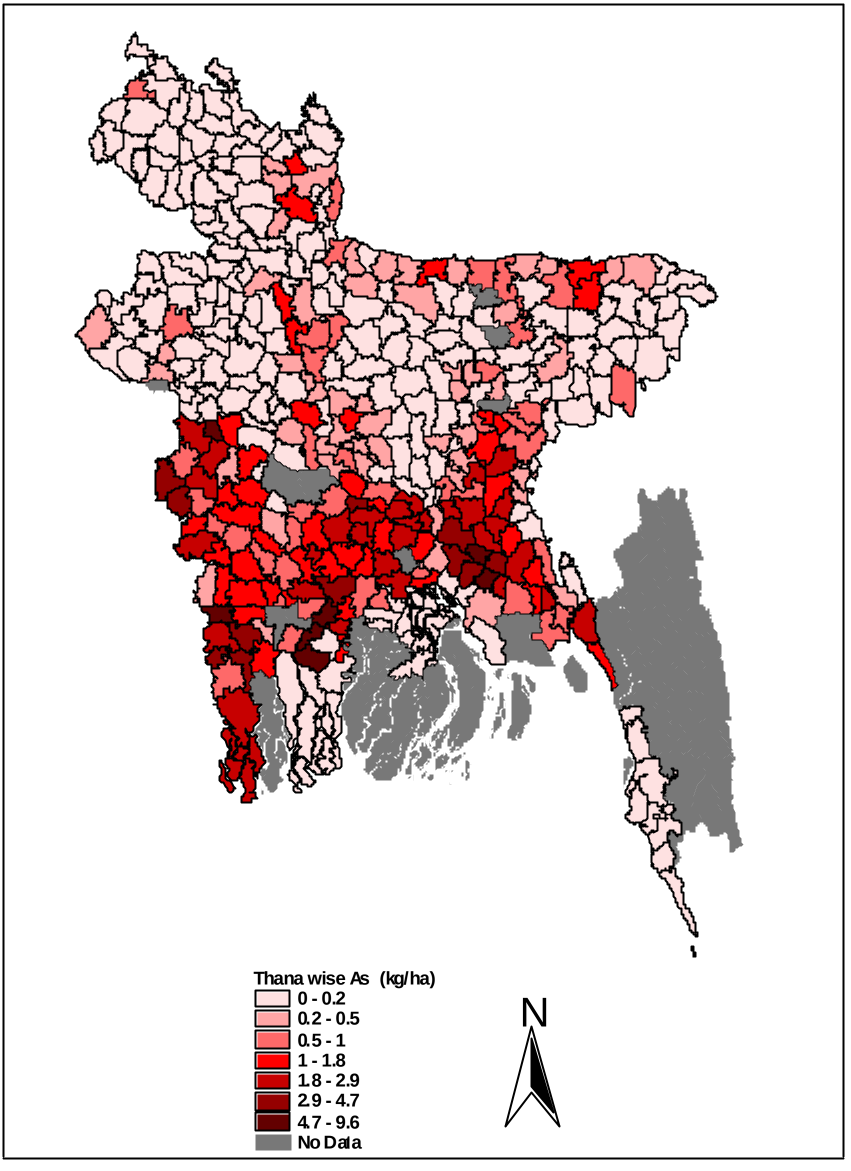

Figure 6: Estimates of arsenic deposition per hectare of irrigated area

In this study, it has been assumed that except for shallow tubewell, water derived from all other technologies is free from arsenic. Thus the number of people using shallow tubewell was calculated as the total population minus the population using the other technologies. For this calculation, it was assumed that each deep tubewell serves 101 people (DPHE, 1999), each PSF serves 500 people and each VSST/SST serves 75 people. In the absence of *thana*-wise population data from the 2001 Census, it was assumed that the ratio of population of a particular *thana* to the total population is the same as it was in 1991 Census. Thus for each *thana*, the population using shallow tubewell was estimated.

Based on the results of a study on water use (Ahmed and Smith, 1987), the average daily per capita use of water was assumed to be about 20 liters. Arsenic concentration in the well water was taken as the average of the values reported for that *thana* in the arsenic-database developed by DPHE/BGS (2000). Based on this simple methodology, it was estimated that about 46 metric tons of arsenic is extracted each year along with groundwater extracted from domestic tubewells. As expected, this amount is significantly lower compared to the estimated amount extracted with irrigation water.

FATE OF ARSENIC IN SOIL-WATER-PLANT ENVIRONMENT

As noted earlier, so far most research works on arsenic in Bangladesh have focused on its presence in and exposure through drinking/cooking water. Only limited research works have so far been carried out on understanding fate of arsenic in the soil-water-plant environment. Understanding fate of arsenic extracted through tubewell water in soil-water-plant environment is vital for assessing its impacts on the food chain and the environment in general.

Figure 7 schematically shows the fate of arsenic, extracted through groundwater, in the soil-water-plant environment. The arsenic pumped with tubewell water can (i) undergo transformation (e.g., through redox or microbial processes), (ii) volatilize into the atmosphere as a result of different biological transformations, (iii) undergo adsorption-desorption and thus become retained onto soil, washed away by surface runoff or leached into the groundwater, and (iv) be taken up by plants, and subsequently enter into the food chain.

The arsenic pumped with tubewell water primarily exists as As(III). In the irrigation field, it may undergo photo-oxidation in the presence of sunlight. Limited data suggest presence of both As(III) and As(V) as well as MMA and DMA in agricultural soil. Adsorption-desorption, volatilization as well as plant uptake of arsenic depend, to a large extent, on chemical forms/transformations of arsenic. For example, among the different arsenic species, arsenate is most strongly adsorbed and retained onto soil. However, the processes of transformation/ bio-transformation of arsenic in the agricultural fields are not clearly understood.

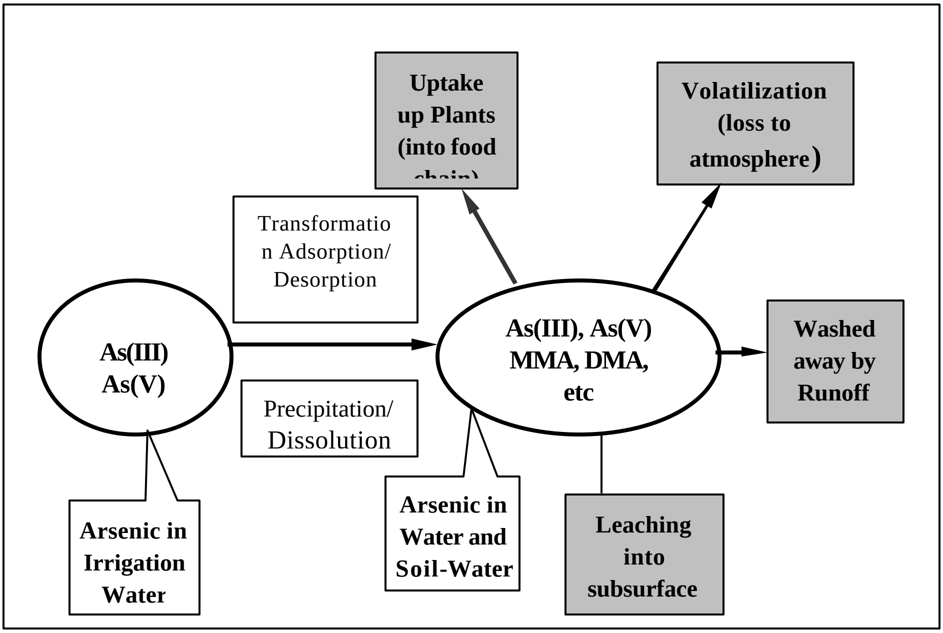

Figure 7: Fate of arsenic in soil-water-plant environment

Although considerable work has been done on microbial methylation (and volatilization) processes of arsenic, primarily as it applies to bioremediation of arsenic-contaminated soils, importance of such processes in determining the fate of arsenic in agricultural fields is not clearly understood. Increased bio-methylation and volatilization of gases such as di- and tri-methylarsine from soil can reduce arsenic accumulation in agricultural fields. However, the importance of such processes in significantly reducing arsenic levels in non-manipulated soils (i.e., natural agricultural soils) has been questioned (McLaren et al., 2001).

Adsorptoin-desorption of arsenic onto soil is key to the understanding of its fate in the environment. In irrigated agricultural land, water lost by evaporation will leave arsenic along with other minerals in the topsoil. A large fraction of this arsenic is not likely to be washed out by flood or rainwater in oxidized condition due to its affinity for iron, manganese, aluminum and other minerals in soil. As a result, a cumulative accumulation of arsenic in surface soils is expected and some recent data (Huq et al., 2001; Alam and Sattar, 2000; Ullah, 1998) suggest arsenic concentration as high as 83 mg/kg in topsoil, against a background concentration of about 3-9 mg/kg. In general, higher arsenic concentrations have been reported in the top layer of soil (Huq et al., 2001). From available data it appears that most of the arsenic accumulation in irrigated agricultural fields is restricted to the top 150 to 200 mm of soil. However, data on accumulation of arsenic on irrigated agricultural soil over time is not available. Also there appears to be a lack of information on desorption kinetics of arsenic from soil, which is needed for better understanding of its long-term retention on soil or its leaching back into the subsurface. Microbial influences on adsorption-desorption is also unclear.

The plant uptake is another important pathway governing the fate of arsenic extracted through tubewell water. Plant uptake of arsenic and translocation to plant top is highly variable among plant species and is also influenced by soil characteristics, soil fertility, and concentration and chemical forms of arsenic in soil. Uptake studies have showed significant variation in uptake of both As(III) and As(V) among varieties. In a recent study with paddy, active uptake of both As(III) and As(V), at about the same rate, was observed (Meharg et al., 2001). The organic species MMA and DMA were taken up to a lesser extent than the inorganic species. Since phosphate and arsenate are analogous in certain respects (e.g., adsorption characteristics), effect of phosphate fertilizer on plant-uptake of arsenic is of particular interest. In a recent study, it has been shown that high rates of phosphate fertilizer did not significantly affect arsenic uptake by paddy (Meharg et al., 2001). It has been argued that conversion of soil As(V) to As(III) and subsequent uptake of As(III) by plant is the reason behind the lack of effect of phosphate.

CONCLUSIONS

Shallow tubewells are widely used for irrigation in Bangladesh. According to a recent BADC survey (BADC, 2002), a total of 865213 shallow tubewells and 23182 deep tubewells were used for irrigation during the 2001 *boro* season. The contribution of groundwater to total irrigated area was over 75% in 2001, and shallow tubewells accounted for over 60% of irrigated area. For Bangladesh, attainment of self-sufficiency in food production is strongly related to its ability to produce food during the dry season with the help of irrigation. Since we are increasingly depending on shallow aquifer (a large part of which is arsenic contaminated) for irrigation water, a huge quantity of arsenic is being added in the agricultural fields each year with irrigation water.

High concentrations of shallow irrigation wells could be found in northern and north-western Bangladesh. Areas with heavy concentrations of irrigation wells are, in general, different from those with highest concentrations of arsenic in tubewell water (e.g., southern, central and north-eastern region). If all irrigation wells run at full capacity, over 900 metric tons of arsenic could be cycled each year through irrigation water. The estimates are particularly high for south-western and south-central (excepting the hill districts) regions of Bangladesh, where both irrigation intensity and arsenic concentration in shallow wells are very high. According to this study, the districts with highest cycling of arsenic per unit of irrigated area include Chandpur, Munshigonj, Comilla, Gopalgonj, Faridpur, Madaripur, Jessore, Jhenaidah, Bagerhat, and Kushtia. The highest value of 5.5 kg of arsenic per hectare of irrigated area was estimated for the Raipur thana of Laksmipur district. Amount of arsenic extracted with groundwater from domestic tubewells was estimated to be about 46 metric tons per year, with is about 20 times smaller than that extracted with irrigation water.

The huge quantity of arsenic being withdrawn with irrigation and domestic wells is a major concern. Arsenic in irrigation water poses a potential challenge to the agriculture sector. Ingestion of food items irrigated with arsenic contaminated groundwater may be a major route of human exposure to arsenic. More studies are needed to develop a better understanding of arsenic accumulation in soil and food chain and its possible long-term impacts.

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