Fate of Arsenic in the Environment

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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. Besides huge quantities of water from shallow aquifer is also used for irrigation during the dry season. 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 provides an overview of the research needs for better understanding of the fate of arsenic in the environment.

Since its detection in late 1993 in Bangladesh, much of the research on arsenic has 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. In Bangladesh, in the absence of surface water in the dry season, irrigation is heavily dependent on shallow tubewell. As shown in Figure 1, during the last fifteen years, the area under irrigation has been increased to raise food production mainly by installation of shallow tubewell, a large proportion of which yields water with high levels of arsenic. However, limited research works have so far been carried out on understanding fate of arsenic 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 result of different biological transformations, (iv) undergo adsorption-desorption and thus become retained onto soil, washed away by surface runoff or leached into the groundwater, and (v) be taken up by plants, and subsequently enter into the food chain. Limited data suggest presence of both As(III) and As(V) as well as organic arsenic in agricultural soil and the processes of transformation/bio-transformation of arsenic are not clearly understood. Although considerable work has been done on microbial methylation (and volatilization) processes of arsenic, primarily as it applies to bioremediation of As-contaminated soils, importance of such processes in determining the fate of arsenic in agricultural fields is not clearly understood.

Adsorption-desorption of arsenic onto soil is key to the understanding of its fate in the environment. In irrigated agricultural land, water lost by evaporation and evapo-transpiration will leave arsenic along with other minerals in the topsoil. This arsenic is not likely to be dissolved or 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 4-8 mg/kg. 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 the long-term retention of arsenic on soil.

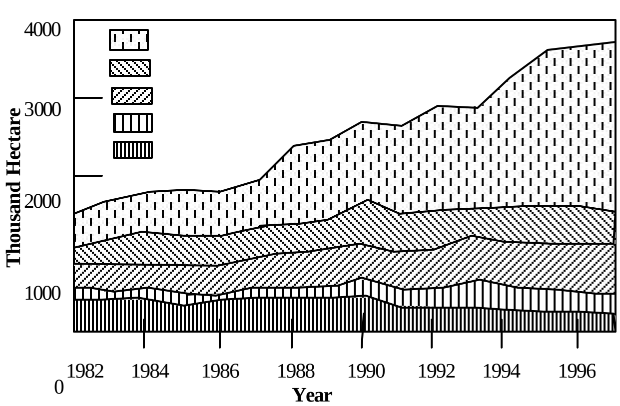

Figure 1: Increase in irrigated area in Bangladesh by different technology during 1982-1997 (WARPO, 1999).

The increased concentration of arsenic in irrigation water and in topsoil in the root zone is likely to result in increased concentration in plant and food grains. The preliminary findings of UNDP/FAO studies in Bangladesh showed that arsenic content in rice produced by irrigation with arsenic contaminated water is higher but the relative increase is not significant. The highest concentration of arsenic was found in the roots of rice plant, then comparatively a lower concentration in stem and leaves and the lowest concentration was found in rice grain. A Bangladesh rice variety BR11 irrigated with water containing 8 mg/L arsenic accumulated 0.6 mg/kg of arsenic in grain and as high as 100 mg/kg of arsenic in straw (Meharg, 2001). It appears that arsenic is not readily translocated in the rice grains. A relatively higher concentration of arsenic has been found in leafy vegetables; the concentration of arsenic in arum, a vegetable/food in Bangladesh has been found to be 20 mg/kg (Huq et al., 2001). 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. Limited available data suggest significant variations of arsenic content among different varieties of crop/vegetable and also among different parts of the same plant. More studies are needed to develop a better picture of arsenic accumulation in the food chain. Arsenic in the agriculture environment can be fairly complex and a good understanding of the fate of arsenic pumped with groundwater is essential for the development of good management and remediation strategy.

In addition to transfer of arsenic in the environment through pumped groundwater, fate of arsenic in arsenic-rich wastes generated from household or community-based arsenic removal units/systems is also a major concern. Majority of the arsenic-rich waste materials can be classified into: (a) wastes generated from coagulation based systems, and (b) wastes generated from systems based on absorptive filtration and others techniques (e.g., ion exchange). The waste belonging to the first category is primarily slurry containing coagulated flocs of alum or iron salt, rich in arsenic. Currently, disposal of such wastes in cow-dung bed or in nearby land is widely practiced. It has been suggested that biochemical processes in cow-dung bed and in nature result in volatilization of arsenic. However, data supporting such processes are scant. The wastes belonging to the second category are primarily spent adsorption/ion-exchange media. With increasing use of arsenic removal units, concerns have been raised regarding safe disposal and long-term stability of these wastes, and possible contamination of environment from arsenic present in the wastes. However, there is only limited data on the quantities and characteristics of these wastes and possible mobilization of arsenic from them. The widely used Toxicity Characteristics Leaching Procedure (TCLP) of USEPA used for evaluating stability of hazardous wastes may not adequately assess the long-term stability of these wastes. New test methods need to be developed for this purpose.

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