

Groundwater Arsenic Variations in Bangladesh: The Role of Depth, Seasons, Locations and Age of Tube Wells

M.T. Iqbal

Department of Agricultural Sciences, La Trobe University, Victoria (Melbourne) 3086, Australia

✉ toufiq_iqbal@yahoo.com

Received February 6, 2009; revised and accepted September 7, 2009

Abstract: Groundwater arsenic contamination is now one of the most significant problems in Bangladesh. Role of depth, seasons, locations and age of tube well for groundwater arsenic variation in Bangladesh was studied. MERCK arsenic test kit was used to determine arsenic concentration variation. Tube well water depth was measured with the help of an avometer, measuring tap and plastic insulated wire. Also, depth and age of the tube wells were determined through asking questions, secondary sources of DPHE and Union Council. Results indicate that arsenic concentration levels are about 41.31% under WHO guideline (0.01 mg/l), 29.69% are within the permissible level (0.05 mg/l) and 29% exceed the permissible level (> 0.05 mg/l). No relation was observed between arsenic concentration and water table depth. At depth below 15 m, 92.68% of tube wells were arsenic level under WHO guideline (0.01 mg/l), 4.88% within permissible limit (0.05 mg/l) and 2.44% exceeding permissible limit (> 0.05 mg/l). At depth between 15 and 30 m, 40.43% of tube wells were arsenic levels under WHO guideline, 34.04% within the permissible limit and 25.53% exceeding the permissible limit. At depths between 31 and 46 m, 25.49% of tube wells were arsenic levels under WHO guideline, 39.22% within the permissible limit and 35.29% exceeding the permissible limit. At depth between 46 and 76 m, no tube well was arsenic level under WHO guideline, 40% within permissible limit and 60% exceeding permissible limit. But, there were many significant changes observed in each depth from below 30 m to above 70 m. Less arsenic concentration was observed in the dry season as compared to the wet season. Less significant difference was observed within locations. Result showed that from less than 15 m to 76 m depth arsenic concentration trend is higher in each tube well that was installed since eighties.

Key words: Arsenic, depth, seasons, age of tube wells, Bangladesh.

Introduction

Arsenic enrichment in Bangladesh groundwater is considered to be one of the greatest current environmental disasters in the world. Out of 64 districts, 61 have arsenic concentration above the maximum permissible limit of 0.05 mg/l (Iqbal, 2004). Source of As in groundwater is naturally occurring geological deposits at shallower depths (usually 12-46 m). The Department of Public Health Engineering (DPHE) first detected arsenic in groundwater in 1993 and the issue came in limelight at the beginning of 1995. Population exposed to As poisoning through drinking water is about 36 millions. It is suspected that over 0.2 million people are suffering from arsenic-related diseases ranging from melanosis to

skin cancer and gangrene. So far, about 38,000 As-patients are clearly identified and it is predicted that 0.2 to 0.27 million people will die of cancer from drinking As contaminated water and foods in Bangladesh alone (Meharg et al., 2003).

In the present paper, the author presents the distribution of arsenic level in groundwater, to detect the arsenic level in some tube wells for identifying the sources of high, medium and low arsenic content, depth-wise distribution of arsenic in tube wells, amount of arsenic content in groundwater, arsenic concentration variations in different depths during dry and wet seasons and arsenic concentration variations with locations and age of tube wells.

Materials and Methods

Sampling Procedure for Drinking Water

Data was collected from four southern districts of Bangladesh i.e., Faridpur, Madaripur, Magura and Kustia. Arsenic concentrations were tested from those tube wells of the area in which arsenic concentration was not tested earlier. This information was gathered from local people, Union Council and Department of Public Health Engineering. Each sample was collected in plastic containers that were labeled separately with a unique identification number. It also included the information on the collection date, depth of the tube well and whether previously arsenic test was done or not. This was done to prevent possible contamination with other samples in the laboratory. The relationship between arsenic contamination and depths of tube well were also analyzed from collected data.

Procedure of Tube Well Age Determination

Tube well ages were determined in two ways. One was from the secondary source of Department of Public Health Engineering. Other was through asking questions of tube well owners as well as surrounding neighbours when tube well was installed. Maximum people informed taking war of independence (1971) as a basis of response e.g., after three years of independence and so on. At the end tube well age were verified through DPHE, Union Council and number of respondents' opinion.

Procedure of Tube Well Water Depth Measurement

Tube well water depths were measured with the help of avometer, measuring tape and plastic insulated wire. A small heavy weight of rod piece was bonded tightly at one end of the wire and other end of the wire was kept open to connect with avometer. Before measurement of water depth, tube well was opened at the top of the pipe. During depth measurement, tube well was opened and then rod end of the wire entered the pipe of the tube well till avometer showed indication. It means rod end had touched water level. After that with the help of measuring tape water depth was measured.

Role of Test Kits in Measuring Arsenic

Test kits are relatively inexpensive, portable and generally operate on measuring/observing an immediate chemical reaction. However, in practical terms, field test kits have inherent limitations to their use in isolated village situations. They require replenishment of chemical

reagents, so incur maintenance costs and their results can be easily validated unless the chemical protocols that eliminate cross-contamination are adhered to strictly.

Test kits may be very good for demonstrating the presence of particular chemicals or pathogens, but currently they are not always sufficiently sensitive, or accurate for quantitative assessments. Test kit results should be regarded as initial indicators. Their main limitation is that in raw water samples many chemical reactions may be masked by others occurring in the same solution. The range of technical accuracy of test kits varies generally with their price, but none currently on the market is sufficiently sensitive to provide the data needed to ensure that particular quality standards are reached.

Arsenic's propensity to switch valency states means that As^{3+} is more likely to be indicated by test results, while the presence of As^{5+} may not be identified because it reacts more slowly. Test kits therefore commonly underestimate total arsenic presence. The most effective use for portable test kits is to indicate the presence of arsenic. As a general principle, these guidelines recommend that, if the test kit demonstrates the presence of arsenic, alternative safe drinking water sources need to be identified.

Testing Through MERCK Arsenic Kit

Collected water samples were tested using MERCK Arsenic Test Kit no.1.17926.0001. Zinc and sulfuric acid were added to compounds of arsenic(iii) and arsenic(v), liberating arsenic hydride, which in turn reacts with mercury(ii) bromide contained in the reaction zone of the analytical test strip to form yellow-brown mixed arsenic mercury halogenides. The concentration of arsenic(iii) and arsenic(v) were measured by visual comparison of the reaction zone of the analytical test strip with the field of a colour scale. Measuring range/colour scale graduation were 0.00 - 0.01 - 0.025 - 0.05 - 0.1 - 0.5 mg/l $\text{As}^{3+/5+}$.

Remove an analytical test strip and immediately reclose the tube. With the reaction zone first insert the test strip about half way through the slot in the stopper of the reaction vessel. By means of the syringe, 10 ml of the solution is transferred to be tested in the reaction vessel and add two measuring spoonfuls of reagent As^{-1} (zinc). Rapidly add 10 drops of reagent As^{-2} (sulfuric acid), immediately close the reaction vessel with the stopper and swirl it gently. The sample solution does not come in contact with the test strip. Leave it to stand for 30 minutes, and gently swirl two or three times. Remove the test strip, briefly dip into water, and shake off excess

liquid to determine which colour field on the label coincides with the colour of the reaction zone most exactly. Read off the corresponding concentration value in mg/l As^{3+/5+}. If an exact colour match could not be achieved, estimate an intermediate value. If the colour of the reaction zone is equal to or more intense than the colour field for 0.5 mg/l As^{3+/5+}, use the Merckoquant Arsenic Test cat No. 1.10026.0001 (measuring range 0.1-3 mg/l As^{3+/5+}). But in our observations any sample could not exceed 0.5 mg/l As^{3+/5+}.

The Merck kit, which is manufactured in Germany, has a major drawback that it can only measure down to 0.10 mg/l, that is, double the regional arsenic standard of 0.05 mg/l. However, it is widely acknowledged that none of the test kits are very accurate at low concentrations and that Merck reagents are of very high quality.

The Merck field test kit is extremely simple, with emphasis on ensuring replicable and reliable results. The kit and all the individual reagents (zinc powder, hydrochloric acid, mercury bromide papers) carry expiry dates and the well-packaged reagents ensure that users normally achieve about 100 tests per kit. Despite not having additional reducing reagents, or a method of removing sulfide interface, evaluations have found the Merck kit to be at least as accurate and reliable as other more complex field kits.

Results and Discussions

Distribution of Arsenic Level in Groundwater

Arsenic contaminated aquifers have no regular pattern and varies both horizontally and vertically within short distances. Data on arsenic concentration in the southern region of Bangladesh were relatively scarce. The data on arsenic concentration of 305 groundwater TWs provided a solid basis for evaluating arsenic contamination in the southern region of Bangladesh. These data were particularly useful because arsenic testing in this study was done using standard testing method, which provide reliable results. Figure 1 represents the distribution of arsenic in the tube wells located in the southern region of Bangladesh. It indicates that the arsenic concentration level is about 41.31% under WHO guideline (0.01 mg/l), 29.69% is within permissible level (0.05 mg/l) and 29% exceeds the permissible level (> 0.05 mg/l). Out of the total 405 tube wells from southern region, arsenic concentrations in 174 were found to be below 0.01 mg/l, 140 were found in the range of 0.01 to 0.05 mg/l and 91 were found to be above 0.05 mg/l. More tube wells need to be tested for identifying

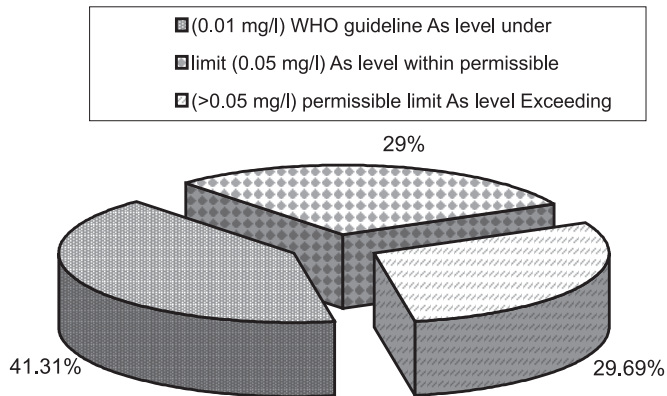


Figure 1: Distribution of arsenic level in ground water.

the pattern of arsenic contamination in the southern region of Bangladesh.

A survey of well waters ($n = 3534$) throughout Bangladesh, excluding the Chittagong Hill tracts, have shown that water from 27% of the 'shallow' tube wells, that is well less than 150 m deep, exceeded the Bangladesh standard for arsenic in drinking water (0.05 mg/l), 46% exceeded the WHO guideline value of 0.01 mg/l. Figures for 'deep' wells (greater than 150 m deep) were 1% and 5%, respectively. Since it is believed that there are a total of some 6-11 million tube wells in Bangladesh, mostly exploiting the depth range 10-50 m, some 1.5-2.5 million wells are estimated to be contaminated with arsenic according to the Bangladesh standard, 35 million people are believed to be exposed to an arsenic concentration in drinking water exceeding 0.05 mg/l and 57 million people are exposed to a concentration exceeding 0.01 mg/l (Kinniburgh and Smedley, 2001). However, according to Islam and Uddin (2002), the distribution of arsenic in the groundwater is related to the geology of the country rather than just the depth of the water table. According to them, the division of the aquifer system from the geological point of view – like the Upper Holocene aquifer, Middle Holocene aquifer, Upper Pleistocene-Early Holocene aquifer, Pilo-Pleistocene aquifer and older aquifers – is more logical when applied to the depth of the tube well pumping system as is customarily adopted in Bangladesh. They conclude that most of the arsenic-contaminated tube wells are drawing water from the Middle and Upper Holocene sediments.

Depth-wise Distribution of Arsenic in Tube Wells

Arsenic contamination is commonly associated with fluctuating water tables and flooding cycles particularly in acid sulfide/sulfate soils or where iron and/or manganese-enriched layers or saline-layered aquifers

occur. Under these conditions the complex chemistry of arsenic will result in changes depending on exposure either to air or saturated soils. Levels of arsenic contamination in water supplies can vary through a year adding to the difficulties of identification and monitoring. A depth-wise variation of arsenic concentration in the wells is shown in Figure 2. It indicates that the arsenic contamination increase with the increase of depth. Total 49 numbers of tube well samples from depth below 15 m were tested. Out of the tested samples, 92.68% of tube wells had arsenic level under WHO guideline (0.01 mg/l), 4.88% within the permissible limit (0.05 mg/l) and 2.44% exceeding the permissible limit (>0.05 mg/l). Depth between 15 and 30 m total 94 tube well samples was tested. Out of the tested samples, 40.43% arsenic levels under WHO guideline (0.01 mg/l), 34.04% within the permissible limit (0.05 mg/l) and 25.53% exceeding the permissible limit (>0.05 mg/l). Depths between 31 and 46 m total 51 numbers of tube well samples were tested. Out of tested samples 25.49% of tube wells had arsenic levels under WHO guideline (0.01 mg/l), 39.22% within the permissible limit (0.05 mg/l) and 35.29% exceeding the permissible limit (>0.05 mg/l). Depth between 46 and 76 m total 51 numbers of tube well samples were tested. Out of tested samples none of tube wells had arsenic levels under WHO guidelines (0.01 mg/l), 40% within permissible limit (0.05 mg/l) and 60% exceeded the permissible limit (>0.05 mg/l). The rest of the tube wells were not considered due to the lack of data about water table depth.

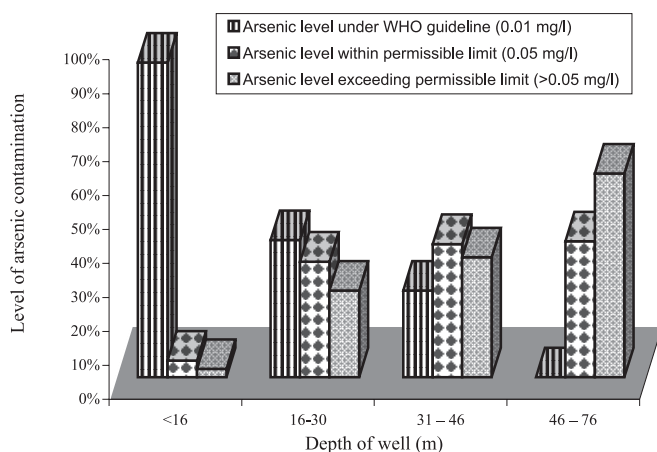


Figure 2: Depth-wise distribution of arsenic in tubewells.

Arsenic Concentration Variations in Different Seasons, Depths and Locations

During the course of the study, hand tube wells were monitored for arsenic, water levels and seasonal variations of arsenic contamination. No clear or consistent

changes in arsenic were detected during the monitoring period. However, long-term monitoring of the wells is required to establish whether there will be significant seasonal and long-term trends in water chemistry. The relatively small variations in arsenic concentrations observed in many of the wells emphasize the need for very careful sampling and high precision analysis if seasonal or long-term trends are to be detected reliably.

Arsenic concentrations in monitored wells were largely constant during the monitoring period. None of the shallow wells showed any seasonal response in As to rainfall. Concentrations were a little more variable during the early stages of sampling but this may be due to temporary disturbances in the groundwater chemistry following drilling. Table 1 shows the mean arsenic concentration at different season. Significant difference was observed between dry and wet seasons. Less arsenic concentration was observed in dry season as compared to wet season. No difference was observed within each season.

Table 2 displays the mean arsenic concentration at different depths. Significant variation was observed among different depths with arsenic concentration. Lower arsenic concentrations were observed up to 39 m depths

Table 1: Mean arsenic concentration (mg/l) at different seasons

Seasons	Arsenic concentration (mg/l)
Dry seasons	0.04
Wet seasons	0.56
SED	0.021
LSD	0.056
Level of significance	*

SED denotes standard errors of differences of means; LSD denotes least significant differences of means; *denotes $P < 0.01$

Table 2: Mean arsenic concentration (mg/l) at different depths

Depths	Arsenic concentration (mg/l)
> 30 m	0.03
30-39 m	0.08
40-49 m	0.44
50-59 m	0.34
60-69 m	0.41
< 70 m	0.51
SED	0.037
LSD	0.096
Level of significance	*

SED denotes standard errors of differences of means; LSD denotes least significant differences of means; *denotes $P < 0.01$

and more arsenic concentration were observed above 39 m depths. Within each depth arsenic concentration varied more significantly. Also, there were many significant changes observed in each depth from below 30 m depths to above 70 m depths.

According to Table 3, less significant differences were observed within locations. The difference in arsenic concentration within four locations is very small. So, it was observed that arsenic concentration varies more significantly with depth as compared to seasons and locations. Similar results were found from other study. Arsenic concentration is strongly dependent on depth. The highest concentrations of arsenic and the highest probability of exceeding thresholds for arsenic, most often occur in wells screened between 20 and 60 m but the precise depth of the maximum varies between regions and the sharpness of the concentration peak differs from place to place (Karim et al., 1997). The depth distribution shows to be fallacious, the belief that drilling deeper than 100 m provides arsenic-free water, it will do so in some

Table 3: Mean arsenic concentration (mg/l) at different locations

<i>Locations</i>	<i>Arsenic concentration (mg/l)</i>
Faridpur	0.24
Madaripur	0.28
Magura	0.33
Kustia	0.36
SED	0.037
LSD	0.096
Level of significance	*

SED denotes standard errors of differences of means; LSD denotes least significant differences of means; *denotes $P < 0.01$

parts of Bangladesh, but not, for example, in the region of the Sylhet Basin. A sharp upper limit to high concentrations of arsenic appears to occur at about 10-15 m depth; few data are available for wells in the depth range 0-10 m, so this may be an artefact of data distribution. That it is not is suggested by the fact that dug wells, which are mostly much less than 10 m deep, are rarely polluted with arsenic (Chakraborty, 2001). Below 200 m, arsenic concentrations rarely exceed a few milligrams per litre (Frisbie et al., 1999).

Arsenic Concentration Variation with Age of Tube Wells

One of the questions which was of concern to many was whether the tube wells currently safe will remain so in the future or the concentration of arsenic will change with time in the aquifers for worse due to stress imposed by abstractions. In order to obtain answers to such questions data have to be collected over extended period of time. Delay for such observation was not possible, as answers were needed immediately. It was found suitable proxy parameters that can reasonably replace the time parameter. One such proxy could be the age of the tube wells. As tube wells were sunk without specifically taking into consideration the aquifer properties, the average concentration of arsenic in tube wells sunk at any given period should be statistically the same as any other period. So, any change in the concentration of arsenic with tube well age should represent its abstraction-induced effect. Average concentrations for arsenic in tube wells grouped by age were calculated for all the tube wells and also for the depth segregated groups. The results are shown in Figure 3.

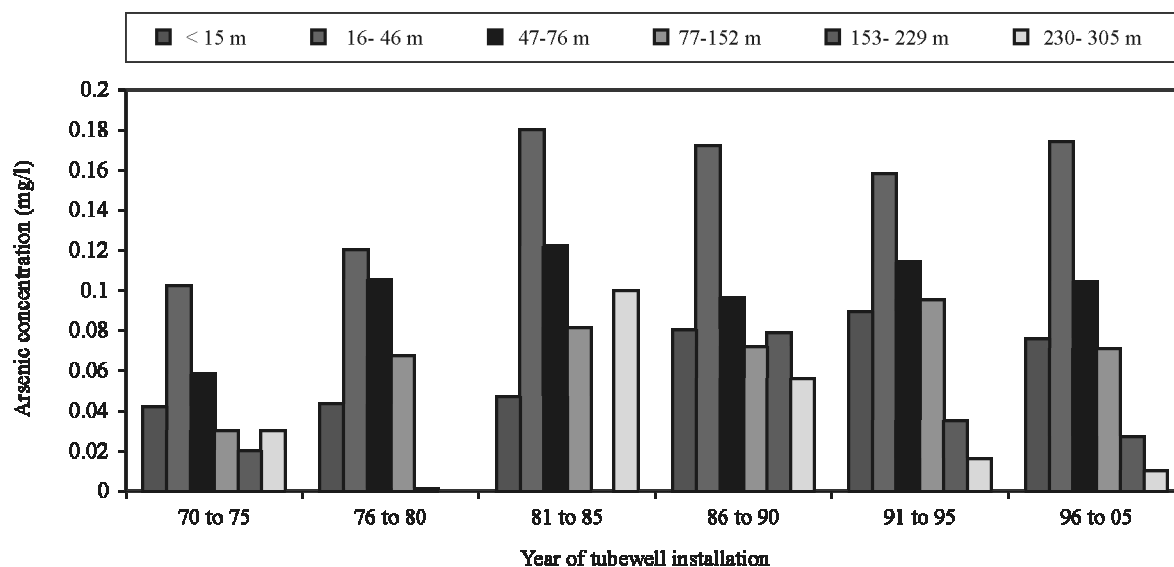


Figure 3: Arsenic concentration variation with depth and age of tubewell.

It can be seen that for all the groups except >305 m, the concentrations do not appreciably change with tube well age. There appears a slight decrease with time but this may not be very significant as these mostly relate to tube wells dating back to seventies. As pointed out earlier data for these tube wells may not be all that accurate. In the case of tube wells of depth greater than 305 m, there may be even greater problem with data and it may be probably reflected in the increase in the arsenic concentration for the tube wells during the period 1970-80. Also, in eighties trends of mean arsenic concentration was higher in all categories of depth.

Conclusions

Groundwater with high arsenic concentrations from naturally occurring sources is the primary source of drinking water for millions of people in Bangladesh resulting in major public health crises of recent times. Arsenic concentration levels are 41.31% under the WHO guideline (0.01 mg/l), 29.69% within permissible limit (0.01-0.05 mg/l) and 29% exceeds the permissible limit (>0.05 mg/l) in southern Bangladesh. In case of depth-wise variation, 92.68% under WHO guideline, 4.88% within permissible limit, 2.44% exceeding permissible limit for depth below 15 m. For depth between 15 and 30 m, 40.31% under WHO guideline, 34.04% within permissible limit and 25.53% exceeding permissible limit. For 31-46 m and 46-76 m depths, 25.49% and 0% under WHO guideline, 39.22% and 40% within permissible limit and 35.29% and 60% exceeding permissible limit were observed in southern Bangladesh. Mean arsenic concentrations are less upto 39 m depth and after that concentration tends to be higher. Arsenic concentration increase with the increase of well depth. For depth between 46 and 76 m, 60% of tube wells were exceeding permissible limit (>0.05 mg/l). Significant difference was observed between dry and wet seasons. Less arsenic concentration was observed in the dry season as compared to wet season. No difference was observed within each season. More arsenic concentration was observed in dry season as compared to wet season. In all four locations i.e. Faridpur, Madaripur, Magura and Kustia, mean arsenic concentrations were 0.24, 0.28, 0.33 and 0.36 mg/l respectively. Relationship among arsenic concentration, depth and age of tube well provides evidence that arsenic concentrations are always higher

in 16-46 m depth from 1970 to 2005 years of tube well installation. Data on age of tube well indicate that arsenic concentrations have been increasing from eighties in which tube wells were installed.

These studies demonstrate groundwater arsenic variance with some factors like depth, seasons, location and age of tube wells. However, the extent of these factors varies considerably and is influenced by several biogeochemical processes during sediment water interactions in the Holocene aquifers in the country.

Acknowledgement

The author is grateful to University of Rajshahi, Bangladesh.

References

- Chakraborti, D. (2001). Probable explanation why dugwells are safe with respect to arsenic in the arsenic affected villages of West Bengal-India and Bangladesh. <http://www.geocities.com/broadway/wing/3014/dcsesju.html>
- Frisbie, S.H., Maynard, D.M. and B.A. Hoque (1999). The nature and extent of arsenic-affected drinking water in Bangladesh. *In: Metals and Genetics* (B. Sarker, ed.), Kluwer Academic/Plenum Press, New York.
- Iqbal, S. (2004). Rural Drinking Water Supply and Sanitation in Bangladesh: A Case Study of Satkhira, South-Western District (Khulna Division). AIT Thesis no.EV-04-27
- Islam, M. N. and M. N. Uddin (2002). Hydrology and Arsenic Contamination in Bangladesh, *In: Arsenic Mitigation in Bangladesh* (eds. M. Feroze Ahmed and Chowdhury Mufad Ahmed) Local Government Division, Ministry of Local Government Rural Development & Cooperatives, Government of the People's Republic of Bangladesh, Dhaka.
- Karim, M., Komori, Y. and M. Alam (1997). Arsenic occurrence and depth of contamination in Bangladesh. *Journal of Environmental Chemistry*, **7(4)**: 783-792.
- Kinniburgh, D.G and P.I. Smedley (2001). Arsenic contamination of groundwater in Bangladesh. BGS Technical Report WC/00/19. Volume 1. pp.1-21.
- Meharg, A.A. and M.M. Rahman (2003). Arsenic Contamination of Bangladesh Paddy Field Soils: Implications for Rice Contribution to Arsenic Consumption. *Environmental Science and Technology*, published by American Chemical Society, **37(2)**: 229-234.