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Recommendations for water supply in arsenic mitigation: a case study from Bangladesh†

BA Hoque[1]*, AA Mahmood[1], M Quadiruzzaman[2], F Khan[1], SA Ahmed[1], SAKAM Shafique[2], M Rahman[1], G Morshed[1], T Chowdhury[1], MM Rahman[3], FH Khan[3], M Shahjahan[3], M Begum[3] and MM Hoque[4]

[1]*International Centre for Diarrhoeal Disease Research, Bangladesh;* [2]*Department of Public Health Engineering, Bangladesh;* [3]*Elected Local Government Union Chairman;* [4]*Bangladesh University of Engineering and Technology, Bangladesh*

Arsenic problems have been observed in several countries around the world. The challenges of arsenic mitigation are more difficult for developing and poor countries due to resource and other limitations. Bangladesh is experiencing the worst arsenic problem in the world, as about 30 million people are possibly drinking arsenic contaminated water. Lack of knowledge has hampered the mitigation initiatives. This paper presents experience gained during an action research on water supply in arsenic mitigation in rural Singair, Bangladesh. The mitigation has been implemented there through integrated research and development of appropriate water supply options and its use through community participation. Political leaders and women played key roles in the success of the mitigation. More than one option for safe water has been developed and/or identified. The main recommendations include: integration of screening of tubewells and supply of safe water, research on technological and social aspects, community, women and local government participation, education and training of all stakeholders, immediate and appropriate use of the available knowledge, links between intermediate/immediate and long term investment, effective coordination and immediate attention by health, nutrition, agriculture, education, and other programs to this arsenic issue. *Public Health* (2000) **114,** 488–494.

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Introduction

Arsenic concentrations significantly higher than drinking water standards allow have been found in groundwaters from large parts of Argentina, Chile, Taiwan, Inner Mongolia, and Western USA, although the worst case identified affecting by far the largest population is that of Bangladesh and West Bengal.[1] After fluoride, it is the naturally occurring constituents of groundwaters that causes most health related problems. Arsenic contamination in drinking water has been reportedly associated with skin problems and skin cancer,[2,3] hypertension[4] and/or with increases in the risk of cancer is the liver, bladder, kidneys and lungs.[3] The relative toxicity of an arsenical compound depends primarily on its chemical type, valence state, solubility, and physical form. With few exceptions, inorganic arsenic is more toxic than organic arsenic.[3] The physical and chemical characteristics of arsenic, together with other qualities of water, also determine the treatment requirements in the water supply.

In Bangladesh, arsenic was first detected in groundwater in Chapai Nawabganj of Rajshahi division in 1993.[1] Until the recent observation of arsenic in groundwater of Bangladesh, the country was recognized as one of the few developing countries that had achieved remarkable success in the supply of safe drinking water through tubewells. About 95% of its people drink hand pumped water. Surface water is abundantly available in Bangladesh, but it is heavily polluted with fecal and other matters. Extensive technical, social, financial and other efforts at local as well as international level over 2–3 decades were required to bring this change in drinking water practice to groundwater from surface water.

The source of arsenic in Bangladesh is of natural and geological original.[1,2,4] More than one widely accepted study on arsenic content in sampled handpump water (using standard laboratory techniques) indicated that: (i) about 25% of the tested shallow handpump water samples showed higher than 50 ppb arsenic (Bangladesh standard), (ii) about 80% of the districts had at least one well (handpump) exceeding the 50 ppb, (iii) even in areas of generally low arsenic concentrations, there are occasionally 'hot spots', where a cluster of wells with unusually high concentrations of arsenic exist, and (iv) there were distinct differences between the scale of the problem and the depth of the handpump wells.[4–6] It is estimated that about 30 million people are exposed to arsenic from water exceeding 50 ppb.[4] Bangladesh is overburdened with one of the highest population densities, lowest literacy, highest water related diseases, lowest per capita income and highest malnutrition problems in the world. It is encouraging that a large numbers of government departments, non-government and private organizations, UN agencies and donor agencies are involved in arsenic mitigation in Bangladesh. These activities have so far included: screening of tubewells, creating awareness, demonstrating options of safe water supply in negligible areas and rarely managing arsenic patients.[7] Although thousands of tubewells have been screened and the worst affected areas have been more or less identified, almost all people still drink the same arsenic contaminated water. Lack of information and knowledge is often mentioned as one of the main challenges in arsenic mitigation.

*Correspondence: BA Hoque, World Bank, Dhaka, Bangladesh.
E-mail: bhoque@worldbank.org
†The views expressed are the authors' own and not necessarily those of their employers.
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Here we present our experience gained during a brief action research on arsenic mitigation in two unions of Singair subdistrict, and draw selected recommendations based on this information as well as from other literature.

Methods

Study area and subjects

This brief action research on arsenic mitigation was carried out in Charigram and Singair unions of Singair subdistrict, Manikganj from late 1997 to 1998. There were about 64 000 people in those rural unions. The rates of no schooling and agriculture based profession among the main earning members of the study families were about 60% and 37%, respectively. A study on social mobilization for sanitation was conducted there from 1995–1997 by some of us through the International Centre for Diarrhoeal Disease Research, Bangladesh (ICDDR, B) in collaboration with the Department of Public Health Engineering (DPHE) and with financial assistance from Swiss Development Co-operation. The rates of use of sanitary latrines and of washing both hands before eating increased from about 23% to 64% and from about 6% to 71% respectively. The community people under the guidance of Union Water and Sanitation Committees (UWATSAN) planned and implemented the activities with Village Water and Sanitation Committees (VWATSAN).[8,9] These Committees were locally formed with representatives from elected political leaders, social leaders, government health departments, non-government organizations, schoolteachers, and women volunteers. The project staff (ICDDRB and DPHE) conducted training, provided technical assistance in selection and installation of the technologies and carried out monitoring and evaluation. The details of the project may be found elsewhere.[8,9] This arsenic mitigation action research was carried out in response to the request of the local people, our moral obligation, and considering the knowledge needs in 1997. Singair was regarded as an arsenic-free area during early 1997. Arsenic was first detected in 11 wells by the project staff during April/May 1997. We shared that sensitive information first with selected social and political leaders. Then the UWATSAN and VWATSAN Committees requested us to carry out the arsenic mitigation through action research while they would play the same roles as they did in social mobilization for sanitation.

The main objectives of this action research were to: (i) identify arsenic contaminated handpump wells, (ii) develop safe water supply options, (iii) study community and multi-partner participation, (iv) study willingness to share costs for handpump screening and water supply options and (v) share the results at national and international levels.

Promotion and option development

The same community based mechanism for promotion and mobilization for sanitation was conducted and continued for the arsenic mitigation initiative. The modified E-Merck kit method was selected to screen the tubewells following the results from our laboratory study on the comparison of E-Merck, NIPSOM, AQUA, and modified E-Merck kits (mainly doubling of the volumes of sample and ingredients) against a standard laboratory method (silver diethyl dithiocarbamate). Project field staff, and selected local health workers and volunteers, were given extensive training on the use and handling of the kits. About 20% of the kit tested samples were repeated at the laboratory using the standard method. Eleven different options, including the options promoted then by the main organizations, selected from literature and developed by the project were studied. These options were selected considering the emergency and appropriateness of the situation.

Data collection and dissemination

Data was collected on level of awareness and participation at various stakeholder levels, performance and use of the options and sharing of costs. Interviewing, observation and laboratory techniques were used as required. Three hundred randomly selected households were studied before arsenic mitigation at community level during the late 1997 (baseline survey) and again during late 1998 (final survey). Water samples from an option were analyzed for arsenic, fecal coliform bacteria, pH, chemical oxygen demand, iron, residual chlorine, conductivity, temperature and other parameters, depending on the nature and purpose of the options. The details of the methods and results may be found elsewhere.[10] The findings were disseminated in an international workshop organized by us,[11] a national conference organized by the Government of Bangladesh in early 1999[6] and in various local meetings.

Results

The community participation

Observed results are summarized in Table 1. Overall, the community and multi-partner participation in the arsenic mitigation was high, as in the social mobilization for sanitation. Volunteer women, social and elected political leaders, schools students, and health workers participated in the planning, promotion and implementation of the activities as members of the UWATSAN and VWATSAN Committees or as their nominated volunteers. The elected political Chairman of the Unions (that is, from local government) vis-à-vis the Chairman, UWATSAN and women volunteers played the key roles in planning and implementation of the activities. They discussed the impacts, mitigation issues, water supply options, sharing of the costs at mass and lack of knowledge at courtyard and/or schools meetings. Selected messages were also disseminated through rallies and public announcements (mikings). The planning, existing situations and progress of the work were discussed at the offices of the Union chairman during UWATSAN committee meetings held at monthly intervals under the leadership of the Union chairman. These UWATSAN meetings were often combined with the monthly Union level (local government) meetings. The Subdistrict Administrator (Thana Nirbajhi Officer) facilitated awareness, motivation, planning, co-ordination and monitoring at subdistrict level. He also participated in mass awareness meetings. His involvement influenced interest in other unions as well.

The women volunteers, who also represented their respective villages, participated in these meetings and then carried over their educational and promotional/

Table 1 Summary of observed results of the studied option at field level

Name of option	Source of original water	Level of option	Nature and type of option	Observed characteristics/performance
1 Sharing of safe hand pumps	1 Ground water	1 Neighborhood	1 Alternative option	1a Both bacterial and arsenic qualities acceptable 1b Access and availability varied from easy to difficult 1c Acceptance high in presence of the option within a neighbourhood
2 Pond sand filters (PsF) (after more or less slow sand filtration principle)	2 Surface water	2 Community based	2 Alternative option	2a Bacteriological quality of water associated with regular and timely maintenance 2b Bacteriological quality of water fluctuated between little over the WHO/Bangladesh standard to hundreds of times higher than the standard 2c Quality of water varied with season and improved with the addition of bleaching powder solution (when further developed) 2d Chemical quality of water doubtful; results of chemical oxygen demand and biochemical oxygend demand were higher than standards 2e Community participation in operation and maintenance poor 2f Acceptance high in absence of other safe option within that neighbourhood
3 Rainwater harvesting	3 Rain water	3a Community based 3b Home based	3 Alternative option	3a Quality of water almost acceptable provided maintained properly 3b Relatively easy to maintain at home level 3c Storage facilities and practices beyond rainy season not studied 3d Acceptance high during the peak period
4 Dugwell	4 Ground water	4 Home based	4 Alternative option	4a Bacteriological contamination unacceptable 4b Arsenic contamination rarely observed above the standard 4c Acceptance for drinking not high
5 Dugwell handpumps	5 Handpump installed in a covered dugwell	5 Home based	5 Alternative option	5a Bacteriological quality improved and maintained at acceptable level by regular chlorination 5b Acceptance higher but complaints about the chlorine smell immediately after chlorination 5c Availability of water varied with season
6 Solar disinfection (SODIS) in plastic bottles	6 I Pond water 6 II Dug well water	6 I Home based 6 II Home based	6 Alternative option	6a Substantial reduction in bacteriological count over pond water but not acceptable 6b Quality of dugwell water was better than that of pond water after the disinfection 6c People did not appreciate this disinfection work load on daily basis in small amount

Table continued

Table 1 *Continued*

7 Alum treatment of arsenic contaminated water from tubewell	7 Ground water	7 Home based	7 Treatment of arsenic	7a Treatment or removal of arsenic varied between nil to 48% of original arsenic based on original contamination, and nature of arsenic as well as other characteristics of water 7b The concentration of remaining arsenic content in most of the cases remains higher than the standard 7c Health risk of alum remaining in water noted but not measured
8 Twenty four hour storage and setting of arsenic	8 Ground water	8 Home based	8 Treatment of arsenic	8a Treatment or removal of arsenic varied between nil to 32% of original arsenic based on concentration and nature of arsenic along with other characteristics of water 8b The concentrations of remaining arsenic were usually higher than the standard 8c Acceptance high
9 Distributed chemical package	9 Tubewell water	9 Home based	9 Treatment of arsenic	9a The composition of chemicals in the package not made public or printed in the label 9b Removed 99% of detected arsenic 9c Very high concentration of residual chlorine and smell remained in the water 9d People did not accept it or use it
10 GARNET home made filter (GHM) consisted of two containers one above another. Each filled with brick chips (about 0.75 inches diameter) and sand layers of more than six inches depth. The layers separated by a synthetic cloth. Flow rate varied between 15 to 30 l/days	10 Arsenic contaminated groundwater	10 Home based	10 Treatment of arsenic	10a Removed about 90–100% of detected original concentration up to about 1.0 mg/l arsenic content. Not studied at concentration above 1.0 mg/l 10b Bacteriological quality was acceptable 10c Acceptance satisfactory, particularly with plastic containers as opposed to earthen containers (chari)
11 Community based arsenic treatment filter	11 Arsenic contaminated groundwater	11 Community based	11 Treatment of arsenic	11a Removed about 75–100% of detected original arsenic concentration up to 1 mg/l. The removal efficiency improved and stabilized with the addition of bleaching when the concentration was higher than 0.4 mg/l solution 11b People did not appreciate the maintenance needs

motivational roles to their villages. The women volunteers conducted the courtyard meetings and other activities at the grassroots level. They worked on average about 2 hours per day. The need of some incentive to them was discussed on more than one occasion. The project had no such provision and so they carried out their self-volunteered roles from the view of emergency needs.[10] The government subdistrict physician and health workers also participated in promotional and screening activities.

School students and volunteers brought water samples from their neighborhoods to a specified public area, such as schools or Government health clinics. Trained health workers, and local volunteers conducted these water tests under the guidance of Project staff.

Proper education, training and regular sharing of the information with the stakeholders were identified by the Committees as the main driving factors behind their spontaneous participation. However, lack of information, education and communication materials for the promoting/motivating of stakeholders as well as for the people was found to hamper the activities/results.

Screening of the handpumps

About 76% and 42% of the tested 700 tubewell water samples showed the presence of higher than 50 ppb arsenic in Charigram and Singair, respectively. No arsenic was detected from pond water samples but it was heavily contaminated with fecal coliform bacteria. Six schools had arsenic contaminated handpumps and children were drinking water from those handpumps. The proportion of arsenic III was about 3 times higher than arsenic V in most of the tested water samples. The ranges of total arsenic and total iron varied between less than 10–1200 ppb and less than 0.5–12 mg/l, respectively.

Water use

About 96% reported drinking tubewell water in our baseline survey. About 36% of the studied families during the baseline survey and 88% of the families during the final survey were observed and/or reported collecting water from options which discharged less than 50 ppb arsenic and less than 30 cfu fecal coliform bacteria/100 ml water.

300 home-made filters, 2 pond sand filters, 3 community-based rainwater harvesting options, 4 community-based arsenic treatment options, and 8 dugwell handpumps were installed and used by the people. These options were used by about 900 families. We discussed with the people and members of UWATSAN and VWATSAN about the required technical conditions, expected level of performance and the actual cost in installing and maintaining the other various options. The users selected their options based on their affordability and other existing conditions. They often consulted members of the UWATSAN and VWATSAN Committees. About 33% of the families studied often collected rainwater using their normal containers. About 73% of families reported that they collected drinking and cooking water from the identified arsenic-safe handpumps which either they or their neighbours owned.

The management committee of only one school showed interest in installing an option. The other schools were not interested in taking on the operation and maintenance responsibilities of any option. They reported that the children would be told to drink water from their home or neighbourhood families until an appropriate system can be arranged. The one school requested a rainwater harvesting option on a trial basis. It was installed free.

Children and families from the neighbourhood drank water from that option. But the option had to be removed to a family in the neighbourhood after about three weeks as it was not properly operated and maintained after repeated requests by us. That option was then operated and maintained properly by the family. Schoolchildren and neighbours were observed sharing water from that option.

Development of the options

The main results on the development of options are summarized in Table 1 and the details may be found in the literature.[10] The laboratory and field observations were carried out over a period of only 3–12 months due to financial limitations. About 6 options, such as sharing of identified arsenic-safe tubewells, rainwater harvesting, dugwell handpump, GARNET home-made filters, pond sand-filters with chlorination and community-based arsenic treatment filter gave satisfactory performance under the given conditions. The passive sedimentation or alum treatment of arsenic contaminated water produced water with more than 50 ppb of arsenic in more than 71% of the cases out of 15 trials in different locations by this study. We did not promote these two options, tea bags, dug well and SODIS after the laboratory and controlled field observations, because these options would need substantial improvement to make them more or less acceptable for use. However, some people used passive sedimentation or alum treatment options as these were promoted by some organizations previously. These people, particularly women, were confused and not happy when we approached them to change that practice. Here people were drinking water with high arsenic content even after they had made efforts to treat arsenic and brought change in their behaviours.

Cost sharing

Water samples from about 700 tubewells were tested. The owners/users of these hand pumps paid US$0.60 per tested water sample, which was about 50% of the cost (cost of kit and implementation). The usual practice is to test for free.

The users also shared 10–50% of the costs of the installed options, based on family affordability, type and total cost of an individual option. The costs of the options varied between approximately US$6.0 to US$500 per option, based on the type and size of the option. The shared estimated average costs for a particular option varied between about US$1.0 per family to about US$20 per family. We only suggested that the users pay 25% of the cost but had to pay at least US$0.50 per family for the community based options and US$1.0 per family for home-based options distributed by the Project. However, the community based options were used by many families who did not show interest using the options at the planning phase and so did not share the costs.

Discussion

The problem of arsenic in drinking water in Bangladesh is huge and complex. The causes, impacts, magnitude, ingestion modes, appropriate technologies, and other mitigation issues of the problem are not yet properly known. However, drinking or supply of safe water cannot wait that long. This brief action research has shown how an empowered and mobilized community addressed their arsenic problem immediately when they were informed about it and educated on how to solve it under emergency conditions. In general, the elected political leaders and women volunteers through a locally designed multi-partner initiative carried out the mitigation. It has clearly demonstrated that the various partners and people have the potential to plan, implement and manage the arsenic mitigation responsibilities if they are educated properly and provided with the technical assistance.

This study has indicated that the role of local government in mitigation is important. The incentive for their involvement may be related to their election interest. Women have once again proved their interest and potentials in management of domestic water supply in Bangladesh[12] and elsewhere.[13] It is important that women are encouraged to participate in drinking water management through an enabling environment. If women are expected to give regular time input into this issue at community level, their claim for incentives should be considered properly. The involvement of health workers in screening and promotional activities was encouraging. But the role played by schools was discouraging. It may be mentioned that no public sector, except the DPHE (lead water and sanitation agency), was participating in arsenic mitigation at the country level. But their participation is essential. The testing of water samples from hand pumps in health related clinics and schools, and the installation and use of safe water supply options will have implications for safe water supply and wide demonstration, in addition to other effects. The level of participation of non-government organizations was not mentioned, as it was low. It may be difficult for them to respond so quickly to such unusual emergencies at institutional level. But they have been playing remarkable roles in the water sector.[14]

The provision for discussing and choosing a water supply option from more than one option by the informed users encouraged user acceptance and their participation in the overall mitigation effort. It was encouraging to observe that more than one option can be promoted under emergency conditions while other options are developed. Thus screening and water supply mitigation can go in parallel with the examples, set out in this study. This study has also documented that people should not be confused with options which do not show acceptable results under minimum evaluation. The potentials for sharing of the costs in screening of tubewells as well as in installation of the options have been observed also. However, the part of the study on field testing and use of options was carried out only over a period of several months. The need for building the knowledge on the results obtained here remains. The need for proper promotion and implementation of the specifications about the studied water supply options is strongly emphasized. Lack of proper and adequate information about the options and non-implementation of the stated conditions/specifications may lead to reduction or wide variation in the level of performance of the options. Even under emergency conditions selection of the options based on minimum evaluation/follow-up helped to reduce promotion of the other options.

The use of combined laboratory and modified E Merck field kit methods in the screening of the wells worked out satisfactorily. Proper training in the use and handling of the kits, as well as close supervision, was essential to maintain the quality of the results. The need for an appropriate kit was once again felt. We are not sure if the implemented modified method can be used under normal conditions as we closely supervised its use.

Overall, the emergency and/or immediate measures were studied. The cost effectiveness, continuity and sustainability aspects in all the presented and other relevant aspects needs to be studied further.

Recommendations

1. Mitigation initiatives should include both screening and supply of safe water.
2. The available appropriate technologies should be promoted with the required minimum specification.
3. Basic and applied research on technological and social aspects of arsenic mitigation from the immediate, as well as the long term, perspectives should be strongly supported.
4. Timely and proper use of the research knowledge should be encouraged and coordinated for simultaneous screening and supply of safe water as well as to accelerate the progress in arsenic mitigation initiatives
5. Community (people, social leaders and elected representatives) and multi-partners (such as DPHE, Administration, Education, Health, NGO) should be involved in every stage of arsenic mitigation based on respective comparative advantages.
6. Appropriate participation by health, nutrition, school, agriculture. They should be asked to test the wells in their premises and install safe water options immediately.
7. The links, needs and benefits in emergency, short-term and long term options and strategies should be studied.
8. More than one water supply option (after technical consideration) should be promoted. The users should be educated and allowed to select the option. The required operation and maintenance of the options should be given due consideration.
9. Proper education and training of community level partners as well as other stakeholders should be included in the priority activities.
10. Every water supply option should be promoted, after reliable basic/essential evaluation for both emergency and normal situations.
11. Cost sharing in mitigation should be considered from long term and sustainability perspectives. Affordability for the poor and creation of an enabling environment for access to safe water for all should be considered.

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