Bangladesh arsenic mitigation programs: lessons from the past

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Ensuring access to safe drinking water by 2015 is a global commitment by the Millennium Development Goals (MDGs). In Bangladesh, significant achievements in providing safe water were made earlier by nationwide tubewell-installation programme. This achievement was overshadowed in 1993 by the presence of arsenic in underground water. A total of 6 million tubewells have been tested for arsenic since then, the results of which warranted immediate mitigation. Mitigation measures included tubewell testing and replacing; usage of deeper wells; surface water preservation and treatment; use of sanitary dug wells, river sand and pond sand filters; rainwater collection and storage; household-scale and large-scale arsenic filtrations; and rural pipeline water supply installation. Shallow tubewell installation was discouraged. Efforts have been made to increase people's awareness. This paper describes the lessons learned about mitigation efforts by the authors from experience of arsenic-related work. In spite of national mitigation plans and efforts, a few challenges still persist: inadequate coordination between stakeholders, differences in inter-sectoral attitudes, inadequate research to identify region-specific, suitable safe water options, poor quality of works by various implementing agencies, and inadequate dissemination of the knowledge and experiences to the people by those organizations. Issues such as long-time adaptation using ground water, poor surface water quality including bad smell and turbidity, and refusal to using neighbor's water have delayed mitigation measures so far. Region-specific mitigation water supply policy led by the health sector could be adopted with multisectoral involvement and responsibility. Large-scale piped water supply could be arranged through Public Private Partnerships (PPP) in new national approach.

Keywords: *arsenic; mitigation; lessons*

Received: 5 May 2011; Revised: 21 March 2012; Accepted: 21 March 2012; Published: 30 April 2012

Millennium Development Goal (MDG) 7 addresses environmental sustainability, with a target (target 10) to 'halve by 2015 the proportion of people without sustainable access to safe drinking water and basic sanitation' (1). Meeting the MDG goal through using of proper water supply, saving productive time in accessing safer water sources and sanitation facilities, and contributing to workforce health would contribute substantially in reducing poverty (target 1) and hunger (target 2). Furthermore, improved water supply and sanitation also promotes economic equity. In working towards the MDG target for water and sanitation, understanding resource requirements, resource gaps and where resources need to be deployed are critical. An estimated spending required in developing countries on new coverage to meet the MDG target is US\$ 42 billion for water (1). Corresponding assessments

need to be based on reasonable estimates of cost at global, regional and country levels. Moreover, comparing estimated finances required for funding the existing program would help to mobilize resources and to direct efforts to specific contexts (e.g. rural or urban) and to countries that are not meeting the MDG targets.

Bangladesh has seen great success in providing safe drinking water to its population. Nearly 90% of the rural population had access to safe water using tubewells (2). This immense success of having access to safe water has contributed to the reduction of infant and neonatal deaths. To avoid bacteriologically contaminated water, many inhabitants switched to tubewells. The cleaner ground water from such wells stopped the frequent cholera epidemics. However, since 1996, high arsenic contamination of underground water has caused an important public health threat of great magnitude.

Considering arsenic contamination in Bangladesh, approximately 35–77 million people have been exposed to arsenic through drinking water. Although the pace of mitigation programmes (programmes that provided various arsenic free water supply options to the people), especially supply of drinking water for this vast population (3), has been slower than expected, a lot of stakeholders are still working with mitigation options. Shallow tubewells containing arsenic $<10\text{ }\mu\text{g}/\text{mL}$ could be used as alternative source. One of the main challenges in arsenic mitigation efforts has been to develop sustainable mitigation options that rural and disadvantaged people can adopt and implement themselves to overcome possible public health hazards and to protect future generations. This paper discusses some of the important lessons learned from the past in the context of Bangladesh arsenic mitigation programmes.

Global disease burden considering exposure

Approximately, 35–77 million people in Bangladesh have been exposed to arsenic through their drinking water (3). Therefore, these people chronically exposed to arsenic are at increased risk of developing adverse health effects, such as skin lesions, various chronic diseases, such as cardiovascular diseases and hypertension, diabetes mellitus, and chronic obstructive pulmonary diseases, and several external and internal cancers, such as Bowen's disease, cancers of lung, urinary bladder and liver, etc. To date, risk estimates of cancers due to chronic arsenic exposure have largely been derived from ecological data. Ecological study design has limitation for any health risk estimation. Arsenic is a known carcinogen. Mortality and morbidity is attributable to chronic arsenic exposure in humans. Eventually it encouraged policy makers to refocus programs for promoting child and adult survival (4). A recent study reported an estimated 9,136 deaths per year and 174,174 disability-adjusted life years (DALYs, undiscounted) lost in Bangladesh per year among the individuals exposed to arsenic concentration $>50\text{ }\mu\text{g}/\text{L}$ (5). This constitutes 0.3% of the total burden of diseases.

Global scenario considering mitigation programs

In many countries, once arsenic contamination has been detected, the most important action has been to provide safe water to these affected communities. Action was taken, for example, in Taiwan, Chile and Inner Mongolia. In these countries, piped water supplies were introduced. In the developed world, safe water is available at an affordable cost. In Chile, arsenic was removed by coagulation method which proved to be efficient and cost effective (6). In the US, only a few water supplies have higher levels of arsenic than 10 ppb, the US EPA permissible limit. In India, many organizations have been

working towards safe water promotion since 1996. These organizations have been working mainly towards partnering for simple, locally developed sustainable solutions, which included filtering water, dug well programs, etc.

In Bangladesh, arsenic in tubewell water was first detected in 1993. Since 1996, the Government of Bangladesh (GOB) started implementing programmes with support from development partners and some national and international NGOs. The programmes included first nationwide tube well screening, awareness generation in affected areas and primary level of mitigations, such as three pitchers filter, rain water harvesting, dug wells, etc. That was a pilot level mitigation programme. National Policy for Arsenic Mitigation and Implementation Plan was published by the GOB in 2004. After finishing national screening campaign, arsenic mitigation programmes started through a variety of mitigation options, including re-sinking and deepening of tube wells. As the clear nature of arsenic contaminated tube well water seemingly harmless for people, extra installation and maintenance cost of options and improper sustainability of options reduced the pace of introducing acceptable safe water options. Moreover, geographical variability constrained the development of a unique mitigation model. Many years have passed, but no significant established mitigation options have been developed in Bangladesh. Pipeline water supplies have been implemented in Taiwan (replacing artesian wells, the main source), Argentina and Chile to mitigate arsenic contamination in drinking water.

Scale-up of mitigation programs in Bangladesh

In 1997, the Department of Public Health Engineering (DPHE), with assistance from the United Nations Children's Fund (UNICEF), conducted a nationwide survey of approximately 23,000 tube wells. The survey used field-test kits that only classified the arsenic concentration of the water as above or below 100 ppb, which was higher than 50 ppb, the maximum permissible level of arsenic in drinking water for Bangladesh. In 1998–99, Department of Public Health Engineering (DPHE)/British Geological Survey (BGS) analyzed a subsample of water samples that confirmed the arsenic contamination. In 1999, Bangladesh Rural Advancement Committee (BRAC), an international developmental organization in Bangladesh, initiated two pilot mitigation activities included testing wells, distributing mitigation options, and awareness building (7). Later on, other NGOs such as NGO Forum for Drinking Water Supply and Sanitation, Proshika, launched a number of arsenic mitigation programmes in arsenic affected areas.

Arsenic levels in drinking water

In Bangladesh, the largest water quality screenings were conducted by identifying initially 270 upazilas (sub-districts). Blanket screening programs were carried-out for testing of every single well in these 270 upazilas. The testing was done during 2000–2006. Over 5 million wells have been tested, with the field workers who tested the tubewell water providing information about arsenic to tube well owners, and painted the wells after getting test results—red for wells above the permissible limit of 50 ppb and green for wells within the limit. Well testers also recorded basic demographic information, which is recorded in the national database (8). In most of these programmes, arsenic was detected at the field level using arsenic detecting field kits, the validity and reliability of which are questionable (9). For scaling-up arsenic mitigation programs, several organizations have been involved in installing arsenic mitigation options in several arsenic contaminated areas. Many options have been introduced in Bangladesh (Table 1). BAMWSP (Bangladesh arsenic mitigation water supply project) nationally co-ordinated these water options installation and monitoring activities. Many options included well tested and switching, use of deeper wells, surface waters after preservation and treatment, sanitary dug wells, river sand filters, pond sand filters, rainwater collection and storage, household scale arsenic filtration, large scale arsenic filtration, and rural pipeline water supply. Based on options installed, deep tube wells have been the most frequently provided option in arsenic affected areas. Although, deep aquifers is a popular mitigation option, its long-term effect is still unknown (10). Additionally, rainwater harvesting systems and dug-wells has also been provided to large number of households.

Many people at risk (11) have changed their water sources—either to an existing green shallow tube well (12), or to one of the more than 100,000 new arsenic-free water points that have been installed in arsenic-prone areas since 2000 (8). The priority strategies for arsenic mitigation program in Bangladesh fall into four categories: proper health education, policy and standards; health systems support; assessment of availability and acceptability of community-based mitigation options; and support in the community. In considering scaling-up this program, many activities tailored at the end of the project with minimum achievements.

Outcome of mitigation results

An estimated total of 6268 dug wells, 3521 pond sand filter (PSF), 13,324 rain water harvester (RWH), 74, 809 deep well (DW), 3,771 arsenic iron removal filters (AIRF), 33 Pipe water supply, 5,080 slow sand treatment (SST), 133 DSP totaling 106,939 mitigation options were constructed by different stakeholders (13).

However, as estimated ≈ 5 million exposed population should be covered through these options, which was intended to be cheap, easy and accessible with an estimated cost of more than US\$100 million. Considering all arsenic mitigation programs in Bangladesh, various drinking water options carry the risk of allowing water-borne pathogens or chemical hazards, such as fecal pathogens and animal faeces that cause enteric disease, and several toxins may lead to adverse health effects. Monitoring of these options raised many questions and thus many options, installed for public use, were later found to be ineffective.

Mitigating the arsenic problem: major challenges

We have identified seven major challenges for arsenic mitigation programs in Bangladesh, such as: i) Inadequate coordination among the stake holders, ii) Perceptive difference in different government's attitudes, iii) Inadequate research works to find suitable mitigation options, iv) Inadequate research works to find out region specific suitable safe water options, v) Poor quality of the works by many organizations, vi) Inadequate scientifically sound approach, vii) Inadequate dissemination of the knowledge and experiences by the organizations. However, national action plan has adopted number of easy accessible, cheap and affordable steps, although lacking in maintaining proper integration and goals.

Lesson learned

Arsenic contamination in drinking water is predominantly a public health problem. Therefore, understanding the public health dimension of the problem is an essential prerequisite to successful arsenic mitigation programme. Failure to understand the complicated nature of the arsenic problem at the policy level complicates the mitigation efforts in a country, such as Bangladesh, with very limited resources. This is further complicated by lack of coordination between health and drinking water supply authorities. As this is a public health problem, public health experts should play the leading role in arsenic mitigation programmes in Bangladesh.

Provision of arsenic free, safe drinking water remains at the core of any arsenic mitigation efforts. In the absence of any single suitable alternative to tube wells that could supply more than 80% of the rural Bangladeshi population, we need to consider region-specific water supply options. Given the variations in geohydrological situations, soil types and water chemistry, development and provision of region-specific water supply options are likely to be more effective. Information on water chemistry is particularly important to develop arsenic removal technologies because the performance of most of these removal technologies substantially depend on water qualities, especially pH (14). There are a number of filters that were used as

Table 1. Treatment of arsenic contaminated water

Technology	Advantages	Disadvantages	Cost
1. Alcan Enhanced Activated Alumina Developed based on adsorption process.	<ul style="list-style-type: none"> * Efficiency very high, acceptance high * Unit available for both community and household level. * The main unit can produce >3,600 litres/12 hours that is sufficient for >100 families. * Requires no chemical addition. 	<ul style="list-style-type: none"> * pH sensitive. * Media getting fouled or clogged by precipitated iron is high. * Regeneration of saturated alumina is required once the column gets totally saturated. * Activated Alumina seems to decrease in removal efficiency after regeneration. * Media requires regular cleaning to prevent bacteriological contamination. * May get clogged if excess iron is present in the feed water or if the water flow is stopped. 	<ul style="list-style-type: none"> * Main unit cost is 170 US\$, filter material costs 220 US\$ for first 80,000 litres of processed water, replacement cost of filter material is 220 US\$ for further 80,000 litres. * Household unit: Initial cost US\$ 34 for 11,000 litres, replacement cost of filter material 14 US\$ for further 11,000 litres. * 6 US\$. * The cost of a replacement Kolshi including iron fillings and coarse sand is 1.10 US\$.
2. Three kolshi (Pitcher) filter Developed Based on indigenous filtration process. Also known as 'Sono three Kolshi filter'.	<ul style="list-style-type: none"> * Efficiency is high. * Acceptance high * It produces 40 litres of water/12 hours adequate for 5 member-family. * The filter uses sand, iron fillings, charcoal and brick chips, which are locally available. * Can be manufactured at the community level. 	<ul style="list-style-type: none"> * Addition of chemicals is required. * May not remove adequately when arsenic concentration in the feed water is more than 500 ppb. * Sand bed used for filtration requires washing at least twice a week to prevent clogging by flocs. * The structure is not robust. 	<ul style="list-style-type: none"> * Installation cost is 35 US\$. * Chemical cost is 3.50 US\$.
3. Stevens Institute Technology Developed based on coagulation, filtration and adsorption process.	<ul style="list-style-type: none"> * Arsenic removal efficiency is high. * Well accepted by the community. * It produces 169 litres of water/12 hours adequate for 5 families. * Can be manufactured at the community level. 	<ul style="list-style-type: none"> * Resin needs to be regenerated once it becomes exhausted. * The system required pre oxidation of arsenite by sodium hypochloride. 	<ul style="list-style-type: none"> * 216 US\$ (imported) and 138 US\$ (local). * Regeneration cost is 0.65 US\$.
4. Tetrahedron Developed based on ion exchange resin process.	<ul style="list-style-type: none"> * Arsenic removal efficiency is high. * Fairly acceptable to the community. * It produces 624 litres of water/12 hours adequate for 20 families. * Risk of bacteriological contamination is very low or almost nil. 	<ul style="list-style-type: none"> * Regular cleaning of the filter material is essential to prevent bacteriological contamination. * Produce less amount of water. 	<ul style="list-style-type: none"> * 6.50 US\$ including media. * 1 kg of replacement media is 1.72 US\$.
5. Shapla arsenic removal Filter Developed as a household filter designed with iron coated brick dust as an adsorption medium.	<ul style="list-style-type: none"> * Arsenic removal efficiency is high. * Fairly acceptable to the community. * All the filter materials are locally available. * Can be manufactured at the community level. 	<ul style="list-style-type: none"> * Removal efficiency varies when the arsenic concentration exceeds 200 ppb in the feed water. * The plant requires periodical cleaning of the filter materials for optimum performance. 	<ul style="list-style-type: none"> * 18 US\$.
6. Arsenic Iron Removal Plant (AIRP) Developed on the principle of aeration, sedimentation and filtration.	<ul style="list-style-type: none"> * Arsenic removal efficiency is satisfactory. * Well accepted by the community. * Removes iron along with arsenic. * Can produce sufficient water for 15–20 families. 		

arsenic mitigation option, with the SONO filter being one of those. Technical and social evaluation of it revealed that the users are reluctant to repair the broken filter by their own. Maintenance problem, lack of proper sludge disposal guidance, slow flow rate and lack of ownership were other problems of the filter (15). Other filters had similar drawbacks to the SONO filters. So, adequate research works need to be completed as a priority to identify the region-specific water supply options to plan an effective arsenic mitigation options. Although this was supposed to be completed at the initial phase, unfortunately appropriate scientific approach has been lacking in the whole arsenic mitigation efforts in Bangladesh.

A large proportion of the resources (time, manpower, money) from both public and private sources have already been spent to increase awareness nationwide. Several stakeholders also play a pivotal role in mitigation activities (Table 2). The majority of the people are now aware about the adverse effects of arsenic contamination in drinking water. Nevertheless, compliance with using arsenic free safe drinking water varies from population to population. Inadequate access to safe drinking water has been one of the main reasons for non-compliance. Additionally, a number of factors influence the compliance including turbidity, bad smells and taste of drinking water, distance and time constraints to fetch water from a distant source, and social conflicts (16). It was quite convenient to collect water from tube wells for the rural people. With their long time adaptation to underground water through tube well, many of the people are still finding it difficult to shift towards other water options, which are not as convenient as tube wells (16). Exposed individuals with visible arsenical skin lesions are more compliant to use safe drinking water than individuals exposed to arsenic with no visible arsenical skin lesions and individuals not exposed to arsenic through drinking water (17). Careful analysis of the factors influencing compliance to safe drinking water is essential to successfully promote safe drinking water options.

Future action plan

With change of the government in the past, arsenic was not considered as a priority issue earlier. The present government has been addressing the arsenic issue as a current priority. Lack of coordination between stakeholders is an important factor that needs to be considered to mitigate arsenic related problem in Bangladesh. Monitoring and quality control of the projects are other areas where serious drawbacks were observed in the past (18).

A reasonably large proportion of the public and donors' funds were spent to do poor quality mitigation works. Adequate supervision, feedback and accountability were less available, especially from the government side. This led to completion of mitigation projects with

poor outcomes (19). In future, this aspect of the programme should receive sufficient attention.

There are currently areas with high arsenic contamination and arsenicosis patients, who need urgent intervention (20,21). Management of the arsenicosis patients has been another area that deserves urgent attention. Field based evidence suggests an increase in the arsenic related mortality and morbidity in Bangladesh (22). A few trials are currently being undertaken to determine effective treatment for the arsenicosis patients. (23) As some of these study findings are available, these should be translated into action as early as possible. Finally, involvement and ownership by local communities has been the key to any successful arsenic mitigation programmes (14). Community participation is also necessary for any sustainable public health programme. Local Government Institutes (LGIs) are currently being involved in water and sanitation programmes for more than five years within a relatively new area for the sector (18).

Conclusion

A large proportion of people in Bangladesh do not have formal education, live below the poverty line and are less aware of the future catastrophe of negative health and economic effects attributable to high arsenic exposure. Moreover, limited resources of the country urgently demand appropriate strategic planning and its quick implementation to combat the inevitable environmental health related catastrophe that the nation has ever seen.

At first, a region-specific water supply based mitigation policy could be adopted in the country with multi-sectoral involvement. Selection of a leading sector and inter-sectoral responsibilities allocation might be beneficial for sustainability and monitoring of the progress. Advocacy in policy level in favor of the strategy and awareness on health hazards and mitigation could be continuously disseminated. Several mitigation options are available but social factors play an important role in consumption of drinking water from a mitigation option and which mitigation option will be implemented most successfully (24, 25). Identification, mapping and surveillance of water-points with water quality assessment facility needs to be established. In spite of the government's efforts and donor's support, a new strategy (PPP-Public Private Partnership), which has been recently introduced in Bangladesh, could be applied for installation of large-scale pipe water supply. Finally, the health sector should take a pivotal role, as they tackle and interact closely with the visible affected section of people and who might be catalysts for sustainability of any intervention. Arsenic mitigation efforts should be considered as an ongoing priority issue in Bangladesh.

Table 2. Stakeholders and their responsibilities for mitigation activities

Government of Bangladesh	
Stakeholders	Ministry of Health and Family welfare: Directorate General of Health Services NIPSOM (National Institute of Preventive and Social Medicine) Institute of Public Health NIPORT Ministry of Local Government, Rural Development and cooperative Department of Public Health Engineering Water Development Board
Responsibilities	Formulate, implement, monitor and evaluate policies and strategies for arsenic mitigation programs including proper case searching and management, well water testing and proper awareness build-up, financial and organizational resources for implementation of the national strategy for arsenic mitigation
Professional bodies and research institutions	
Stakeholder	Medical colleges, university and institutes Bangladesh Medical Association NIPORT/NIPSOM Geological Societies ICDDR
Responsibilities	Education and training for all service providers Aware about active case searching and referral system, well testing, GIS mapping, geological endpoint matching Promote achievement and maintenance of health facilities
Non-governmental organizations	
Stakeholders	Leading NGOs such as BRAC, Grameen Bank, NGO Forum for Drinking Water Supply and Sanitation and other NGOs community support group
Responsibilities	Provide members with up-to-date, accurate information about arsenic mitigations, awareness and capacity building Integrate skilled support for community based mitigation interventions and ensuring effective linkage with respective systems
Other groups	
Stakeholder	Education authorities Mass media
Responsibilities	Provide accurate information through schools, madrasas and other education channels to promote greater awareness and positive perceptions about the problem
International organizations	
Stakeholders	UN agencies, international NGOs
Responsibilities	Advocate and make available human, financial and institutional resources for implementation of National Strategy support local and national capacity building support policy development and promotion integrated with governmental system

Conflict of interest and funding

The authors have not received any funding or benefits from industry to conduct this study.

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