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Arsenic Catastrophe in Bangladesh: Mitigation Perspective and Implementation Challenges

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Abstract: One of the worst health hazards in Bangladesh is arsenic contamination of drinking water, which demands immediate and urgent remedial measures. About 29 percent of the tested tubewells in the shallow aquifers are contaminated with arsenic beyond safe limit of Bangladesh standards and about 81 percent of the villagers are now affected with this poison where 27 percent of those are beyond Bangladesh standard. This study identifies treatment technologies and alternative water supply options presently available in Bangladesh for minimizing this catastrophe. The paper reveals that deep tubewells, well accepted by the communities during the past few decades, emerge to be a more suitable alternate option to mitigate this crisis in Bangladesh. Finally the paper identifies the challenges for institutionalizing these treatment technologies or alternative water supply options in arsenic problem areas.

Key words: Arsenic, technology, Bangladesh.

Introduction

Arsenic contamination in drinking water is a major concern affecting more than 50 million people worldwide (WHO, 2006). Around the Bengal deltaic region, particularly in Bangladesh, the presence of this contaminant in alarming portion has been reported to be the biggest arsenic calamity in the world in terms of the affected population (WHO, 2006). Arsenic contamination in primarily shallow aquifers has made it unsafe to extract water for drinking purposes. This has reduced the coverage of safe water supply (water supply within one kilometre of their home or 30 minutes total collection time) from around 97 percent (of the population in Bangladesh before the detection of arsenic in ground water) in 1993 to around 74 percent (LGD, 2002).

The status of arsenic contamination in Bangladesh reveals that 1.4 million tubewells out of 4.73 million (29% of tubewells tested through a blanket screening in 54,000 villages i.e., 62% of the total villages) are contaminated by arsenic (Table 1). In these tubewells contamination of arsenic exceeded the concentration of 50 µg/L (Bangladesh standard for drinking water). Studies undertaken by Department of Public Health Engineering (DPHE), British Geological Survey (BGS) and Mott MacDonald Ltd. (MML) (DPHE-BGS-MML, 1999) and report published by Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) (2001) reveal that around 25 percent of the samples tested exceed the concentration of 50 µg/L and 42 percent samples tested exceeded 10 µg/L, which is the provisional World Health Organization (WHO) guideline value for arsenic in drinking water. In shallow tubewells 27 percent samples tested exceeded the concentration of 50 µg/L and 46 percent tested samples exceed the concentration of 10 µg/L.

It is evident that millions of people in Bangladesh are at risk of arsenic poisoning from drinking of groundwater with arsenic in excess of acceptable limit. BGS and DPHE (2001) furnished two estimates of population exposure based on projected population of 125.5 million in 1999. The total population exposed to arsenic contaminated water above 50 µg/L and 10 µg/L are estimated as 32.5 million (25.9% of total population) and 56.7 million (45.2%) respectively. Based on *thana* (lowest administrative unit) statistics the total population exposed to arsenic contaminated water above

Table 1: Status of arsenic contamination in Bangladesh (Rahman and Al-Muyeed, 2008)

Total population (million) of the country in 2007 (est.)	150.5
Total area (sq. km.) of the country	147,570
Estimated total number of villages in country	87,319(100)*
Estimated total number of villages screened	54,041(62)*
Estimated total number of villages not screened	33,278(38)*
Total number (million) of tubewells in the country	8.61 (100)*
Total number (million) of tubewells tested for As	4.73 (55)*
Total number (million) of tubewells marked green (safe)	3.33 (39)*
Total number (million) of tubewells marked red (unsafe)	1.4(16)*(29% of total tested tubewells)
Villages where less than 40% of the tubewells are contaminated	70,610(81)*
Villages where 40-80% of the tubewells are contaminated	8,331(10)*
Villages where 80-99% of the tubewells are contaminated	6,062(7)*
Villages where all tubewells are contaminated	2,316(3)*
As affected shallow tubewells above 0.05 mg/L	27% **
As affected shallow tubewells above 0.01 mg/L	46% **
As affected deep tubewells (strainer depth >150 m) above 0.05 mg/L	1% **
As affected deep tubewells above 0.01 mg/L	5% **
Number of arsenicosis patients reported so far	38,000
Population (million) exposed to arsenic contamination >0.05 mg/L	28.1-32.5 (22.4-25.9%)
Population (million) exposed to arsenic contamination >0.01 mg/L	46.4-56.7 (37-45.2%)

** % of total tested tubewells
* Figure in ( ) indicates the percent of total as of 2006 (UNICEF, 2007)

50 μg/L and 10 μg/L are estimated as 28.1 million (22.4%) and 46.4 million (37%) respectively. The magnitude of the problem is increasing as more detailed studies are carried out.

Arsenic Policy Support Unit (APSU) reported around 38,000 arsenicosis patients in 2004 in Bangladesh, out of which 46 percent were male and 54 percent were female (APSU, 2005). Using EPA model and distribution of population exposed to different level of arsenic, Local Government Division (LGD) (2002) estimated the incidence of excess lifetime skin cancer for different level of arsenic contamination of drinking water in Bangladesh. The incidences of excess skin cancer are 0.29 percent, 0.043 percent and 0.012 percent for drinking arsenic contaminated water at existing level of arsenic contamination, satisfying the Bangladesh Standard (50 μg/L) and satisfying WHO guideline value (10 μg/L) respectively. Hence, the access to safe water is an urgent human need to minimize arsenic catastrophe in Bangladesh.

In most cases, except few cities and towns of Bangladesh, no centralized water supply system has yet been established and most of the drinking water supply sources are hand pumped tubewells installed at shallow aquifers. The status of water supply coverage of Bangladesh as of February 2008 reveals 67.41 percent functional water supply options from shallow tubewells (Table 2). Thus the solution to the problem of arsenic contamination demands technologies and water supply options that can be implemented at household or small community level relatively at a very low/reasonable cost. This paper is aimed at reviewing technologies available for arsenic removal, and the challenges ahead in embedding these technologies in diverse socio-political context in arsenic affected areas of Bangladesh.

Treatment of Arsenic Contaminated Water: A Review

There are number of reviews of arsenic removal technologies. The most commonly used processes of arsenic removal from water have been described by Cheng et al. (1994), Hering et al. (1996), Joshi and Chaudhuri (1996), Kartinen and Martin (1995), and Rahman and Al-Muyeed (2009). A detailed review of arsenic removal technologies has been presented by Sorg and Logsdon (1974). In view of lowering the standard of the United States Environmental Protection Agency (US-EPA) for the maximum permissible levels of arsenic in drinking water, a review of arsenic removal technologies

Table 2: Water supply coverage of whole Bangladesh by different options

Options	*Total number of functional waterpoints*	*Coverage by WS options*
Shallow	870,867	67.41%
Tara	178,062	13.78%
Tara-2	1688	0.13%
Deep	200,396	15.51%
Tara Deep	9693	0.75%
SST/VSST/Sp	10,473	0.81%
PSF/I.G.	4018	0.31%
Ringwell	15,894	1.23%
RWHS	786	0.06%
Total running water source	12,91,877	
Rural population, 2007 (number)	11,15,71,090	
Coverage (persons per water source) Feb, 2008	98	

was carried out considering the economic factors involved in implementing more stringent drinking water standards for arsenic (Chen et al., 1999). Murcott (2000) compiled a list of companies involved in arsenic removal technologies. Comprehensive reviews of arsenic removal processes have been documented by Johnston and Heijnen (2001), Rahman and Al-Muyeed (2005, 2009), and Rahman et al. (2003).

The basic principles behind treatment of arsenic contaminated water are based on conventional techniques of oxidation, co-precipitation and adsorption on coagulated flocs, adsorption onto sorptive media, ion exchange, and membrane filtration. Oxidation of As(III) to As(V) is an essential process of these treatment techniques. The different mechanisms of arsenic treatment are critically reviewed and are summarized in Table 3.

Several treatment methods/technologies for reducing arsenic from drinking water have been tried in Bangladesh by a number of organizations/researchers. Through the process a number of innovative technological options for arsenic removal have emerged. To test the suitability of use by the rural isolated communities, however, most of these technologies are introduced in small and experimental scale (Rahman and Al-Muyeed, 2008). Tables 3 and 4 together summarize descriptions of some of the key technologies for arsenic removal along with their advantages and disadvantages, with special references to experiences gained from field level application. The relative comparison of average arsenic removal efficiency of different technologies is presented in Figure 1. Table 3 depicts that membrane nanofiltration technology may give the highest removal efficiency of arsenic, but it is imperative to consider the cost especially for developing country like Bangladesh. Thus the application of all the above mentioned arsenic removal mitigation technologies mostly depend on the cost incurred by the residents. Moreover, arsenic removal efficiency will vary according to many site-specific chemical, geographical, and economical conditions. As many factors that can affect arsenic removal efficiency (including arsenic concentration, speciation, pH and co-occurring solutes), the technologies should be tested using the actual water to be treated, before implementation of any arsenic removal system at field scale.

Table 3: Summary of arsenic treatment through different arsenic removal technologies

Technology	*Removal Efficiency*		*Cost*
	As (III)	*As (V)*	
Oxidation		Up to 90%	Inexpensive.
Coagulation with iron salts	Up to 60%	90%	Relatively inexpensive.
Coagulation with alum	Less than 30%	90%	Relatively inexpensive
Ion exchange resins	Less than 30%	90%	Moderately expensive.
Activated alumina	Up to 60%	90%	Moderately expensive.
Membrane method	Up to 90%	More than 90%	Relatively expensive, especially if operated at high pressures.

Table 4: Comparison of different arsenic removal technologies

Technology	*Advantages*	*Disadvantages*
Passive sedimentation, In situ oxidation, solar oxidation	• Oxidizes the impurities and kills bacteria • Relatively simple technology, maintenance easy but slow process	• Removal efficiency is relatively low and hence widely practiced as pretreatment process in large scale treatment system.
Activated alumina, ion exchange, Read-F, Granular ferric-hydroxide	• Available technology in the commercial market • Simple technology • Easy practice by the user	• Not applicable containing phosphates water • Sludge is relatively higher • Relatively high cost • Sometimes maintenance is clumsy by the users
AIRPs	• Relatively simple in operation using hand tube-well • Able to serve small community demand of drinking water • Can remove iron also	• Sludge is generated • Maintenance is critical considering efficiency • The beneficiaries need to contribute equally, which is sometimes difficult to find in the rural area
Bucket/Sono filter	• Very simple technology • Household purpose use • Removal efficiency is relatively higher • Very cheap	• Maintenance is needed considering scale of treatment • Removal efficiency mostly depend on the maintenance of the system
Coagulation and filtration	• Relatively simple in operation • Chemicals are available in the commercial market • Low cost	• Not applicable containing phosphates water • Toxic sludge generation • Removal efficiency is relatively low
Membrane technology	• High removal efficiency of As removal • Applicable to large scale treatment • Ability to disinfect other impurities and microbes • No toxic sludge	• High technology • High capital and operation cost • Arsenic-rich rejected water is produced • May not be suitable to use in rural household areas

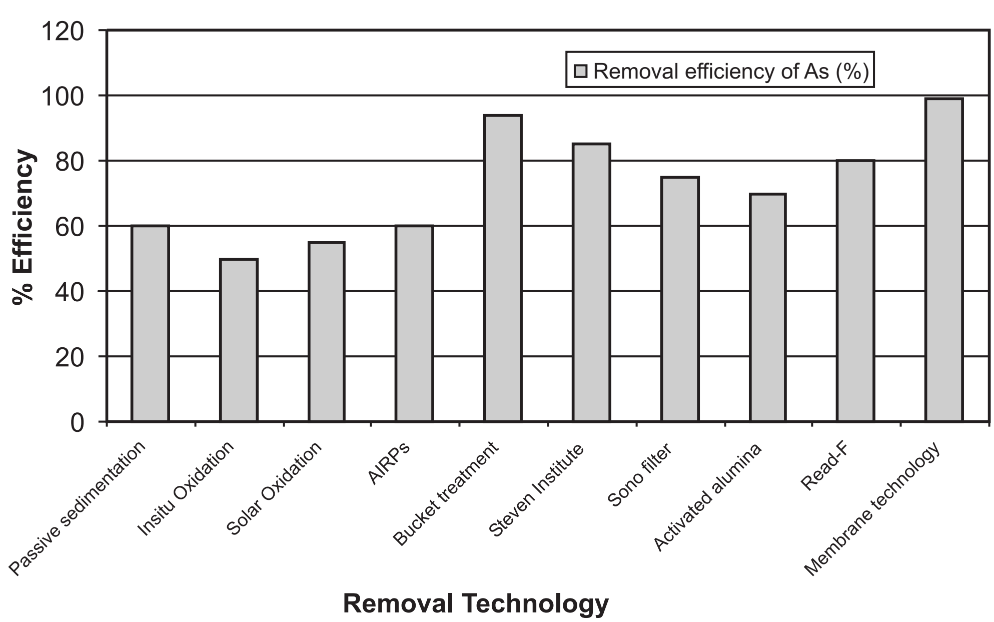

Figure 1: Removal efficiency of different Arsenic removal technologies (Rahman and Al-Muyeed, 2008).

Alternative Water Supply Options in Bangladesh

Despite availability of both surface and ground water, the drinking water supply in Bangladesh is heavily dependent on groundwater resources. The quality of water from many of these sources is the main constraint for the development of safe, efficient and affordable water supply options. In the context of emerging water supply problems in Bangladesh this study reviews a number of water supply options that can deliver safe drinking water and at the same time are acceptable to the community. The detailed cost comparison of different water supply technologies is presented in Table 5. Table 6 presents various aspects of available alternative water supply technologies in Bangladesh. Considering the efficiency in terms of safety from bacterial contamination as well as arsenic, deep tubewell might be a safe and sound technology to be adopted in Bangladesh, other than the coastal belts of the country. Also because of low maintenance requirement, for the last few years, this option has become very common and acceptable technology to the countrymen as a source of safe drinking water.

Table 5: Installation, operation and maintenance costs of selected water supply technologies

Water supply technology	*Unit cost (US$)*	*Population served per day*	*Installation cost (US$/person)*	*Operation and maintenance cost (US$/person/year)*
Fill and draw	250	5	50	3.0
Rainwater harvesting	106	5	21.2	0.34
Dug well	560	120-150	4.0	0.01
Large urban arsenic removal unit	230,000	60,000	3.8	0.15
PSF	560	150-200	3.2	0.04
Small-community type AIRP	140	40-50	3.1	0.07
Deep tubewell	775	250-300	2.8	0.05
Sono 45-25	13	5	2.6	0.2
Shrouded tubewell	175	100-120	1.4	0.10
Bucket treatment	7	5	1.4	5.0
Shallow tubewell	105	120-150	0.8	0.06

Table 6: Various aspects of alternative water supply technologies in Bangladesh

Water supply technology	*Bacterial removal efficiency*	*Arsenic removal efficiency*	*Institutional experience and issues*
Deep tubewell	+++	+++	The aquifers in Bangladesh are stratified and the deep aquifers are separated from the shallow ones by impermeable layers; so arsenic-free groundwater is found in the deep aquifers except for very few places in the north-western region. But these deep tubewells are rather expensive than establishing shallow tubewells.
Shallow tubewell	++	++	Groundwater with low arsenic content is available in shallow or in very shallow aquifers of the Bangladesh. Shrouding, the artificial sand packing around the screen increases the yield of the tubewell and prevents entry of fine sand into the screen.
Dug well	+	++	Percolation of contaminated surface water is the most common route of pollution of well water. Satisfactory protection against bacteriological contamination is possible by sealing the well top with a watertight concrete slab.

(*Contd.*)

(*Contd.*)

Pond sand filters (PSFs)	++	++	The water from the pond is pumped by a manually operated hand tubewell to feed the filter bed, which is raised from the ground, and the treated water is collected through tap(s). On an average, after every two months the sand in the bed needs to be cleaned and replaced. The treated water may require chlorinating to meet drinking water standard.
Conventional surface water treatment plant	+++	+++	Perennial water sources are not available in many places of Bangladesh and the investment cost is also high.
Rainwater harvesting	++	+++	There are shortcomings regarding the quantity that is limited by the rainfall, and the storage system is expensive. Common in the coastal areas of Bangladesh.
Solar distillation	+++	+++	Experiments with solar distillation plants by Rahman (1998) showed that the average yield of a conventional solar desalination plant was around 1.4 L/m^2/day. The water produced by this method is free from all chemicals including arsenic but this technology cannot produce enough water at a reasonable cost.

Key: +++ Consistently > 90% removal; ++ Generally 60-90% removal; + Generally 30-60% removal.

Provision of Sustainable Safe Drinking Water

The information regarding the number of mitigation/safe-water technologies installed (Table 7) were collected by APSU (2005) from approximately 120 different projects/programs/pilot projects in arsenic contaminated areas of Bangladesh. Considering 10 households for Arsenic and Iron Removal Plants (AIRPs), rainwater harvesting for individual household and 50 households for other technological options mentioned in Table 7, it is estimated that these mitigation options can serve more than 4.55 million population or 38 percent of the total households in arsenic affected areas. In addition, more than 20 thousand household level arsenic removal filters and in excess of 100 community-based arsenic removal technologies are operational in Bangladesh. It is apparent from Tables 2 and 7 that ground water is the main source of drinking water even in severely arsenic contaminated areas, where the installed (total 106,939) arsenic mitigation/safe water options are: tubewells (70%), dug wells (5.9%), shallow shrouded tubewells (4.8%) and AIRPs (3.5%). Other technologies such as rainwater harvesting, pond sand filter, and deep-set pumps and piped water supply systems account for 12.5 percent, 3.3 percent and around 0.2 percent respectively. Different arsenic mitigation options should provide water that is arsenic-safe whilst controlling other potential health risks at a level that is tolerable. In this context critical evaluation of four alternative options namely Dug-well (DW), Deep Tubewell (DTW), PSF and Rainwater Harvesting System was carried out by ITN-BUET and APSU (RAAMO, 2005). The study shows, in general, that microbial disease burdens were a greater proportion of the total Disability Adjusted Life Years (DALYs) attributed to each technology option under different weather condition with the exception of the median DALY estimates for the shallow tubewell option, where the arsenic DALY dominated. The lowest risk options in terms of disease burden were the deep tube wells and the rainwater harvesting systems although both can indicate a significant upper 95th percentile microbial risk (Figure 2).

Table 7: Different safe water supply technologies operating in arsenic contaminated areas of Bangladesh

Installed technology	*Number (%)*
Tubewells	74,809(70)
Rainwater harvesting	13,324(12.5)
Dug wells	6,268(5.9)
Shallow shrouded tubewells	5,080(4.8)
Arsenic-iron removal plants	3,771(3.5)
Pond sand filter	3,521(3.3)
Deep-set pump	133 (0.1)
Piped water supply system	33(0.03)
Total number	106,939*

* This figure does not include household filters and a few arsenic removal technologies

Table 8: Operation and maintenance activities of different safe water supply technologies (DPHE and JICA, 2008)

Frequency	*OM activities*	*DTW*	*PSF*	*DWSF*	*AIRP*
Daily	Clean the leaf and wastage from the platform and the drain	✓	✓	✓	✓
	Ensure chlorination of the filtered water by adding bleaching powder from morning to evening.		✓	✓	✓
	When taking water, pump the tube well and close the tap after taking water.		✓	✓	✓
Weekly	Clean the filter's roof, surrounding areas and drainage facilities.		✓	✓	✓
	Open the drainage valve of gravel tanks until the clean water comes.		✓	✓	✓
	Clean excess or died algae from the SSF tank.		✓	✓	✓
	Clean the substance, leaf or wastage found in the pond around the inlet screen pipe.		✓		
	Remove the calcium carbonate crystal (white/brown) from the gravel, slow sand filter and supply tanks.			✓	✓
Monthly	Put oil or grease if necessary or replace the inactive parts.	✓	✓	✓	✓
	Scrape 1-2 cm of slow sand filter top sand to remove sludge. Scraped sand can be reused after proper washing.		✓	✓	✓
	Wipe out unnecessary plant/weed near filter sites.		✓	✓	✓
	Clean if any things fall into the pond or inside dug well.		✓	✓	
	Cover the hole between platforms to ground by mud.	✓	✓	✓	✓
Half yearly	Remove all the gravels from the gravel chambers, and wash it properly by water. Clean the inside walls of all chambers with brush and bleaching powder. In case of AIRP, sand of slow sand filter must be washed too.		✓	✓	✓
Yearly	New sand should be re-added in SSF tank.		✓	✓	✓
	Repair embankment if damaged.		✓	✓	
	Re-excavate the dug well.			✓	
	Repair the necessary parts.	✓			
Long term	Pond should be re-excavated after every 10 years to preserve enough water.		✓		
	Sand of slow sand filter should be replaced if it is seen that after washing the sand, the performance of arsenic removal is decreased.		✓	✓	✓

Jakariya (2007) distributed and examined more than 10 thousand water supply technologies in two sub-districts of Bangladesh, named Sonargaon and Jhikargacha. It is evident from his study that around 62 percent of the total tubewells tested in Sonargaon and around 48 percent in Jhikargacha were contaminated with arsenic above Bangladesh standard. The main safe water technologies promoted in this region were: pond sand filter, different household arsenic and iron removal filter units, rainwater harvesting and tubewells in deep aquifer. The community acceptability of these technologies was assessed by Jakariya (2007) in 2004 and found that less than two percent of them were found to be in use except tubewells in shallow aquifers that were marked green (safe for drinking purposes) and tubewells in deep aquifers. These two approaches have emerged from people's initiatives, which are making rapid and positive contribution to the provision of safe drinking water in arsenic affected areas of Bangladesh. The aquifers in Bangladesh are stratified and the deep aquifers are separated from the shallow ones by impermeable layers so arsenic-free ground water is found in the deep aquifers except for a very few places in the north-western region. Therefore, sinking of deep tubewells for fetching water from uncontaminated deep aquifers with a protective overlaying impermeable layer appears to be a promising and sustainable option for safe drinking water, and is well accepted by the communities during the past few decades.

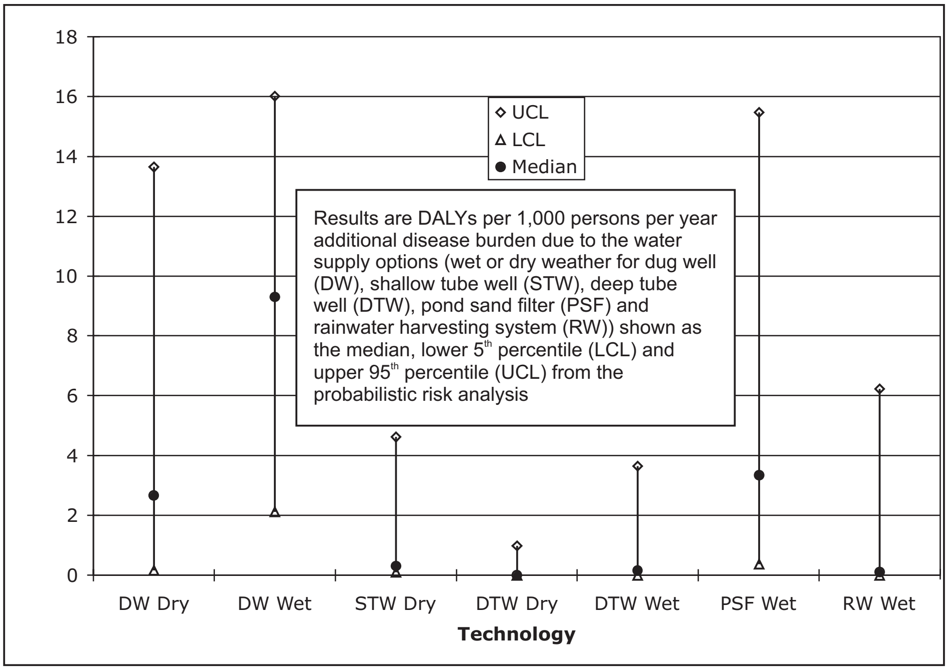

Figure 2: Total DALY output of selected water supply options (RAAMO, 2005).

Challenges in Implementing Safe Water Options

In Bangladesh, extensive works would be required to understand the sources, causes, occurrences and distribution of arsenic contamination and its health effects. A National Arsenic Mitigation Information Center (NAMIC) was set up in 1998 under BAMWSP Project to collect, process, interpret, manage and disseminate relevant information with the view that NAMIC, in time, will become a one-stop information clearinghouse for easy access to arsenic related data (Kabir et al., 1999). GIS-based database and website were developed by NAMIC during the project period. However, after completion of the project in 2002 the database and other pertinent information were not preserved systematically and the website is no longer accessible. In addition to different studies, coordination among various departments and sectors in resolving this gigantic problem is needed for effective and efficient utilization of resources to attain the common goal. Involvement and participation of the beneficiaries from planning stage is a key factor for the sustainability of a safe water option. This sense of ownership of safe water option among the community in combination with building their technical capability in the operation and maintenance (O&M), will ensure effective maintenance of these systems. This is a challenge, as most of the alternative water supply options require different kinds of O&M on yearly, monthly and even daily basis. Some options like PSF require more than 17 types of maintenance work on long-term as well as short-term basis. On the other hand, deep tubewells, which may malfunction due to improper use, require significant cost for repairing. But unfortunately in most cases, the authority has insufficient budget to repair those immediately. Moreover, due to lack of technical knowledge, many malfunctioned deep tubewells could not be revived to ensure safe drinking water. Out of 216,004 deep and Tara deep tubewells installed till 2008, a total of 5915 (2.74%) of these technologies have choked up (DPHE, 2008). Therefore, support from outside and occasionally highly technical expertise support become necessary to ensure a sustainable safe water supply.

Bangladesh is not economically strong enough to invest in a large scale in water and sanitation sector. The country is suffering with large growth of population and as a result ensuring sustainable and safe drinking water for everyone is highly challenging. However, the Government has already formulated the Sector Development Programme (SDP) for water and sanitation sector considering three scenarios to figure out the investment required for the rural water supply for the first five years (2005-2010) and the next five years (2010-2015). The first scenario: Basic service levels considered cent percent coverage target would be achieved during the first five years and the next five years will serve the additional population due to population growth. The second scenario: Moderate growth in service levels

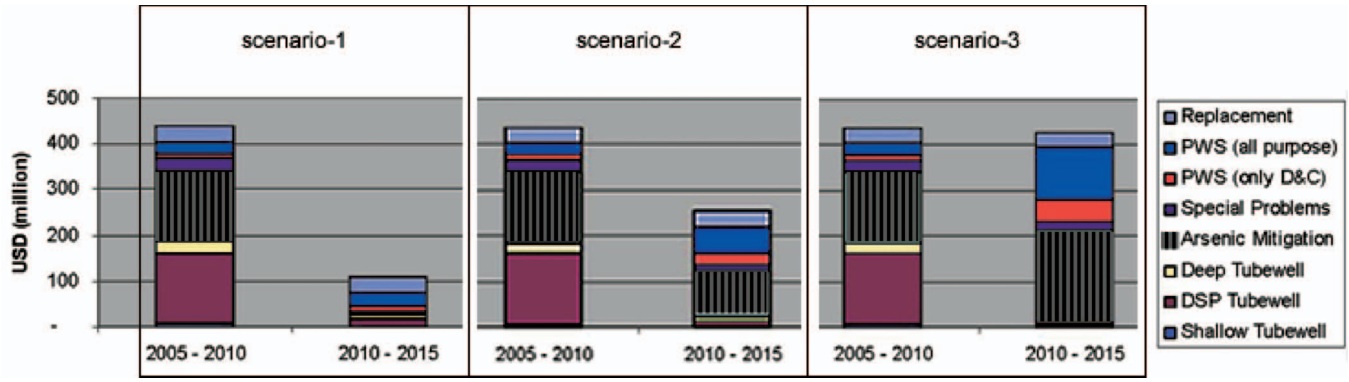

Figure 3: Total investment requirement during first five years and second five years (SDP, 2005).

considered the first five years same as first scenario but in the second five years the standards of arsenic mitigation technologies and special problem area technologies are improved from basic level of one installation to serve 125 persons to one for 75 persons including six percent of the population covered by piped water supply. The third scenario: Accelerated growth in service levels considered a favourable investment climate during the second five years and accelerated growth in service levels for the rural population. The service standards for arsenic and problem area technologies are further improved to the level now for tubewell technologies, i.e. one installation for 50 persons. Piped water supply in 10 years will cover 10 percent of the population, the cost sharing (or private sector contribution), in case of piped water supply for drinking and cooking only, is expected to increase for 20 percent to the level of piped water supply for all purposes, i.e. 50 percent (SDP, 2005). According to all these scenarios, investment need in the first five years is USD 446 million where arsenic mitigation will take the largest share of more than USD 150 million (Figure 3). The investments required in the next five years for arsenic mitigation according to second and third scenarios are around USD 125 and 200 million respectively (Figure 3). This high investment required for arsenic mitigation is also a major challenge for implementing the water supply options.

Conclusion

It is apparent from this study that comprehensive development in arsenic removal technologies has taken place during the last few years where some technological options have good potentials to be used in small isolated communities and/or municipalities, which depends on many factors including arsenic concentrations present before removal, speciation and co-occurring solutes. But no single option can serve the whole cross-section of arsenic affected population in Bangladesh of diverse social and economic background. Sinking of deep tubewells in uncontaminated deep aquifers with a protective overlaying impermeable layer (which is common in Bangladesh) appears to be a very promising and sustainable option for supply of safe drinking water in arsenic contaminated areas. These tubewell technologies are well accepted by the communities during the past few decades. However, the socio-economic status of the community and more sectoral investment from both the local government and abroad must be addressed for overcoming the challenges in implementing the safe water options and ensure a sustainable arsenic-free society in Bangladesh.

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