Case Study

Water and Sanitation Program

An international partnership to help the poor gain sustained access to improved water supply and sanitation services

Developing Private Sector Supply Chains to Deliver Rural Water Technology

Arsenic Mitigation in West Bengal and Bangladesh

Helping households respond to a water quality crisis

In the rural water supply and sanitation sector, goods and services (technology, training, repair services, financial and technical services, and facility management) are supplied to customers through a supply chain from manufacturers, importers, and service providers through a network of distributors. Payment flows in the opposite direction.

BASIC SUPPLY CHAIN

CUSTOMERS (COMMUNITIES, INDIVIDUALS)

Payment ↓ ↑ Goods and Services (Handpumps, spare parts, repairs, credits)

DISTRIBUTORS (RETAILERS, WHOLESALERS)

Payment ↓ ↑ Goods and Services

SUPPLIERS (MANUFACTURERS, SERVICE PROVIDERS)

The Supply Chains Initiative is a global initiative led by the Water and Sanitation Program. Collaborating partners include government departments, NGOs, and bilateral and multilateral agencies. The aim of this initiative is to develop practical tools that enable and encourage the private sector to provide goods and services related to rural water supply and sanitation. The initiative's first phase will focus on increasing the understanding of the dynamics of the private sector supply chains for handpumps, spare parts, and sanitation equipment.

ALTAF HOSSAIN, MATRIC PHOTO AGENCY/GOVERNMENT OF BANGLADESH

Testing tubewell water with a field test kit.

Summary

Groundwater is an important source of domestic water in Bangladesh and West Bengal, but it is now clear that much of the groundwater in these two areas is contaminated with naturally-occurring arsenic. This contamination is beginning to have a significant impact on the health of the rural population, and it is imperative that solutions are found soon. Household arsenic removal units and field test kits are two products that have the potential to enable rural households to manage the arsenic crisis. This case study examines the effectiveness of supply chains for arsenic mitigation products, and the potential of the private sector to assist in the supply and distribution of these goods.

Introduction

The vast majority of rural water supplies in West Bengal (India) and Bangladesh are obtained from groundwater, and it is now clear that much of this groundwater contains dangerously high levels of arsenic. This contamination is beginning to have a significant impact on the health of the rural population, and finding a rapid solution is now essential.

The major challenge is how to rapidly reduce and monitor the arsenic consumption of millions of people scattered over a huge area. The respective governments, External Support Agencies (ESAs) and non-governmental organizations (NGOs) are already pooling their resources to determine the extent of the groundwater contamination, and develop long-term solutions to the problem. However, it has been estimated that it may take 10 to 15 years to provide sustainable arsenic-free water supply options to all of the threatened areas (World Bank, 1999).

Millions of households in the region have invested in private handpump tubewells, and surveys suggest that despite the risks associated with arsenic contamination, many of them are unwilling to abandon these assets for less convenient alternatives. Given the enormous infrastructure requirements, and the comprehensive behavioral change needed for the adoption of alternative water sources, household arsenic removal units could offer a low-cost and appropriate solution to short-term arsenic mitigation.

One of the current priorities is to screen all the existing tubewells for arsenic contamination, and to set up sustainable arsenic monitoring systems. In addition, arsenic removal technologies need to be monitored to ensure that arsenic is consistently removed to below permissible limits (currently 0.05 mg/l in both India and Bangladesh). At present, there are very few water quality testing facilities in the rural areas, and insufficient capacity regionally for large-scale testing. 'Field test kits', portable units that can give a relatively rapid and cost-effective estimation of arsenic concentration, may provide an interim solution until this capacity is improved.

The private sector has clear advantages in efficient large-scale production, marketing, and national level distribution of goods and services, and it may provide the most efficient way of getting arsenic-related products, such as household arsenic removal units and field test kits, to the affected population. This case study examines the effectiveness of supply chains for arsenic mitigation technologies in West Bengal and Bangladesh. In particular, it focuses on low-cost methods of household arsenic removal and arsenic measurement, and evaluates the potential of the private sector to assist in rapid implementation, at scale, of these technologies.

Background

Bangladesh and the neighboring Indian state of West Bengal have much in common. Both are heavily populated and have high levels of rural poverty. The fertile soils of the Ganges-Brahmaputra Basin and Delta are vital to the largely agricultural economies of both, and are also the main source of water supply in the region.

Traditionally, most of the region's rural population got its drinking water from surface ponds, but these sources were often polluted, and more than a quarter of a million children died every year from water-borne diseases (World Bank, 1999). ESAs actively encouraged intensive efforts by the respective governments, and by NGOs, to shift rural water supplies from surface water sources to microbiologically purer groundwater sources. Shallow water tables and favorable geological conditions made installation of low-cost handpumps relatively simple, and millions of handpumps have been installed since the 1970s. It is now estimated that 97 per cent of rural drinking water supplies in Bangladesh are obtained from groundwater.

Unfortunately, the presence of arsenic in groundwater is not readily apparent to users as it does not alter the physical water quality (taste, smell, color, etc.), and the symptoms of arsenic poisoning are undetectable in its early stages[1]. The first indication of the problem was when arsenic-related

[1] The adverse effects of arsenic poisoning can take more than 10 years to become apparent.

health problems were diagnosed in West Bengal in 1983. Groundwater contamination was soon identified as the cause of these problems, but the more serious contamination in Bangladesh was not recognized until 10 years later.

Since then, large-scale water quality investigations have detected dangerous levels of arsenic in the groundwater of 9 out of the 18 districts in West Bengal, and in 59 of the 64 districts in Bangladesh (SOES, 1999; DFID, 2000). Hundreds of deaths have already been linked to long-term ingestion of contaminated water supplies. Thousands more cases of arsenic dermatosis have been diagnosed, and it is clear that millions of people are currently ingesting dangerous amounts of arsenic (ibid).

ORIGIN OF ARSENIC CONTAMINATION

The unprecedented scale and the seriousness of the arsenic contamination are inarguable. Unfortunately, the origins of the contamination, and thus the best approach for long-term mitigation of the hazard, are uncertain. It is generally agreed that arsenic occurs naturally in the alluvial sediments of the region, but there is considerable debate as to how the arsenic is released into the groundwater, and whether the problem is manmade or not.

One group of scientists believe that increased groundwater extraction has caused the problem, by exposing previously submerged sediments to the air, while another has suggested that phosphates from chemical fertilizers are displacing arsenic from the sediments. Groundwater levels are dropping in much of the region, and unusually high phosphate levels have been noted in Bangladesh, so both of these explanations have some merit. However, there is no observable correlation between the areas of most intense arsenic contamination and the distribution of groundwater extraction, and "none of the anthropogenic explanations can account for the regional extent of groundwater contamination in Bangladesh and West Bengal" (DPHE/BGS/MMIL, 1999).

Several other studies have shown that the groundwater in the region is generally in a reducing state (because of the presence of relatively high concentrations of sedimentary organic matter), and suggested that arsenic is being released when arsenic-iron complexes in the sediments are reduced by oxygen-deficient groundwater. The implication is that the process is a natural one, and that groundwater extraction does not cause or exacerbate the arsenic contamination.

The resolution of this debate, and a fuller understanding of regional hydrogeology, is critical for long-term solutions to the arsenic crisis, that is, whether to continue using tubewells for domestic water supply or irrigation. However, this debate should have little bearing on emergency responses, as there is no reliable evidence that short-term groundwater extraction exacerbates arsenic contamination.

Arsenic Mitigation

There are two approaches to arsenic mitigation:

- Provide an arsenic-free water supply, that is, an alternative to contaminated tubewells.
- Provide an arsenic removal technology, that is, treat water from contaminated tubewells.

In many rural areas, there are few alternatives to the contaminated tubewells. The provision of additional community water supplies, such as hand-dug wells[2], deep tubewells[3], or pond sand filters, to all of the affected areas will require enormous funds and take a considerable time. Rainwater harvesting is a good alternative, but it is only a partial solution because of the prolonged dry season[4]. Arsenic removal technologies offer a cheap and rapid form of arsenic mitigation, and also allow rural households to continue using their private handpumps.

Arsenic contamination is often associated with water that has high iron content. Iron-rich water tastes metallic, and has a visible reddish tinge that can discolor clothes and affect the taste and color of food. In areas with significant iron contamination, it is common practice for women to cook using pond water, and for households to use some sort of indigenous iron removal system[5] to treat tubewell water before drinking. As a result, household water treatment and the use of multiple water sources are familiar concepts in many parts of West Bengal and Bangladesh.

The next section examines the more promising arsenic removal technolo-

[2] Groundwater in hand-dug wells is usually arsenic-free (probably due to passive sedimentation). [3] Deep aquifers are generally arsenic-free. [4] Usually 3 to 4 months (and most affordable rainwater tanks only provide storage for a few weeks). [5] The author witnessed households in Bangladesh using clay bowls filled with sand and brick chips to remove iron contamination, and several studies have noted household use of alum to improve water quality.

gies currently being tested in West Bengal and Bangladesh, and assesses whether they are likely to develop effective and sustainable supply chains.

Two Bucket Treatment Unit

The two bucket treatment unit (2BTU) is now the most widely implemented household arsenic removal technology in the region. Since 1998, more than 13,000 2BTUs have been installed in Bangladesh[6], and program staff claim that, as a result of intensive arsenic awareness and social marketing campaigns, as many as 90 per cent of these units are still in use.

The 2BTU consists of two 20-liter plastic buckets stacked vertically, connected with a plastic tube. It removes arsenic by co-precipitation, whereby the combined action of alum, a coagulant, and potassium permanganate, an oxidizer, removes arsenic from the contaminated water, and binds it to flocs that are then filtered out by a sand layer in the bottom bucket.

The total cost of the 2BTU is only Taka 300 (US$ 6.00)[7]. At present, the powdered reagent, a mixture of alum and potassium permanganate, is only available from the projects, which purchase the chemicals from wholesalers in Dhaka and then transport them to the project areas[8]. The chemicals need to be crushed into a fine powder to achieve optimal arsenic removal. Initially, a Dhaka-based entrepreneur was contracted to crush the chemicals, but the costs were high (around Taka 10 per kg, equivalent to 25 per cent of the total reagent cost). The projects have now bought crushing, mixing, and packaging machinery, and have set up reagent production centers in each of the three project areas. The premixed reagent currently costs Taka 10 (US$ 0.10) for a 250 g pot, which lasts an average household about one month.

The programs target low-income households (as identified by project fieldworkers), who only have to contribute 10 per cent, or about Taka 30 (US$ 0.60), towards their unit. Demand for the units has exceeded the program's capacity, so recent interest from the private sector led to project staff training two private traders and a local NGO to manufacture units. The private traders recently started selling units for Taka 350 (US$ 7.00). The project coordinators are also encouraging local companies to become involved in reagent production, as they feel that industrial processes could produce better quality reagents at lower prices, and that experienced pharmaceutical companies may be able to produce the reagents in a more user-friendly tablet form.

There has been significant criticism of the 2BTU. The Technical Advisory Group (TAG) of the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) does not recommend promotion of the 2BTU, as they feel that it is very difficult "to control the various parameters in the field" (BAMWSP, 2000). The results from monitoring indicate that 75 per cent of the units are removing arsenic to below 0.05 mg/l. However, other surveys have indicated that users do not like putting chemicals in their drinking water, and that incorrect dosing or minimal stirring can result in poor arsenic removal. There is also concern about the adverse health effects of over-use of reagents[9] — in particular, whether increased alum dosing will lead to dangerous levels of aluminum in the treated water (*see box*). This concern led the DPHE-Danida project to test samples for aluminum residuals, but all but one showed less than 0.06 mg/l Al (WHO guideline is 0.2 mg/l).


GUY STUBBS/WSP-SA

Where testing indicates a tubewell contains dangerous levels of arsenic, the spout of the handpump is painted red.

The efficacy of the 2BTU may be debatable, but the early results from the Danida-funded programs suggest that it can be rapidly introduced at scale, and that it is significantly reducing the amount of arsenic being ingested in the project areas. Furthermore, by using materials that are both available in Bangladesh and affordable, and by stimulating demand, the programs have begun to interest the private sector in the 2BTU, and thus to develop supply chains. What remains to be seen, is how sustainable these supply chains will be without donor assistance.

Three Kalshi Filter Unit

Another household arsenic removal unit being implemented in Bangladesh is the three kalshi filter unit. During early 2000, BRAC distributed more than 9,000 three kalshi filters, and Dhaka Community Hospital (DCH) report that they distributed 3,000[10] four kalshi filters[11]. Both organizations have been distributing the units free.

The typical unit is based on a traditional water filter and comprises three clay pitchers, or kalshi, stacked verti-

[6] DPHE-Danida 4,000; NGO Forum 9,000 (the majority have been installed since July 1999). [7] Official Exchange Rate in June 2000 was US$1.00 = approx. 50 Bangladesh Taka. [8] The DPHE-Danida pilot project purchased 10,000 kg of chemicals for the first year of the project; transport costs were about Taka 600 (US$ 12) per tonne, adding about five per cent to total reagent costs. [9] Reagent over-use has been regularly reported in evaluations of other household treatment units, often because users believe that higher reagent doses will produce water of a much better quality. [10] NB: UNICEF progress reports note only 820 units distributed by DCH up to the end of May 2000. [11] DCH are promoting a slightly modified design using four kalshis, where the top kalshi, which contains no filter media, provides additional storage and aeration prior to the normal three kalshi filter unit.

ALUMINUM IN DRINKING WATER

Confusion and misinformation surround the health risks associated with aluminum in drinking water. The link between neurological effects and aluminum in drinking water is particularly elusive because of the high intake of aluminum from food (average adult intake 5.0 mg/day: WHO, 1998), which obscures the effects of aluminum ingested in water from additives such as alum. However, after a recent, detailed study, the WHO concluded that:

"Aluminum has not been demonstrated to pose a health risk to healthy, non-occupationally exposed humans. There is no evidence to support a primary causative role of aluminum in Alzheimer's disease, and … there is insufficient health-based evidence to justify revisions to existing WHO guidelines … [and] inadequate scientific basis for setting a health-based standard for aluminum in drinking water." (WHO, 1997: p.11)
after Johnston et al., 2000

cally in a frame. The top kalshi contains a layer of iron filings and a layer of coarse sand, the middle kalshi contains a layer of charcoal and a layer of fine sand, and the bottom kalshi collects the filtered water. Operation is extremely simple as no reagents are involved. The exact mechanisms of the arsenic removal are unclear, but it seems likely that the major removal process is adsorption of arsenic by the iron oxide (rust) on the iron filings.

ALTAF HOSSAIN, MAATRIK PHOTO AGENCY/GOVT OF BANGLADESH

The three kalshi filter unit.

The total cost of the three kalshi unit is Taka 250 to 300 (US$ 5 to 6), of which about 50 per cent is the cost of the stand. Monitoring by BRAC shows that arsenic removal is good, but declines rapidly after three to four months. Unfortunately, the iron filings cannot easily be cleaned or removed from the kalshi, as they rust into a solid lump after 10 days or so of use. Therefore, BRAC has been providing a completely new kalshi, including fresh media, whenever monitoring reveals that arsenic removal is declining, or if the household complains that the flow rate is too low. Replacement kalshi, including media, cost about Taka 55 (US$1.10).

DCH report that their four kalshi units are more successful. No replacement kalshi have been needed so far, as DCH's monitoring has found no arsenic 'breakthrough' (arsenic levels above 0.05 mg/l) in the last six months. It is not clear whether these results are due to the particular aquatic chemistry of the DCH project area (Bera District), or whether some change in the removal mechanism, such as the extra aeration provided by trickling the water from the fourth kalshi, has improved the arsenic removal capacity of the unit. DCH also found that, because of the numerous machine shops in Pabna, they did not need to source their iron filings from Dhaka. Furthermore, bamboo is widely grown in the DCH project area, and bamboo filter stands were found to be 30 per cent cheaper than metal ones.

Despite the differences observed, it is clear that in both cases there was demand for the three/four kalshi filter units, and that most of the units distributed were effective in removing arsenic. However, the households who received the filter units made no financial contribution towards the unit, so it is hard to ascertain how genuine the demand was. The supply chains for three kalshi filter units are effective, but the provision of a 100 per cent subsidy appears to have lowered willingness to pay for arsenic mitigation among other low-income households in the project areas[12]; and has deterred private sector participation.

RKM Filter Unit

Since October 1999, the Rama Krishna Mission (RKM) have distributed 135 filter units to households in West Bengal through one of their 'cluster organizations'[13]. Based on an All India Institute of Hygiene and Public Health (AIIH&PH) unit, the RKM filter unit is a particularly low-cost and appropriate design, developed by RKM in conjunction with a local potter.

The unit comprises two clay pitchers (one of them containing a 'tripura' candle filter[14]) and a plastic bucket. Like the two bucket treatment unit, it uses co-precipitation to remove arsenic, with a pinch of powdered 'ferric alum'[15] as the coagulant, and a few drops of

[12] Based on findings from a small number of interviews conducted by the author in June 2000. [13] Swamiji Seba Sangha in Lakshmipur, North 24 Parganas, West Bengal. [14] An indigenous product imported from Tripura state in northeast India, made from locally available materials including clay and rice husks. Their main advantage over ceramic candle filters is that they have a larger diameter, and thus a significantly higher flow rate. [15] A ferric salt (usually chloride or sulfate).

bleaching powder solution as the oxidant. The 'tripura' candle filter ensures that the arsenic-rich flocs are retained in the top kalshi.

The total cost of a unit is Rs 200 (US$ 4.60)[16]. In the RKM project, households contribute 50 per cent of the cost, or Rs 100 (US$ 2.30). The reagents are prepared by the cluster organization, and a packet of reagents sufficient for one month's use is sold for Rs 10 (includes 100 ml bleaching powder solution and one small packet of 'ferric alum'). Initially, the reagents were bought locally and supplied only in powder form, but RKM found that these chemicals were of low quality, and resulted in poor arsenic removal. Therefore, all the chemicals are now bought from reputable wholesalers in Calcutta and transported and distributed by RKM *(for more information, read 'The West Bengal Pilot Project: Responding to community demands for safe drinking water in an arsenic affected area', published by WSP-SA, August 2000).*

RKM has done very little monitoring of the filter units. Each of the household filters was checked immediately after installation and found to remove arsenic to below 0.05 mg/l, but there was no evidence of any further monitoring. It was also noted that, since the pilot project had stopped, the cluster organization had run out of reagents for their field test kit, and were completely reliant on RKM to provide more reagents (as they were not available locally).

The provision of an arsenic-free deep tubewell by the local council (Panchayat), and the recent installation of an activated alumina handpump unit[17] in the village, have diminished use of the filter units in the RKM project area. Several of the users stated that they continued to use their filters to provide water for cooking, as they gave a higher flow rate than traditional filters, but that they no longer used any reagents, and tended to collect their drinking water from the council tubewell or the new activated alumina handpump unit. The few households who still use their filters as intended, do, so they say, live too far away to collect water from the arsenic-free sources, so the filter provides their only means of obtaining uncontaminated water.

The RKM filter unit is a low-cost unit that has potential as an appropriate arsenic mitigation technology but, at present, the Rama Krishna Mission does not have the capacity or the experience to refine the technology, or to develop the supply chains that will be necessary for its sustainability.

Amal Domestic Water Purifier

Oxide (India) started production of the Amal domestic water purifier in September 1998, and have now sold more than 600 units through a network of seven dealers around West Bengal. Little performance data is available to date[18], but one of the dealers reported that arsenic removal was still good after four months (based on checks with a field test kit).

The Amal unit comprises a conventional two-chamber domestic candle filter body, with a layer of activated alumina granules in the top chamber (in place of a ceramic candle filter). The activated alumina media is a granulated form of aluminum oxide that has a strong affinity for dissolved arsenic, and removes it from solution by adsorbing arsenic molecules onto its surface. The media has a finite adsorption capacity, but can be regenerated by flushing with sodium hydroxide and acid.

The Amal unit is available in a range of sizes and materials, costing from Rs 1,650 to 2,400 (US$ 38 to 56). The activated alumina costs only Rs 100 per kg (US$ 2.30) and makes up less than 20 per cent of the total cost. The claimed design life of the activated alumina is two years, but several customers have already paid Rs 150 (US$ 3.45) to have their media replaced, and it appears that, in some areas, saturation is reached in less than six months. High iron loads quickly clog the purifier, and require regular removal of the media for cleaning. Initially, the activated alumina granules were loose and this process was difficult, but now the media is supplied in a porous cloth bag that makes cleaning and replacement easy.

The manufacturer believes that there is considerable scope to make the unit more affordable. Oxide (India) are investigating using cheaper materials for the body, as the body accounts for about 30 per cent of the cost of the unit. The dealer's commission, which is included in the price, is currently 25 per cent. Oxide (India) did not have a rural distribution network, and found that they had to offer a high commission to persuade the dealers to become involved in promoting the Amal purifier.

The Amal domestic water purifier is not as cheap as the other household arsenic removal units examined here, but it is simple to operate and appears to provide good arsenic removal. After some initial problems, Oxide (India) have managed to improve their product, develop a network of dealers, and they are in the process of stepping up marketing efforts. Their main challenge now is to make the Amal purifier more affordable, so that they can increase

[16] Official Exchange Rate in June 2000 was US$1.00 = approx. 43 Indian Rupees. [17] Designed by BE College and funded by the US NGO Water for People. [18] Laboratory tests conducted by BE College in 1997-98 indicated that small-scale activated alumina units (media volume 2.7 liters) were effective in reducing arsenic contamination to below 0.05 mg/l, and that this volume of media could treat 35 liters of water a day for more than six months without becoming saturated.

their market size and establish sustainable supply chains.

Passive Sedimentation

The simplest approach to household arsenic removal is passive sedimentation, whereby water is aerated (by pouring into a bucket, or by stirring) and then left to settle for 12 hours or so. The success of this approach depends on the local groundwater chemistry (particularly iron content and pH), and on the acceptability of drinking water that has warmed during its lengthy storage[19]. Therefore, this method cannot provide safe water nationally. It should also be noted that WaterAid (Bangladesh) found that the increased storage times can lead to high levels of fecal contamination. More research is needed to confirm the cause of this contamination, as several of the arsenic removal methods discussed in this study involve storage of water overnight.

Despite the reservations above, passive sedimentation offers a simple method of reducing arsenic concentration when the aquatic chemistry is suitable, and so should be considered as an emergency mitigation measure in areas where no better alternative exists.

Co-precipitation Using Tablet Reagents

Early attempts to develop packaged reagents, such as the NIPSOM sachets (*see box*), were unsuccessful, but several researchers are now experimenting with reagents in tablet form.

The School of Environmental Studies (SOES) at Jadavpur University in West Bengal has been testing tablets in a similar system to the RKM filter unit. The black colored tablets, which are currently hand-mixed, contain a ferric salt, an oxidant and activated charcoal (SOES, 2000). Arsenic removal in the laboratory was high (95 to 100 per cent) and the tablets were reported to have a shelf life of 15 months, but initial trials suggest that the arsenic removal efficiency in the field is often lower, possibly due to poor storage of the tablets by rural households.

In Bangladesh, the Stevens Institute of Technology (SIT) has developed a system using a tablet containing a ferric coagulant and highly adsorbent sand. The cost of a year's supply of the tablets is estimated at Taka 100 (US$ 2.00), and SIT plans to manufacture the tablets locally (DFID, 2000). The technology is being investigated by BAMWSP, but no findings are available yet.

Arsenic Removal by Adsorption

There are also numerous private companies sponsoring research and testing of arsenic removal units using adsorptive media[20]. On paper, some of these proprietary media, such as Harbauer's granular ferric hydroxide, have significantly higher adsorption capacities than activated alumina. This means that they require a smaller volume of media for effective arsenic removal, and have a longer useful life. However, none of these media are produced in India or Bangladesh and, with import duties being as high as 70 per cent, the media are up to 10 times the price of the locally available activated alumina (which is produced by at least seven companies in India).

Several of these technologies are being field tested by BAMWSP, but the high iron content of the water in the test area causes continual clogging of the filters, and a combination of

CASE STUDY: AN EARLY ATTEMPT TO DEVELOP A METHOD OF HOUSEHOLD ARSENIC REMOVAL

In 1998, the National Institute of Preventive and Social Medicine (NIPSOM) developed a reagent sachet, known as the 'NIPSOM tea-bag'. Based on a WHO 'recipe' from Latin America, it contained a coagulant-oxidant mixture designed to remove arsenic by co-precipitation. NIPSOM contracted out the manufacture of the sachets to General Pharmaceuticals Limited (GPL), a reputable pharmaceutical producer in Dhaka.

In all, NIPSOM bought 400,000 sachets from GPL under three contracts, at a total cost of about Taka 1.0 million (US$ 21,000). The cost of each sachet was only Taka 2.65 (US$ 0.05), but they were distributed for free under an emergency mitigation program. Unfortunately, there were significant problems with the quality of the chemicals. Initially, the bleaching powder used was too weak and didn't remove arsenic well, then, in the second batch, it was too strong, and made the water undrinkable. There were other problems: the reagents corroded the plastic sachet wrappers, and many of the sachets leaked; and the shelf life of the reagents was only four months, so most of the sachets were past their expiry date before they were even distributed. The sachets were not popular and, two years later, NIPSOM is left with many cartons of unused sachets.

[19] One of the reasons that water from handpump tubewells is so popular in rural areas is that, when drunk directly from the handpump, it is 'fresh' and cool. Water stored for long periods is considered stale, and is not liked for drinking (based on author's interviews). [20] West Bengal: Pal Trockner (Harbauer), Aquabind XP (Apyron); Bangladesh: Sidko (Harbauer), Shin Nihon Salt (READ-F), Water for All (Arsen-X), Tetrahedron Inc. (Tetrahedron).

Cost of Adsorption-based Household Arsenic Removal Units				
Promoter	**Flow rate***	**Cost (local)**	**Cost (US)**	**Proprietary Media**
Shin Nihon Salt Co. (Japan)	25 l/hr	Taka 2,000	$ 40	READ-F
Pal Trockner (India-Germany)	30 l/hr	Rs 3,000	$ 70	Harbauer (granulated ferric hydroxide)
Water for All (USA)	60 l/hr	Taka 7,000	$ 140	Arsen-X
Tetrahedron Inc. (USA)	30 l/hr	Taka 12,000	$ 240	Tetrahedron

** as claimed by manufacturers*

inadequate backwashing facilities, a lack of 'ownership', and the availability of alternative water sources nearby, has resulted in most of the test units being abandoned within the first month of use[21].

Arsenic Measurement

Arsenic is poisonous even at extremely low concentrations. Standards for safe levels of arsenic in drinking water vary from around five parts per billion (0.005) to 50 parts per billion (0.05 mg/l), thus devices that can reliably measure arsenic down to these levels are essential for arsenic mitigation.

Several laboratories in West Bengal and Bangladesh have the equipment, and the trained staff, to carry out accurate arsenic tests at these low levels of concentration. However, they do not have the capacity to test every handpump in the region, or to provide regular monitoring services for thousands of household arsenic removal units. Lab tests are expensive, and more affordable alternatives are needed, at least until more laboratories are operating and the cost of lab tests decreases. At present, the only alternatives to lab testing are the Arsenator[22], or one of the many types of field test kits on the market.

Although they use different reagents[23], both the field test kits and the Arsenator use a similar 'mercury bromide paper' method to measure arsenic concentration. In the field test kits, zinc and hydrochloric acid are added to arsenic contaminated water to liberate arsine gas, which reacts with dry mercury-bromide impregnated filter paper to produce a yellow to brown coloration. The higher the concentration of arsenic in the water, the darker the stain on the mercury-bromide paper.

The Arsenator uses a semi-automatic photometric sensor to measure the color of the mercury-bromide paper, and provides a digital readout of the arsenic concentration. The field test kits contain a color chart, and rely on the operator to determine the approximate arsenic concentration by comparing it with the mercury-bromide paper by eye.

There are several good examples of the local manufacture of field test kits, including three in West Bengal (AIIH&PH, Aqua and Sumeet), but the GPL kit has been the most successful, thus it is profiled here.

GPL Field Test Kit

In 1999, GPL sold more than 900 field test kits in Bangladesh, largely to institutional buyers such as UNICEF, WaterAid and NIPSOM. However, problems with the quality of the reagents[24], most of which were purchased from Indian suppliers, and doubts over the consistency of the mercury-bromide impregnation and its shelf life[25], led to the cancellation of several orders and, eventually, to GPL stopping production in late 1999.

The GPL field test kit is based on the Asia Arsenic Network (AAN) kit, and involves two additional stages to the basic mercury-bromide paper process. Reducing agents (potassium iodide and a tin salt, stannous chloride) are used to ensure that all of the arsenic in solution is liberated, and a cotton plug impregnated with lead acetate is used to limit interference[26] from hydrogen sulfide gas (produced by the reduction of sulfur compounds in the sample).

GPL were popular because they were a local manufacturer, and their kits, which cost Taka 1,800 to 2,200 (US$ 36 to 44), were cheaper than imported kits. Another critical advantage was that the GPL kit (like the other AAN-type kits) was supposed to be able to measure arsenic concentrations down to 0.02 mg/l, that is, below the Bangladesh standard of 0.05 mg/l, whereas Merck only claimed to be able to measure down to 0.10 mg/l with their kit. A joint evaluation of field test kits (including the old GPL kit) conducted

[21] Author's site visits on 14 June 2000 found that 4 out of 5 units (2 Arsen-X, 1 Tetrahedron and 2 READ-F) were clogged and no longer in use. [22] An arsenic measuring device invented by an Austrian researcher, Dr Walter Kosmus. [23] The Arsenator uses a solid acid and reductant (sodium borohydride). [24] The reagents contained significant amounts of impurities, including measurable quantities of arsenic. [25] GPL admit that their mercury-bromide paper has a shelf life of about three to four months (interview with author, June 2000). [26] Sulfides can react with the mercury-bromide paper and give false readings.

by the NGO Forum and SOES (NGO Forum, 1999) concluded that "the mercury-bromide stain method is incapable of providing a quantitative meaningful result below [a] concentration of 0.15 mg/l" and found that, at the 0.05 mg/l level, the risk of false negatives[29] was unacceptably high (7 to 14 per cent).

BAMWSP recently decided to procure 50,000 field test kits as part of their national handpump tubewell screening program. As there is no other local manufacturer in Bangladesh, GPL were encouraged to try again, and their new kit contains several improvements. All the reagents are now being imported from Merck-BDH (UK) under a recent agreement. Delivery to Bangladesh takes three months, but GPL claim that the quality of the reagents, and the reliability of the supply from Merck-BDH, outweigh the inconvenience of importing the reagents. GPL claim that their new kit can measure down to 0.01 mg/l, but there is little evidence that the process is any more accurate or reliable than before.

PERMISSIBLE ARSENIC LEVELS

There is considerable debate around lowering the permissible arsenic level in drinking water in India and Bangladesh. Both countries have a standard of 0.05 mg/l, but the WHO guideline value is 0.01 mg/l[27].

There are two key arguments in the debate. The WHO guideline value is derived from studies of the health effects of arsenic, and is based on a healthy 70 kg person drinking two liters of water a day over his or her lifespan. However, people in rural India and Bangladesh tend to drink more than this because of the heat and the lack of cheap alternatives[28]. There is also evidence that people with poor nutrition levels are more affected by arsenic contamination than healthy people (SOES, 1999). Therefore, a given level of arsenic in the drinking water of India and Bangladesh, where there are millions of malnourished people drinking large quantities of water daily, is likely to be far more dangerous than a similar concentration in Europe or the USA, and thus arsenic standards in India and Bangladesh should be lower than international standards.

The second argument makes a case for keeping the current standard of 0.05 mg/l, and rests on the practical and economic difficulties associated with a lower standard, and the risk of adverse social impacts. At present, none of the arsenic removal units available can reliably remove arsenic to below 0.01 mg/l, and none of the field test kits can reliably measure down to this level. The imposition of an arsenic standard of 0.01 mg/l would threaten the viability of most of the appropriate and low-cost arsenic mitigation technologies currently available, and would probably delay arsenic mitigation efforts until new, possibly more expensive, solutions are found. The number of people that could be assisted through arsenic mitigation programs would be reduced, and water treatment technologies and arsenic testing services would become less affordable, which may have a significant impact on the health and well-being of the poor.

Merck Field Test Kit

The Merck kit, which is manufactured in Germany, is slightly more expensive than the GPL kit, costing around Taka 2,600 (US$ 52), but has the 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. Therefore, in view of the problems with the GPL kit (and similar concerns about other locally manufactured kits[30]), most agencies in Bangladesh now use the Merck field test kit. In 1999, G A Traders (Merck's sole agent in Bangladesh) sold about 8,000 Merck test kits, and, following their recent success in winning a contract to supply BAMWSP with 8,000 Merck kits, sales in the year 2000 were likely to be considerably higher.

The Merck field test kit is extremely simple, with the 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 80 tests per kit[31]. Despite not having additional reducing reagents, or a method of removing sulfide interference, evaluations have found the Merck kit to be at least as accurate and reliable as other more complex field kits.

Merck do not market the reagents separately from the kit, so users have to purchase a whole kit when one of the reagents runs out. A breakdown of costs for the Merck kit was not available but, based on estimates made by other manufacturers, the kit's plastic case accounts for about 20 per cent of

[27] European Union standard is 0.01 mg/l and the United States Environmental Protection Agency (USEPA) is in the process of revising its standard (probably to 0.005 mg/l). [28] A study conducted in West Bengal (Mandal, 1998) found that the average water consumption of adults in the arsenic affected areas is about four liters a day. [29] Arsenic contaminated water (>0.05 mg/l) being identified as safe (<0.05 mg/l). [30] Manufacturers in West Bengal include AIIP&PH, Aqua, and Sumeet (all use Indian chemicals in their reagents). [31] Enough reagents for 100 tests are provided (note that most AAN-type kits only achieve about 40 to 60 tests per kit).

the total cost, so Merck's policy of not selling separate reagents is probably increasing the cost of testing by a similar proportion.

Merck have recently introduced an improved version of their field test kit, which is supposed to be able to measure down to 0.01 mg/l. The new kit was not in production in June 2000, but it is understood that the greater accuracy is achieved by doubling the volume of the sample (thus doubling the amount of arsine gas liberated) and by use of a more finely calibrated color chart. As commented earlier, there is currently little evidence that the mercury-bromide stain method is reliable in measuring arsenic at such low concentrations.

Arsenator

The Arsenator has to be imported from Europe, and is expensive. Although it is not yet in full commercial production, prices quoted to potential buyers varied from about US$ 3,000 in West Bengal, to US$ 5,000 in Bangladesh. The reagents for the Arsenator are proprietary and are currently only available from the sole manufacturer in Austria.

Several Arsenators have been field tested in Bangladesh and West Bengal. The users reported that the initial results were impressive, but that the instruments needed regular maintenance, and that this was problematic because of the complexity of the instrument and the lack of local repair services.

Waste Disposal

The benefits of any new technology must be weighed against its costs, including the safe disposal of any waste products and any adverse health effects that its use may involve. The disposal of arsenic-rich sludge, or washings from arsenic removal units, is an important environmental health issue. The main concern is the possibility that, whatever form the arsenic is in, and wherever it is stored, it may leach into solution and re-contaminate the local groundwater.

Co-precipitation methods of arsenic removal, like the two bucket treatment unit, produce arsenic-rich wastewater after every addition of reagents, usually at least twice a day, and thus need a simple disposal method that is appropriate for regular use in rural households. Users of co-precipitation units are being advised to put the sludge and wastewater down their latrine (if they have one), or in their manure pit. There is some debate as to the validity of this practice, but the theory is that bacterial action will methylate the arsenic and transform it into a volatile compound that is lost to the air. There is no evidence that this practice will lead to recontamination of the groundwater, and it appears to be an appropriate method of local waste disposal.

Units that remove arsenic by adsorption retain most of the arsenic on the surface of the media until their adsorption capacity is exhausted and they are regenerated, or disposed of. This can take as long as six months, so the arsenic is significantly more concentrated and thus more difficult to dispose of safely. Therefore, the second approach is containment. In West Bengal, B E College is using sand-filled chambers for disposal of the arsenic and iron-rich wastewater from filter backwashes, and it is proposed that subsequently the contaminated sand will be mixed with iron hydroxide slurry and incorporated into cement blocks. Oxide (India) have already begun collecting exhausted activated alumina and returning it to their Durgapur factory for regeneration. They intend to adopt a similar iron hydroxide and cement stabilization method for permanent disposal of the arsenic-rich wastes produced during regeneration, and for disposal of activated alumina granules that can no longer be regenerated. This approach requires the establishment of networks of waste collectors, and considerable expense for the manufacturers. However, the stabilization technology is not complicated, and there are large decentralized networks in place, such as concrete latrine ring manufacturers, that could be utilized.

Market Size in West Bengal

The population of the nine arsenic-affected districts in West Bengal is estimated at 39 million (SOES, 1999) and the Public Health Engineering Department (PHED) in Calcutta estimate that there are 22,000 public tubewells, and as many as 400,000 private tubewells in the area[32]. In the last 10 years, SOES has tested about 70,000 water samples in their laboratory. They found that approximately 30 per cent of these samples had arsenic concentrations above 0.05 mg/l (SOES, 1999). This figure is probably an overestimate of the degree of contamination, as SOES generally do most of their fieldwork in arsenic 'hot spots'. However, SOES alone have

[32] Other estimates range as high as 900,000 private handpump tubewells.

discovered more than 20,000 handpump tubewells with unsafe levels of arsenic, and it seems likely that there are as many as 100,000 unsafe handpump tubewells in West Bengal.

To date, there are insufficient time series data to determine whether arsenic concentrations in tubewells are increasing with time, but it is clear that tubewells that are being used for domestic water supply need to be regularly monitored for arsenic. Assuming tests are carried out every six months, as many as 800,000 tests per year will be needed just for the private handpump tubewells. Given that the laboratories in West Bengal have tested only about 100,000 samples in the last 10 years, this implies that as many as 10,000 field test kits a year may be needed in West Bengal.

The number of households without access to a safe water supply, and thus who may be in need of a household arsenic removal unit, is harder to quantify. In some areas, an arsenic-free water supply is already available (from deep tubewells, rainwater harvesting, pond sand filters, or hand-dug wells) and many more are being planned. However, it is possible that as many as 400,000 households[33] will not have access to safe water for some periods, for example, during the dry season, and thus will require household arsenic removal units.

Market Size in Bangladesh

The scale of the arsenic crisis in Bangladesh is greater both in terms of a real extent and in the number of tubewells and people affected. The current population of Bangladesh is 126 million (World Bank, 2000), and 59 out of the 64 districts are said to be arsenic-affected (DFID, 2000). In some villages, 90 per cent of the tubewells are unsafe, and there are few alternatives to groundwater. Estimates of the number of people currently ingesting unsafe levels of arsenic in their drinking water generally range from 20 to 40 million.

There is uncertainty over the total number of private handpump tubewells in Bangladesh, but it is commonly reported that there are over four million (Johnston et al., 1999). DPHE report that 29 per cent of the 51,000 water samples they have tested have arsenic levels greater than 0.05 mg/l[34], and note that this correlates well with the results of the national survey conducted by DPHE/BGS/MMIL, which found 27 per cent contamination. Therefore, more than a million tubewells may be unsafe, and as many as three million households in need of alternate water supplies, or some form of arsenic removal unit.

Arsenic Mitigation Units in Use		
Technology	**Bangladesh**	**West Bengal, India**
Household arsenic removal units	30,000	<1,000
Arsenic field test kits	17,500	1,000

Differences between West Bengal and Bangladesh

There are major differences in institutional arrangements in the two countries. Bangladesh has a highly developed and effective NGO sector, and the government has welcomed foreign assistance. West Bengal, being a 'communist' state, favors government intervention, and is less amenable to foreign assistance. For instance, both UNICEF and the World Bank are playing leading roles in arsenic mitigation in Bangladesh, but are doing relatively little in West Bengal. In Bangladesh, NGO projects currently cover about 75 per cent of villages, reaching a quarter of the population, and attracting more than US$ 500 million annually from foreign donors (Haq, 1997 in Hossain et al., 1999). The existence of these extensive NGO networks, and their close links with donors, has helped raise arsenic awareness and expand mitigation efforts more rapidly than has been possible in West Bengal.

More than 9,500 field test kits have already been sold in Bangladesh (of which 90 per cent have been Merck kits), and more than 200,000 arsenic tests have been completed using field test kits. In May 2000, another 8,000 Merck kits were ordered by BAMWSP, and tenders for a further 50,000 kits are currently being evaluated. In contrast, sales of field test kits in West Bengal total only about 1,000 kits. The figures for Bangladesh look more impressive, but conceal the fact that

[33] Assuming 100,000 unsafe tubewells and four households per tubewell. [34] Interview with DPHE, Dhaka in June 2000.

both countries have only provided arsenic removal units to about one per cent of the affected households.

Another difference has been in the role of the private sector. In Bangladesh, the government owns 92 per cent of modern industries and privatization efforts have been relatively slow (Hossain et al., 1999). BAMWSP is coordinating closely with the NGO sector, and most stakeholders are waiting for BAMWSP to validate technologies before they consider large-scale implementation. Local manufacturers have limited research and development budgets, and are waiting to see which technologies are going to be validated before investing in production. Thus, innovation and experimentation by the private sector are being stifled.

In West Bengal, there has been little coordination of arsenic mitigation efforts, and it appears that many in government favor the provision of alternative water sources over arsenic removal units. Despite this, there is evidence of genuine private sector participation, albeit at quite a small scale. Oxide (India) have developed and refined their own arsenic removal unit, built a network of seven dealers, made more than 500 private sales, and are actively engaged in marketing, including printing 5,000 leaflets for distribution through their dealers, and running a stall at a trade fair run by the Bengal Chamber of Commerce. There are also three local manufacturers involved in the production of field test kits. It has been suggested that longer awareness of arsenic contamination in West Bengal has contributed to this higher private sector participation, but there is little evidence to support this, and it seems likely that any differences have been created by the dissimilar institutional arrangements.

Field test kits provide an example of technology difference. The imported Merck field test kit has become standard in Bangladesh, but has not been very successful in West Bengal, where AAN type field test kits are preferred. There are several possible explanations for this difference. Firstly, the smaller scale and seriousness of the arsenic crisis in West Bengal has combined with lower ESA involvement to result in less scrutiny of field kit performance than in Bangladesh. Secondly, local reagents and raw materials are cheap and freely available in India, while import duties are high (Merck kits are more expensive in India than in Bangladesh). Finally, anecdotal evidence suggests that groundwater sulfide levels are generally higher in India, so field test kits without a sulfide removal stage, such as the Merck kit, are less effective.

Another striking difference is in the adoption of arsenic removal units using adsorptive media. There have been a number of field trials in Bangladesh, but few of them have been successful and there was no evidence of the adoption of adsorption units on a larger scale. In India, sales of the Amal filter are growing, and there are several community handpump units operating successfully. Again, there are several possible explanations. Most of the successful adsorption installations are based on activated alumina, which is manufactured in India, whereas manufacturers in Bangladesh have to import the media, and are hindered by import duties and bureaucratic delays. Another factor may be the aquatic chemistry. The areas of Bangladesh visited during this study had exceptionally high levels of iron in the groundwater, which created severe clogging in any sort of filtration unit, and severely limited the viability of single stage adsorption units.

Effectiveness of Supply Chains

At present, despite recent increases in implementation, there are no effective supply chains for household arsenic removal units, or for field test kits. Household arsenic removal units are not available outside project areas (except for the Amal purifier) and arsenic testing services are being provided on an ad hoc basis, with field test kits only available from manufacturers in Calcutta or Dhaka.

Affordability

South Asia is one of the poorest regions in the world, but West Bengal and Bangladesh are particularly poor. A 1994 survey found that the average rural income in West Bengal was only Rs 3,157 (US$ 73) per year, which is 70 per cent of the average rural income in India (Sharriff, 1999). More than 50 per cent of the rural populations of West Bengal and Bangladesh live below the absolute poverty line[35] (Hossain et al., 1999). Clearly, in the context of these high levels of poverty, affordability is a critical issue.

A comparison of the cheapest arsenic removal technologies currently available *(see table on page 13)* shows that the two units being implemented at large scale, namely the two bucket treatment unit and the three kalshi filter unit, are among the most affordable, and have the lowest operation

[35] Food poverty line of 2,122 kcal per adult equivalent; minimum base income required to satisfy the recommended calories is US$ 125 per capita per annum at 1990 prices (Hossain et al., 1999).

Relative Costs of Arsenic Removal Units				
Type	Cost (local)	Cost (US$)	Annual O&M Cost	Annual O&M Cost (US$)
RKM filter	Rs 200	4.70	Rs 120	2.80
3 Kalshi filter	Taka 300	6.00	Taka 110	2.20
2 Bucket unit	Taka 350	7.00	Taka 120	2.40
Amal purifier	Rs 1650	38.40	Rs 150	3.50
READ-F filter	Taka 2000	40.00	-	-
Pal Trockner filter	Rs 2200	51.20	-	-

and maintenance costs. However, very few have been sold at full price, and running costs are currently being subsidized.

Both UNICEF and DPHE-Danida are intending to increase cost-sharing considerably during the next phase of their programs, but it appears that there will need to be major efforts to reduce costs further, and to improve awareness, before low-income households will be prepared to invest in household arsenic removal units.

Critics of the field test kits suggest that they are fundamentally inaccurate and unreliable, and that additional laboratory facilities are the answer to the region's ever-increasing testing requirements. In the short-term, this is neither practical nor affordable. Atomic Absorption Spectrophotometer (AAS) lab tests currently cost about Taka 400 (US$ 8.00) per test, whereas field tests range from about Taka 10 to 40 (US$ 0.20 to 0.80) per test. In addition, samples for lab tests need to be collected, acidified, and transported, and after testing, the users need to be notified of the results. Once laboratories have been established in every district, or mobile laboratories are in operation, the costs will come down, as will the logistical challenges. Until then, there are few alternatives to field test kits for large-scale, rapid surveys.

The Arsenator has been proposed as one such alternative, but it costs several thousand dollars per unit, and each test costs Taka 100 (US$ 2.00). It is also a relatively new technology, so there are no established manufacturers and few economies of scale in the production. Both UNICEF (Bangladesh) and WaterAid (Bangladesh) have reported problems with the electronics in their Arsenators, compounded by the lack of a local company capable, or authorized, to carry out repairs (Khandaker, 1999). However, the Arsenator Lite, a smaller and much cheaper unit, is supposed to be available soon, and it is possible that this will prove effective competition for the field test kits.

Some international manufacturers have stated that, if the arsenic mitigation programs are prepared to place large orders with them, they will invest in research and development to improve technology. Their argument is that economies of scale will allow them to cut their production costs, and lead to better products at reduced prices. This approach works well during the life of large, subsidized programs and is important as part of an emergency response, but it fails to stimulate local production or to develop more appropriate and sustainable local solutions.

Recent competitive bidding for the supply of field test kits, such as the BAMWSP tender for 50,000 field test kits, has raised private sector interest in the arsenic sector, but a few large companies have managed to monopolize these contracts at the expense of local producers. The size of the BAMWSP order did stimulate new research and development, and economies of scale allowed bidders to bring their prices down significantly[36], but requirements such as a bid deposit of Taka 800,000 (US$ 13,000), favor large international companies and limit the involvement of smaller local producers. The size of the order also increases the significance of the shelf life of the products, and prevents the benefits of incremental improvements being utilized.

Reliability

Evaluations of arsenic removal technologies and field test kits are still under way in both West Bengal and Bangladesh, and it may be some time before there is enough sufficiently rigorous evidence available to allow vali-

[36] Merck managed to reduce their price from Taka 2,600 to Taka 1,400 (a reduction of more than 45 per cent).

dation of these arsenic mitigation products. One of the reasons for this caution is a legitimate concern about the implications of advocating or implementing unreliable or inappropriate technologies. However, while it is reasonable to want a coordinated approach that gives clear messages to the people in the arsenic-affected areas, this should not happen at the expense of people's health.

Any technology that can reduce the amount of arsenic that people are currently ingesting (without decreasing the water quality in other ways), and any test kit that can make people more aware of badly contaminated sources, is beneficial, even if it is not 100 per cent reliable.

Some stakeholders have expressed doubts about the viability of 'household' arsenic units, and have suggested that 'community' arsenic removal units are preferable. They note the difficulties associated with persuading millions of households to use arsenic removal units, and in ensuring that they are used reliably, and the advantages of centralized operation and maintenance, including arsenic testing, by trained caretakers. They also express concern about the effect of private sector involvement, with its emphasis on commercial viability, on the poor. However, these compelling statements ignore history.

The failure of concerted efforts to provide community water supplies for all is what led to the massive growth in private handpump tubewells in the first place, and existing investments in community water treatment units, such as pond sand filters, or iron removal plants, have rarely produced safe or sustainable water supplies. It is clear that people in West Bengal and Bangladesh are prepared to make private investments in a reliable and convenient water supply, and this suggests that affordable household arsenic removal units will be an appropriate solution to arsenic mitigation in the region. The technology behind most household arsenic removal units is not particularly reliable, but the most important determinant of performance is usually the users. Therefore, the simplest and most appropriate technologies, which are often the cheapest, are most likely to be successful. For instance, the three kalshi filter unit and the two bucket treatment unit are among the cheapest units reviewed, but have been shown to be effective at scale, and appropriate to local conditions.

Field test kits are not accurate enough, or reliable enough, to determine arsenic concentrations below about 0.10 mg/l, but they have been found to be reasonably reliable in confirming the absence of arsenic, and in identifying badly contaminated groundwater. Currently, field test kits are not considered suitable for monitoring household arsenic removal units, where the main requirement is dependable identification of arsenic levels between 0.05 and 0.10 mg/l, but in many areas there are few alternatives available.

Interestingly, a recent evaluation (NGO Forum, 1999) noted little difference between the performances of locally manufactured or imported field kits, and suggested that, therefore, more attention should be given to improving local manufacture. The BAMWSP tender for 50,000 field test kits encouraged the design of several potentially more reliable and accurate kits, including a low-cost Chinese kit that uses gold-chloride paper instead of mercury-bromide paper. These continuing improvements suggest that field test kits may eventually provide a reliable and appropriate solution to household arsenic monitoring.

Conclusions

The considerable uncertainty surrounding the arsenic crisis is constraining arsenic mitigation efforts, and is proving a disincentive to private sector participation. Furthermore, some of the issues that are contributing to the uncertainty, such as the controversy over the mechanism for the release of arsenic, the long-term effects of large-scale groundwater extraction on water quality, and the costs or benefits of lowering drinking water standards for arsenic, are unlikely to be resolved in the near future.

Arsenic mitigation programs have increased their scope enormously in the last two years, and NGOs in both West Bengal and Bangladesh are using their extensive rural networks to raise awareness and conduct pilot projects. Despite these efforts, the number of household arsenic removal units distributed, and the number of field test kits in use, remain mere fractions of the quantities needed. Neither the governments involved, nor the ESAs and NGOs, have the funds or the capacity to provide adequate arsenic mitigation for all of the millions of people drinking contaminated water, within a reasonable length of time. These actors do have a significant role to play in raising awareness, in coordinating responses, and in ensuring that low-income households are not excluded from arsenic mitigation efforts, but the private sector also has an important role to play.

Most stakeholders agree that there

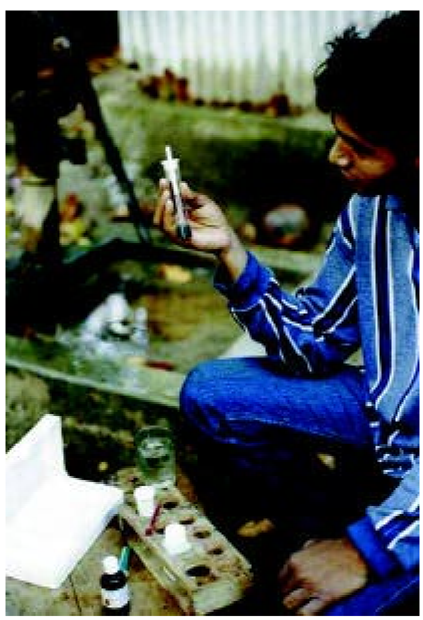
is a need for a variety of arsenic mitigation technologies, and that demand will be massive and long-term once public awareness and confidence in the technologies increases. However, willingness to pay for arsenic mitigation is still very limited in villages or localities that do not have confirmed arsenic patients, and most of the rural poor believe that arsenic mitigation is a government responsibility. Private investment in the local manufacture of arsenic mitigation products, such as household arsenic removal units or field test kits, is unlikely to increase until technologies are implemented on a wider scale, and larger private markets are seen to develop.

The private sector has clear advantages over the public and the NGO sectors in reducing production costs, and in the efficient distribution of goods and services. Both West Bengal and Bangladesh bear testament to the private sector's success in creating effective supply chains for Number 6 suction handpumps, for sanitary goods, for treadle pumps, and for oral rehydration salts (ORS). Ten years ago, most of these products were either not available, or were only available in limited numbers from government programs. Today, they are available from private traders throughout the country, and competition between traders keeps prices reasonable and products reliable.

This case study has profiled several arsenic mitigation technologies that are both appropriate and affordable, and may offer potential for the development of sustainable and effective supply chains. In the last two years, programs in Bangladesh have distributed about 30,000 household arsenic removal units. In each case, the agency or NGO responsible has built supply chains between specific suppliers (of kalshi, buckets, chemicals, sand) and project areas. The suppliers in these chains have limited risk, as the programs offer fixed prices, large volumes of business, and reliable payments. It is not clear whether the same suppliers would be interested if their business were entirely dependent on the whims of private buyers. However, the networks do now exist, and the success of the units distributed has built on the awareness campaigns, and generated sufficient demand in the project areas for local traders to become interested in supplying household arsenic removal units[37], despite having to compete with subsidized units.

[37] Notably the 2BTU.

The next phase of these programs must begin the transition from program supply to private supply. The first step of this transition should be to make their long-term plans explicit, as knowledge of future levels of subsidy can have an enormous impact on private sector participation, and on private customers' willingness to pay.


ALTAF HOSSAIN, MAATRIK PHOTO AGENCY/GOVT OF BANGLADESH

Field testing using the Merck kit.

There have been problems with the quality and reliability of reagents for locally manufactured field test kits, and the manufacturers are now marketing improved kits, which use imported reagents. However, there is potential for the production of analytical grade reagents in both West Bengal and Bangladesh. Several of the large chemical and pharmaceutical companies, such as Bengal Chemical (India) and Glaxo (Bangladesh), have suitable production facilities, but are not convinced that the market for 'arsenic' reagents is large enough, or long-term enough, to warrant investment. Government and ESA policies must consider the sustainability and long-term cost-effectiveness of using imported products, and strive to offer technical advice and assist local manufacturers towards competitive production. Specifically, these institutions could provide tax incentives for the production of equipment and chemicals, reduce start-up costs by offering credit to manufacturers, establish research grants, link experts with local manufacturers, encourage international companies to form joint ventures with local companies, and facilitate the transfer of manufacturing knowledge and quality control procedures.

It is clear that arsenic mitigation in the region is an enormous task, and that there is no single solution. A range of approaches and technologies are needed to suit the different locations, cultures, and groups of people, involved. Existing supply chains are unlikely to become sustainable or effective without increased private sector participation, and it seems likely that it will be a considerable time until arsenic-free water, or at least treated water, is widely available in the arsenic-affected areas.

Unfortunately, the uncertainty surrounding the arsenic crisis is constraining emergency responses. Thousands of tubewells have been screened for arsenic contamination and many more are being tested every month, but most of the people that discover that they are drinking unsafe water have no alternative, and none is being offered (except in the project areas).

It is vital that the public, private and NGO sectors begin working together in the development and promotion of the more promising technologies discussed in this study, and that they cultivate effective supply chains to make affordable arsenic mitigation technologies available throughout the region as rapidly as possible.

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Prepared by Andy Robinson.

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For more information, contact Clarissa Brocklehurst, Supply Chains Series Co-ordinator for South Asia, at cbrocklehurst@worldbank.org

Water and Sanitation Program

1818 H Street NW
Washington DC 20433 USA

Phone: +1 (202) 4739785
Fax: +1 (202) 5223313, 5223228
E-mail: info@wsp.org
Web site: http://www.wsp.org

Water and Sanitation Program-South Asia
55 Lodi Estate
New Delhi 110 003, India
Phone: (91-11) 4690488-89
Fax: (91-11) 4628250

Flat # 03-04, Building 'A'
Priya Prangan, 2 Paribagh,
Dhaka 1000, Bangladesh
Phone: (880-2) 8611056-68
Fax: (880-2) 8615351

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