30th WEDC International Conference, Vientiane, Lao PDR, 2004

PEOPLE-CENTRED APPROACHES TO WATER AND ENVIRONMENTAL SANITATION

Cost of water supply options for arsenic mitigation

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Arsenic contamination of groundwater-based water supply has become a great concern in many countries of the world. Provision of alternative arsenic-safe water supply is a priority for protection of health but it requires mobilization of huge financial resources in highly affected countries. This paper presents a comparative analysis of costs of treatment of arsenic contaminated water and utilization of alternative water sources for safe water supply in arsenic affected areas. Because of the complexities in arsenic removal, the cost of treatment of arsenic contaminated water at the present level of technological advancement is high and beyond affordability of the low-income rural population. Some alternative water supply options can provide water at comparatively low cost but are not suitable at all locations. The costs of arsenic-safe water supply, convenience and limitations of most technological options for arsenic mitigation have been discussed.

Introduction

Arsenic is present in the environment and humans all over the world are exposed to small amounts of arsenic, mostly through food, water and air. But the presence of high levels of arsenic in groundwater, the main source of drinking water in many countries around the world has drawn attention of the scientific community. Groundwater, free from pathogenic microorganisms and available in adequate quantity in shallow aquifers in the flood plains of many countries, provides low-cost drinking water to the scattered rural population. Unfortunately, millions of these people are exposed to high levels of inorganic arsenic through drinking this ground water. It has become a major public health problem in many countries in Asia and a great burden on water supply authorities. In developing countries like Bangladesh and India, high prevalence of contamination, isolated habitat pattern, poverty of the rural population and high cost and complexity of treatment of arsenic contaminated tubewell water and polluted surface water have imposed a programmatic and policy challenge in water supply on an unprecedented scale.

Treatment of arsenic contaminated water for the removal of arsenic to an acceptable level is one of the options for safe water supply. As increased detection of arsenic in groundwater has occured, a lot of effort has been mobilized for treatment of arsenic-contaminated water to make it safe for drinking. During the last few years many small scale arsenic removal technologies have been developed, field tested and used under different programmes in developing countries. Treatment of arsenic-contaminated water, in contrast to many other impurities, is difficult and it is much more difficult for rural households supplied with scattered hand pump tubewells. Comprehensive reviews of arsenic removal processes have been documented by Ahmed et. al (2001), Johnstone et al (2000), Ahmed (2003). American Water Works Association conducted comprehensive study on arsenic treatability options and evaluation of residuals management issues (AWWA, 1999). The most common arsenic removal technologies can be grouped into the following five categories:

- Oxidation and sedimentation,
- Coagulation and filtration,
- Sorptive filtration
- Ion exchange and
- Membrane filtration.

Source substitution is often considered more feasible than arsenic removal in some cases. The use of alternative sources requires a major technological shift in water supply. Apart from treatment of arsenic contaminated water, the potential alternative water sources for arsenic-safe water supplies include:

- Deep Tubewell
- Dug/Ring Well
- Rainwater Harvesting
- Treatment of Surface Water
- Piped Water Supply from an Arsenic-safe Source

Arsenic contamination has been found in shallow aquifers of recent geological origin while deep aquifers are relatively free from arsenic contamination. Installation deep tubewells is considered as one of the options for arsenic-safe water supply. Rain and surface waters are arsenic-safe and dug/ring wells abstract water of low arsenic content from surface of aquifers recharged and diluted each year by rain or surface water infiltration. Piped water supply using any of the above-mentioned arsenic-safe sources is considered as another options for water supply in arsenic affected areas.

Since detection of arsenic contamination of ground water, many alternative water supply options have been installed under action research programmes by government and non-government organizations. This paper deals with the cost implications of these options and is based on available information about the technological options for arsenic mitigation implemented, piloted, tested and verified in Bangladesh and India.

Methodology

The main components of cost of technology include cost of acquisition of the technology/materials, transportation cost, installation/construction cost, operation and maintenance (O & M) costs and cost of waste management. However, the first three components are non-recurring cost and can be considered as total capital cost (TCC). In order to estimate the annual cost of TCC, the total capital cost of the technology needs to be annualized and expressed as cost per year. For up-front capital costs, the annualization includes compound interest charge over the period of repayment of the capital. In case of water supply technology, it is assumed that the payment plan will spread the TCC over the lifetime of the technology. In order to find an annualized effective cost, the capital cost is to be multiplied by the capital recovery factor (CRF) or amortization factor.

The capital recovery/amortization factor has been calculated using the following formula:

$$CRF = \frac{(1+i)^N}{((1+i)^N - 1)/i} \qquad (1)$$

Where CRF = Capital recover/amortization factor
i = interest rate
N = number of years (lifetime of the technology)

The operation and maintenance costs include salary of personnel, costs of consumable chemicals and power, costs of replacement and repair of parts, costs of media replacement and regeneration, monitoring and services costs and opportunity cost of time and efforts of users. However, the costs of treatment and safe disposal of wastes generated from the technologies are considered as operational cost and included under O & M cost of the technology.

The arsenic mitigation technologies are mostly household (hh) or community units but some units can serve a large community or small town. In order to standardize and compare the cost of water supply by the different systems, the unit cost (cost/m3) of water produced by the systems is computed. The unit cost is the sum of the annualized TCC and O & M costs divided by the volume of water produced per year. The capital and O&M costs of major alternative technological options were available from various organization involved in arsenic mitigation in Bangladesh (GoB, 2002). The costs of arsenic removal technologies used in this study were derived from cost figures submitted by proponents of those technologies in Bangladesh and India for verification under Environmental Technology Verification for Arsenic Mitigation (ETV-AM) program (BCSIR, 2003). The minimum water requirement of a household based on the experiences in Bangladesh and India is taken as 45 L/household/day or 16.4 m3/hh/year.

Costs Estimation

Arsenic Removal Technologies

The cost of arsenic removal technology is an important factor for the adoption and sustainable use in the rural context. The cost of the technologies depends on many factors such as the materials used for fabrication of components, quantity of media/chemicals used, quality of groundwater etc. Most of the technologies have been installed and are being operated at field testing and pilot-scale. Hence, the costs of installation, operation and maintenance of all the arsenic removal systems are not yet known or need to be standardized based on modifications to suit the local conditions. The available costs of some arsenic removal technologies are presented in Table 1.

Table 1: Unit costs of water produced by arsenic removal technologies

Technology	Tech Life (Years)	Annualized Capital Recovery, (US $)	O & M Cost,(US$)/Year	Water Production, m^3/Year	Unit Cost, (US$)/$m^3$
Arsenic Treatment (Households) based on					
Iron Coated Sand/Brick dust	6	0.9	11	16.4	0.73
Iron Filling (Zero valent Iron)	5	3	1	16.4	0.24
Cerium Oxide	5	1.2	29	16.4	1.84
Activated Alumina	4	3.2	36	16.4	2.39
Coagulation-Filtration	3	3	25	16.4	1.70
***Arsenic Treatment (Community)* based on**					
Coagulation-filtration	10	45	250	246	1.21
Granulated Ferric Hydroxide	15	620	500	820	1.37
Granulated Iron oxide	10	530	430	900	1.06
Activated Alumina	10	123	500	200	3.11
Ion-Exchange	10	53	35	25	3.52
Air Oxidation-filtration (Urban water supply)	20	32,000	7,500	660,000	0.06

Since arsenic cannot be destroyed, all arsenic treatment technologies ultimately concentrate arsenic in sorptive media, sludges or in liquid media. The United States Environmental Protection Agency (USEPA) has developed a Toxic Characteristic Leaching Procedure (TCLP) test to identify the wastes likely to leach toxic chemicals into groundwater. Extensive work has been done on leaching characteristics of arsenic and it has been observed that in almost all cases arsenic leaching was very small and well below the level required for classification as hazardous wastes for disposal in landfills. However, the TCLP test may not represent the conditions under which arsenic is released in water. Confinement and then burial of arsenic-rich media and sludge is considered as a safe option and cost of waste disposal has been estimated based on this method.

Arsenic removal technologies use water from existing contaminated wells. Hence, the costs of arsenic removal technologies do not include the cost of the wells, It may be observed that cost of arsenic treatment is very high and is beyond the reach of the low-income villagers. A study in Bangladesh shows that a low-income household is willing to pay about US$ 0.75 per month for arsenic-safe water (Ahmad et. al., 2003), which is not adequate even to meet the O & M costs of most water supply systems. The cost of arsenic removal with iron by simple aeration-filtration is comparatively low but the efficiency of the method is dependent on the presence of iron and optimum alkalinity in natural water. The method is not reliable, when the arsenic content of raw water is very high.

Verification of some arsenic removal technologies in Bangladesh shows that the performances of the technologies are very dependent on pH, and presence of phosphate and silica in natural groundwater and most technologies do not meet the claims of the proponents in respect of treatment capacity (BCSIR, 2003). A reduction in the rated capacity will further increase the cost of treatment per unit volume of water.

Alternative water supply options

The unit costs of water produced by different alternative water supply systems have been calculated on the basis of annualized capital recovery for annual interest rate of 12 percent, charged by banks in some Asian countries. and presented in Table 2. CRF at other interest rates can be computed using equation (1). The quality and quantity of water, reliability, cost and convenience of collection of water of the different alternative options vary widely. Among the options, small bore (38mm) manually operated deep tubewell, 150-300m in depth can provide water at nominal operation and maintenance cost but deep tubewells are not technically feasible, nor able to provide arsenic-safe water at all locations. The presence of a relatively impermeable layer separating the deep and shallow contaminated layers is a prerequisite for installation of a deep tubewell for arsenic-safe water. The annular spaces of the bore holes of the deep tubewells are also required to be sealed at least at the level of impermeable strata to avoid percolation of arsenic contaminated water as shown for manually operated deep tubewell in Figure 1.

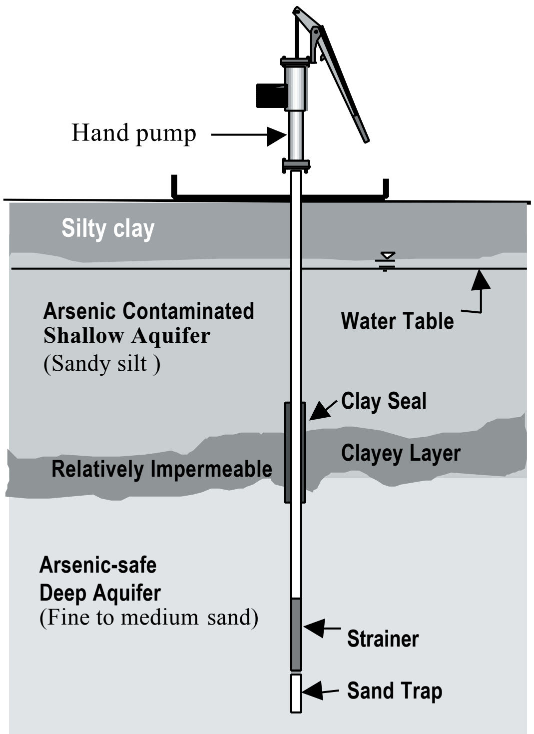

Figure 1.Manually operated deep tubewell with clay seal at the level of impervious layer

Dug/ring well is the next option, which can provide water at moderate installation and nominal O & M costs. It is very

Table 2: Unit costs of water produced by alternative water supply options

Technology	Tech Life (Years)	Annualized Capital Recovery, (US$)	O & M Cost, (US$/)/Year	Water Production, m^3/Year	Unit Cost, (US$)/$m^3$
Alternative WS Options					
Rainwater Harvesting	15	30	5	16.4	2.134
Deep Tubewell with handpump	20	120	4	820 (4,500*)	0.15 (0.03*)
Pond Sand Filter	15	117	15	820 (2,000*)	0.16 (0.07*)
Dug/Ring Well	25	102	3	410 (1450*)	0.26 (0.07*)
Conventional Treatment Unit	20	2,000	3700	16,400	0.35
Piped Water	15	5,870	800	16,400 (73000*)	0.41 (0.09*)

difficult to control bacteriological quality of dug well water in most places within acceptable level. Abstraction of large quantity of water in arsenic affected areas results in the ingress of arsenic contaminated water in dug well. About 46% of dug wells constructed in a highly contaminated area in Bangladesh have been found to be contaminated with arsenic exceeding Bangladesh Standard of 50µg/L (JICA & AAN, 2004). Many surface water sources are too contaminated for treatment by slow sand filtration at a low-cost while small-scale treatment by conventional methods for rural communities is costlier than large-scale treatment.

Piped water supply can be provided at a higher capital cost and with relatively higher O & M costs but the convenience and health benefits would be much higher. Because water of adequate quantity and relatively superior quality for all domestic purposes including sanitation will be available at residences or within close proximity of the residences. An increase in the number of household under piped water supply reduces costs. The cost of installation of rainwater harvesting system at household level with about only 50% reliability is very high. Installation of community rainwater harvesting systems should be cheaper but maintenance and operation of such systems may be difficult.

Community water points like deep tubewell, dug/ring well and pond sand filter have potential to produce more water at no additional cost and effective utilization of this additional water within the command area of the technology can significantly reduce the unit cost of water (Table 2). Conventional treatment unit is also a community water point but an increase in production involves additional cost. Rainwater systems are constructed very close to the consumption points and thus offer greater convenience over other options. The service levels of piped water system are not uniform. The low-income groups are served by standposts, while the mid- and high-income groups are served by yard taps and house connections respectively. The cost of piped water supply becomes reasonably low for densely populated habitats.

Conclusions

The problem of treatment of arsenic contaminated groundwater arises from the requirement for its removal to very low levels to meet the stringent drinking water quality standards and guideline value for arsenic. Arsenic removal technologies have improved significantly over the last few years but reliable, cost effective and sustainable treatment technologies are yet to be developed to meet the requirements. Because of the cost and operational complexity involved in arsenic removal technologies, alternative water supply options based on arsenic-safe sources are often given preference in arsenic mitigation. Deep tubewell and dug/ring well can provide water at low cost but are not suitable at all locations. Dug/ ring wells are difficult to construct in some areas and may not produce water of desirable quality. Surface water of acceptable quality is not always available for low-cost water supplies treated by slow sand filtration, while cost of small-scale treatment of surface water by conventional coagulation-sedimentation-filtration and disinfection processes is high. Rainwater harvesting, a household option of water supply, is costly in the countries having unequal distribution of rainfall throughout the year.

The people in arsenic affected areas need variety of technological options to meet the requirements of diverse socio-economic groups. This paper, to some extent, will help people and communities to take informed decisions regarding selection of technologies for arsenic mitigation based on cost, convenience and quality of water produced.

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