Arsenic-polluted groundwater in West Bengal: A cost-effective remedy

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Groundwater in a large part of the West Bengal Delta contains high levels of arsenic. A large number of people are compelled to drink water with arsenic concentration above the permissible limit. Water pumped for human use gets exposed to atmospheric oxygen, resulting in oxidation of soluble ferrous iron to Fe(III) oxyhydroxide and arsenic species to As(V). Pentavalent arsenic, being less reactive and less soluble, gets quickly adsorbed onto amorphous Fe(III) hydroxide and suspended particles in water and is easily removed using clay-candle domestic filter. In 62% of the water samples studied, more than 60% of the contaminant is removed and water with arsenic below the prescribed permissible limit is obtained.

A large number of people dwelling in the deltaic regions of West Bengal use water with arsenic in excess of the limit prescribed suitable for human health. The risk involved in such prolonged exposure has been a matter of global concern for the last twenty years. The affected areas, confined within the Ganga–Brahmaputra Delta (GBD), expose 30–35 million people in Bangladesh and nearly 6 million people in West Bengal, India[1]. At present, the primary source of drinking water in rural areas are the private domestic tube wells, tapping water from shallow aquifers (50–200 ft). Data from different sources indicate high arsenic content in water from such shallow aquifers in extensive areas in the delta. However, in many areas the deeper (> 500 ft) aquifers too show arsenic content above the permissible limit of 0.05 mg/l according to the Indian standards. Since the first detection of arsenic-induced hypopigmentation and keratosis in the 1980s, campaigns are being organized to create general awareness and several measures have been deployed to provide safe drinking water. The most common of these in rural West Bengal are the community-based online filters that work on the principle of arsenic removal by adsorption, oxidation and precipitation by Fe, Al oxides/hydroxides. Capital cost for these filters is high and they require periodic maintenance and community involvement, with high recurring expenditure. We, instead, emphasize the effectiveness of inexpensive, easily available, domestic clay-candle filters in removing arsenic. The cheaper alternative uses a porous clay stick through which water passes and filtration of suspended particles as well as some iron compounds is effectively done. These are traditional and easily available in the markets of rural West Bengal. This communication presents field-generated data indicative of effective and optimum arsenic removal by these filters. The emphasis lies on the cost-effectiveness, as the arsenic-affected areas house one of the poorest population segments of the world.

Study area and data generation

Data have been collected from domestic tube wells in two districts of Nadia and 24 Parganas (N) in West Bengal, India during the course of an arsenic distribution mapping programme of the Geological Survey of India. The area, lying east of the Hooghly river, forms the lower deltaic part of the GBD (Figure 1). The GBD is occupied by a thick sequence of Holocene sediments deposited by the Ganga, Brahmaputra and associated rivers, as well as their precursors. The present study area, falling in the southwest part of GBD, is chiefly made up of channel fill, channel bar and interfluve floodplain sediments stacked over and changing into each other vertically and horizontally respectively, in response to the dynamic process of delta formation and tectonism. The shallow aquifers in the study area are interconnected, unconfined to semi-confined sand bodies, which are recharged vertically and flushed laterally. It is reported that there is an order in the apparently chaotic pattern of the high-arsenic zones that could be explained in terms of distribution of palaeogeomorphic units[2]. Other factors that appear to control the pattern are the present-day flood situation, depth of aquifer, local physico-chemical parameters prevailing in the aquifer and bacterial activity that determine arsenic speciation, fixation and mobility[3]. Water from different wells (59 samples) was analysed for arsenic using E-Merck arsenic determination kit. The same water was put in a domestic filter and the filtered water was analysed to record the difference in arsenic content. Also, a set of 15 samples was analysed before and after filtration through a 0.45-micron membrane filter.

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Arsenic content in groundwater

Arsenic content in 59 contaminated tube wells varies from 0.02 to 0.5 mg/l. The tube-well depth ranges from 50 to 500 ft, the median depth being 100 ft. The mean and median of arsenic content are 0.12 and 0.08 mg/l respectively. The depth-wise arsenic distribution indicates highest average in 150–170 ft depth zone (Table 1). The sedimentary package in the study area is more or less continuous sand from the surface down to a depth of 120 ft. Maximum number of tube wells extract water from aquifers within this depth zone. The aquifers are semi-confined to unconfined and the average arsenic content is 0.11 mg/l. The other depth zones where tube wells are sunk represent multi-level coarser sand–gravel zones separated by finer sand and silt. The deeper aquifer, beyond 450 ft, is separated from those above by a clay layer. It is important to note that the deeper aquifer (450 to 500 ft) is also contaminated, though the average arsenic content is less (Table 1).

Effect of filtration

Arsenic concentration in unfiltered water and in water filtered by a clay-candle domestic filter is plotted in Figure 2. In 66% of the samples, the level of arsenic has been reduced below the permissible limit of 0.05 mg/l according to the Indian standard. Table 2 shows that in 62% of the wells, more than 60% of arsenic has been removed. However, percentage of arsenic removal does not depend on the initial concentration. In Figure 3, the regression of percentage arsenic removal against arsenic concentration produces a best-fit line that parallels the abscissa. The data are interpreted to indicate that irrespective of the initial arsenic content, 60% of arsenic is removed by filtration using the clay-candle filter. Since arsenic is removed by filtration, it should be present in the adsorbed state on fine particulate matter.

A set of 15 samples has been analysed for arsenic before and after filtration with a 0.45 μm membrane filter. Removal of particulate arsenic with size more than 0.45 μm is responsible for any change in arsenic concentration. Figure 4 demonstrates a comparison of arsenic concentration in unfiltered and filtered samples. In 87% of the samples, lowering of arsenic concentration in filtered samples is recorded. However, when percentage decrease is considered, unlike that of the clay filter, only 34% of tube wells show arsenic removal of over 60% (Table 3). Here again, the depth of tube well does not have any control over arsenic removal. The regression of arsenic level on percentage arsenic removal produces an exponential best-fit line that represents decreasing arsenic removal with greater arsenic content (Figure 5).

Discussion

In natural water most of the arsenic is present in inorganic form, and its mobility is controlled by sorption onto Fe(III) oxyhydroxides, humic substances and clay minerals[4]. The element is known to occur in water dominantly as soluble oxyanions As(III) and As(V). Changing redox conditions from reducing to oxidizing, have a great impact on As retention because As(V) and As(III) have different sorption isotherms with pH[5]. In groundwater pumped from the aquifer for human use, such change in redox condition is automatically achieved by exposing the water to atmospheric oxygen. The condition favours oxidation of solu-
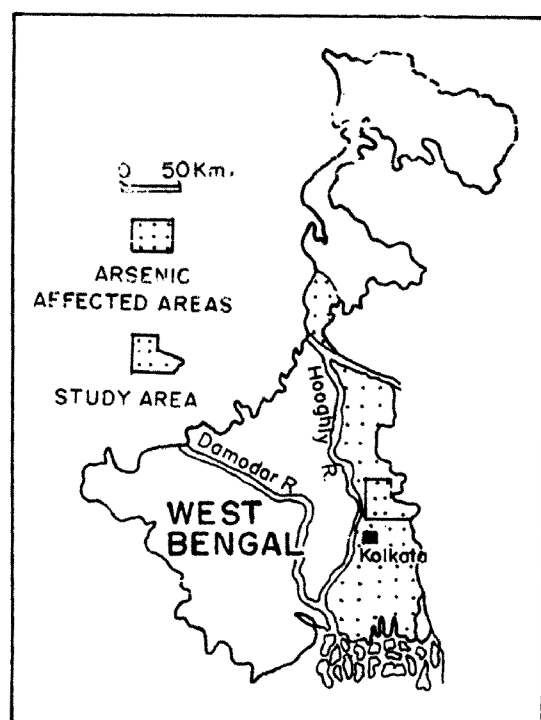

Figure 1. Arsenic-affected areas of West Bengal with the location of the study area.

Table 1. Depth-wise arsenic distribution of tubewells

Depth of tube well (ft)	As (average) (mg/l)	No. of samples
50–120	0.11	34
150–170	0.23	4
230–280	0.09	3
350–400	0.13	6
450–500	0.09	12

Table 2. Arsenic removal in percentage by domestic clay candle filter

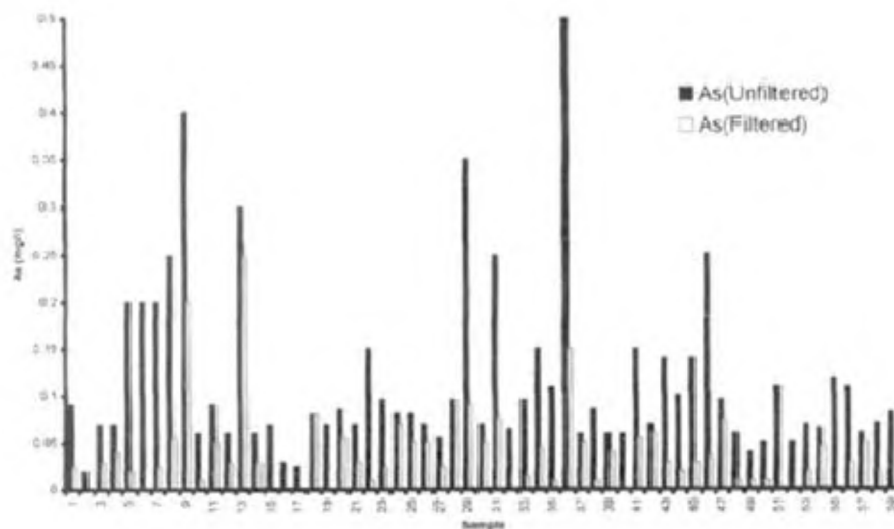| Percentage arsenic removal	No. of samples	Percentage	CUM %	Arsenic range (mg/l)	Depth range (ft)
100	12	20	20	0.02–0.2	50–470
80–99	11	18	38	0.05–0.2	50–450
60–79	14	24	62	0.04–0.5	50–490
40–59	8	14	76	0.06–0.4	50–100
20–39	7	12	88	0.06–0.09	80–450
0–19	7	12	100	0.06–0.3	70–500

Figure 2. Plot showing arsenic concentration in unfiltered versus filtered (domestic filter with clay-candle) water samples from wells of Nadia and 24 Parganas (N) districts of West Bengal.
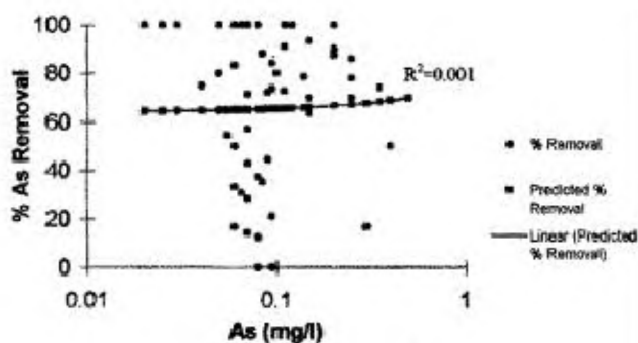

Figure 3. Arsenic concentration–percentage of arsenic removal regression plot of water samples (filtration by clay-candle domestic filter) from wells in Nadia and 24 Parganas (N) districts of West Bengal.
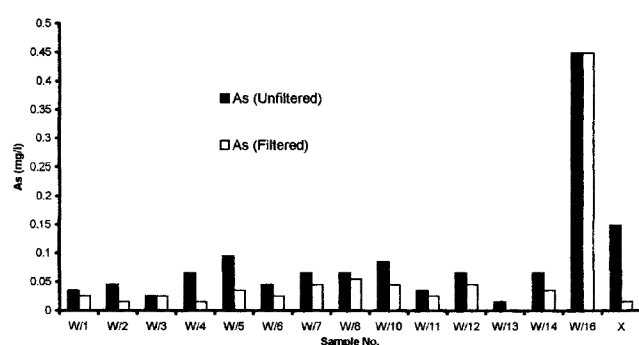

Figure 4. Plot showing arsenic concentration in unfiltered versus filtered (45 μm membrane filter) water samples from wells of Nadia and 24 Parganas (N) districts of West Bengal.

ble ferrous iron in the groundwater to insoluble Fe(III) oxyhydroxide, which precipitates as protoferrihydrite and acts as sinks for arsenic[6,7]. Protoferrihydrite is the strongest As adsorbent among the Fe(III) oxyhydroxides and its

maximum sorption[8] is at a pH of approximately 7. Change in redox condition also oxidizes the arsenic species to As(V), which is inferred to be microbially mediated[9]. Oxidation of ferrous iron happens earlier, followed by oxidation of arsenic species. Conversion to As(V) makes the sorption and retention of arsenic more effective because the pentavalent species is less reactive, less soluble and adsorbed more on Fe(III) oxyhydroxides[8].

However, amorphous Fe(III) oxyhydroxides may not be the only arsenic sink, as oxidation of arsenic species to As(V) plays an important role in deciding the efficiency of adsorption of the element. Other suspended fines like illite, biotite, chlorite grains with high specific surface area may act as equally important sinks for the element.

While filtering groundwater using domestic clay-candle filter or 0.45 μm membrane filter, change in redox condition is introduced. Insoluble Fe(III) oxyhydroxide precipitates on the clay-candle or the membrane, which is evident by the change in colour of the filter elements after use. The oxyhydroxide precipitate being in the amorphous state, has large specific surface area and therefore has greater capacity to adsorb arsenic in the ionic state. The level of iron present in a particular water sample will, therefore, exert significant control on the amount of arsenic which may be removed through adsorption. Another parameter, which ought to have an influence, is the time of exposure of water to atmospheric oxygen prior to and during the filtration process. Adsorption onto other particulate matter, mostly iron-bearing oxide and silicate minerals, is guided by the same principles. These particulate materials carrying adsorbed arsenic onto their surface would also be screened during the filtration process.

Variation in percentage removal of arsenic observed among members of the present set of samples is an artifact of the variation in iron content of water and also the
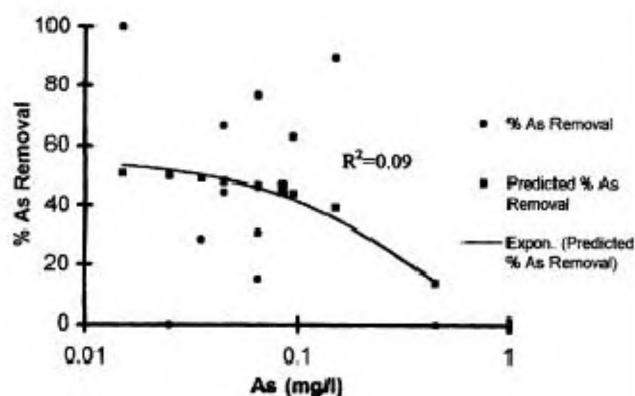
Figure 5. Arsenic concentration–percentage of arsenic removal regression plot of water samples (filtration by 45 µm membrane filter) from wells in 24 Parganas (N) and Nadia districts of West Bengal.

Table 3. Arsenic removal in percentage by 0.45 µm membrane filter

Percentage arsenic removal	No. of samples	Percentage	CUM %	Arsenic range (mg/l)	Depth range (ft)
100	1	7	7	0.015	30
80–99	1	7	14	0.150	30
60–79	3	20	34	0.045–0.095	90–220
40–59	3	20	54	0.045–0.085	90–160
20–39	4	26	80	0.035–0.065	50–120
0–19	3	20	100	0.025–0.450	50–120

time required for filtration. However, the data indicate that in 20% of the cases, complete removal of arsenic can be achieved by this simple and cheap method. Even 60% removal achievable in 62% of the cases is good enough for providing drinking water with arsenic below permissible limit for a large number of people.

Difference in percentage removal is observed when clay-candle and membrane filter data are compared. This reflects the difference in effectiveness of the two types of filters used. With membrane filter only 7% of the samples record 100% removal, compared to 20% samples showing 100% removal using clay-candle filter. Sixty per cent removal is effected for 34% samples using membrane filter compared to 62% using clay-candle filter. The relation between percentage removal and arsenic concentration in the samples also registers differences for the two types of filters (Figures 4 and 5).

It is now known that a myriad of metal species pass through 0.45 µm membrane filter, including metals bound in colloids with clay[10]. Clay-candle filters remove arsenic in three different ways: namely (i) arsenic adsorbed on the surface of particulate matter; (ii) arsenic adsorbed on insoluble Fe(III) oxyhydroxide, and (iii) arsenic ion getting adsorbed directly on the surface of the clay-candle. In contrast, with the membrane filter, only the first two processes are operative. Combining with the less effective nature of the membrane filter in screening particulate

metals, this would mean less efficient arsenic removal by them compared to clay-candle filters.

Conclusion

Managing the problem of arsenic pollution needs an understanding of the process creating the contamination. It also needs effective planning, smooth operation of the administrative machinery and institutionalized expenditure. In the densely populated areas of West Bengal delta, providing and maintaining expensive community-based filters require huge resources. Data presented here suggest that part of the total arsenic in water samples is in the adsorbed state on fine particles and the remaining as soluble oxyanions. Groundwater pumped out for use is exposed to atmospheric oxygen causing transformation of soluble ferrous iron to insoluble amorphous Fe(III) oxyhydroxide. Arsenic species converted to As(V) during the course of the same oxidation process is substantially adsorbed on Fe(III) oxyhydroxide. Arsenic adsorbed on both types of substrate can be removed using clay-candle domestic filters.

Proportion of soluble and particulate arsenic varies from place to place and this information can be utilized for formulating area-specific strategies. Areas where optimum arsenic removal is possible using domestic filters, could be easily identified. This will reduce the expenditure involved for remediation programmes to a great extent and at the same time domestic mitigation plans can be introduced without the population waiting for institutional assistance for solution of the problem.

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