

EVALUATION OF LOW-COST ARSENIC MITIGATION TECHNOLOGIES AND COMMUNITY ACCEPTABILITY FOR SAFE DRINKING WATER IN RURAL CHHATTISGARH

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Abstract

Groundwater in parts of Rajnandgaon and Mohla-Manpur-Ambagarh Chowki districts of Chhattisgarh carries arsenic at 148 to 985 $\mu\text{g/L}$, far above the drinking water limit of 10 $\mu\text{g/L}$. Many low-cost technologies have been promoted for such water, but their record in the field is mixed, and none has been evaluated against the chemistry of this hard-rock aquifer. This study evaluates seven low-cost household technologies, community treatment units and non-treatment alternatives on four criteria: the removal efficiency the local water requires, cost, reliability in the field, and acceptance by the people who must use them. Published performance and survey data were re-analysed and applied to the local water chemistry. The local water needs 93 to 99 per cent arsenic removal to reach 10 $\mu\text{g/L}$, whereas the household technologies remove 30 to 95 per cent. At the mean local concentration of 506 $\mu\text{g/L}$, the best household filter leaves about 25 $\mu\text{g/L}$, and it can bring only two of twenty reported wells below the limit. The technologies based on iron also leave fluoride, which occurs in the same wells at 3.7 to 27 mg/L , untreated. Field evidence shows that technical capacity is not the main constraint: 82 per cent of 577 community arsenic removal plants surveyed in West Bengal were not useful, mainly for want of maintenance and community participation, and 28 per cent of household iron filters in a Bangladesh study were out of use. Among households with access to a safe option, use ranged from 37 per cent for rainwater harvesting to 86 per cent for piped water and 93 per cent for household filters, and distance to the safe source was the leading reason for non-use. The study concludes that no single low-cost technology is sufficient for rural Chhattisgarh. A tiered approach is recommended: switching to tested safe wells and treated surface water where available, community units with activated alumina where both arsenic and fluoride must be removed, and household iron filters only as an interim measure for wells below about 200 $\mu\text{g/L}$. A local acceptability survey is needed before any option is scaled up.

Keywords: arsenic removal; low-cost technology; activated alumina; zero-valent iron; community acceptability; rural water supply; fluoride; Chhattisgarh

1. Introduction

Arsenic in drinking water is a proven cause of skin lesions and of cancers of the skin, lung and bladder, and the World Health Organization recommends that drinking water should not contain more than 10 $\mu\text{g/L}$ (WHO, 2011). The Indian standard IS 10500 adopts the same value (BIS, 2012). In rural India the difficulty is not in knowing the limit but in meeting it. Most arsenic-affected villages depend on hand pumps, have no piped supply, and cannot bear the cost of conventional treatment plants. This has led, over three decades, to the development of a large number of low-cost arsenic removal technologies intended for use at the household or the hand pump.

The record of these technologies is uneven. Many perform well in the laboratory and in the first months of

use, and then fail in the field because media are not replaced, units clog, or users return to the nearer contaminated well. A technology that removes arsenic but is not used gives no protection. For this reason the evaluation of a mitigation option has two parts of equal weight: whether it can treat the water in question, and whether the community will accept, pay for and maintain it.

The Ambagarh Chowki area of Chhattisgarh presents this problem in a severe form. Arsenic was first reported there in 1999, with skin lesions in 42 per cent of adults examined in the worst affected village (Chakraborti et al., 1999). The contamination originates in arsenic sulphide minerals in granite and pegmatite and is confined to a belt of villages around Kaudikasa (Shukla et al., 2010). A detailed hydrochemical study recorded 148 to 985 $\mu\text{g/L}$ of arsenic in twenty tube wells, together with fluoride at 3.7 to 27 mg/L (Patel et al., 2017). The affected population is rural, largely tribal and dependent on groundwater.

Almost all the evidence on low-cost arsenic mitigation comes from the alluvial plains of Bangladesh and West Bengal, where the water chemistry and the social setting are both different. No study has asked which of these technologies would work with the water of rural Chhattisgarh, or how its communities would receive them. This study addresses that gap. Its objectives are:

- to determine the removal efficiency that the local groundwater requires of any treatment technology;
- to compare low-cost technologies on removal performance and cost, and to apply their reported performance to the local water chemistry;
- to examine the reliability of household and community systems under field conditions;
- to analyse published evidence on community acceptance and use of arsenic-safe water options; and
- to derive an integrated evaluation and a set of recommendations for rural Chhattisgarh.

2. Materials and Methods

2.1 Design and data sources

This is an analytical study based on published data. No field survey or laboratory experiment was carried out. The sources and the use made of each are as follows.

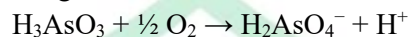
- **Local water chemistry.** Arsenic, iron, fluoride and pH in twenty tube wells of the Kaudikasa area (Patel et al., 2017) define the water that a technology must treat.
- **Technology performance and cost.** Removal efficiency, flow rate, capital cost and running cost of household technologies were taken from a published technical compendium (Akvopedia, n.d.), and the cost of a community wellhead unit from a field report (Stevenson, 2008).
- **Field reliability.** A survey of 577 community arsenic removal plants in West Bengal (Hossain et al., 2006) and a technical and social evaluation of household iron filters in Bangladesh (Shafiquzzaman et al., 2009).
- **Community acceptance.** A survey of 1,268 households with access to eight arsenic-safe water options in Bangladesh (Inauen et al., 2013), and the user-preference data of Shafiquzzaman et al. (2009).
- **Local trials.** A batch study of rice husk as an adsorbent using water samples from the Ambagarh Chowki region (Sahu and Pillai, 2026).

2.2 Chemical basis of the technologies

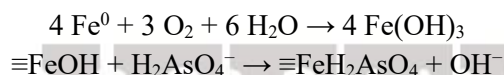
All the low-cost technologies rely on a small number of chemical processes, and their limits follow from that chemistry.

Oxidation. Arsenic occurs in groundwater as arsenite, As(III) , and arsenate, As(V) . Below pH 9.2 arsenite is present as the uncharged molecule H_3AsO_3 , which is poorly held by any adsorbent. Arsenate is present

as the anions H_2AsO_4^- and HAsO_4^{2-} , which are readily adsorbed. Efficient removal therefore requires arsenite to be oxidised first, by air, sunlight or a chemical oxidant such as hypochlorite or permanganate:

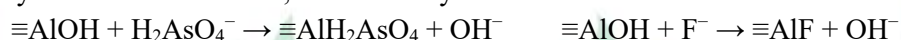


Adsorption and co-precipitation on iron. Iron-based filters contain zero-valent iron as nails, filings or a cast composite. The iron corrodes in aerated water and forms hydrous ferric oxide, on which arsenate is bound as a surface complex:



Coagulation with an iron or aluminium salt works in the same way, except that the hydroxide is formed by adding the salt and is removed with the arsenic by settling and filtration. Passive and solar oxidation depend on the iron naturally present in the water.

Adsorption on activated alumina. Activated alumina binds arsenate on its surface hydroxyl groups and binds fluoride by the same mechanism, which is why it is also the standard defluoridation medium:



Its capacity is highest in slightly acidic water and falls as pH rises above 7. The medium is exhausted after a certain volume and must be regenerated with alkali and acid or replaced.

2.3 Evaluation criteria and calculations

Each option was evaluated on four criteria: adequacy of arsenic removal for the local water, cost, reliability in the field, and community acceptance. The removal efficiency required to bring a raw water concentration C_0 down to a target C_t , and the residual concentration C_r left by a technology of efficiency R , were calculated as:

$$\text{Required removal (\%)} = (1 - C_t / C_0) \times 100 \quad C_r = C_0 \times (1 - R)$$

The highest raw concentration that a technology can bring down to the target is $C_t / (1 - R)$. Capital cost was annualised by dividing it by the reported service life. Where a study reported both the share of units in operation and the share meeting the standard, the two were multiplied to give an effective protection rate. Costs are quoted in United States dollars as reported in the sources and are not adjusted for inflation.

3. Results and Discussion

3.1 What the local water demands of a technology

Table 1 gives the removal efficiency required at the concentrations reported from the twenty tube wells of the Kaudikasa area.

Table 1. Arsenic removal required to treat the groundwater of the study area

Raw water arsenic ($\mu\text{g/L}$)	Basis	Removal needed to reach 10 $\mu\text{g/L}$ (%)	Removal needed to reach 50 $\mu\text{g/L}$ (%)
148	Lowest tube well	93.2	66.2
506	Mean of tube wells	98.0	90.1
713	Mean raised by 41% (pre-monsoon)	98.6	93.0
985	Highest tube well	99.0	94.9

Even the least contaminated well needs more than 93 per cent removal to meet the limit, and the mean needs 98 per cent. Arsenic in these wells rises by up to 41 per cent in the pre-monsoon season, so a unit sized for post-monsoon water will be under-designed for the summer. Three other features of the water matter for the choice of technology.

- **Low natural iron.** Dissolved iron averages 1.63 mg/L (range 0.90 to 2.25 mg/L), only about three times the arsenic by mass. Technologies that rely on natural iron cannot work here: solar oxidation is

reported to remove 75 to 90 per cent of arsenic only where iron exceeds 8 mg/L, and less than 50 per cent where iron is below 5 mg/L.

- **Fluoride in the same wells.** Fluoride at 3.7 to 27 mg/L exceeds its limit of 1.5 mg/L in every well. A technology that removes arsenic alone leaves the water unfit to drink.
- **Near-neutral to alkaline pH.** The pH is 6.4 to 7.9 after the monsoon and up to 8.3 before it, which is above the range in which activated alumina has its highest capacity. The water is oxygenated at the well head, which suggests that much of the arsenic is already present as arsenate, but speciation has not been measured and pre-oxidation should not be omitted.

3.2 Technical performance of low-cost technologies

Table 2 summarises the household technologies for which removal and cost data are published. Table 3 applies their removal efficiencies to the mean local concentration, and Figure 1 shows the residual arsenic at the best reported efficiency of each.

Table 2. Reported performance and cost of low-cost household arsenic removal technologies

Technology	Principle	Arsenic removal (%)	Capital cost (US\$)	Running cost and service life
Passive oxidation	Overnight settling with natural iron	30–50	Minimal	None
Bucket treatment unit	Alum coagulation with permanganate	About 60	10	Chemicals US\$ 15–20 a year
2-Kolshi filter	Iron salt coagulation with hypochlorite	90	10	Chemicals US\$ 15–20 a year
Shapla filter	Iron-coated brick chips	80–90	10	Media US\$ 10–15 a year; media last 3–6 months
Nirmal filter	Activated alumina with ceramic candle	80–90	10–15	Regeneration every 6 months
Magc-Alcan filter	Activated alumina, two buckets	80–85	35–50	Media last 6–12 months
Sono filter	Composite iron matrix, sand, charcoal	90–95	40–50	No chemicals; unit replaced after 3–5 years

Table 3. Arsenic remaining after treatment of water containing 506 µg/L (local mean)

Technology	At lowest reported efficiency (µg/L)	At highest reported efficiency (µg/L)	Highest raw water treatable to 10 µg/L (µg/L)
Passive oxidation	354	253	20
Bucket treatment unit	202	202	25
Magc-Alcan filter	101	76	67
Nirmal filter	101	51	100
Shapla filter	101	51	100
2-Kolshi filter	51	51	100
Sono filter	51	25	200

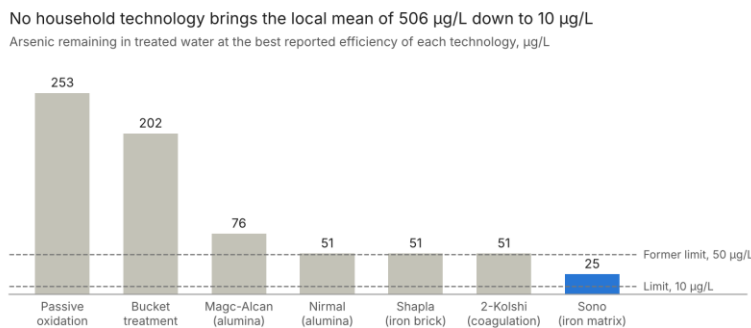


Figure 1. Arsenic remaining in treated water at the local mean concentration, by technology.

The result is clear. None of the household technologies brings water of 506 µg/L down to the 10 µg/L limit. The best of them, the composite iron filter at 95 per cent removal, leaves about 25 µg/L at the mean and about 49 µg/L at the highest well. Applied well by well to the twenty tube wells, 95 per cent removal brings only two wells below 10 µg/L, although it brings all twenty below the former limit of 50 µg/L. At 90 per cent removal no well meets 10 µg/L and only ten meet 50 µg/L. A filter of this class can treat raw water to the limit only where arsenic is below about 200 µg/L.

These figures need two qualifications. First, percentage removal is not a fixed property of a filter. It depends on pH, on competing ions such as phosphate and silicate, and on the age of the medium, and the published efficiencies were measured on alluvial groundwater with a few hundred µg/L of arsenic. Performance on the local water may be better or worse and must be established by trial. Second, the calculation concerns arsenic only. Iron-based filters and coagulation do not remove fluoride to any useful extent, so on local water they cannot produce drinkable water whatever their arsenic performance. Of the technologies in Table 2, only those using activated alumina address both contaminants, and their arsenic removal of 80 to 90 per cent is not sufficient alone at these concentrations. Two-stage treatment, or treatment in a larger column with longer contact time, is indicated.

A locally available adsorbent has also been tested. Rice husk at 5 g/L removed a mean of 68 per cent of arsenic from fifteen water samples of the Ambagarh Chowki region (Sahu and Pillai, 2026). The raw samples in that study contained only 1.97 to 6.79 µg/L, which is already below the limit. The result shows that the material has some affinity for arsenic, but it says nothing about performance at several hundred µg/L, where adsorbent capacity and not affinity is the controlling factor. Rice husk cannot be recommended for the affected wells on present evidence.

3.3 Cost

Table 4 expresses the costs on a common basis of one household for one year.

Table 4. Indicative cost of arsenic treatment per household per year

Option	Capital cost (US\$)	Service life	Annualised capital (US\$ per household)	Recurring cost (US\$ per household per year)
Bucket treatment or 2-Kolshi	10	Not reported	Not calculated	15–20 (chemicals)
Shapla filter	10	Not reported	Not calculated	10–15 (media)
Sono filter	40–50	3–5 years	8–17	None reported
Community wellhead unit, activated alumina	2,000 for up to 300 families	10–15 years	0.4–0.7	Regeneration every 8–12 months and caretaker; not reported

A household filter costs roughly US\$ 8 to 20 per household per year. A community unit serving up to 300 families costs about US\$ 7 per family in capital, or well under US\$ 1 per family per year over its life, to which regeneration and a caretaker must be added. On capital cost alone the community unit is cheaper by an order of magnitude, provided that the families it is designed for actually use it. In Bangladesh, households paid a mean of 16 taka a month for community arsenic removal and 62 taka a month for piped water (Inauen et al., 2013).

Willingness to pay is far below cost. In the Bangladesh evaluation the iron filter cost US\$ 45 to 50, households had paid about US\$ 2 for it, and only about 30 per cent of households were willing to pay anything for a household filter, the amounts offered being US\$ 1 to 5 (Shafiquzzaman et al., 2009). A subsidy of 90 per cent or more was therefore needed. The same must be expected in rural Chhattisgarh, and a programme that distributes subsidised filters without funding their replacement after three to five years only postpones the problem.

3.4 Reliability in the field

Laboratory efficiency and cost describe what a technology can do. Field surveys show what it does. Two bodies of evidence are available.

Community arsenic removal plants. Of about 1,900 plants attached to hand pumps in five districts of West Bengal, 577 were surveyed (Hossain et al., 2006). The findings were as follows.

- 145 plants (25.1 per cent) were defunct.
- Among 264 working plants whose raw water exceeded 50 µg/L, 140 (53.1 per cent) failed to bring arsenic below 10 µg/L and 73 (27.7 per cent) failed to bring it below 50 µg/L. The highest arsenic found in treated water was 705 µg/L.
- Of 217 treated samples tested for iron, 175 (80.6 per cent) exceeded 0.3 mg/L. Treated water from 44.2 per cent of plants turned coloured on standing and 5.8 per cent had a bad odour.
- Forty-eight plants had been installed on wells whose raw water was already below 50 µg/L.
- Overall, 475 plants (82.3 per cent) were judged not useful.

The causes identified were improper maintenance, sand gushing from the tube well, lack of user-friendliness and the absence of community participation. None of these is a failure of chemistry. At about US\$ 1,500 per plant, the 1,900 plants represent an outlay of some US\$ 2.85 million; if the surveyed proportion held for all of them, about US\$ 2.3 million was spent on plants that did not deliver safe water. By contrast, a programme of 110 wellhead units with activated alumina in the same state, each managed by a village water committee with a paid caretaker and periodic regeneration of the medium, was reported to be serving more than 33,000 people (Stevenson, 2008). The difference between the two programmes lies in management, not in the adsorbent.

Household filters. In a Bangladesh study of 198 composite iron filters, 142 (72 per cent) were in operation and 56 (28 per cent) were out of use, most of them through breakage within the first year (Shafiquzzaman et al., 2009). The working filters removed about 93 per cent of arsenic, from about 200 µg/L to 14 ± 10 µg/L. All met the 50 µg/L standard, but only half met 10 µg/L. Multiplying the two proportions, the effective protection rate was 72 per cent against the 50 µg/L standard and 36 per cent against the 10 µg/L limit. Frequent clogging was reported by 41 per cent of users and an insufficient daily volume by 36 per cent.

The lesson for Chhattisgarh is direct. A filter that is 93 per cent efficient in the hands of its users protects about a third of households to the present standard, and that was achieved with raw water at 200 µg/L, less than half the local mean.

3.5 Community acceptance and use

Table 5 and Figure 2 give the proportion of households that used an arsenic-safe option when they had access to one, from a survey of 1,268 households in Bangladesh.

Table 5. Use of arsenic-safe water options by households with access to them

Option	Households with access	Using the option (%)
Household arsenic removal filter	154	92.9
Piped water supply	277	85.6
Well-sharing (neighbour's safe well)	205	73.2
Community arsenic removal filter	161	69.6
Deep tube well	396	54.0
Pond sand filter	168	50.0
Dug well	189	45.0
Rainwater harvesting	178	36.6

Piped water and household filters are used most; dug wells and rainwater least
Households with access to each arsenic-safe option that actually use it, per cent

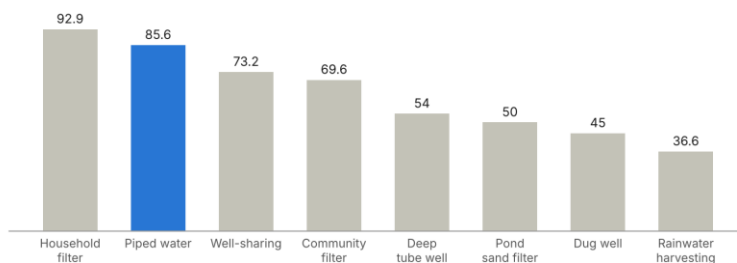


Figure 2. Use of arsenic-safe water options among households with access.

Although every household surveyed had access to at least one safe option, only 62.1 per cent were using one. Access alone leaves more than a third of the population unprotected. Use varied widely between options. Household filters and piped water were used by more than 85 per cent of those who had them; the authors caution that the figure for household filters may be biased upward by a high refusal rate. Dug wells and rainwater harvesting were used by fewer than half. The pattern is explained by what the users reported. Piped water was rated well for taste and temperature and as taking little time. Dug wells received the lowest ratings for taste and temperature. Deep tube wells, dug wells, pond sand filters and shared wells were all rated as time-consuming. Households that had made a financial contribution to an option were more likely to use it.

Table 6 and Figure 3 give the reasons stated by households that continued to drink from contaminated wells in the second Bangladesh study.

Table 6. Reasons given by households for continuing to use contaminated wells

Reason	Households (%)
Safe source too far away	56
Lack of awareness	About 15
No alternative available	13
Cost	9
Indifference to health risk	5

Distance, not cost, is the main reason households keep using unsafe wells
Reasons given by households still drinking from contaminated wells, per cent

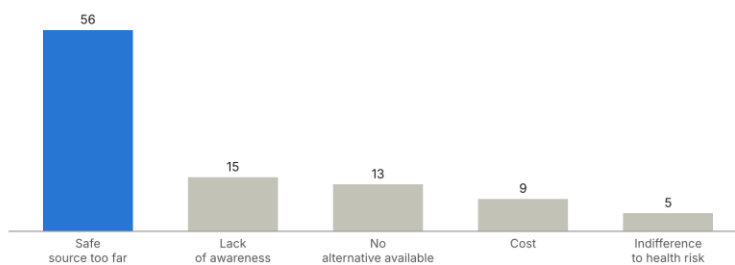


Figure 3. Reasons for continued use of contaminated wells. data of Shafiquzzaman et al. (2009).

Distance outweighed every other reason, and cost was named by fewer than one household in ten. Asked which option they would prefer, households divided almost equally between a household filter and a deep tube well; community filters were the first choice of only 3 to 5 per cent, and pond sand filters and rainwater harvesting of none. People want safe water at or near the home, and they prefer a source that needs no effort from them.

Three findings carry over to rural Chhattisgarh, with the caution that no acceptability survey has been conducted there.

- **Convenience decides use.** The water point must be as near as the contaminated hand pump it replaces. In dispersed tribal hamlets a single community unit at the village centre will not be used by outlying households.
- **Taste, colour and temperature matter.** Treated water that turns coloured on standing, as iron-rich water does, will be rejected even if it is safe. Iron in the local wells (0.90 to 2.25 mg/L) is well above the 0.3 mg/L limit and must be removed along with arsenic.
- **Participation predicts sustainability.** Units managed by a village committee, with a caretaker and a small monthly contribution, have lasted; units installed without the involvement of users have not.

3.6 Integrated evaluation for rural Chhattisgarh

Table 7 brings the four criteria together for the options that are realistic for the study area. The ratings are the judgement of this study, based on the evidence set out above.

Table 7. Integrated evaluation of mitigation options for the study area

Option	Arsenic removal adequate for local water	Removes fluoride	Cost	Field reliability	Community acceptance	Overall
Switching to tested safe wells	Yes, where a safe well exists	Only if the well is also low in fluoride	Very low	High	Good if nearby (73% use)	First choice where available
Dug wells	Uncertain; each must be tested	Uncertain	Low	Moderate	Poor (45% use)	Limited
Rainwater harvesting	Yes	Yes	Moderate	Seasonal	Poor (37% use)	Supplementary
Household iron filter	Only below about 200 µg/L	No	US\$ 8–17 a year	Moderate (72% in use)	Good	Interim only
Household alumina filter	No, at 80–90% removal	Yes	Low to moderate	Low; frequent regeneration	Not reported	Not sufficient alone
Community alumina unit with committee	Possible with adequate design	Yes	Under US\$ 1 a year capital	Depends on management	Moderate (70% use)	Recommended
Piped treated surface water	Yes	Yes	Highest	High	Best (86% use)	Long-term solution

No single low-cost technology satisfies all four criteria. The household iron filter is well accepted but cannot treat the local water to the limit and does not touch fluoride. The household alumina filter treats fluoride but not enough arsenic. The community alumina unit is the only treatment option that can address both contaminants at low cost, but its success depends entirely on how it is managed. Options that avoid treatment altogether, namely a tested safe well nearby or piped surface water, score best on reliability and acceptance. The Shivrath river has been reported to contain less than 10 µg/L of arsenic (Acharyya, 2002), so surface water supply is technically feasible, though it is not a low-cost option.

Nationally, the number of arsenic-affected habitations reported to Parliament fell from 14,020 in August 2019 to 314 in December 2024, with the remainder served through community water purification plants (Down To Earth, 2024). The experience reviewed here suggests that such figures record provision, not use. Whether a habitation is protected depends on whether its plant is working, whether the treated water meets the limit, and whether households draw their drinking water from it.

4. Recommendations

The evidence supports a tiered strategy for the affected villages of Rajnandgaon and Mohla-Manpur-Ambagarh Chowki.

1. **Test and mark every source.** Each hand pump and dug well in the affected belt should be tested for arsenic and fluoride in the pre-monsoon season and marked safe or unsafe. Well-switching costs almost nothing and is used by about three-quarters of households when the safe well is near.

2. **Install community units where no safe source is within reach.** Units should use activated alumina, or an iron-based stage followed by activated alumina, so that arsenic, fluoride and iron are all removed. They should be designed for pre-monsoon concentrations and placed at hamlet level and not only at the village centre.
3. **Make community management a condition of installation.** A village water committee, a trained and paid caretaker, a small monthly contribution and a fixed schedule for regeneration and for testing of treated water should be in place before a unit is commissioned.
4. **Use household iron filters only as an interim measure.** They are suitable for wells below about 200 µg/L of arsenic and with acceptable fluoride. Their replacement after three to five years must be funded.
5. **Do not rely on passive or solar oxidation, or on untested adsorbents.** The natural iron content of the local water is too low for the first two, and rice husk has not been tested at the concentrations that occur.
6. **Plan for piped surface water.** Treated river water is the most accepted and most reliable option and should be the long-term goal for the affected belt.
7. **Conduct a local acceptability survey.** Before any option is scaled up, households in the affected villages should be surveyed on present water sources, distance, taste preferences, willingness to pay and readiness to manage a shared unit.

5. Conclusion

The groundwater of the affected villages requires 93 to 99 per cent arsenic removal to meet the drinking water limit, and it carries fluoride and iron as well. Low-cost household technologies remove 30 to 95 per cent of arsenic. At the local mean of 506 µg/L the best of them leaves about 25 µg/L, and it can treat to the limit only where the raw water is below about 200 µg/L. Technologies based on iron do not remove fluoride, and those that depend on natural iron cannot work in this water.

Cost is not the decisive factor. Household filters cost US\$ 8 to 20 per household per year, and a community unit costs far less per family, but households are willing to pay only a small fraction of either. What decides the outcome is reliability and acceptance. More than four-fifths of the community plants surveyed in West Bengal were not useful, for reasons of maintenance and participation. Only about a third of household filters in a Bangladesh study delivered water within the present limit. Among households with access to a safe option, more than a third did not use it, and distance was the main reason.

For rural Chhattisgarh the appropriate response is therefore a combination: safe wells where they exist, community units with activated alumina under village management where they do not, household iron filters as a temporary measure for the less contaminated wells, and piped surface water in the long term.

Limitations. This study rests on published data. Technology efficiencies and costs come from a secondary compendium and from studies on alluvial groundwater, and may not hold for the local water. The acceptance data come from Bangladesh, where settlement pattern, income and culture differ from those of tribal Chhattisgarh. The costs are in historical dollars. The integrated ratings are judgements. Pilot trials of the recommended units on local water, and a household survey in the affected villages, are needed to confirm these conclusions.

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