Cost and Efficiency of Arsenic Removal from Groundwater: A Review

Yina Shan, Praem Mehta, Duminda Perera and Yurissa Varela

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# CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>EXECUTIVE SUMMARY</td>
<td>5</td>
</tr>
<tr>
<td>INTRODUCTION</td>
<td>6</td>
</tr>
<tr>
<td>METHODOLOGY</td>
<td>7</td>
</tr>
<tr>
<td>RESULTS AND DISCUSSION</td>
<td>8</td>
</tr>
<tr>
<td>Summary of Reviewed Studies</td>
<td>8</td>
</tr>
<tr>
<td>Laboratory Studies</td>
<td>8</td>
</tr>
<tr>
<td>Field Studies</td>
<td>9</td>
</tr>
<tr>
<td>Review Limitations</td>
<td>14</td>
</tr>
<tr>
<td>CONCLUSIONS AND RECOMMENDATIONS</td>
<td>14</td>
</tr>
<tr>
<td>ACKNOWLEDGMENTS</td>
<td>16</td>
</tr>
<tr>
<td>REFERENCES</td>
<td>16</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

Hundreds of millions of people worldwide are exposed to arsenic-contaminated drinking water, leading to significant health complications, and social and economic losses. Currently, a wide range of technologies exists to remove arsenic from water. However, despite ongoing research on such technologies, their widespread application remains limited. To bridge this gap, this review aims to compare the effectiveness and costs of various arsenic remediation technologies while considering their practical applicability. A search conducted using the Medline and Embase databases yielded 31 relevant articles published from 1996 to 2018, which were categorized into laboratory and field studies. Data on the effectiveness of technologies in removing arsenic and associated costs were extracted and standardized for comparison as much as was possible, given the diversity of ways that studies report their key results.

The twenty-three (23) technologies tested in laboratory settings demonstrated efficiencies ranging from 50% to ~100%, with the majority reaching relatively high removal efficiencies (>90%). Approximately half achieved the WHO standard of 10 µg/L. Laboratory studies used groundwater samples from nine (9) different countries - Argentina, Bangladesh, Cambodia, China, Guatemala, India, Thailand, the United States, and Vietnam. The fourteen (14) technologies tested in the field achieved removal efficiency levels ranging between 60% and ~99%, with ten (10) attaining above 90% removal efficiency. Of these, only five (5) reached established the WHO standard. Some of the technologies under-performed when their influent water contained excessive concentrations of arsenic. Only six (6) countries (Argentina, Bangladesh, Chile, China, India, and Nicaragua) were represented among the studies that implemented and tested technologies in the field, either at household or community level.

For technologies tested in the laboratory, the cost of treating one cubic meter of water ranged from near-zero to ~USD 93, except for one technology which cost USD 299/m³. For studies conducted in the field, the cost of treating one cubic meter of water ranged from near-zero to ~USD 70. Key factors influencing the removal efficiencies and their costs include the arsenic concentration of the influent water, pH of the influent water, materials used, the energy required, absorption capacity, labour used, regeneration period and geographical location. Technologies that demonstrate high removal efficiencies when treating moderately arsenic-contaminated water may not be as efficient when treating highly contaminated water. Also, the lifetime of the removal agents is a significant factor in determining their efficiency.

It is suggested that remediation technologies that demonstrate high arsenic removal efficiencies in a laboratory setting need to be further assessed for their suitability for larger-scale application, considering their high production and operational costs. Costs can be reduced by using locally available materials and natural adsorbents, which provide near zero-cost options and can have high arsenic removal efficiencies.

A notable feature of many arsenic removal approaches is that some countries with resource constraints or certain environmental circumstances – like typically high arsenic concentrations in groundwater – aim to reach resultant arsenic concentrations that are much higher than WHO’s recommended standard of 10 µg/L. This report maintains that – while this may be a pragmatic approach that helps progressively mitigate the arsenic-related health risks – it is unfortunately not a sustainable solution. Continuing exposure to higher levels of arsenic ingestion remains harmful for humans. Hence arsenic-removal technology should only be seen efficient if it can bring the water to the WHO standard. A less radical approach effectively shifts the attention from the origin of the problem in addressing the impacts and postpones achieving the best possible outcome for populations.

The quantitative summary of costs and effectiveness of arsenic remediation technologies reviewed in this report can serve as a preliminary guideline for selecting the most cost-effective option. It may also be used as an initial guideline (minimum standard) for summarising the results of future studies describing arsenic remediation approaches.

Looking ahead, this study identifies four priority areas that may assist in commercializing wide-scale implementation of arsenic removal technologies. These include: i) focusing efforts on determining market viability of technologies, ii) overcoming practical limitations of technologies, iii) determining technology contextual appropriateness and iv) concerted effort to increase knowledge sharing in and across regions to accelerate the implementation of research on the ground. Overall, the current science and knowledge on arsenic remediation technologies may be mature enough already to help significantly reduce the global numbers of affected populations. The missing link for today’s arsenic removal challenge is the ability to translate research evidence and laboratory-level successes into quantifiable and sustainable impacts on the ground. Achieving this requires a concerted and sustained effort from policymakers, engineers, healthcare providers, donors, and community leaders.

Keywords: Arsenic; drinking water; groundwater; arsenic removal technology; arsenic removal efficiency; remediation cost
INTRODUCTION

Contamination of groundwater with arsenic is a major environmental concern affecting the health of some 140 million people in over 50 countries worldwide (WHO, 2018). Arsenic, a naturally occurring metalloid, is present in inorganic and organic forms (Carlin et al., 2016). Organic arsenic is relatively safe, but its inorganic form is toxic. In natural water, arsenic takes its inorganic form - most commonly as arsenite [trivalent arsenic, As(III)] and arsenate [pentavalent arsenic, As(V)] (Abernathy et al., 1999; Hughes et al., 2011). These two forms of inorganic arsenic can be absorbed and accumulated in tissues and bodily fluids.

Sources of arsenic contamination can be categorized into two main groups: geogenic (naturally occurring) and industrial. Under natural conditions, specific geological settings facilitate the mobilization of arsenic. These can include the weathering of arsenic-rich rocks or conditions in arid areas, where high pH can mobilize arsenic in oxygen-rich groundwater (Schwarzenbach et al., 2010; Liao et al., 2011). Arsenic contamination is also mobilized by human interventions, such as mining, the use of fertilizers and pesticides, waste disposal, and industrial manufacturing (Duker et al., 2005). Globally, the primary route of human exposure to arsenic is through the ingestion of contaminated drinking water, or irrigation water that makes its way into food through plant roots (Hughes et al., 2011; Naujokas et al, 2013; Chung et al., 2014; EFSA, 2014; WHO, 2018).

Exposure to arsenic leads to severe health, social and economic implications, including arsenicism (e.g. muscular weakness, mild psychological effects), skin lesions and cancers of lung, liver, kidney, bladder, and skin (Ahmed et al., 2011; Mahmood and Halder, 2011; Naujokas et al 2013; Abdul et al., 2015). The social implications of arsenic-induced health impacts include stigmatization, isolation, and social instability for affected individuals (Brinkel et al., 2009). In addition, arsenic-related health complications and mortality lead to significant economic losses. In Bangladesh, the economic burden resulting from lost productivity due to arsenic-attributable mortality is estimated to reach USD 13.8 billion by around 2030 (Flanagan et al., 2012).

The toxicity and carcinogenicity of arsenic attract international attention and response (Ng et al., 2003; Tchouwou et al., 2003). In 2010, the WHO designed 10 μg/L as the acceptable limit for arsenic concentrations in drinking water (WHO, 2011). Furthermore, Sustainable Development Goal 3 (SDG 3 - “good health and well-being”) of the 2030 Agenda, adopted by all United Nations (UN) the Member States in 2015, recognized the need to remove hazardous chemicals, including arsenic, from the world’s ecosystems. SDG target 3.9 specifically aims to “substantially reduce the number of deaths and illnesses from hazardous chemicals and air, water, and soil pollution and contamination” (https://sustainabledevelopment.un.org). This was further recognized under SDG 6 (“Clean water and sanitation”) which includes target 6.3 calling for an “improvement to water quality by reducing pollution, eliminating dumping and minimizing the release of hazardous chemicals and materials” (https://sustainabledevelopment.un.org). The SDGs clearly state that addressing the arsenic challenge is a critical step in achieving sustainable development.

High natural levels of inorganic arsenic exceeding the WHO limit are a characteristic feature of groundwater in many countries, including Bangladesh, India, Nepal, Mongolia, and the United States (WHO, 2018). Some countries with resource constraints and with certain social or environmental context have set limits higher than WHO’s recommended 10 μg/L to mitigate the arsenic-related health risks progressively. But this policy approach is not well-conceived as it does not effectively resolve the issue. On the contrary, it shifts the attention from the origin of the problem in addressing the impacts and does not prevent humans from exposure to higher arsenic concentrations. For example, in Bangladesh, where the nationally acceptable arsenic limit in water is set to 50 μg/L (Smith et al., 2000), over 20 million people are estimated to still consume water with even higher arsenic levels than the national standard (Yunus et al., 2016). Furthermore, despite international efforts, millions of people globally continue to be exposed to concentrations reaching and exceeding 100 μg/L (WHO, 2011, 2018).

The primary strategies for the provision of safe, arsenic-free or low-arsenic water are mitigation and remediation. Mitigation involves providing safe water from alternative sources. For example, high-arsenic groundwater can be replaced with low-arsenic rainwater. Remediation involves removing arsenic from water using centralized or household arsenic removal technologies (WHO, 2018). The success of any of these interventions relies on effective community education and engagement (Smith et al., 2000). Remediation is the most viable solution, particularly in regions with limited or no access to alternative sources of clean water. Globally, significant investments are being made in these kinds of treatments, but the total positive impact of these efforts is difficult to assess. Despite this progress, the global population affected by arsenic-contaminated water remains high. This is due largely to a lack of commercially available remediation technologies. These technologies vary widely, and their implementation depends on the quality of the source water (Ravencroft et al., 2009). Given the economic limitations of certain nations, communities, and households, it is critical to have a clear understanding of what are the most cost-effective remediation options.
for low-income settings. Currently, there is a myriad of reportedly ‘low-cost’ technologies for treating arsenic-contaminated water (Kabir and Chowdhury, 2017). But the specific costs associated with these technologies are rarely documented.

This report examines peer-reviewed literature on the state-of-the-art of technologies for remediation of arsenic-contaminated water. It evaluates the relative costs and effectiveness of these technologies and considers any limitations of their applicability. The scope of the report is global. The main objective is to help accelerate the wide-scale implementation of remediation solutions to alleviate, and ultimately eradicate, the problem over the next decade – over the remaining duration of the SDGs timeline. This report aims to inform decision-makers who face an arsenic public health challenge, of the specific costs and effectiveness of technologies tested in laboratory or field settings. It also urges researchers to present cost and effectiveness data cohesively to better inform planners’ and policymakers’ choice of the best arsenic remediation technologies.

METHODOLOGY

Over the past few years, numerous studies have been done on the problem of arsenic contamination of groundwater, and comprehensive literature on the subject has been published (e.g., Ravenscroft et al., 2009; Eawag, 2015). A quick survey done for this report on the Scopus database (www.scopus.com/home.uri) suggests that from 2014 to 2018, over 17,400 arsenic-related publications were produced (in various related fields including medicine, biology, engineering, socio-economic, and environment) by the top ten countries publishing on the subject – China, USA, India, Germany, UK, Italy, Spain, Japan, Australia, and Canada. A significant number of publications have originated from arsenic-hit countries such as China, USA, India, Taiwan, Poland, Bangladesh, Argentina, and Brazil.

For this study, focusing exclusively on arsenic-remediation technologies, the two major databases of biomedical scholarly literature searched to identify relevant entries for analysis were Medline (www.nlm.nih.gov/bsd/pmresources.html) and Embase (www.elsevier.com/solutions/embase-biomedical-research). Medline database provides free access to information on biomedical literature from around the world. Embase provides access to additional 2,900 peer-reviewed biomedical and life sciences journals.

Search terms were organized under three categories combined with the “and” operator: water sources (“drinking water” or “fresh water” or “groundwater” or “lake water” or “river water” or “sea water” or “surface water” or “tapwater” or “wellwater” or “drinkingwater” or “water supply” or “water resources”), arsenic (“arsenic”), and cost (“cost” or “economic” or “investment”). Only peer-reviewed literature published between 1996 and 2018 and written in the English language was included. The query was not geographically limited.

After the search was conducted in each database, the titles and abstracts of the resulting articles were examined for relevance to this review, yielding 62 articles in Medline and 20 articles in Embase after the removal of duplicates. Articles that only made general statements regarding costs (i.e., ‘low-cost’) without providing numerical values were excluded. Articles focusing on mitigation efforts beyond remediation or removal methods, such as screening programs and field test kits, mass media and communication tools, and alternative water supply sources, were also excluded. In the case of different papers evaluating identical technologies, only the first was included, if the cost and effectiveness were consistent between the papers. The above screening and filtering resulted in 31 full-text papers that were eventually included in this review.

The following information was extracted from the included studies when provided:

- Geographic location
- Study design (i.e., laboratory, field, or review)
- The Scale of research (i.e., laboratory, household, or community)
- Water source
- Remediation technology and process
- Efficiency outcomes (i.e., influent and effluent concentrations, removal efficiency, meeting national or WHO standards)
- Cost of producing and/or operating remediation technology

The extracted data were used to calculate specific parameters for technology effectiveness and cost, when possible. To standardize the data on effectiveness, the following formula was used to calculate the arsenic removal efficiency of each technology, where $n$ is the arsenic removal efficiency, $C_0$ is the influent arsenic concentration of the water sample, and $C_e$ is the effluent arsenic concentration.

\[ n(\%) = \left( \frac{C_0 - C_e}{C_0} \right) \times 100 \]

To compare costs, all non-USD currencies were converted to USD based on the exchange rate for January 1 of the year of publication. Wherever possible, the cost of treating one cubic meter ($m^3$) of water was calculated to facilitate cost comparison between technologies. In certain cases, this calculation involved a unit conversion from the cost per litre of treated water. For other studies,
the total reported cost was divided by the volume of treated water. To standardize costs, all values were adjusted for inflation using the US Inflation Calculator tool (www.usinflationcalculator.com) which converts the cost value from the year in which the article was published to their equivalent value for 2018.

RESULTS AND DISCUSSION

Summary of Reviewed Studies

The review covered six (6) major types of remediation technologies presently available to remove arsenic from water: i) oxidation; ii) coagulation, precipitation and filtration iii) adsorption, iv) membrane technologies, v) bio-remediation and vi) ion exchange. Some remediation technologies and processes utilized a combination of these types (Garelick et al., 2005; Alçada et al., 2009; Singh et al., 2015).

Oxidation (OXI) involves the transformation of trivalent arsenic [As(III)] to pentavalent arsenic [As(V)]; the latter can form oxoanions, which facilitate many of the remediation technologies mentioned above process (Bissen and Frimmel, 2003). Many technologies benefit from this oxidative process which can be biologically catalyzed by bacterial species to enhance arsenic removal (Katsoyiannis and Zouboulis, 2004). For example, solar oxidation and removal of arsenic (SORAS) is a multi-step process involving the photochemical oxidation of As(III) to As(V), which is subsequently adsorbed onto ferric oxides and co-precipitated (Bundschuh et al., 2010). In general, co-precipitation (Co-P) requires arsenic to bind to the surface of the precipitate, which could occur via adsorption or another mechanism (Twidwell et al., 2005).

Coagulation (C), Precipitation (P) and Filtration (F): These combined processes typically follow three-steps: i) arsenite is oxidized to arsenate; ii) metal coagulants, usually iron or aluminum salts, convert arsenate to an insoluble compound; and iii) the solid particles are removed by filtration (Wickramasinghe et al., 2004; Sancha, 2006).

Adsorption (ADS) technologies are also very common, and a wide range of naturally occurring and synthetic adsorbents are currently being used or investigated. Many adsorbents, such as those based on aluminum, require the oxidation of arsenite to arsenate, but other adsorptive media can function without pre-oxidation (Mohan and Pittman, 2007).

Membrane (MEM) technologies rely on the use of synthetic membranes that contain billions of microscopic holes that act as selective barriers which control the movement of molecules. This is often done under pressure ranging from low to high (Figoli et al., 2016).

Bio-remediation (BIO) involves the use of biological techniques found in nature to remove arsenic from contaminated water. Among these are such methods as phytoremediation, where renewable plant biomass is used as an adsorbent, and bio-filtration (Tu et al., 2004; Pokhrel and Viraraghavan, 2009).

Ion Exchange (ION) is a physical-chemical process in which ions are swapped between a solution phase and solid resin phase. For an effective ion exchange process oxidization of arsenite to arsenate is essential (Clifford et al., 1990).

Most of the investigated technologies used adsorption or precipitative processes, reflecting the greater volume of literature on adsorbents and precipitation. Several technologies employed both processes.

Technologies were also grouped into ‘laboratory’ or ‘field’ categories based on the settings in which they were implemented and evaluated. Significantly more of the reviewed studies were conducted in laboratories (23) than in the field or community (14). In both categories, the majority of studies originated from either Bangladesh or India and followed by fewer studies from Argentina, Chile, China, Cambodia, Guatemala, Nicaragua, Thailand, USA, and Vietnam.

Table 1 summarizes, in alphabetic order of the lead author, the efficiency of arsenic removal and costs of the remediation technologies from identified studies.

Laboratory studies

The 23 technologies tested in laboratory settings demonstrated efficiencies ranging from 50% to ~100%, with the majority reaching high removal efficiencies (>90%). It is important to note though that only 12 of these technologies achieved arsenic levels within the WHO 10 µg/L standard. Of the eight technologies that did not meet the WHO standard, four were able to achieve effluent concentrations below 50 µg/L, which is the national standard in Bangladesh and India. As mentioned earlier in this report, this hardly resolves the problem of arsenic remediation, and hence such technologies should be seen, strictly speaking, as inefficient. There were no data on whether four of the technologies extracted from the review by Visoffsettiareth and Ahmed (2008) met the WHO standard. One of the critical factors to achieve WHO or national threshold limits is the influent arsenic concentration. Most of the technologies which failed to achieve these standards, remove arsenic from the highly concentrated influent. So, while they could not reach the required standards, they may be seen as useful in reducing arsenic concentrations from very high
to lower levels. There may be a scope here to combine/cascade technologies to achieve the required standard.

The cost differences between these technologies ranged from nearly zero to ~USD 299. Six technologies were nearly zero-cost as they used only naturally-occurring materials or processes, such as biomass or natural co-precipitation processes in groundwater. The removal efficiency of the near zero-cost technologies ranged from 50% to 99%. There were discrepancies in the outcomes reported by studies investigating laterite, a natural geological adsorbent. Visoottiviseth and Ahmed (2008) reported a 50% to 90% range for removal efficiency, where Bundschuh et al. (2011) reported a removal efficiency of up to 99%. Similarly, for natural co-precipitation with metals in groundwater, the review by Visoottiviseth and Ahmed (2008) reported a lower efficiency than the study by Mantaz and Bache (2000). Discrepancies between these removal efficiency figures are due to various factors including the concentration of the materials used and the composition of influent water. Options that demonstrate high removal efficiencies when treating moderately contaminated water may not be as efficient when treating highly contaminated water sources.

Six technologies cost under USD 1 per cubic meter of treated water. For instance, the Mg-Fe-based hydrotalcite-like compound evaluated by Kato et al. (2013) and Kumasaka et al. (2013), which had a removal efficiency of 99.8%, cost between USD 0.01 and USD 0.38 per cubic meter. Another novel adsorption-based technology - Arsenic Removal Using Bottom Ash (ARUBA) - achieved 98% removal efficiency and cost USD 0.74 per cubic meter (Mathieu et al., 2010).

Three technologies proved to be significantly more expensive (in the range of USD 15.8 to USD 299). The most expensive of these was the ZeroWater® water pitcher filter which required replacing filters every 15 gallons (~57 litres). The original price of the ZeroWater® water pitcher (and filter) is ~USD 36 and requires the use of 17 more filters (~USD 15/filter) to treat one cubic meter of water, bringing the total to ~USD 299/m³ of treated water. The hydrogel adsorbent and chitosan goethite bio-nanocomposite beads are two novel adsorbents that demonstrated very high removal efficiencies – up to 99.8% and 98% respectively – but were relatively costly at ~USD 93 and ~USD 16 per cubic meter of treated water (Bundschuh et al., 2010; He et al., 2016). Eight laboratory studies published their estimated costs based on the operational duration of the technology or material used (such as cost per cubic meter of filter materials, cost per year, cost per 1 kg of absorbent etc.) that could not be standardized into cost per cubic meter of treated water, limiting direct cost comparisons.

Field Studies

Studies that reported implemented and technologies tested in the field – at the household or community level – originated from six countries, including Argentina, Bangladesh, Chile, China, India, and Nicaragua. The cost of treating one cubic meter of water ranged from near-zero to USD ~70.

Among the 14 field-tested technologies, ten attained 90% removal efficiency, and only three achieved 98%. Of these, only five technologies reached the WHO standard of 10 µg/L. Many of the field studies referenced 50 µg/L as the target effluent concentration. Six of the eight technologies that did not consistently reach the WHO standard were able to lower arsenic concentrations to below this target.

For the most part, the field studies investigated community-level treatment plants and household-level filtration systems. Four of the five treatment plants included in this review used adsorption processes with various adsorbents, including activated alumina and ferric hydroxide, and one used electrocoagulation. The technologies had high removal efficiencies of 90% to 99%. The cost to treat one cubic meter of water ranged from near-zero to USD 1.76, with the exception of the treatment plant using iron filings and sand, which costs ~USD 70 (Visoottiviseth and Ahmed, 2008). The most inexpensive option used ferric hydroxide as the adsorbent and was able to reduce arsenic concentrations to below 10 µg/L (Sen Gupta et al., 2009). However, it is unclear whether the same parameters were used to derive the costs for each plant. Certain publications explicitly mentioned capital and maintenance costs, where others only presented the cost per unit of treated water.

The studies evaluating household filters reported similar removal efficiencies and costs. The three filters employing adsorption techniques demonstrated efficiencies from 86% to over 95% (Shafiquzzaman et al., 2009; Shan et al., 2013; Smith et al., 2017). One of the filters reached the WHO standard, and the remaining two reached 50 µg/L level. The cost of each filtration unit was approximately USD 40. The filters using only conventional filtration techniques were much lower in cost, at under USD 5 per unit, but varied widely in efficiency (Haque et al., 2004; Hasan et al., 2012). In all cases, the longevity of the filter is one key factor influencing the long-term cost.

Technologies applied in the field face challenges such as the presence of competing ions in natural groundwater, longer periods of use, the need for maintenance by users and lack of community awareness and acceptance (de Espanza, 2006; Baig et al., 2013; Inauen et al., 2013). For example, the removal efficiency of treatment plants and household filters may decrease with sustained periods of
Table 1. Salient features of published technologies for remediation of arsenic-contaminated water

<table>
<thead>
<tr>
<th>Author(s); year</th>
<th>Origin of influent water</th>
<th>Remediation technology description</th>
<th>Initial concentration (µg/L)</th>
<th>Final concentration (µg/L)</th>
<th>Removal efficiency (%)</th>
<th>WHO standard reached?</th>
<th>Cost per m³ of treated water (USD)</th>
<th>Benefits</th>
<th>Limitations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barnaby et al., 2017</td>
<td>United States</td>
<td>ZeroWater® water pitcher filter</td>
<td>1000, 100</td>
<td>99.7, 100</td>
<td>Yes</td>
<td>Yes</td>
<td>299</td>
<td>• Highly effective</td>
<td>• High cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Generate less plastic than bottled water</td>
<td>• Short-term solution</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Similar cost to bottled water alternative</td>
<td>• Low practicality</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• High maintenance</td>
<td>• High maintenance</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Produces plastic waste</td>
<td>• Produces plastic waste</td>
<td></td>
</tr>
<tr>
<td>Bundschuh et al., 2010</td>
<td>Argentina</td>
<td>Hydrogel adsorbent</td>
<td>40 - 5000</td>
<td>Up to 99.8</td>
<td>Yes</td>
<td>Yes</td>
<td>92.8</td>
<td>• Highly effective</td>
<td>• Not affordable for isolated population</td>
</tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Similar cost to water alternative</td>
<td>• Access to laterite may be limited</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Low absorption time (5-10 minutes)</td>
<td>• High transportation costs</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>• Produces sludge</td>
<td>• Leaves trace elements</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• High cost</td>
<td>• Too high pH reduces As absorption</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Some As leaching (in controlled environment)</td>
<td>• No comparable local market costs/products available</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>• Effective over wide pH variation (2-8)</td>
<td>• Inaccessible to isolated population</td>
<td></td>
</tr>
<tr>
<td>Campos and Buchler, 2008</td>
<td>Water synthesised in laboratory</td>
<td>Activated powdered carbon block filters</td>
<td>500</td>
<td>81</td>
<td>No</td>
<td>Yes</td>
<td>N/A</td>
<td>• Highly effective</td>
<td>• Produces sludge</td>
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<td>• Low-cost and practical</td>
<td>• Produces more solid residue</td>
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<td></td>
<td></td>
<td>• No use of toxic chemicals</td>
<td>• Some As leaching</td>
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<td></td>
<td>• Biodegradable</td>
<td>• Produces sludge</td>
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<td></td>
<td>• Little/no leaching</td>
<td>• High cost</td>
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<td></td>
<td>• Minimum technical support needed</td>
<td>• Large-scale trial testing required to determine local social acceptance</td>
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<td></td>
<td>• Suitable for rural areas with water supply systems</td>
<td>• Highly technical process</td>
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<td></td>
<td></td>
<td>• In-situ synthesis process</td>
<td>• Limited access to materials needed</td>
<td></td>
</tr>
<tr>
<td>Chakravarty et al., 2002</td>
<td>India</td>
<td>Ferruginous manganese ore (FMO)</td>
<td>40 - 180</td>
<td>98.5 - 99.8</td>
<td>Yes</td>
<td>Yes</td>
<td>N/A</td>
<td>• Highly effective</td>
<td>• Controlled lab experiment</td>
</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>• High practicality</td>
<td>• Not commercially available</td>
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<td></td>
<td></td>
<td>• No As leaching (in controlled environment)</td>
<td>• Not commercially available</td>
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<td></td>
<td></td>
<td>• Effective over wide pH variation (2-8)</td>
<td>• Highly technical process</td>
<td></td>
</tr>
<tr>
<td>Cui et al., 2015</td>
<td>China</td>
<td>Two-bucket system with ferric sulfate (FS) and polyferric sulfate (PFS)</td>
<td>13.6 - 1067</td>
<td>95 - 100</td>
<td>Yes</td>
<td>Yes</td>
<td>0.46</td>
<td>• Highly effective</td>
<td>• Controlled lab experiment</td>
</tr>
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<td></td>
<td>• Affordable</td>
<td>• Not commercially available</td>
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<td></td>
<td>• Low-cost and practical</td>
<td>• Not commercially available</td>
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<td>• No use of toxic chemicals</td>
<td>• Not commercially available</td>
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<td>• Biodegradable</td>
<td>• Not commercially available</td>
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<td>• Little/no leaching</td>
<td>• Not commercially available</td>
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<td>• Minimum technical support needed</td>
<td>• Not commercially available</td>
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<td>• Suitable for rural areas with water supply systems</td>
<td>• Not commercially available</td>
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<td>• In-situ synthesis process</td>
<td>• Not commercially available</td>
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<td>• Highly technical process</td>
<td>• Limited access to materials needed</td>
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<td>• Limited access to materials needed</td>
<td>• Not commercially available</td>
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<tr>
<td>Kumasaka et al., 2013</td>
<td>Bangladesh</td>
<td>Mg-Fe-based hydrotalcite-like compound (MF-HT)</td>
<td>308</td>
<td>99.8</td>
<td>Yes</td>
<td>Yes</td>
<td>0.01</td>
<td>• Highly effective</td>
<td>• Controlled lab experiment</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>• Low cost</td>
<td>• Not commercially available</td>
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<td>• Low adsorption period (&lt;15 s)</td>
<td>• Not commercially available</td>
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<td>• Limited access to materials needed</td>
<td>• Not commercially available</td>
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<td>• Controlled lab experiment</td>
<td>• Not commercially available</td>
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<td>• Highly technical process</td>
<td>• Limited access to materials needed</td>
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<td></td>
<td>• Limited access to materials needed</td>
<td>• Not commercially available</td>
<td></td>
</tr>
<tr>
<td>Kato et al., 2013</td>
<td>Bangladesh, Vietnam</td>
<td>Mg-Fe-based hydrotalcite-like compound (MF-HT)</td>
<td>92.3 - 459 (mean = 298)</td>
<td>99.8</td>
<td>Yes</td>
<td>Yes</td>
<td>0.38</td>
<td>• Highly effective</td>
<td>• Controlled lab experiment</td>
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<td></td>
<td></td>
<td>• Low cost</td>
<td>• Not commercially available</td>
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<td>• Low adsorption period (&lt;15 s)</td>
<td>• Not commercially available</td>
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<td>• Highly technical process</td>
<td>• Limited access to materials needed</td>
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<td></td>
<td></td>
<td>• Limited access to materials needed</td>
<td>• Not commercially available</td>
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</tr>
</tbody>
</table>

Note: [C, F, ADS] indicates the use of chitosan goethite bio-nanocomposite (CGB), activated powdered carbon block filters, and ferrUGINous manganese ore (FMO), respectively. [ADS, OXI] indicates the use of activated powdered carbon block filters and ferric sulfate (FS), respectively. [ADS, ION] indicates the use of Mg-Fe-based hydrotalcite-like compound (MF-HT), respectively.
<table>
<thead>
<tr>
<th>Authors, Year</th>
<th>Location</th>
<th>Arsenic Source</th>
<th>Treatment Method</th>
<th>Size (mg/L)</th>
<th>Removal Efficiency (%)</th>
<th>Cost</th>
<th>Pros</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kim et al., 2006</td>
<td>Water synthesised in laboratory</td>
<td>Lignocellulose adsorption medium (LAM)</td>
<td>4100</td>
<td>72.7</td>
<td>No</td>
<td>N/A</td>
<td>• Effective</td>
<td>• Low treatment time</td>
</tr>
<tr>
<td>Lee et al., 2016</td>
<td>Water synthesised in laboratory</td>
<td>Carbon composite electrode</td>
<td>1000</td>
<td>98.8</td>
<td>No</td>
<td>N/A</td>
<td>• Highly effective</td>
<td></td>
</tr>
<tr>
<td>Majumder et al., 2013</td>
<td>India</td>
<td>Citric acid from lemon, tomato, and lime (SORAS)</td>
<td>430, 270, 110</td>
<td>82.2 (lemon); 93.9 (tomato); 67 (lime)</td>
<td>No</td>
<td>0.84 (lemon); 0.65 (tomato); 0.49 (lime)</td>
<td>• Effective and low cost • Affordable • Accessible • Eco-friendly • Efficient (4 hr) • No hazardous wastes products</td>
<td>• Relies on use/repeated use of plastic bottles • Reliant on ~4 hours of sunlight • Treated water must be decanted • More research needed on monitoring</td>
</tr>
<tr>
<td>Mamatz and Bache, 2000</td>
<td>Bangladesh</td>
<td>Naturally occurring iron in groundwater</td>
<td>200</td>
<td>91.9</td>
<td>No</td>
<td>Near zero-cost</td>
<td>• Effective • Affordable</td>
<td></td>
</tr>
<tr>
<td>Mathieu et al., 2010</td>
<td>Bangladesh, Cambodia</td>
<td>ARUBA (Arsenic Removal Using Bottom Ash)</td>
<td>2000 ± 100 (synthetic), 67-880 (in situ)</td>
<td>98.1, 64.3 - 98.4</td>
<td>No (Yes with higher doses of ARUBA)</td>
<td>0.74</td>
<td>• Effective • Affordable alternative • Scalable practical (&lt;1hr) • No secondary contaminants • Also removes manganese • Safe for disposal in ordinary landfill</td>
<td>• Requires use of waste material • Access to material may be limited</td>
</tr>
<tr>
<td>Miahbuddin and Fariauddin, 2002</td>
<td>Bangladesh</td>
<td>Water hyacinth (Eichhornia crassipes)</td>
<td>400</td>
<td>98.25</td>
<td>Yes</td>
<td>Near zero-cost</td>
<td>• Highly effective and low cost • Removes other impurities • Low treatment time (6 hr) • Minimal tools needed</td>
<td>• Large-scale trial testing required • Research on accessibility needed • Research on commercialization needed</td>
</tr>
<tr>
<td>Nguyen et al., 2009</td>
<td>Vietnam</td>
<td>Treated magnetite waste (TMW)</td>
<td>380</td>
<td>92.1</td>
<td>No</td>
<td>Near zero-cost</td>
<td>• Effective • Made from waste material • Low cost</td>
<td></td>
</tr>
<tr>
<td>Thakur and Mondal, 2017</td>
<td>India</td>
<td>Aluminum electrode</td>
<td>550</td>
<td>98.5</td>
<td>Yes</td>
<td>0.37</td>
<td>• Highly effective • Low cost • Highly practical</td>
<td></td>
</tr>
<tr>
<td>Visoottiviseth and Ahmed, 2008</td>
<td>Bangladesh</td>
<td>Iron filings (zero valence)</td>
<td>—</td>
<td>&gt; 94 - 99</td>
<td>N/A</td>
<td>—</td>
<td>• Highly effective • Unitised local materials</td>
<td>• Rapidly clogged if groundwater contains excessive iron • High maintenance over time</td>
</tr>
<tr>
<td>Visoottiviseth and Ahmed, 2008</td>
<td>Bangladesh</td>
<td>Iron salts</td>
<td>—</td>
<td>&gt; 90</td>
<td>N/A</td>
<td>—</td>
<td>• Effective over a wider range of pH • Short treatment time</td>
<td>• pH dependent (between 6.0 to 8.5) • Efficiency affected by composition of influent water</td>
</tr>
<tr>
<td>Visoottiviseth and Ahmed, 2008</td>
<td>Thailand</td>
<td>Immobilised green alga (Chlorella vulgaris)</td>
<td>—</td>
<td>85 - 90</td>
<td>Near zero-cost</td>
<td>—</td>
<td>• Highly effective • Low cost natural materials</td>
<td>• Maintenance required (alginate beads must be changed every 3 months) • Requires disposal following absorption</td>
</tr>
<tr>
<td>Visoottiviseth and Ahmed, 2008</td>
<td>—</td>
<td>Laterite</td>
<td>—</td>
<td>50 - 90</td>
<td>Near zero-cost</td>
<td>—</td>
<td>• Effective and low-cost</td>
<td></td>
</tr>
<tr>
<td>Author(s); year</td>
<td>Origin of Influent Water</td>
<td>Remediation technology description</td>
<td>Initial concentration (µg/L)</td>
<td>Removal efficiency (%)</td>
<td>Final concentration (µg/L)</td>
<td>WHO standard reached?</td>
<td>Cost per m³ of treated water (USD)</td>
<td>Benefits</td>
</tr>
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</tr>
</tbody>
</table>
| Visoottiviseth and Ahmed, 2008 | Bangladesh | Naturally occurring iron and/or manganese | — | 70 - 80 | No | Near zero-cost | • Effective  
• Low cost | • As concentration must be below 100 µg/L to be effective |
| Yavuz et al., 2010 | United States | Magnetic crystals | 500 | 99.2 | Yes | N/A | • Highly effective  
• Low maintenance  
• Accessible for rural areas with no electricity or pumps | • Large initial and maintenance costs  
• Extensive need of materials  
• Highly technical process |
| Amrose et al., 2014 | India | Electro-Chemical Arsenic Remediation (ECAR) reactor | 266 ± 42 | 99.2 | Yes | 0.89-1.11 | • Highly effective and low cost  
• Reliable  
• Sludge can be turned into concrete (to be evaluated further) | • Produces As sludge (deemed non-hazardous)  
• As leaching risk  
• Turbidity levels did not meet WHO standard |
| Bundschuh et al., 2010 | Argentina, Bangladesh, Chile, Nicaragua | Modified SORAS | 1250 | Up to 95 | No | Near zero-cost | • Highly effective and low cost | • Technologies are available, but more trial research needed  
• Needs abundant iron |
| Chen et al., 2015 | China | Ferric chloride | 117 | 82.1 | No | 0.01 | • Effective and low cost  
• Easy operation  
• Marginal ecological impact | • Relied on outside chemicals  
• Large-scale implementation requires equipment and spraying machines  
• Lower efficiency than other alternatives  
• Met the Bangladesh standard (<50 µg/L) but not WHO standard (<10 µg/L) |
| Hasan et al., 2012 | Bangladesh | Household ceramic filter | 178 - 585 | 60 - 93 | No | N/A | • Effective and low cost  
• Made of locally available materials  
• Minimal maintenance  
• Higher user acceptance, satisfaction and sustained use | • Lower practicality (slow filter rates)  
• High/difficult maintenance  
• Discharged poor quality water |
| Hoque et al., 2004 | Bangladesh | Household filters | 400 | — | — | N/A | • Effective  
• Useful in emergencies | • Five-year lifespan |
| Mondal et al., 2017 | India | Activated laterite | 60 - 504 | Up to 98 | Yes | 0.36 | • Highly effective and low-cost  
• Low maintenance  
• No power required  
• Naturally prepared  
• Abundantly available material  
• Scalable to large scale  
• Does not require regeneration  
• Does not lead upon disposal  
• High local acceptance | • Five-year lifespan |
<table>
<thead>
<tr>
<th>Authors, Year</th>
<th>Location</th>
<th>Adsorbent</th>
<th>Cost Range</th>
<th>Plant Load (%)</th>
<th>Sludge produced</th>
<th>As leaching</th>
<th>Non-As leaching</th>
<th>Maintenance cost</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sarkar et al., 2010</td>
<td>India</td>
<td>Activated alumina or hybrid anion exchanger as adsorbent</td>
<td>140</td>
<td>—</td>
<td>No</td>
<td>0.74 (plus 1606 capital, 591 annual maintenance)</td>
<td>No significant As leaching</td>
<td>Produces harmful sludge, Sludge requires disposal</td>
<td></td>
</tr>
<tr>
<td>Sen Gupta et al., 2009</td>
<td>India</td>
<td>Ferric hydroxide as adsorbent</td>
<td>—</td>
<td>Yes</td>
<td>0.59</td>
<td>• Effective</td>
<td>No sludge produced</td>
<td>Requires installation and equipment (e.g. oxidation station, storage tank, pipelines, etc.)</td>
<td></td>
</tr>
<tr>
<td>Shafiquzzaman et al., 2009</td>
<td>Bangladesh</td>
<td>Sono arsenic filter</td>
<td>200</td>
<td>93</td>
<td>No</td>
<td>0.31-0.33</td>
<td>• Effective</td>
<td>High local social acceptance</td>
<td>Met the Bangladesh standard (&lt;50 µg/L) but not WHO standard (&lt;10 µg/L), High maintenance cost, Produces sludge, Slow flow rate, Lack of long-term sustainability</td>
</tr>
<tr>
<td>Shan et al., 2013</td>
<td>China</td>
<td>Iron minerals and limestone</td>
<td>318 - 635</td>
<td>&gt;95</td>
<td>Yes</td>
<td>0.11</td>
<td>• Effective and low cost</td>
<td>Suitable for rural areas, Locally available materials</td>
<td>Effectiveness depends on particle size, groundwater pH, and ratio of limestone to Fe mineral in solid mixture, Replacement of material after 5 years, Leaching of As after absorption</td>
</tr>
<tr>
<td>Smith et al., 2017</td>
<td>China</td>
<td>Modified bio-sand filter</td>
<td>226 - 240</td>
<td>86 - 95</td>
<td>No</td>
<td>N/A</td>
<td>• Highly effective</td>
<td>Can purchase materials locally</td>
<td>Filter clogs, Research on monitoring long term As removal of the filter needed</td>
</tr>
<tr>
<td>Visoottiviseth and Ahmed, 2008</td>
<td>India, Bangladesh</td>
<td>Activated alumina metal oxide as adsorbent</td>
<td>—</td>
<td>90 - 96</td>
<td>No</td>
<td>1.17-1.76</td>
<td>• Highly effective</td>
<td>Low Cost, Safe disposal, Non-leachable</td>
<td>Short lifespan (three to four regenerations), Only effective with pH 5.5 to 6.0, Requires environmentally safe disposal for residuals</td>
</tr>
<tr>
<td>Visoottiviseth and Ahmed, 2008</td>
<td>—</td>
<td>Iron filings and sand as adsorbent</td>
<td>—</td>
<td>90</td>
<td>No</td>
<td>70.5</td>
<td>• Effective</td>
<td></td>
<td>Expensive, Does not meet WHO standard</td>
</tr>
</tbody>
</table>

‡ The standard of 50 µg/L was met.
use, especially if the technologies are not correctly used or maintained (Sarkar et al., 2010). Additionally, field studies may involve larger installation costs and ancillary costs for transportation or sludge disposal, for example (Sarkar et al., 2010; Amrose et al., 2014).

Conversely, laboratory studies may only consider the cost of producing the technology and not quantify the overall benefit to a community who may use them. There are more variables influencing the effectiveness and cost of field studies. For these reasons, researchers and decision-makers need to consider the implications of replicating laboratory results in the field.

The field experiments were predominantly conducted in Bangladesh and India, the countries with widely and severely arsenic-contaminated water sources (Rahman et al., 2001). Some studies aimed to reduce arsenic concentrations to national standards (such as 50 μg/L of Bangladesh) as opposed to the WHO standard of 10 μg/L. Lower targets are seen locally as being more feasible, considering the high degree of natural arsenic contamination of groundwater, and the limited availability of economic and infrastructural resources. As mentioned earlier, this approach constitutes only a partial solution. Also, some field studies only reported whether or not the national standard was met, without including specific effluent concentrations or removal efficiencies. In this contest, the ability of these filters to meet the WHO standard remained unclear.

Review limitations

This review suggests that there are gaps in the literature related to the cost of arsenic remediation technologies. The initial search yielded a high number of studies evaluating options labelled as ‘low-cost’ but lacked specific cost data. Consequently, these studies were not included in this review, even though they may have presented economically and technically viable options. It is important that future reports on ‘low-cost’ technologies provide specific costs associated with their production and use. The inconsistencies in the parameters used to assess cost between the reviewed studies limited direct comparison in some cases. For example, the total cost associated with point-of-use filters, which are typically used at the household level, depends on the cost and longevity of the filter apparatus, and the cost and capacity of each cartridge (Campos and Buchler, 2008). Costs associated with a community filter plant would depend on different factors, such as the plant’s installation, maintenance, and operation (Sarkar et al., 2010). In contrast, the laboratory studies included in this review typically only reported the cost of raw materials, which account for a portion of total costs required to use the technology in a household or community setting.

The studies reviewed also used a number of different standards to report on effectiveness. The standards chosen depended on the technology itself and the study design. For example, most of the laboratory studies examining adsorbents measured adsorption capacity, which is not applicable to other remediation processes such as electrocoagulation. Due to the difficulty in directly comparing the range of technologies, most literature reviews have focused on a specific category, such as adsorbents. This review used arsenic removal efficiency to compare various technologies, as it depends solely on arsenic influent and effluent concentrations. When comparing the removal efficiencies, it is important to consider the influent concentration of the contaminated water, as options demonstrating high removal efficiencies when treating moderately contaminated water may not be as efficient when treating highly contaminated water sources.

The water samples varied in their initial arsenic concentration and sources. Certain laboratory studies used only synthetically prepared samples (mixed clean water and contaminant), where other experiments used synthetic and in-situ groundwater. Arsenic removal depends on various parameters of the water sample, including the pH, the presence of other ions, and the initial arsenic concentration (Gao et al., 2011). The differences in these properties will influence the removal efficiency that is observed. This aspect was not accounted for in this review.

CONCLUSIONS AND RECOMMENDATIONS

One observation that emerged from this assessment was that some countries have set a higher national threshold for arsenic content in water than the WHO limit of 10 μg/L. While this may help national policymakers report better results for their national arsenic reduction efforts, it may have the opposite effect on public health. Higher thresholds will not help solve this public health crisis. On the contrary, if a country has a feeling that the arsenic situation is coming under control, this may reduce the sense of urgency in policy circles to eradicate the problem, while the population continues to suffer from arsenic poisoning.

For technologies tested in the laboratory and the field, the key factors influencing the removal efficiencies include the concentration of arsenic in the influent water as well as the presence of other components. Technologies that demonstrate high removal efficiencies when treating moderately contaminated water may not be as efficient when treating highly contaminated water. The lifetime of the removal agents is also a significant factor in determining their efficiency. Key factors influencing the range of costs include materials used,
energy and labour required, regeneration period and geographical location.

Results suggest that technologies implemented in the field are marginally different in cost-effectiveness from those tested in the laboratory, except for the ZeroWater®. Technologies that demonstrate high removal efficiencies in the laboratory need further assessment to assess their suitability for larger-scale application, considering their high production and operation costs. However, costs can be reduced by using locally available materials and natural adsorbents, which provide near zero-cost options and are highly efficient for arsenic removal. In this review, the removal efficiencies for these technologies ranged from 50% to ~100%. Conversely, various household filters that have been tested in community-wide field studies are inexpensive but may exhibit lower removal efficiencies, high maintenance costs, and lower social acceptance.

The quantitative summary of costs and effectiveness of remediation technologies reported in peer-reviewed literature over more than 20 years (in English language publications – see Table 1) can be used as a preliminary guideline for selecting the most cost-effective remediation methods for arsenic-contaminated water. It can also possibly be used as an initial tentative format (minimum standard) for summarising the results of every new study describing arsenic remediation approaches. Moving forward, to “arsenic-free water world”, the following recommendations can be made.

More focus must be put on determining the market viability of remediation technologies. One of the major limitations to the practical application of existing arsenic remediation methods is a lack of attention to their market viability. As a result, methods proven to be effective in laboratory settings may remain trapped in the research and development phase and unable to continue to commercialization. This is true for environmentally-friendly, low-cost and simple arsenic removal methods which require follow-up field trials. Assessing market viability is crucial for attracting investment and developing efficient supply chains to make new arsenic removal technologies more accessible in remote regions.

Dealing with the practical limitations of existing remediation methods need to receive more attention. Limitations of existing remediation technologies may include high maintenance, issues of leaching and disposal of toxic components. Some methods that are effective and low-cost also result in secondary contaminants and require additional treatment or disposal. Other highly-effective and low-cost solutions require chemicals to synthesize the process, which may be impractical for regions without abundant access to these materials. Finally, many treatment solutions require specific controlled conditions to be effective in removing arsenic from groundwater. This means that training needs to be provided. This factor has to be considered and includes in cost calculations if the technology is to be widely implemented.

Remediation methods must be contextually appropriate. A key challenge to the practical application of arsenic remediation technologies is that different contexts require different technologies. One technology [process] may work in one region but not in another. The viability and long-term sustainability of each technology are highly dependent upon its social acceptance, and this can be influenced by costs, access to materials, maintenance needs or cultural settings. Community willingness to use and maintain a technology are key factors that influence if an approach or technology can be effective in practice. Even if a technology is more expensive, it may be a more economical long-term solution when considering the reduced risk of microbial contamination and gastrointestinal illness.

For example, studies of arsenic-contaminated groundwater in West Bengal and Argentina using laterite (Bundschuh et al., 2011; Mondal et al., 2017) generated two very different results. In West Bengal, activated laterite proved to be extremely effective, scalable, low cost, low maintenance and with high local acceptance. In contrast, in Argentina, field trials with laterite found that remediation approaches met with varied social acceptance due to high transportation costs for laterite - depending on the area; and low absorption rates - depending on soils used.

An extensive study conducted by Ahmad et al. (2006) surveying 2700 rural households in Bangladesh found that 72% of the respondents would prefer a community-based system over a household filter due to its perceived convenience of use and maintenance. Users may also prefer more environmentally friendly options with moderate effectiveness over highly effective methods that produce toxic sludge as a byproduct, such as electrocoagulation (Hossain et al., 2015). Overall, the contextual appropriateness of technology for a particular setting or population needs to be assessed and understood, alongside the technology's cost and removal efficiency.

A concerted effort to increase knowledge sharing across the global research and development community and across the regions is needed. A major obstacle to the practical application of arsenic remediation technologies at scale across affected areas is the lack of knowledge sharing at the R&D level on existing/proven methods. This leads to inefficiencies and duplication of effort in research and development. One example is a field study using household filters in Bangladesh (Hoque
et al., 2004) that recommended a shift from household filters to community-based water treatment solutions, as the former registered low social acceptability with the affected communities. Despite this, numerous subsequent reports continued to focus on developing low-cost household filters, ignoring field-based recommendations. They continued to develop methods that the local population had said were undesirable (Hoque et al., 2004; Amrose et al., 2014). Language barriers may add another obstacle to technology promotion and information exchange across regions.

Today, the current science and knowledge on arsenic remediation technologies may be mature enough to help significantly reduce the numbers of people affected by this public health problem. However, the effective translation of research evidence and laboratory-level successes into quantifiable and sustainable impacts on the ground requires a concerted and sustained effort from policymakers, engineers, healthcare providers, donors, and community leaders.

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