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REVIEW ARTICLE

Assessing sustainability bottlenecks in technology-led arsenic mitigation programs in the Indian subcontinent

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ABSTRACT

Major countries of the Indian subcontinent are witnessing severe water crisis with significant portion of their population living under the threat of water poverty. One of the major reasons for this crisis is contamination of groundwater resources with arsenic, a heavy-metal well known for deteriorating human health. Arsenic contamination has emerged as a global public health concern, despite execution of various mitigation programs particularly in India. Recent technological efforts towards arsenic mitigation, through various public- and private-funded programs, have shown positive affectivity towards arsenic contamination; however various technical, social, economical, and environmental issues pose sustainability bottlenecks towards acceptance and success of these technologies. With a broad objective of generating policy interventions towards extenuating arsenic-led health concerns, this review cumulates major arsenic mitigation efforts and the related sustainability-bottlenecks.

Keywords: *Arsenic; Mitigation technologies; Social issues; Innovation; National governance*

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INTRODUCTION

The geogenic and anthropogenic contamination of water resources is a major cause of increasing water crisis around the globe with millions of people suffering from water poverty due to inadequate access to safe water. Arsenic (As), a naturally occurring metallic element, found ubiquitously in air, water, and soil, is a serious health hazard to mankind across the globe. Varying exposures to arsenic have been reported to cause skin lesions, cardiovascular and respiratory diseases, and even cancers [1]. There are no known effective treatments for symptoms of arsenic exposure and consumption of arsenic-free water has been identified as the only way to palliate these symptoms as well as reducing the risk of exposure on affected population [2]. The scale of this menace at the global level can be understood by a report that identifies approx 296 million people living under the risk of arsenic toxicity in nearly 107 countries. India and Bangladesh stand among the worst impacted countries with nearly 135 million individuals potentially exposed to arsenic through contaminated drinking, cooking and irrigated water [3].

The environmental flux of arsenic originates from natural sources including volcanic action, erosion of rocks and forest fires. Moreover, human activities, involving utilization of chemicals for timber preservation, agricultural pesticides, electronics and medicines inflate arsenic exposure to the biosphere in the environment [4]. Use of arsenic contaminated groundwater for drinking and cooking is the most common route for long-time exposure of arsenic in human beings [5]. World health organization (WHO) lists 'Arsenic' as one of the ten chemicals of major public health concerns and various national organizations have recommended the maximum permissible limit of arsenic in drinking water as 10 μg/L, however, many developing nations including South-Asian countries still retain older norms of permissible limits (50 μg/L) due to economical and technical challenges [6]. Further, the use of contaminated ground water for irrigation in many countries affect crop productivity on land, and cause bio-accumulation of arsenic in different crop tissues which ultimately leads to contamination and its magnification in the food chain [7]. Recent efforts towards development of arsenic mitigation options in endemic areas have largely focused on technological advancements of domestic/community based arsenic removal units, however, these units have majorly faced abandonment by the affected population in endemic areas [5]. This review elucidates the R&D landscape (important events/stakeholders involved during the process of research and development of technology) of arsenic mitigation technologies and enlists the related reasons behind their abandonment by end-users. Culmination of this data will provide a scientific basis for development of policy framework towards sustainable solutions for arsenic mitigation in the affected regions.

GLOBAL SCALE OF ARSENIC TOXICITY

Although, the very first report of arsenic contamination dates back to 1885 [8], health adversaries due to arsenic started to be documented since 1917. From that time the number of countries and population affected with arsenic toxicity has been on a steep rise because of both identification of new arsenic contaminated sources as well as increase in population in those areas [9]. According to the UNICEF, recognition of groundwater arsenic contamination as a global issue happened in the 1990s, with South-Asian countries like India, Bangladesh, China, Taiwan, and Thailand being the worst affected locations [10]. Presently, more than hundred countries across the globe have been found out to possess arsenic contaminated water resources thereby posing a risk to local population. Majority of the countries have been identified with arsenic contaminated ground water in the last 10-15 years indicating arsenic contamination in yet unknown locations/countries. With such widespread issues of pollution, arsenic has caused deterioration of health of millions of people [11].

AFFECT ON HUMAN HEALTH

Realization of the inimical effects of arsenic on human health has been cornerstone for major clinical studies and research in this area. Consumption of arsenic through food and water leads to its accumulation in tissues such as nails, hair and skin, resulting in various clinical symptoms including hyper-pigmentation and keratosis. Neuropathy and Cardiovascular diseases have also been linked to arsenic consumption [12]. Increased fetal loss, premature delivery, and decreased birth weights of infants, have been reported to occur even at low (<10 μg/L) exposure levels of arsenic [13]. Malnourished people have been identified to be more predisposed to arsenic-related toxicity as compared to people getting adequate nutrition. Moreover women and children are identified to be more vulnerable to arsenic toxicity than males and at the same time face worst wrath of society with social occlusion from work as well as home [14].

CHEMISTRY BEHIND ARSENIC TOXICITY IN GROUND WATER

Arsenic exists in various oxidation states and forms. The inorganic forms of arsenic have geological origin and are more toxic. It has been identified that shallow alluvial-aquifers formed by thick sequences of young sediments are quite often the sites of high ground water arsenic concentration. Relative concentrations of carbonates, sulphates, phosphates and ammonium ions lead to reductive dissolution of Iron- and Manganese-hydroxides which in turn facilitate the release of arsenic from sediments to ground water [15]. Chemicals having arsenic in the trivalent oxidation state are considered most toxic because of their ease in mobility into the environment [16]. This basic understanding about geogenic arsenic contamination of ground water provides scope for development of robust and comprehensive technologies/schemes towards arsenic mitigation.

SCENARIO OF ARSENIC TOXICITY IN INDIAN SUBCONTINENT

According to WHO, the Ganga-Brahmaputra plains in India (involving seven states) and the Padma-Meghna plains in Bangladesh together constitute the world's most widespread arsenic affected regions. The ground water potential of the Ganges and Brahmaputra-Meghna basin in India has been assessed as 171 BCM (Billion Cubic Meter) and 26 BCM, respectively, which together accumulate to approx 45.7% of the total annual replenishable groundwater resources of India [17]. Extensive research over the past two decades elucidates that the sediments from Himalayan rocks which collected in the fluvial plains of Ganga-Brahmaputra-Meghna, form the holocene shallow aquifers. These holocene aquifers are the major source of arsenic contamination in ground water [18] and are confined upto the depth of 120 m below ground level [19].

VARIOUS ARSENIC MITIGATION OPTIONS

In areas where arsenic is present above permissible limits in the drinking water supply, there are two possible ways of keeping off from its exposure i.e. i) use of alternative uncontaminated water source, or ii) bringing down the levels of arsenic in contaminated water below permissible limits before consumption [20]. Moreover, it has to be well taken care of that uncontaminated water sources (new aquifers) do not get contaminated with arsenic [4]. To this end, various arrangements like piped water supply, dug wells, deep tubewells, rainwater harvesting and surface water sources have been suggested which provide alternative sources of arsenic free water in or near the arsenic affected areas.

In large parts of arsenic affected areas, unavailability of alternative source of safe drinking water leads to adoption of arsenic removal technologies as the only option for access to potable water. There has been development of arsenic treatment plants/ arsenic removal units (ARUs) for lowering the levels of arsenic from contaminated water, in absence of alternate water source, at the house-hold or community level (Table 1). A large number of physio-chemical techniques have been conventionally used for both on-site and off-site removal of arsenic from ground water including oxidation, lime treatment, coagulation–flocculation, ion exchange, electro-coagulation, adsorption on solid media and membrane filters. Recent technologies include biological treatment processes like biological sorption, and water treatment using micro-organisms. Lately advanced, hybrid, and integrated technologies have been generated utilizing frontier research on chemical understanding of arsenic. Accordingly, technologies like direct-contact-membrane-distillation (DCMD), integrated reverse osmosis membrane-distillation (RO-MD) and forward osmosis (FO) pose a promising candidature for the replacement of currently used technologies [3,21]. In the past two decades remarkable development in arsenic removal technologies has been observed however each technology has its own risks and benefits.

R&D LANDSCAPE OF ARSENIC MITIGATION TECHNOLOGIES

Since its first report from West Bengal, India in the year 1983 [22]. , identification of arsenic contamination in groundwater has been witnessed in many other states and is still on the rise [23]. With millions of people living under the threat of arsenic toxicity, various central and state government departments have taken up a number of initiatives for mitigation and remedy of arsenic contamination (Table 2) through exploring multidimensional approaches viz. i) identification of arsenic-contaminated and uncontaminated water reserves in affected areas, ii) efforts towards technological developments in arsenic treatment plants at household and community level, iii) making arrangements for alternate fresh water supply in affected areas etc. (Table 3).

In the past two decades, understanding the mechanism of arsenic dissolution in water, arsenic lead toxicity, arsenic sequestration and arsenic remediation have been a topic of immense research and understanding. Scientific attributes generated through R&D learning fostered by various public-/private-funded organizations have laid down the foundation stone for creation of a robust R&D landscape for development of arsenic mitigation technologies in India (Table 4, Table 5).

As of today there are large numbers of technologies available for treating water to lower down the levels of arsenic contamination and making it safe for drinking and cooking purposes [24]. Huge numbers of public- and private-funded organizations have used these technologies to produce point-of-use arsenic removal systems which can bring dissolved arsenic concentration in water below acceptable limits (Table 6). However, in the arena of arsenic mitigation technology development, there is still a pursuit for a technology which can sustain in field conditions.

BOTTLENECKS IN SUSTAINABILITY OF ARSENIC MITIGATION TECHNOLOGIES

Arsenic removal technologies at the household or community level are designed to provide emergency/short-term response for increasing efficiency and improving the cost-benefit balance in endemic areas having non-availability of alternate safe drinking water sources [3]. However, at the same time, these technologies are expected to be sustainable until arrangements for long-term/permanent safe drinking water source is not made available. The literature is full of reports about national and international technology ventures in different areas of the world severely affected with arsenic toxicity [2]. Majority of these reports have also identified four main sustainability bottlenecks for technology failure in affected areas i.e. technological, social, economical or environmental bottlenecks.

Technological bottlenecks towards sustainability

For any water purification technology to be successful, the minimum requirement is its capability to bring the level of contaminant within acceptable limits for drinking, without compromising the physico-chemical or microbial quality standards of water [25]. Moreover, a technology should provide adequate quantity of water to serve the requirements of a house-hold or a community at any given point of time, independent of regional lithography and changes in climate conditions at the point-of-use. However, it has been observed that every technology has its own intrinsic merits and limitations (Table 7).

Social-economic bottlenecks towards sustainability

As arsenicosis has been found out to majorly affect the marginalized population, there are various socio-economic aspects which directly or indirectly affect the sustainability of arsenic mitigation technologies. Studies have shown that approx 15% of the affected population constitutes illiterate inhabitants living below the poverty line whereas rest of the population was found not being in a much better economic or educational situations [26]. Women, children and infants are more vulnerable to the toxic effects of arsenic than male and adults because they are not just the most undernourished but also face extreme social pressure. There has been little or no social education concerning the treatment of persons affected by arsenic toxicity and about ill effects of using Arsenic contaminated water. It has been reported that symptoms of arsenicosis like skin lesions and amputations are often considered, among village people as contagious diseases leading to social occlusion of the suffering individual [27,28,29]. Because of poor economic conditions, illiteracy, and lack of information, people do not adopt to the use of arsenic removal technologies and prefer to use arsenic contaminated water for drinking and cooking purposes.

Environmental bottlenecks towards sustainability

The arsenic laden sludge generated by arsenic removal technologies poses a big threat for re-entry of arsenic contamination in the environment, especially in the vicinity of arsenic treatment plants. Therefore safe disposal and sustainable management of this sludge is one of the biggest challenges in the way towards sustainability of arsenic mitigation technologies [2]. Therefore it can be inferred that, to overcome the sustainability challenge, an arsenic removal unit should not just be technically sound but should also harmonize with the intrinsic social, economical and environmental issues (Table 8) through innovative and combinatorial advances. As every arsenic mitigation technology (weather it is conventional, advanced or hybrid type) has its own merits and limitations, it has been rightly suggested that there need not be a blanket technology for all arsenic affected areas. Moreover a technology should be utilized for a region after identifying the local issues of region and due assessment of merits/limitations of the technology [30]. Immediate steps towards addressing such issues can foster the sustainability goals of upcoming technologies.

NEED FOR A NATIONAL POLICY FRAMEWORK

The global challenge of arsenic contamination in drinking water has resulted in development and modifications of national policies in various countries, on the basis of evidence based research, technological resources, economic resources, and public awareness towards risk [31,32]. Countries like Chile, Taiwan, Argentina and Mongolia introduced piped water supply to make safe water available for the affected communities [33,34. Chile also adopted the coagulation method to remediate arsenic contamination. These methods and technologies were adopted on the basis of their efficiency and cost-effectiveness in the existing scenario [35-36]. In China occurrence of geogenic arsenic in ground water along with human activities have elevated the problem of arsenic contamination of drinking water sources especially in South-China region [37]. Two major national programs were initiated by the Chinese authorities towards heavy metal mitigation, which include monitoring and controlling discharge of heavy metals in the environment by anthropogenic activities along with reducing the heavy metal releasing enterprises [38]. In Bangladesh, all possible mitigation strategies including pond-sand filters, house-hold and community scale filters, deep tube wells, rain-water harvesting, and piped water supplies have been piloted and adopted. The government of Bangladesh started implementation programs in 1996 and published a national policy for arsenic mitigation and implementation plan in 2004 [35]. Under the Science, technology & innovation policy (STIP) 2013, Indian government seeks to direct STI enterprises for achieving inclusive innovation and deliver solutions to address various pressing national challenges in the field of food, education, health, employment and other critical areas. Inclusive innovation can lead to inclusive growth where people at the base of pyramid i.e. the poor, marginalized and underprivileged people, are involved in contributing to inclusive innovation by providing them with access to appropriate technology and infrastructure [39,40]. As majority of the population living under the threat of arsenic toxicity, is marginalized, it is of prime importance for concerned authorities to create a favorable atmosphere for fostering inclusive innovations towards feasible and sustainable arsenic mitigation options in affected areas. For creating an environment to spur innovation, there is need of a milieu of resources including trained personnel, research facilities, public participation, funds and a robust national policy.

POLICY SUGGESTIONS

Technology driven approaches to alleviate socio-economic issues are usually market oriented and tend to seek technical superiority over the existing ones, thereby deprioritizing the cultural variability among affected population especially in the developing countries. A national policy which can address the issues of all arsenic endemic areas of a country at the grass-root level needs to take into consideration each and every aspect related to the problem. Some of the foremost policy interventions/suggestions which need to be included are: i) The policy should promote creation of technologies which are not just culturally and economically acceptable to the end users but also resilient towards complicated maneuvering and maintenance of the product; ii) technologies utilizing locally available material for the removal of arsenic should be facilitated in the concerned area; iii) one of the most important aspects to be addressed by a policy must be the sensitization and awareness of affected population towards harmful effects of arsenic consumption; iv) further, there should be creation of an overarching monitory-body comprising of scientific experts, local authorities and end-users which can together not only provide feedback of different arsenic mitigation programs and products to the concerned authorities but also act as a transparent review system/ support system to assess the acceptance and success of arsenic removal technologies within a community. In this way the scientific community will be able to build trust among the end-users thereby facilitating technology diffusion and acceptance.

Table 1: List of various arsenic mitigation options:

I	**Alternative water supply options**		Piped water supply, Deep tubewells, Rain water harvesting, Dug wells
II	**Arsenic removal units**		
	Conventional technologies		
	a	**Oxidation**	Oxidation and filtration, Photochemical oxidation, Photocatalytic oxidation, Biological oxidation, In situ oxidation
	b	**Coagulation-Flocculation**	Fe-As removal, lime treatment, Alum-As removal
	c	**Adsorption**	Activated aluminia, Iron-based sorbents, Zero valent Iron, bio-adsorbents (rice husk, jute stick, fly ash, egg shell etc.), Miscellaneous solvents, Metal organic frameworks
	d	**Ion exchange**	Cation exchangers (Ce, Cu, Fe, La), Anion exchangers (XAD-7)
	e	**Membrane technology**	Microfiltration, Ultrafiltration, Nano filtration, Reverse osmosis
	Application of Nanoparticles		
			Carbon Nanotubes, Titanium nanoparticles, Zero-Valent Iron Nanoparticles, Ceria Nanoparticles , Iron Oxide Nanoparticles, Zirconium Oxide Nanoparticles
	Treatment with Bio-organisms		
			Prokaryotes (*Geobacter, Sulfurospirillum*), Eukaryotes (*Pteris vittata*), genetically modified microbes
	Metal organic frameworks		
			MIL-(53)Al, Fe-BTC, ZIF-8
	Hybrid and Advanced technologies		
			Direct contact membrane distillation (DCMD), RO+MD (Reverse osmosis & Membrane distillation), Forward osmosis (FO),

Source: [3,4,25]

Table 2: List of Indian ministries and concerned departments/missions/programs dedicated for providing potable water to affected population:

Ministry	Department/Missions/Programs	Web Links
Ministry of Water Resources, River Development & Ganga Rejuvenation	Central Ground Water Board-National Aquifer mapping program	http://cgwb.gov.in/WQ/WQMAPS/Arsenic.pdf
Ministry of Agriculture & Farmers Welfare	Department of Agricultural Research and Education (DARE)	https://icar.org.in/files/reports/icar-dare-annual-reports/2008-09/01.Overview.pdf
Ministry of Drinking water & Sanitation	National Water Quality Sub Mission (NWQSM)	https://jalshakti-ddws.gov.in/sites/default/files/201707111554.pdf
Ministry of Science & Technology	DST-Water Technology Initiative (WTI)	http://www.dst.gov.in/water-technology-initiative-programme-wti
Ministry of Health & Family welfare	Department of Health Research (DHR)	https://dhr.gov.in/sites/default/files/ICMR-12Plan-2012-2017_1_0.pdf
Ministry of Environment Forest & Climate Change	Water Quality Assessment Authority (WQAA)	https://www.cpcb.nic.in/ind-pollution-control-2/?&page_id=ind-pollution-control-2

Table 3: Objectives and financial support provided under various International/ National missions reinforcing potable water supply and arsenic mitigation:

Mission/Programs	Objectives	Funds in INR (approx.)	Web Links
Har Ghar Nal Ka Jal (World Bank & Asian Development bank)	Making potable water available in selected states of India	More than 40 Billion (Yr 2018-onwards)	http://www.ptinews.com/news/9996367_Arsenic-free-water-across-Bihar-by-2020--PHED-minister.html
Newton Bhabha Fund	Understanding the geogenenic arsenic contamination along Ganga river basin	Fund information not available (Yr 2018-onwards)	https://www.business-standard.com/article/pti-stories/newton-bhabha-fund-for-arsenic-research-in-ganga-basin-118031301049_1.html
National Water Quality Sub-Mission	Proving sustainable solution to arsenic endemic areas in India	36 Billion (Yr 2016-onwards)	https://indiawater.gov.in/IMISReports/dashboard.html
NITI Aayog recommendation	Short term measures by installation of Community Water Purification Plants	10 Billion (Yr 2016)	https://jalshakti-ddws.gov.in/sites/default/files/201601011636.pdf
National Aquifer Mapping Program	Mapping of aquifers with arsenic contamination	Fund information not available (Yr 2016)	http://cgwb.gov.in/AQM/India.pdf
WB-Public health & Engineering Dept	Short term measures by Installation of Arsenic removal units (ARUs)	9 Billion (Yr 2009)	https://www.downtoearth.org.in/coverage/arsenic-control-39447
Water Technology Initiative	Developmental research for meeting water challenges	50 Billion (Yr 2007-14)	http://www.dst.gov.in/water-technology-initiative-programme-wti

Table 4: R&D landscape of public funded projects for arsenic mitigation technologies in India

Institution	Technology	Tech developer	Funding agency	Year of Pub
BARC-Mumbai	Ultra filtration membrane	Head, TTCB-BARC	BARC	-
IIT-Madras	Coconut inspired	Prof T Pradeep	DST	2013
IIT-Kanpur	Iron Chitosan based filter	Prof N Verma	DST	2009
IIT-Kharagpur	Laterite base filter	Prof S De	DST	2015
IIT-Mumbai	Zero-Valent Iron	Dr S Chaudhari	DST	2015
IIT-Roorkee	Zinc oxide nanoparticles	Dr V Agarwala	DST	2010
IIT-Delhi	Polyacrylonitrate filtration	Dr GP Aggarwal	DST	2014
Univ. of Calcutta	Nano-Alumina beads	Prof P Sarkar	DST	2010
Gauhati Univ.	Clay based bio-sorbent	Prof K G Bhattacharya	DST	2015
Jadavpur Univ.	Co precipitation, adsorption	Dr A Mazumdar	DST	2015
Presidency Univ.	Manganese-Iron oxide filter	Dr S Chakrabarti	DST	2012
Tezpur Univ.	Oxidation-coogulation	Dr RK Dutta	DST	2016
CSMCRI, Gujrat	Ion based resins	Dr KM Popat	DST	2018
Hindustan College of S&T, Mathura	Detection through nano particles	Prof MS Gaur	DST	2015
IACS-Kolkata	Removal through mineralization	Dr A Bhaumik	DST	2015
CGCRI, Kolkata	Ceramic membrane based contactor	Mr S Majumdar	DST	2013
INST-Mohali	Low cost cartridge	Prof A Ganguli	DST	-
ARI-Pune	Microbial oxidation alumina Adsorption	Dr KM Paknikar	DST	2013
NMRL-Ambernath	Co precipitation, adsorption	Dr N Das	DRDO	-
IIG, Guwahati	Vegetable oil membrane	Dr PK Saha	DST	2014

- "--" indicates information is not available related to technology development

Source: Annual reports of WTI (http://www.dst.gov.in/water-technology-initiative-programme-wti)

Table 5: R&D landscape of private funded projects for arsenic mitigation technologies in India

Institution	Technology	Tech developer	Funding agency	Year of Pub
ApyronTech-Kolkata	Inorganic granular Metal-oxide	Greg Gilles	Private funded	-
Doctor water-Kolkata	Arsenic removal filter	Mr Mitra, Proprietor	Private funded	-
Harbauer-Kolkata	Granular Ferric oxide	-	Private funded	-
3G Aqua	Nobel/SemiNobel metal-redox	-	Private funded	-
Sehgal Foundation	Bio Sand filter	Dr Sharma	Private funded	2016
Development alternatives	Jal-TARA filter	-	Collaboration with DST	-
Membrane Filters Pvt Ltd	Disposable granulated media	-	Private funded	-
Fontus Water Pvt Ltd	Electro chlorination	-	Private funded	-
Water System India Pvt Ltd	Reverse Osmosis	-	Private funded	-
HES Water Engineers India Pvt Ltd	Oxidation-Precipitation-Filtration	-	Private funded	-
Ion Exchange India Ltd	Ion Exchange India Ltd	-	Private funded	-
United Waters India Pvt Ltd	Semi-aerobic microbs	Mr R Martinell	Private funded	-
Mobile Plus Pvt Ltd	Alumina based filter	-	Private funded	-
Aquasphere Greentech Solutions Pvt Ltd	Capacitive-deionization	-	Private funded	2015
Vision Earthcare	Soil and microorganism formulation	-	Private funded	-
Luminous Water Tech.	Iron based adsorbent	Dr Gadgil	Private funded	2009

- "--" indicates information is not available related to technology development

Source:

- Report on "R&D activities related to arsenic contamination in drinking water" by DST (June 2015).
- Report on "Rural technologies in Sanitation and drinking water quality for transforming India" by Ministry of Drinking water and sanitation, GoI (2015)
- Compendium on innovative technologies on rural drinking water and sanitation

Table 6: List of commercially available arsenic removal products and related costs

Technology	Product name	Utility	Capacity (lit/hr)	Cost of product (Rs)	Cost of water (Rs)	Meeting WHO standards
Single stage: adsorbtion	Low coat laterite based Arsenic filter	Domestic & community	100 & 1,000	2,500 & 15,000	Rs 30/m^3	Yes
Double stage: Gravel filtration + Iron supplimentation	IITB Arsenic filter	Community	600 - 1,000	60,000- 75,000	Rs 3.30/m^3	Yes
Multiple stage: filtration & supplementation	AMRIT	Domestic & community	3 & 1,000	1,500 & 99,000	Rs 30/m^3	Yes
Multiple stage: oxidation-coogulation & Sand filtration	Arsiron Nilogon	Domestic & community	200 & 500	600 & 10,000	Rs 31/m^3	Yes
Multiple stage: co-precipitation and Filtration	DRDO arsenic removal filter	Domestic	15	2,000	Rs 0.015/m^3	Yes
Multiple stage: oxidation, adsorption & filtration	ARI groundwater arsenic treatment plant	Community	40	74,000	Rs 10/m^3	Yes
Double stage: Co-precipitation & adsorption	Arsenic removal unit	Community	800 - 1,000	1,75,000	Rs 3.6/m^3	Yes

Source: Report on “R&D activities related to arsenic contamination in drinking water” by DST (June 2015)

Table 7: List of various arsenic mitigation technologies, their advantages and disadvantages (Mondal et al., 2013; Ghosh et al., 2018)

Treatment process	Features	Merits	Limitations
Oxidation	Pre oxidation of As(III) to As(V)	Low operating cost Process works over a wide pH range	Process is very slow Smell and color in drinking water.
Coagulation–flocculation	Added coagulants formed larger particles	Low operating cost Process works over a wide pH range	Production of large sludge
Adsorption	Activated alumina, iron oxide coated sand etc	Conventional and effective technology	Systematic addition of coagulants Post-filtration is required
Biological Sorption	Anaerobic and fungal biomass adsorbed	Generated sludge is eco-friendly	Maintenance of microbial culture is laborious
Ion-exchange	Synthetic resin beds are Used	Process is independent of pH	Anions interfere with removal Resin should be replaced time to time
Membrane filtration	Membranes are used with different porosities	Wide ranges of dissolved salts can be removed. No toxic sludge generation	As(III) removal is not very effective Establishment and maintenance cost are very high
Treatment with bio-organisms	Plants and microorganisms	Eco friendly	Not applicable in large scale. GE microbe is costly.
Electro-coagulation	Adsorbtion of arsenic by self-sacrificial electrods	Less maintenance cost and low sludge generation	High monetary requirements

Source- [3,4]

Table 8: List of sustainability bottlenecks for arsenic mitigation technologies

Features	Sustainability Bottlenecks
Technical (Product efficiency)	Meeting BIS standards of arsenic level
	Robustness in wide range of arsenic, pH, salinity
	Removal of pathogenic contaminations
	Affecting taste, smell, appearance
	Catering to daily consumption
	Steady flow of water
	Corrosion, clogging, deposition
Social (User friendliness)	Operation & maintenance
	Need of electricity, fuel
	Need of skilled manpower
	Need of filter cartridge, resin etc.
Economical (Willingness to pay)	One time installation costs
	Recurring O&M costs
	Area requirement
Environmental (Health & Environmental safety)	Usage of chemicals
	Wastage of water
	Generation of Sludge

CONCLUSION

Millions of lives in the Indian-subcontinent live under the threat of arsenic toxicity. South-Asian countries like India and Bangladesh stand among the worst affected countries due to presence of arsenic in their natural water resources. In the past two decades there has been a number of efforts towards development and dissemination of various arsenic mitigation technologies in the endemic areas. When these arsenic remediation products move out of the laboratory and get installed in the household or community, they bring down arsenic levels in drinking water within the standard limits, however they face rejection from the end-users due to various socio-economic, environmental and technological issues.
In under-developed/developing nations the societies are very heterogenous due to preservation of their ethnic nature and therefore, socio-economic variability is high among different societies. Due to poor economic conditions, there is less access to modern knowledge which ultimately impacts the adoption of technologies. Some of the most frequently encountered issues responsible for rejection of these technologies have been discussed in this review however acceptance or rejection of a technology majorly depends on complex socio-economic values of the community like awareness towards toxicity, acceptance of treated water, and willingness to pay cost of mitigation products. Therefore, foremost consideration should be given to socio-economic conditions and cultural values of the end-users while development of new technological solutions. Moreover, there is an immediate need of extensive research to evaluate the feasibility and practicability of various existing techniques by recognizing priorities and perceptions of affected communities/households. This immediate need cannot be relinquished until and unless a robust and inclusive national policy framework for arsenic mitigation is not created in arsenic affected countries.

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COMPETING INTERESTS
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