Policy intervention for arsenic mitigation in drinking water in rural habitations in India: achievements and challenges

Brajesh K. Shrivastava

ABSTRACT

This article provides updated status of the arsenic affected rural habitations in India, summarizes the policy initiatives of the Ministry of Drinking Water & Sanitation (Government of India), reviews the technologies for arsenic treatment and analyses the progress made by states in tackling arsenic problems in rural habitations. It also provides a list of constraints based on experiences and recommends suggested measures to tackle arsenic problems in an holistic manner. It is expected that the paper would be useful for policy formulators in states, non-government organizations, researchers of academic and scientific institutions and programme managers working in the area of arsenic mitigation in drinking water, especially in developing countries, as it provides better insights compared to other available information in India on mitigating arsenic problems in drinking water in rural areas.

Key words | arsenic, groundwater, habitations, India, National Rural Drinking Water Programme, rural

Brajesh K. Shrivastava
Ministry of Drinking Water & Sanitation,
9th Floor, Paryavaran Bhavan, CGO Complex, Lodhi Road,
New Delhi 110003,
India
E-mail: *brajeshchem@gmail.com*

INTRODUCTION

High concentrations of arsenic in drinking water have been reported in various parts of the world, such as Argentina, Bangladesh, Chile, China, Hungary, India, Mexico, Pakistan, Thailand, USA and Vietnam (Guha Mazumder *et al.* 1998; Csalagovits 1999; Smith *et al.* 2000; Milton *et al.* 2005; Bundschuh *et al.* 2006). Bangladesh, China and India are the worst arsenic affected countries in Asia in terms of exposure of arsenic contaminated water to the rural population (Chakraborti *et al.* 2009). In India, West Bengal State has been one of the worst arsenic affected states. The first report of arsenic groundwater contamination and its health effects in the Ganga plain from West Bengal was published in 1984 (Garai *et al.* 1984). Since then, many researchers have focused their studies on arsenic contamination in West Bengal State and have highlighted this problem (Guha Mazumder 1998; Smith *et al.* 2000; Chakraborti *et al.* 2004). However, most of the research papers have been limited to states situated in the Ganga-Brahmaputra River belt (Nickson *et al.* 2007; Chakraborti *et al.* 2008). There is a lack of information on arsenic contamination in other states (Chetia *et al.* 2011). Further, there is no available policy paper on arsenic contamination in India which provides authentic information, year-wise and state-wise, on the status of the arsenic problem in India, policy initiatives taken at Government of India level and their impact in mitigating the problem. This is the first ever policy paper on the status of arsenic contamination in rural areas throughout the country, the various initiatives taken at Government of India level and their impact on mitigating the arsenic problem in India along with the constraints and recommendations based on ground realities.

Groundwater constitutes more than 85% of drinking water sources in India and arsenic is a geogenic contaminant, which is found in some of the states in drinking water sources, especially in groundwater in India (Ministry of Drinking Water & Sanitation 2013a). Arsenic occurs naturally in the environment and can be released into water through natural activities such as hydrothermal action and

doi: 10.2166/wh.2016.014

dissolution of rocks. It may also come from industrial sources or from arsenic containing insecticides, herbicides or rodenticides. Arsenic is used in the cotton industry and in electronics, especially in photocopying and high speed computers. Lead arsenate and sodium/calcium arsenite are used as pesticides, monosodium arsenite and dimethyl arsenite are used as weed killers, and fluorochrome arsenate phenol and chromated copper arsenate are wood preservatives (Jain 2012).

Health impact of excess arsenic

Inorganic arsenic compounds in which arsenic is present in trivalent form are known to be the most toxic (Chappell *et al.* 1999). Table 1 shows the acute toxicity of a number of arsenic compounds.

The first visible symptoms caused by exposure to low arsenic concentrations in drinking water are abnormal black-brown skin pigmentation known as melanosis and hardening of palms and soles known as keratosis. If the arsenic intake continues, skin de-pigmentation develops resulting in white spots that look like raindrops (medically described as leukomelanosis). Palms and soles further thicken and painful cracks emerge. These symptoms are described as hyperkeratosis and can lead on to skin cancer (WHO 2001). The diseases caused by chronic arsenic ingestion are called arsenicosis and develop when arsenic contaminated water is consumed for several years (Figure 1).

Arsenic may attack internal organs without causing any visible external symptoms, making arsenic poisoning difficult to recognize. Long-term ingestion of arsenic in water may also lead to problems with kidney and liver function. Arsenic can disrupt the peripheral vascular system leading to gangrene in the legs, known in some areas as black foot disease. This was one of the first reported symptoms of chronic arsenic poisoning observed in China (province of Taiwan) in the first half of the 20th century (Petrusevski *et al.* 2007).

Table 1 | Acute toxicity for different arsenic compounds (arsenic form oral LD50 (mg/kg body weight))

S. no.	Arsenic compound	Value
1	Sodium arsenite	15–40
2	Arsenic trioxide	34
3	Calcium arsenate	20–800
4	Arsenobetane	>10,000

Source: Chappell *et al.* (1999).

National standards on arsenic

WHO *Guidelines for Drinking Water Quality* (1996) specified provisional value of 0.01 mg/L for arsenic in drinking water. A number of European countries have adopted the WHO provisional guideline of 0.01 mg/L as their standard. Australia adopted an even more stringent standard of 0.007 mg/L for arsenic in drinking water in 1996. In the USA, Environmental Protection Agency (EPA) interim maximum contaminant level for arsenic in drinking water was 0.05 mg/L but EPA adopted a new standard of 0.01 mg/L of arsenic in drinking water in 2001. From the year 2006 onwards, all drinking water supply agencies in the USA are following new standards of 0.01 mg/L (USEPA 2001).

Countries where the national standard for arsenic in drinking water remains at 0.05 mg/L include Bangladesh, China and India. In India, drinking water quality standards are specified by the Bureau of Indian Standards (BIS). BIS has specified two types of values for general physico-chemical parameters and toxic elements in drinking water: (1) maximum desirable limit and (2) permissible limit in the case of absence of alternative drinking water sources. BIS specification for drinking water (IS 10500: 2003) specified both the values as 0.05 mg/L. However, in 2012, BIS reduced the maximum desirable limit of arsenic from 0.05 mg/L to 0.01 mg/L. The permissible limit (in the case of absence of alternative sources) for arsenic remains unchanged as 0.05 mg/L (BIS 2012).

Rural drinking water supply in India

Rural drinking water supply is a state subject in India. It has been included in the Eleventh Schedule of the Constitution, among the subjects that may be entrusted to Gram Panchayats (GPs) (elected local village group for self governance) by the states. The Ministry of Drinking Water & Sanitation (MDWS) (Government of India) provides financial assistance under the National Rural Drinking Water Programme (NRDWP) to the states for rural drinking water supply schemes.

Figure 1 | Adverse effect of consumption of excess arsenic in drinking water. *Source:* Ministry of Drinking Water & Sanitation (Presentation in workshop on Arsenic and JE/AES. Gorakhpur, Uttar Pradesh, 8 December 2012).

NRDWP

The NRDWP provides grants to all the states for construction of rural water supply schemes with special focus on water-stressed and water quality affected areas, rainwater harvesting and groundwater recharge measures, and for operation and maintenance including minor repairs. Allocated funds are released to the states in three installments (40%, 40% and 30%, respectively) during each year. Under the NRDWP, powers to plan, approve and implement the water supply schemes which inter alia includes, selection of suitable treatment technologies rest with the states.

Arsenic affected habitations in India

Since the year 2009, the physical and financial progress of NRDWP in states is reported by states on the online Integrated Management Information System (IMIS) of the Ministry of Drinking Water & Sanitation website. In the year 2009, nine states reported a total of 9,504 habitations affected with arsenic contamination in drinking water on the online IMIS on the website of the ministry (Ministry of Drinking Water & Sanitation 2013b). The severity of arsenic, state-wise, is indicated in Figure 2. Hydrogeological surveys and exploratory drilling in arsenic affected areas in the Indo-Gangetic Plains reveals that arsenic contaminated aquifers are generally confined to 120 m below ground level in the alluvial areas.

The extent of arsenic problems in India is much greater in reality, considering that some states, such as Punjab and West Bengal, have recently informed the ministry that there are more arsenic affected habitations in their states than reported on the online IMIS of the ministry. It has been communicated to the ministry that there are nearly 200 arsenic affected rural habitations in Punjab while there are nearly 5,000 arsenic affected rural habitations in West Bengal. While detection of nearly 200 arsenic affected rural habitations in Punjab is a recent finding, and could be attributed to anthropogenic reasons (over-exploitation and pesticides/fertilizers in the manufacturing industry), West Bengal state has been known to be one of the most arsenic affected states in India due to arsenic content in the flood plain of Ganga.

METHODOLOGY

This is a practical paper, which is based on the information provided by the states on the online IMIS on the website of the Ministry of Drinking Water & Sanitation (Government of India), initiatives of the Ministry of Drinking Water & Sanitation, field observations, reports of the ministry and discussions held in meetings of state officials dealing with rural drinking water and sanitation with senior officials of the ministry. Relevant research/review/background papers and presentations made by the ministry, were also referred to.

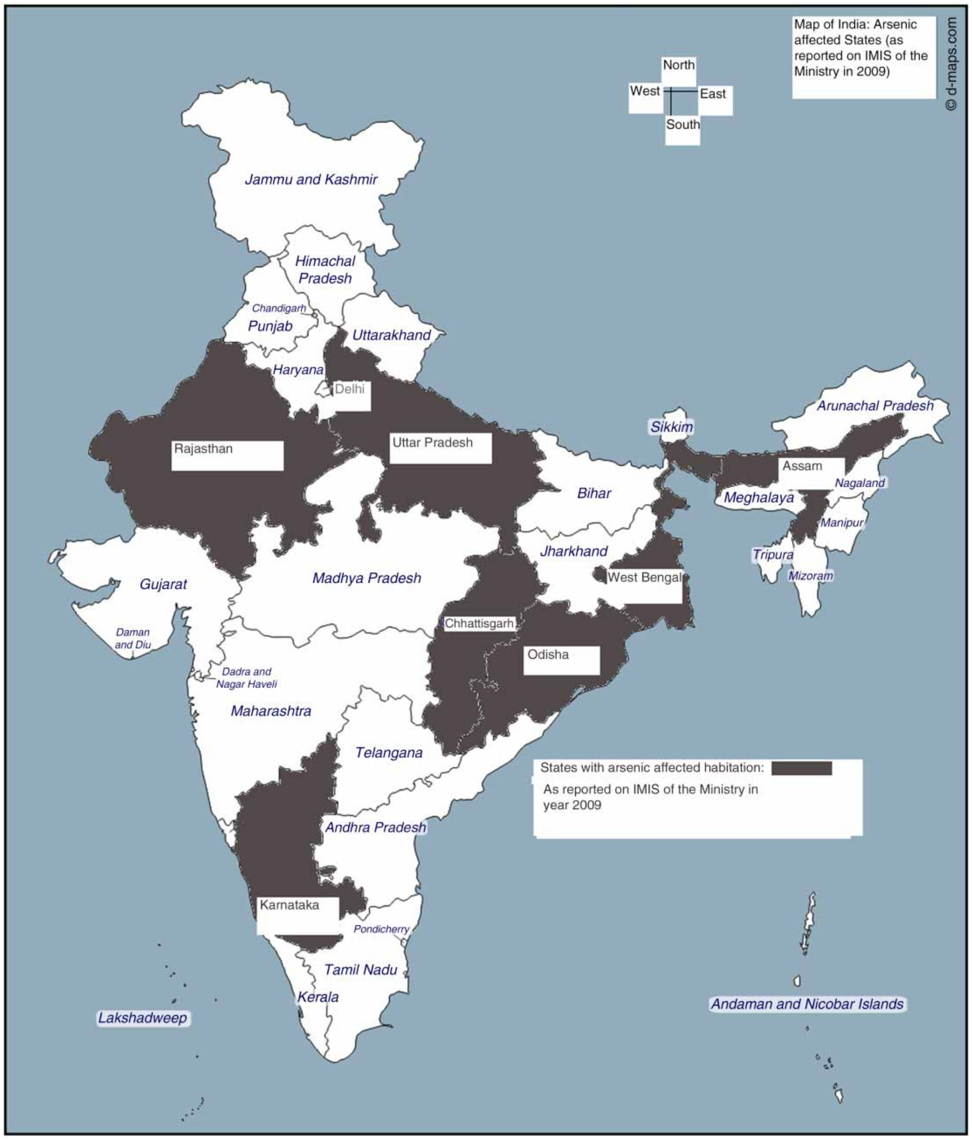

Figure 2 | Arsenic affected rural habitations in India, as reported by states on IMIS of Ministry of Drinking Water & Sanitation (Government of India). *Source:* National Informatics Centre, Ministry of Drinking Water & Sanitation (2012).

POLICY INITIATIVES BY GOVERNMENT OF INDIA TO MITIGATE THE ARSENIC PROBLEM IN DRINKING WATER UNDER THE NRDWP

Under the NRDWP, there is a provision for the states to utilize 20% of their annual NRDWP fund allocation for providing safe water in the quality affected habitations. In the case where states want to utilize more funds for addressing water quality problems, they can use funds up to 67% of the total state allocation to address water quality problems. Some of the major policy initiatives taken at Government of India level to mitigate the arsenic problem are shown below.

Inception of National Drinking Water Quality Monitoring & Surveillance Programme in 2006

The National Rural Drinking Water Quality Monitoring & Surveillance Programme (NDWQM&S) was launched in February 2006 with the prime objective of institutionaliza- tion of community participation and involvement of

Panchayat Raj Institution (PRI) for water quality monitoring & surveillance of all drinking water sources. The key elements of NDWQM&S are as follows:

- To set-up the district and sub-district drinking water quality testing laboratories (or upgrade the existing ones) for routine and regular testing of water quality of rural drinking water sources.
- To provide field test kits (FTKs) and bacteriological vials to GPs for on the field testing of important general parameters (including arsenic).
- Awareness generation of the community at large on water quality and health issues.
- Capacity building of five grass root workers in each GP for testing of water sources within their jurisdiction using simple FTKs and confirmation from the nearest water testing laboratory for positively tested samples.
- Conduct sanitary survey by trained Panchayat personnel for the possibility of bacteriological contamination.

Under the programme, 100% funding is provided to all the states for information, education and communication (IEC) activities, human resource development activities, strengthening of district level drinking water quality testing laboratories, procurement of FTK for testing drinking water, travel and transportation cost, data reporting cost, stationery cost, honorarium to district level surveillance coordinators, water testing, documentation and data entry costs to the states for strengthening water quality monitoring facilities as per approved norms for water quality monitoring and surveillance programme and NRDWP guidelines. The WQMS Programme has been subsumed in the NRDWP since the year 2009.

Inception of 5% water quality earmarked funds to the states in the year 2011

The earmarked funding was started in the year 2011 with 100% funding pattern from the ministry. Under this scheme, states are not required to provide a matching contribution. Three-quarters (i.e., 75%) of the 5% NRDWP funds is provided for tackling chemical contamination (fluoride, arsenic, iron, nitrate and salinity) based on the population residing in these affected habitations. Populations residing in fluoride and arsenic affected habitations have been given top priority (45%) and (40%), respectively, followed by equal weightage (5% each) for iron, nitrate and salinity affected habitations. The remaining 25% earmarked funds are allocated to the 60 priority districts affected with Japanese encephalitis/acute encephalitis syndrome (JE/AES) problem in five states.

Setting up district and sub-district water quality testing laboratories

States have set up state level, district level and sub-district level drinking water quality testing laboratories using 100% grant-in-aid from NRDWP funds and also from their own resources. As reported by the states on the online IMIS of the ministry, up to 1/4/2015, 28 state level laboratories, 780 district level laboratories and 1,288 sub-district/block level laboratories have been set up.

Research and development activities sponsored by the ministry

The ministry has identified seven thrust areas for research and development (R&D) activities in the sector for which 100% funding from the NRDWP is provided to institutions/universities. Thus far, 167 R&D projects worth Rs. 15.37 crore ($24.39 million) have been approved for states, of which 137 projects have been completed. Some institutions have piloted technologies in arsenic affected rural areas in India (Figures 3 and 4).

Technology assistance to the states and important publications

The most commonly used technologies for arsenic treatment are oxidation, co-precipitation and adsorption onto coagulated flocs, lime treatment, adsorption onto sorptive media, ion exchange resin and membrane techniques. Techniques available for the removal of arsenic from contaminated water are based mainly on six principles:

1. Oxidation and filtration.
2. Biological oxidation: oxidation of As(III) to As(V) by microorganisms and then removal of As(V) by iron and manganese oxides.

Figure 3 | Wall mounted household ATUs, devised by Council of Scientific & Industrial Research, Central Salt & Marine Chemical Research laboratory were provided in Sangrampur, Merudandi and Basirhat areas in West Bengal State during 2009. *Source:* P. S. Anand (2013). Approaches to arsenic removal from drinking water sources and learning from field experiences. Workshop on Arsenic Removal Technologies, organized by Ministry of Environment & Forest, Government of India, Kolkata.

Figure 4 | Use of Kanchan arsenic filter in rural areas at household level. *Source:* Presentation by Shri A. Paul on Use of affordable ATUs (2011).

3. Co-precipitation: oxidation of As(III) to As(V) by adding a suitable oxidizing agent followed by coagulation, sedimentation and filtration.
4. Adsorption: activated alumina, activated carbon, iron based sorbents, zero valent iron and hydrated iron oxide, etc.
5. Ion exchange through suitable cation and anion exchange resins (mostly anion exchanger).
6. Membrane technology: reverse osmosis, nano-filtration and electro-dialysis.

The ministry is promoting application of innovative and cost-effective arsenic removal plants. Some of the technologies which have been found very useful are shown below.

Electro-chemical arsenic remediation technology

The Gadgil Laboratory at the University of California, Berkeley and Lawrence Berkeley National Lab has developed and patented electro-chemical arsenic remediation (ECAR) technology to meet international drinking water quality standards for arsenic. In ECAR, a highly effective iron-based adsorbent is generated *in situ* when a small voltage is applied (via solar or intermittent grid) to ordinary steel plates in arsenic contaminated water. As(III) (a more toxic form of arsenic which is generally difficult to remove) is oxidized to AS(V) during the process. This technology is being piloted in West Bengal.

Ferrate

Recently, ferrate (Fe(VI), iron in +6 oxidation states) has gained great attention as an environmentally friendly oxidant and coagulant for water and wastewater treatment. Fe(VI) is a known powerful oxidant over the entire pH range. It has been reported to be especially effective for treating various nitrogen and sulfur containing contaminants in water. The removal of arsenic by Fe(VI) is carried out in two steps: i.e., oxidation of As(III) to As(V) by Fe(VI) and subsequent removal of As(V) by its coagulation with Fe(III) produced by the reduction of Fe(VI).

Solar oxidation and removal of arsenic

This is a simple method that uses irradiation of water with sunlight in polyethylene terephthalate (PET) or other UV transparent bottles to reduce the arsenic level in drinking water. The process has been developed by the Swiss Federal Institute of Environmental Science and Technology, Switzerland (EAWAG) and Swiss Agency for Development and Cooperation. The method is based on photochemical oxidation of As(III) followed by precipitation or filtration of As(V) adsorbed on Fe(III) oxides. Field tests in Bangladesh have shown removal efficiency between 45 and 78% with an average of 67%. Solar oxidation and removal of arsenic (SORAS) can treat raw water having an arsenic concentration below 100–150 μg/L. The method was conceived for usage at household level to treat small quantities of drinking water at virtually no cost. There is virtually no cost associated with it and this is useful at household level.

Kanchan arsenic filter

A Kanchan arsenic filter is a modified slow sand filter with additional arsenic removal capacity, consisting of a plastic or concrete container filled with gravel, sand and iron nails. At the top of the filter, non-galvanized iron nails are exposed to air and water, rusting quickly and producing ferric hydroxide on the iron nails' surface, which absorbs arsenic from the water. Some arsenic loaded iron particles are flushed on to the sand layer below, and are trapped in the top few centimetres of the fine sand due to straining. As ferric hydroxide particles 'exfoliate' from the iron nails, new iron surfaces are created, providing additional arsenic adsorption capacity. This technology has been used in some areas in Assam state.

Release of important publications

Handbook of Drinking Water Treatment Technology

The Ministry of Drinking Water & Sanitation has released two editions of the *Handbook of Drinking Water Treatment Technology*, the first edition in 2011 and the second edition in 2013, for technological assistance to the states. The Technology Manual provides information on the technologies available for treatment of contaminants such as arsenic, fluoride, nitrate, iron, salinity, chromium and uranium, etc., along with the cost of the treated water (Ministry of Drinking Water & Sanitation 2013c).

Uniform Drinking Water Quality Monitoring Protocol

An Expert Committee constituted under the Ministry of Drinking Water & Sanitation, prepared a key policy document, Uniform Drinking Water Quality Monitoring Protocol, which was released in February 2013 and issued to all the states (Ministry of Drinking Water & Sanitation 2013d). Salient features of the Uniform Drinking Water Quality Monitoring Protocol are as follows:

- Provision for setting up/up-gradation of drinking water testing laboratories at state, district and sub-district level in each state using NRDWP water quality support funds.
- Roles and responsibilities to tackle drinking water quality problems at national level, state level, district/sub-district level and at village/GP level are defined clearly.
- Staffing patterns for each level of laboratory (state, district and sub-district laboratories) along with amount of honorarium to be paid (for each level of contractual/outsourced staff engaged in collecting and analysing samples) mentioned.
- Drinking water quality parameters, to be monitored at each level (state, district and sub-district level laboratories) considering revised specifications for drinking water quality (IS 10500: 2012) specified.
- Implementation of water safety plan which inter alia includes sanitary inspection for different types of water supply schemes.
- Suggestive minimum infrastructure (space, chemicals, instruments, equipment, etc.) at each level of laboratory (state, district and sub-district).

Commencement of community water purification system in water quality affected habitations

Piped water supply schemes take nearly 4–5 years to commission. Since the population residing in these habitations cannot be put at risk of arsenic contaminated drinking water, the ministry started a new scheme under NRDWP in 2014 for installation of community water purification plants in 25,836 rural habitations with problems of arsenic, fluoride, toxic elements and pesticides and fertilizer, etc. in drinking water sources. Arsenic and fluoride affected habitations have been given the highest priority where community water purification plants are required to be installed. It has been suggested that all the states should install arsenic treatment community water purification plants in identified arsenic affected habitations by March 2017.

Constitution of Inter-Ministerial Group

A high level Inter-Ministerial Expert Group, constituted within the Ministry of Water Resources, River Development & Ganga Rejuvenation (MoWR, RD & GR) has also been formed which is monitoring the arsenic problem from all dimensions. The National Human Right Commission (NHRC) and the relevant Parliamentary Committees are also reviewing progress pertaining to the arsenic problem in drinking water. The Ministry of Drinking Water & Sanitation has informed the NHRC and Parliamentary Committees to tackle all existing arsenic affected habitations by March 2017.

RESULTS AND DISCUSSION

As per the NRDWP-IMIS report of the Ministry of Drinking Water & Sanitation, the total number of arsenic affected habitations has decreased from 9,504 habitations in 2009 to 1,800 as reported by the states up to March 2015, which shows that so far 7,704 reported arsenic affected habitations have been provided with safe drinking water during the last 6 years (Table 2). West Bengal addressed 3,977 arsenic affected habitations during the last 6 years followed by Bihar and Uttar Pradesh which addressed 2,444 and 834 habitations, respectively. Some states, such as Assam, Karnataka and Punjab, have also reported an increase in the number of arsenic affected habitations during these years and this may be attributed to enhanced monitoring activities. However, as per the information provided by the states on the online IMIS of the ministry in the year 2015, there are still 22.32 lakh (2.232 million) rural populations living in 1,800 rural habitations of six states – West Bengal, Assam, Punjab, Bihar, Uttar Pradesh and Karnataka – that are affected by excess arsenic in

Table 2 | Changes in arsenic affected habitations in India during 2006 to 2015

S. no.	States/UTs	2006*	2009**	2015***	Reduction since year 2009
1	Andhra Pradesh	0	0	0	0
2	A & N Islands	0	0	0	0
3	Arunachal Pradesh	0	0	0	0
4	Assam	730	810	290	520
5	Bihar	794	2,510	66	2,444
6	Chandigarh	0	0	0	0
7	Chhattisgarh	11	12	0	12
8	D & N Haveli	0	0	0	0
9	Daman & Diu	0	0	0	0
10	Delhi	0	0	0	0
11	Goa	0	0	0	0
12	Gujarat	0	0	0	0
13	Haryana	0	0	0	0
14	Himachal Pradesh	0	8	0	8
15	Jammu & Kashmir	0	0	0	0
16	Jharkhand	18	0	0	0
17	Karnataka	0	21	9	12
18	Kerala	0	0	0	0
19	Lakshadweep	0	0	0	0
20	Madhya Pradesh	0	0	0	0
21	Maharashtra	0	0	0	0
22	Manipur	0	0	0	0
23	Meghalaya	0	0	0	0
24	Mizoram	0	0	0	0
25	Nagaland	0	0	0	0
26	Orissa	0	2	0	2
27	Pondicherry	0	0	0	0
28	Punjab	0	0	178	−178
29	Rajasthan	0	66	0	66
30	Sikkim	0	0	0	0
31	Tamil Nadu	0	0	0	0
32	Tripura	106	0	0	0
33	Uttar Pradesh	0	873	39	834
34	Uttarakhand	0	0	0	0
35	West Bengal	5,408	5,195	1,218	3,977
Total		**7,067**	**9,497**	**1,800**	7,697

*Report of first survey.
**Reported by states first time on IMIS of the ministry.
***Status during current financial year, i.e., 2015–2016.

groundwater-based drinking water sources and that require safe drinking water.

The following types of measures (but not limited to these) have been adopted for tackling the arsenic problem in drinking water in the states (depending upon the prevailing situation at that time):

- Colouring of the identified arsenic affected handpumps with an indication to not use the arsenic contaminated water for drinking purposes.
- IEC activities to raise awareness in rural areas.
- Complete sealing/closure of the handpumps/tubewells where arsenic was found to be higher than the permissible limit of 0.05 mg/L.
- New hand pumps on tubewells at deeper aquifers.
- Ring wells at upper aquifers.
- Installation of arsenic treatment units (ATUs) in existing hand pumps and water supply systems.
- Use of new large diameter tubewells at deeper aquifer for existing groundwater-based piped water supply schemes.
- Arsenic removal plants in existing groundwater-based piped water supply schemes.
- Groundwater-based new piped water supply schemes.
- Surface water-based new piped water supply schemes with river water or pond water as source.

Private sector Indian companies as well as institutions from other countries working in the area of arsenic mitigation are contributing immensely in states by either providing excellent instrumentation facilities or by taking up installation of arsenic removal plants and their operation and maintenance.

CONSTRAINTS AND RECOMMENDATIONS

- The organizational structure of the departments dealing with drinking water (Public Health Engineering/Jal Nigam/Board/Authority/Rural Development) in many states is very conventional and lacking scientific perspective. In many states, hydrogeologists, chemists, microbiologists, IEC specialists, statisticians, etc. are either not employed or are grossly inadequate. The states of Tamil Nadu, Gujarat, Andhra Pradesh and Rajasthan have better institutional structures than other states. Water quality issues in many states are not properly attended to due to lack of professionally qualified experienced staff. The conventional institutional structure needs to be changed. For this, the number of professionals from multidisciplinary professionals should be increased in order to meet the challenges of various types of drinking water quality issues including the arsenic problem.
- The BIS is in the process of reducing the maximum permissible limit of arsenic in drinking water to 0.01 mg/L from the existing limit of 0.05 mg/L. If the arsenic limit in drinking water is reduced to 0.01 mg/L, an additional 10,003 new arsenic affected habitations comprising 1.2 crore (0.12 billion) population will emerge, for which, funds to the tune of Rs. 8,000 crore (US$ 1.2 billion) would be further required. This requires a greater contribution of funds from the states.
- There is a lack of awareness in villages about sources of arsenic, its adverse effects and the remedial measures. Poverty is also a prime reason as many rural people are not able to afford a nutritional diet to buffer the effect of arsenic to some extent. Although MDWS has advised intensive IEC to the states, its impact at grassroot level has not been significant. Arsenic awareness camps should be conducted at regular intervals and interpersonal communication should be encouraged by the state.
- States should undertake initiatives on deepening of shallow dugwells and borewells in arsenic affected habitations because deeper level aquifers have been found to contain less arsenic as compared to the shallow ones. The present approach, although it places emphasis on deepening handpumps and tubewells in arsenic affected areas, does not focus much on revival of dugwells.
- There is an inability of GPs timely to take up the problem with the concerned departments of the state and sometime apathy of the state officials dealing with the arsenic problem in the states.
- Not reporting/under reporting/higher reporting of the data on online IMIS regarding NRDWP has been noted. It has also been observed that the data provided on IMIS by the states sometime do not reflect reality on the ground. It is necessary that the data/figures reported are true and reflect the ground reality.
- Non-functionality of the drinking water testing laboratories to timely identify the problem and address it is one of the

major problems. Many laboratories in states are not equipped with the qualified manpower and appropriate instruments/equipment although they have sufficient funds.

- Arsenic testing kits/arsenators are not procured and distributed by the concerned department/board/authority in sufficient quantity. Experience shows that in many cases, arsenic testing kits/arsenators are not available even in arsenic affected habitations. There is a need to make arsenic testing kits available to each affected habitation with provision to designate a custodian for it.
- 100% source testing in quality affected habitations along with GPS coordinates and depth of groundwater may be immediately taken up, once each in the pre-monsoon and in the post-monsoon season.
- Arsenic is always thought to be a geogenic problem. Although pesticides, weedicides and insecticides are used extensively in some states, the problem of arsenic leaching from pesticide/weedicides/insecticides (due to lead arsenate, sodium/calcium arsenite, monosodium arsenite or dimethyl arsenite, etc.) and pigments in groundwater and surface water are not studied and documented adequately in India. Research should also address the multidimensional interface of arsenic including its mobility in different environments. There is an urgent need to monitor agricultural practices to ensure the lowest level of arsenic contamination from food sources such as specific types of rice and vegetables with the development of a national database on soil, rice and vegetables.
- An arsenicosis patient registry system in arsenic affected habitations in the states would be useful to ensure early identification of arsenicosis patients through a robust surveillance programme and to share the data with the water supply agencies/health department and other concerned departments.
- Untreated industrial effluents and leachates especially from electronic waste processing industries and pesticide manufacturing industries increases the probability of arsenic and other toxic metals intrusion into surface and groundwater. Hence, it is essential that these industries not only use the effluent treatment plants for the treatment of industrial effluents for the maximum period but also monitor drinking water quality for toxic elements in nearby villages under corporate social responsibility.
- Long gestation period of water supply schemes: sometimes, even a single village drinking water supply scheme takes many years to complete and it aggravates the arsenic problem in rural people. Water supply schemes should be implemented in a time-bound manner.
- Operation & maintenance (O&M) of ATUs is not included during installation resulting in early non-functionality of the arsenic treatment plant. All arsenic mitigation schemes should have at least 3–5 years O&M provision at the time of installation.
- Most states do not undertake innovative R&D projects, case studies, door-to-door surveys, evaluation studies involving professional organizations in water quality affected habitations.
- Multidisciplinary research should be undertaken to understand the uptake of arsenic by rice and vegetables from soil irrigated by water high in arsenic. Further, greater understanding is required for the linkages between arsenic from food and uptake by the human body.
- The issue of reject management of arsenic containing sludge has also been raised by many experts. Although there are various stabilization methods available for arsenic containing sludge, bioremediation of arsenic containing sludge is one of the most environmental friendly options, if constant monitoring is done and qualified manpower is available in the field.
- States should use microwave stabilization technique which offers the advantage of selective, uniform, rapid heating and stabilization of the arsenic contaminated sludge due to the characteristics of polar oscillation and the effect of dielectric losses (Biswajit 2013). The technology is useful for large capacity arsenic treatment plants but it can be applied elsewhere if a systematic procedure of collection of arsenic containing sludge is active. Alternatively, arsenic containing sludge may also be used for making bricks and other hard materials which do not leach arsenic back to the environment easily (Figure 5).

CONCLUSION

The progress of the arsenic affected states is slow in tackling arsenic affected habitations keeping in view that only 7,697

Figure 5 | Towards safe disposal of arsenic containing sludge: use of arsenic containing sludge in making bricks. *Source:* Presentation in Workshop on Arsenic Removal Technologies. Organized by MoEF, Government of India, Kolkata (2013).

arsenic affected rural habitations have been provided with safe drinking water since the year 2009. However, there is no doubt that the policy initiatives at Government of India level, which really began in 2009, has created awareness about analysis of arsenic in drinking water sources among state officials. The different initiatives have also strengthened arsenic testing in drinking water through arsenators and in laboratories. The increased testing of arsenic in drinking water has also brought to the fore more arsenic affected habitations to deal with. IEC activities in rural areas should also focus on awareness about availability of some of the simple, user-friendly and affordable arsenic treatment systems so that they can procure these systems themselves individually or through community contribution as an interim measure, until a piped water supply is provided at household level. Technologies such as SORAS offer remediation even for the poorest of the poor for treatment of arsenic in the medium range (100–150 μg/L of arsenic contamination) without use of electricity at virtually no cost.

Success of the arsenic mitigation programme will depend primarily upon planning at state level and implementation of effective O&M protocol of the technology selected. Since installation of handpumps is not encouraged as per the revised policy of the NRDWP and the focus now is to increase access of piped water supply and household tap connections to ensure safe drinking water in rural areas, the success of the arsenic mitigation would ultimately depend upon the speed of the implementation of piped water supply schemes from alternate safe sources. Since implementation of multi-village water supply schemes also requires acquisition of public and private land and clearance from Highway, Railways, Forests (if pipelines are laid in areas under these departments), proper coordination of state Rural Water Supply & Sanitation departments with all other concerned departments, such as Highway, Railway, Forest, Land, etc., is also important to avoid delay and for timely completion of piped water supply schemes. Arsenic affected states should also focus more on capping of arsenic containing aquifers, revival of arsenic affected dugwells by further deepening them, and on protection of village ponds as these water sources offer excellent localized solutions which are also less capital intensive. Since the arsenic mitigation programme has been given priority and progress is being monitored separately by Parliamentary Committee, it is expected that all arsenic affected habitations, where the arsenic level is 0.05 mg/L or more, should be tackled by March 2017. However, for arsenic affected habitations where the arsenic level is 0.01 mg/L or higher, and which has not been reported, greater preparedness is required by the concerned state governments.

ACKNOWLEDGEMENTS

The author thanks senior officials of the Ministry of Drinking Water & Sanitation for providing valuable information on different aspects of remediation of arsenic in drinking water in states. Sincere thanks also to IRC International Water and Sanitation Centre for making the Thematic Overview Paper on Arsenic in Drinking Water online, study and reference of which was very useful for preparation of this paper. The views expressed are the author's personal views.

REFERENCES

Biswajit, R. 2013 Microwave Assisted Stabilization of Arsenic-Iron Contaminated Water Treatment Plant Sludge. Presentation made in Research & Development Advisory Committee Meeting of Ministry of Drinking Water & Sanitation at Nirman Bhavan, New Delhi, India.

Bundschuh, J., Garcia, M. E. & Birkle, P. 2006 Rural Latin America: a forgotten part of the global groundwater arsenic problem. In: *Groundwater for Sustainable Development: Problems, Perspectives and Challenges* (P. Battacharya, ed.). Taylor and Francis, London, UK.

Bureau of Indian Standards 2012 *Indian Standard on Drinking Water Specification IS 10500 (Second Revision)*. BIS, New Delhi, India.

Chakraborti, D., Sengupta, M. K., Rahman, M. M. & Ahamed, S. 2004 Groundwater arsenic contamination and its health effects in the Ganga-Meghna-Brahmaputra plain. *J. Environ. Monit.* **6**, 74–83.

Chakraborti, D., Singh, J. K., Das, B., Babar, A. S., Hossain, M. A., Nayak, B., Ahamed, S. & Singh, N. R. 2008 Groundwater arsenic contamination in Manipur, one of the seven North-Eastern Hill states of India: a future danger. *Environ. Geol.* **56** (2), 381–390.

Chakraborti, D., Bhaskar, D., Mohammad, M. R., Uttam, K., Chowdhury, U. K., Biswas, B., Goswami, A. B., Nayak, B., Pal, A., Sengupta, M. K., Ahamed, S., Hossain, A., Basu, G., Roychowdhury, T. & Das, D. 2009 Status of groundwater arsenic contamination in the state of West Bengal, India: a 20-year study report. *Mol. Nutr. Food Res.* **53**, 542–551.

Chappell, W. R., Abernathy, C. O. & Calderon, R. L. 1999 Arsenic exposure and health effects. In: *Proceedings of the Third International Conference on Arsenic Exposure and Health Effects*, 14–18 July 1998, San Diego, CA, USA.

Chetia, M., Chatterjee, S., Banerjee, S., Nath, M. J., Singh, L., Srivastava, R. B. & Sharma, H. P. 2011 Groundwater arsenic contamination in Brahmaputra river basin: a water quality assessment in Golaghat (Assam), India. *Environ. Monit. Assess.* **173**, 371–385.

Csalagovits, I. 1999 *Arsenic-bearing artesian waters of Hungary*. Annual Report of the Geological Institute of Hungary, 1992–1993/II, pp. 85–92.

Garai, R., Chakraborty, A. K., Dey, S. B. & Saha, K. C. 1984 Chronic arsenic poisoning from tube well water. *J. Indian Med. Assoc.* **82**, 34–35.

Guha Mazumder, D. N., Haque, R., Ghosh, N., De, B. K., Santra, A., Chakraborty, D. & Smith, A. H. 1998 Arsenic levels in drinking water and the prevalence of skin lesions in West Bengal, India. *Int. J. Epidemiol.* **27** (5), 871–877.

Jain, C. K. 2012 Arsenic removal using adsorptive media treatment process. In: *India Water Week 2012–Water, Energy and Food Security: Call for Solutions*, 10–14 April 2012, New Delhi, India.

Milton, A. H., Smith, W., Rahman, B., Hasan, Z., Kulsum, U. & Dear, K. 2005 Chronic arsenic exposure and adverse pregnancy outcomes in Bangladesh. *Epidemiology* **16**, 82–86.

Ministry of Drinking Water & Sanitation 2013a A comprehensive note on drinking water quality in rural areas in the country.

Ministry of Drinking Water & Sanitation 2013b Information furnished by States on IMIS (Integrated Management Information System) of the Ministry of Drinking Water & Sanitation under Basic information, Format B-13 (List of Quality Affected habitations, Financial Year 2009 -10, 2010 -11, 2011 -12, 2012 -13). Available at: http://indiawater.gov.in/imisreports/Reports/Physical/rpt_RWS_NoOfQualityAffHabitations_S.aspx?Rep=0&RP=Y&APP=IMIS.

Ministry of Drinking Water & Sanitation 2013c *Handbook on Treatment Technology*, 2nd edn. Ministry of Drinking Water & Sanitation, New Delhi.

Ministry of Drinking Water & Sanitation 2013d Uniform Drinking Water Quality Monitoring Protocol.

Nickson, R., Sengupta, C., Mitra, P., Dave, S. N., Banerjee, A. K., Bhattacharya, A., Basu, S., Kakoti, N., Moorthy, N. S., Wasuja, M., Kumar, M., Mishra, D. S., Ghosh, A., Vaish, D. P., Srivastava, A. K., Tripathi, R. M., Singh, S. N., Prasad, R., Bhattacharya, S. & Deverill, P. 2007 Current knowledge on the distribution on arsenic in groundwater in five states of India. *J. Environ. Sci. Health Part A* **42** (12), 1707–1718.

Petrusevski, B., Sharma, S., Schippers, J. C., Shordt, K. & van Wijk, C. 2007 Arsenic in Drinking Water, Thematic Overview Paper 17, IRC International Water and Sanitation Centre.

Smith, A. H., Lingas, E. O. & Rahman, M. 2000 Contamination of drinking-water by arsenic in Bangladesh: a public health emergency. *Bull. World Health Organ.* **78**, 1093–1103.

United States Environmental Protection Agency (USEPA) 2001 Safe Drinking Water Act, Arsenic Rule. Available at: http://water.epa.gov/lawsregs/rulesregs/sdwa /arsenic/regulations.cfm.

World Health Organization 1996 *Guidelines for Drinking Water Quality*, 2nd edn. WHO, Geneva, Switzerland.

World Health Organization 2001 Arsenic in drinking water. Fact sheet No. 210, rev. edn. Available at: http://www.who.int/mediacentre/factsheets/fs210/en/.

First received 25 December 2015; accepted in revised form 20 April 2016. Available online 6 June 2016