The Status of Arsenic Contamination in India

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Abstract The presence of arsenic (As) in the groundwater threatens human health throughout the world. The problem is severe in southeastern parts of Asia especially India, Bangladesh, China, etc. because the population density is very high in comparison to the other western countries. Groundwater, which is the main source of drinking water in these areas, has been found to have As as high as 300 ppb. Out of 29 states in India, reports of As contamination have emerged from 17 states. The number of As-affected districts and the number of people affected have grown ever since the initial reports of As contamination came to knowledge in the 1980s. The present situation of As contamination in India is of great concern. This chapter focuses on presenting the As contamination status of India and also elaborates the possible reasons for groundwater As contamination in the Indo-Gangetic region.

Keywords Arsenic · Assam · Bihar · West Bengal · Uttar Pradesh · Manipur

1 Introduction

The growing population of the world creates a shortage of almost all natural resources (de Sherbinin et al. 2007). The problem is of grave concern for developing countries like India and Bangladesh, where a large percentage of the total world population lives in a relatively small area of the world (Bavel 2013). One of the most crucial natural resources is drinking water (Ledder et al. 2002). The two major sources of drinking water include surface water and groundwater. The surface water, which is mainly available in the form of rivers, ponds, and lakes, has become increasingly loaded with tons of toxic chemical compounds and pathogens and is thus unfit for consumption (Mishra and Dubey 2015). Hence, in many urban and

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rural areas, people have switched to and continue to switch over to groundwater. But since the past few decades, the groundwater resources are also facing the problem of natural and anthropogenic pollution (Tiwari et al. 2019).

Arsenic contamination of groundwater has emerged as a huge problem. Arsenic is a toxic element and has been placed in the group I class of carcinogens by IARC (IARC Monograph 2004). Arsenic groundwater contamination is estimated to affect more than 150 million people across the world. The major regions affected are deltas and river basins, for example, Paraiba do Sul delta (Brazil), Bengal Delta (India and Bangladesh), Mekong Delta (Cambodia), Danube River Basin (Hungary), Hetao River Basin (Mongolia), Duero Cenozoic Basin (Spain), Zenne River Basin (Belgium), etc. (Shankar et al. 2014). In India, As groundwater contamination in West Bengal was first noticed in the year 1978 (Mandal and Suzuki 2002). The first case of As poisoning came under the light in the year in 1983 (Rahman et al. 2005). Since then, As contamination has been detected in many states of India including West Bengal, Uttar Pradesh, Jharkhand, Bihar, Haryana, Punjab, Andhra Pradesh, Chhattisgarh, Assam, Karnataka, Rajasthan, Gujarat, etc. (Chaurasia et al. 2012). Bangladesh has eight divisions, namely, Barisal, Chittagong, Dhaka, Khulna, Rajshahi, Rangpur, Sylhet, and Mymensingh. Among these, the most affected areas are Dhaka, Khulna, Rajshahi, Sylhet, Mymensingh, and Chittagong with the recorded concentration of As being more than 50 ppb (Hossain 2006).

The main source of As contamination in the Gangetic river basin and delta sediments is believed to be Himalayan mountains and Shillong Plateau. Apart from this, there are other geological sources like the Gondwana coal region in Rajmahal basin in eastern India, Bihar mica belt in eastern India, the pyrite-bearing region in Vindhya Range in central India, Son River Valley gold belt in the eastern area, and sulfides regions of eastern Himalayas, which have been considered as probable sources of As (Acharyya et al. 2000; Bhattacharya et al. 2015). According to the BGS (2000) reports, the natural sources of As contamination are sulfide and oxide mineral. Pyrite oxidation and sediments transportation have been attributed to the release of As and sulfates in this region. While sulfates were quickly lost in the form of salts in the sea, As was adsorbed by iron oxides, which accumulated over time in the delta region. The worst affected aquifers are the alluvial deposits beneath the floodplains of four major rivers, namely, Ganga, Brahmaputra, Meghna, and Tista (Hossain 2006; Ahmad et al. 2004). There are several industrial processes also, which result in the release of As to the environment, for example, metal mining, iron and steel production, coal combustion, etc. (Pandey et al. 2015), cement production, pharmaceutical industries, and manufacturing of paints and varnishes (Hossain 2006). Further, fertilizers, herbicides, pesticides, insecticides, and fungicides play a crucial role in contaminating agriculture land (Bhattacharya et al. 2011).

Different countries have different permissible limits of As content in drinking water. The World Health Organization (WHO) guideline for drinking water is 10 ppb (10 μg/L) (WHO 1993). Initially, WHO had set 200 ppb as As standard for drinking water in the year 1958. This was later reduced to 50 ppb in 1963 and to 10 ppb in the year 1993 with knowledge and case reports about the adverse health impacts of As that included cancer also (WHO 1958, 1963, 1993, 2011). In the year 2001, USEPA also revised As limit from 50 ppb to 10 ppb as the maximum contaminant level keeping in mind the cost, benefits, and ability of the public water system to detect and remove contaminants (USEPA 2013). In India and Bangladesh, the permissible limit of As in drinking water is 50 ppb (Pal et al. 2009).

2 Arsenic Mobilization and Transportation in Groundwater

There are four main hypotheses for the mobilization and transportation of As in groundwater (Bhattacharya et al. 2015): oxidation of pyrite, competitive ion exchange, reductive dissolution of iron oxyhydroxides, and reduction and re-oxidation. Pyrite oxidation has been considered to play an important role in alluvial sediments of India and Bangladesh where excessive use of groundwater for irrigation has created oxidizing conditions in the aquifers (Chakraborty et al. 2015). The theory of competitive ion exchange suggests the competition between As oxyanions and phosphate ions to be the cause of As release in aquifers (Fakhreddine et al. 2015). However, this is not considered a major factor of As contamination of India and Bangladesh. The most widely accepted theory for India and Bangladesh scenario is the reductive dissolution of iron oxyhydroxides. This theory suggests the release of As through reductive dissolution of metal oxides and Fe hydroxides. In general, most of the As-contaminated water throughout the world has found to have very low redox potential which is an indicator of reducing conditions. This can also be explained by a good relationship between As and bicarbonates present in water. Even the redox potential of such water has been found in the range of Fe^{3+} and As^{5+}. Another hypothesis which also explains As menace is reduction and re-oxidation theory. The first step is the mobilization of As via reduction of Fe oxyhydroxides followed by re-oxidation of pyrite. The reduction and re-oxidation process helps in sequestration of As, but due to reducing environment, complete immobilization of As is not possible, thus making As bioavailable (Bhattacharya et al. 2015).

3 Areas Affected by Arsenic in India

A total of 17states in India along with one union territory have been reported to have As content beyond BIS maximum permissible limit (BIS 2012) of 50 ppb (Fig. 1). Around 19% of Indian population is at risk of As poisoning, i.e., almost 25.46 lakh people. In recent Lok Sabha reports, it has been revealed that around 65% of Assam population, 60% of Bihar population, and 44% of West Bengal population are under sever risk of As poisoning (Jadhav 2017). The occurrence of As in groundwater in India can be broadly classified into two categories: the alluvial terrains of West Bengal, Uttar Pradesh, Bihar, Jharkhand, Assam, Manipur, Punjab, and Haryana and the hard-rock terrain of Karnataka and Chhattisgarh. Other parts, where As contamination is reported in recent years, are Rajasthan, Andhra Pradesh, Telangana, Tamil Nadu, and Gujarat (Bhattarcharya and Lodh 2018).

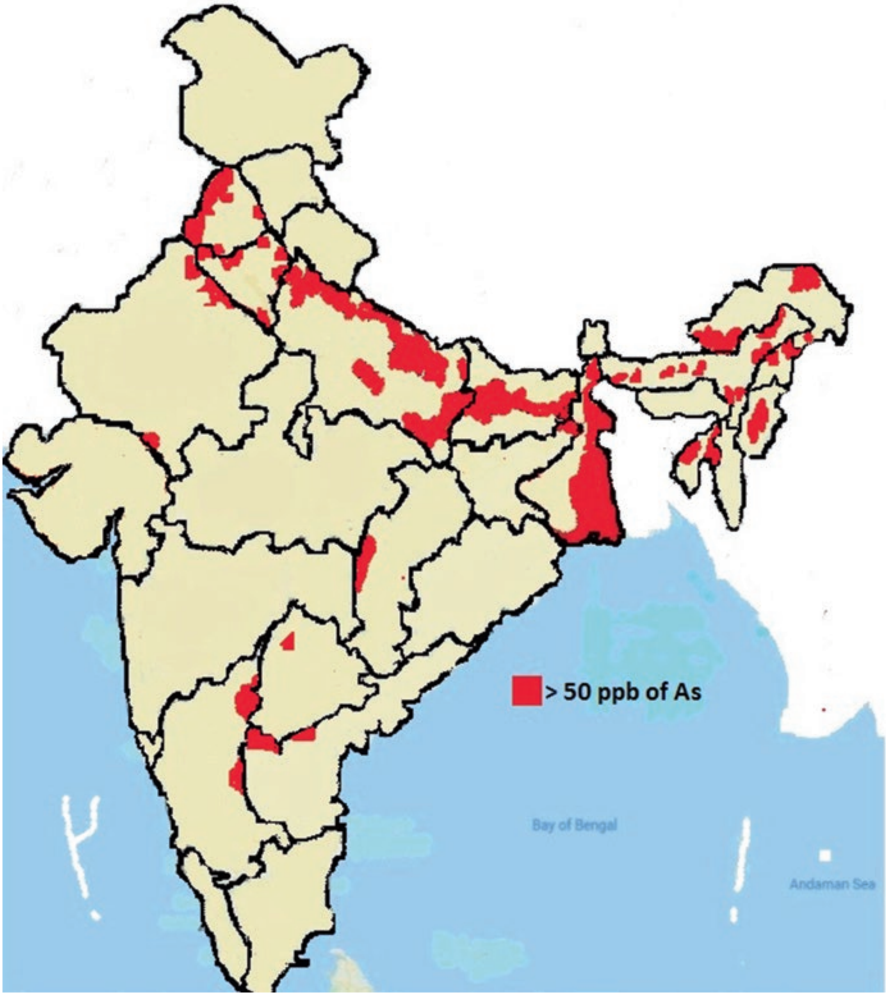

Fig. 1 Indian states that have groundwater or surface water affected with As contamination above than 50 μg/L. In total there are 16 states that are showed here having As level above than BIS permissible limit. (1) Punjab, (2) Haryana, (3) Rajasthan, (4) Uttar Pradesh, (5) Chhattisgarh, (6) Telangana, (7) Karnataka, (8) Andhra Pradesh, (9) Bihar, (10) Jharkhand, (11) West Bengal, (12) Assam, (13) Arunachal Pradesh, (14) Nagaland, (15) Manipur, (16) Tripura

3.1 West Bengal

According to NIH (National Institute of Hydrology, India) and Central Ground Water Board reports (CGWB, West Bengal), there were a total of 9 districts out of 23 in West Bengal in the year 2008, which were reported to have As-contaminated groundwater. The severely affected districts are Murshidabad, North 24 Parganas, South 24 Parganas, Nadia, and Kolkata to the east and Howrah, Purba Bardhaman, and Hugli to the west of Bhagirathi/Hugli and Malda to the north of the Ganges

(CGWB, West Bengal). The concentration of As in these districts was found to be even more than 300 ppb in some places. The severity of this problem in this state has been classified into three subcategories: (i) severely affected areas having more than 300 ppb As, (ii) mildly affected area with As concentration in range of 10–50 ppb (six districts: Darjeeling, Jalpaiguri, Koch Bihar, Dinajpur North, Dinajpur South, and Paschim Bardhaman), and (iii) unaffected area with less than 10 ppb (eight districts: Alipurduar, Kalimpong, Birbhum, Bankura, Purulia, Jhargram, Purba Medinipur, and Paschim Medinipur). There are no reports of As contamination documented till now from As safe districts (Rahman and Sinha 2012; Dey et al. 2014). The alarming fact is that with every new and advanced survey, the number of contaminated villages are increasing resulting in more number of people exposed to As. The severity of the problem has been found to be more on the left side of the Bhagirathi River along the direction groundwater flow. The area has thick alluvial deposition of Quaternary age. In total, about 20% of West Bengal population living in nine severely affected districts (around 19 million people) is affected due to As contamination (Santra 2017).

3.2 Bihar

The presence of elevated As concentration in groundwater was first reported in 2002 from two villages Semaria Ojha Patti and Barisban in Bhojpur district (CGWB, MER, Patna (2013)). The location of this region comes under the flood prone belt of the Sone-Ganga interfluvial region. The As concentration detected was as high as 178 ppb (Bhattacharya and Lodh 2018). Out of 38 districts, 17 districts, namely, Buxar, Bhojpur, Patna, Saran, Darbhanga, Vaishali, Samastipur, Begusarai, Khagaria, Katihar, Munger, Bhagalpur, Lakhisarai, Kishanganj, Supaul, Siwan, and Muzaffarpur, were found to be affected by As concentration of more than 50 ppb (Singh et al. 2014). Simri village (As concentration-1929 ppb) and Tilak Rai Ka Hatta village (As concentration-1908 ppb) were the two most affected villages of Buxar district, and, therefore, it is known to be the most affected district of Bihar by As contamination (Kumar et al. 2016; Singh et al. 2014). It is estimated that more than five million people are drinking water having As concentration of more than 10 ppb (Abhinav et al. 2016). Most of the contaminated districts are located along the course of river Ganga in Bihar. Quaternary alluvium having multi-aquifer system representing medium to fine sands is the primarily geological formation of this region (Bhujal News, CGWB 2010).

3.3 Uttar Pradesh

In Uttar Pradesh, the first report of As contamination of groundwater surfaced in the year 2003 from the survey of nearly 25 villages in Ballia districts (Mukherjee et al. 2006; Bhattacharya and Lodh 2018). Then in the year 2008, two more districts, Ghazipur and Varanasi, were detected with As groundwater contamination (Mukherjee et al. 2006). Currently, 31 districts have higher than 10 ppb As, and in 18 districts, more than 50 ppb As levels are reported by UP Jal Nigam and UNICEF combined report (Pandey et al. 2015). Pandey et al. (2015) reported Bahraich, Ballia, and Lakhimpur Kheri to be the highly contaminated districts with As level of more than 50 ppb. Further, districts like Ambedkar Nagar, Bareli, Basti, Bijnaor, Chaudauli, Faizabad, Ghazipur, Gorakhpur, Meerut, Sant Ravidas Nagar, Shahjahanpur, Siddharth Nagar, Sitapur, Unnao, and Kanpur are also having As level above 10 ppb. The reasons for such a scenario are the same as that of Bihar with almost all the As-affected districts falling along the course of river Ganga and its tributaries and having the same kind of geological formation as that of Bihar (Bhujal News, CGWB 2010).

3.4 Jharkhand and Chhattisgarh

In the year 2003–2004, groundwater As contamination above 50 ppb was reported in Sahebganj district of Jharkhand (Chakraborti et al. 2004). Three blocks that are most affected in this region are Sahibganj, Rajmahal, and Udhawa (Nickson et al. 2007; Nayak et al. 2008; Chaurasia et al. 2012). Till date, only this district is reported for As contamination, and the reason is its geographical location as the river Ganga enters West Bengal from Bihar via Sahibganj district (Nayak et al. 2008). In Chhattisgarh, the only As-affected district reported by CGWB is Rajnandgaon. The As level in this area is more than 50 ppb with the most affected block being Ambagarh Chowki (CGWB, Chhattisgarh 2019; Ghosh et al. 2010). A number of people were detected with arsenical skin lesions and keratosis. The water-bearing formation in the state is weathered and fractured rocks of Proterozoic age, semi-consolidated Gondwana formation with weathered limestone and sandstone having the huge number of aquifers, and unconsolidated sediments including alluvium and laterite. Such geographical formation allows all possible mechanisms of As mobilization and transportation to occur (CGWB, Chhattisgarh 2019).

3.5 Punjab and Haryana

In the year 2004, CGWB surveyed Punjab state and reported that five districts, namely, Amritsar, Gurdaspur, Hoshiarpur, Kapurthala, and Ropar, have As level more than 10 ppb. In many places, the As content in alluvial aquifers was found to be in the range from 3.5 to 688 ppb. The status of As has been therefore classified into various subcategories: (i) low (<10 ppb), (ii) moderate (10–25 ppb), (iii) high (25–50 ppb), and (iv) very high (>50 ppb) (Thakur et al. 2016). In 2012, Government of Punjab also reported As level of more than 50 ppb in five densely populated districts: Amritsar (99 ppb), Rupnagar (91 ppb), Tarn Taran (83 ppb), Gurdaspur

(58 ppb), and Firozpur (55 ppb). Out of 22 districts, 13 districts of Punjab are affected with As in groundwater. Some districts like Amritsar, Fazilka, Tarn Taran, Kapurthala, Mansa, and Rupnagar have As level above the permissible limit (50 ppb) set by BIS, India. The range of As level reported in some areas of these districts is from 10 to 390 ppb (Thakur et al. 2016). The geographical location of this state is in the alluvial region of Indo-Gangetic Plains, which is the home for the sediment forming aquifers. Agricultural, industrial, and even domestic needs of water are fulfilled by using groundwater, and thus, As is released in the environment during the process of heavy abstraction of groundwater (Singh et al. 2015).

In Haryana, Chandigarh was the first district where As concentration of more than 50 ppb was reported (Datta and Kaul 1976). However, to date, there are no reports of arsenical skin lesions and keratosis from any part of Haryana. The districts like Yamunanagar, Karnal, and Sonipat which are reported to have As contamination are located along the course of Yamuna river and its tributaries (Bhattacharya and Lodh 2018). Other districts which are reported with 50 ppb and above As concentration in groundwater are Ambala, Nuh, Mewat, and Fatehabad (Kapur 2015).

3.6 Karnataka, Andhra Pradesh, and Telangana

In Karnataka, As in groundwater initially got reported from two districts, Raichur and Yadgir, famous for gold mining and other related activities. The occurrence of As was reported in the Mangaluru greenstone belt, Hutti gold mines (Lingasugur Taluk) of Raichur district, and Shorapur Taluk of Yadgir district. The maximum As load was recorded as 303 ppb in Hutti gold mine area (Chakraborti et al. 2013). The first ever case of arsenicosis and As-related cancer in Karnataka was identified in Kiradalli Tanda village in July 2009 (Sivanandan 2009a, b; Chakraborti et al. 2013). Arsenic is released from arsenopyrite, which is a chemical waste produced during the extraction of gold. This waste chemical compound produces mobile As when it reacts with the rainwater. The As released percolates down in groundwater or flows to the nearest surface water bodies. In the year 2016, another district, Chitradurga, was reported with alarming As concentration of about 103–235 ppb. The occurrence of such high concentration was reported in the copper and gold mines area of Ingaldhal located in Belliguda Hill (Hebbar and Janardhan 2016).

Arsenic problem in Andhra Pradesh and Telangana region is growing rapidly. The leading district is Medak (Telangana), and the area which is highly affected is the industrial belt region of Patancheru. The recorded As level was found to be in range from 140 to 7350 μg/L ppb (IARC Monograph 2004). Other districts with higher than 10 ppb As level recorded are Kurnool and Guntur (CGWB, Andhra Pradesh 2015–2016). The main source of As contamination in Patancheru region is anthropogenic activities. The major contribution comes from industries like Park Trade Center and Gaddapotharam Bulk Drug factories, which manufacture veterinary drugs based on arsonic acid (Kishan 2001; IARC Monograph 2004; Mukherjee et al. 2006).

3.7 Gujarat, Daman and Diu, and Rajasthan

Though the As problem in Gujarat is not that severe, still there are many districts where As level of more than 10 ppb has been recorded. However, none of them was found to have As above 30 ppb (CGWB, Gujarat and Daman and Diu 2015–2016). The districts having more than 10 ppb As are Amreli, Anand, Bharuch, Bhavnagar, Dohad, Patan, Rajkot, and Vadodara. These regions are geographically located on the central part of Kutch and Saurashtra plateau, which are soft rocks and unconsolidated formations holding a large amount of groundwater. The excessive withdrawal of groundwater is giving rise to high As levels (CGWB, Gujarat and Daman and Diu 2015–2016).

Arsenic contamination is reported in 6 out of 33 districts of Rajasthan that include Churu, Hanumangarh, and Sri Ganganagar (Duggal et al. 2012). The land formation of Hanumangarh and Sri Ganganagar comprises of alluvium and windblown sand as these are situated along the river Ghaggar. The active aquifers beneath the surface release As in groundwater. Churu was found to have severe As problem because of the stone and marble mining. Other districts with high As content are Jhunjhunu and Udaipur. These areas are the copper mining area (Khetri and Zawar mines) in Rajasthan, and the mining waste (tails/dumps) produced during extraction and mineralization process is the main source of As contamination (Bhattacharya et al. 2015).

3.8 Assam, Manipur, and Other Northeastern States (Arunachal Pradesh, Tripura, and Nagaland)

In Assam, As was first reported in the year 2004 in three districts, Karimganj, Dhemaji, and Dhubri, with a concentration above 50 ppb (IMGAM 2015). Out of 23 districts, 18 districts have As content beyond 10 ppb with around 2571 habitations being severely affected (Devi et al. 2009; Bhattacharya and Lodh 2018). The districts having more than 50 ppb As are Nagaon (48.1–112 ppb), Jorhat (195–657 ppb), Lakhimpur (50–550 ppb), Nalbari (100–422 ppb), Golaghat (100–200 ppb), Dhubri (100–200 ppb), Darrang (200 ppb), Barpeta (100–200 ppb), Dhemaji (100–200 ppb), Cachar (50–350 ppb), and Karimganj (293 ppb) (Shah 2012; Bhattacharya et al. 2015). The possible reason for the contamination of south Assam is that it is located in the low-lying areas of Barak valley, which is composed of Holocene sediments. The aquifers in this region along with the tertiary Barail hill range are the main reason for groundwater contamination (Shah 2012). Other parts of Assam lie along the Brahmaputra basin, which contains active aquifers of Holocene sediments. The reductive dissolution of Fe hydroxides present in these aquifers releases the adsorbed As. Another major reason for As contamination is extensive use of groundwater for agriculture and domestic use (Chetia et al. 2011).

In Manipur, out of 16 districts, 5 have been found to have As-contaminated groundwater with the maximum As detected in Thoubal district (maximum As level, 881 ppb) (Bhattacharya et al. 2015). Other districts which showed As concentration above 50 ppb are Kakching, Imphal East, Imphal West, and Bishnupur (Ghosh et al. 2010). Imphal East had As content >500 ppb followed by other districts with 150–200 ppb of As in groundwater (Chakraborti et al. 2008). The districts, which are reported in Arunachal Pradesh with As content above 50 ppb, are Papum Pare (74 ppb), West Kameng (127 ppb), East Kameng (58 ppb), Lower Subansiri (63–159 ppb), Dibang Valley (618 ppb), and Tirap (90 ppb) (Bhattacharya et al. 2015). Out of eight districts in Tripura, three are reported with high As level in groundwater above 50 ppb (Bhattacharya et al. 2015). Among them, Dhalai was found to have the maximum As contamination in groundwater (65–444 ppb) followed by North Tripura (122–283 ppb) and West Tripura (191 ppb). In Nagaland, Mon and Mokokchung were reported with high As load in groundwater with As concentrations of 67–159 ppb and 50–278 ppb, respectively (Bhattacharya et al. 2015).

4 Conclusions

Arsenic contamination in groundwater is a huge menace for both the countries impacting millions of lives altogether. Each year thousands of people die due to cancer caused by As exposure. The situation is alarming; therefore, together with the help of our governments, we need to find some appropriate solutions to combat this situation. The wells and tube wells found to have higher As concentration should be immediately closed and covered with sand and soil. The municipality of that particular area should provide safe drinking water by processing the surface or groundwater. Follow-up monitoring and educational programs should be done regularly in these areas. The government should promote research which has the potential to find out the affordable solutions on a large scale. Tap water that is supplied by municipality should meet at least drinking water standards for carcinogens and other dangerous compounds. Further, WHO and other international agencies should give sufficient funds to these nations and should even make the problem of As contamination as important as polio, hepatitis, etc. so that the increasing number of cancer patients in these countries could be controlled and reduced with time.

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