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Arsenic Contamination in States of India: A Brief Overview

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ABSTRACT:
The presence of arsenic (As) in the environment threatens human health throughout the world. The problem is very intense in Asia especially in countries like India and Bangladesh, in comparison to the western countries. In India, reports of As contamination have emerged from more than 20 states. The first reports of As contamination came into limelight in the 1980s, and since then the number of As-affected districts and the number of people affected have increased tremendously. The current situation of As contamination in India is of great concern. This review focuses on the present As contamination in the states of India and presents a concise account of the same.

KEYWORDS: Arsenic,toxicity, India

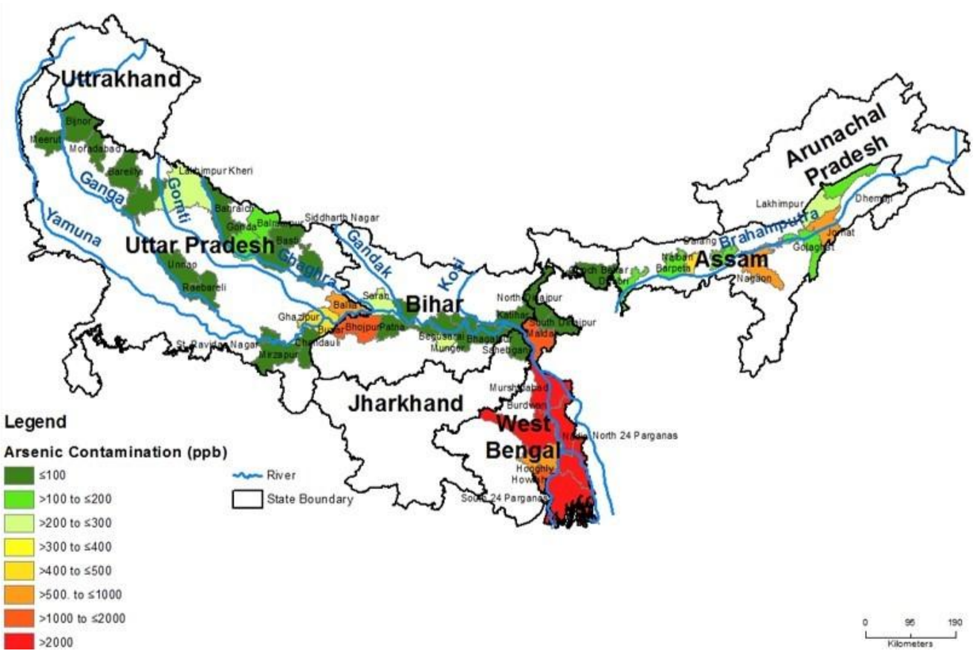
INTRODUCTION:
Arsenic (As) is a ubiquitous element which ranks 20th in abundance in the earth's crust, 14th in the seawater, and 12th in the human body [1]. Eversince Asdiscovery in 1250 A.D. by Albertus Magnus, it has been a controversial element in human history.Arsenic, a notorious poison, which elicits a fearful response in most people, is now recognized to be one of the world's greatest environmental hazards, threatening the lives of several hundred million people. Arsenic toxic effect is one of the major health issues throughout the world. Around 108 countries that account for more than 230 million people worldwide are at huge risk of arsenic intoxicationprimarily through drinking water and food[2]. Arsenic is a metalloid in group VA of the periodic chart. It exists in nature in the oxidation states +V (arsenate), +III (arsenite), 0 (arsenic), and -III (arsine) [3]. Soils hold both organic and inorganic species of arsenic. Inorganic As species include arsenite and arsenate, which are the most abundant forms found in the environment [4]. Most typical environmental exposuresto arsenic do not pose a health risk;however, several areas of the worldare exposed to arsenic from natural or anthropogenic sources at levelsthat create a toxicological concern. Many of these zones havebeen recognized, and efforts are being done to either amelioratethese areas or limit contact to them [5].The first report of widespread environmental problems with As involved the leaching of the metal from mine tailings in Australia, Canada, Mexico, Thailand, the United Kingdom, and the United States. Later, As-contaminated aquifers were reported in Argentina, Bangladesh, Cambodia, Chile, China, Ghana, Hungary, Inner Mongolia, Mexico, Nepal, New Zealand, Philippines, Taiwan, the United States, and Vietnam[6]. Consumption of water from these

contaminated aquifers eventually led to chronic As poisoning in many such locations, with the worst situation in Bangladesh. Arsenic pollution was not known until the 1970s. The 1980s may be seen as the period when the extent of arsenic pollution began to be recognized. Arsenic poisoning related to well water was discovered in West Bengal (India) in 1983 by K.C. Saha, although it took the rest of the decade for the size of the affected areas to be appreciated[6].

In India, the presence of elevated levels of As in groundwater has been confirmed in states of West Bengal, Bihar, Uttar Pradesh, Jharkhand, the north eastern states, Andhra Pradesh, parts of Chattisgarh, Haryana, Himachal Pradesh and Punjab [6,7-26].

Detailed investigations by the Central Ground Water Board (CGWB) of India revealed that arsenic contamination (>0.05 mg/L) hasprimarily affected the state of West Bengal. The Bengal Delta Plain (BDP) which is covering Bangladesh and West Bengal in India (fig. 1) is the most severe case of groundwater arsenic contamination [27].

Figure 1. Arsenic contamination in ground water of different districts of IGP & Brahmaputra region, India



West Bengal

It is estimated that in West Bengal, 111 blocks in 12 districts have beyond permissible limit of 50 ppb As [11]. Around 35.48% of the total population of the state live in the As risk zone. The first cases of arsenicosis in West Bengal were identified in 16 patients from one village of a district in July 1983 [7, 28]. From then, numerous agencies have worked on As pollution in this area [29]. In year 2006, Mukherjee and his group have analyzed 140,150 water samples from hand-tubewells in West Bengal and found that 48.2% had arsenic concentrations of >10 μgL^{-1} and 23.9% had >50 μgL^{-1}[29]. A socioeconomic study in arsenic-affected villages indicated that villagers were living in very poor conditions. Researchers at the School of Environmental Studies (SOES), Jadavpur University, Kolkata, India, have observed from their last 35years' field experience in West Bengal that poor people with poor nutrition have been suffering more. Arsenic-affected people have also been facing serious social problems.

[1]Professor Debashis Chatterjee's research group working from the Department of Chemistry at Kalyani University, West Bengal, have published a fairly large number of research articles concerning contamination of groundwater with arsenic in different parts of West Bengal. These studies mainly involved investigations pertaining to groundwater geochemistry to interpret the geological controls of the contaminants. These workers also studied migration of arsenic contaminated groundwater and suggested methods for short- and long-term remediation. This research group identified andpostulated multi-depth and multi-mechanism of arsenicmobilization in various parts of the contaminated areas ofthe Bengal Delta Plain. Laboratory and field-scale studieswere also conducted on bio-availability of arsenic incontaminated soil. They madetypological groundwater comparisons between delta frontand delta plain to suggest role of sea-level changes forarsenic sourcing in the Bengal Basin along withanthropogenic factors. According to them, no unique mechanism can be universally applied to addressthe heterogeneous distribution of arsenic [30].

Chakrabortiand his group in 2009 studied the groundwater arsenic contamination status of Ganga-Meghna-Brahmaputra plain. They concluded that most of the highly arsenic-affected districts of West Bengal are on the Eastern side of the Bhagirathi River [31]. In another study which is based on the intensity of arsenic concentrations, they haddemarcated West Bengal into three zones: highlyaffected, mildly affected, and unaffected. Nine districts(Malda, Murshidabad, Nadia, North-24-Parganas, South-24-Parganas, Bardhhaman, Haora, Hugli and Kolkata), inwhich an arsenic concentration of more than 300 $\mu gL^{-1}$was found insome tube wells, were considered as highly affected. These authorsanalyzed 135 555 samples from these nine districts out of which 67306(49.7%) had arsenic concentrations above 10 μgL^{-1}, 33470(24.7%) above 50 μgL^{-1}, and 4575 (3.4%) above 300 μgL^{-1}.Out of these nine highly affected districts, five (Malda,Murshidabad, Nadia, North-24-Parganas, South-24-Parganas)are widely affected [31].

In three districts (North-24-Parganas,Nadia, Murshidabad) more than 95% of the blocks had arsenic above 50 μgL^{-1}. Three (Haora, Hugly, Bardhhaman) of these nine highly arsenic affected districts, are on the western side of River Bhagirathi, but once the highly arsenic-affected blocks of these three districts lay on the eastern side of Bhagirathi River which over a geological era changed its course. Due to this, these three districts/ blocks are highly but not widely affected. Districts like Jalpaiguri, Darjeeling, Koch Bihar, Dinajpur-North and Dinajpur-South, reportedAs mostly below 50 μgL^{-1}, are therefore mildly contaminated. They analyzed 2923 water samples from these districts, 285 (9.8%)had arsenic concentration between 3 and 10 μgL^{-1}, 163 (5.7%) above 10 $\mu gL^{-1}$and 6 (0.2%) above 50 μgL^{-1}.Bankura, Purulia, Medinipur East,Birbhum,and Medinipur West were largely unaffected and are considered arsenic safe. All the samples from these areas (n = 1672) had an arsenic concentrations below 3 μgL^{-1}[31].

Arsenic contamination due to anthropogenic sources is also reported.Arsenic pollution in the residential area of Behala, Kolkata, was quite known during the period 1969-1989 [20, 32, 33]. Of 79 people examined, representing 17 families with age ranging from 1 to 69 year(s), 53 were detected with chronic arsenicosis[20]. Clinical investigation of these affected persons showed typical skin pigmentation and palmar and plantar keratosis; gastrointestinal symptoms, anaemia, and signs of liver disease and peripheral neuropathy were seen in many. The primary suspect for this arsenic episode was the chemical

[1] Source: Banerjee et al 2012. Status Report on "Contemporary Ground water Pollution Studies in India: A Review".

factory located on B.L. Saha Road, and P.N. Mitra Lane, which happens to be located at the back of this factory. This factory was producing several chemical compounds, including the insecticide Paris-Green (acetocopperarsenite). For about 20 years until 1989, this factory had been producing about 20 tonnes of Paris-Green per year. Soil analysis adjacentto the dumping ground of the waste exhibitedalarminglevels (up to 10,000 ppm) of arsenic. Samples also reported high levels of copper and chromium. Analysis of water samples from 19 hand-tubewellsexpressed arsenic in the range 100 to 38,000 ppb. Concentrations of arsenic in all the wells studied decreased with increasing distance from the dumping ground. A follow-up study in the affected areas was made eight years later [16], showed that total arsenic in these wells had decreased by only 10-15%. Eight people who had arsenical skin lesions died, of whom three died of internal cancer[29].

Arsenic status as well as its entry in the human food-web and the entire groundwater-soil-plant-animal-human continuum has been investigated by the scientists at Bidhan Chandra KrishiViswavidyalaya (BCKV), Mohanpur and several of its Partners in a consortium mode over more than the past 15 years. These Partners included, among others, the Geological Survey of India (GSI) and the Central Ground Water Board (CGWB), both of the Government of India;the State Water Investigation Directorate (SWID) of the Government of West Bengal; the SAUs, namely Uttar BangaKrishiViswavidyalaya (UBKV), Pundibari and West Bengal University of Animal & Fisheries Sciences (WBUAFS), Mohanpuras well as the ICAR Research Institutes, namely the Regional Centre at Kolkata of the National Bureau of Soil Survey & Land Use Planning (NBSS & LUP), the Eastern Regional Centre of the National Dairy Research Institute (NDRI) at Kalyani and the Central Inland Fisheries ResearchInstitute (CIFRI), Barrackpore and also a NGO, namely DNGM Research Foundation, led by an eminent physician, namely Professor (Dr.) D. N. GuhaMazumdar of Kolkata. Indeed the scientists at BCKV have conducted sustained and intensive works pertaining toarsenic contamination, andespecially in groundwater, and its effect on agricultural systems.Reports by Rahamanand his group in 2013 [34]stated that Malda district in West Bengal is severely under As pollution. Nearing 50 million of people are at health risk from arsenic contamination at Ganga–Meghna–Brahmaputra basin.Das and coworkers in 2013 [35] studied As toxicity in rice grown in West Bengal and stated that As accumulation by plant parts followed the order, root>stem>leaf>economic produce.A yield reduction of 80.8% was also observed at the highest dose of As. Another group led by Kunduin 2013 [36] studied response of different wheat cultivars towards As contamination in soils of West Bengal, India.The scientists have also studied As accumulation in rice, sesame, coriander, etc., and their risk potential for humans [11]. Majumderand his group in 2012 [37]found that retting of jute grown in arsenic environmentspollutes surface water body by raising its As level. The same group in 2013 isolated As-resistant bacterial strains from contaminated soils of West Bengal which closely resembled the genus *Bacillus* and *Geobacillus*[38]. These strains exhibited considerable As (III) oxidizing ability, i.e., they efficiently oxidized toxic As (III) to less toxic As (V) species. This might be exploited for the remediation of As in contaminated environments. The gene responsible was aoxB gene.Research group ofProfessor S. K. Sanyal at Bidhan Chandra KrishiViswavidyalaya (BCKV) also studied transport of As in selected affected soils of Indian subtropics through both horizontal andvertical column investigations. These authors concluded that As retention capacity of these soils is attributed to the clay content, especially the illiticclays, organic matter, specific surface area, and amorphous iron and aluminium content [39].Further, the scientists at the BCKVhave also confirmed the earlier observation of Prof. Sanyal [40] that relative abundance of As fractions in affected soils increased in the order: water-soluble

As <Ca-As < Al-As < amorphous Fe-As < crystalline Fe-As.The group led by Prof. Das in 2011 studied the fractionation of As in soil in relation to crop uptake [41]. Results revealed the concentrationof different arsenic fractions in the order: As held at the internal surfacesof soil aggregates (20.7%) > freely exchangeable As (20.3%) > calcium associatedAs (18.7%) > chemisorbed As (17%) > residual As (15.7%) > labile As (3.29%). This observation may be accredited to the mineralogical content of the experimental soils along withsome physical and chemical factors. Sinha and Bhattacharyya in 2011 [42]confirmed the earlier observation of Mukhopadhyay and Sanyal, 2004 [43]on the retention and release isotherm of arsenicin arsenic–humic/fulvic equilibrium and reportedsulphate, molybdate, andnitrate to exhibit hightendency to displace Asfrom the organo-arsenic complexes.Ghosh et al. in 2012compared the arsenic complexation abilities of native HA/ FA fractions of selected affected soils, a few organic manures, as well as the organic matter fractions of the manure treated soils [44]. These authors reported that the dependence of such complexationis on nature and properties of the humic polymers, influencing thereby the retention/ release of arsenate from the soil humic acid (HA)/ fulvic acid (FA) fractions. GuhaMazumder et al.in 2013 and2014carried out investigation relating to the correlationof As intake through diet witharsenic level in urine (an early bio-marker of arsenic poisoning in humans) in people residing in arsenicendemic region, supplied with arsenic-safe water [45, 46]. Their study clearly suggested that dietary arsenic intake was a potential pathway of arsenicexposure even where arsenic intake through water was reduced significantly in arsenic endemic region in West Bengal. These authors also stated that people with skin lesions were found to have higher levels of As in urine and hair as compared to those without skin lesions [45].

Bihar

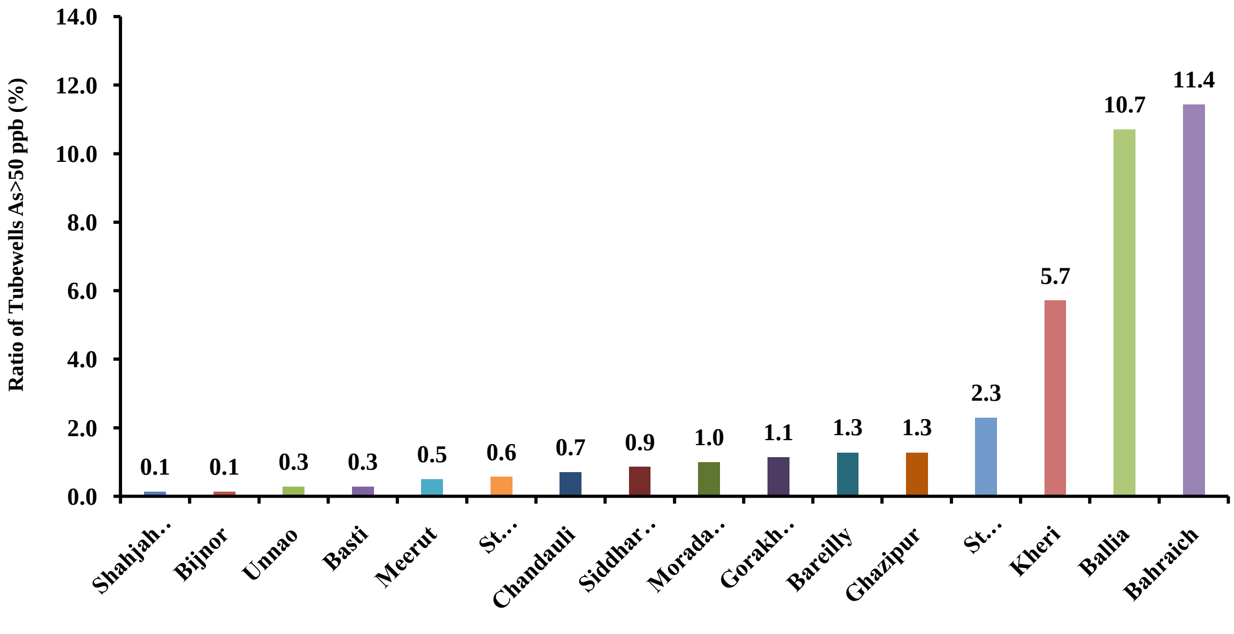
According to reports, 15 districts of Bihar are under high arsenic contamination risk [47]. During June 2002, arsenic in groundwater was first reported in SemariaOjha Patti village in Bhojpur district of Bihar [18]. Bihar is situated in the Middle Ganga Plain. According to estimates by Mukherjee et al.in 2006, around 39% of 9,597 samples analyzed showed arsenic >10 ppb and 23% contained >50 ppb. Of 4,513 persons screened for arsenical skin lesions, 525 (5.5%) were registered with skin lesions [29].

The researchers (D. Saha) of the Central Ground Water Board (CGWB), Government of India contributed immensely to the study of groundwater arsenic contamination in the Middle Ganga Plains (MGP) of Bihar. According to them, in several isolated sectors, mostly along the Ganga, the groundwater in the upper parts of the shallow aquifer (~50 m depth), had arsenic load beyond the regulatory limit of 50 ppb. Since its detection in 2002 in Bhojpur district, the CGWB hasexplored various issues like spatial distribution of arsenic, mechanism of mobilization, identification of arsenic-safe aquifers, behavior of contaminated and non-contaminated aquifers and evolution of the alluvial geomorphology in the affected area[30].

Uttar Pradesh

A study, jointly conducted by U.P. Jal Nigam and UNICEF, showed that arsenic contamination is geogenic in nature in U.P. and is found in the younger alluvium. On this basis, 49 additional districts of UP were identified at risk. In the identified blocks of 49 districts,the test results showed arsenic above 50 ppb (limit set as safe by Department of Drinking Water, Government of India) in 18 districts and arsenic in the range of 10 (limit set by WHO) to 50 ppb in 31 districts[2].

Figure 2. Ratio of As> 50 ppb Tube Wells in districts of Uttar Pradesh [48]



Mukherjee and coworkers detected arsenic contamination in Ballia district (Uttar Pradesh) during the survey conducted in September-October in the year 2003,on the basis of analysis of 914 water samples, found that nearly three blocks, eight Gram Panchayats and 25 villages of the district were arsenic-contaminated [29]. During the survey, they examined 307 villagers and registered 53 patients with arsenical skin lesions. Based on these data, they published the first report on As contamination in Uttar Pradesh in January, 2004[3]. Of the 3,901 water samples analyzed from Uttar Pradesh, 46.57% contained arsenic >10 µg L^{-1}, and 30.47% contained >50 µg L^{-1} in 91 villages from 10 blocks surveyed from three districts (Ballia, Ghazipur and Varanasi). Survey by Government of India, shows the ratio of arsenic polluted government tubewells (GTW) (As > 50 ppb) in the 20 districts of Uttar Pradesh. In this study, 3 severe contaminated districts were identified asKehri, Ballia, and Bahraich[48] as illustrated in fig.2.

Chhattisgarh

Arsenic contamination in groundwater is reported along the N-S trending 80 km stretch of Kotri lineament from Chhattisgarh State. The severity is found in the eastern part of AmbagarhChowki block of Rajnandgaon district. Arsenic affected villages are mainly Kaurikasa, Joratari, Sonsaytola, Jadutola, Muletitola[27]. Groundwater samples from the Kaudikasa village in Rajnandgaon district of Chattisgarh, were analyzed by Wagtech Digital Arsenator by D. Shukla and C.S. Dubey's research group of the University of Delhi. The analysis shows high concentration of arsenic with the maximum value

[2] Source: Report of the Central Team on Arsenic mitigation in rural drinking water sources in Ballia district, Uttar Pradesh State 14-17 September 2011, Ministry of Drinking Water and Sanitation Government of India New Delhi.

[3] Source: Groundwater arsenic contamination and arsenicosis patients in Uttar Pradesh (UP)—India: first report. Kolkata: School of Environmental Studies, Jadavpur University, 2004:1-7.

exceeding 250 μg L^{-1}. Petrographic studies of the country rock granite displayed the presence of altered realgar/pararealgar, orpiment, and tennantite which are the ores bearing arsenic.

Jharkhand

Arsenic groundwater contamination was detected in December, 2003.Mukherjee et al. in 2006 surveyed four blocks namely Shahibganj, Mandaro, Taljhari, Rajmahal from Shahibganj districtand reported that while one blockShahibganjhad arsenic concentration >50 μg L^{-1}, all of them had As concentrationsexceedingthe WHO guideline value (10 μg L^{-1}) [29]. Of water samples analyzed from 17 villages, 30% had arsenic concentrations >10 ppb, while 19.4% had >50 ppb. Of four villages surveyed for arsenical patients, As patients were found in three villages. Of 320 villagers screened, around 87 were registered with arsenical skin lesions[4].

Delhi

Study of 120 surface and groundwater samples from the Yamuna Flood Plains in the capital city encompassing Geeta Colony, MayurVihar, Wazirabad, NigambodhGhat, KotlaMubarakpur and Rajghat, Indraprastha and Badarpur coal-based thermal power plants revealed high arsenic concentrations beyond the WHO standard with maximum recorded up to 180 ppb[30]. Nearly 55% of these samples have arsenic content more than WHO limit of 10 ppb. Coal samples used in these power plants contain arsenopyrite (a prime source of arsenic). Maximum concentration of arsenic contamination is found within a 5-km radius from the power plant, hence it can be stated that arsenic in the waters of Delhi is primarily anthropogenic and is linked to coal-based thermal power plants. An estimate shows 5.5 t/year of arsenic is being discharged into the Yamuna River from the Rajghat power plant.

Punjab and Haryana

Reports state that in districts like Ropar, Chandigarh, Patiala and Ambala, etc., the arsenic concentration in water from wells and springs were higher than the WHO safe limit for human consumption with 0.05 – 0.545 mg As L^{-1}[49].

Madhya Pradesh

Arsenic contamination of groundwater in Koudikasa village of Rajnandgaon district, Madhya Pradesh with a population of 1.5 million was reported first in 1999. Most of the villagers of Koudikasa used water from a forest dug-well (0.52 mg As.L^{-1}) along with a PHED tube-well (0.88 mg AsL^{-1}). Out of the total number of adults (150 in number) and children (58 in number) examined at random, 42 and 9%, respectively, have arsenical skin lesions. The source of arsenic contamination is speculated to be relatedto percolation of gold and uranium mine’s tailings. Indeed arsenic is often considered a path finder to locate gold deposits since arsenic is generally associated with gold ores [6].

North- Eastern states

Reports revealed that thousands of underground water sources here are mostly notfit for consumption due to highly alarming levels ofarsenic [50]. 28,181 water sources analysed in Assam show contamination with arsenic, iron and fluoride-bearing inorganic materials. This is followed by 2,931 in

[4] Source: Report: groundwater arsenic contamination and people suffering from arsenicosis from Jharkhand state in Middle Ganga Plain, India, January 2004. Kolkata: School of Environmental studies, Jadavpur University, 2005:1-16.

Tripura, 566 in Arunachal Pradesh, 136 in Nagaland, 124 in Meghalaya, 76 in Sikkim, 37 in Manipur and 26 in Mizoram [51].

Maximum arsenic concentration content of 490 µg L^{-1} was observed in Jorhat (Titabor, Dhakgorah, Selenghat and Moriani blocks), Dhemaji (Sissiborgoan and Dhemaji blocks), Golaghat district (Podumani block) and Lakhimpur (Boginodi and Lakhimpur blocks), Assam [52].In Thoubal district of Manipur, about 25% of the collected samples had As in the range 798–986 µg L^{-1}. The sediment in the northern region contains a high percentage of clay and organic compounds [53], which may retain and release As in the groundwater aquifers. A study by Baruah in 2003 on carbonaceous matter in Arunachal Pradesh, Assam, Nagaland and Meghalaya reflected that the mean As concentration of samples from the four regions was 95.1 $mgkg^{-1}$[54]. It is believed that the weathering of sulphidelinked with carbonaceous matter may have formed As-rich iron oxyhydroxide, which in turn, released As (after reduction) to the existing sedimentary environment [55,56]. Results indicated increased As enrichment from east to west in Northeast India(fig. 3) [51].

Agartala news reports in 2007, reported arsenic to be present in Jirania and Bishalgarh in West Tripura district, Salema, Halahali, Kamalpur, Joynagar in Dhalai district, Sanitala, Rajbari, Dharmanagar, Kailishahar, Kanchanpur and Jampui in North Tripura district. The NERIWALM report said arsenic levels in Assam, Manipur, Tripura and Arunachal Pradesh were above 300 parts per billion [51].

Figure 3. Distribution of arsenic in groundwater of northeastern states [51]

With the discovery of arsenic contamination of groundwater in these regions, and consequent health implications, several initiatives were undertaken which included supply of oxygenated surface river water through piped networks to the arsenic contaminated areas. Brahmaputra Floodplain has enormous availability of surface water, hence such an initiative for arsenic mitigation is a viable option. The Greater Titabor Piped Water Supply Scheme is one such initiative where surface water from two major rivers- Dhansiri and Doiangrivers is supplying arsenic-free safe water to nearly 2 lakh population of Titabor in the Jorhat District in Assam. Ring Well Scheme, multi-village water supply scheme, rainwater harvesting and water recharging are some of the other options being adopted by PHED for arsenic mitigation in Assam [30].

Andhra Pradesh and Telangana

An industrial estate, Patancheru in Medak district is a living example of environmental decay with many reported cases of arsenic poisoning [21-23, 57]. Many soil, groundwater, and surface water samples obtained from the study site showed elevated levels of arsenic [24]. The primary source of arsenic has been revealed as Park Trade Centre inGaddapotharam Bulk Drug Factory, which makes veterinary drugs, based on arsonic acid. There are also other sources, such as the pesticide and drug intermediate industries [24]. The solid wastes of these industries are indiscriminately dumped near the KazipallyLake, representing a source of contamination to nearby surface water and soils [21]. Chandra Sekharand his group, while reporting high arsenic concentrations in surface and groundwater,assessed the possibilityof its entry into human systems [24]. This constitutesone of the major sources of arsenic entry into the human system. It was also reported that levels of arsenate were higher than those of arsenite(ratio 4:1). Also, vegetables grown on these contaminated soils are rich in arsenic (ranging over0.87-12.8 mg As. kg^{-1}), and this provides yet another possible source of entry of arsenic into the human food-chain [24].

CONCLUSION: The most important action in affected communities is the prevention of further exposure to arsenic by the provision of a safe water supply for drinking, food preparation and irrigation of food crops. There are a number of options that are available for reducing the exposure to arsenic, which includes setting guideline values, reviewing evidence and providing risk management recommendations. The current recommended limit of arsenic in drinking-water is 10 µg/L, although this guideline value is designated as provisional because of practical difficulties in removing arsenic from drinking-water. Every effort should therefore be made to keep concentrations as low as reasonably possible and below the guideline value when resources are available.

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