Global Groundwater Arsenic Contamination: Impacts on Agriculture, Human Health and Social Life

By Golam Kibria, Ph.D; November 2013

Key points

Arsenic (As) poisoning via groundwater has become a worldwide problem, with 21 countries experiencing groundwater arsenic contamination. Most documented As contaminated groundwater in Asia are as follows: (a) *Bangladesh*: most districts including Chandpur, Munshiganj, Noakhali, Satkhira; (b) *India*: West Bengal, Bihar; (c) *China*: Inner Mongolia, Xinjiang and Shanxi Province; (d) *Nepal*: Terai region. Arsenic sulfides, arsenic-rich pyrite, and arsenic-rich iron oxyhydroxides are the most commonly found natural sources of arsenic contamination in groundwater worldwide and most researchers agree that arsenic contamination comes from the reductive dissolution of arsenic-rich iron oxyhydroxide. Over the past 14 years, research scientists collected and analysed 52,202 hand tubewell water samples from 64 districts in Bangladesh. These investigations found that, out of 64 districts, the arsenic level in 60 districts have exceeded WHO recommended guidelines of 10 µg/L and in 51 districts it exceeded Bangladesh recommended guidelines of above 50 µg/L. Rangamati, Khagrachari, Bandarban and Cox's Bazar were found to have groundwater arsenic levels less than 10 µg/l. Soil, water, vegetables, rice and recently cow milk were found contaminated with arsenic in Bangladesh. The exposure of human to arsenic via water and foods can lead to skin cancer. Socio-economic problems like social uncertainty, social injustice, social isolation, poverty and problematic family issues are reported due to arsenicosis. The most common arsenic mitigation option would be well switching, i.e. switching from an arsenic unsafe well to an arsenic-safe drinking water source, use of deep tubewells, use of arsenic filters and pond sand filter. There is also a need of arsenic education programme for an increasing awareness about arsenic. A regular monitoring of arsenic level in water and food would further help in reducing risks to humans. Arsenic is toxic, bio-accumulative and carcinogenic and is not essential for humans and has been classified as group/class 1 carcinogenic by IARC.

Contents

1. Introduction

Worldwide, approximately one billion people do not have access to safe water [1]. This is due to contamination of water by chemical and biological pollutants [2,3]. One of the sources of contamination is the naturally occurring chemical arsenic (As) in groundwater, which affects millions of people in many countries worldwide (Figure 1 and Table 1). To date, unacceptably high As levels in groundwater resources have been found in several parts of Bangladesh, Cambodia, China, Chile, Ghana, India, the Lao People's Democratic Republic, Mexico, Mongolia, Myanmar, Nepal, Pakistan, Taiwan, Thailand, USA and Viet Nam [4,5 see also section 3]. Within developing countries, groundwater is generally the preferred drinking source since it provides an alternative to polluted surface water and thereby reduces the incidence of water-borne diseases.

2. Chemistry: speciation, mobility and toxicity

Arsenic is a toxic metalloid element (properties intermediate between those of a metal and a non-metal) that occurs in nature in both organic and inorganic compounds. In groundwater's, inorganic arsenic species, arsenite (As^{III}) and arsenate (As^{v}) are predominantly detected. The organic forms (monomethylarsenic acid, dimethylarsenic acid) are mostly found in either surface waters or in areas severely affected by industrial pollution [6]. The two most important factors controlling the speciation of arsenic (and, to some extent, solubility) are pH and redox (Eh). Under aerobic conditions (oxidizing environment), As^{V} is predominant, whereas As^{III} predominates under anaerobic conditions (reducing environment) [7]. It was reported, in an experimental paddy field, that under non-flooded conditions 30% of the As was present as As^{III} and up to 70% as As^{III} under flooded conditions [7,8].

Arsenic contamination of groundwater from natural sources worldwide has been attributed to several geochemical processes. Arsenic sulfides, arsenic-rich pyrite, and arsenic-rich iron oxyhydroxides are the most commonly found natural sources of arsenic contamination in groundwater worldwide. In case of Bangladesh and West Bengal, the alluvial Ganges aquifers used for public water supplies are polluted with naturally occurring arsenic. Arsenic is naturally derived from eroded Himalayan sediments, and is believed to become mobile following reductive release from solid phases under anaerobic conditions [9].Several researchers attribute arsenic contamination in this region directly to oxidation of arsenic-rich pyrite in the aquifer sediments as atmospheric oxygen invades the aquifer in response to lowering of the water level by abstraction, whereas other researchers suggest that arsenic contamination comes from the reductive dissolution of arsenic-rich iron oxyhydroxides, which are derived from weathering of base metal sulfides [reviewed by 10]. The latter hypothesis (reductive dissolution of arsenic-rich iron oxyhydroxides) is accepted by most researchers. Arsenic is susceptible to mobilise under the pH conditions typically found in groundwater (pH=6.5–8.5) and over a wide range of redox (reduction-oxidation) conditions [11].

Arsenic in general about four times as poisonous as mercury and the trivalent Arsenic As^{III} is considered 60 times more toxic than the pentavalent As^{V} [12].The inorganic arsenic compounds are about 100 times more toxic than organic arsenic compounds [13,14]. Arsenic is toxic, bio-accumulative and carcinogenic. Arsenic is not essential for humans and has been classified as group/class 1 carcinogenic by IARC [2].

3. Global overview of groundwater arsenic contamination

3.1: Global: Arsenic poisoning (As) via groundwater has become a worldwide problem with 21 countries experiencing arsenic groundwater contamination [15]. Some of the best-documented and most severe cases of arsenic contaminated groundwater have been found in aquifers in Asia are as follows: (a) *Bangladesh*: most districts including Chandpur, Munshiganj, Noakhali, Satkhira; (b) *India*: West Bengal, Bihar*;* (c) *China*: Inner Mongolia Xinjiang and Shanxi Province; (d) *Nepal*: Terai region) and South America (*Argentina: Salta province*, *Mexico: Legunea region*) [2,16,17; see also Figure 1, Table 1]. Arsenic in groundwater in most countries is less than 10 µg/ L (e.g. UK, USA [reported by 10], however in contaminated countries it shows a very large range from 1 to 5000 µg/L (Table 1) (*note:* a WHO drinking water guidelines for arsenic is 10 µg/L; a Bangladesh drinking water guidelines is 50 µg/L).

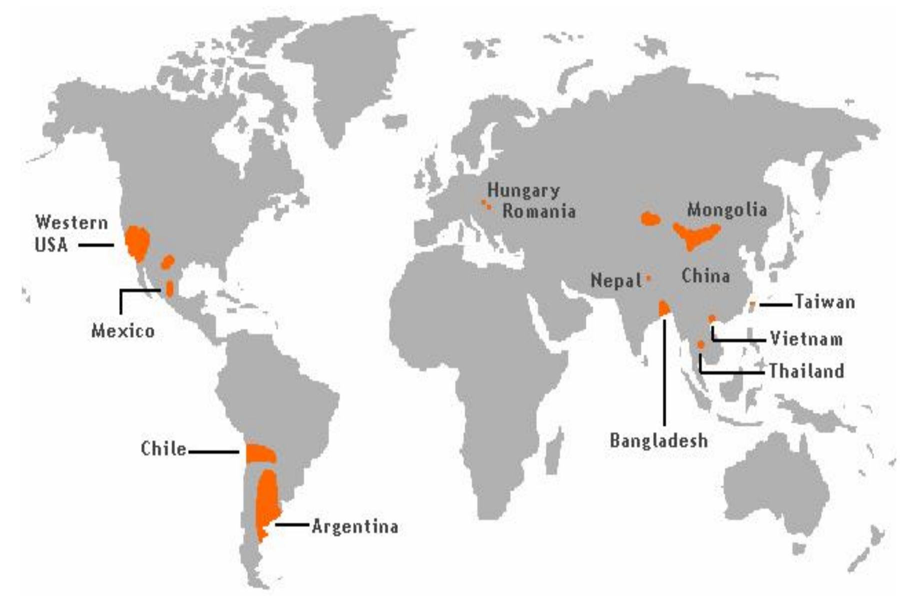

Figure 1: ***Groundwater arsenic contamination areas in the world*** [18]

Table 1: ***Worldwide occurrences of arsenic in groundwater*** *[compiled by 2,10].*

Country	**Source**	**Range in µg/ L or ppb**	**Estimated population exposed**
Argentina	Natural	100-2000	200,000
Bangladesh	Natural – deriving from geological strata	<1-4700	57 millions exposed to As>10 µg/L and 35 millions exposed to As> 50 µg/L
Chile	Natural – associated with quaternary volcanism	900-1040	437,000
China	Natural, in reducing environment		5.6 million
Ghana	Mining actvities	NA	100,000
Hungary and Romania	Natural	2-176	400,000
India (West Bengal)	Natural – deriving from geological strata	<10-3700	Over 5 millions exposed to As >50 µg/ L; 300,000 suffering from arsenicosis

Mexico	Natural	1-5000	400,000
Nepal	Natural	<10-34	550,000 exposed to As >50 μg/L and 3.19 million exposed to As>10 μg/ L
Taiwan	Natural	10-1820	10,000 (?)
Thailand	Mining actvities	1-5000	15,000
USA	Natural, geothermal and mining related sources	Varied	13 million exposed to As = 10 μg/ L
Vietnam	Natural	1-3100	>1 million

3.2: Bangladesh: Globally, Southeast Asian countries are the most severely affected by groundwater arsenic contamination with Bangladesh being the worst of all. The groundwater arsenic poisoning in Bangladesh is regarded as the largest disaster/mass poisoning in the history of human civilization where more than 77-100 million people is believed to be drinking arsenic-poisoned water or at risk on a daily basis [2,14,15,19]. Various investigations were carried out to assess the level of As contamination in Bangladesh [in the past see 20,21, and in recent time see 22,23]. In Bangladesh, the arsenic contamination of groundwater was first identified in 1992 [19] and confirmed in 1993 [14]. Over the past 14 years, Chakraborti *et al* 2010 [22] and Chakraborti *et al.* 2013 [23], collected and analysed 52,202 hand tubewell water samples from the four principal geomorphologicals regions of Bangladesh consists of Tableland, Flood plain, Deltaic region and Hill tract in 64 districts [see 22,23]. These investigations found that out of 64 districts, the arsenic level in 60 districts have exceeded WHO recommended guidelines of 10 μg/L and in 51 districts it exceeded Bangladesh recommended guidelines of above 50 μg/L [22,23 and see also Table 2, Figures 2 and 3]. Based on the analysis of 52,202 water samples, 40.3 % of hand tube wells had arsenic level of above 10 μg/L; 26.3 % above 50 μg/L; and 7.1 % above 300 μg/L (the threshold concentration associated with arsenical skin lesions) [23]. The key findings of the above investigations [22,23] are highlighted below:

(a) *The groundwater of the Tableland and Hill tract regions are generally found free from As contamination while that of the flood plain and deltaic region are heavily As contaminated (note: the flood plain and deltaic region where most As contamination found contains Holocene sediments)*

(b) Four districts comprising Rangamati, Khagrachari, Bandarban and Cox's Bazar (out of 64 districts) found to have groundwater As levels less than 10 μg/l (all these districts are located in the Eastern hills of Chittagong and underlain with a thick medium to coarse sand and gravel bed of Pliocene epoch known as Dupi Tila, no Holocene flood plain deposit found in these area]

(c) *As concentration was observed to decrease with increasing tubewell depth*

(d)*The arsenic concentration of the hand tube-well water sample from Chiladi village of Senbag upazila in the Noakhali district was found to be 4,730 μg/L (believe to be the most severe As contamination in the world; 72 tubewells had As above 100 μg/l and 21 tubewells had As above 1000 μg/L)*

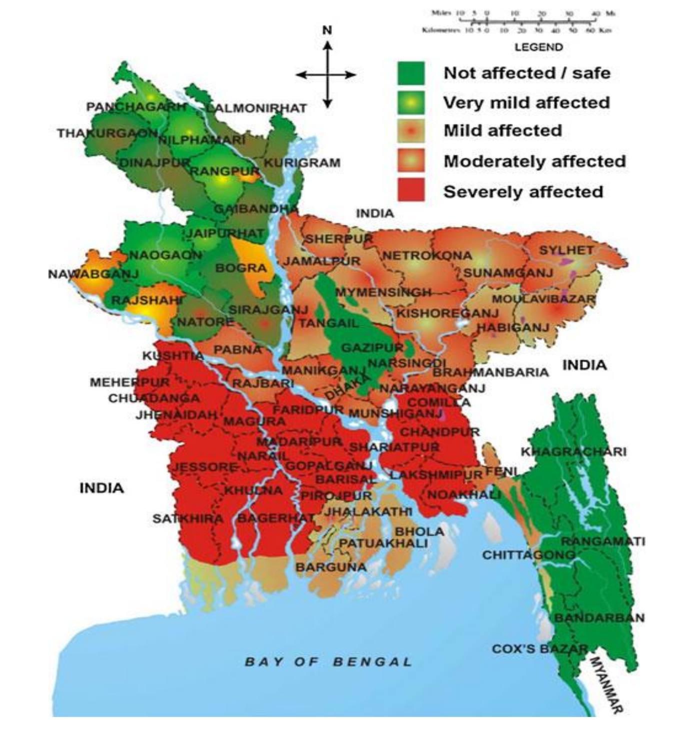

Figure 2: ***Arsenic-contaminated and uncontaminated districts in Bangladesh*** *[23];Not affected/As-safe (As < 10 μg /l ; very mildly affected (As=10-50 μg/l); mildly affected (As 50-100 μg /l);), moderately affected (As= 100-300 μg/l); highly affected (As > 300 μg/l,) (classification based on [22].*

Table 2: ***Severely affected and unaffected districts based on Bangladesh As standard of 50 μg/L*** *[this table has been prepared based on data of [Chakraborti et al 2010, 22, pages 5793-5794].*

Severely affecetd *(50% or more tubewells samples exceeded 50 μg/L)*	**Khulna Div:** Satkhira (80.27%), Narail (59.02%), Bagerhat (56.33%) **Barisal Div:** Barisal (63.56%) **Sylhet Div:** Sunamganj (55.5%) **Dhaka Div:** Munshiganj (89.39%), Narayanganj (76.69%), Madaripur (59.6%), Gopalganj (58.32%) **Chittagong Div:** Chandpur (90.3%), Noakhali (86.59%), Lakshamipur (79.73%), Comilla (74.5%), Brahmanbaria (55.32%)
Not affecetd *(all tube wells samples below 50 μg/L)*	**Rangupr Div:** Dinajpur, Kurigram, Lalmanirhat, Nilphamari, Panchagarh **Rajshahi Div:** Joypurhat,Naogaon **Barisal Div:** Barguna, Bhola, Patuakhali **Chittagong Div:** Bandarban, Coxs Bazar, Khagrachari, Rangamati (these four districts had As levels <10 μg/L)

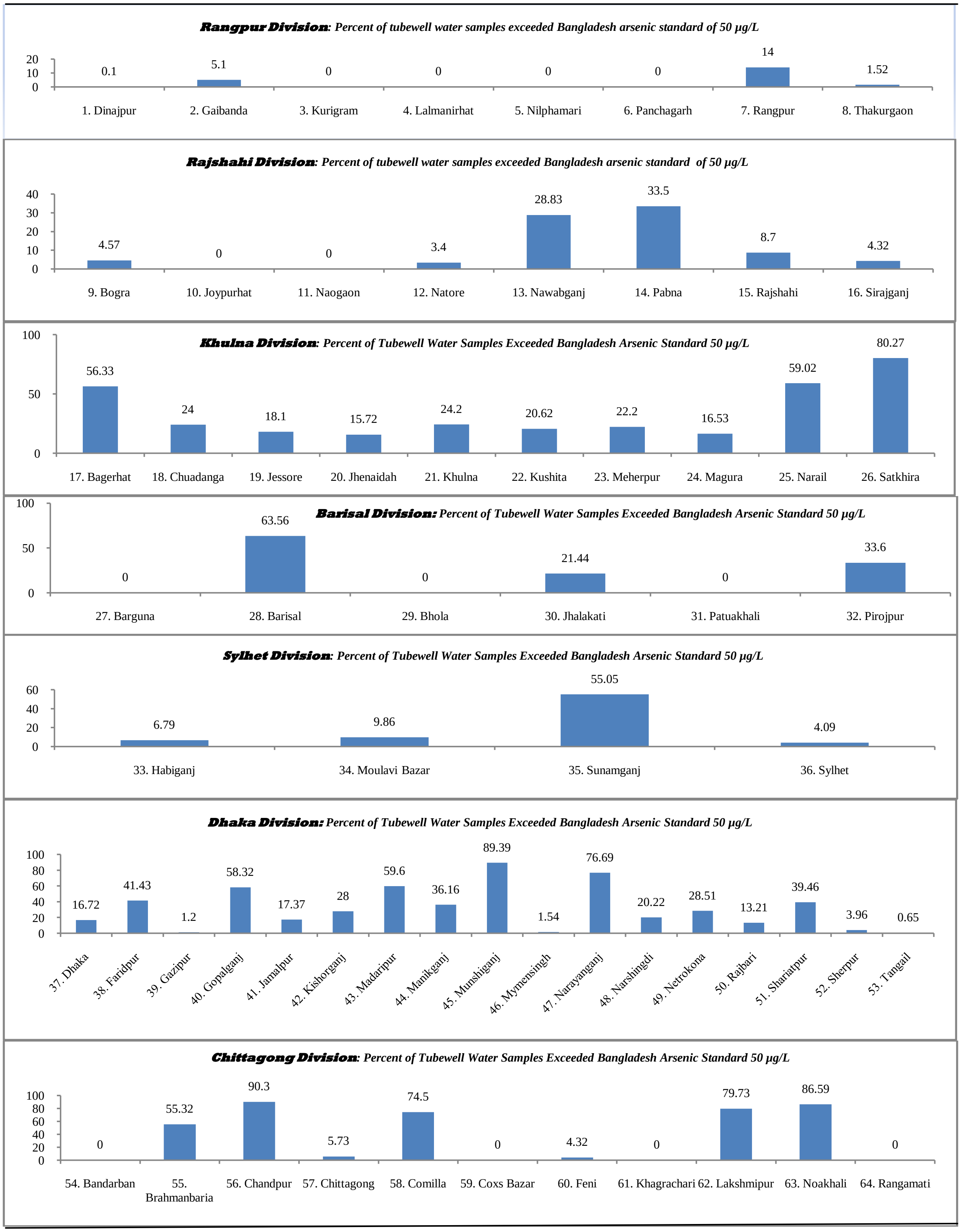

Figure 3: ***Graphs showing arsenic concentrations in seven divisions and sixty four districts of Bangladesh as% tube wells water samples exceeding Bangladesh standard of 50 µg/L*** *[note: graphs produced based on data of 22; Chakraborti et al 2010, Water Research 44: 5789-5802].*

3.3: India (West Bengal): The first case of arsenic in India was reported in 1976 from Chandigarh [5]. Since then widespread arsenic contamination has been reported in groundwater from many parts of India (Figure 4, Table 2) including West Bengal (Figure 5), Bihar, Chhatisgarah, Jharkhand, Uttar Pradesh, Bihar, and Assam and other regions of Punjab, Haryana, and Himachal Pradesh, surroundings of New Delhi, the union territory of Chandigarh, and the state of Rajasthan [23]. Among them, the most severely contaminated state is West Bengal (Figure 5) where 12 districts and 2,60,00,00 people are affected [5,22,23]. The affected districts in West Bengal are Maldah, Murshidabad, Nadia, North 24 Parganas, South 24 Parganas, Howrah, Hooghly, Koch Bihar, South Dinajpur, North Dinajpur, Burdawan, and Kolkata. Groundwater of West Bengal found with As ranged from <1 to 3700 µg/L. Among the twelve districts, nine districts considered severely affected are Malda, Murshidabad, Nadia, North 24-Parganas, South 24-Parganas, Bardhaman, Howrah, Hooghly, and Kolkata, where more than 300 µg/L arsenic concentrations were found in tube wells. In the past 20 years, 140,150 hand tube-well water samples have been analysed for arsenic in all 19 districts of West Bengal. Out of 140,150 samples analysed, 48.1 % had arsenic above 10 µg/L and 23.8 % above 50 µg/L and 3.3 % above 300 µg/L. A total of 187 (0.13 %) hand tube wells were determined as highly contaminated (1,000 µg/L). A summary of research findings [23] are highlighted below:

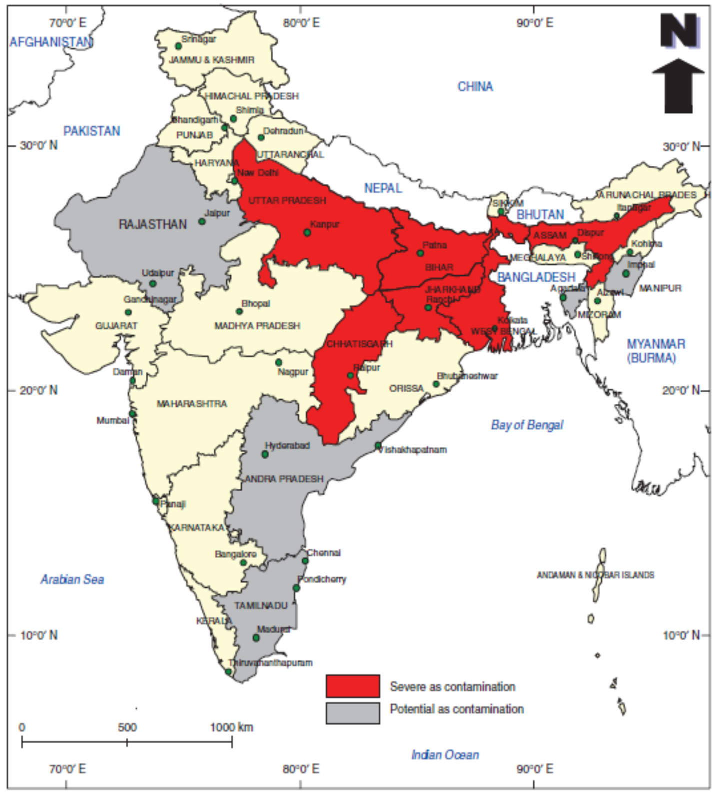

Figure 4: ***The scenario of the extent and severity of elevated concentration of arsenic in groundwater's of India*** *[From 24, Bhattacharya et al. 2011, page 152].*

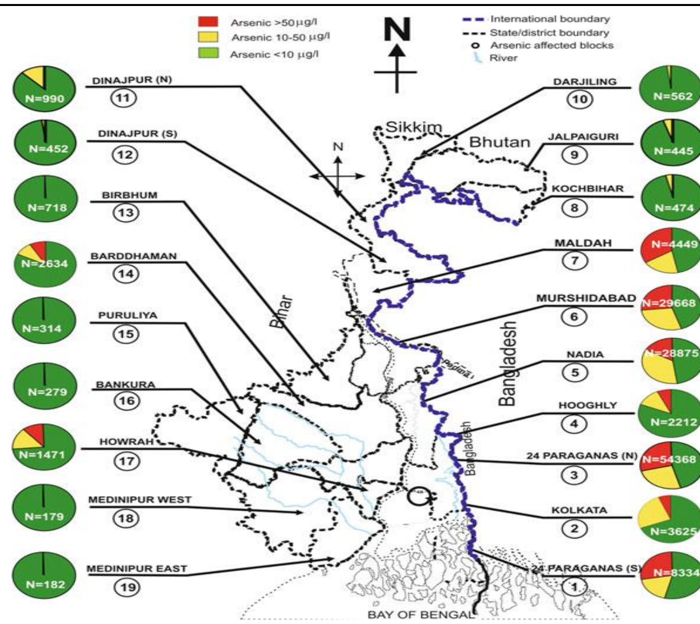

Figure 5: ***Groundwater arsenic contamination status of all 19 districts in West Bengal, India*** *[from 23, Chakraborti et al. 2013, page 5]***.**

-A total of 187 (0.13 %) hand tube wells were determined as highly contaminated (1,000 µg/L).

-The maximum arsenic concentration (3,700 µg/L) was found in Ramnagar village of Gram Panchayet (GP) Ramnagar II, Baruipur block, in South 24 Parganas district (this is a private tubewell where all the nine members of the owners' family had arsenical skin lesions and seven of them who had severe arsenical skin lesions had already died; five of them within the age range below 30 years died).

-Nine districts are severely affected/contaminated are Maldah, Murshidabad, Nadia, North 24-Parganas, South 24-Parganas, Bardhaman, Howrah, Hooghly, and Kolkata), where more than 300 µg/L arsenic concentrations were found (Figure 5).

-The five districts (Koch Bihar, Jalpaiguri, Darjeeling, North Dinajpur, and South Dinajpur) showing concentrations mostly below 50 µg/L

-The five districts comprising Bankura, Birbhum, Purulia, Medinipur East, and Medinipur West are unaffected or arsenic safe.

Table 2: ***Occurrence of high arsenic (> 50 μg/L) in groundwater in India [****compiled by 5, Thakur et al. 2013****].***
NA=not available

State	Districts having As > 50 μg/L	Number of people affected
Assam	Dhemaji	5,71,994
Bihar	Begusarai, Bhagalpur, Bhojpur, Buxar, Darbhanga, Katihar, Khagaria, Kishanganj, Lakhisarai, Munger, Patna, Purnea, Samastipur, Saran, and Vaishali	1,04,71,869
Chattisgarah	Rajnandgaon	NA
Jharkhand	Sahibgunj	NA
Manipur	-	NA
Uttar Pradesh	Agra, Aligam, Balia, Balrampur, Gonda, Gorakhpur, Lakhimpur Kheri Mathura, and Muradabad	60,00,000
West Bengal	Bardhaman, Hooghly, Howrah, Malda, Murshidabad, Nadia, North 24 Pragannas, South 24 Pragannas, and South Calcutta	2,60,00,000

3.4: China**:** The first As contamination in China was reported in Xinjiang Province in the 1970s. Up to year 2012, endemic arsenicosis distributed over 45 counties in nine provinces, while 19 provinces had been found to have As concentration in drinking water exceeding the standard level of 50 μg/L or 0.05 mg/L. A systemic research was carried out on endemic arsenicosis affected and suspicious areas by China government during 2004 and 2010 which covered 12,835 villages with a total population of around 1.25 billion. The result showed 844 villages with 697,000 people were exposed to high-arsenic drinking water (>50 μg/L) [25]. In general, high-As groundwaters in China is mainly found in Zone I (water shortage areas located in the north of China (Figure 5). In general, high As groundwater water are mostly found in arid or semi arid climate under reducing environment (Table 3). According to the above research, Inner Mongolia, Xinjiang and Shanxi Provinces are As ''hotspots''. According to Hei and Charlet 2013 [26], an estimated 1.85 million people may be at risk and believed to be drinking water with arsenic level of above 50 μg/L [26]. It is further reveals that high-As groundwater are located in closed basins where As is hard to be flushed away or be diluted. Affected areas are usually low-lying zones with high pH value (~8.5; see Table 3), which is favorable for As being released and exchanged from minerals or rocks [27].

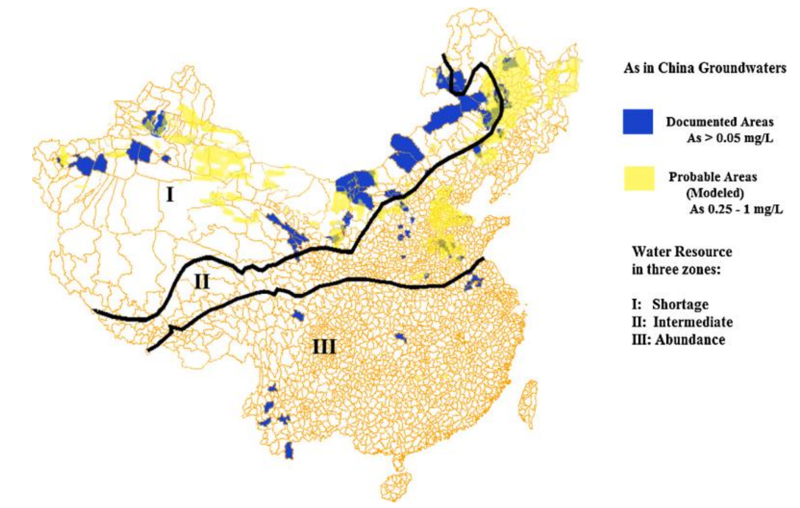

Figure 5: ***Water resource distribution in China and comparison of map of documented high-As groundwaters and modeled map of probability of geogenic high-As groundwater*** *[26, Hei and Charlet 2013, page 84].*

Table 3: ***Summary of documented cases of geogenic high arsenic groundwater's of China [****data and information compiled by 26, Hei and Charlet 2013 based on various authors****].***

Province/Region	Concentration ranges (μg/L)	Aquifer type	Groundwater conditions
Inner Mongolia (including Hetao Plain and Hubao Plain)	Up to 1740	Holocen alluvial and lacustrine sediments	Strongly reducing conditions, neutral pH, high alkalinity
Xinjiang (Tianshan Plain)	40-750	Holocene alluvial plain	Reducing, deep wells (up to 660 m) are artesian
Shanxi (Datong Basin)	105-1932	Quaternary sedimentary basin	Reducing, high pH (8.09), high concentration of phosphate and organic matters
Jilin and Heilongjiang (Songnen Plain)	Upto 152.4	Quaternary sedimentary basin	Reducing, high pH (8.09), high concentration of phosphate and organic matters
Ningxia (Yinchuang Plain)	<10-177	Holocen alluvial and lacustrine sediments	Reducing and oxidizing, highest As level exists in reducing environment, pH (7.18–8.58)
Kuitun, Xinjiang	Up to 880	Quaternary alluvial and lacustrine sediments	Reducing and oxidizing. Some tubewells water contain mainly As(V)
Qinghai (Guide Basin)	<0.112-0.318	Artesian aquifer, metamorphic rocks and volcanic	Geothermal water (18.5–34.6 ^{0}C), high pH (>8)

4. Impacts of arsenic on agricultural food, human health and social life

4. 1: Impacts of arsenic on agricultural food

4.1.1: Vegetables and rice

Arsenic concentration in uncontaminated soils in some Bangladesh districts ranged between 0.10 and 2.75 mg/kg. In contrast, in areas where irrigation is carried out with contaminated groundwater, the soil As level is reported to be upto 81 mg/kg [28,29]. The elevated level of As in soil has resulted in elevated concentrations of As in food since crops receiving arsenic contaminated irrigated water can uptake As during the phyto-extraction process and bio-accumulate in different degrees in different parts of plants (e.g. roots, stems, and grains). Several research studies have found high concentrations of arsenic in vegetables and rice in areas where concentrations of arsenic in soil and water are also high for example, the greatest concentration of arsenic was found in leafy vegetables (in particular in arum or *kochu;* upto 153.2 mg/kg) followed by other vegetables (Table 4). Higher concentrations of arsenic were also reported in rice plants (*boro* rice) in the following orders: rice roots –> rice stem –> rice leaf –> rice grain –> rice husk [28]. It is therefore evident that, the food chain could be a significant pathway of As ingestion by the people of Bangladesh, reviewed by [2, see also Table 4]. Bhattacharya *et al*. 2010 [24], showed that the arsenic-contaminated irrigation water (0.318– 0.643 mg/L) and soil (5.70–9.71 mg/ kg) considerably influenced in the accumulation of arsenic in rice, pulses, and vegetables in West Bengal, India. The highest and lowest mean arsenic concentrations (mg/kg) were found in potato (0.654) and in turmeric (0.003), respectively. The mean arsenic concentrations (mg/kg) were observed in other crops was as follows: Boro rice grain (mean 0.451; range 0.19–0.78), arum (mean 0.407; range 0.24–0.87), amaranth (mean 0.372; range 0.13–0.41), radish (0.344), Aman rice grain (mean 0.334; range 0.06–0.60), lady's finger (mean 0.301; range below detection limit–0.49), cauliflower (mean 0.293; range 0.14–0.48), and Brinjal (0.279; range 0.01–0.41). Arsenic concentration in rice grown in the areas mapped as contaminated in West Bengal ranges between 0.03 and 1.83 mg/ kg, and therefore can be considered as a great risk to human (from arsenic exposure) (see section 5.2). Arsenic concentrations in rice grain as high as 2.0 mg /kg and in rice roots up to 178 mg/kg have been reported [see 24 for details]. Similarly, recent research found cow milk from Bangladesh is also contaminated with As via food chain (see section 4.1.2)

Table 4: ***Arsenic in common food plants of Bangladesh from uncontaminated and contaminated areas*** *[28,29]*.

Common name (local name)	Botanic name	Uncontaminated areas (mg/kg)	Contaminated areas (mg/kg)*
Arum (kochu)	*Colocassia antiqourum*	0.077-0.387	0.13-153.2
Aubergine (egg plant- begun)	*Solanum melongena*	0.23	2.3
Bean (shim)	*Dolicos lablab*	0.092	0.3-1.16
Bitter gourd (karola)	*Momordicum charantia*	1.56	2.12
Chilli (morich)	*Capsicum spp.*	0.41	1.52
Green papaya (pepe)	*Carica papaya*	0.212-0.46	0.04-2.22
Indian spinach (pui shak)	*Brasilia alba*	0.102-0.146	0.07-1.00
Long bean (barboti)	*Vicia laba*	0.3	0.37-2.83
Potato (alu)	*Solanum tuberosum*	0.62	0.71-2.43

***Recommended guideline threshold levels of As in food is 1 mg/kg.

4.1.2: Cow milk and cow dung

A new research study [30] shows some alarming news that As contamination is not only limited to crops and vegetables but also to cow's milk via paddy straw fed to cows. This is a new threat to cattle industry since paddy straw accounts for main source of dairy ration in Bangladesh. Additionally, small-scale dairy farms provide an unprecedented range of relatively low-cost milk and milk products for consumers. Research carried out by [30] found that paddy straw is the main source of As contamination in dairy rations. They reported more As in Boro straw compared to Aus and Aman straw. Their results showed that a wide range of As in milk of cows, cow urine, dung in Bangladesh (see Table 5). This creates a potential dietary risk to human. The study

Table 5: ***Arsenic in cow milk, urine and dung in some selected areas of Bangladesh*** [30].

	Milk (μg/L)	**Urine (μg/L)**	**Cow dung (μg/kg [dw])**
Chandpur	18.8 ± 5.9	150.3± 16.1	1,590.0± 142.6
Faridpur	24.2± 6.1	92.3± 16.8	1,767.1±148.7
Jessore	49.3± 6.3	103.0± 17.2	1,804.5± 152.0
Madaripur	24.7± 5.9	171.2± 15.8	1,495.5±139.8
Satkhira	16.1± 6.0	93.2± 16.5	1,841.1±145.5

also found that cow dung is also contaminated with As (Table 5). It is important to mention here that in Bangladesh and India, cow dung is generally used as manure and fuel. Burning As-rich cow dung cakes in unventilated ovens releases As loads to the environment, thereby can affect people through direct inhalation [31]. It is also possible recontamination of the food-chain in case the cow dung is used as fertilizer in conventional or organic farming [30].

4.2: Impacts of arsenic on human health

Arsenic is one of the most toxic and carcinogenic of all the natural groundwater contaminants (IARC class I carcinogen). Arsenic exposure from contaminated drinking water of more 50 µg/l is a significant cancer risk. The exposure of human to arsenic contaminated water and foods can lead to some physical changes on the skin such as the appearance of small black or white marks (*melanosis*), then thickening of the skin on the palms and the feet (*keratosis*), followed by skin lesions and eventually skin cancer. The development of internal cancer in humans may take 10 years to develop and is often the result of long term exposure to arsenic. The long term ingestion or exposure (10-15 years) of arsenic can lead to a disease called 'Arseniasis, arsenicosis, and arsenicism' [reviewed by 2]. Chronic exposure to arsenic has been linked to carcinogenic effects in both humans and animals. These include cancer of the various skin and various internal organs (lung, bladder, liver and kidney) reproductive and developmental effects; cardiovascular disease; reduced intellectual function in children and mortality. Non-cancer endpoints include hyper-pigmentation, hypo-pigmentation, keratosis of skin, peripheral vascular disease (black foot disease), cardiovascular disease, hypertension and neurotoxicity. There are some claims that chronic exposure of arsenic may also cause diabetes development and prostate cancer [32,33,34]. The short term and long term effects of arsenic on health are given in Table 6.

Table 6: ***Short and long term health effects arsenic to humans*** [5].

Short term effect	Long term effect
Abdominal pain Changing in skin colour Vomiting Dryness/tightness in throat Thirst Convulsions Cramps Clammy sweat	Skin, kidney, prostate, bladder and lung cancer Limb loss Immunological disorders Diabetes Reproductive problems Developmental problems

4.3: Impacts of arsenic on social life

The arsenic problem can cause significant social problem (Figure 6), for example, marriage, employment, and social interaction can be difficult or impossible [5]. A number of socioeconomic problems like social uncertainty, social injustice, social isolation, poverty and problematic family issues are reported due to arsenicosis. In some circumstances, children of arseniocosis are not allowed to attend at school or social or religious functions and even they are not allowed to take baths in any of village ponds. Separation and marital breakdown (divorce) are also reported [14]. Arsenic poisoning people are generally depressed which may cause ultimately committing suicide. Research studies found that more than one third of the populace affected with arsenic is economically poor and living below the poverty line. In some circumstance, affected people are sent back to their home by their employer with believe that the disease will spread from one to another (in principle, arsenic related diseases are not spreadable disease). It is also difficult to either sex to marry in the same village and in many places jobs or services are denied to the arsenic affected persons. Once either husband or wife is singled out as an arsenic patient, they generally lose their social connection and live in isolation. Primary survey conducted in West Bengal, India found that poor households incurred the largest number of sick days and person suffering from arsenic disease worked only 2.73 h per day compared to 8 h work per day. Khan (2007) [35] studied health impacts and costs associated with arsenic groundwater contamination using primary data from Bangladesh

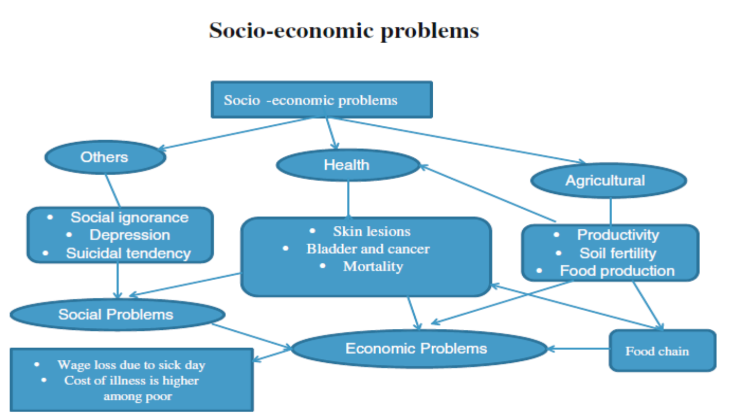

Figure 6: ***Socio-economic problems of groundwater arsenic contamination*** *[14, page 175].*

(based on household production function on 900 tube-wells and 878 household). The author [35] estimated that the total cost of illness from arsenic was found to be US $9 to US $17 million per annum which was nearly 0.6 per cent annual income of the affected households.

5. Climate change and arsenic

Climate change/climate variability is projected to increase extreme weather events such as floods; droughts and sea-level rise and are likely to result in the release of some of chemicals including metals, metalloids and persistent organic compounds [2,3,36]. For example, where intense rainfall is expected to increase, pollutants such as pesticides, heavy metals, fertilisers and organic matters will be increasingly washed from soils to water bodies. Alternate floods and droughts have been found associated with the release of arsenic and contamination of groundwater in Bangladesh. In addition, agriculture soil and water contamination and variation of levels of contaminants have been associated with alternated periods of floods and droughts [2,3,37]. It is expected that uptake and toxicity of metals including As in crops, vegetables and fish may be enhanced with increasing temperatures/global warming [2,3]. Of the metals likely to become more prevalent in human environments due to climate change, inorganic arsenic is of great concern because it is a potent human carcinogen, which alters the immune system (IARC Class 1 carcinogen). More than 100 million people worldwide are exposed to arsenic through groundwater contamination [36].

6. Arsenic remediation and mitigation

Millions of people in Bangladesh and other poor developing countries (India) continue to drink well water containing elevated levels of arsenic even though arsenic-safe water is often available from other wells located within a short walking distance (100 m [34,35]. The most common arsenic mitigation option in poor countries would be well switching, i.e. switching from an arsenic unsafe well to an arsenic-safe drinking water source(Figure 7), use of deep tubewells (deep aquifers are generally lower in arsenic such as > 150-200 m in case of Bangladesh; see Figure 8) and use of arsenic filters and pond sand filter. There is also a need of arsenic education program for an increasing arsenic awareness about safe uses of arsenic-contaminated water. There are at least eight low-cost safe water alternatives can be implemented to provide arsenic-safe and pathogen-free water as listed below [34] :

- deep tube wells that tap deeper, arsenic-free aquifers
- rainwater harvesting
- household arsenic removal filters
- community arsenic removal filters
- rural piped water supply that provide safe water by distributing deep tube well or filtered pond and river water
- pond sand filters, which remove pathogens from arsenic-free surface water
- dug wells, that is, arsenic-safe, very shallow hand dug wells, and
- wells switching that is, switching to neighbors' uncontaminated shallow tube wells

Figure 7: ***Tube wells marked green are safe for drinking*** *[43]*

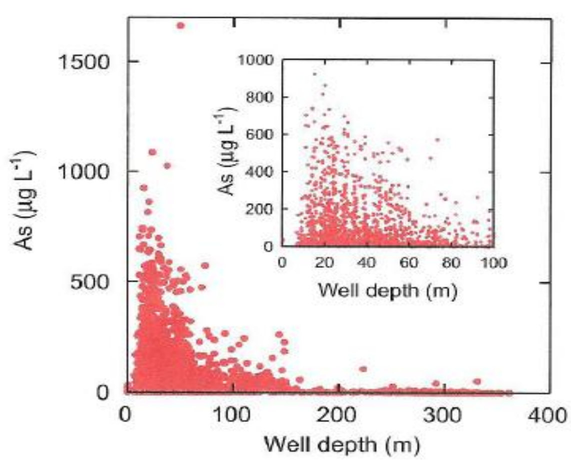

Figure 8: ***Arsenic concentration of groundwater (tube-wells) in Bangladesh.*** *The highest concentration and greatest range are found in groundwater pumped from tube-wells below 75m. Tube-wells deeper than 150m are relatively free of arsenic [42, page 3].*

A regular monitoring of arsenic level in water (affected areas) and common food (rice, vegetables, fish, and cow's milk) would help reducing risks and threats to human

7. Conclusion

Arsenic calamity of Bangladesh is greater than the environmental disasters at Bhopal, India in 1984 and Chernobyl, Ukraine in 1986 [38]. The World Bank [39] estimated that 43,000 out of 68,000 villages in Bangladesh are presently or could be at risk in the future from arsenic contamination. There is need of arsenic education program for an increasing awareness about safe uses of water. There should also be provision to supply arsenic free, biologically and chemically safe alternative sources of drinking water to the vast majority of the Bangladesh population. In this regard identification of community tube-wells that have water with a low arsenic content would be required. Other options are: (a) supply of water filters for household, (b) supply of chemicals to remove arsenic from household drinking water (hydrated ferric oxide may remove arsenic), (c) supply of surface water sources that have been treated by filtration and chlorination, (d) sinking deep tube wells (> 150m) for the communities. Furthermore, closure of highly contaminated tube-wells may discourage people from using arsenic contaminated water. Other measures to reduce the risks of arsenic exposure to humans would be:

- Use of arsenic tolerant crop varieties
- Breeding of rice plants that are tolerant to arsenic and have a limited arsenic uptake *[note: a recent research by [Shaban et al. 2013; 40] discovered low-arsenic rice in Bangladesh. Scientists identified an aromatic variety of rice that has far lower arsenic concentrations than found in non-aromatic rice. Their research results showed Sylheti rice to have a far lower arsenic concentration than similar types of rice from other regions of Bangladesh. Results also showed that the arsenic concentration in aromatic rice was 40% less than non-aromatic varieties [40,41]*
- Use of hyper-accumulating plants such as Chinese brake fern, *Pteris vittata* which are reported to be extremely efficient in extracting arsenic from soils.
- Clean up As contaminated top soils.
- Cooking of rice in excess water or removal of tuber/vegetable skins

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