Chapter-2
Arsenic Menace in India- An Appraisal

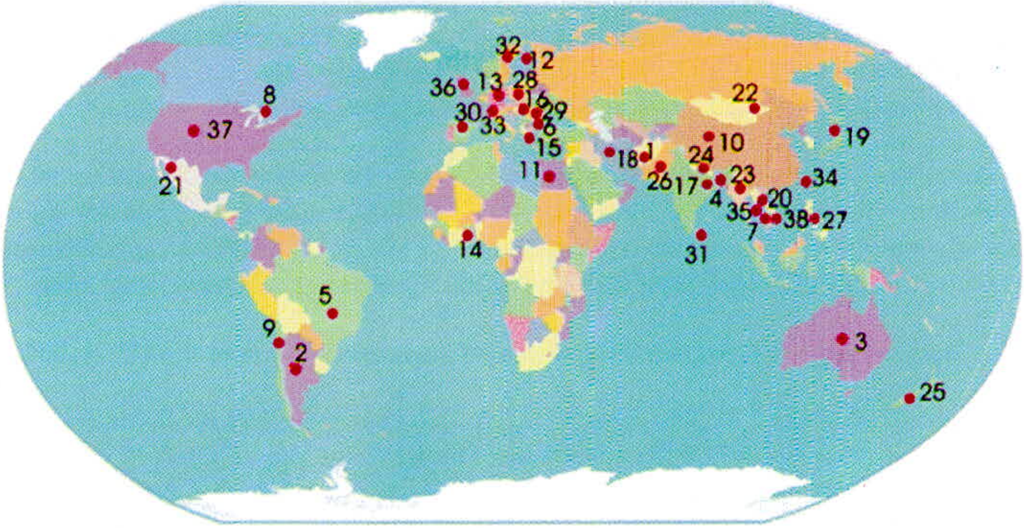
Groundwater arsenic contamination in India from the states of West-Bengal, Jharkhand, Bihar, Uttar Pradesh is in flood plain of Ganga River; in Assam and Manipur it is in flood plain of Brahamaputra and Imphal rivers. Groundwater of Rajnandgaon village in Chhattisgarh state is also arsenic contaminated and some people had arsenical skin lesions but the source of arsenic in Chhattisgarh is not from flood plains of Newer Alluvium (Holocene) as in Ganga, Brahmaputra, and Imphal rivers. The magnitude of arsenic contamination in Chhattisgarh state is much less compared to flood plain contamination in Ganga-Brahmaputra plain. People in these affected states are chronically exposed to drinking arsenic contaminated hand tube-wells water. Since the groundwater arsenic contamination first surfaced in 1983 from nearly 33 villages in 4 districts of West Bengal, up till 2008; 9 districts covering 3417 villages in 111 blocks in West Bengal, 15 districts covering 57 blocks in Bihar, 3 districts covering 69 villages in 7 blocks in Uttar Pradesh, 1 district covering 68 villages in 3 blocks in Jharkhand, 3 districts covering 9 blocks in Assam, 4 districts in Manipur, and 1 district covering 4 villages in 1 block in Chhattisgarh have been detected for groundwater arsenic contamination above permissible limit of 50 µg/L. Many more North-Eastern Hill States in the flood plains are suspected to have the possibility of arsenic in groundwater. Even, after twenty-five years, with every new survey, new arsenic affected villages and people suffering from arsenic related diseases are being reported. The area and population of these states are 529674 km^2 & approx. 360 million respectively, in which 88688 km^2 and approximately 50 million people have been projected vulnerable to groundwater arsenic contamination.

Analysis of 169698 hand tube-well water samples from all these 7 states for arsenic detection by School of Environmental Studies, Jadavpur University (SOES, JU) reported presence of arsenic in 45.96% and 22.94% of the water samples more than 10 µg/L (WHO guideline value of arsenic in drinking water) and 50µg/L (Indian standard of arsenic in drinking water) respectively. And a preliminary survey screening 100,731 people by SOES from arsenic affected villages of West Bengal, Jharkhand, Bihar, Uttar Pradesh, and Chhattisgarh; reported 10118 patients with different kinds of arsenical skin lesions. Arsenic neuropathy as well as adverse pregnancy outcomes such as spontaneous abortion, still-birth, preterm birth and low birth weight were also reported along with other arsenic related diseases. Infants and children drinking arsenic contaminated water were also found severely effected. Analyses of biological samples from arsenic affected areas showed elevated level of arsenic in both patients and non-patients indicating that many are sub-clinically affected (SOES, 2008). It has been estimated that in Ganga-Meghna- Brahmaputra plain (including Bangladesh) alone around 100 million people are at risk from groundwater arsenic contamination above WHO guideline. People in newly arsenic identified states could be in more danger, as many are not aware of their arsenic contamination in hand tube-wells and unknowingly continue drinking arsenic contaminated groundwater. In arsenic contaminated areas often arsenic contaminated groundwater is used for agricultural irrigation resulting in excessive amount of available arsenic in the crops in that area. It has been reported that second to the ingestion of arsenic, after the direct consumption as drinking arsenic contaminated water, is through food chain, particularly use of contaminated rice followed by vegetables. This eventually indicates that the effects of this occurrence are far-reaching; sooner we search sustainable solutions to resolve the problem, lesser be its future environmental, health, socioeconomic and socio-cultural hazards.

Even after spending huge amount of money for providing arsenic safe water to the villagers from contaminated hand tube-wells and other sources, the overall result suggests requirement of more concentrated and focused efforts in planning and management to cope up with such gigantic calamity. Attempts made so far to combat the menace of groundwater arsenic contamination, like, to identify the causes, to provide arsenic free drinking water to people dependent on groundwater supply, to reduce the arsenic related social and socio-economic problems and to develop cost effective technology for eradication of arsenic contamination have proven inadequate, fragmented and less responsive, as evident from the rise in number of arsenic affected areas with every new survey. There is, therefore, a need for adopting holistic approach to resolve solution considering management of science-society-resources together, but not merely healing the pain externally. Proper watershed management, possibility of tapping of freshwater aquifer linking to proper aquifer management, in-situ remediation of the problem and economical utilization of all available alternative safe sources of water need to be explored. To combat the arsenic crises we need to aware and educate the villagers the dangers of arsenic toxicity and importance of using arsenic safe water. This can only be achieved by active community participation and whole-hearted support from government and arsenic researchers.

2.1 Global Arsenic Scenario

Most of the cases of arsenic toxicity in the medieval and early modern age were due to arsenic intake through medicine, smelting or genocide activities. Around the middle of 20^{th} century arsenic poisoning surfaced from some countries where people ingested arsenic contaminated water. This toxicity manifested on mass scale rather than the mere individual cases. The major affected countries were Argentina, Chile, Mexico and Taiwan. Close to the end of 20^{th} century groundwater arsenic contamination and sufferings of people came to lime light from three more Asian countries (West-Bengal-India, China and Bangladesh). The source of arsenic was contaminated hand tube-wells. In global arsenic contamination scenario 38 countries are affected at present **(Figure 2.1)**. In Asia alone 13 countries are arsenic affected and Asian countries are worse arsenic affected in global arsenic scenario. In Bangladesh alone out of its total 64 districts, 60 districts have groundwater arsenic contamination above WHO guideline value (10μg/L) . In India, flood plains of all the states in Ganga and Brahamaputra rivers are arsenic affected. **Figure 2.2** shows the major arsenic affected regions in Asia.



1. AFGANISTHAN	11. EGYPT	21. MEXICO	31. SRI LANKA
2. ARGENTINA	12. FINLAND	22. MONGOLIA	32. SWEDEN
3. AUSTRALIA	13. GERMANY	23. MYANMAR	33. SWITZERLAND
4. BANGLADESH	14. GHANA	24. NEPAL	34. TAIWAN
5. BRAZIL	15. GREECE	25. NEW ZEALAND	35. THAILAND
6. BULGARIA	16. HUNGARY	26. PAKISTHAN	36.UNITED KINGDOM
7. CAMBODIA	17. INDIA	27. PHILIPPINES	37. USA
8. CANADA	18. IRAN	28. POLAND	38. VIETNAM
9. CHILE	19. JAPAN	29. ROMANIA	
10. CHINA	20. LAO PDR	30. SPAIN	

Figure 2.1 : Global Scenarios of Arsenic Contamination Affected Countries

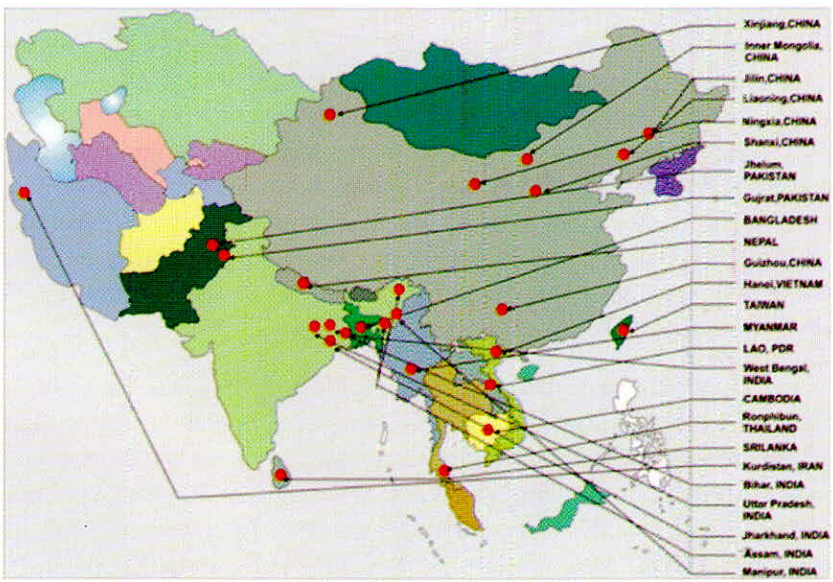


Figure 2.2 : Major Arsenic Affected Regions in Asia (Source : British Geological Survey, 2001).

Most of the world's high-arsenic in groundwater is the result of rock water interaction. The majority of large-scale high-arsenic provinces are in young unconsolidated sediments usually of Quaternary age and often belong to Holocene (<12 thousand years). These sedimentary deposits holding the arsenic contaminated aquifers can broadly be grouped into two: (i) large alluvial and deltaic plains (eg., Bengal delta, Yellow River plain, Irrawaddy delta, Red River delta), and (ii) inland closed basins in arid or semi-arid setting (eg. Argentina, Mexico, south-western United States). The most interesting fact is that these aquifers do not appear to contain abnormally high concentration of arsenic bearing minerals, but, do have geochemical and hydrogeological conditions favorable for mobilization and retention of arsenic in solution.

2.2 Background of Groundwater Arsenic Contamination in India (1976-2008)

During the middle of 20th century, South Asian countries like India and Bangladesh (then East Pakistan) had two major problems. The first was providing food for the huge population and the second was preventing water contaminated diseases like diarrhoea, cholera, typhoid, dysentery, etc. The yearly rainfall, though among the highest in the world in Bangladesh and in West Bengal, India, was not potent enough to satisfy the needs. Moreover, India and Bangladesh, with plenty of available surface water, did not have the necessary infrastructure for the preservation, distribution, and purification facilities. The overall watershed management was poor. The farmer had to plea desperately for the rains in order to grow a harvest. The annual rainfall allowing a single harvest a year was not enough for the population and the situation would be even worse if there was a drought. Such circumstances called for alternative remedies. Sometime during the year 1950, in Charmajdia, a small village of the district Nadia, West-Bengal, the first induction of groundwater by pump created a furor. Villagers fled at the sight of water gushing out from the earth. They shrieked, 'Devil Water' is coming. They believed underground was the proverbial Hell where Satan resided. Hence, they refused to use that water. Nevertheless, this water came at a trying period for the struggling people. These trusting people, thoroughly advised by the government and aid-agencies, finally decided to use the forbidden water. They were given assurance that with this groundwater, the bliss of God would bring green revolution and good health. The revolution did come and the discovery of devil water became mere annals of history. The underground water survived the test of time and faith. It overcame the stigma of being a tool of the devil. The villagers drank cold water during the summer and moderately warm water during winter by merely pushing the handle of a small machine known as a Tube-Well.

In 1976, Dr D V Dutt from Chandigarh, North India, while treating patients in Chandigarh and surrounding areas noticed some patients suffering from noncirrhotic portal hypertension (NCPH). He came to know that the drinking water used by those patients came from arsenic contaminated tube wells. In 1982, six years after the Chandigarh incident, a patient from North-24 Pargana district of West Bengal came to the Dermatology Department of Calcutta, School of Tropical Medicine (CSTM). Dermatologist Dr. K,C.Saha noticed that the patient's skin lesions were not like the usual skin diseases. Dr Saha learnt from the patient that many people in his village suffered from such afflictions in soles of their feet, palms of their hands, and bodies. Then soon another patient arrived with similar symptoms but more severe and he had an ulcer on his finger. After biopsy Dr Saha diagnosed cancer. Then Dr Saha visited the village from which such diseases were being reported. Together with Dr A K Chakrabarti and Dr Garai of All India Institute of Hygienic and Public Health (AIIH&PH), and Dr A K Saha, Professor of Geology, Presidency College, Calcutta, Dr Saha conducted a thorough research in that village for one year. He concluded that the tube well water used for drinking in the village was heavily arsenic contaminated, and was responsible for such diseases. After that, Dr D N Guha Majumdar diagnosed Liver Fibrosis among arsenic patients in the SSKM Hospital, Calcutta, and the same disease that was indicated by Dr D. V. Dutt in 1976. Soon the disease was found to exist in districts like South 24 Pargana, North 24 Pargana, Nadia, and Murshidabad. Nearly 33 villages in these four districts were reported affected by this malady. It was Dr. Saha who brought out first document on Arsenic menace in groundwater in four districts of West Bengal.

From 1983 onwards a number of organizations in West-Bengal are working on the groundwater arsenic contamination investigations, problem identification and mitigation. They are largely: (a) School of Tropical Medicine (STM), (b) All India Institute of Hygiene and Public Health (AIIH&PH), (c) Central Ground Water Board (CGWB), (d) Centre for Study of Man and Environment (CSME), (e) School Environmental Studies(SOES), JU, (f) WB Government Public Health Engineering Department (PHED), (g) School of Fundamental Research (SOFR), (h) Seth Sukhlal Karnani Memorial Hospital, and (i) WB Directorate of Health Services, Government of West Bengal, etc. In addition to these organizations, there may be a number of other Institutions/units working on Arsenic problem in West Bengal across the Country. Recently Government of West-Bengal has started a project worth Rs. 2100 crores to supply arsenic safe water to the arsenic contaminated districts of West-Bengal.

In continued surveys and investigations after 1983 in West Bengal, in every additional survey, more and more arsenic affected areas and districts have been added to the list of arsenic affected areas. Year wise addition of detected arsenic affected areas, compiled from database of SOES, is given in the following table that could help recognize the progression of this menace:

Year	No of district & Name of district	No. of villages (Blocks)
Year, 1983	4 (South 24 Pargana, North 24 Pargana, Nadia, and Murshidabad)	33 (*)
Up to 1991	6 (North 24-Pargana, South 24-Pargana, Nadia, Murshidabad, Malda, and Bardhaman)	93 (*)
Up to 1994	6 (North 24-Pargana, South 24-Pargana, Nadia, Murshidabad, Malda, and Bardhaman)	312 (37)
Up to 1995	6 (North 24-Pargana, South 24-Pargana, Nadia, Murshidabad, Malda, and Bardhaman)	405 (37)

Up to 1997	9 (Malda, Murshidabad, Bardhaman, Nadia, Howrah, Hooghly, North 24-Parganas, South 24-Parganas and Kolkata.)	830 (58)
Up to 1999	9 (Malda, Murshidabad, Bardhaman, Nadia, Howrah, Hooghly, North 24-Parganas, South 24-Parganas and Kolkata.)	985 (69)
Up to 2002	9 (Malda, Murshidabad, Bardhaman, Nadia, Howrah, Hooghly, North 24-Parganas, South 24-Parganas and Kolkata.)	2700 (*)
Up to 2004	9 (Malda, Murshidabad, Bardhaman, Nadia, Howrah, Hooghly, North 24-Parganas, South 24-Parganas and Kolkata.)	3200 (85)
Up to 2008	9 (Malda, Murshidabad, Bardhaman, Nadia, Howrah, Hooghly, North 24-Parganas,South 24-Parganas and Kolkata.)	3417(111)

(*) Not reported

Since 1983 when there were only 33 affected (As > 50 μg/L) villages in four districts, the number of villages has increased to 3417 in 111 blocks in nine districts in till 2008 in West Bengal alone. There can be several other lists of arsenic affected areas prepared by different organizations, which may differ from one to another, because of number of reasons, e.g.,(i) number of samples analyzed, and different sampling locations (ii) compilation of information may be different, etc. However, the fact is that during last 25 years, with every additional survey, an increasing number of contaminated villages and more affected people have been identified. Those raise questions: whether all those identified areas were already under the grim of arsenic contamination but not got exposed; or they resulted from the mobilization from the adjoining contaminated areas or triggered from the in-situ source material by the excessive groundwater exploitation over the passage of time. It needs a mention here that in 1992, the problem of arsenic groundwater contamination, and people suffering from arsenical skin lesions were also reported in Padma-Meghna-Brahmaputra (PMB) plain of Bangladesh. Bangladesh is considered worst affected in global arsenic contamination scenario.

In 1999, the arsenic groundwater contamination and its health effects in Rajnandgaon district were also identified from the analysis of water samples from Rajnandgaon district of Chhattisgarh by SOES.

In 2002, the arsenic contamination was also reported in Bihar in middle Ganga plain. It was also apprehended in adjoining areas of Uttar Pradesh. In Bihar, two villages, Barisban and Semaria Ojhapatti, in Bhojpur district, located in the western part of the Bihar state, were reported having contamination exceeding 50 μg/L. As of now, according to CGWB and PHED, Govt. of Bihar, out of 38 districts of Bihar, 57 blocks from 15 districts having total population nearly 10 million have been reported affected by arsenic groundwater contamination above 50 μg/L.

During 2003, 25 arsenic affected villages of Ballia district in Uttar Pradesh and people suffering from skin lesions came to limelight.

During 2003-2004, the groundwater arsenic contamination and consequent suffering of hundreds of people were reported by SOES in 698 hand tube-wells from 17 villages of the Sahibgunj district of Jharkhand state, India, in the middle Ganga plain.

In 2004, arsenic concentration above 50µg/L was also reported in Assam in pockets of 2 districts. In 2007, arsenic groundwater contamination from Manipur state, one of the seven North-Eastern Hill States, came to limelight. It is also apprehended by SOES that groundwater of flood plains of all the seven North-Eastern Hill states of India (Arunachal Pradesh, Meghalaya, Assam, Tripura, Nagaland, Manipur, Mizoram) may have the possibility of arsenic. **Table 2.1** shows the demography and appreciable groundwater arsenic contamination situation in Indian states at a glance and **Figure 2.3** shows the positions of arsenic affected states in India. **Figure 2.4** shows position of arsenic affected areas in Ganga Plains in India with reference to the Ganga-Meghna-Brahmaputra Plains

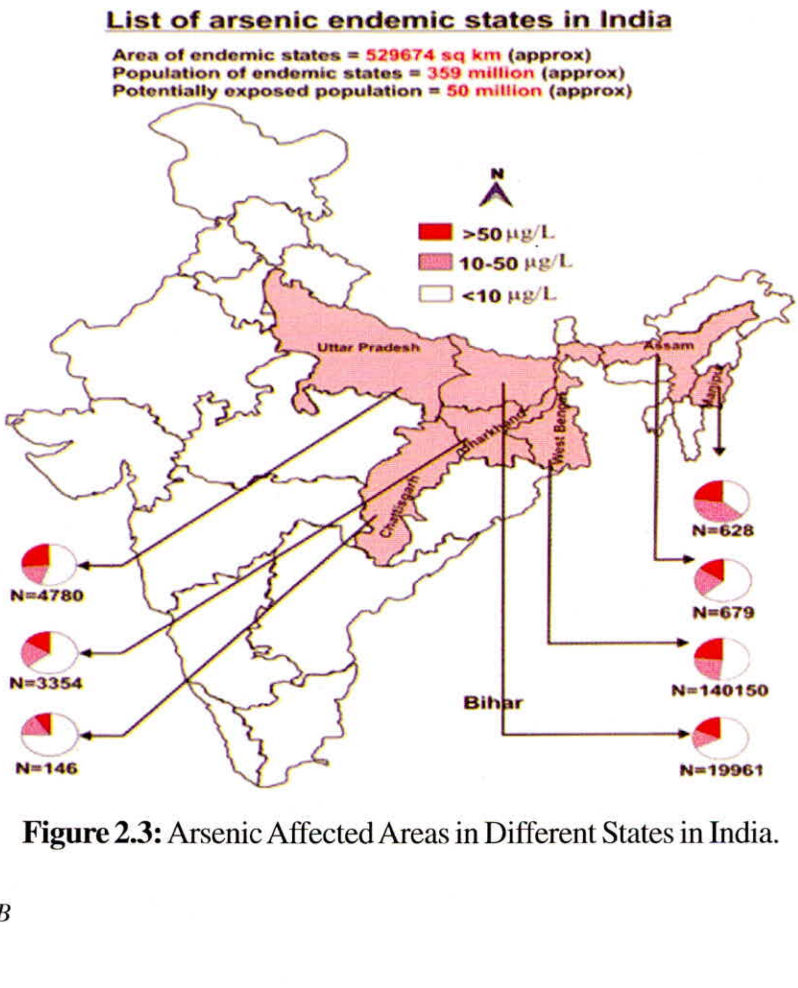


Figure 2.3: Arsenic Affected Areas in Different States in India.

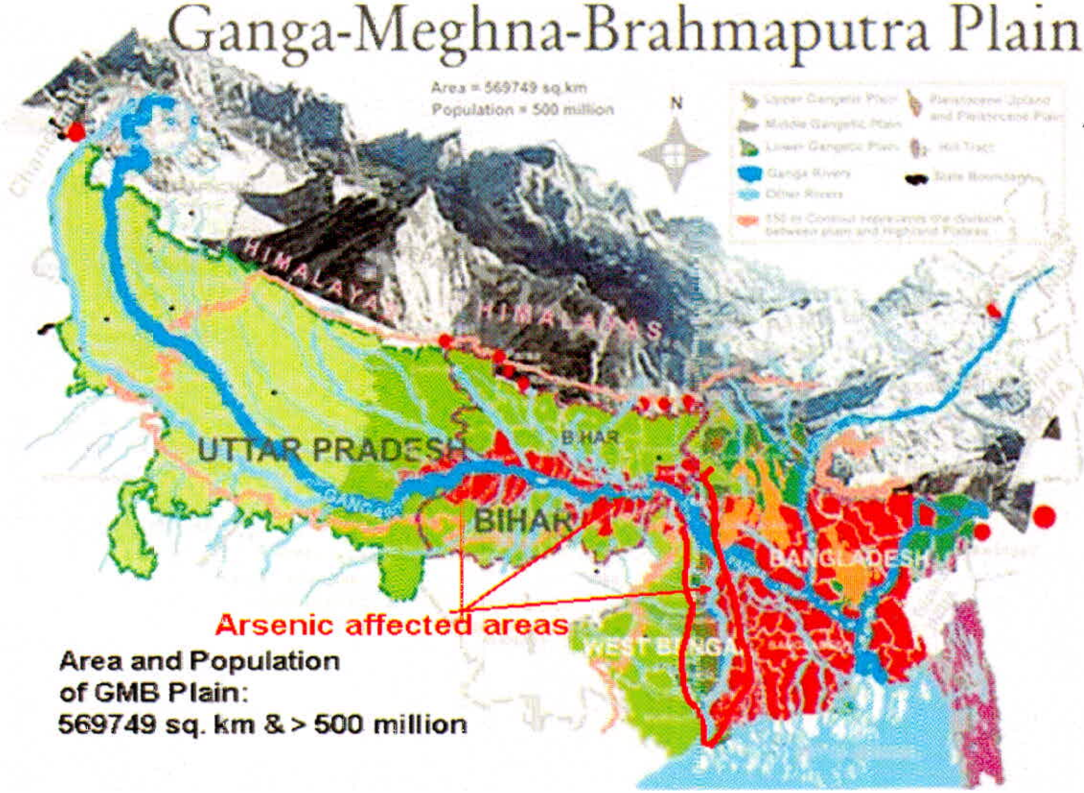


Figure 2.4: Arsenic affected stretches in Ganga Plains in India with reference to Ganga-Meghna-Brahmaputra Plains.

The demographic survey of the affected areas and analysis of water samples by many organizations (SOES alone analyzed nearly 211955 water samples; CGWB, State PHED, WB and Bihar, and other organizations also analyzed quite a large number of water samples) estimated that more than 13.85 million people could be under the threat of contamination level above 10 μg/L, in which more than 6.96 million people could be above 50 μg/L, against the total population of those areas of the order of 50 million. And a huge number of live-stock has also been exposed to arsenic contaminated groundwater. Arsenic contaminated groundwater is also in use for agricultural irrigation in the arsenic affected areas. Recently possibility of arsenic exposure through food chain is also considered not only in contaminated areas but also in uncontaminated areas due to open market. If we focus on the dimension of the emerged problem, the points arising before us are: (i) a large number of people have been exposed to arsenic groundwater contamination and its consumptions in various forms of usages, (ii) with persistence usages of groundwater from vulnerable aquifers, having deposit of source material, number of arsenic detected areas has increased with continuing survey of new areas, (iii) what are the source, causes and mechanisms of groundwater arsenic contamination ?, (iv) how the problem has been triggered ? (v) how could people, livestock and groundwater dependant usages be safeguarded from hazards of arsenic contamination ? (vi) What alternate planning and management of water resources in those affected and vulnerable areas are to be adopted ? (vii) What remediation/corrective measures are necessary to restore the affected aquifers ? (viii) What short-term and long-term planning and management strategies are to be put in place ? Etc.

2.3 Magnitude of Groundwater Arsenic Contamination and its Effects on Health in Arsenic Affected States of India

2.3.1 Impacts of arsenic on human health in chronically exposed population

Arsenic can exert its toxic effects through impairment of cellular respiration by inhibition of various mitochondrial enzymes and uncoupling of oxidative phosphorylation. The As(III) species can react with -SH group of protein and enzymes, thereby making them inactive and increase reactive oxygen species in the cells causing cell damage. It is also reported that arsenic could inhibit 200 enzymes in the body. It has been regarded that multisystemic non-cancer effect could be due to deactivation of essential enzymatic functions by trivalent arsenic compounds and subsequent oxidative stress to cell.

More recent studies have detected along with all the 4 species [As(III), As(V), MMA(V), DMA(V)] also the presence of MMA(III) and DMA(III) in urine. It is also considered that inorganic As(III) and the reduced forms of MMAIII and DMAIII formed during methylation are highly reactive and contribute to the observed toxicity of inorganic arsenic.

So far no evidence has been found that inorganic arsenic directly causes genetic mutations affecting cancerous cells. However, it appears that inorganic arsenic indirectly enhances susceptibility to cancer inducing chromosomal alterations, inhibition of DMA repair process, oxidative stress and cell proliferation.

Arsenate (AsO_4^{3-}) has similar structure as phosphate (PO_4^{3-}) and thus can substitute PO_4^{3-} in adenosine diphosphate (ADP). This substitution prevents conversion of ADP to ATP (adenosine triphosphate) which produces energy to cell.

The available health effect reports, after ingestion of arsenic contaminated groundwater, are mainly from the epidemiological study of chronic arsenic exposure. Number of incidents and studies related to acute arsenic toxicity are meager compared to chronic arsenic exposure. During the last decade plenty of chronic arsenic exposure incidents have been reported from Asian countries due to use of arsenic contaminated groundwater and associated health effects. More and more studies have been carried out to know various health effects due to chronic exposure. During the last decade 4 monographs (IARC 2004, IPCS 2001, NRS 1999, NRS 2001) along with large number of reports and special issues have been published to include the research activities of chronic arsenic exposure and various carcinogenic and non-carcinogenic health effects.

It is evident now that inorganic arsenic exposure deactivates the function of enzymes, some important anions, cations, transcriptional events in cells and causes other direct or indirect effects. Such activities of inorganic arsenic result in numerous illnesses that have been also confirmed by repeated epidemiological investigations. Examples of the same are :(i) Dermal effects, (ii) Cardiovascular effects, (iii) Respiratory effects, (iv) Gastrointestinal effects, (v) Endocrinological effects (diabetes mellitus), (vi) Neurological effects, (vii) Reproductive and developmental effects, (viii) Cancer effects, and (ix) other effects. Symptoms of arsenicosis are primarily manifested in the form of different types of skin disorders such as skin lesions, hyper keratosis and melanosis.

2.3.2 Arsenical health effects in India

West Bengal's groundwater arsenic contamination and health effects surfaced in 1983. West-Bengal is one of the worst arsenic affected areas in the world arsenic scenario. During last 25 years, more scientific and medical investigations have been carried out in this state by (a) School of Tropical Medicine (STM), (b) All India Institute of Hygiene and Public Health (AIIH&PH), (c) Central Ground Water Board (CGWB), (d) Centre for Study of Man and Environment (CSME), (e) WB Government Public Health Engineering Department (PHED), (f) Arsenic group in Seth Sukhlal Karnani Memorial Hospital, and (g) WB Directorate of Health Services, Government of West Bengal (h) Kolkata Medical College, etc. In very preliminary work, medical group of SOES examined around 96,000 individuals, including children (age range: infants to 11 yr), for arsenic toxicity from arsenic affected villages of West Bengal and 9,356 of them showed skin lesions; in children, these numbers were 5.6% ($n = 14,000$). Various types of skin manifestations and other arsenic toxicity were observed from melanosis, keratosis, hyperkeratosis, dorsal keratosis, and non pitting edema to gangrene and cancer.

Neurological examination was generally done for arsenocosis patients whose skin lesions were already diagnosed by experienced dermatologist. Overall prevalence of clinical neuropathy was noted in various studies in populations of 24- Pargana-North, 24- Pargana-South, Murshidabad, Nadia, and Bardhaman districts of West Bengal and in the states of Bihar, Uttar Pradesh, Jharkhand and Chhattisgarh.

Arsenic exposure during pregnancy can adversely affect several reproductive endpoints. In several studies the association between arsenic exposure and adverse pregnancy outcome, including spontaneous abortion, preterm birth, stillbirths, low birth weight and neonatal and pre-natal mortality have been documented from arsenic affected villages of West-Bengal and other states in India.

2.3.3 Other multi-systemic common features in arsenic affected areas.

The following features were commonly noted (1983-2006) mainly from the arsenic endemic areas of India and Bangladesh. Most of the population suffering from arsenic skin lesions is from a poor socio-economic background.

(i) Skin itching to sun rays, Burning and watering of eyes, Weight loss, Loss of appetite, Weakness, Lethargy and easily fatigued limited the physical activities and working capacities.

(ii) Chronic respiratory complaints were also common. Chronic cough with or without expectoration was evident in more than 50%. As reported by the villagers, the unique sound of "cough of arsenicosis" was reported from adjacent village homes at night to create an unusual atmosphere. The cough may be painful and sputum may contain blood to be misdiagnosed as pulmonary tuberculosis. In late stages, shortness of breath might predominate.

(iii) Gastrointestinal symptoms of anorexia, nausea, dyspepsia, altered taste, pain in abdo men, enlarged liver and spleen, and ascites (collection of fluid in abdomen) were also observed in 50% patients.

(iv) Moderate to severe anemia was evident in some cases.

(v) Conjunctival congestion, Leg edema was less common.

2.3.3.1 West Bengal

Table 2.2 shows an overview of arsenic contamination status in West Bengal up to 2008 (Chakraborti, 2008a). Out of 140150 samples analyzed for arsenic, 48.1% had found arsenic above 10 µg/L and 23.8% above 50 µg/L. Importantly, 3.3% of the analyzed tube-wells had arsenic concentrations above 300µg/L, the concentration predicting overt arsenical skin lesions. A total of 187 (0.13%) hand tube-wells were reported highly contaminated (> 1000 µg/L). The maximum arsenic concentration (3700 µg/L) was found in Ramnagar village of GP Ramnagar II, Baruipur block, in South 24-Parganas district. This tubewell was a private one. **Figure 2.5** depicts groundwater arsenic contamination status of all 9 districts of West Bengal.

Table 2.3 represents the survey report by SOES for all the 19 districts (including Kolkata) in West Bengal. Based on the arsenic concentrations found in the 19 districts of West Bengal the severities have been classified into three categories: Severely affected (>300 µg/L), mildly affected (between 10 and 50 µg/L, and unaffected (< 10 µg/L). Nine districts (Malda, Murshidabad, Nadia, North 24-Parganas, South 24-Parganas, Bardhaman, Howrah, Hooghly and Kolkata), where more than 300 µg/L arsenic concentrations was found in tube-wells are categorized as severely affected. Out of 135,555 samples analyzed from these nine districts 67,306 (49.7%) had arsenic concentrations above 10µg/L and 33,470 (24.7%) above 50 µg/L.

It can be noted from **Figure 2.5** that all 9 severely affected districts (concentration > 50 µg/L) are in a linear track along the river Bhagirathi (the stretches of the river Ganga passed through Kolkata). Most of the affected areas lie along the left hand side of the river along the direction of groundwater flow. The groundwater flow direction in those areas is towards south-east direction, and the affected areas also swell mostly along the same direction. The geological formations in those areas are of thick recent alluvial deposits of Quaternary age. Arsenic contaminated ground water strata lies largely in the intermediate zone depth that ranges between 15m to 50 m.

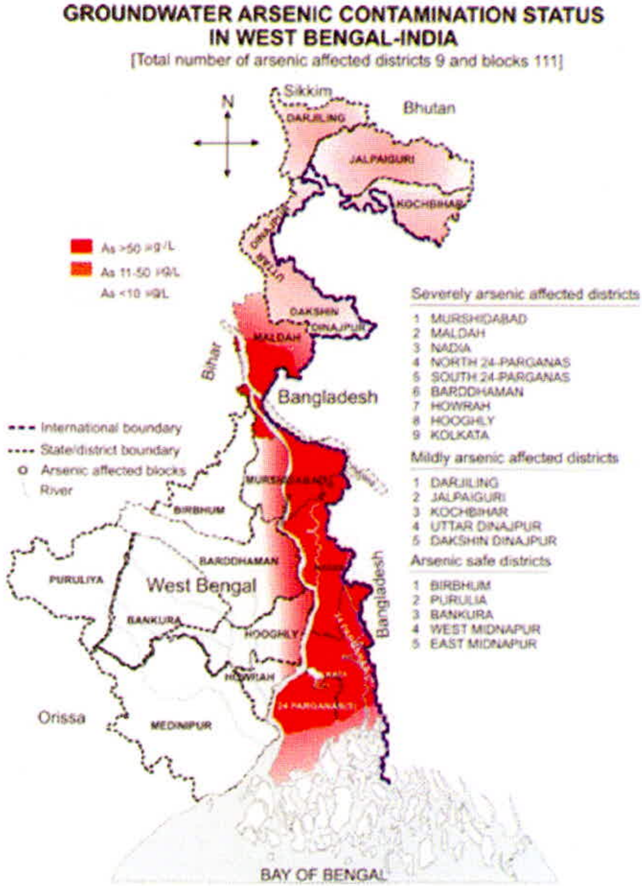


Figure 2.5 : Groundwater Arsenic Contamination status in West Bengal up to the year 2008.

2.3.3.1.1 A detailed study on groundwater arsenic contamination and its effects on health in Murshidabad, one of the nine arsenic affected districts in West Bengal.

A detailed study was conducted by SOES for 3 years in Murshidabad, one of the nine highly arsenic affected districts of West-Bengal, to know the magnitude of arsenic contamination situation and its effects on health. Murshidabad lies between the latitudes of $23^0 43' 30''$ to $24^0 50' 20''$ N and longitudes of $87^0 49' 17''$ to $88^0 44'$ E. The river Ganga forms its northern and eastern boundaries and separates it from Bangladesh. The river Bhagirathi flows across the district and divides it into two equal parts. The area and population of the district is 5324 km^2 and 58,66,569 respectively. There are 26 blocks in this district and all the 26 blocks were surveyed. A total of

29,668 hand tubewell water samples from 1833 villages/wards of 2414 villages/wards from all the 26 blocks were collected and analyzed. On the basis of the analysis, arsenic concentration in 25 blocks was found above the WHO guideline value of arsenic in drinking water (10 µg/L). **Table 2.3** shows the detailed block wise distribution of arsenic concentration. It was observed that 46.2% of the tube-wells could meet the WHO guideline value (10 µg/L) while 73.3% could meet the Indian standard (50 µg/L). Overall 4.5% of the samples exceeded 300 µg/L limit (the concentration predicting overt arsenical skin lesions). It was also observed that arsenic contamination in Jalangi block was worst where 78% of the total samples (n=1917) exceeded the WHO limit (10 µg/L) and 2% (n=38) samples were found to be contaminated above 1000 µg/L. **Figure 2.6** shows the situation of arsenic contamination in all the 26 blocks of the district.

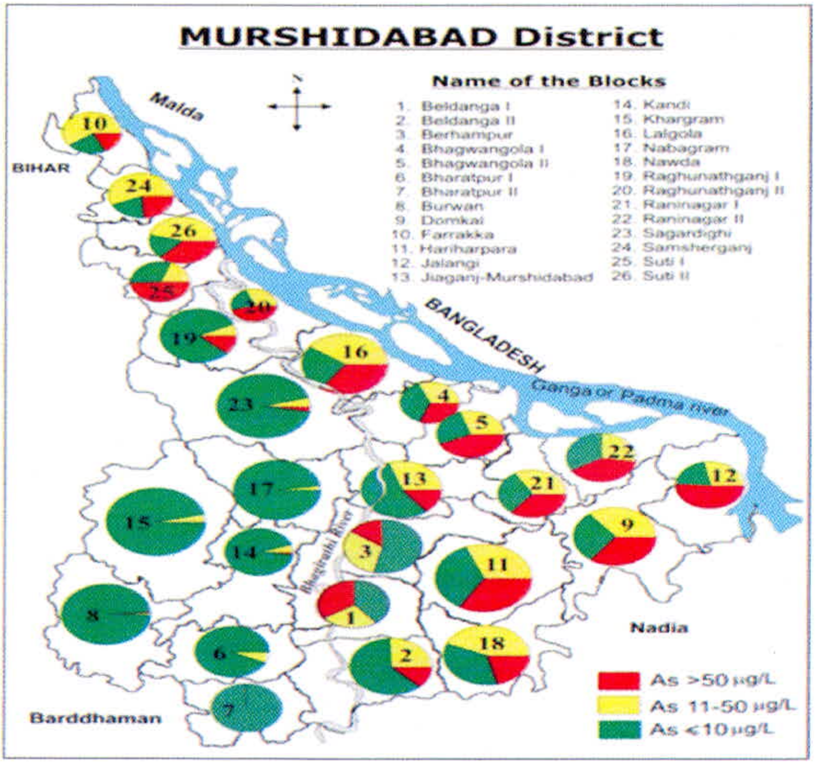


Figure 2.6: Scenario of detailed groundwater arsenic contamination study carried out in Murshidabad district in West Bengal by SOES.

When Comparison of the results obtained from water analysis **Table 2.4** with **Figure 2.6** was made, it appeared that the blocks situated in the western side of river Bhagirathi were less affected compared to the blocks situated on the eastern side. It was observed that the groundwater of Bharatpur-II block was safe, all the samples (n=625) analyzed from this block found arsenic below 3 µg/L (the determination level of our instrument with 95% confidence limit.

2.3.3.2 Bihar

In 2002, groundwater arsenic contamination first surfaced in two villages, Barisban and Semaria Ojhapatti in the Bhojpur district of Bihar in the Middle Ganga Plain. The area is located in the flood-prone belt of Sone-Ganga inter-fluve region. Investigations by Central Ground Water Board and Public Health Engineering Department, Bihar indicated contamination as high as .178 µg/L in the surrounding villages, affecting the hand pumps, which are generally at 20-40 m below ground surface. With ongoing study, more and more contaminated districts have surfaced. It was reported (CGWB, 2008) that by the year 2008, out of 38 districts, 15 districts covering 57 blocks are exposed to groundwater arsenic contamination above 50 µg/L. These districts are: i) Buxar ii) Bhojpur, iii) Patna, iv) Lakhisarai v) Saran, vi) Vaishali vii) Begusarai, Samastipur, ix) Munger, x) Khagaria, xi) Bhagalpur xii) Darbhanga, xiii) Purnea xiv) Katihar xv) Kishanganj **(Figure-2.7)**. These districts are mostly distributed along the course of the river Ganga in Bihar except three; (i) Darbhanga, (ii) Purnea and (iii) Kishanganj, which are in isolated and scattered places showing no distinct routes of connection to one-another **(Figure 2.7)**. It was also predicted that the districts lying in the area where Ganga and other tributaries, originating from the Himalaya, shifted in course of time, would be arsenic contaminated **(Figure 2.8)**. The blocks identified as arsenic affected in each district are given in **Table-2.5** (CGWB, 2008). The geological formations in the affected areas are of Quaternary deposits of multi-aquifer systems mixed with medium to fine sands having occasional coarse grained followed by medium sand, pebble and gravel, etc. **Figure 2.9** shows some arsenic patients from arsenic affected districts of Bihar.

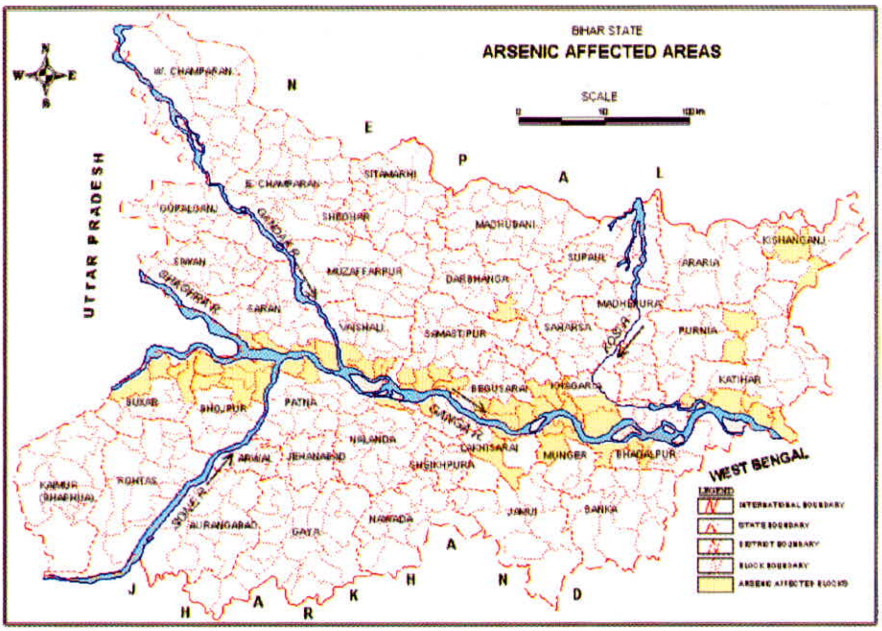


Figure 2.7 : Location of 15 Arsenic affected districts in Bihar.

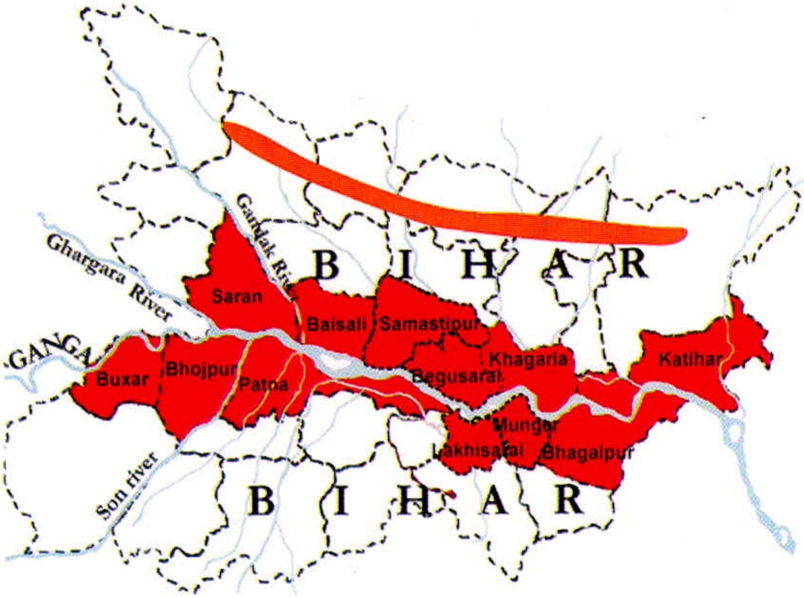


Figure 2.8: Arsenic affected districts along the Ganga river course in Bihar.

Figure 2.9: Photographs showing Some arsenic patients from arsenic affected districts of Bihar (Source : SOES)

2.3.3.3. Uttar Pradesh (UP)

Groundwater arsenic contamination in UP was first exposed in 2003 by SOES from survey of 25 villages in Ballia district. Thereafter, with continued survey two more districts, Gazipur and Varanasi were detected for arsenic groundwater contamination. As of 2008, 3 districts covering 69 villages in 7 blocks in Uttar Pradesh were found affected by arsenic groundwater contamination and people suffering from arsenical skin lesions. The used to drink water of hand pump operated tube wells. All those tube wells tap groundwater from shallow aquifer below about 20-30 m. **Figure 2.10** and **Table 2.6** show the arsenic contamination situation in UP. Ironically it was interesting to note that, all the arsenic affected districts in UP and 12 districts in Bihar are aligned along the linear track of the river Ganga, so is the position in West Bengal where it is along the river Bhagirathi. Questions are: whether are they from same genesis and are of same outcrops and sources? What are the reasons of activation along the flood plains of the river course? Etc. A thorough survey is required to understand the root causes and magnitude of arsenic contamination in UP, as well. Areas of UP adjacent to arsenic contaminated Terai region need investigations. **Figure 2.11** shows some arsenic affected patients from UP.

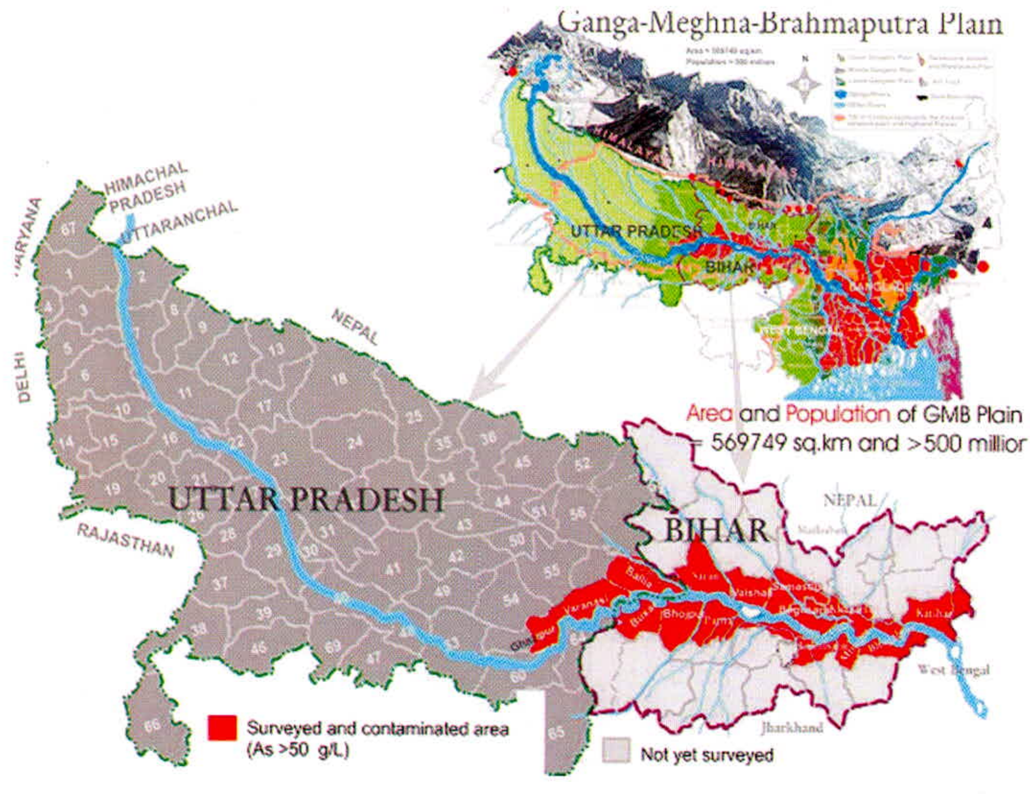


Figure 2.10 : Arsenic affected districts in UP and Bihar along the river course of the Ganga (Source: SOES).

Figure 2.11: Photograph showing some arsenic affected patients from UP (Source : SOES)

2.3.3.4. Jharkhand

During 2003-2004, groundwater arsenic contamination above 50 µg/L was first reported by SOES in the Sahibganj district of the Jharkhand, in the middle Ganga plain. Later on (2006-07), it was confirmed by CGWB through detailed investigation. Arsenic contamination is close to the Ganga River and in those areas from where the Ganga River shifted during recent past. The hand pump tube-wells of depth range 25-50 m were reported to be contaminated, and the affected areas had similar geological formations as in adjacent Bihar and West Bengal. The dug wells were reported free from arsenic contamination (CGWB, 2008). **Figure 2.12** and **Table 2.7** show the arsenic contamination situation in Jharkhand.**Figure 2.13** shows cancer patient with arsenical skin lesions from Jharkhand.

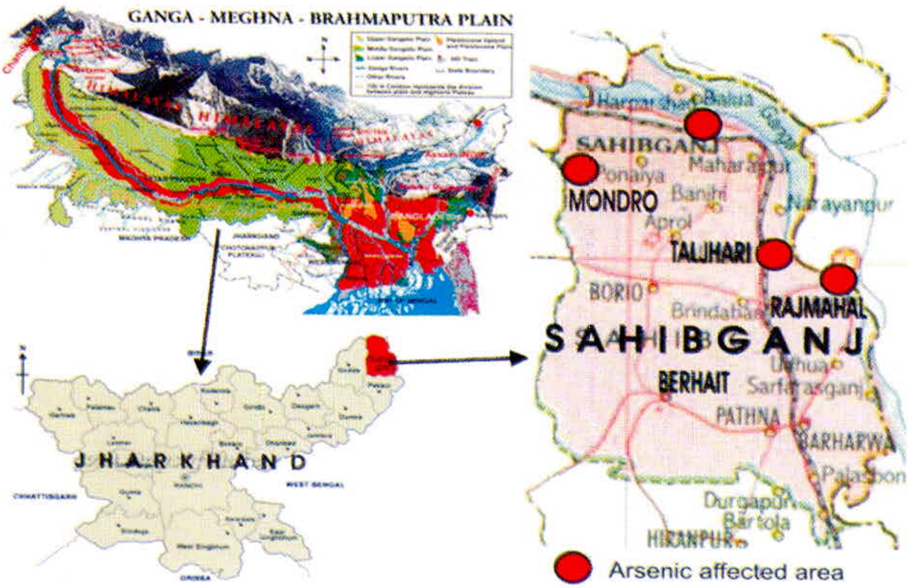
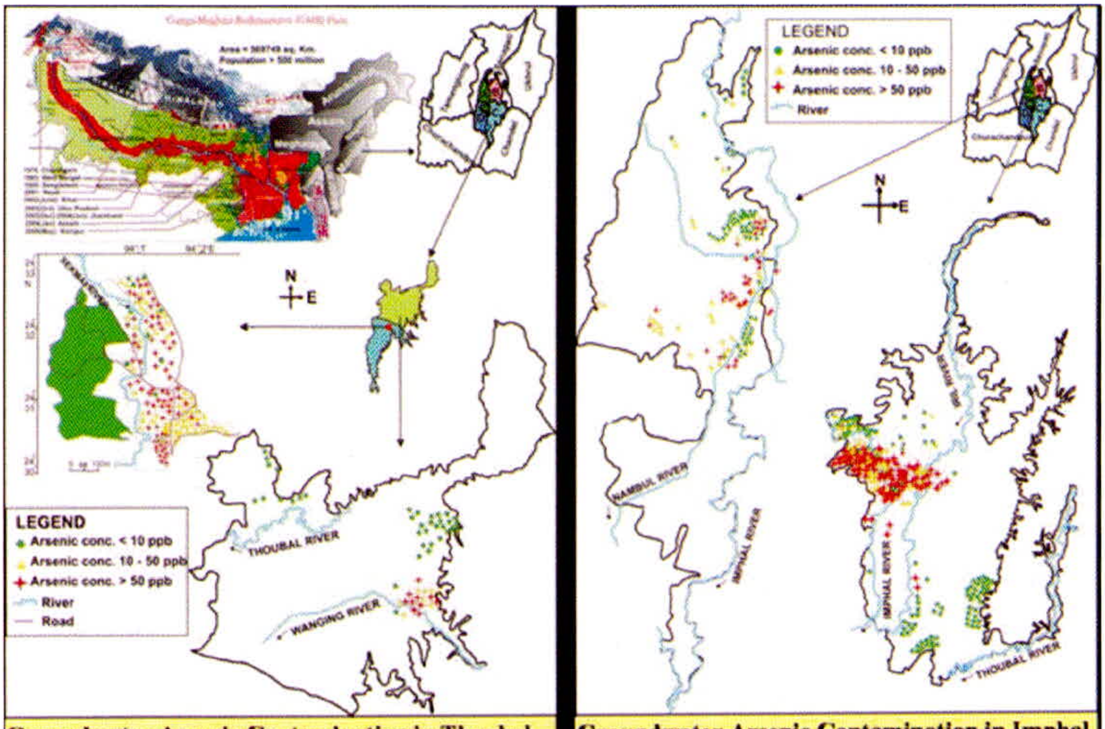


Figure 2.12 : Arsenic affected areas in Jharkhand (Source: SOES)

Figure 2.13: Photograph showing cancer patient with arsenical skin lesions from Jharkhand state (Source: SOES)

2.3.3.5. Assam & Manipur in North Eastern Hill states

There are seven states in North Eastern Hills. They are Manipur, Mizoram, Assam, Tripura, Arunachal Pradesh, Nagaland, and Meghalaya. Groundwater arsenic contamination was reported from Assam and Manipur states. A preliminary survey indicated that hand tube-well water in flood plains of these two states had some arsenic contamination above 50 µg/L and the magnitude was much less compared to Ganga-Padma- Meghna plain. Recently UNICEF reported arsenic contamination from Assam and found arsenic contamination in 18 out of 23 districts of Assam above 50 µg/L. **Table 2.8** shows the results. Recently SOES reported groundwater arsenic contamination situation from Manipur state. Mainly valley districts of Manipur are arsenic contaminated. These districts are Kakching, Imphal east, Imphal west, Bishnupur. The area of these 4 districts is 10% of total area of Manipur but about 70% of total population lives in these 4 districts. In Manipur at present people are not using hand tube-wells water for drinking, cooking and agricultural purposes. **Figure 2.14** and **Table 2.9** show the arsenic groundwater contamination situation in Manipur state. Arsenic patients have not been yet identified from states of Manipur and Assam.



Groundwater Arsenic Contamination in Thoubal district of Manipur

Groundwater Arsenic Contamination in Imphal East Imphal West districts of Manipur

Figure 2.14: Arsenic affected areas in Manipur (Source: SOES)

2.3.3.6 Chhattisgarh

Other than above flood plain areas of Ganga-Brhamaputra-Barak rivers, groundwater arsenic contamination was detected from Rajnandgaon district of Chhattisgarh state. **Table 2.10** shows the study report of SOES. A few hundred people were suffering from arsenical skin lesions from affected villages. One cancer patient (with arsenical skin lesions) and many patients with keratosis were identified **(Figure 2.15).**

Figure 2.15: Photograph showing arsenical skin lesions patients with keratosis from Chattisgarh state (source: SOES).

2.4 Effect of Arsenic Poisoning in Children

Infants and children are often considered more susceptible to the adverse effects of toxic substances than adults.

Normally children under 11 years of age do not show arsenical skin lesions although their biological samples contain high level of arsenic. However exceptions are observed when (i) arsenic content in water consumed by children is very high (≥1000 μg/l) and (ii) arsenic content in drinking water is not so high (around 500 μg/l) but the children's nutrition is poor. High arsenic content in their biological samples prove that children in the arsenic affected areas of the GMB plain have a higher body burden, though dermatological manifestations are few.

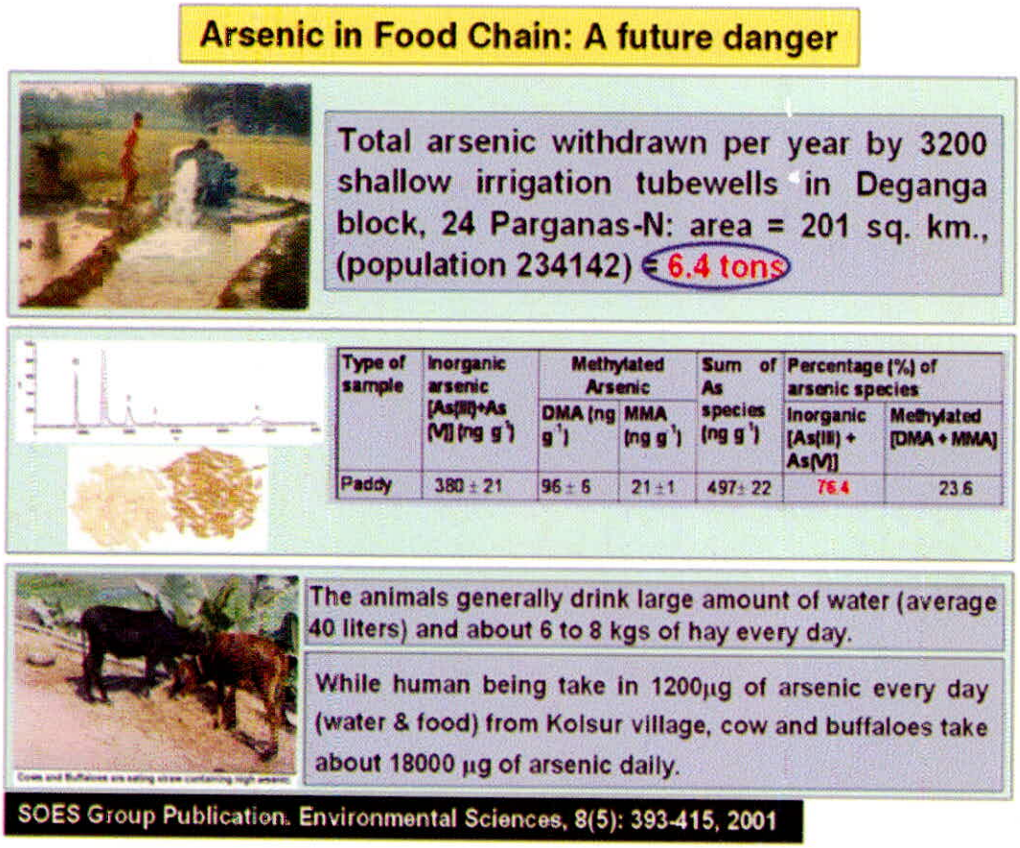
The children in the arsenic contaminated areas are often more affected than the adults. Children's body try very hard to expel the poison from their systems, but in trying to do so; their internal organs become badly damaged. That in turn retards their further growth, both physical and mental. The sufferings of children in arsenic affected areas in GMB plain had also been reported in many literatures. **Figure 2.16** shows a group of children and 60% of these children had arsenical skin lesions.

Figure 2.16 : Showing susceptible children affected by arsenical skin lesions.

2.5 Arsenic in Food Chain

In most of the developing countries including India, as such, there is no regulation imposing restriction in withdrawal of groundwater. As a result, groundwater is exploited excessively, leading to a substantial wastage of water especially that which is used for agriculture. For the summer crops, we depend totally on groundwater. In the arsenic-affected areas the water used from tube wells for irrigation is often arsenic contaminated. Many researchers reported that food is the second largest contributor to arsenic intake by people after direct ingestion of arsenic contaminated water. In food, rice is the maximum sensitive to arsenic followed by vegetables. When arsenic contaminated groundwater is used for crops irrigation, a part of this arsenic becomes incorporated into the food chain.

Many investigators consider water-soil-crop-food transfer, cooking water, and direct ingestion of arsenic contaminated water as the major exposure pathways of arsenic. Over 75% of this arsenic present in the crops is inorganic in nature (**Figure 2.17**). Arsenic gathers first of all in the roots, then in the stem and after that in the crop proper.



Type of sample	Inorganic arsenic [As(III)+As(V)] (ng g⁻¹)	Methylated Arsenic		Sum of As species (ng g⁻¹)	Percentage (%) of arsenic species	
		DMA (ng g⁻¹)	MMA (ng g⁻¹)		Inorganic [As(III) + As(V)]	Methylated [DMA + MMA]
Paddy	380 ± 21	96 ± 6	21 ± 1	497 ± 22	76.4	23.6

Figure 2.17: Effect of Arsenic in food chain.

The effects of this occurrence are far-reaching. First, as the people take in contaminated water along with contaminated food, the chances of damage become greater. Secondly, the food crops are sold off to other places, including uncontaminated regions where the inhabitants may consume arsenic from the contaminated food. Thirdly, the domestic animals, like cattle etc. in arsenic-affected areas regularly take in arsenic along with their drinking water and food, like straw. If human beings consume the meat from such infected animals, they may consume arsenic as well. A full-grown cow eats 10-12 kg straw and drinks 30-40 litres of water per day. From this example, it is possible to calculate how much arsenic cattle consume every day. Almost all of Southeast Asia uses rice as its staple food. Due to irrigation with contaminated water, rice grains could have excessive amounts of arsenic. According to a leading scientist, this contamination of rice with arsenic may give rise to a new danger in the South -East Asia.

2.6 Socio-economic Effects of Arsenic Contamination

A good portion of 500 million people, living in the 5 69749 sq km of the Ganga-Meghna-Brahmaputra belt, live in danger of drinking arsenic contaminated water. Around 30 % of this populace is constituted of illiterate inhabitants who live below the poverty line. Affected populace are those who are economically backward and lack in nutritious food. Women are affected the most compared to men. Further, infants and children are adversely affected than the adults. An arsenic patient loses his strength and cannot work outdoors, but his family incurs more expenses than before because of his illness. Many of them borrow money from the local moneylender who charges them a high rate of interest, i.e. 5-10% monthly compound interest. Often villagers lose all their earthly possessions including the roof over their heads, trying to pay the moneylender back. Society too, turns an arsenic patient into an outcast. The arsenic problem, thus, has a major effect on the socioeconomic structure. People often mistake symptoms of arsenic poisoning for leprosy or other contagious skin diseases, and thus marriage, employment, and even the simplest social interaction become impossible for the victim. Thus, an arsenic patient often becomes depressed and sometimes even tries to commit suicide.

2.7 Summary

Up till 2008, 9 districts covering 3417 villages in 111 blocks in West Bengal, 15 districts covering 57 blocks in Bihar, 3 districts covering 69 villages in 7 blocks in Uttar Pradesh, 1 district covering 68 villages in 3 blocks in Jharkhand, 3 districts covering 9 blocks in Assam, 4 districts in Manipur, and 1 district covering 4 villages in 1 block in Chhattisgarh have been detected for groundwater arsenic contamination above permissible limit of 50 μg/L. Many more North-Eastern Hill States in the flood plains are suspected to have the possibility of arsenic in groundwater Even, after twenty-five years since 1983, with every new survey, new arsenic affected villages and people suffering from arsenic related diseases are being reported. Almost all the identified arsenic affected areas in the Gangetic plains except areas in Chhattisgarh and 3 districts in Bihar namely, Darbhanga, Purnea and Kishanganj, are in a linear tract on either side of the River Ganga in UP, Bihar, and Jharkhand, and the River Bhaghirathi in West Bengal; while the areas in Assam and Manipur are in the flood plains of the Brahmaputra and Barack, respectively. All the arsenic affected river plains have the river routes originated from the Himalayan region.

Arsenic groundwater contamination has far-reaching consequences including its ingestion through food chain, which are in the form of social disorders, health hazards and socioeconomic dissolution besides its sprawling with movement, and exploitation of groundwater.

Thus the Questions arise and whose answers are to be amalgamated to find logical solutions are:

(i) What are the sources, genesis, causes and mechanisms of groundwater arsenic con tamination?

(ii) How the problem has been triggered in many hydrogeological conditions along a fluvial track and in different scattered places in the Ganga and Brahmaputra plains and deltas?

(iii) What technological, scientific understanding and knowledgebase are required to combat such a large scale groundwater related disasters/menace?

(iv) How could people, livestock and groundwater dependant usages be safeguarded from hazards of arsenic contamination?

(v) What short-term and long-term planning and management of water resources are rquired for ensuring supply of arsenic-free water both for drinking and irrigation requirement in those affected and vulnerable areas?,

(vi) What remediation/corrective measures are necessary to restore the affected aquifers? These are some of key issues that need to be addressed. Proper watershed management coupled with deep aquifer tapping, sustaining efforts to evolve and provide cost effective and eco-friendly arsenic treatment techniques for supply of drinking water along with the water education of the villagers and their active participation appear to be potential solutions to resolving the present arsenic crisis, till a sustainable groundwater arsenic mitigation strategy is scientifically perfected.

Table 2.1: Groundwater arsenic contamination in states of India (according to latest survey report up to January, 2006 by SOES)

Parameters	West Bengal	Bihar	UP	Jharkhand (Sahibganj district)	Assam	Manipur	Chattisgarh (Rajnandangaon District)
Area (sq km)	88,750	94,163	2,38,000	1600	78438	22327	6396
Population (in million)	80.2	83	166	1	26.6	2.29	1.5
Arsenic affected area in sq. km.	38,861	21271	10375	725	8822	2238	6396
Total arsenic affected districts (As >50 µg/L)	12	12*	3	1	3	4	1
Total arsenic affected blocks/PS (As > 50 µg/L)	111	36*	7	3	9	-	1
No. of villages where groundwater arsenic >50 µg/L	3417	235*	69	68	-	-	4
Total hand tubewell water samples analyzed	1,40,150	19961	4,780	3354	679	628	146
% of samples having arsenic > 10 µg/L	48.1	32.70	45.48	36.1	36.82	63..3	25..34
% of samples having arsenic > 50 µg/L	23.8	17.75	26.51	15.4	15.02	23..2	8.22
Total number of biological samples analyzed (Hair, Nail, Urine)	39,624	1833	258	367	-	57 (urine)	242
People registered with arsenical skin lesions	9,356	457	154	71	-	-	68

* *According to CGWB assessment in 2008: In Bihar No. of affected district = 25, No. of affected blocks = 57 having population about 10 million.*

Table 2.2: Summary of groundwater arsenic contamination status in West Bengal, India (Chakraborti et al 2008a)

Parameters	West Bengal
Area in sq. km.	88,750
Population in million	80.2
Total number of districts (no. of district surveyed)	19 (19)
Total number of water samples analyzed	1,40,150
% of samples having arsenic > 10 $\mu g\ L^{-1}$	48.1
% of samples having arsenic > 50 $\mu g\ L^{-1}$	23.8
Maximum arsenic concentration so far we analyzed ($\mu g/L$)	3700
No. of severely arsenic affected districts *	9
No. of mildly arsenic affected districts*	5
No. of arsenic safe districts*	5
Total population of severely arsenic affected 9 districts in million	50.4
Total area of severely arsenic affected 9 districts in sq. km.	38,861
Total number of blocks/ police station	341
Total number of blocks/ police station surveyed	241
Number of blocks / police station having arsenic >50μgL^{-1}	111
Number of blocks / police station having arsenic >10μgL^{-1}	148
Total number of village	37910
Total number of village surveyed	7823
Number of villages/paras having arsenic above 50 μgL^{-1}	3417
People drinking arsenic contaminated water >10 μgL^{-1} (in million)	9.5
People drinking arsenic contaminated water >50 μgL^{-1} (in million)	4.6
Population potentially at risk from arsenic contamination > 10 $\mu g\ L^{-1}$ (in million)	26
No. of districts surveyed for arsenic patients	9
No. of districts where arsenic patients found	7
Villages surveyed for arsenic patients	602
Number of villages where we have identified people with arsenical skin lesions	488

Table 2.3: Block wise distribution of arsenic concentration in West Bengal (Chakraborti et. al. 2008b)

Districts	Area in km^2	Population	Total no. of blocks	No. of blocks surveyed	No. of blocks with As >10 µg/L	No. of blocks with As >50 µg/L	No. of samples analyzed	Distribution of total samples in different arsenic concentration (µg/L) ranges: ≤3	4-10	11-50	51-100	101-200	201-300	301-500	501-1000	> 1000	Max. As. conc. (µg/L)
Highly affected																	
North-24-PGS	4094	8934286	22	22	22	21	54368	22221	3129	13001	6403	5531	2249	1308	477	49	2830
South-24-PGS	9960	6906689	29	17	12	11	8333	4407	427	1141	743	741	327	305	212	30	3700
Murshidabad	5324	5866569	26	26	25	24	29668	11471	2244	8042	3267	2366	941	884	382	71	3003
Nadia	3927	4604827	17	17	17	17	28794	11431	2613	9810	2265	1520	630	360	152	13	3200
Maldah	3733	3290468	15	14	13	9	4449	1754	373	810	488	559	183	163	97	22	1904
Haora	1467	4273099	14	12	12	7	1471	889	226	192	87	41	22	12	1	1	1333
Hugli	3147	5041976	18	17	16	11	2212	1469	346	251	77	52	14	2	1		600
Kolkata	185	4572876[a]	141[b]	100[b]	65[b]	30[b]	3626	2224	855	345	85	75	27	10	5		800
Bardhaman	7024	6895514	31	24	12	7	2634	2091	79	244	86	89	27	11	6	1	2230
Sub Total	38861	**50386304**	172	149	129	107	135555	57957	10292	33836	13501	10974	4420	3055	1333	187	
Mildly affected																	
Koch Bihar	3387	2479155	12	5	4	1	474	403	57	13	1						54
Darjiling	3149	1609172	12	4	3	0	562	502	50	10							19
Dinajpur (N)	3140	2441794	9	7	6	2	990	817	57	112	4						68
Dinajpur (S)	2219	1503178	8	6	2	1	452	398	47	6	1						51
Jalpaiguri	6227	3401173	13	7	4	0	445	355	74	16							27
Sub Total	18122	**11434472**	54	29	19	4	2923	2475	285	157	6						
Unaffected																	
Bankura	6882	3192695	22	17	0	0	279	279									<3
Birbhum	4545	3015422	19	11	0	0	718	718									<3
Purulia	6259	2536516	20	15	0	0	314	314									<3
Medinipur (E)[c]	14081	9610788	25	10	0	0	182	182									<3
Medinipur (W)			29	10	0	0	179	179									<3
Sub Total	31767	**18355421**	115	63	0	0	1672	1672									
Grand Total	88750	**80176197**	341	241	148	111	140150	62104	10577	33993	13507	10974	4420	3055	1333	187	

Table 2.4 : Block wise distribution of hand tubewells against arsenic concentration ranges (g/L) in Murshidabad district of West-Bengal, India.

Block	Total samples analysed	Distribution of total samples in different arsenic concentration (µg/L) ranges =3	4 -10	11-50	51-100	101-200	201-300	301-500	501-1000	%of Samples with As >10µg/L	% of Samples with As >50µg/L	Max. conc. µg/L (samples with As . >1000µg/L
Beharampur	1821	797	180	560	180	79	15	7	3	46.3	15.6	635
Beldanga I	1396	459	86	368	194	126	52	64	45	61.1	34.7	1700(2)
Beldanga II	1037	529	130	248	78	39	12	1		36.5	12.5	345
Bhagowangola I	1775	592	96	544	170	256	72	33	10	61.2	30.6	1285(2)
Bhagowangola II	819	137	96	234	134	83	51	57	23	71.6	43.0	1852(4)
Bharatpur I	616	533	47	34	2	-	-	-	-	5.8	0.3	82
Bharatpur II	625	625	-	-	-	-	-	-	-	-	0	<3
Burwan	702	684	10	6	2	-	-	-	-	1.1	0.3	64
Domkal	3371	729	295	1166	429	392	161	139	58	69.6	35.0	1300(2)
Farrakka	489	84	33	285	81	6	-	-	-	76.1	17.8	150
Hariharpara	1520	436	123	453	182	117	88	93	27	63.2	33.4	1160(1)
Jalangi	1917	317	109	516	288	233	129	178	109	77.8	50.9	2040(38)
Jiaganj	1235	492	205	360	123	49	6	-	-	43.6	14.4	286
Kandi	932	832	64	28	7	1	-	-	-	3.9	0.9	140
Khargram	715	670	22	20	3	-	-	-	-	3.2	0.4	75
Lalgola	1030	180	98	397	174	138	16	14	12	73.0	34.5	1028(1)
Nabagram	705	656	41	8	-	-	-	-	-	1.1	0	40
Nawda	1208	420	17	516	141	63	18	20	12	63.8	21.1	3003(1)
Raghunathganj I	515	394	21	34	36	9	9	6	1	19.4	12.8	3003(5)
Raghunathganj II	1233	266	40	371	355	146	26	23	6	75.2	45.1	875
Raninagar I	778	132	116	253	122	123	24	6	1	68.1	35.6	1018(1)
Raninagar II	2219	489	261	610	189	253	165	191	54	66.2	38.7	1652(7)
Sagardighi	707	637	28	25	15	1	-	-	1	5.9	2.4	560
Samsherganj	878	120	69	480	111	77	21	-	-	78.5	23.8	287
Suti I	443	130	9	85	104	67	30	17	1	68.6	49.4	700
Suti II	982	131	48	441	147	108	46	35	19	81.8	36.9	1852(7)
Total	29668	11471	2244	8042	3267	2366	941	884	382	53.8	26.7	3003(71)

Table 2.5: Arsenic affected blocks in 15 districts in Bihar (Source: CGWB, 2008)

Sl. No	District	Block	Population of affected Block
1	**Patna**	1.Maner	201345
		2.Danapur	325457
		3.Bakhtiarpur	172531
		4.Barh	162381
2	**Bhojpur**	1.Barhara	194439
		2.Shahpur	185911
		3.Bihea	139374
		4.Koilwar	169564
		5.Udwant Nagar	132258
		6.Arrah	369644
3	**Begusarai**	1.Matihani	127090
		2.Begusarai	418614
		3.Barauni	228026
		4.Balia	148155
		5.Sabehpur Kamal	155057
		6.Bachwara	153699
4	**Khagaria**	1.Khagaria	295480
		2.Mansi	74297
		3.Gogri	243303
		4.Parbatta	192212
5	**Samastipur**	1.Mohiuddin Nagar	142472
		2.Mohanpur	88930
		3.Patori	143832
		4.Vidyapati Nagar	122240
6	**Bhagalpur**	1.Jagdishpur	471457
		2.Sultanganj	200123
		3.Nathnagar	122120
7	**Saran**	1.Sonepur	220271
		2.Dighwara	107912
		3.Chapra Sadar	363036
		4.Revelganj	99010
8	**Munger**	1.Jamalpur	181751
		2.Dharhara	104037
		3.Bariarpur	92406
		4.Munger	297741
9	**Katihar**	1.Mansahi	62581
		2.Kursela	52997
		3.Sameli	67261
		4.Barari	220955
		5.Manihari	149250
		6.Amdabad	132107
10	**Buxar**	1.Brahmpur	163855
		2.Semary	181003
		3.Chakki	34133
		4.Buxar	229521
11	**Vaishali**	1.Raghopur	187722
		2.Hajipur	349694
		3.Bidupur	207421

		4.Desri	77741
		5.Sahdei Bujurg	99459
12	**Darbhanga**	1.Biraul	233029
13	**Kishanganj**	1.Kishenganj	185535
		2.Bahadurganj	205888
14	**Purnea**	1.Purnea East	349118
		2.Kasba	143784
15	**Lakhisarai**	1.Lakhisarai	261620
		2.Pipariya	31020
Total Population			**10,471869**

Table 2.6: Summary of groundwater arsenic contamination status in Uttar Pradesh, India (Chakraborti et. al. 2008a)

Physical parameters	Uttar Pradesh
Area in sq. km.	238000
Population in million	166
No. of districts surveyed so far	3 (Ballia, Gazipur & Varanasi)
Arsenic affected area in sq. km.	10375
Total population in arsenic affected 3 districts (in million)	6
Number of arsenic affected districts where groundwater arsenic >50μg/L	3
No. of blocks surveyed so far	10
Number of arsenic affected blocks where groundwater arsenic >10 μg/L	9
Number of arsenic affected blocks where ground water arsenic >50 μg/L	7
Total number of hand tube-well water samples analyzed	4780
Number of arsenic affected blocks where groundwater arsenic >10 μg/L	45.48
Number of arsenic affected blocks where ground water arsenic >50 μg/L	26.51
% of hand tube-wells having arsenic concentration >300 μg/L	10
Maximum arsenic concentration so far we analyzed (μg/L)	3192
Number of arsenic affected villages with ground water arsenic >50μg/L	69
Number of arsenic affected villages with ground water arsenic >10μg/L	100
Population potentially at risk from arsenic contamination > 10 μg L^{-1} (in million)	3

Table 2.7: Summary of the arsenic contamination scenario in Jharkhand (Chakraborti et. al. 2008a)

Physical parameters	Sahibganj district
Area in sq. km	1600
Population in million (according to 2001 Census)	1
Arsenic affected area in sq. km.	725
Total number of water samples analyzed	3354
% of samples having arsenic > 10 μg/L	36.1
% of samples having arsenic > 50 μg/L	15.4
% of samples having arsenic > 300 μg/L	2.61
Maximum arsenic concentration analyzed (μg/L)	1018
No. of block surveyed	9
Number of village surveyed	115
Number of arsenic affected villages where groundwater arsenic above 50 μg/L	68
Number of arsenic affected villages where groundwater arsenic above 10 μg/L	91
Population potentially at risk from arsenic contamination > 10 μg L^{-1} (in million)	0.4

Table 2.8: Summary data on arsenic in groundwater in Assam (Nickson et. al. 2007).

District	No. blocks affected	Total sources tested	Sources 10-50 μgL^{-1}	Sources > 50 μgL^{-1}	% Sources > 50 μgL^{-1}	District population	Projected population at risk
Barpeta	5	130	21	7	5.4	1,647,201	-
Bongaigaon	3	100	15	6	6.0	904,835	-
Cachar	7	210	68	59	28.1	1,444,921	-
Darrang	4	254	92	9	3.5	1,504,320	-
Dhemaji	5	539	128	83	15.4	571,944	-
Dhubri	6	435	130	21	4.8	1,637,344	-
Goalpara	2	145	11	3	2.1	822,035	-
Golaghat	5	268	67	30	11.2	946,279	-
Hailakandi	4	159	45	11	6.9	542,872	-
Jorhat	6	224	96	24	23.1	999,221	-
Kamrup	1	261	39	1	0.4	2,522,324	-
Karimganj	6	811	150	61	7.5	1,007,976	-
Lakhimpur	5	218	50	9	4.1	889,010	-
Marigaon	1	271	40	2	0.7	776,256	-
Nagaon	1	314	55	1	0.3	2,314,629	-
Nalbari	5	148	25	14	9.5	1,148,824	-
Sibsagar	3	206	72	15	7.3	1,051,736	-
Sonitpur	3	227	34	6	2.6	1,681,513	-
TOTAL	72	4920	1138	362	7.4	22,413,240	-

Table 2.9: Summary of present groundwater arsenic contamination status in Manipur (Chakraborti et. al., 2008c)

Parameters	Manipur
Area in sq. km.	22327
Population in million	2.29
Total number of districts (no. of district surveyed)	9 (4)
Arsenic affected area in sq. km.	2238
Total population of arsenic affected 4 districts in million	1.35
Total number of water samples analyzed	628
% of samples having arsenic > 10 $\mu g\ L^{-1}$	63.3
% of samples having arsenic > 50 $\mu g\ L^{-1}$	23.2
Maximum arsenic concentration analyzed (μg/L)	502
Total number of village surveyed	88

Table 2.10: Summary of groundwater arsenic contamination status in Rajnandangaon district Chhattisgarh state, India (Chakraborti et. al. 1999)

Parameters	Rajnandangaon
Area in sq. km.	6396
Population in million	1.5
Total number of water samples analyzed	146
% of samples having arsenic > 10 $\mu g\ L^{-1}$	25.34
% of samples having arsenic > 50 $\mu g\ L^{-1}$	8.22
Maximum arsenic concentration so far we analyzed (μg/L)	880
Total number of blocks/ police station surveyed	1
Total number of village surveyed	22
Number of villages having arsenic above 10 $\mu g L^{-1}$	8