ARSENIC AND FLUORIDE IN DRINKING WATER IN WEST BENGAL: CHARACTERISTICS, IMPLICATIONS, AND MITIGATION

I. INTRODUCTION

1. The Government of West Bengal, through the Government of India, sought support from the Asian Development Bank (ADB) to achieve its Vision 2020 to provide safe, reliable and sustainable drinking water for selected districts in West Bengal.[1] The proposed West Bengal Drinking Water Sector Improvement Project will provide safe and reliable drinking water as per the standards set by the Government of India to about 1.65 million people in the arsenic-, fluoride- and salinity-affected selected areas of Bankura, North 24 Parganas and Purba Medinipur districts of West Bengal (project districts).[2] The project will also introduce an innovative and sustainable institutional framework and advanced technology for smart water management to enable inclusive, resilient, and sustainable service delivery of drinking water in project districts.

2. Vision 2020 implementation in West Bengal encompasses the provision of a permanent supply of drinking water to rural areas at 70 liters per capita per day, which encourages piped water-supply schemes with provision for household connections and aims to phase out water supply from hand-pumped tube wells to surface water based sustainable sources. As of 1 April 2015, 48% of the rural West Bengal population had access to safe drinking water from piped supply schemes.

3. West Bengal is the fourth largest state by population and 13th largest state by land mass among the 36 states of India, with a land area of 88,752 square kilometers (sq. km) (2.8%). Its population density is also the highest in India at 1,029 people per sq. km (Census, 2011). The total rural population of West Bengal is 91,300,000 (Census, 2011), spread over 3,354 *Gram Panchayats*[3] in 23 districts of the state.

4. This report was prepared by the British Geological Survey of the United Kingdom and national hydrogeologists, engaged by the ADB during the project preparatory stage, who conducted a detailed analysis of arsenic and fluoride in drinking water in West Bengal including their characteristics, implications, and mitigation, as well as lessons learned from elsewhere. It. provides background data and information on occurrence, distribution, and implications of arsenic and fluoride problems in groundwater on scales varying from global to local, to assist the Government of West Bengal in preparing a state-level action plan on water quality improvement for West Bengal and in designing the project. This information provides context for the scale of problems encountered using available information from the three project districts: Bankura, North 24 Parganas and Purba Medinipur. North 24 Parganas is one of the state's most arsenic-affected districts, and Bankura is one of the state's most fluoride-affected districts. Purba Medinipur is affected by salinity (not covered under this report). Murshidabad district is also covered under the report, as it is the second most arsenic-affected district in West Bengal after North 24 Parganas.

5. The report also outlines some experiences of other regions in tackling problems with arsenic and fluoride and the cost-effectiveness of several mitigation innovations.

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[1] Government of West Bengal. 2011. Public Health Engineering Department. 2011. Vision Plan – 2020, Kolkata. Available at http://www.wbphed.gov.in/main/index.php/vision-2020.

[2] The design and monitoring framework for the project is in Appendix 1. A neighbouring block in South 24 Parganas is also included in the North 24 Parganas water supply scheme under the project.

[3] *Gram panchayats* are the village-level or the first tier of the local administrative body of the Government of West Bengal. Population covered under the 66 project *Gram Panchayats* is around 16,000–26,000.

II. GLOBAL OCCURRENCE OF ARSENIC AND FLUORIDE IN GROUNDWATER

6. Together, arsenic and fluoride pose by far the greatest inorganic threat to health from the world's drinking-water resources. More than 200 million people worldwide are estimated to be chronically at risk from drinking water with arsenic concentrations above the 10 micrograms per liter (µg/L) WHO guideline value (Naujokas et al., 2013), while a further 200 million or more are considered at risk from fluoride concentrations above the 1.5 mg/L WHO guideline value (Edmunds and Smedley, 2013). The hazard is from groundwater, and the origin is overwhelmingly from natural sources.

7. Arsenic is highly toxic and long-term use of drinking water with high concentrations can lead to a wide range of health problems in humans. Arsenic is carcinogenic, mutagenic, and teratogenic.[4] Symptoms of chronic arsenicosis include skin lesions such as melanosis and keratosis, and skin cancer. Bladder and lung cancers and other symptoms including cardiovascular disease, respiratory problems, and diabetes have also been linked to arsenic exposure. There is no evidence of a beneficial role for arsenic in human metabolism, and it is unclear whether any dose is safe for humans.

8. Arsenic problems have been identified in numerous countries across the world, but extensive groundwater arsenic provinces are documented in Argentina, Bangladesh, Cambodia, Chile, the People's Republic of China, Hungary, India, Mexico, Nepal, Pakistan, Romania, the United States of America, and Viet Nam (Smedley and Kinniburgh, 2002). By far the greatest exposure, however, is in populations from the alluvial and deltaic plains of South and Southeast Asia which host both dense populations, supported by abundant water and fertile soils, and aquifers with high arsenic concentrations.

9. The most prevalent health problems related to chronic exposure to fluoride from drinking water are dental or skeletal fluorosis, the severity of the disease corresponding largely with the dose. Dental fluorosis ('mottled enamel') is a condition where fluoride interacts with tooth enamel causing discoloration and possible weakening or loss of teeth. At extreme exposures to fluoride (of the order of 8 mg/L and higher), crippling skeletal fluorosis is a painful and debilitating condition. Children are particularly at risk as the fluoride affects the development of growing teeth and bones. Once developed, the symptoms of fluorosis are irreversible. While not life-threatening, fluorosis has severe consequences for social inclusion, quality of life, health, and livelihoods.

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[4] Carcinogenic means having the potential to cause cancer; mutagenic is an agent that increases the occurrence of mutations in genetic material; teratogenic is a substance that can disturb the development of the embryo or fetus.

10. Many high-fluoride groundwater provinces have been recognized worldwide, typically in arid and semi-arid regions. Prevalent regions have been documented in Argentina, the People's Republic of China, India, Mexico, Pakistan, Sri Lanka, Western United States of America, and numerous countries in Africa. Occurrences are typically associated with large sedimentary basins, granites, and volcanic and geothermal terrains

III. OCCURRENCE IN INDIA

A. Aquifer Characterisation

11. India is the largest user of groundwater in the world. Annual usage is estimated at around 230 cubic kilometers (World Bank, 2010), which supports around 85% of rural water supply schemes, a varying but often large percentage of urban schemes, and more than 60% of irrigated agriculture. Reliance on groundwater increased significantly over the last 5 decades, largely to combat water-borne diseases arising from the use of surface water for drinking. In that, the borehole expansion programme has been hugely successful and, for most, the microbial quality of groundwater has been a significant advance on previous traditional supplies. However, in some groundwater sources, the occurrence of arsenic or fluoride in high concentrations poses a replacement threat to health and livelihoods.

12. India's groundwater falls into two main categories: shallow, low-storage crystalline basement aquifers (basalt, granite, gneiss), which constitute around 65% of the aquifer areal extent, mainly in peninsular India; and high-storage alluvial-deltaic aquifers of the Indo-Gangetic Plain (World Bank, 2010). The availability of groundwater in the basement aquifers is much lower than that in alluvial sediments but is highly dependent on weathering and fractures, which can be spatially variable.

13. The distribution of arsenic and fluoride in the groundwater in India tend to be defined by the hydrogeological provinces, with arsenic found principally in association with young alluvial-deltaic aquifers and fluoride principally from granite-gneiss basement aquifers. Exceptions occur in more localized areas of metalliferous mineralization within the basement, where weathering of arsenic-enriched sulfide minerals can release arsenic into groundwater and the environment.

IV. ARSENIC IN INDIAN GROUNDWATER

A. National Distributions in Groundwater

14. According to BIS 10500:2012,[5] specifications for drinking-water standards (revised in 2015), the permissible limit for arsenic in water used for human consumption is 10 µg/L, superseding an earlier limit of 50 µg/L. Statistics reported for arsenic exceedances and exposure in Indian groundwater are, therefore, often mixed, with a large proportion of older reports citing the higher value. Statistics for exceedances also vary substantially with the amount of testing and implementation of mitigation. As such, it is difficult to assess exposure estimates accurately at a given time or scale, especially using different databases.

15. The Ministry of Drinking Water and Sanitation estimates that, as of August 2016, 14,180 habitations in India are arsenic-affected (10 µg/L), impacting some 12.9 million people across 11 states (Integrated Management Information System, Ministry of Drinking Water & Sanitation)

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[5] Bureau of Indian Standards (BIS). 2012. *Drinking Water Specification (Second Revision)*. New Delhi. Available from http://cgwb.gov.in/Documents/WQ-standards.pdf.

Table 1).[6] Most of the affected states are in the Ganga–Brahmaputra alluvial plains with Assam, Bihar, and West Bengal hosting around 92% of the affected population. West Bengal has 69% of the affected population (8,066 habitations) (Table 2). Concentrations up to 1 mg/L are found there. Arsenic problems were first recognized in the Ganga–Brahmaputra plains in the early 1980s. The estimated number of tube wells in 8 of the highly affected districts in West Bengal is 1.3 million, and estimated population drinking arsenic contaminated water above 10 and 50 µg/L were 9.5 and 4.2 million, respectively (Chakraborti et al., 2009). Since 1988, 14,0150 water samples were analysed from tube wells in all 19 districts of West Bengal for arsenic, out of which 48.1% had arsenic above 10 µg/L, 23.8% above 50 µg/L, and 3.3% above 300 µg/L (concentration predicting overt arsenical skin lesions) (Chakraborti et al., 2009).

Table 1. Most Arsenic-Affected Habitations and Populations in India

State	No. habitations	Population	Habitations affected	Population in affected habitations	% of affected population
Assam	88,099	29,658,323	3,726	1,236,964	9.6
Bihar	110,234	99,454,050	1,077	1,666,039	12.9
Haryana	7,948	18,407,573	45	142,944	1.1
Jharkhand	120,067	26,899,888	130	115,862	0.9
Karnataka	60,248	40,277,798	21	47,141	0.4
Kerala	11,883	26,874,598	3	7,651	0.1
Maharashtra	100,066	64,445,038	1	87	0.0
Meghalaya	10,475	2,667,743	1	169	0.0
Odisha	156,468	35,652,623	2	42	0.0
Punjab	15,384	17,989,668	492	590,103	4.6
Rajasthan	121,648	50,806,731	3	0	0.0
Tripura	8,723	4,491,866	1	1,118	0.0
Uttar Pradesh	260,801	168,768,908	262	159,572	1.2
West Bengal	105,905	74,637,222	8,066	8,950,460	69.1

Source: Government of India, Ministry of Drinking Water and Sanitation. Integrated Management Information System (IMIS). Data valid as of 6 August 2017.

16. Since the late seventies, with more testing programs available and conducted in India both by the government of India and the states, more states and districts have been identified as having groundwater arsenic problems, such as the observations in some 20 districts in Uttar Pradesh and pockets in Jharkhand (see Table 1). All these are associated with the Ganga floodplain. Observed exceedances in the north-eastern states include Assam, associated with the Brahmaputra–Barrack floodplain, and Manipur, associated with the Imphal alluvial system. Occurrences have also been reported in Punjab, associated with the Ravi–Beas Rivers, and in Haryana with the Yamuna river plain (IMG, 2015).

17. Documented drinking-water arsenic problems related to metalliferous mineralization in basement areas are less common in India but have been identified in the Rajnandgaon District in Chattisgarh. Concentrations in groundwater from the worst-affected village, Koudikasa (Chowki block) have been observed between less than 10 µg/L and 880 µg/L, with 8% being more than 50 µg/L (Chakraborti et al., 1999). Several villagers in Koudikasa display arsenic-related skin

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[6] Government of India. 2017. Ministry of Drinking Water and Sanitation. Integrated Management Information System (IMIS). http://indiawater.gov.in/imisreports/nrdwpmain.aspx/.

disorders. Epidemiological studies indicated that 42% of adults and 9% of children are suffering from arsenical skin lesions, and a high concentration of arsenic has been observed in urine (89%), hair (75%), and nails (91%), among the village (Koudikasa) population (Chakraborti et al., 1999). Since 2008, observations have identified arsenic exceedances in groundwater from Karnataka, also associated with basement aquifers (IMG, 2015). The recognized occurrences bring the number of identified arsenic-affected states (>10 µg/L) to 11, though the magnitude of exceedance vary widely between them.

18. Precise figures for the populations exposed may be hampered by uncertainties in factors such as the total number of wells and users of each, history of mitigation measures, water consumption patterns, uncertainties in the adoption of practices such as well switching, and potential temporal variation in groundwater arsenic concentration.

V. DISTRIBUTIONS IN WEST BENGAL

19. Table 2 indicates a total of 8,066 habitations with 10.9 million people impacted by arsenic in West Bengal. Worst-affected districts are Malda, Murshidabad, Nadia, and North 24 Parganas. These all lie to the east of the Ganga (Hooghly) River. Numbers of affected blocks in each district are given in Table 3.

Table 2. Habitations in Arsenic-Affected Districts of West Bengal

District	No. habitations	Population	Affected habitation	Affected population	% of district population affected
Bankura	6,638	3,403,362	1	3,115	0.1
Bardhaman	5,386	5,271,056	142	291,224	5.5
Hooghly	11,762	3,975,186	178	98,050	2.5
Howrah	2,130	3,116,331	1	2,876	0.1
Maldah	7,787	5,717,269	836	1,156,620	20.2
Murshidabad	3,105	6,790,427	1,439	3,895,605	57.4
Nadia	3,944	4,248,441	2,448	3,030,716	71.3
North 24 Parganas	7,334	5,184,365	2,699	2,196,158	42.4
South24 Parganas	9,039	7,405,677	322	252,114	3.4
Total	**57,125**	**45,112,114**	**8,066**	**10,926,478**	**24.2**

Source: Government of West Bengal, Public Health Engineering Department, Integrated Management Information System (IMIS). Data valid as of 30 April 2016.

Table 3. Blocks in West Bengal Affected by Arsenic

District	Arsenic-affected blocks	No. blocks
Burdwan	Katwa I, Katwa II, Kalna II, Purbasthali I, Purbasthali II	5
Hooghly	Balagarh, Pandua	2
Howrah	Bally-Jagachha, Uluberia II	2
Maldah	English Bazar, Kaliachak I, Kaliachak II, Kaliachak III, Manickchak, Ratua-I, Ratua-II	7
Murshidabad	Beldanga-I, Beldanga-II, Berhampur, Bhagwangola-I, Bhagangola-II, Domkal, Hariharpara, Farakka, Jalangi, Kandi, Lalgola, Murshidabad-Jiagang, Nawda, Raghunathganj-I, Raghunathganj-II, Raninagar I, Raninagar II, Samserganj, Sagardighi, Suti-I, Suti-II	21
Nadia	Chakdaha, Chapra, Hanskhali, Haringhata, Kaliganj,Karimpur I, Karimpur II, Krishnaganj, Krishnanagar I, Krishnanagar-II,	17

District	Arsenic-affected blocks	No. blocks
	Nabadwip, Nakashipara, Ranaghat I, Ranaghat II, Santipur, Tehatta I, Tehatta II	
North 24 Parganas	Amdanga, Baduria, Bagda, Barasat I, Barasat II, Barrackpur I, Barrackpur II, Basirhat I, Basirhat II, Bongaon, Deganga, Gaighata,Habra I, Habra II, Haroa, Hasnabad, Hingalganj, Minakhan, Rajarhat, Sandeshkali I, Sandeshkhali II, Swarupnagar	22
South 24 Parganas	Baruipur, Bhangar I, Bhangar II, Bishnupur I, Bishnupur II, Joynagar I, Mograhat II, Sonarpur	8
Total		**83**

Source: Government of West Bengal, Public Health Engineering Department, Integrated Management Information System (IMIS). Data valid as of 30 April 2016.

20. Growing awareness of the arsenic crisis in West Bengal groundwater led the Government of West Bengal to set up a working group in December 1983 to address the problem. The group confirmed exceedances of arsenic beyond the maximum drinking-water limit on an unprecedented scale. In 1988, the government set up a state-level investigation, funded by the Technology Mission of the Government of India, and initiated a state-level Arsenic Task Force in 1993. The Task Force tested some 132,000 public hand-pumped tube wells in the arsenic-affected areas, and those deemed safe were painted blue to identify them. It also initiated awareness campaigns. In 1996, the Task Force made recommendations for surface-water supply schemes. Figure 1 shows the main arsenic affected areas of West Bengal.

21. The state government instigated a comprehensive Arsenic Master Plan with assistance from the Government of India to provide arsenic-free drinking water for the rural population. The master plan identified short-, medium-, and long-term measures for mitigation, ranging from rainwater harvesting to piped supplies.

22. According to the website of the Public Health Engineering Department (PHED) of the Government of West Bengal, as of May 2017, 61.4% of the rural population of 4,304,314 (total 10,111,442) in North 24 Parganas were served by piped water supplies, in 21 blocks.[7]

23. As of January 2017, 48.9% of the rural population of 5,703,115 (total population 7,103,807) in Murshidabad was served by piped water supplies, in 26 blocks. However, ‘piped water’ by PHED in rural areas means water supply through public stand-posts and not through household connections.

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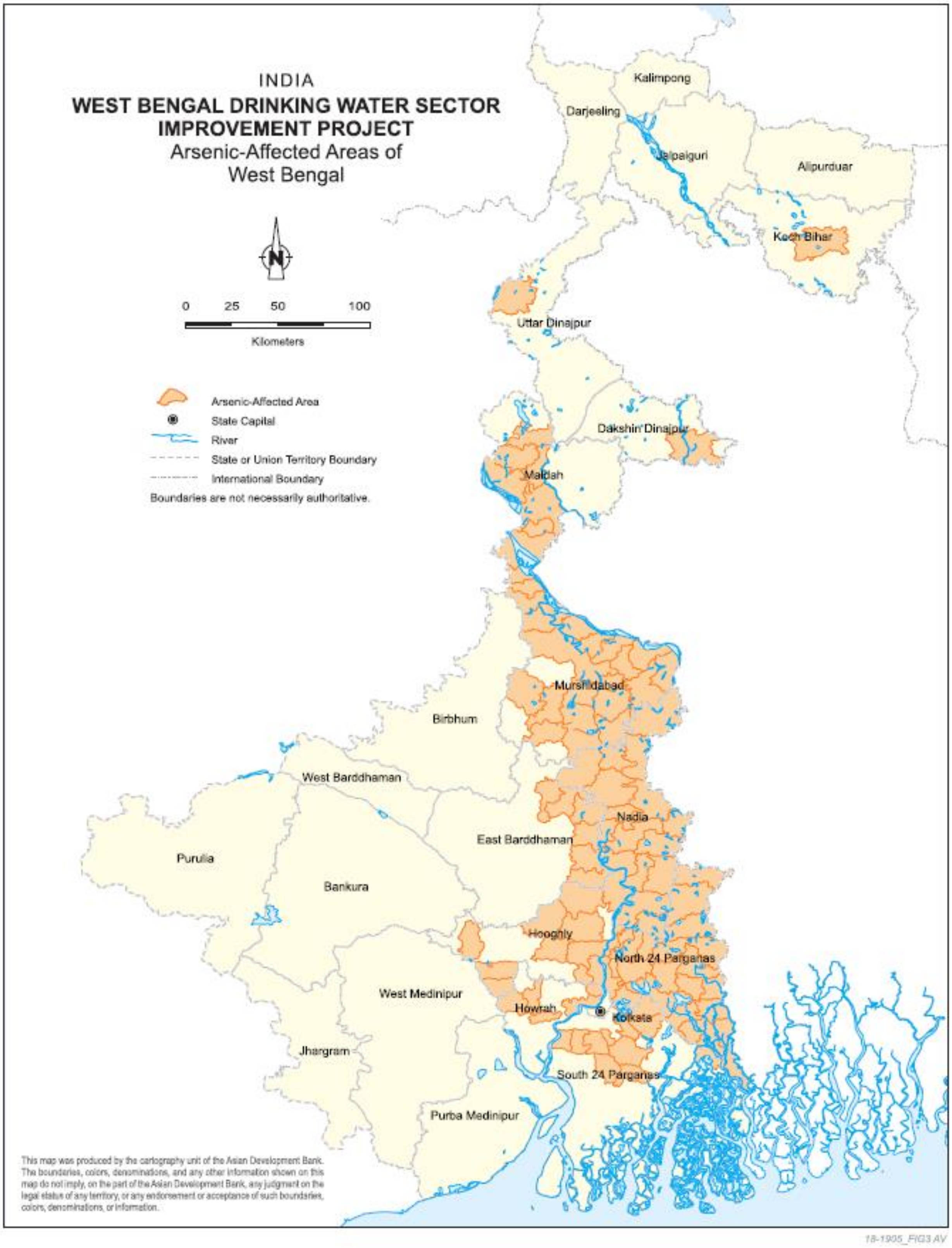
[7] Public Health Engineering Department, Government of West Bengal. http://app1.wbphed.gov.in/phed_v2_view/CVF00000/home.html

Figure 1. Arsenic-Affected Areas of West Bengal



Source: Government of West Bengal. Public Health Engineering Department. 2014 http://maps.wbphed.gov.in/.

VI. DISTRIBUTIONS IN NORTH 24 PARGANAS DISTRICT

24. The Government of India, Ministry of Drinking Water and Sanitation, integrated management information system (IMIS) groundwater data for the 3 years, 2014–2017, indicate that out of 47,062 water samples tested from 22 blocks in North 24 Parganas, 8,609 (18.3%) exceeded 10 µg/L (Table 4).[8] More than 30% of the tested samples in Baduria, Basirhat I, Gaighata, Habra I, and Swarupnagar had arsenic concentrations above the 10 µg/L limit. Distributions of the arsenic exceedances in the district are shown in Figure 2. Details of sample design are not known, but the distribution of arsenic concentrations is assumed to be representative of the distribution in the groundwater of the district.

Table 4. Summary of Arsenic Distributions in North 24 Parganas District

Blocks	**No. habitations affected by arsenic** (>10 µg/L)	**No. samples tested**	**No. samples with arsenic >10 µg/L**	**% samples with arsenic >10 µg/L**
Amdanga	58	2,676	205	7.66
Baduria	155	4,537	1,366	30.1
Bagda	140	2,312	434	18.8
Barasat I	106	2,461	194	7.88
Barasat II	135	2,251	510	22.7
Barrackpur I	30	1,168	51	4.37
Barrackpur II	2	946	3	0.32
Basirhat I	234	2,762	1,157	41.9
Basirhat II	88	1,894	160	8.45
Bongaon	167	2,082	583	28.0
Deganga	181	2,354	599	25.5
Gaighata	174	2,113	805	38.1
Habra I	198	2,337	714	30.5
Habra II	192	2,044	414	20.3
Haroa	61	2,170	123	5.67
Hasnabad	78	2,460	210	8.54
Hingalganj	9	1,447	13	0.90
Minakhan	10	2,340	21	0.90
Rajarhat	87	1,844	175	9.49
Sandeshkhali I	1	709	1	0.14
Sandeshkhali II	4	1,627	4	0.25
Swarupnagar	205	2,528	867	34.3
Total	**2,315**	**47,062**	**8,609**	**18.3**

Source: Ministry of Drinking Water & Sanitation. Government of India. Integrated Management Information System (IMIS), 2014–2017.

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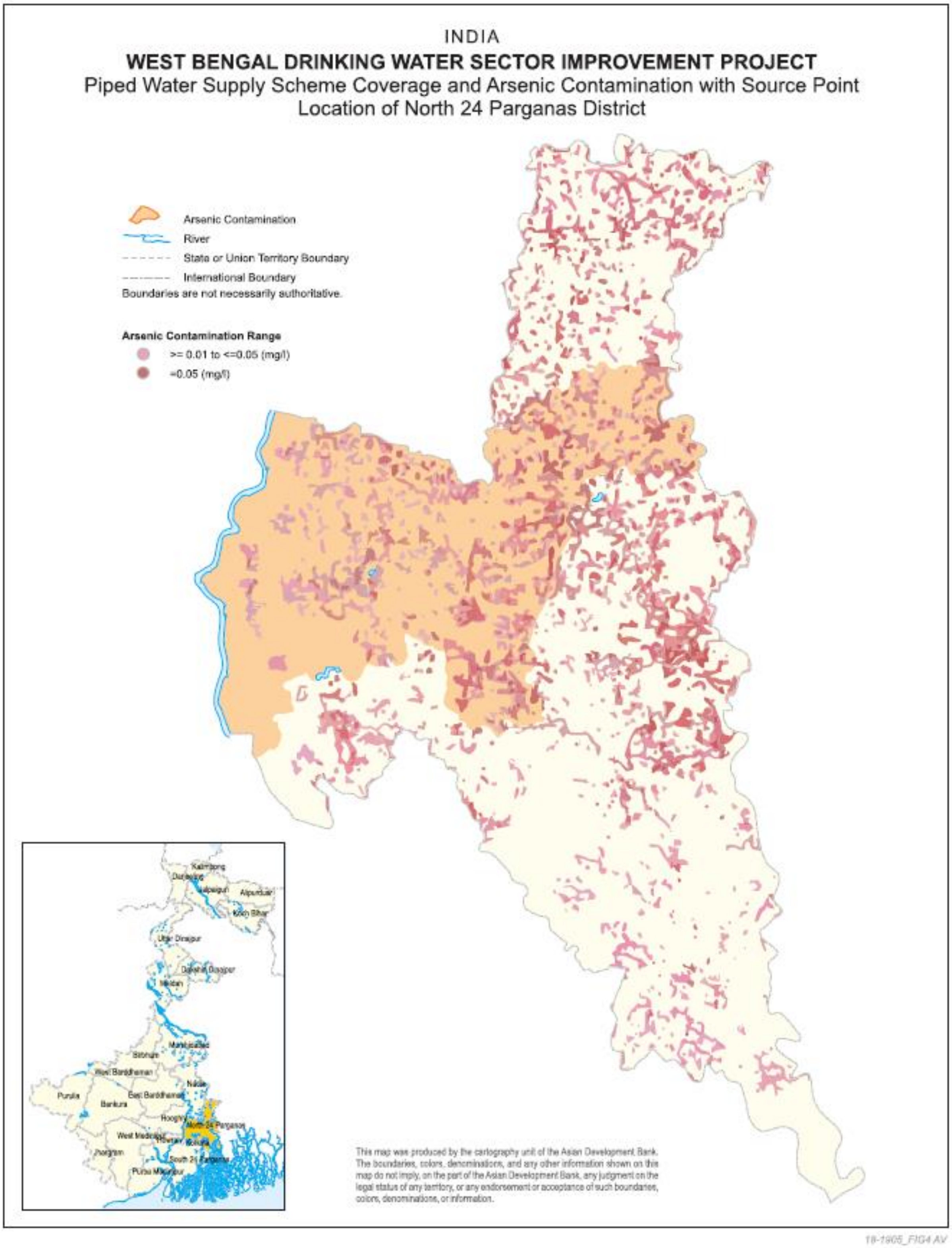
[8] Ministry of Drinking Water & Sanitation. Government of India. Integrated Management Information System (IMIS), 2014–2017. http://indiawater.gov.in/imisreports/nrdwpmain.aspx.

Figure 2. Spatial Distribution of Arsenic in North 24 Parganas District, West Bengal



This map was produced by the cartography unit of the Asian Development Bank. The boundaries, colors, denominations, and any other information shown on this map do not imply, on the part of the Asian Development Bank, any judgment on the legal status of any territory, or any endorsement or acceptance of such boundaries, colors, denominations, or information.

Source: Government of West Bengal, Public Health Engineering Department, Data valid as of 30 April 2016. http://maps.wbphed.gov.in/

25. Data from the Ministry of Drinking Water & Sanitation, Government of India, IMIS database (2014–2017) indicate that 2,315 habitations (33.3%) have sources with arsenic concentrations above 10 µg /L. The block-wise categorization of distributions is summarised in Table 5.[9]

26. According to longer-term IMIS groundwater data, least-affected areas of North 24 Parganas occur mainly in the coastal areas.

Table 5. Percentage Distribution of Arsenic-Affected Habitations in North 24 Parganas

% habitations affected by arsenic (>10 µg /L)	**Block**	**No. blocks**
<50%	Bagda, Barasat I, Barrackpur I, Barrackpur II, Basirhat II, Bongaon, Gaighata, Haroa, Hasnabad, Hingalganj, Minakhan, Rajarhat, Sandeshkhali I, Sandeshkhali II	16
50–75%	Barasat II, Deganga, Habra I, Habra II, Swarupnagar	5
>75%	Basirhat I	1

µg = microgram, no. = number, < = less than, > = more than.
Source. Ministry of Drinking Water & Sanitation. Government of India, Integrated Management Information System (IMIS), 2014–2017 data. https://mdws.gov.in/.

VII. DISTRIBUTIONS IN MURSHIDABAD DISTRICT

27. A study of arsenic in groundwater in Murshidabad by Rahman, et al. (2005) reported analyses from 29,612 hand-pumped tube wells across the district, of which 26% were found to have arsenic concentrations above 50 µg/L and 53.8% above 10 µg/L. Of the 26 blocks in Murshidabad, 24 were found to have some occurrences of arsenic >50 µg/L. The investigation estimated that 2.5 million people were exposed to drinking water with more than 10 µg/L with 1.2 million people exposed to more than 50 µg/L. The total population of the district was estimated at 5.3 million and the total number of tube wells at 0.2 million.

28. Mukherjee, et al. (2005) carried out health screening of 25,274 people from 139 arsenic-affected villages in Murshidabad and found arsenicosis symptoms in 4,813 (19%). Of 2,595 children screened, 122 (4%) had symptoms.

29. According to PHED (2006) data, using population statistics from the 2001 Census and a threshold of 50 µg/L, a total of 4 million people in Murshidabad inhabit 19 blocks affected by high-arsenic drinking water (Table 6). These affected blocks are located mainly to the east of the Bhagirathi River.

Table 6. Population of Arsenic-Affected Blocks in Murshidabad District

Arsenic-affected block (>50 µg/L)	**Population of block**
Beldanda I	259,000
Beldanga II	210,000
Berhampur	379,000
Bhagwangola I	163,000
Bhagwangola II	130,000
Domkal	312,000

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[9] Ministry of Drinking Water & Sanitation. Government of India. Integrated Management Information System (IMIS) 2014–2017 data. http://indiawater.gov.in/imisreports/nrdwpmain.aspx.

Arsenic-affected block (>50 µg/L)	**Population of block**
Farakka	220,000
Hariharpara	222,000
Jalangi	216,000
Lalgola	268,000
Murshidabad-jiaganj	200,000
Nawda	196,000
Raghunathganj I	154,000
Raghunathganj II	193,000
Raninagar I	155,000
Raninagar II	156,000
Samserganj	212,000
Suti I	139,000
Suti II	213,000
Total	**3,997,000**

Source: Public Health Engineering Department. Government of West Bengal. Data valid as of 30 April 2016.

VIII. MECHANISMS OF ARSENIC MOBILISATION

30. High arsenic concentrations in the Ganga–Brahmaputra plains are a feature of shallow aquifers from the Holocene Age (<12,000 years). The sediments comprise grey sand, silt and clay deposits derived from Himalayan and north-eastern India basement complexes. Short-range variability in arsenic concentrations in these aquifers is often large. The high-arsenic groundwaters are anoxic with often high concentrations of dissolved iron, manganese, phosphate, high alkalinity and organic-matter content, and low concentrations of sulfate.[10] The reduced (trivalent) form of arsenic tends to predominate, and the release of arsenic into the water is largely accepted as a function of desorption from, and dissolution of, iron oxides within the sediments (Fendorf et al., 2010).[11] The process is microbially mediated (Islam et al., 2004). Despite much consensus, opinion remains divided on the origins of the organic matter that drives the oxidation-reduction reactions towards anoxic conditions and arsenic release. Some argue that naturally-occurring organic material buried along with the sediments at the time of deposition is responsible (in soluble or solid form, or both) (e.g., BGS and DPHE, 2001). Others consider that recent pollution from, for example, latrines or ponds is the origin of the organic carbon (Harvey et al., 2002). Others have suggested that petroleum hydrocarbons from deeper sedimentary formations may be partially responsible (Rowland et al., 2006). The origin of organic carbon has practical significance since a surface source of pollution implies a human impact on the development of the arsenic problem in the Bengal Basin and for the management of the aquifer.

31. A deeper Pleistocene aquifer underlying the Holocene aquifer tends to have low groundwater arsenic concentrations, below 10 µg/L. The sediments in the Pleistocene aquifer are typically reddish-brown and are less reducing than those within the Holocene strata. The iron oxides within them have different sorption properties, and the arsenic is much more strongly bound to the sediments (Radloff et al., 2011). The depth to the surface of the Pleistocene aquifer is not well-defined across the region, but a working cut-off of 150 meters (m) has been used on the basis of observations from Bangladesh (BGS and DPHE, 2001; Pal et al., 2002). Field studies have suggested that depth variation is likely from about 50–80 m below ground in Murshidabad,

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[10] The United States Geological Survey defines anoxic groundwater as those with dissolved oxygen concentration of less than 0.5 milligrams per liter.

[11] Arsenite (Trivalent) is the most stable soluble form of arsenic in reducing environments compared to other forms of Arsenic, such as Arsenate (Pentavalent).

to about 30–60 m in Nadia, to 100 m or more in North 24 Parganas, to ca. 180–200 m or more in South 24 Parganas (Ghosal et al., 2015; Mukherjee and Fryar, 2008).

32. It has been argued that the red-brown Pleistocene sediments are not present everywhere across West Bengal and that in sections where thicker Holocene alluvial deposits (paleochannels) occur, groundwater arsenic concentrations can exceed the drinking-water limits to deeper levels (Ghosal et al., 2015). Concerns have been raised that the underlying red-brown Pleistocene aquifer is also potentially vulnerable to arsenic contamination by drawdown from above if the aquifer were to be heavily pumped (Fendorf et al., 2010; Ghosal et al., 2015). This is especially the case in areas noted to lack a thick separating clay layer between the Pleistocene sands and the overlying Holocene aquifer. Murshidabad, Nadia, and North and South 24 Parganas are all said to have a relatively thin clay barrier and so heavy use of the deep Pleistocene aquifer in these districts could be unsustainable (PHED, 2006).

33. A different mechanism of arsenic release is responsible for the groundwater arsenic problems observed in the basement aquifers of Chattisgarh and Karnataka. In the Rajnandgaon District in Chattisgarh, high-arsenic groundwater is from shallow wells and boreholes (<50 m deep) (Chakraborti et al., 1999) and the source is concluded to be weathering of arsenic-rich sulfide minerals, closely associated with gold deposits. The sulfide minerals oxidize under oxic conditions and release arsenic into solution. Arsenic problems are a localized feature of the area of sulfide mineralization—in a toxic environment, the released arsenic becomes absorbed by iron oxides, which are themselves formed by the sulfide–mineral oxidation process. Similar processes are likely in the affected areas of Karnataka, where in 2013, tube wells in 16 habitations were found to have arsenic concentrations above 50 µg/L. Sulfide mineralization, here associated with gold and copper deposits, is a likely origin of the arsenic in the groundwater (Annapoorna and Janardhana, 2016).

IX. GROUNDWATER ARSENIC MITIGATION MEASURES

34. Mitigation of groundwater arsenic problems has involved a range of options including survey and monitoring for low-arsenic groundwater sources, use of alternative (Pleistocene) aquifers, treatment of arsenic-contaminated water at the surface, and on-site methods. Other non-groundwater options include rainwater harvesting, provision of treated surface water at community scale (pond sand filter) or piped surface-water supply (The World Bank, 2005) (Table 7).

35. Use of the deeper Pleistocene alluvial aquifers has long been a component of arsenic mitigation programmes in the Bengal Basin and other alluvial-deltaic plains of South and Southeast Asia. Careful management of these aquifers is needed, and various internal and external studies have given numerous warnings that their overexploitation risks drawdown of arsenic-rich groundwater (Fendorf et al., 2010; Radloff et al., 2011). Studies have indicated that this process may already have occurred in some heavily stressed aquifers, especially those lacking a robust aquitard layer between the two aquifer units (e.g., Vietnam, Winkel et al., 2011).

36. Dug wells (large-diameter wells, ‘ring’ wells) are also commonly observed to have relatively low concentrations of dissolved arsenic, typically below 10 µg/L. This is due to the toxic nature of the shallowest horizons of the Holocene aquifers, close to the piezometric surface.

37. Dug wells offer some prospects for mitigation of groundwater arsenic problems but suffer the limitations of reduced yields in the dry season when water levels fall and the increased risk of surface-borne pollution. Sustainability of these sources is therefore questionable in some areas.

38. On-site or *in-situ* methods for removal of arsenic have been applied on a pilot scale in some western countries (e.g., the United States of America, Paul et al., 2010; Welch, et al., 2008) and in recent years in South and Southeast Asia (Sarkar and Rahman, 2001) (Box 1). In-situ methods rely on one of two basic principles, one based on aeration of the groundwater in the presence of dissolved iron and the other on reducing the groundwater to facilitate sulfate reduction. Both are microbially-mediated. In the first method, aerated (oxidized) water is introduced into the affected aquifer to promote oxidation of the reduced trivalent arsenic to the oxidized pentavalent form. This, in turn, promotes iron oxide precipitation as grain coatings locally around the tube well inlet, with sorption of the pentavalent arsenic onto the oxide mineral surfaces. The aeration approach is based on long-established on-site methods for removal of iron and manganese in groundwater. For example, the *in-situ* removal method, Vyredox® method (Hallberg and Martinell, 1976), first developed in Finland, is in use in several places in Europe.

39. In the second method, sulfate and organic carbon with or without zero-valent iron, are introduced to the affected aquifer to promote precipitation of iron sulfide or arsenic sulfide with co-precipitation or sorption of dissolved arsenic (O'Day et al., 2004). The sulfide-reducing method has been tested less widely than the aeration method. Although several laboratory studies of microbial sulfate-reduction methods have been carried out (Xie et al., 2016), few field-based operations have been tested.

40. One 2009 study of artificial recharge of rainwater collected via a recharge pit into a shallow high-arsenic tube well (16 meters deep) in Ashoknagar, Habra I block, North 24 Parganas, also indicated a reduction in concentrations of arsenic over the period of investigation. An initial concentration of 128 pg/L in the tube well was reduced to 80 pg/L after 1 month and to <1 pg/L after 3 months during the dry season.[12]

Table 7. Pros and Cons of Groundwater Arsenic Mitigation Options, West Bengal

Mitigation measure	Pros	Cons
Dug well	Inexpensive, many exist already	Not well accepted by the people of West Bengal; prone to surface-borne contamination. Limited supply may dry up in the dry season
Hand-pumped tube well	Inexpensive, simple to install. Statistical distributions indicate that many are low in arsenic, even in affected areas.	Needs to be tested for arsenic, identified, and monitored. Involves major testing program.
Rainwater harvesting	High rainfall allows storage	Contamination of water during collection and storage. May be insufficient storage for perennial supply.
Pond sand filter		Untreated water may be contaminated with surface pollutants; requires installation, maintenance, monitoring
Deep tube well	Free from surface-borne contaminants	Needs careful management to counter over-abstraction; needs monitoring; deep aquifer may not exist in all areas; more expensive

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[12] T. Talukdar, A Kr. Ghosh, K.K. Srivastava. 2009. Arsenic in Ground Water of North 24 Parganas District, West Bengal. *Bhujal News Quarterly Journal, April-Sept, 2009*. Available at India Water portal. (http://hindi.indiawaterportal.org/node/53084)

Mitigation measure	Pros	Cons
		to install and pump than shallow tube wells
Off-site arsenic removal from groundwater		High maintenance demands; needs regular monitoring, sludge removal; domestic systems typically small volume and time-consuming; long-term sustainability doubtful
On-site arsenic removal plant	No sludge removal	Pilot schemes: no major uptake of methodology; long-term sustainability questionable; vulnerability to clogging of aquifer
Piped water supply (surface water or groundwater)	Potential for household supply, improved water quality and hygiene, convenience. Improved long-term security. Centralised treatment with efficiencies.	High capital cost; requirement for maintenance; requirement for monitoring.

Box 1. Subterranean Arsenic Removal

In West Bengal, a pilot aeration-based in-situ subterranean arsenic removal (SAR) water treatment plant was set up in Kasimpore, North 24 Parganas, in 2004. The project was funded by the European Union and led by researchers at Queen's University Belfast (Sen Gupta et al., 2009). Subsequent funding by the World Bank led to the installation of six operational plants in 2008 (http://www.insituarsenic.org). The operation involves storage of aerated tube well water in tanks with reintroduction to the aquifer via the abstraction tube well. Some 20% of the water is reintroduced, the remainder provided for use by the community. Water-quality monitoring has been set up to test for arsenic. Initial groundwater arsenic contents of some 100–250 mg/L have been reduced to less than 50 mg/L. Each treatment plant has been delivering 3,000–4,000 liters of low-arsenic, low-iron drinking water per day to the rural community since 2008, without clogging of the aquifer pore spaces. Typical production costs are $1 per 2,000 liters. The plants and technology set up in West Bengal have won a number of innovation awards. On-site plants have also been installed in Bangladesh, Cambodia, Malaysia, and Viet Nam.

The efficacy of the methodology is dependent on factors such as initial concentrations of arsenic and iron. The reduction of the drinking-water standard from 50 µg/L to 10 µg/L poses an additional challenge for remediation. Addition of ferrous iron may improve the efficacy in low-iron groundwater conditions. Pilot schemes with addition of ferrous iron have been tested in the United States of America (Paul et al., 2010; Sheffer, 2010) and the People's Republic of China (Wang, 2017). On-site methods have the advantage of reduced requirement for surface infrastructure and no sludge disposal compared with off-site systems. Areas of uncertainty include site variability (e.g., in the iron/arsenic ratio in the groundwater, reaction times, reductive capacity of the aquifer, porosity, and sustainability). Clogging of aquifer pore spaces over time is a concern.

On-Site Water Treatment Plants Installed in West Bengal by the World Bank-Funded Project Consortium Led by Queen's University Belfast

Location	District
Basirhat, Merudandi	North 24 Parganas
Basirhat, Purbapara	North 24 Parganas
Nilgunj, Rangapur	North 24 Parganas
Chakdah, Ghetugachi, Gotra,	Nadia
Gobardanga, Tepul	North 24 Parganas
Naserkul, Ranaghat	Nadia

X. MITIGATION EXPERIENCES ELSEWHERE

41. The earliest observations of arsenic occurrence in drinking water with its resultant health problems were possibly made in Argentina in the early 1900s, subsequently in 1950s in a couple of other countries of South America and East Asia region problems were tackled in these regions by the provision of piped water supplies (treated groundwater in Argentina and Mexico; treated surface water in other countries). In the Lagunera area of Mexico, a 100 km long aqueduct supplied treated water to the affected area, with cost recovery through tariffs (Alaerts and Khouri, 2004). Arsenic problems in these regions are now largely historical.

42. Discoveries of arsenic contamination in the large alluvial aquifers of South and Southeast Asia are a more recent phenomenon, beginning with West Bengal in 1988. Problems are most commonly associated with Holocene alluvial and deltaic aquifers occupying the major river deltas of the region, originating from the Himalayan highlands.

43. Arsenic problems were first recognized in Cambodia in 2000 (Feldman et al., 2007). Occurrences have analogies with those of West Bengal, contamination being observed in groundwater from the lower part of the Mekong River Basin. The population at risk in Cambodia is estimated to 100,000 , and installation of arsenic removal plants in tube wells appears to be the most common mitigation option (Sampson et al., 2008). International organizations such as ADB and UNICEF have supported Cambodia in installing small-scale domestic arsenic filters. As of 2012, some 27,000 rural households had been supplied with arsenic filters.

44. Occurrences in Viet Nam also emerged in 2000 (Berg et al., 2001). High arsenic concentrations are found in groundwater from the Red River and Mekong River deltas. Around 1 million people are estimated to be or have been at risk. Public drinking-water supply is pumped from a deep Pleistocene low-arsenic aquifer at 150–250m depth. Mitigation of rural water supplies has included domestic water treatment and small-scale piped supply schemes.

45. The country considered to be worst-affected by groundwater arsenic problems is Bangladesh. Problems were first identified in 1993 in the western part of Bangladesh, across the border from West Bengal. Rapid surveys identified the problem as widespread, and estimates of exposure were placed at 57 million people above a concentration of 10 µg/L and 35 million people above 50 µg/L (BGS and DPHE, 2001). The government made a commitment in 2004 to prioritise mitigation through supply of treated surface water, but measures implemented have varied, including well switching and surface treatment (short-term), and longer-term options using deep tube wells, rainwater harvesting, centralised iron removal plants, and pond sand filters in places where piped water supply is not geographically or economically feasible (The World Bank, 2016). Mitigation measures are undertaken with community participation. Arsenic-contaminated tube wells have been painted red, and mitigation efforts include awareness campaigns and arsenic testing. Testing of groundwater for arsenic from 5 million tube wells up to the mid-2000s resulted in the switching of some 29% of the affected population from high- to low-arsenic tube wells. A further 12% of the affected population was served by the construction of deep low-arsenic tube wells (Hug et al., 2008). According to the World Bank-supported Bangladesh Rural Water Supply & Sanitation Project (The World Bank, 2016), rural piped water supply schemes have been set up in 37 villages on a pilot demonstration basis through private–public partnership as of 2016. The project reports that 924,000 people have been supplied with improved water sources, 14,000 tube wells have been constructed or rehabilitated, 100% of new tube wells installed have been tested for arsenic, and 28,000 households have been connected to new piped supplies (The World Bank, 2016). Despite mitigation interventions, however, Human Rights Watch still estimates some 20 million people are exposed to arsenic in drinking water (above 50 µg/L)

(Human Rights Watch, 2016). Although well switching has been responsible for the greatest reduction in arsenic exposure to date, it can only be considered a short-term measure in conditions where the switched well offers a non-sustainable supply (Milton et al., 2012).

46. The varying operational responses to arsenic contamination of groundwater mentioned in paras. 35–47 indicate the complexities of the problem and the lack of unifying appropriate approach. Responses depend on scale, population and its distribution, hydrographic, geological, and hydrogeological conditions, and socio-economic and institutional factors.

XI. FLUORIDE IN INDIAN GROUNDWATER

B. National Distribution of Fluoride in Groundwater

47. The desirable limit for fluoride in drinking water in India is 1.0 mg/L, although the acceptable limit set by WHO guideline value is 1.5 mg/L. Studies estimate that some 67 million people in India are at risk from drinking water with fluoride concentrations above the WHO guideline and national limit (Saxena and Sewak, 2015). Some 18 million people are estimated to be affected by dental fluorosis and 8 million by skeletal fluorosis nationwide (Saxena and Sewak, 2015). The Ministry of Health and Family Welfare of government of India indicated that the total number of fluorosis cases nationwide was 1.2 million people as of 1 April 2014 (https://mohfw.gov.in/...health.../national-programme-prevention-and-control-fluorosis).

48. Groundwater-fluoride problems have been recorded in over 200 districts in 19 Indian States.[13] In Andhra Pradesh, Gujarat, Rajasthan, and Telangana, 50–100% of districts are affected by high-fluoride drinking water. In Bihar, Haryana, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Orissa (Odisha), Punjab, Tamil Nadu, and Uttar Pradesh, 30–50% of districts are affected; and in Chhattisgarh, Delhi, Kerala, and West Bengal, the figure is less than 30% (RGNDWM, 1993). The numbers of districts in the most affected states are in Table 8.

49. In West Bengal, 225 villages in 43 blocks of seven districts (Birbhum, Bankura, Puruliya, Maldah, South 24 Parganas, Dakshin Dinajpur and Uttar Dinajpur) are identified as endemic for fluorosis and people in these regions are at risk of fluoride contamination. The fluoride concentrations in the contaminated groundwater of those areas are as high as 1.06-1.75 mg/l.[14] According to the PHED the rural population of West Bengal at risk from fluoride contamination of drinking water is some 7,400,000 (11.9% of the rural population).[15]

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[13] Fluorosis Research & Rural Development Foundation (FR&RDF). Districts Endemic for Fluorosis. India. (http://www.fluorideandfluorosis.com/fluorosis/districts.html).

[14] West Bengal Pollution Control Board State of Environment Report. 2016. www.wbpcb.gov.in/writereaddata/files/SOE_Report_2016.pdf.

[15] Public Health Engineering Department. Government of West Bengal. IMIS, Data valid as of 30 April 2016. www.wbphed.gov.in.

Table 8. Fluoride-Affected States and Districts in India Containing Groundwater Sources with Fluoride Concentrations >1.5 mg/L[16]

State	No. districts affected	Districts
Andhra Pradesh	16	Ananthapur, Chittoor, Cuddapah, Guntur, Hyderabad, Karimnagar, Khammam, Krishna, Kurnool, Mahbubnagar, Medak, Nalgonda, Nellore, Prakasam, Rangareddy, Warangal
Bihar	6	Bhagalpur, Gaya, Jamual, Munger, Nawada, Rohtas
Delhi	7	Central Zone, East Zone, North East Zone, North West Zone, South West Zone, South Zone, West Zone
Gujarat	24	Ahmedabad, Amreli, Anand, Banaskatha, Bharuch, Bhavnagar, Dahod, Gandhinagar, Godhara, Jamnagar, Junagarh, Kutchh, Mehsana, Nadiad, Narmada, Navsari, Patan, Porbandar, Rajkot, Sabarkantha, Surat, Surendranagar, Vadodara, Valsad
Haryana	12	Bhaiwani, Faridabad, Gurgaon, Jhind, Kaithal, Karnal, Kurukshetra, Mohindragarh,Rewari, Rohtak, Sirsa, Sonipat
Jharkhand	5	Deoghar, Girdh, Pakur, Palamu, Sahabganj
Karnataka	16	Bangalore Rural, Belgaum, Bellary, Bijapur, Chikmagalur, Chitradurga,Dharwad, Gadag, Gulbarga, Kolar, Mandya, Mangalore, Mysore, Raichur, Shimoga, Tumkur
Madhya Pradesh	14	Chhindwara, Dhar, Dindori, Gwalior, Jubua, Mandla, Mandsour, Neemuch, Raisen, Sehore, Seoni,Shivpuri, Ujjain, Vidhisha
Maharashtra	10	Akola, Amravati,Bhandara, Buldhana, Chanderpur, Jalgaoun, Nagpur, Nanded, Sholapur, Yavatmal
Orissa	18	Angul, Balasore, Bhadrak, Bolangir, Boudh, Dhankanal, Ganjam, Jagatsinghpur, Jajpur, Kalahandi, Keonjhar, Khurda, Koraput, Mayurbhanj, Nayagarh, Pulbani, Puri, Rayagada
Punjab	17	Amritsar, Bhatinda, Faridkot, Fategarh Sahib, Ferozpur, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Ludhiana, Mansa, Moga, Muktsar, Nawanshahar, Patiala, Ropar, Sangrur
Rajasthan	32	Ajmer, Alwar, Banswara, Baran, Barmer, Bharatpur,Bhilwara, Bikaner, Bundi, Chittaurgarh, Churu, Dausa, Dholpur, Dungarpur, Ganganagar, Hanumangarh, Jaipur, Jaisalmer, Jalor, Jhalawar, Jhunjhunun, Jodhpur, Karauli, Kota, Nagaur, Pali, Rajsamand, Sawai Madhopur, Sikar, Sirohi, Tonk, Udaipur
Tamil Nadu	9	Coimbatore, Dharmapuri, Erode, Krishnagir, Madurai, Salem, Thiruchirapally, Vellore, Virudunagar
Uttar Pradesh	7	Farukhabad, Hardoi, Kaunauj, Pratapgarh, Raebareily, Unnao, Varanasi
West Bengal	7	Bankura, Birbaum, Dakshin Dinajpur, Malda, Purulia, 24 South Parganas, Uttar Dinajpur

Source: Fluorosis Research & Rural Development Foundation (FR&RDF). Districts Endemic for Fluorosis. India. http://www.fluorideandfluorosis.com/fluorosis/districts.html.

50. According to the Government of India, Ministry of Drinking Water & Sanitation, IMIS database (August 2016), there are approximately 13,736 fluoride-affected habitations with wells having concentrations of more than 1.5 mg/L.[17] These are spread across the states shown in

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[16] List only includes states where the number of districts affected by Fluoride is five and above.

[17] Ministry of Drinking Water & Sanitation. Government of India. Integrated Management Information System (IMIS), August. 2016 data. http://indiawater.gov.in/imisreports/nrdwpmain.aspx/.

Table 9 in comparison with the distribution across the states cited by fluoride and flourosis.com data in Table 8. The IMIS database recorded no exceedances for measured sampling points from Delhi or Tamil Nadu, while it separated Telangana from Andhra Pradesh data in contrast to Table 8. The total population estimated to be affected by fluoride according to the IMIS database is 8.5 million people (Table 9).

Table 9. Most Fluoride-Affected Habitations in India
(Fluoride >1.5 mg/L)

State	Number of Habitations	Population	Habitations affected	Population affected	% of total affected population
Andhra Pradesh	48,342	36,632,785	421	292,899	3.4
Assam	88,099	29,658,323	155	19,729	0.2
Bihar	110,234	99,454,050	1043	1,128,975	13.3
Chattisgarh	74,647	19,795,446	75	24,484	0.3
Gujarat	36,066	37,117,600	11	19,077	0.2
Haryana	7,948	18,407,573	200	487,889	5.7
Himachal Pradesh	53,604	6,686,071	0	0	0.0
Jharkhand	120,067	26,899,888	998	482,050	5.7
Karnataka	60,248	40,277,798	1038	479,224	5.6
Kerala	11,883	26,874,598	73	91,996	1.1
Madhya Pradesh	128,067	52,813,783	136	5,519	0.1
Maharashtra	100,066	64,445,038	100	112,297	1.3
Odisha	156,468	35,652,623	65	21,609	0.3
Punjab	15,384	17,989,668	285	335,296	3.9
Rajasthan	121,648	50,806,731	6849	2,985,305	35.1
Telangana	24,582	22,738,920	1041	1,299,331	15.3
Uttar Pradesh	260,801	168,768,908	200	204,445	2.4
West Bengal	105,905	74,637,222	1046	517,509	6.1

Source: Ministry of Drinking Water & Sanitation. Government of India. IMIS database (August 2016).

51. Fluoride-contaminated groundwater was first detected in West Bengal in 1997. Exceedances were noted in the Nasipur area of Nalhati I block in the district of Birbhum, after which the government took rapid action to provide an alternative water supply based on river-bed tube wells from River Tripita.

52. The Geological Survey of India (GSI) undertook a follow-up study during 1999–2000[18] covering an area of some 600 sq. km of West Bengal in order to determine the scale and cause of contamination. Fluoride problems were found to be mostly associated with tube wells abstracting from basaltic rocks of the Rajmahal Traps (http://www.wbphed.gov.in). Shear zones in Precambrian rocks were also found to be associated with high-fluoride groundwater in parts of Purulia and Bankura districts. Dug wells, ponds, and shallow tube wells tapping alluvium had low fluoride concentrations (<1.5 mg/L).

53. A fluoride committee constituted by PHED with the involvement of several organizations, instigated a rapid assessment of fluoride in groundwater sources across West Bengal in 2003.

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[18] Public Health Engineering Department. Government of West Bengal. A Note on Fluoride Contamination of Ground Water in West Bengal,2008 ((http://www.wbphed.gov.in).

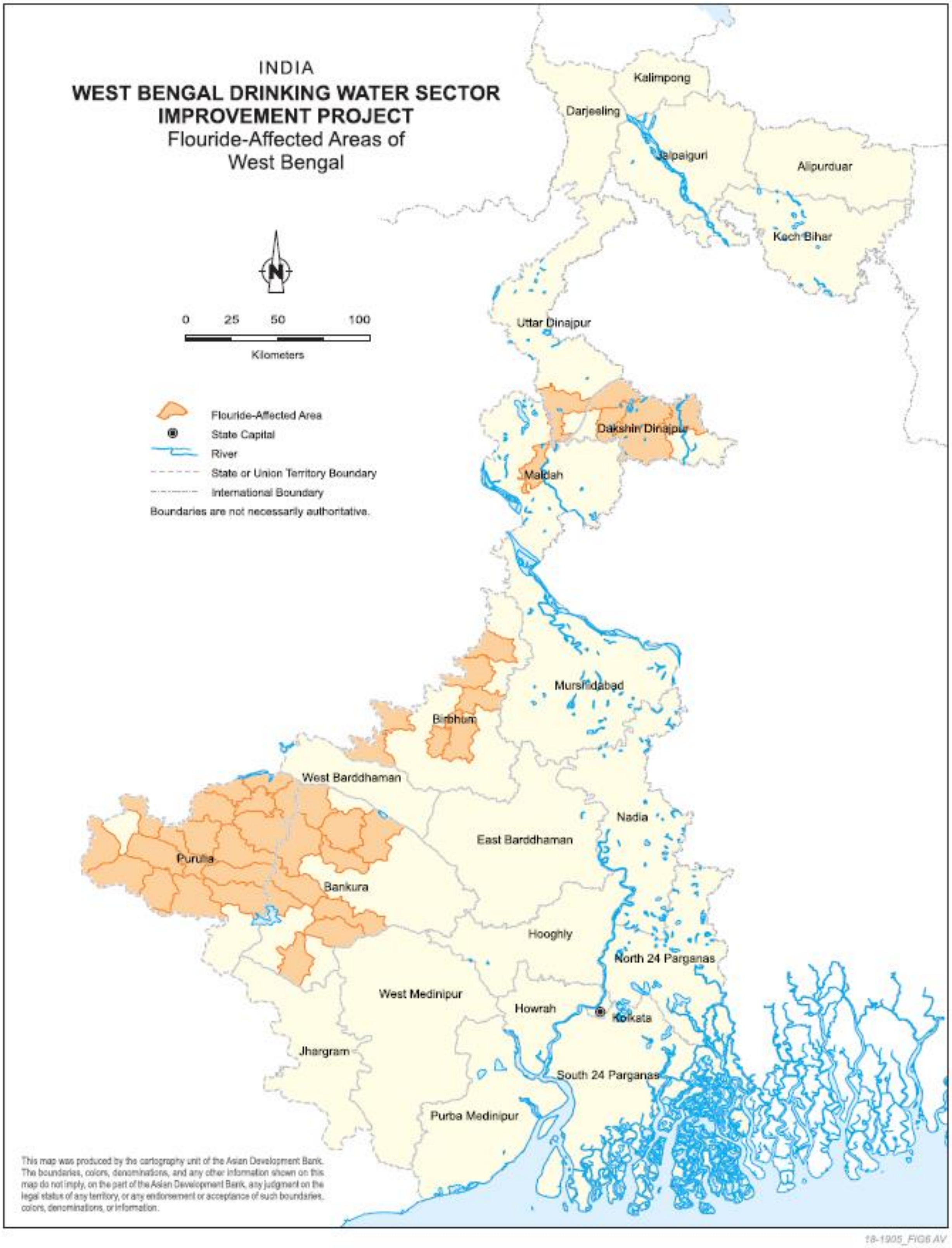
The survey covered 107 blocks in 12 districts and found fluoride concentrations exceeding 1.5 mg/L in groundwater from 43 blocks in seven districts (Table 10) (PHED, 2013). Subsequent testing of all hand-pumped tube wells in the 43 blocks found 3.88% exceeding the acceptable government standard.

Table 10. Blocks in West Bengal Affected by Fluoride at Concentrations >1.5 mg/L

District	Fluoride-affected blocks	No. blocks
Bankura	Bankura II, Barjora, Chhatna, Gangajalghati, Hirbandh, Indpur, Raipur,Saltora, Simlapal, Taldangra	10
Birbhum	Khoyrasol, Mayureswar I,Nalhati I, Rajnagar, Rampurhat I, Sainthia, Suri II	7
Dakshin Dinajpur	Bansihari, Gangarampur, Kumarganj, Kushmundi, Tapan	5
Malda	Bamangola, Ratua II	2
Purulia	Arsha, Bagmundi, Balarampur, Barabazar, Hura, Jaipur, Jhalda I, Kashipur, Manbazar I, Neturia, Para, Puncha, Purulia I, Purulia II, Raghunathpur I, Raghunathpur II, Santuri	17
S 24 Parganas	Baruipur	1
Uttar Dinajpur	Itahar	1
Total		**43**

Source: Government of West Bengal, Public Health Engineering Department 2013.

Figure 3. Map of Fluoride-Affected Areas in West Bengal



Source: Public Health Engineering Department. Government of West Bengal. 2014 http://maps.wbphed.gov.in//.

54. Data from the PHED shows that as of August 2016, an estimated 615,000 people in the state were affected by fluoride >1.5 mg/L (Table 11).[19]

55. Interventions by PHED to reduce fluoride exposure in the affected districts have resulted in the provision of piped water supplies in Birbhum, Dakshin Dinajpur, and Purulia.

Table 11. Fluoride-Affected Habitations in West Bengal

District	No. habitations	Total population	Affected habitation	Affected population	% population affected
Bankura	6,638	3,403,362	43	30,570	0.90
Birbhum	4,335	3,416,742	51	55,671	1.60
Dakshin Dinajpur	4,788	1,480,800	701	251,917	17.00
Maldah	7,787	5,717,269	4	2,110	<0.05
Purulia	4,363	2,802,601	229	245,900	8.80
Uttar Dinajpur	3,687	2,672,341	18	28,985	1.10
Total	**31,598**	**19,493,115**	**1046**	**615,153**	**3.20**

Source: Government of West Bengal, Public Health Engineering Department. Integrated Management Information System (IMIS). August 2016 data.

XII. DISTRIBUTIONS IN BANKURA DISTRICT

56. According to the Central Ground Water Board of Government of India (CGWB), high fluoride concentrations in 10 blocks of the Bankura district are associated with fractured granite or older alluvium in tube wells at 40–50 meters depth.

57. The distribution of fluoride exceedances according to the water quality monitoring and surveillance system adopted by the PHED is shown in Figure 4. Green dots denote fluoride concentrations of 1.0–1.5 mg/L; orange dots greater than 1.5 mg/L.

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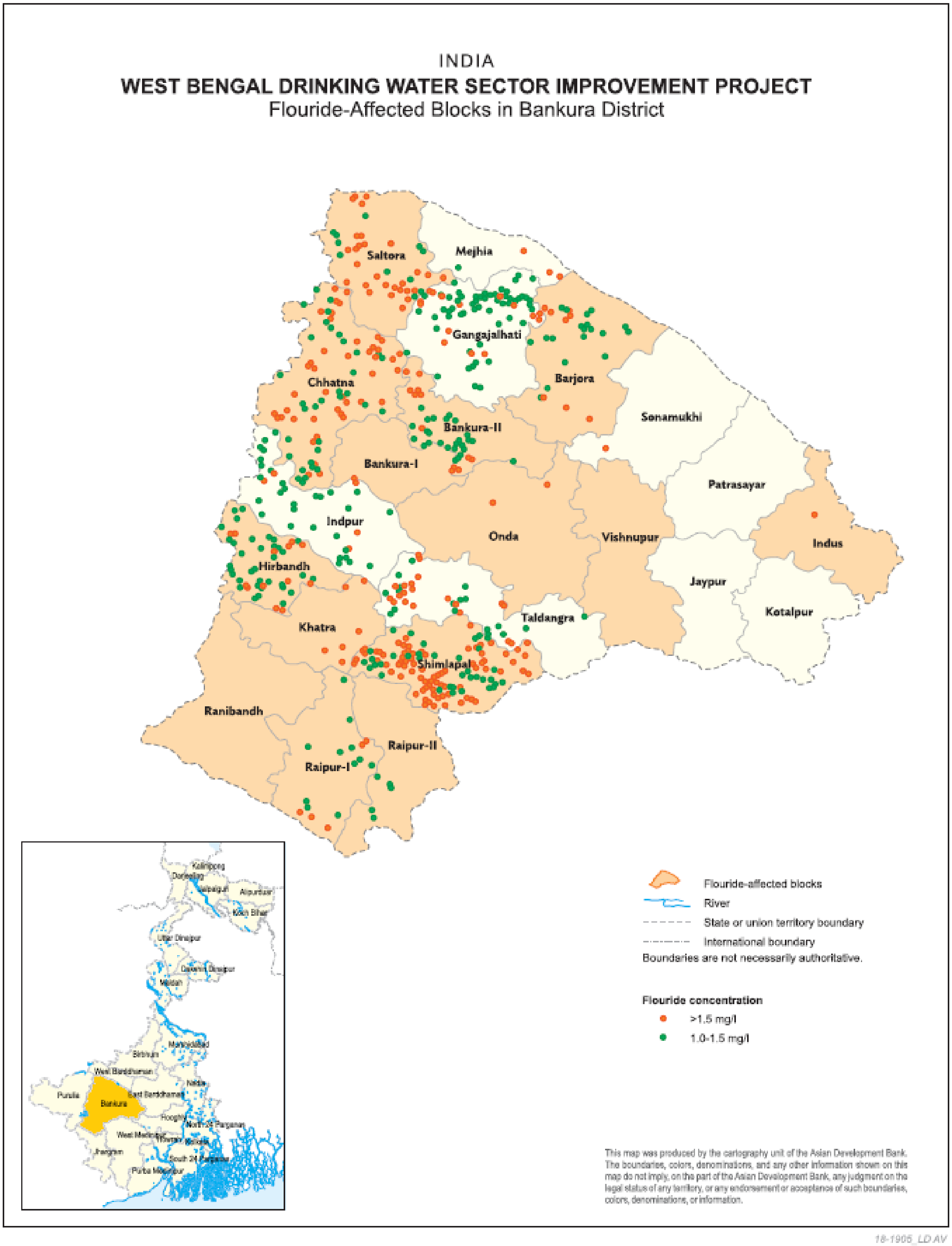
[19] Public Health Engineering Department. Government of West Bengal. Integrated Management Information System (IMIS).2016 (http://www.wbphed.gov.in).

Figure 4. Map Showing Distributions of Fluoride-Affected Blocks in Bankura District



Source: Public Health Engineering Department. Government of West Bengal. 2016. http://maps.wbphed.gov.in/.

58. Government of India, Ministry of Drinking Water & Sanitation. Integrated Management Information System (IMIS). 2013–2017 data for fluoride in groundwater for the years 2013–2017 are summarized in Table 12. The data reveal that 275 habitations were affected by high-fluoride groundwater. Of 52,834 samples tested across 21 blocks, 413 samples (0.78%) exceeded 1.5 mg/L. Most of these were from tube wells. The 1,046 samples (1.98%) had concentrations between 1.0 and 1.5 mg/L.

Table 12. Fluoride-Affected Blocks in Bankura District

		Fluoride >1.5 mg/L		**Fluoride 1.0–1.5 mg/L**		**Habitations**	
Name of block	**Samples tested**	**No.**	**%**	**No.**	**%**	**>1.5 mg/L**	**1.0–1.5 mg/L**
Bankura I	1854	2	0.11	29	1.56	2	18
Bankura II	2657	25	0.94	95	3.58	19	53
Barjura	2751	18	0.65	35	1.27	13	20
Bishnupur	2368	0	0.00	3	0.13	0	3
Chhatna	5,250	67	1.28	198	3.77	47	137
Ganjagalghati	5,007	26	0.52	259	5.17	20	107
Hirabandh	1,684	10	0.59	53	3.15	10	41
Indpur	2,651	7	0.26	36	1.36	7	27
Indus	2,077	2	0.10	2	0.10	2	2
Jaypur	2,054	0	0.00	0	0.00	0	0
Khatra	1,842	6	0.33	4	0.22	5	4
Kotulpur	1,737	0	0.00	2	0.12	0	2
Mejia	867	4	0.46	61	7.04	4	23
Onda	3,378	1	0.03	1	0.03	1	1
Patrasayer	1,704	0	0.00	0	0.00	0	0
Raipur	2,462	11	0.45	29	1.18	5	22
Ranibundh	2,104	0	0.00	6	0.29	0	5
Saltora	1,969	43	2.18	131	6.65	31	59
Sarenga	1,425	2	0.14	0	0.00	2	0
Simlipal	2,149	167	7.77	68	3.16	95	57
Sonamukhi	1,704	1	0.06	0	0.00	1	0
Taldangra	3,140	21	0.67	33	1.05	12	19
Total	**52,834**	**413**	**0.78**	**1,046**	**1.98**	**276**	**600**

Source: Ministry of Drinking Water & Sanitation. Government of India. Integrated Management Information System (IMIS). 2013–2017. http://indiawater.gov.in/imisreports/nrdwpmain.aspx.

59. Ten blocks were found to have groundwater sources with more than 0.4% fluoride exceedance, five were found to have <0.4% exceedances, and five more had no exceedances (Table 12). Simlipal is the worst-affected block with 95 habitations recording fluoride concentrations >1.5 mg/L.

60. An independent analysis carried out with updated data sourced from PHED indicated that 296 habitations were affected by fluoride in 17 blocks of Bankura district (Table 13).

Table 13. Fluoride-Affected Blocks in Bankura District

Name of block	**Fluoride-affected habitations** (>1.5 mg/L)
Bankura I	5
Bankura II	27
Barjora	12

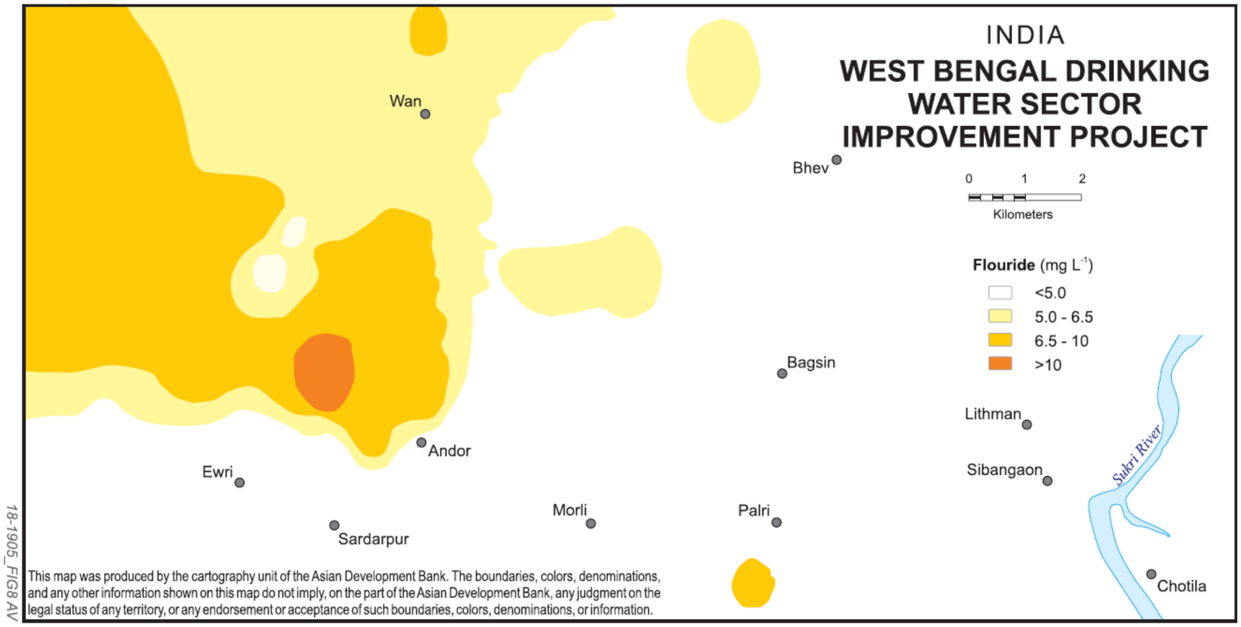
Name of block	Fluoride-affected habitations (>1.5 mg/L)
Chhatna	52
Ganjagalghati	19
Hirabandh	10
Indpur	7
Indus	1
Khatra	8
Mejia	4
Onda	2
Raipur	6
Saltora	28
Sarenga	2
Simlipal	100
Sonamukhi	1
Taldangra	12

Source: Public Health Engineering Department. Government of West Bengal. Integrated Management Information System (IMIS).30 April 2016.

XIII. MECHANISMS OF FLUORIDE MOBILISATION

61. High-fluoride ground waters in India are not exclusive to but are a particular problem of arid and semi-arid regions. Here, groundwater movement is slow, chemical reactions in aquifers pronounced, and evaporation rates high. Solutes derived by the reactions and concentrated by evaporation are less diluted by recharge. Fluoride problems are a feature of the areas of crystalline basement, particularly those composed of granite or gneiss. Granitic rocks contain a high proportion of fluorine-rich minerals (Edmunds and Smedley, 2013). As an example, Figure 5 shows the close relationship between occurrences of granite and groundwater fluoride concentrations in a region of Rajasthan.

Figure 5. Fluoride Distributions and Geology of Sirohi District, Rajasthan



Source: P. B. Maithani et al. 1998. Anomalous fluoride in groundwater from western part of Sirohi district, Rajasthan, and its crippling effects on human health. *Current Science*. Vol. 74, 773-777.

62. An important additional feature of high-fluoride groundwater is the usually low range of dissolved calcium concentrations. This is because fluoride mobility is largely controlled by the solubility of the mineral fluorite (CaF_2) such that presence of dissolved calcium limits the amount of dissolved fluoride. Granitic rocks have low calcium contents, and the increased influence of groundwater evaporation in arid conditions may promote precipitation of the mineral calcite ($CaCO_3$) with further calcium loss, creating the conditions for increased fluoride dissolution in ground water.

63. Fluoride concentrations in groundwater have been observed to vary with water levels, for example, pre- and post-monsoon periods. Das and Nag (2016) observed either no change or reductions in post-monsoon relative to pre-monsoon fluoride concentrations in groundwater from 26 tube wells in Suri I and Suri II blocks, in the Birbhum district, West Bengal. The variations can be explained by post-monsoon dilution of groundwater, as a result of recharge from the rains into the ground water. Investigations carried out revealed that, two sites out of the 26 had groundwater with more than the 1.5 mg/L drinking-water limit, in both pre-monsoon and post-monsoon conditions (up to 2.8 mg/L).

64. In some situations, fluoride concentrations in groundwater have been observed to increase with depth (e.g., Brindha et al., 2016). Where apparent, this observation has typically been explained by increasing groundwater residence time and water-rock reactions. Depth variations in fluoride concentrations may also be a response to differing geology (surface-weathered layers vs. deeper fresher rock with mineralized fractures) (Brindha et al., 2016). The depth variation has led in some cases to the promotion of shallow groundwater, e.g., from dug wells. However, concentrations have been reported in some cases to decrease with depth and recommendations against the use of water from shallow dug wells have also been made (Bhagavan and Raghu, 2005). Depth variation is therefore seemingly not easily predictable, and groundwater fluoride distributions are site-specific.

XIV. GROUNDWATER FLUORIDE MITIGATION MEASURES

65. PHED has prepared a comprehensive action plan on fluoride mitigation in West Bengal. This has an estimated cost of $235 million and will be implemented in a phased manner in the 43 fluoride-affected blocks of seven districts (Bankura, Birbhum, Dakshin Dinajpur, Malda, Purulia, South 24 Parganas, and Uttar Dinajpur). Technological options for fluoride treatment are being explored where no alternative surface-water source is available nearby (Table 14).

Table 14. Pros and Cons of Groundwater Fluoride Mitigation Options, West Bengal

Mitigation measure	Pros	Cons
Dug well	Inexpensive, many exist already	Not well accepted by the people of West Bengal; prone to surface-borne contamination. Limited supply. May dry up in the dry season.
Hand-pumped/motorized tube well	Many are low in fluoride, even in affected areas	Needs to be tested for fluoride and monitored.
Rainwater harvesting	Sufficient rainfall to allow collection	Contamination of water during collection and storage.
Off-site fluoride removal	Household or community scale, various established methods	Requires regular maintenance; may impart taste to treated water; some residues may remain; sludge disposal;

Mitigation measure	Pros	Cons
		requires monitoring; capacity may be limited; sustainability is questionable.
Managed aquifer recharge (MAR) schemes	No sludge removal, various methods applicable for differing settings	May not be effective against fluoride, needs monitoring.
Piped water supply (groundwater or surface water)	Potential for household supply, improved water quality, and hygiene; convenience. Improved long-term security. Centralised treatment with efficiencies	High capital cost, requires maintenance and monitoring.

66. A significant number of piped water-supply schemes have already been commissioned in fluoride-affected districts, and others are in progress to supply fluoride-free drinking water in the affected areas of the state (Table 15).

Table 15. Coverage by Piped Supply Schemes in Fluoride-Affected Districts of West Bengal

District	Rural population	Total population	No. blocks	No. water supply schemes	Scheme Started	% served by piped supplies
Bankura	3,296,901	3,596,674	22	60	May 2017	21.3
Burbhum	3,052,956	3,502,404	19	64	Jun 2017	35.0
Dakshin Dinajpur	1,439,981	1,676,276	8	54	May 2017	33.4
Malda	3,447,185	3,988,845	15	116	May 2017	58.1
Purulia	2,556,801	2,930,115	20	42	May 2017	27.0
South 24 Parganas	6,074,188	8,161,961	29	189	May 2017	46.1
Uttar Dinajpur	2,644,906	3,007,134	9	67	Jun 2017	17.4

Source: http://www.wbphed.gov.in/main/

67. Of the recognized fluoride-affected districts, two of the least well-served are Bankura and Uttar Dinajpur (Table 15).

68. The options for mitigation of fluoride problems are more limited in drought-prone areas, which are typical of fluoride terrains. Mitigation measures include survey and monitoring of tube wells/dug wells to identify groundwater sources with sustainably low concentrations (<1.5 mg/L), rainwater harvesting (possibly for parts of the year), community-scale groundwater or surface-water treatment (Haldar and Ray, 2014), shallow aquifer storage ('subsurface' storage), managed aquifer recharge (MAR), or piped supply.

69. The main objectives of MAR schemes are to increase storage volume in aquifers or to treat water or wastewater via subsurface filtration (Maliva, 2014). MAR is an established technology that has operated successfully over many years in many countries, including India. It has been adopted effectively in arid and semi-arid areas (Tuinhof and Heederik, 2002). MAR schemes have shown a marked expansion in India since the mid-1990s; Chadha (2002) described a national master plan for the development of a total area of 450,000 km^2 for MAR to store 36 billion m^3 of water, including 37,000 percolation tanks, 110,000 check dams, 48,000 recharge wells, and 26,000 gabion structures.

70. The MAR schemes tend to be economically viable provided that hydrogeological conditions are favorable and end use is high value (i.e., potable water) (Maliva, 2014). Potential additional benefits include reduced groundwater pumping costs, maintenance of spring flows and alleviation of saline intrusion.

71. MAR has long been suggested as a means to reduce fluoride concentrations in groundwater, as well as to augment groundwater resources. MAR schemes have been implemented through the construction of check dams, recharge wells, percolation ponds and/or tanks, and infiltration galleries (Box 2). Positive benefits in terms of fluoride concentrations have been demonstrated in water-supply wells locally from the introduction of check dams (Bhagavan and Raghu, 2005; Brindha et al., 2016) and dug recharge wells (Brindha et al., 2016).

72. Despite these observations, documentation on MAR implementation appears to suggest mixed outcomes for fluoride mitigation (Brindha et al., 2016) as well as for water budgets (Boisson et al., 2015). Some supply wells have shown limited changes, or even increased fluoride concentrations (Bhagavan and Raghu, 2005). Raising the groundwater level can bring previously unsaturated aquifer horizons into the zone of water-level fluctuation, the mineralogy, and texture of which may influence water quality (e.g., Hallett et al., 2015). Raising the groundwater level to a point near the ground surface could also increase concentrations of fluoride and dissolved salts through evaporation. The potential of MAR schemes for fluoride mitigation is therefore significant, but the outcomes are site-specific and require monitoring.

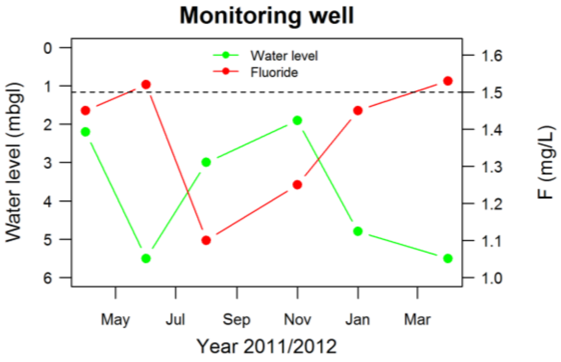
Box 2. Managed Aquifer Recharge for Fluoride Mitigation

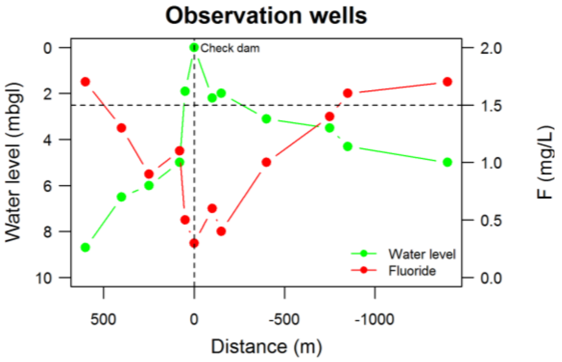
Enhancing recharge to a shallow aquifer via the introduction of structures such as percolation ponds, check dams, infiltration galleries, and recharge wells can help to mitigate problems with high concentrations of fluoride in groundwater, as well as replenishing stocks of groundwater.

Recharge wells: One pilot project in Dharmapuri-Krishnagiri: Harur Taluk in Tamil Nadu, set up by academics of Anna University, created a 1.5 m wide structure to induce recharge to a nearby well. Concentrations of fluoride in the well were observed to fall from 4 mg/L to 0.2 mg/L over time, which allowed use for potable supply.

Induced recharge structure, Dharmapuri district, Tamil Nadu

Check dams: Check dams have also shown evidence of reducing local groundwater fluoride concentrations (<1 km radius of influence). A pilot in Tamil Nadu also showed a reduction in fluoride concentrations over the area of influence of the recharge (<1 km).





The graphs above show a reduction in fluoride concentration with increased groundwater level in a MAR monitoring well. Observation wells across the area of influence have lower fluoride concentrations close to the check dam across the Pambar River, highlighting the diluting effect of MAR on local groundwater (Brindha et al., 2016). In these cases, dilution has brought concentrations of fluoride down from just above the drinking-water limit within the area of influence.

73. In other nations, where mitigation efforts have been instigated to reduce fluoride exposure from groundwater, approaches tend to involve surface treatment of varying scales (domestic to municipal and centralized) or installation of piped supplies. Coagulation with alum—a form of the Nalgonda technique—has probably been applied most widely, including in Ethiopia, Kenya, and

Tanzania as well as in India. However, frustrations with the efficacy and operation of the Nalgonda technique due to the partial removal of fluoride and production of sludge, have more recently led to a shift towards the use of bone char as a fluoride removal medium in East African countries (Dahi, 2016). This has greater removal efficacy than alum and is usually readily available locally.

74. In the People’s Republic of China, fluoride occurrences have been mitigated most commonly by the provision of piped water supplies, although defluorination methods (e.g., activated alumina or electrodialysis) have also been applied in some areas (Wang et al., 2012).

XV. CONJUNCTIVE WATER USE

75. The stated aim of the Government of West Bengal’s Vision 2020 program is to move away from reliance on groundwater from hand-pumped tube wells for potable supply. This staged transition involves the implementation of piped water supply schemes with household connection where feasible but recognizes the value of the conjunctive use of surface water, good-quality groundwater, and rainwater as part of an integrated water supply strategy for the state.

76. The strategy includes construction of check dams and tanks or bunds, development and rehabilitation of surface ponds, development of shallow groundwaters and infiltration galleries in stream beds (sub-surface sources), use of collector wells, and development of protected dug wells with hand pumps where feasible. Rainwater harvesting is an additional option that has been little tested in West Bengal but offers some prospects, especially for part of the year. All methodologies have pros and cons, with feasibility dependent in each case on local geological, socio-economic, land use, and climatic factors.

77.

Table 16 provides a list of piped supply schemes implemented or planned by PHED in West Bengal. Schemes include both surface water, groundwater sources, and sub-surface water schemes (riverbed abstraction), instigated for mitigation of arsenic and fluoride.

Table 16. Piped Supply Schemes (Groundwater or Surface Water, Planned or Implemented for Arsenic or Fluoride) in West Bengal

Piped supply scheme	District	Blocks	No. villages to be covered	Population (2011) to benefit	Est. cost (lakh Rs.)	Est. commission date	Water source
Bally Jagacha	Howrah	Bally Jagacha	9	209,504	15,068	2017	River Hooghly
Bally-Jagachha	Howrah	Domjur	19	68,125	4,588.00	2019	River Hooghly
Balupur	Malda	Ratua-I	24	54,390	2,239.76	2007	River Fulhar
Bankura	Bankura	Bankura - I, Bankura - II, Barjora, Bishnupur, Chhatna, Hirbandh, Indus, Khatra, Onda, Raipur,	1897	2,141,370	101,122	2016 (partially commissioned)	Surface Water/ Sub-Surface water and Groundwater: River Dwarakeswar

Piped supply scheme	District	Blocks	No. villages to be covered	Population (2011) to benefit	Est. cost (lakh Rs.)	Est. commission date	Water source
		Ranibundh, Saltora, Sarenga, Simlapal					, Kangsabati, Damodar
Barasukjora	Paschim	Binpur II	36	16,868	2,136.09	2016	Surface water (Dam)
Beldanga	Murshidabad	Beldanga I	58	754,451	6,708.78	2017	River Bhagirathi
Beldanga	Murshidabad	Beldanga Municipality	4 Wards	72,911	1,279	2003	River Bhagirathi
Beniagram	Murshidabad	Farakka	16	82,967	2,146	2016	River Bhagirathi
Birbhum	Birbhum	Suri-I, Suri-Ii & Sainthia	58	61,569	5,759.53	2018	Sub-surface water of River Mayurakshi
Bolpur–Raghunathpur	Birbhum	Bolpur-Sriniketan	144	316,489	8,797.38	2002	Groundwater
Surface water scheme for Chakdah	Nadia	Chakdah (P)	114	406,103	10,198	2014	River Bhagirathi
Chunakhali	South 24 Parganas	Basanti	5	26,285	1,327.19	2015	Groundwater
Dakshin Dinajpur	Dakshin Dinajpur	Tapan	279	250,504	16,550.05	2018	River Punarbhaba
Darjeeling	Darjeeling	Darjeeling Municipal, en-route villages		134,390	6,618.00	2012	Balason River
Dherua	Paschim Medinipur	Midnapur	96	32,701	2,147.08	2016	River Bank TW
Dual-use solar pump	Bankura/Purulia/ Paschim Medinipur	Raipur, Sarenga, Ranibandh, Simlapal	161	20,125	5,167.36	2016	Groundwater
Falta-Mathurapur	South 24 Parganas	Kulpi, Diamond Harbour I, II, Falta, Jaynagar II, Kultali, Magrahat I, Mandir Bazar, Mathurapur I, II	902	2,251,277	133,241	2016	River Hooghly
Goubazar Ichhapur	Burdwan	Durgapur-Faridpur	19	21,156	1,699.19	2016	Ajoy River
Gour and Mahadipur	Malda	English Bazar	24	23,187	691.19	2008	River Bhagirathi
Surface water scheme for Haringhata	Nadia	Chakdah (P), Haringhata	137	371,773	11,898	2014	River Bhagirathi
Hingalganj	North 24 Parganas	Hingalganj	7	34,428	2,979.6	2018	Groundwater
Jaigaon Development Area (JDA)	Alipurduar	Kalchini			9,372		River Torsa

Piped supply scheme	District	Blocks	No. villages to be covered	Population (2011) to benefit	Est. cost (lakh Rs.)	Est. commission date	Water source
Jamgara Jagannathpur	Burdwan	Durgapur-Faridpur	9	14,549	971.72	2016	Ajoy River
Kalabani	Purulia	Hura	20	26,682	1,406.14	2017	Surface water of Futiary Dam
Madandi	Purulia	Neturia	18	13,028	1,668.76	2018	Sub-surface water of River Damodar
Mahayampur	Murshidabad	Beldanga-I	6	53,486	654.31	2008	River Bhagirathi
Malda Phase I	Malda	Manikchak, English Bazar	122	403,542	8,848	2000	River Fulhar
Malda Phase II	Malda	Kaliachak-I, II & III	158	702,722	4,300	2009	River Bhagirathi
Manbazar II	Purulia	Manbazar-II	57	44,591	4,036.46	2016	Surface water (Dam)
Mathurabil	North 24 Parganas	Barrackpur-I	15	61,814	1,192.63	2017	Pond water
Mukutmanipur	Bankura	Khatra	72	73,616	2,171.06	2008	Mukutmanipur Dam
Mukuundobag/ Jiaganj-Azimganj	Murshidabad	Murshidabad Jiaganj (part), Azimganj Municipality	27	46,673	1,677	2016	River Bhagirathi
Murshidabad Central Sector	Murshidabad	Hariharpara, Berhampur (pt)	105	659,684	18,346	2016	River Bhagirathi
Surface water scheme for Murshidabad Central	Murshidabad	Murshidabad-Jiaganj & Berhampore	135	379,692	10,722.4	2014	River Bhagirathi
Surface water scheme for Nadia	Nadia	Nadia/Kaliganj, Nakashipara, Krishnanagar-II (P), Nabadwip (P)	291	910,638	24,594.96	2010	River Bhagirathi
Nayagram	Paschim	Nayagram	192	76,539	7,495.00		River Subarnarekha
North 24 Parganas	North 24 Parganas	Habra-I&II, Gaigahta,Amdanga (Part), Deganga (Part), Barrackpore	335	11,854	57,772	2018	River Hooghly
North 24 Parganas	North 24 Parganas	Block (Tapas)	6	37,823	6,353.29	2017	Groundwater
Surface water scheme for North 24 Parganas	North 24 Parganas	Barrackpur-I, Barasat-I, Amdanga, Deganga	234	719,555	14,314	2008	River Hooghly
Surface water scheme for	South 24 Parganas	Budge Budge-II, Bishnupur-I	688	2,951,000	39,537	2007	River Hooghly

Piped supply scheme	District	Blocks	No. villages to be covered	Population (2011) to benefit	Est. cost (lakh Rs.)	Est. commission date	Water source
South 24 Parganas		& II, Bhangar-I, Baruipur, Sonarpur, Mograhat-II, Joynagar-I					
Panskura-II	Purba/ Medinipur	Kolaghat	112	247,000	18,662.52	2017	River Rupnarayan
Pardeonapur	Maldah	Kaliachak III	17	39,324	3,128.08	2017	Surface water
Purbasthali	Bardhaman	Purbasthali-II	62	123,455	3,978	2011	River Bhagirathi
Purulia	Purulia	Purulia-I/II, Pura, Hura, Puncha, Kashipur, Raghunathpur-I, Manbazar-I, Barabazar	1098	1,046,758	117,310	2019	River Kumari, Kangsabati, Dwarakeswar
Raghunathganj	Murshidabad	Raghunathganj – I	63	184,564	5,108	2013	River Bhagirathi
Raghunathpur	Purulia	Neturia, Raghunathpur-I & II	101	110,622	46,822.43	2002	River Utala
Raipur	Bankura	Raipur	26	34,612	2,120	2017	River Kangasabati
RCFA Part I	Bardhaman	Salanpur, Barabani, Asansol (Part), Kulti (Part)	217	1,241,335	365	1973	Surface water of Maithon Reservoir
RCFA Part II	Bardhaman	Jamuria, Asansol, Raniganj,Ondal, Hirapur, Durgapur-Faridpur	119	712,000	5,325	2003	Subsurface flow of River Damodar (collector well)
RCFA Part III	Bardhaman	Durgapur-Faridpur	26	96,176	1,900	2008	Subsurface flow of River Ajoy
Siliguri	Darjeeling	Siliguri Municipal Corporation	47 Wards	509,709	4,617.55	2000	Tista Mahananda Link Canal
Sub-surface fluoride scheme	Dakhin Dinajpur	Gangarampur	203	237,628	14,501.52	2018	River Punarbhaba

Source: Government of West Bengal. http://www.wbphed.gov.in/main.

78. Water treatment to remove arsenic or fluoride has been a common practice in affected areas of West Bengal, but these are short-term solutions pending the provision of a more sustainable potable supply. Problems with maintenance, lack of testing, user acceptability, and disposal of arsenic, fluoride concentrated sludge are critical issues, all of which compromise on available treatment systems as sustainable options for arsenic and fluoride mitigation. On-site treatments for arsenic offer more promise on a local scale but are dependent on local factors such

as aquifer permeability and initial groundwater chemistry. They also require local maintenance and have not been widely adopted in West Bengal. On-site treatments may constitute a local mitigation option in some areas but are unlikely to be a large-scale and long-term solution. MAR schemes are better established for enhancing recharge and improving overall water quality but still need further evaluation as a sustainable mitigation strategy for fluoride. For both on-site strategies (for either arsenic or fluoride), a proportionate and reliable water-quality testing regime is required.

XVI. WATER-QUALITY TESTING

79. Improved provision has been made for laboratory testing facilities since the Government of India initiated a national rural drinking-water-quality monitoring and surveillance program in 2006. In West Bengal, some 116 testing laboratories are operational, managed by PHED and NGOs. Capabilities include testing for arsenic, fluoride, and salinity. Sanitary surveys are also conducted routinely, and data are georeferenced. Data are entered into a web-based system and stored on the Ministry of Drinking Water and Sanitation integrated management information system (MDWS IMIS) database. Local stakeholder engagement (e.g., at *Gram Panchayat* level) ensures collaboration in sample collection, sharing of analytical results, awareness campaigns, and demand for monitoring and surveillance services.

80. Testing of water samples follows protocols in Standard Methods for Examination of Water and Wastewater (APHA). Some 5% of samples are retested in a PHED laboratory. As of 2013, some 130,000 samples for arsenic and 52,000 for fluoride had been tested in West Bengal.[20] Data are mapped in a global information system.

81. Some NGOs used field test kits (e.g., for arsenic), but these have not been adopted significantly by government-managed laboratories.

XVII. CONCLUSIONS

82. Around 9–11 million people in West Bengal are estimated to have been drinking water with arsenic concentrations above the BIS limit of 10 µg/L out of a total of 12.9 million nationally. This makes West Bengal the worst-impacted state of India by far.

83. Some 517,000–615,000 people in West Bengal are estimated to be or have been drinking water with fluoride concentrations above the BIS limit of 1.5 mg/L, with an estimated 67 million exposed nationwide.

84. The regional occurrence of high-arsenic and high-fluoride groundwaters across India is distinct, with arsenic problems for the most part being a feature of the large alluvial-deltaic plains of the north-east and fluoride problems a feature of the hard-rock aquifers of central and peninsular India. Exceptions occur where arsenic mobility is associated with metalliferous mineralization, with or without mining activity. In states where both alluvial-deltaic and basement aquifers are represented, problems with both trace elements can result, though not in the same aquifers. Such is the case with West Bengal. Aquifers of the western part of the state are composed of crystalline granite-gneiss complexes, while those of the eastern and northern parts comprise Holocene alluvial-deltaic deposits.

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[20] Government of West Bengal, Public Health Engineering Department. http://www.wbphed.gov.in/main/index.php/water-testing-laboratories.

85. Problems with arsenic in West Bengal are usually restricted to the Holocene alluvial/deltaic aquifer where groundwater is anoxic, and arsenic mobilized from the unconsolidated sediments. Shallow groundwater from dug wells is typically more toxic and has lower concentrations of arsenic (<10 µg/L). Groundwater from a deeper Pleistocene aquifer also has usually low concentrations of arsenic (<10 µg/L) as arsenic is more strongly bound and sediments have been flushed by flowing groundwater for longer periods. Exceptions do occur, however, in both shallow dug wells and deep Pleistocene groundwater. The Pleistocene aquifer is especially vulnerable to contamination from above in the event of aquifer over-pumping and/or completion with poor well seals.

86. In either arsenic- or fluoride-affected districts, not all tube wells have concentrations of arsenic or fluoride above the respective drinking-water limits, and percentage exceedances vary from region to region. The concentrations of both arsenic and fluoride can show considerable variation over short ranges and use of groundwater for potable supply in at-risk areas needs a comprehensive water-quality testing and monitoring program.

87. Large water testing programs have been implemented to ascertain, map and mitigate the occurrence of arsenic and fluoride in groundwater across affected states. Many groundwater sources remain untested, however, and monitoring is uncommon. Understanding the design of surveys from available databases is difficult and the representativeness of sampling therefore not always clear.

88. Many testing laboratories have been set up, often locally, to deal with the major requirement for analytical facilities. Quality assurance information is difficult to obtain, and accreditation of laboratories is little developed.

89. Where groundwater is unsuitable for use, mitigation options include the use of alternative aquifers, rainwater harvesting, locally treated surface water, or treatment of groundwater above ground or on-site, as well as the supply of piped surface water or groundwater. Feasibility and efficacy of these options is element- and location-specific. Feasibility depends on factors such as local hydrography, geology, aquifer permeability, and groundwater level and/or trend, rainfall, and downstream conditions, as well as socio-economic factors such as governance, ownership, and willingness to pay.

90. For fluoride, on-site mitigation is feasible in principle in the form of MAR schemes, which are long-established in India for enhancing groundwater storage and improving water quality, albeit not for fluoride mitigation specifically. For arsenic, on-site treatments are available, but applications in developing countries tend to have been on pilot scales. Methods based on arsenic oxidation are more widely tested than reduction methods.

91. Supply of piped treated water to arsenic- or fluoride-affected areas offers a greater certainty in water quality and water security in the long-term. Decisions depend on prioritization (worst-affected areas), logistics, cost, and feasibility of local alternatives.

XVIII. RECOMMENDATIONS

92. Provision of piped water schemes with household connection is the priority aim of the state government, but potential difficulties for blanket coverage in some rural areas may require flexibility and adoption of conjunctive schemes for water supply provides a pragmatic approach.

93. For mitigation of arsenic problems, development of alternative supplies of groundwater from the deeper Pleistocene aquifer has been implemented in some areas. Questions remain over sustainability of supply from this deep aquifer in the event of increased abstraction, especially in cases of poor tube well integrity, or situations with inadequate separation of the aquifers by an intervening clay layer. Observed exceedances above 10 µg/L in some sources from the Pleistocene aquifer support this concern. The strategy requires care with tube well integrity on construction as well as abstraction management, and a robust monitoring regime to ensure sustainable water quality. A strong case exists for limiting the use of the deep aquifer for purposes other than potable supply.

94. Use of shallow groundwater from dug wells also offers mitigation of arsenic problems, although it presents risks loss of supply in dry periods and contamination from other surface-borne pollutants. Improvements in water quality can be achieved by surface well protection and disinfection. Here, conjunctive use with additional supplies from alternative tube wells or rainwater harvesting could be applied in areas where piped supply is infeasible.

95. On-site treatment schemes for arsenic removal have been tried in some areas, including in West Bengal, and could be developed, at least on a pilot scale, as part of the mitigation strategy. Oxidation schemes have been applied more widely than reduction schemes and will offer the greater amount of experience. Developed schemes require monitoring and efficacy, especially in the long-term. Such schemes are unlikely to develop on a large scale.

96. For fluoride mitigation, many MAR schemes have been implemented although consensus on efficacy in fluoride reduction is so far lacking. Schemes could be adopted more widely in West Bengal as part of a mixed water supply strategy. Specific approaches such as percolation tanks, check dams, recharge wells, infiltration gallerie and/or streambed tube wells, depend on local factors and suitable methodologies will, therefore, be location-specific.

97. Key factors in MAR efficacy and cost-effectiveness include recharge source, volume, mechanism and structure (percolation pond, check dam, infiltration gallery, downstream water needs, groundwater depth and trend, and aquifer mineralogy and storage capacity (permeability). MAR offers significant prospects for fluoride mitigation, but schemes need to be planned and monitoring incorporated into the management strategy.

98. Rainwater harvesting has apparently not been adopted widely in West Bengal but could be developed further if issues with maintaining microbial quality on storage (during the lean season,) can be addressed. Harvesting schemes can form a partial supply option if supplies are not continual (year-round).

99. For either arsenic or fluoride mitigation, off-site (wellhead) treatments at community or domestic scale are not long-term sustainable solutions and should constitute a last resort or short-term measure.

100. With all supply options, a robust testing and monitoring regime for water quality is a requirement to ensure confidence in the continued supply of safe drinking water and compliance with BIS standards. Quality assurance systems are not yet widely adopted in participating laboratories and expansion of such systems is a necessity.

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