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Special Issue

Arsenic in Ground Water in India

Central Ground Water Board
Ministry of Water Resources
Government of India

भू-जल न्यूज़

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Bhu-Jal News - Quarterly Journal of Central Ground Water Board with the objective to disseminate information and highlight various activities and latest technical advances in the field of Ground Water.

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Chairman's Page

Bhujal News, our esteemed journal is now reaching to many individuals interested in reading about latest research in ground water science, as it is made available in the website of CGWB. I am sure that users from different organisations shall have their knowledge enriched by referring the Bhujal News.

Central Ground Water Board is vested with responsibilities to carry out scientific surveys, exploration, monitoring, management and regulation of country's vast ground water resources. Central Ground Water Board through its sixteen Regional chemical laboratories, carry out chemical analysis of major and minor inorganic constituents, including Arsenic in water samples. Central Ground Water Board took a pivotal role in conducting field studies for finding out the causes of high incidence of arsenic and its mobilisation in shallow ground water in West Bengal, Bihar, U.P and also to find out the remedial measures. CGWB in collaboration with Central organisations like NGRI, BARC, NIH etc , State Govt. Organisations and institutes also took several studies to tackle up the Arsenic menace in the country.

During the last 25 years Bhujal News, Journal of CGWB has achieved many milestones by publishing several special issues on important topics related to Ground Water. The present issue on "Arsenic in ground water in India" is another feather in its cap. I am happy to inform that Bhujal News is celebrating its silver jublilee year of publication in 2010 and issues on latest research in ground water will be published in the forthcoming issue of Bhujal News.

B.M.Jha
Chairman, CGWB

Editorial

Arsenic contamination of ground water in India and related health hazards are becoming a growing concern among people, govt organisations and academic institutions. For the last twenty five years, considerable research work has been carried out to understand the causes, effects and remedial measures to combat the Arsenic menace in India and abroad. To disseminate knowledge on the subject for tackling such challenges, it has been decided to publish a special issue of Bhujal News on "**Arsenic in ground water in India**".

The present issue contains 10 selected papers on Arsenic contamination in India. S.Kunar et al in their paper "Arsenic in ground water in India: An overview", elaborates overall scenario of Arsenic in India. M.K.Sengupta along with other co-authors recounts their 19 years study on ground water arsenic contamination in Ganga- Meghna-Brahmaputra plain of West Bengal. Dr A.Mukherji et al have presented the occurrence of high Arsenic in ground water in Chhattisgarh, establishing various geological controls over them. D.Chatterji with his team has enumerated the geochemistry of Arsenic in Bengal delta plain aquifers. P.K.Sikdar et al in their paper have given an approach of wetland management and artificial recharge of arsenic contaminated aquifer in Nadia district. Dr D.Saha, et al have described issues related to high arsenic in ground water in parts of middle Ganga plain of Bihar. T.Talukdar et al have detailed on causes and mobilisation of Arsenic in ground water, including mitigation in North 24 pargana district, West Bengal. G.C.Saha, et al discusses Ground water Arsenic contamination in Majuli island, Jorhat district, Assam. D.S.Pandey et al have described the problem of Arsenic contamination in Balia district, U.P, while K.K.Srivastava et al writes about the technology options for utilisation of Arsenic contaminated ground water. It is hoped that findings of the papers in this issue will benefit our readers.

Dr S.K.Jain
Editor

ARSENIC IN GROUND WATER IN INDIA: AN OVERVIEW

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INTRODUCTION

Drinking water is one of the most important pathways of exposure to arsenic in human population and groundwater as a drinking source is thought to be responsible for the majority of the world's chronic arsenic related health problems. Arsenic contamination in ground water has emerged as a major quality problem and health hazard in parts of the country. In India first reported case of arsenic contaminated ground water was detected in the year 1978 in West Bengal and the first case of arsenic poisoning there were diagnosed in 1983 by the School of Tropical Medicine (STM) and All India Institute of Hygiene and Public Health (AIIH & PH). It was observed that the people suffering from arsenical dermatosis , were consuming ground water and when the samples of ground water of the respective area were chemically analysed, those were found to contain arsenic beyond the permissible limit of 0.05 mg/l.

As per the BIS Standard for drinking water (BIS 1991 and subsequent modifications), the maximum permissible limit of Arsenic concentration in ground water is 0.01 mg/l. The Arsenic concentration in ground water >0.05 mg/l, as permissible limit has been taken up based on recommendation of the task force set up in West Bengal. 0.05 mg/l has been accepted as regulatory limit for the country. This was also recommended as permissible limit by earlier BIS standard.

OCCURRENCE AND DISTRIBUTION OF HIGH ARSENIC IN GROUND WATER

With emphasis on drinking water related public health hazards and enhancement of analytical facility, large-scale analyses of spot sources have been taken up under departmental programme by several Central and State Government agencies and by various academic institutions and research organizations. Investigations by Central Ground Water Board (CGWB) reveals that arsenic contamination (> 0.05 mg/L) is affecting the states of West Bengal, Bihar, Uttar Pradesh, Assam, Chhatisgarh. The Bengal Delta Plain (BDP) covering Bangladesh and West Bengal in India is the most severe case of groundwater arsenic contamination. Besides this high Arsenic ground water has also been reported from Jharkhand and Manipur state.

The details of State wise occurrences are as follows:

West Bengal

The occurrence of high Arsenic in ground water was first reported in 1978 in West Bengal in India.In West Bengal, 79 blocks in 8 districts have Arsenic beyond the permissible limit of 0.05 mg/l. The most affected areas are on the eastern side of Bhagirathi river in the districts of Malda, Murshidabad, Nadia, North 24 Parganas and South 24 Parganas and western side of the districts of Howrah, Hugli and Bardhman. Arsenic in ground water is confined mainly in the aquifers upto 100 m depth. The deeper aquifers are free from Arsenic contamination. At present about 162.6 lakh people(35.48% of the total population of the state) live in the risk zone of potential threat in terms of Arsenic related diseases. The details of affected blocks with maximum concentration of Arsenic are produced in Table-I

Table-I. Affected Blocks of High Arsenic(>0.05 mg/litre)in Ground Water in West Bengal

Sl. No.	District	Name Of Blocks Affected With High Arsenic	Max.Value Of Arsenic In mg/litre
1	Bardhman	Kalna -II	0.620
2	Bardhman	Katwa -I	0.101
3	Bardhman	Katwa -II	0.835
4	Bardhman	Purbasthali -I	0.618
5	Bardhman	Purbasthali- II	0.572
6	Hooghly	Balagarh	0.510
7	Howrah	Shampur- II	>0.05
8	Howrah	Uluberia -II	0.155
9	Malda	English Bazar	0.945
10	Malda	Kaliachak- I	0.747
11	Malda	Kaliachak- II	0.917
12	Malda	Kaliachak- III	1.045
13	Malda	Manickchak	0.944
14	Malda	Ratua -I	0.894
15	Malda	Ratua -II	0.333
16	Murshidabad	Lalgola	0.565
17	Murshidabad	Beldanga I	0.784
18	Murshidabad	Beldanga II	0.631
19	Murshidabad	Berhampur	2.186
20	Murshidabad	Bhagwangola I	3.000
21	Murshidabad	Bhagwangola II	0.840
22	Murshidabad	Domkal	1.605
23	Murshidabad	Farakka	0.508
24	Murshidabad	Hariharpara	1.810
25	Murshidabad	Jalangi	2.037
26	Murshidabad	MurJiaganj	0.890
27	Murshidabad	Nowda	0.727
28	Murshidabad	Raghunathganj II	0.812
29	Murshidabad	Raghunathganj I	0.254
30	Murshidabad	Raninagar I	0.990
31	Murshidabad	Raninagar II	1.210
32	Murshidabad	Samsherganj	0.301
33	Murshidabad	Suti I	0.696
34	Murshidabad	Suti II	0.662
35	Nadia	Chakdah	0.824
36	Nadia	Chapra	0.514
37	Nadia	Hanskhali	0.526
38	Nadia	Haringhata	0.769
39	Nadia	Kaliganj	0.995
40	Nadia	Karimpur I	1.080
41	Nadia	Karimpur II	0.926
42	Nadia	Krishnaganj	0.771
43	Nadia	Krishnanagar I	0.629
44	Nadia	Krishnanagar II	1.161
45	Nadia	Nabadwip	0.712
46	Nadia	Naksipara	0.586
47	Nadia	Ranaghat I	1.072

Sl. No.	District	Name Of Blocks Affected With High Arsenic	Max.Value Of Arsenic In mg/litre
48	Nadia	Ranaghat II	0.741
49	Nadia	Santipur	0.459
50	Nadia	Tehatta I	0.544
51	Nadia	Tehatta II	0.340
52	North 24 Parganas	Amdanga	0.570
53	North 24 Parganas	Baduria	1.331
54	North 24 Parganas	Bagda	0.365
55	North 24 Parganas	Barackpore II	0.128
56	North 24 Parganas	Barackpore I	0.967
57	North 24 Parganas	Barasat I	0.531
58	North 24 Parganas	Barasat II	0.951
59	North 24 Parganas	Basirhat I	1.039
60	North 24 Parganas	Basirhat II	0.634
61	North 24 Parganas	Bongaon	0.539
62	North 24 Parganas	Deganga	0.693
63	North 24 Parganas	Gaighata	0.772
64	North 24 Parganas	Habra –I	0.590
65	North 24 Parganas	Habra –II	3.773
66	North 24 Parganas	Haroa	0.730
67	North 24 Parganas	Hasnabad	0.958
68	North 24 Parganas	Rajarhat	0.413
69	North 24 Parganas	Sandeshkhali II	0.120
70	North 24 Parganas	Swarupnagar	0.673
71	South 24 Parganas	Baruipur	2.560
72	South 24 Parganas	Bhangar- I	0.818
73	South 24 Parganas	Bhangar- II	0.762
74	South 24 Parganas	Bishnupur -I	0.237
75	South 24 Parganas	Bishnupur –II	0.085
76	South 24 Parganas	Budge Budge II	>0.05
77	South 24 Parganas	Joynagar I	0.611
78	South 24 Parganas	Mograhat II	0.217
79	South 24 Parganas	Sonarpur	2.715

Source: CGWB & State agency

Some of the findings of studies taken up by CGWB & Other organizations in the Arsenic affected area are as follows:-

- The top aquifer within 100mbgl is mostly arseniferous. Arsenic free deeper aquifers(below 100 mbgl) are potential with capacity to yield 5-20 litres per second(lps) and cater to the need of both rural and urban water supply.
- Hydrogeological tests on arseniferous aquifers (within 100 mbgl) have been conducted in different arsenic infested areas to observe the Arsenic concentration in ground water consequence to pumping of Arsenic water from the tube well. The results indicate that there is not much impact on Arsenic concentration of ground water due to pumping when the drawdown created remains within 6m (A.Ray, 2009)
- Artificial Recharge studies at Ashoknagar, Habra-II block, North 24 Parganas district, West Bengal has revealed that Arsenic concentration of 0.12 mg/l in ground water has been diluted to < 0.001 mg/l in 3 non monsoon months by recharging Arsenic free water into it.(A.Ray, 2009).
- A collaborative study between CGWB & BARC, Trombay in parts of Murshidabad, Nadia, North and South 24 Parganas district of West Bengal using

environmental stable isotopes (2H, 18O, 34S) and radio isotopes (3H, 14C) indicated that ground water from the shallow aquifers are mostly from modern recharge (< 50 years), whereas deep ground water is old(5000-13000 yrs).

- The major finding of the collaborative project between CGWB and United Nations Industrial Development Organization indicates that Arsenic removal equipments are effective in bringing down the concentration of input water to less than 0.01 mg/L. In few instances treated water had noticeable Arsenic concentration which it can mainly be attributed to poor maintenance and monitoring rather than any inherent weakness in the technology itself.

Bihar

Arsenic groundwater contamination in Bihar was initially detected in the year 2002 from Semariya-Ojhapatti villages of Bhojpur district. Detailed investigations in the Gangetic Plain of Bihar revealed its wide occurrence on both the banks of the river Ganga. Arsenic distribution is marked with wide spatial variability resulting in patchyness in distribution. Fifty seven blocks, in 15 districts, located on both the banks of Ganga are affected (CGWB &PHED, 2005). The list of affected blocks of high Arsenic in ground water in Bihar revealed through survey by CGWB & State agency are given in Table-II

Table-II. Affected Blocks of High Arsenic(>0.05 mg/litre)in Ground Water in Bihar

Sl. No.	District	Blocks Affected With High Arsenic	Max.Value Of Arsenic In mg/litre
1	Begusarai	Bachwara	>0.05
2	Begusarai	Balia	>0.05
3	Begusarai	Barauni	>0.05
4	Begusarai	Begusarai	>0.05
5	Begusarai	Matihani	>0.05
6	Begusarai	Sabehpurkamal	>0.05
7	Bhagalpur	Jagdishpur	>0.05
8	Bhagalpur	Nathnagar	>0.05
9	Bhagalpur	Sultanganj	>0.05
10	Bhojpur	Ara	0.426
11	Bhojpur	Barhara	0.420
12	Bhojpur	Behea	0.080
13	Bhojpur	Koilwar	0.306
14	Bhojpur	Shahpur	1.630
15	Bhojpur	Udawant Nagar	0.051
16	Buxar	Brahmpur	1.220
17	Buxar	Buxar	0.940
18	Buxar	Chakki	>0.05
19	Buxar	Semary	1.400
20	Darbhanga	Biraul	>0.05
21	Katihar	Amdabad	>0.05
22	Katihar	Barari	>0.05
23	Katihar	Kursela	>0.05
24	Katihar	Manihari	>0.05
25	Katihar	Mansahi	>0.05
26	Katihar	Sameli	>0.05
27	Khagaria	Gogri	>0.05
28	Khagaria	Khagaria	>0.05
29	Khagaria	Mansi	>0.05
30	Khagaria	Parbatta	>0.05
31	Kisanganj	Bahadurgarh	0.085

Sl. No.	District	Blocks Affected With High Arsenic	Max.Value Of Arsenic In mg/litre
32	Kisanganj	Kisanganj	0.058
33	Lakhisarai	Lakhisarai	0.230
34	Lakhisarai	Piparia	0.241
35	Munger	Bariarpur	>0.05
36	Munger	Dharhara	>0.05
37	Munger	Jamalpur	>0.05
38	Munger	Munger	>0.05
39.	Patna	Bakhtiarpur	>0.05
40.	Patna	Barh	0.584
41	Patna	Danapur	>0.05
42	Patna	Maner	1.810
43	Purnea	Kasba	0.067
44	Purnea	Purnea East	0.097
45	Samastipur	Mohanpur	0.626
46	Samastipur	Mohinuddin Nagar	0.370
47	Samastipur	Patori	>0.05
48	Samastipur	Vidyapati Nagar	>0.05
49	Saran	Chapra Sadar	0.205
50	Saran	Dighwara	>0.05
51	Saran	Revelganj	>0.05
52	Saran	Sonepur	0.230
53	Vaishali	Bidupur	>0.05
54	Vaishali	Desri	>0.05
55	Vaishali	Hajipur	>0.05
56	Vaishali	Raghopur	>0.05
57	Vaishali	Sahdei Bujurg	>0.05

Source- CGWB & State agency

Some of findings of the studies taken up by CGWB & Other organizations are as follows:-

- The patches of high groundwater Arsenic (>0.05 mg/L) zones are confined in Newer Alluvial belt along the river Ganga affecting both the Active and the Older Flood plains. The contamination, however, is confined within the top ~ 50 m of the thick multi-cyclic sand, clay, sandy clay and silty clay sequence.
- The Arsenic affected aquifers represent young groundwater. In a Joint Study with BARC, Trombay in Younger alluvial belt of Sone Ganga interfluves area covering Bhojpur district the Tritium (^{3}H) concentration of the shallow groundwater (generally 3.42-10.13 TU) reveals a substantial component of modern recharge and the age has been estimated as less than 40 years. Based on ^{14}C concentrations, the age of the groundwater from deeper low-Arsenic aquifers have been worked out as ~3000 years. The older age supports less permeable nature of the middle clay, holding the deeper aquifers under semi-confined to confined condition". (CGWB & BARC, 2009).
- The studies in Bhojpur, Buxar and Patna district (GSI, 2008) reveal that there could be broadly three separate depth zones, (i) down to 50ft (15.24m) from the surface (Arsenic content in ground water mostly <50 ppb and low incidence of Fe (ii) 50ft(15.24m) to 200ft(60.96m) depth (Arsenic content in ground water 10 ppb to >500ppb approx. and mostly with high incidences of Fe in localized pockets), (iii) 200ft (60.96m) to 300ft(91.44m) depth (Arsenic content in ground water <10ppb to 50ppb, and very clear water without any visible incidence of Fe). The available limited data below 300 ft depth suggest that there is no higher incidence of Arsenic (mostly <10ppb). The aquifer in all probability may be the Older Alluvium (Upper Pleistocene to Lower Holocene) occurring below the Older Flood Plain and Present Day Flood Plain Surfaces (Holocene).

Chhattisgarh

Arsenic contamination in ground water is reported along the N-S trending 80 km stretch of Kotri lineament from Chhattisgarh State. The severity is found in eastern part of Ambagarh Chowki block of Rajnandgaon district. The high Arsenic in ground water is restricted to small isolated area and are in cluster of few villages extended over 330 sqkm area and is confined to the Proterozoic rocks. The worst Arsenic affected villages are Kaurikasa, Joratari, Sonsaytola, Jadutola, Muletitola.
Some of the findings of studies conducted by CGWB & Other agencies are as follows:-

- The severely affected villages are situated on rhyolite and granite rocks close to shear zone. Elevated Arsenic in ground water is being controlled by various geological, structural, hydrogeological and geochemical factors. Ground water from basic rock aquifer is found invariably low in arsenic (0.009 to 0.049 mg/l). (CGWB, 2006).
- Bore wells and hand pumps are more affected than dug wells in general. This is more particularly applicable to the area where arsenic contamination is less. However in severly contamination area large numbers of dug wells are also found arsenic contaminated.
- Ground water with higher mineralization (EC> 800 μs/cm) are found invariably containing lower arsenic value, below 0.05mg/l (CGWB, 2006). Such control may also contribute toward providing safe and alternative drinking water.
- The high Arsenic in ground water in the area varies in the range of 0.050 to 1.89 mg/l (NEERI,2000)
- Large temporal variation in concentration of Arsenic is observed in the area. The Arsenic level in individual contaminated wells shows variation up to 35 times in different seasons. Arsenic concentration in ground water is influenced by dynamic ground water levels. (CGWB, 2006)

Uttar Pradesh

Arsenic in ground water (0.05 mg/l) in Balia district was reported in 2003 and further survey indicated the presence of contamination in 7 blocks of the district of Gazipur, Balia and Varanasi (School of Environmental studies(SOES), Jadavpur university). The Arsenic affected districts are mainly aligned along a linear tract along the river Ganga as observed in Bihar and West Bengal. However the reasons for same are not established. The presence of Arsenic in ground water has been observed by CGWB and state agencies as given in Table-III

Table-III. Locations of High Arsenic (>0.05 mg / litre) in Ground Water in U.P

SL.No.	DISTRICT	BLOCK	LOCATION	Arsenic Value(mg/litre)
UTTAR PRADESH				
1	Agra	Agra	Agra	0.062
2	Agra	Etmadpur	Samai	0.054
3	Agra	Fatehabad	Gautam Nagar	0.061
4	Agra	Khairagarh	Kakua	0.053
5	Aligarh	Jawan Sikandarpur	Jawan	0.052
6	Balia	Bairia	Balihar	0.195
7	Balia	Belhari	Rajpur Ekauna	1.31
8	Balia	Murli Chhapra	Murli Chhapra	0.053
9	Balia	Reoti	Gaighat	0.3
10	Balia	Siar	HaldiRampur	0.35

SL.No.	DISTRICT	BLOCK	LOCATION	Arsenic Value(mg/litre)
11	Balrampur	Gaindas Bujurg	Ajgari	0.093
12	Balrampur	Gainsari	Ratanpur	0.063
13	Balrampur	Harraiyya Bazar	Harraiyya Bazar	0.102
14	Balrampur	Pachperwa	Mansurwa	0.143
15	Balrampur	Sriduttganj	Sriduttganj	0.05
16	Balrampur	Tulsipur	Tulsipur	0.091
17	Gonda	Bhelsar	Digsir	0.06
18	Gonda	Colonelganj	Colonelganj	0.112
19	Gonda	Haldarmau	Simra	0.25
20	Gonda	Katrabazar	Binkatra	0.06
21	Gonda	Nawabganj	Kalyanpur	0.08
22	Gonda	Pandari Kripal	Subhag Pur	0.122
23	Gonda	Tarabganj	Tarabganj	0.07
24	Gonda	Wazirganj	Baleshwar ganj	0.087
25	Gorakhpur	Gorakhpur	Urwa bazar	0.07
26	Lakhimpur Kheri	Dhaurahra	Amethi	>0.05
27	Lakhimpur Kheri	Dhaurahra	Laljipurwa	>0.05
28	Lakhimpur Kheri	Dhaurahra	Pradhanpurwa	>0.05
29	Lakhimpur Kheri	Ishanagar	Hulaspurwa	>0.05
30	Lakhimpur Kheri	Ishanagar	Ishanagar	>0.05
31	Lakhimpur Kheri	Ishanagar	Parasia	>0.05
32	Lakhimpur Kheri	Ishanagar	Rudrapur Salim	>0.05
33	Lakhimpur Kheri	NigHassan	Dharmapur	>0.05
34	Lakhimpur Kheri	NigHassan	Khairana	>0.05
35	Lakhimpur Kheri	NigHassan	Pachpera	>0.05
36	Lakhimpur Kheri	Palia	Babaura	>0.05
37	Lakhimpur Kheri	Palia	Kothia	>0.05
38	Lakhimpur Kheri	Palia	Majhgai	>0.05
39	Lakhimpur Kheri	Palia	Trilokpur	>0.05
40	Lakhimpur Kheri	Ramiabehar	Dhanaigaurhi	>0.05
41	Lakhimpur Kheri	Ramiabehar	Lalapurwa	>0.05
42	Lakhimpur Kheri	Ramiabehar	Mathurapurwa	>0.05
43	Lakhimpur Kheri	Ramiabehar	Sujanpur	>0.05
44	Mathura	Mathura	Mathura	0.052
45	Moradabad	Moradabad	Moradabad (Ashiyana)	0.07

Source: CGWB & State agency

Jharkhand

High Arsenic contamination in ground water (>.05mg) are reported from 3 blocks of Sahebganj district of Jharkhand(SOES). CGWB has reported in its studies during 2006-07 that one block i.e Sahebganj block of Sahebganj district was effected with High Arsenic. Later on studies by PHED & CGWB confirmed that three blocks of the districts i.e Rajmahal, Udohwa & Sahebganj located on the alluvial deposits.

North Eastern States

Studies(by SOES) reveal that 27 villages of Dhemaji & Karimganj district of Assam and parts of Thumbil & Imphal district of Manipur are effected by Arsenic contamination(> 0.05 mg/l).

GENESIS OF ARSENIC IN GROUND WATER

Genesis of arsenic in groundwater in India is broadly geogenic. Geogenically contaminated aquifers are embedded in deltaic, alluvial and lacustrine sediments of post-Pleistocene age. Geologically many differences exist between diferent regions of distribution of Arsenic in ground water, but most striking similarity is that, majority of such high-arsenic groundwater provinces lie in unconsolidated sediments, generally of the Quaternary but often confined to Holocene age. In Chattisgarh, however, the contamination is related to some sulphide belt of Dongargarh-Kotri zone in a Precambrian terrain.

In Bengal Delta Plain(BDP), the sources of Arsenic may be i) Transported by the River Ganges and its tributaries from the Gondwana coal, seams in the Rajmahal trap area located at the west of the basin can be of the order of 200 ppm. (Saha, 1991). (ii) Transported by the north Bengal tributaries of Bhagirathi and Padma from the Gorubathan base-metal deposits in the eastern Himalayas (Ray, 1999). (iii) Transported with the fluvial sediments from the Himalayas (e.g., McArthur et al., 2004), which is considered today as the most accepted hypothesis.

In Bihar, the contamination is considered to be geogenic where arsenic in solid phase is released to groundwater under a redox controlled environment. Organic carbon rich clay beds facilitate dissolution of Arsenic. “The abundance of organic carbon in the shallow alluvial stratigraphy allows a part of it to be carried downward with the percolating water from rainfall infiltration. The organic carbon stimulates microbial respiration and triggers reductive dissolution of As and Fe in solid phase. This process also generates HCO3- and so produce the relationship between As and HCO3- in shallow groundwater” (Saha et al., 2009). The Older alluvial deposits in the vast stretches of the South Ganga Plain and also in the North Ganga Plain are contamination free. The source of arsenic contamination in the ground water appears to be associated with the sediments of the Himalayan provenance brought down by the river Ganga and its tributaries of Extra Peninsular (Himalayan) origin (GSI, 2008)

The sources of Arsenic for the high Arsenic ground water in Chowki area, Rajnandgaon district, Chhattisgarh is being established in-situ and geogenic (Acharrya et.al 2001 and 2005, Pandey et.al 2002).

SUM UP

- Arsenic contamination of groundwater and related health hazards are becoming a high-profile problems through out the world. Number of Aquifers have been identified with problems of high Arsenic concentration in ground water.
- The Bengal Delta plain(BDP) covering Bangladesh and West Bengal in India is the most severe cases of ground water Arsenic contamination. The other parts of the country having Arsenic infested ground water include parts of Bihar, U.P,Chhattisgarh, Jharkhand, Assam & Manipur.
- Arsenic contamination in India is mainly geogenic and mostly occur in unconsolidated sediments except in Chhattisagrh where it occurs in aquifers in Precambrian rocks.
- Arsenic infested area of West Bengal forms a part of Ganga-Bagirathi delta, comprising succession of thick Quaternary sediments and mainly restricted in the Upper Delta Plain within a shallow depth. In West Bengal Arsenic free aquifers has been identified (by CGWB) in the depth zone of 120-160 m bgl and 200-250 mbgl where tubewells have been constructed with suitable design to get Arsenic free water.
- In Bihar high concentration of Arsenic in ground water are confined in Newer Alluvial belt along the river Ganga affecting the both the Active and Older Flood plains. The contaminated water is young in age(<40yrs).
- Studies in Chhattisgarh revealed that elevated Arsenic in ground water is being controlled by various geological, structural, hydrogeochemical factors. Ground water

with more than 800 μs/cm EC are found invariably containing lower arsenic value, below 0.05 mg/l. Such controls may also contribute toward providing safe and alternative drinking water in the area.

- Various Arsenic mitigation options include using surface sources, exploring and harnessing alternate arsenic free aquifer, removal of Arsenic from ground water using treatment filters and rainwater harvesting.

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GROUNDWATER ARSENIC CONTAMINATION SITUATION IN WEST-BENGAL, INDIA: A NINETEEN YEAR STUDY

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BACKGROUND

The study is based on our last 19 years survey on groundwater arsenic contamination in Ganga-Meghna-Brahmaputra (GMB) plain. The area comprises of 5,69,749 km^2, with a population of over 500 million. It can be predicted that a good portion of all the states in Ganga-Brahmaputra plain in India (Uttar Pradesh, Bihar, Jharkhand, West Bengal, Assam and other North Eastern hill states) and Bangladesh in Padma-Meghna-Brahmaputra (old) are arsenic affected.

Arsenic crisis in India dates back to as early as 1976 when a preliminary survey (1) on arsenic in dugwells, hand pumps and spring water from Chandigarh and different villages of Punjab, Haryana and Himachal Pradesh in northern India was reported. Officially, arsenic poisoning in West Bengal was first reported by a dermatologist K.C. Saha of School of Tropical Medicine (STM), Calcutta (Kolkata, previously known as Calcutta) to an outdoor patient of village Ramnagar of Baruipur police station in the district of South 24-Parganas on 6th July, 1983 (Docket No. S/158/33/83). Later it came out that many arsenic patients existed in many villages well before 1983 but they could not be clinically diagnosed, so were not highlighted. According to A. K. Chakraborty, an epidemiologist of All India Institute of Hygiene and Public Health (AIIH&PH), Calcutta who reported on 4th December 1983 (2), "for more than a year physicians were baffled by several cases of hyper-pigmentation which kept coming to them at regular intervals".

During 1983-1989 the following organizations in West Bengal viz. (a) School of Tropical Medicine (STM), Calcutta (b) All India Institute of Hygiene and Public Health (AIIH&PH), (c) Central Ground Water Board (Eastern Region) (d) Centre for Study of Man and Environment, Calcutta (e) Public Health Engineering Department (PHED), Government of West Bengal (f) SSKM – Hospital, Calcutta (g) Directorate of Health Services, Government of West Bengal were working on the problem of groundwater arsenic contamination. R. Garai, A. K. Chakraborty, S. B. Dey, and K.C. Saha (3) had first warned of malignancy in the hyperkeratosis spots and liver if the diagnosis was delayed.

Saha and Poddar reported (4) in 1986, 36 villages from 18 police stations/blocks of 6 districts are arsenic affected. These districts were 24 Parganas, Murshidabad, Nadia,

Bardhaman, Maldah and Medinipur. Although one patient from Ramnagar police station of Medinipur was reported in 1986 but later on we found that he was actually from an affected district Nadia but settled in Medinipur. From 36 villages water samples from 207 hand tubewells were analyzed and 105 (50.7%) showed arsenic concentration above 50 μg/L and highest concentration revealed was 586 μg/L. They further stated that cutaneous malignancy found in 3 out of 1000 cases of chronic arsenical dermatosis. Analysis of arsenic in hair, nail, and skin-scale from the people in the affected villages confirmed arsenic toxicity and identified subclinical arsenic toxicity in some people.

Conducting an epidemiological survey in 6 villages from 3 districts (24 Parganas, Bardhaman, Nadia) Chakraborty & Saha reported in 1987 (5), 12 ascites patients out of 197 having arsenical dermatosis and one of whom developed skin cancer eventually. They further added that lowest concentration of arsenic in water producing dermatosis was found to be 200 μg/l. Three deaths were reported due to chronic arsenic poisoning. Out of 71 water samples tested from the affected villages, 55 (77.5%) had arsenic concentration above the Indian permissible limit of 50 μg/l.

In 1988, Guha Mazumder (6) showed evidence of chronic arsenical dermatosis and hepatomegaly in 62 out of 67 members who drank arsenic contaminated water (200 – 2000 μg/l) based on an epidemiological investigation from an arsenic affected area of Ramnagar village, Baruipur block, 24 Parganas. In contrast only 6 out of 96 persons from the same area who drank safe water (below 50 μg/l) had non-specific hepatomegaly, while none had skin lesions.

School of Environmental Studies (SOES), Jadavpur University joined the arsenic work at the beginning of 1988. From August 1989 to December 1991 more information about suffering of people from the blocks of the districts in Maldah, Murshidabad, Bardhaman, Nadia, North 24-Parganas and South 24-Parganas were unearthed by continued research (7-11). The first report of SOES was published in May, 1991 (12) based on a door to door preliminary survey in 5 out of 6 arsenic affected districts (except Bardhaman) of West Bengal. The survey revealed that about 3 million people were at risk in the arsenic affected areas. Our medical survey could identify altogether 600 arsenic patients from 86 villages. In November, 1991 another preliminary report was published (13) exclusively on Bardhaman (also known as Burdwan) district, identifying 77 arsenic patients from 7 villages. In these two reports (12, 13) on the basis of 1800 water samples analysis from 93 villages from 13 police stations and identification of 600 arsenic patients from 1988 to 1991, SOES warned the government of imminent danger.

From July 1992 to early 1995 a considerable number of news articles were published in daily newspapers both in Calcutta as well as in the capital of India, based on the door to door survey report of SOES from the affected six districts (14-25). School of Environmental Studies (SOES) while analyzing the water samples from Calcutta identified arsenic patients in Jadavpur in southern part of Calcutta. At least 10 patients were identified from the area (26). Immediately after the publication of SOES report, the Calcutta Municipal Corporation vehemently opposed this fact stating (27) that 13 tubewells from Jadavpur were all safe with regard to arsenic. In March 1994, SOES published yet another report on arsenic problem of South 24-Parganas (28). In this, other than the magnitude of the spreading calamity and suffering of people, social problems due to arsenical diseases was also stressed. The report stated, “The social problems arising due to arsenical skin lesions in these districts are becoming of serious concern. Even the affected wives are sent back to their parents together with their children. Malnutrition, poor socio-economic condition, illiteracy, food habits and intake of arsenic contaminated water through many years have aggravated the arsenic toxicity”. A news report published in Analyst (29) identified that 312 village, in 37 police stations in 6 districts to be arsenic affected and faced that more than 8,00,000 people in the affected villages were continuing to drink arsenic contaminated water above 50 μg/l.

SOES after working for seven years in arsenic affected villages of West Bengal realized the impact of the problem. In 1994 it was realized by the authorities, scientists, international

aid agencies like WHO, UNICEF as well as common people should be alerted about the magnitude and seriousness of arsenic problem unless the grim arsenic situation in West Bengal would continue to be neglected from all quarters. In order to invite international attention on the problem SOES arranged an international conference of 6-8 February in 1995 with additional 3 days field visit in arsenic affected area. This proved to be a turning point in the history of arsenic research in west Bengal.

SOES placed in this conference (30) their preliminary report of survey conducted for last 7 years in 6 arsenic affected districts. In this it was mentioned that 405 villages/wards from 37 police stations were found to be arsenic affected and more than 1.0 million people might be constantly drinking arsenic contaminated water above 50 μg/l from these six districts. They put an estimate of around 2,00,000 people to be suffering from arsenic toxicity.

During and immediately after the conference most of the national and some of the international media published and aired the articles and programs highlighting the magnitude and severity of the problem. Altogether arsenic experts from 20 different countries participated at the conference and they were horrified by the magnitude of the problem (31, 32). One of the experts Bill Chappell from the University of Colorado, USA who attended the conference said, “The chronic arsenic poisonings occurring in West Bengal represent the single-largest environmental health problem I know of, other than that associated with the Chernobyl disaster” (33). Epidemiologist Allan Smith added, “the problems are very serious and warrant a very high priority for solutions and further investigations” (34). The seriousness of the problem and need of immediate action to be taken were highlighted by various experts (35-38).

Immediately after the conference, the Secretary of Public Health Engineering Department (PHED), Government of West Bengal, the nodal agency to look after the arsenic problem of West Bengal issued a statement in the newspaper in which he apprehended 30 to 40 lakhs people in West Bengal to be potentially at risk of arsenic poisoning through drinking water. The report identified 8 to 10 lakhs of people as already affected and 10,000 – 15,000 as showing positive sign of poisoning (39).

Although the overall attitude of government was not to accept the magnitude of the arsenic calamity, the policy faced criticism from some of the top officials. In a report the Secretary of PHED said, “The state government policy on controlling arsenic poisoning lacks transparency while the functioning of the department needs openness” (40). More and more arsenic incidents, suffering and death started surfacing from the SOES field survey (41) and groundwater arsenic contamination was reported from proper Calcutta by SOES (42). However, Calcutta Municipal Corporation denied any such contamination (43).

In continuing surveys, more and more arsenic affected districts were added to our list in 1997 and SOES reported (44), 830 villages from 58 blocks of 8 arsenic districts of West Bengal to be affected. If we consider Calcutta as separate district the number of affected districts rises to nine. These districts are Maldah, Murshidabad, Bardhaman, Nadia, Haora, Hugli, North 24-Parganas, South 24-Parganas and Calcutta. In the middle of 1997, the World Health Organization (WHO) appointed a team to study the arsenic problem in West Bengal. The team appointed by WHO criticized the state government for lacking initiative and seriousness in tackling the spread of arsenic poisoning (45-47).

In early 1999, on the basis of 58,166 water analysis from 9 arsenic affected districts we reported (48) 985 villages in 69 police stations / blocks as being arsenic affected and 4420 people had already been registered with arsenical skin lesion. Every time we went on a field survey, we identified 10-15 new arsenic affected villages where villagers continued to drink arsenic contaminated water without being aware of the contamination. Even such a situation did not prevent the Chief Engineer (Arsenic), of Public Health Engineering Department (PHED), Government of West Bengal from assuring delegates at the international conference in Bangladesh (49, 50), with the quoted lines ".... in 1994 there were about, 1100 identified cases of arsenocosis, the acute stage of arsenic poisoning, in

areas of West Bengal. The number has since come down to 450. So far we have not found arsenic beyond the permissible level in any tube-well sunk to deeper aquifer in the affected areas. Even if there are traces, those are within the permissible level of 50 μg/l. If it exceeds the limit at any place we have the technology to treat the water by using simple method. Arsenic free drinking water is now supplied to the door steps of the people in the affected areas through pipe line network". It is surprising to note that the Health Minister of West Bengal in an interview on 5th April 1999 with a representative of the Medical World (51) had characterized that the present arsenic situation of West Bengal as being much better than what it was 15 years earlier at such critical juncture. Further, SOES first reported groundwater arsenic contamination in southern part of Calcutta on 8th March 1993 and identified people suffering from arsenical skin lesion (26). Government of West Bengal totally denied the findings. In January 1996 we reported more arsenic affected areas in southern part of Calcutta and our results being denied by both government of West Bengal and Calcutta Municipal Corporation (CMC) (42). Again during October 2000 (52) we reported arsenic to be above WHO maximum permissible limit in two well known private nursing homes (Kothari Medical Centre & Woodland Nursing Home), the Zoological Garden, the National Library and certain Housing Complexes. This report though it was denied at first was confirmed by the government later in January 2001 (53). The arsenic problem of Calcutta City was reported by us in 1993 and it took 8 years for the government to accept the truth.

In 2002, we published a summary of groundwater arsenic contamination situation in West Bengal (54) where we showed on basis of more than 1,05,000 water samples analysis more than six million people from nine arsenic affected districts out of total 19 districts are drinking water containing more than 50 μg/L As and 2700 villages were identified to be affected.

In 2003, we highlighted (55) the groundwater arsenic contamination situation concentrating on one of the nine districts, North 24 Parganas, where we mentioned based on 48,030 sample analyses that 29.2 % of the tubewells had arsenic above 50μg/L; out of 22 blocks in twenty we found arsenic above this limit.

In 2004, we came out with another update (56) on arsenic contamination situation; Based on 1,29,552 samples analysis we showed 24.7% had arsenic above 50 μg/L and we identified 3200 arsenic affected villagers in 85 affected blocks in nine districts. We also predicted in this study that around 6.5 million people in the state could be drinking water having more than 50 μg/L As.

To understand the exact magnitude of groundwater arsenic contamaintion and its health effects in West Bengal, we have studied one arsenic affected district Murshidabad out of nine affected district in details for last five years with twenty people in our group including dermatologist, neurologist, gynecologist, pathologist, analytical chemist, biochemist, geologist, civil engineer etc. We have analyzed about 30,000 water samples from this district alone and screened 24,274 people with our medical group for arsenical skin lesions and other related arsenic toxicity. We have also analyzed 3,843 biological samples (hair, nail, urine and skin scales). Based on our detailed studies in Murshidabad district, we published five papers. We have done semi micro and micro level studies in one block Jalangi (57), one gram Panchayet (cluster of villages) Sagarpara (58), and one village Rajapur (59), and also the district Murshidabad as a whole (60,61).

In 1988 when we commenced arsenic survey in West Bengal, we knew about 22 affected (As > 50 μg/L) villages in five districts now according to our latest survey the number of affected villages increased to 3417 in 111 blocks in nine districts. During last 19 years with every additional survey we noticed an increasing number of contaminated villages and more affected people. These findings have been reported in number of international journals, monographs and book chapters (62-91).

In 1992 we identified arsenic groundwater contamination in Padma-Meghna-Brahmaputra (PMB) plain of Bangladesh where people were drinking arsenic contaminated water and

suffering from arsenical skin lesions (44,92,93). In 2001 groundwater arsenic contamination in the Terai region of Nepal was revealed (94). In June 2002 we discovered arsenic contamination in Bihar in middle Ganga plain and apprehended contamination in Uttar Pradesh lying in middle and upper Ganga plain (95). During Oct. 2003-Dec. 2003 we identified 25 arsenic affected villages of Ballia district in UP and people suffering from arsenical skin lesions. Between Dec. 2003 and Jan. 2004 we further found groundwater arsenic contamination in 698 hand tubewells from 17 villages of the Sahibganj district of Jharkhand state, India in the middle Ganga plain and consequent suffering of hundreds of people. Again a preliminary survey during Jan–Feb 2004 in Assam showed 26% of 137 hand tubewells analyzed in 2 districts had arsenic concentration above 50µg/L. According to our latest estimates, a good portion of all the states and countries in the Ganga-Meghna-Brahmaputra (GMB) plain may be at risk from groundwater arsenic contamination (56). So far (up to December 2005) we have collected and analyzed 140150 water samples from all 19 districts covering 241 of 341 total blocks from West Bengal India. We found arsenic contamination above 10 and 50µg/L in 148 and 111 blocks in 14 and 12 districts respectively. From whole GMB plain we analyzed 211955 water samples. Figure 1 shows the groundwater arsenic contamination status in different countries and different states in GMB Plain. Table 1 shows the contamination situation in GMB plain at a glance and Figure 1 shows the Groundwater arsenic contamination in states and countries of the GMB Plain (according to our latest survey report up to December 2005)

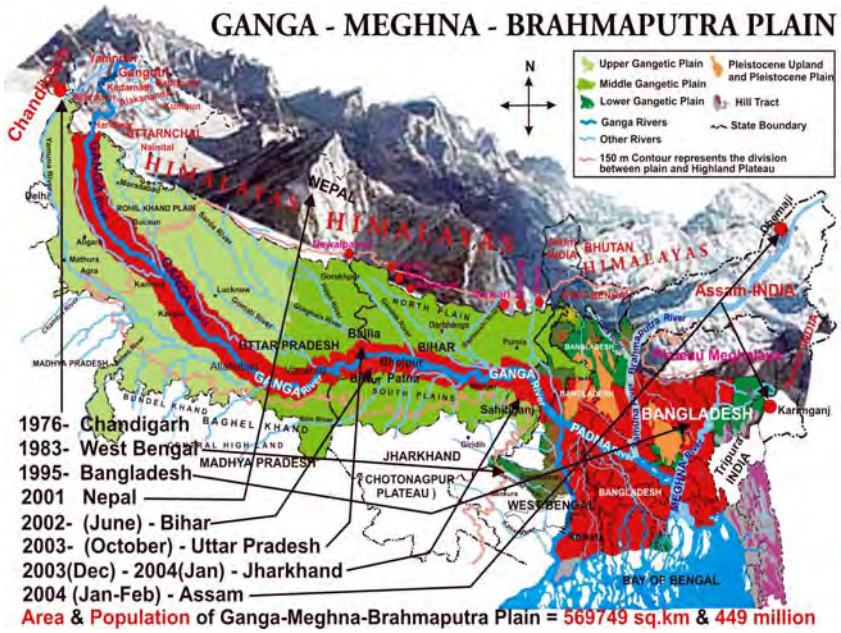
This communication deals with the present ground water arsenic contamination situation of West Bengal along with the consequential health effects on the basis of our last 19 years research work on the issue.

Table 1: Groundwater arsenic contamination in states and countries of the GMB Plain (according to our latest survey report up to December 2005)

Parameters	West Bengal	Bangladesh	Bihar	UP	Jharkhand
Area (sq km)	88,750	1,47,620	94,163	2,38,000	75,834
Population (in million)	80.2	122	83	166	27
Total arsenic affected districts (As >50 µg/L)	12	50	12	3	1
Total arsenic affected blocks/PS (As > 50 µg/L)	111	189	32	9	3
No. of villages where groundwater arsenic >50 µg/L	3417	2000	201	91	21
Total hand tubewell water samples analyzed	1,40,150	51,001	15,000	4,780	1024
% of samples having arsenic > 10 µg/L	48.1	43	33	46.02	30
% of samples having arsenic > 50 µg/L	23.8	31	20	27.71	19.4
Total number of biological samples analyzed (Hair, Nail, Urine)	39,624	10,000	920	178	367
Total people screened by medical group of SOES-JU	96,000	18,841	4,513	989	212
People registered with arsenical skin lesions	9,356	3,725	525	153	87
People at risk of drinking arsenic contaminated water >10 μgL^{-1} (in million)	9.5	50.1	*	*	*
People at risk of drinking arsenic contaminated water >50 μgL^{-1} (in million)	4.6	32.1	*	*	*

*Yet to be estimated

Figure 1: Groundwater arsenic contamination status in different countries and different states of India in GMB Plain.



EXPERIMENTAL METHODS

Study Area and sampling: West Bengal [area 88750 sq km; population 80.1 million] is one of the 29 states of India. Its administrative structure consists of several districts: each district has several blocks/police stations; each block has several Gram Panchayets (GPs), which are cluster of villages. There are 19 districts, 341 blocks and 37910 villages in West Bengal. We collected 1,40,150 water samples, 13,325 hair, 13,468 nail, 12,831 urine and 1000 skin scale samples from all the 19 districts and analyzed for arsenic.

Instrumentation: Flow injection hydride generation atomic absorption spectrometry (FI-HG-AAS) system was assembled from commercially available instruments and accessories in our laboratory. A Perkin Elmer Model 3100 atomic absorption spectrometer equipped with a Hewlett-Packard Vectra Computer with GEM software, Perkin-Elmer EDL system-2, arsenic lamp (lamp current 400 mA) and Varian AAS Model Spectra AA-20 with Hollow Cathode arsenic lamp (lamp current 10 mA) were used. Details of the instrumentation have been described in our earlier publications (96-99).

Reagents and glassware: All reagents were of analytical reagent grade. Distilled deionized water was used throughout. The reducing solution of 1.5% (m/v) $NaBH_4$ (Merck, Germany) in 0.5% (m/v) NaOH (E. Merck, India) and 6.0 M solution of HCl (E. Merck, India) were used for flow injection analysis. Details of the reagents and glassware are given elsewhere (96,98).

SAMPLE COLLECTION PROCESS:

Water sample: Tubewell water samples were collected in 10 ml polyethylene bottles pre-washed with nitric acid water (1:1) and after collection, 1 drop of nitric acid in water (1:2) was added as preservative. Details of the collection procedures have been described in our earlier publications (96,98).

Biological sample: hair, nail, urine and skin scale samples were collected during our field survey. For hair, nail and skin scales samples we determined total arsenic after digestion. The modes of water and biologic samples collection, the digestion procedures for hair, nail and skin scales and the analytical procedures were as reported earlier (96-99). For urine samples, only inorganic arsenic and its metabolites together [arsenite, As (III); arsenate, As (V); monomethyl arsonic acid, MMA (V) and dimethyl arsinic acid, DMA (V)] were measured with no chemical treatment. Under the experimental conditions of FI-HG-AAS, arsenobetaine and arsenocholine do not produce a signal (96). We also collected biological samples from the inhabitants of arsenic safe areas of Medinipur district for comparison purpose.

Analysis procedure: Arsenic in water, urine, acid digested hair and nail was measured by FI-HG-AAS. For urine samples, only inorganic arsenic and its metabolites together [As (III), As (V), MMA (V), and DMA (V)] were measured with no chemical treatment. Under the experimental conditions of FI-HG-AAS, arsenobetaine and arsenocholine do not produce a signal **(96).** Details procedure has been described elsewhere (96-99).

Quality assurance and quality control program: For quality control, inter-laboratory tests were performed for water samples (99,100). Analysis of EPA water standard for arsenic by our technique has been reported elsewhere (99,101).

Statistical analysis: Standard statistical techniques were applied to analyze and present the data. To test the presence of association, Chi-square test was used. An ANOVA was applied to test the homogeneity of arsenic concentrations. Paired t-test was used to test the significance. Statistical package SPSS version 11.5 has been used for data analysis.

RESULTS

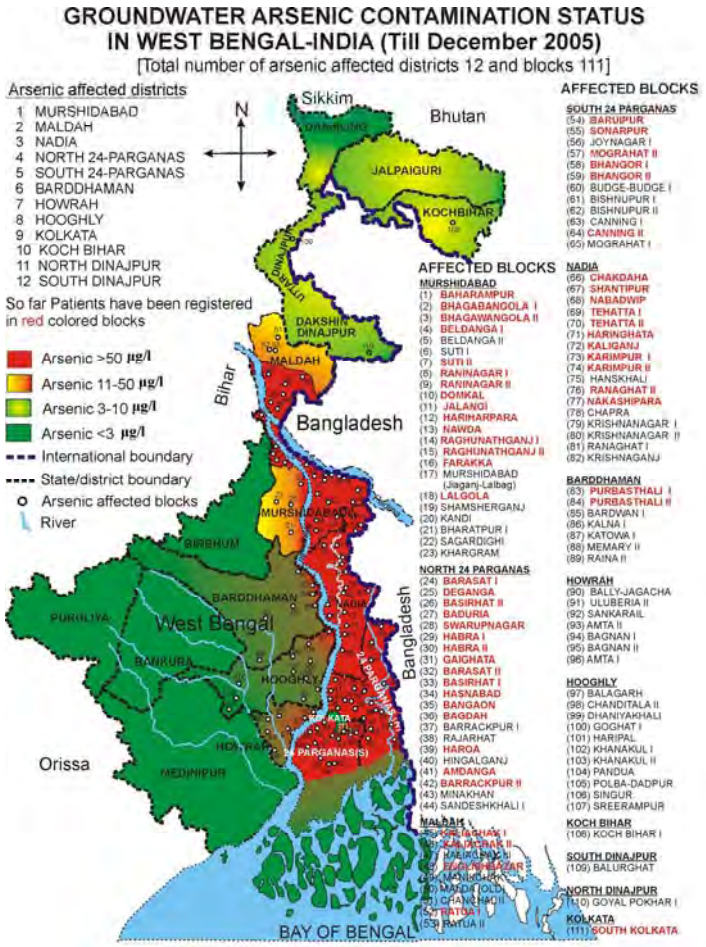
Groundwater arsenic contamination in West Bengal

In last 19 years we analyzed 1,40,150 hand tubewell water samples for arsenic in all 19 districts of West Bengal. Table 2 shows an overview of arsenic contamination situation of West Bengal upto December 2005. Table 3 shows the distribution of tubewells from each of the 19 districts of West Bengal. Out of 1,40,150 samples analyzed for arsenic till date, 48.1% had arsenic above 10μg/L (the WHO guide line value) and 23.8% above 50μg/L (the Indian standard value). Importantly, 3.3% of the analyzed tubewells had arsenic concentrations above 300μg/L (the concentration predicting overt arsenical skin lesions (56). A total of 187 (0.13%) hand tube-wells were 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 and all the nine members of the owners' family had arsenical skin lesions and seven of them who had severe arsenical skin lesions, had already died, five of them died within age range below 30 years. Figure 2 (map) sums up groundwater arsenic contamination status of all 19 districts of West Bengal. Based on the arsenic concentrations found in the 19 districts of West Bengal we have classified them into three categories: Severely affected, mildly affected, and arsenic safe.

Nine districts (Maldah, Murshidabad, Nadia, North-24-Parganas, South-24-Parganas, Bardhaman, Haora, Hugli and Kolkata), where more than 300 μg/L arsenic concentrations were found in tubewells are categorized as severely affected. Out of 1,35,555 samples analyzed from these districts 67,306 (49.7%) had arsenic concentrations above 10μg/L and 33,470 (24.7%) above 50 μg/L.

The five districts (Koch Bihar, Jalpaiguri, Darjiling, North Dinajpur and South Dinajpur) where the contaminated tubewells show arsenic concentrations mostly below 50μg/L (only a few above 50μg/L but none above 100 μg/L), termed as mildly affected. We analyzed 2,923 water samples from these districts, 285 (9.8%) had arsenic concentration between 4 and 10μg/L, 163 (5.7%) above 10μg/L and 6(0.2%) above 50 μg/L.

Figure 2: Groundwater arsenic contamination status in all 19 districts of West Bengal.



The rest five districts (Bankura, Birbhum, Purulia, Medinipur East and Medinipur West), where all the recorded concentrations were below 10 µg/L termed as unaffected or arsenic safe. All the samples (n=1,672) analyzed from these five districts had arsenic concentrations below 3 µg/L (the minimum determination limit of our instrument with 95% confidence level).

Table 2: Physical parameters and arsenic-affected areas of West Bengal

Parameters	
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 µg L^{-1}	48.1
% of samples having arsenic > 50 µg L^{-1}	23.8
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 at risk of drinking arsenic contaminated water >10 μgL^{-1} (in million)	9.5
People at risk of drinking arsenic contaminated water >50 μgL^{-1} (in million)	4.6
No. of districts surveyed for arsenic patients	9
No. of districts where arsenic patients found	7
People screened for arsenic patients including children (preliminary survey)	96,000
No. of adults screened for arsenic patient	82,000
Number of registered patients with clinical manifestations	9,356 (11.0%)
No. of children screened for arsenic patient	14,000
No. of children showing arsenical manifestation	778 (5.6%)
Total hair, nail, urine analyzed	39624
Arsenic above normal/toxic level in hair, nail and urine samples	91%, 97% and 92%

Groundwater arsenic contamination situation of the severely affected districts:

(i) **Contamination situation in North-24-Parganas District**: The district of North 24 Parganas of West Bengal is in the southern part of the Bengal Basin. The geographical extent of the district lies between 88^{0}19' E to 89^{0}10' E and 22^{0}01' N to 23^{0}20' N. The area and population of the district is 4094 km^2 and 89,34,286. In North 24 Parganas, there are 22 blocks. So far we have analyzed 54,368 tubewell water samples covering all 22 blocks. From our analysis we found elevated level of arsenic above 10μg/L in all 22 and above 50μg/L in 21 blocks. It has been found that 29,018 (53.4%) tubewells have arsenic concentration above 10 μg/L, and 16,017 (29.5%) above 50μg/L. Importantly, 1834 (3.4%) of the analyzed tubewells had arsenic concentrations above 300μg/L (the concentration predicting overt arsenical skin lesions). From our analytical result we see that only one block "Sandeshkhali-II" is arsenic safe according to Indian standard (50μg/L). Arsenic level above 1000μg/L was found in 49 tubewells; the maximum arsenic contamination level found in this district is 2830μg/L in the Baduria block**.** Figure 3 shows the groundwater arsenic situation in each block of North 24 Parganas, indicating the blocks where we identified patient with arsenical skin lesions. It also depicts a Pie-diagram of arsenic concentration distributions in the district.

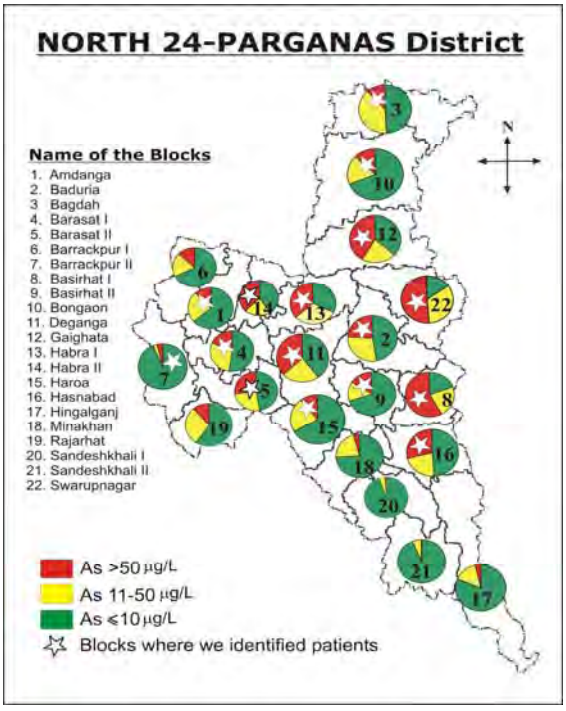


Figure 3: Groundwater arsenic contamination situation in each block of North 24 Parganas district shown by Pie-diagram.

Table 3: Distribution of hand tubewells against arsenic concentration ranges (μg/L) in all 19 districts of West-Bengal, India.

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									Maximum concentration found (μg/L)
								≤3	4 -10	11-50	51-100	101-200	201-300	301-500	501-1000	> 1000	
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	-	-	-	-	3626	2224	855	345	85	75	27	10	5		825
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	
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	-	-	-	-	-	-
Bankura	6882	3192695	22	17	0	0	279	279	-	-	-	-	-	-	-	-	<3
Birbhum	4545	3015422	19	11	0	0	718	718	-	-	-	-	-	-	-	-	<3
Puruliya	6259	2536516	20	14	0	0	314	314	-	-	-	-	-	-	-	-	<3
Medinipur (E)	14081	9610788	54	10	0	0	182	182	-	-	-	-	-	-	-	-	<3
Medinipur (W)	NA	NA	-	8	0	0	179	179	-	-	-	-	-	-	-	-	<3
Sub Total	31767	**18355421**	115	60	0	0	1672	1672	-	-	-	-	-	-	-	-	-
Grand Total	88750	**80176197**	341	241	148	111	140150	62104	10577	33993	13507	10974	4420	3055	1333	187	

* Kolkata has no Blocks (It is an urban area)

(ii) **Contamination situation in South-24-Parganas District**: The area and population of the district is 9,960 km^2 and 69,06,689 divided into 29 administrative blocks. During our survey we collected 8,334 hand tubewell water samples from 17 blocks. After analyzing the samples for Arsenic we found Arsenic concentration in tubewell water samples above 10µg/L in 12 blocks and above 50µg/L in 11 blocks. The studies reveal that 3,499 (42.0%) tubewells have arsenic concentration above 10 µg/L, 2,358 (28.3%) above 50µg/L and in 547 (6.6%) above 300µg/L (the concentration predicting overt arsenical skin lesions). We found arsenic contaminated above 1000µg/L in 30 samples, the maximum concentration 3700µg/L was found in Baruipur block (village: Ramnagar, GP: Ramnagar II). Figure 4 shows the groundwater arsenic situation in each block of South-24-Parganas along with the Pie-diagram of arsenic concentration distributions indicating the blocks where we identified patients with arsenical skin lesions.

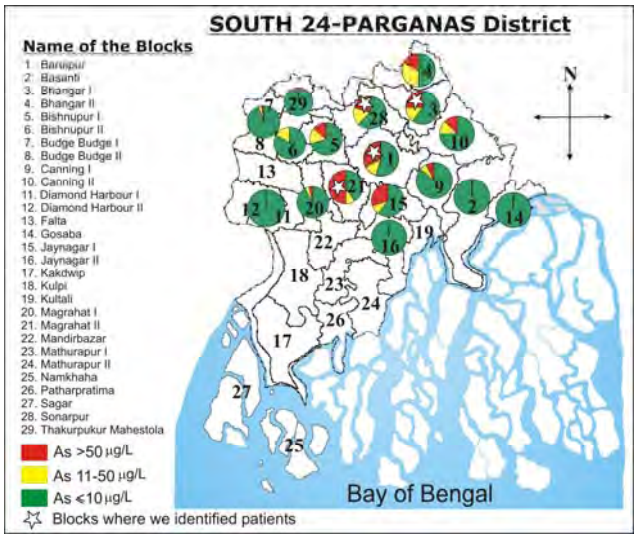


Figure 4: Groundwater arsenic contamination situation in each block of South 24 Parganas district shown by Pie-diagram.

(iii) **Contamination situation in Murshidabad District**: Murshidabad district lies between the latitudes of 23^{0}43'30" N 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 5,324 km^2 and 58,66,569 respectively. There are 26 blocks in this district and we have surveyed all the 26 blocks to collect hand tubewell water samples. So far we have collected and analyzed 29,668 hand tubewell water samples from 1,833 villages/wards of 2,414 villages from all the 26 blocks. On the basis of the analysis, we have found arsenic concentration in 25 blocks above 10 µg/L and in 24 blocks above 50µg/L. The studies reveal that 15,953 (53.8%) of the tubewells are arsenic contaminated above 10µg/L while 7,911 (26.7%) above 50µg/L and 1337 (4.5%) above 300µg/L. It is also observed from the table that Arsenic contamination in Jalangi block is worst, out of total 1917 samples analyzed from this block. 1,491 (77.8%) exceed the WHO limit (10µg/L) and 38 (2.0%) samples were found to be contaminated above 1000µg/L of arsenic. Maximum

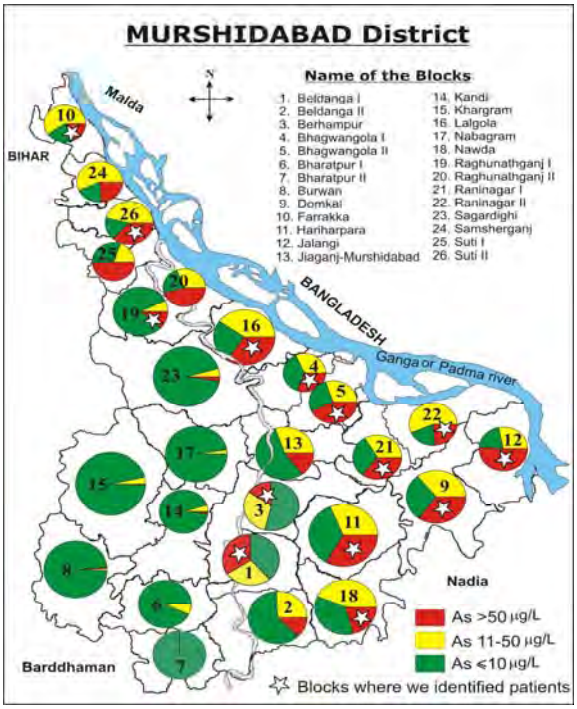


Figure 5: Groundwater arsenic contamination situation in each block of Murshidabad district shown by Pie-diagram.

concentration 3003µg/L was found in two water samples one from each of Nawda and Raghunathganj I blocks. Figure 5 shows the situation of arsenic contamination in all the 26 blocks of the district indicating the blocks where we identified patients with arsenical skin lesions. From the distribution of water analysis (Figure 5), it appears that the blocks situated in the western side of river Bhagirathi are less affected compared to the blocks situated on the eastern side. From our analysis, it appears that the groundwater of Bharatpur-II block is arsenic safe, all the samples (n=625) analyzed from this block found arsenic below 3µg/L (the determination limit of our instrument with 95% confidence level).

(iv) **Contamination situation in Maldah District:** Maldah district is situated between the Latitude and Longitude figures of 24^{0}40'20"N to 25^{0}32'08"N and 88^{0}28'10"E to 87^{0}45'50"E respectively and surrounded by Bangladesh and South Dinajpur in the east, Santal Parganas of Jharkhand state in the west, Uttar Dinajpur in the north and Murshidabad in the south. The area and population of the district is 3,733 Sq. Km. and 32,90,468 respectively. In Maldah, there are 15 blocks. We conducted survey in 14 blocks to collect hand pump tubewell water samples. Till date we have analyzed 4449 water samples for arsenic analysis. On the basis of our analysis 13 blocks have arsenic contamination above 10µg/L and 9 above 50µg/L. The studies reveal 2322 (52.2%) samples have Arsenic contamination above 10µg/L and 1512 (34.0%) above 50µg/L. It also reveals from the table that 282 (6.3%) of the tubewells are arsenic contaminated above 300 µg/L, while 22(0.5%) above 1000 µg/L. The maximum concentration found in this district is 1904µg/L in Kaliachak II block. Figure 6 shows the contamination situation in each of the surveyed blocks by pie-diagram indicating the blocks where we identified patients with arsenical skin lesions.

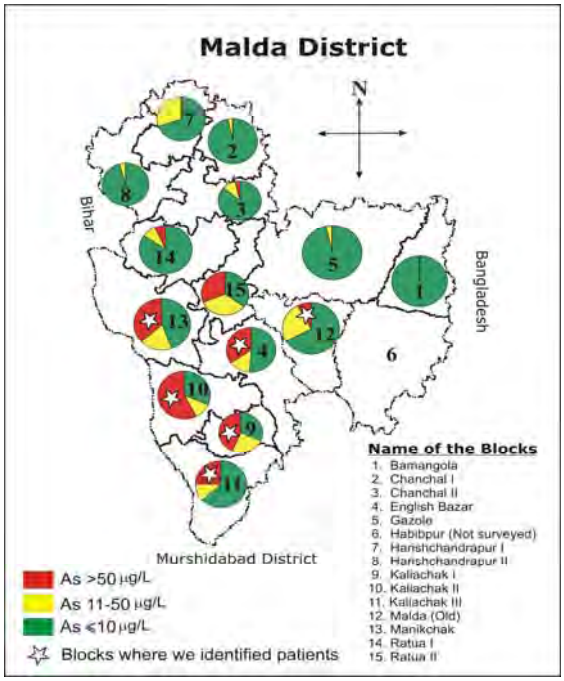


Figure 6: Groundwater arsenic contamination situation in each block of Malda district shown by Pie-diagram.

(v) **Contamination situation in Nadia District:** The geographical extent of the district lies with a latitude of 22^{0}41/ 23// N and longitude of 72^{0}51/ 24//E which covers an area of about 3,927 sq. km. It is situated on both sides of the Hugli (Ganga) river and is divided into 17 administrative blocks (Police stations). The population of the district is about 46,04,827. To date, we have analyzed 28,794 hand tubewell water samples from 777 villages/ wards spread over 143 GP's covering all the 17 blocks. The studies reveal that all the 17 blocks are arsenic contaminated above 50µg/L. On the basis of the analysis, we have found arsenic concentration above 10 µg/L in 14,750 (51.2%) hand

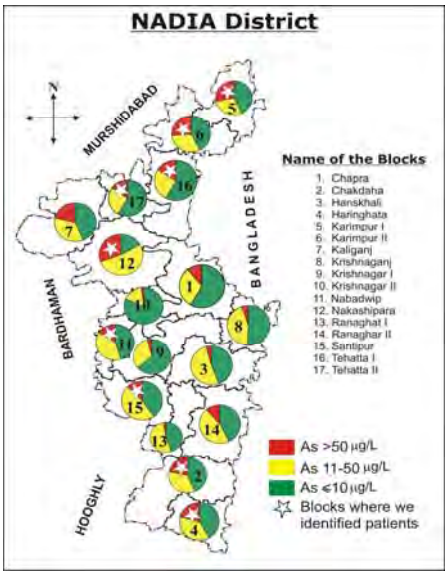


Figure 7: Groundwater arsenic contamination situation in each block of Nadia district

tubewells water samples, while in 4,940 (17.2%) above 50 µg/L. 525 (1.8%) samples are contaminated above 300µg/L while 13 (0.05%) above 1000µg/L. The maximum concentration found in this district is 3200µg/L in Tehatta I block. Figure 7 shows the groundwater arsenic contamination status in all 17 blocks of Nadia with the help of pie-diagram indicating the blocks where we identified patients with arsenical skin lesions.

(vi) **Contamination situation in Kolkata District:** Kolkata, located at 22^{0}28′ N to 22^{0}37′30″ N and 88^{0}17′ 30″ E to 88^{0}25′ E, is at present the largest urban city [area 185 sq.km and night time population 4.6 million] of eastern India. It is situated at the bank of river Ganga. For administrative purpose it is divided into 141 wards, we have analyzed 3,626 hand pump tubewell water samples for arsenic from 100 of them. Fifteen percent of the samples exceed the WHO guideline value (10 µg/L) while 5.5% of the samples exceed the Indian standard (50 µg/L). The maximum arsenic concentration (825µg/L) was recorded in Lake Gardens area of ward no 93 (Table 3). We found arsenic contamination above 10 µg/L in 65 wards and above 50µg/L in 35 wards.

Kolkata is mainly an urban area. The present drinking water demand in Kolkata is around 1262 million litres per day (MLD). Metropolitan authority supply through pipeline 1209 MLD of which 1096 MLD is treated surface water (102) and the rest are groundwater (tubewells having more than 100 m depth). Other than pipeline deep tubewell water supply, in each ward there are roadside hand tubewells of depth around 100m, a good percentage of people collect their drinking water from this source.

(vii) **Contamination situation in Bardhaman District:** Bardhaman district is situated between the Latitude 22.56^o N to 23.53^o N and Longitude 83.25^o E to 86.48^o E. The area and population of the district is 7,024 sq.km. and 68,95,514 respectively. There are 31 blocks in this district. So far we have collected 2634 hand pump tubewell water samples for arsenic analysis covering 24 blocks. Analytical result shows that 12 of the surveyed block is arsenic contaminated above 10µg/L and 7 blocks above 50µg/L. The studies reveal that 464 (17.6%) of the tubewells are arsenic contaminated above 10µg/L, 220 (8.4%) above 50µg/L and 18 (0.7%) of the tubewells are contaminated above 300µg/L. The maximum arsenic concentration was found 2230µg/L in Katwa I block. Only one water sample was Arsenic contaminated above 1000µg/L. Figure 8 represents the pie-diagram of the arsenic concentration in different surveyed blocks of Bardhaman district indicating the blocks where we identified patients with arsenical skin lesions.

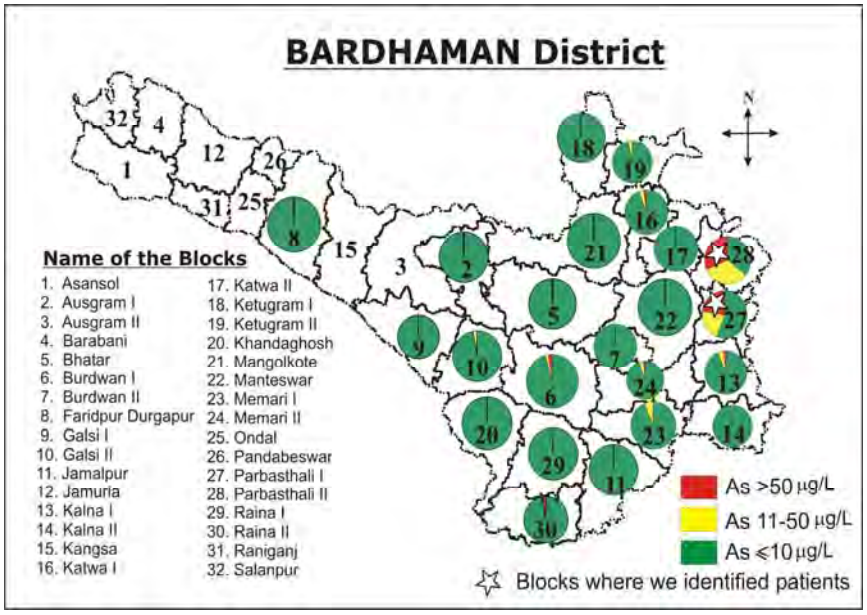


Figure 8: Groundwater arsenic contamination situation in each block of Bardhaman

(viii) **Contamination situation in Haora District:** Haora is a district in the southern part of West Bengal. The area and population of the district is 1,467 sq.km and 42,73,099 respectively. There are 14 administrative blocks in this district and we have covered 12 of them for Arsenic survey. We have collected 1,471 hand pump tubewell water samples for arsenic analysis. The studies reveal that 356 (24.2%) of the samples are arsenic contaminated above 10µg/L and 164 (11.1%) above 50µg/L while 14 samples are contaminated above 300µg/L. The maximum concentration 1333 µg/L of arsenic was found in Amta I block. Figure 9 shows the pie diagram of the arsenic contamination situation in the surveyed blocks.

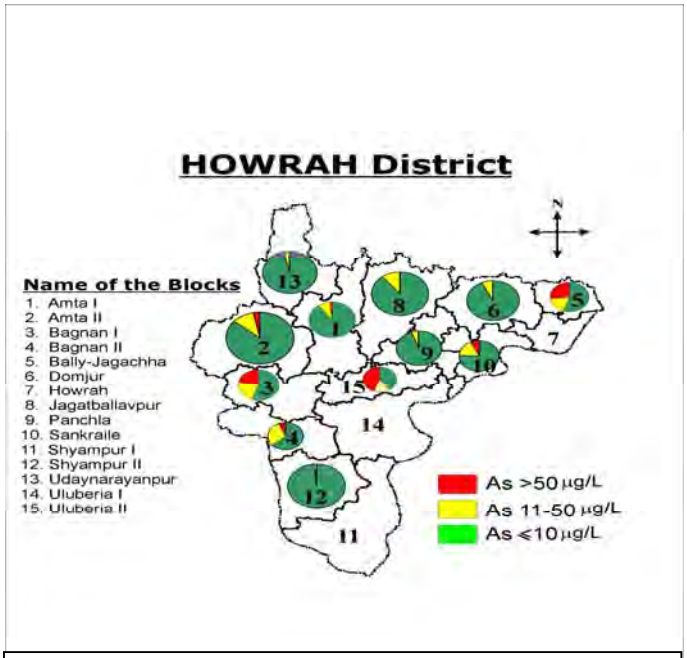


Figure 9: Groundwater arsenic contamination situation in each block of Hoara district shown by Pie-diagram.

(ix) **Contamination situation in Hugli District:** Hugli is a district in the central part of West Bengal. The area and population of the district is 3,149 sq.km and 50,41,976 respectively. There are 18 administrative blocks in this district and we have covered 17 of them for arsenic survey, out of the surveyed blocks we found arsenic concentration above 10µg/L in 16 blocks and above 50µg/L in 11 blocks. We have collected 2,212 hand pump tubewell water samples for arsenic analysis. The studies reveal that 397 (17.9%) of the tubewells have arsenic concentration above 10µg/L while 146 (6.6%) above 50 µg/L. According to our analysis there were 3 tubewells having arsenic concentration above 300µg/L while none of the tubewells have arsenic above 1000µg/L. The maximum concentration found in this block is 600µg/L in Balagarh block. Figure 10 shows the pie diagram of the Arsenic contamination situation in the surveyed blocks of Hugli district.

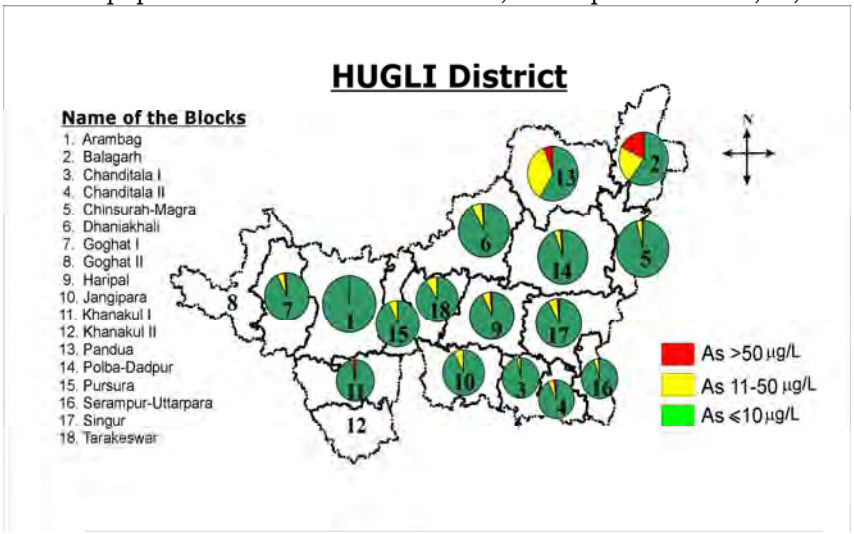


Figure 10: Groundwater arsenic contamination situation in each block of Hugli district shown by Pie-diagram.

From the above discussion it is clear that among the severely affected 9 districts 5 (South-24-Pgs, North-24-Pgs, Maldah, Murshidabad and Nadia) are most severely affected and the contamination is almost all over the district while in the other 4, only part of the district is contaminated.

Figure 11: Groundwater arsenic contamination situation in Northern part of West Bengal

(x) **Contamination situation in Northern part of West Bengal:** Based on the arsenic concentrations found in the Northern 5 districts (Koch Bihar, Jalpaiguri, Darjiling, North Dinajpur and South Dinajpur) of West Bengal we classified them as mildly affected. The analytical results show that arsenic concentration in these districts is mostly below 50µg/L, only a few above 50µg/L but none above 100 µg/L. We analyzed 2,923 water samples from these districts, 285 (9.8%) had arsenic concentration between 4 and 10µg/L, 163 (5.7%) above 10µg/L and 6(0.2%) above 50 µg/L (Table 3). Arsenic contamination situation of Northern part of West Bengal is shown in Figure 11.

(xi) **Contamination situation in Western part of West Bengal:** Based on the arsenic concentrations found in the 5 districts (Bankura, Birbhum, Purulia, Medinipur East and Medinipur West) in western part of West Bengal we classified them as arsenic safe. All the samples (n=1672) collected from these districts and analyzed for arsenic had concentrations below 3 µg/L (the minimum determination limit of our instrument with 95% confidence level) (Table 3). Figure 12 shows the contamination situation in Western part of West Bengal. It is to be noted that we found fluoride in many tubewell water samples in Bankura, Purulia and Birbhum districts and many people have been suffering from fluorosis, a crippling disease (103) in these districts. Though we do not find arsenic in tubewell water samples but, we found arsenic in a few dugwell water samples from Purulia district.

Figure 12: Groundwater arsenic contamination situation in Western part of West Bengal

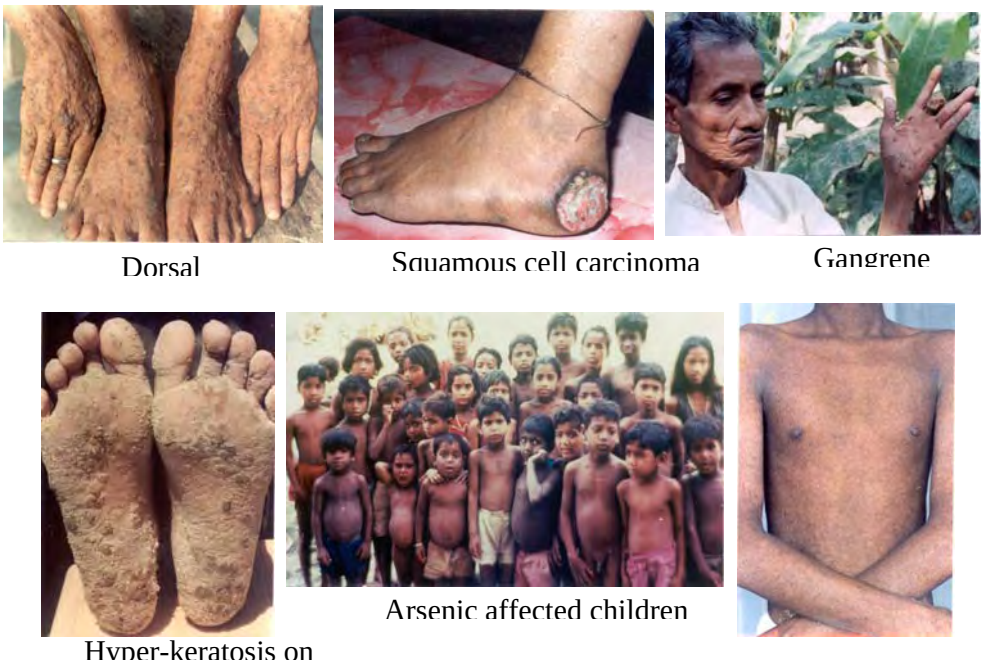
xii) **Estimation of the population may be at risk of drinking arsenic contaminated water at different concentration levels**: Based on the average user of a tubewell and the percentage of tubewell contaminated at different concentration levels, population may be at risk of drinking arsenic contaminated water at different concentration levels was estimated for eight affected districts (Except Kolkata as majority of the people there use supplied water). For the estimation we proceed in three step process (i) total number of tube wells exists in each district/blocks were estimated dividing total population by average number of user per tubewell (ii) estimated no of tubewell at different concentration level for each district/block was calculated by multiplying total tubewell number (obtained in step i) by proportion of tubewell contaminated at different concentration levels in the respective district/block. (iii) Estimated exposed population was calculated multiplying estimated number of tubewell (obtained in step ii) by average number of persons using a tubewell. In order to be more realistic we excluded those blocks /police stations from

calculation where we did not conduct survey. The studies reveal that the estimated exposed population may be at risk of drinking arsenic contaminated water at different concentration levels. About 9.5 and 4.6 million people may be at risk of drinking arsenic contaminated water above 10 and 50 μg/L respectively and, an estimated 0.5 million above 300 μg/L

Arsenical health effects in West Bengal

(i) **Dermatological effects:** West Bengal is one of the worst arsenic affected areas in the world arsenic scenario. In our preliminary work our medical group examined around 96,000 individuals, including children (age range: below 11 yr), for arsenic toxicity from West Bengal, 9356 of them showed skin lesions. We identified 778 children with arsenical skin lesions screening total 14000 children from West Bengal (Table 2). Various types of skin manifestations of arsenic toxicity were observed from melanosis, keratosis, hyperkeratosis, dorsal keratosis, and non-pitting oedema to gangrene and cancer (61, 76, 104). We do not expect such a high percentage of arsenicosis patients in all the arsenic affected districts. Figure 13 shows patients from West Bengal with different arsenical skin manifestations. The large number of people showing arsenical skin-lesions is due to the fact that we had examined villagers from only those villages, which are highly arsenic contaminated and we had prior information of the presence of arsenic patients. Undoubtedly the overall percentage of arsenic affected people is expected to be lower in the less contaminated areas.

Figure 13: Some patients from arsenic affected areas of West Bengal with different arsenical skin manifestations.



(ii) **Arsenical neuropathy**: Neurological examination was generally undertaken for arsenicosis patients whose skin lesions were already diagnosed by experienced dermatologist. The neurological part was conducted by the same experienced neurologist to obviate inter-observer variability for each patient of arsenocosis so tested. Observations were recorded for items considered consistent with peripheral motor and sensory neuropathy and for other neurologic abnormalities as well. Pain history and pain-specific sensory examination were stressed. The items included to characterize neuropathy were (i) pain and paraesthesias (e.g., burning) in a stocking and glove distribution, (ii) numbness, (iii) hyperpathia/allodynia, (iv) distal hypesthesias (reduced perception of sensation to

pinprick/reduced or absent vibratory perception/ affected joint-position sensation/ affected touch sensation), (v) calf tenderness, (vi) weakness/atrophy of distal limb muscles or gait disorder, and (vii) reduction or absence of tendonflexes. Overall prevalence of clinical neuropathy was noted in our studies (61,104,105) in populations of Murshidabad and Nadia districts of West Bengal.

(iii) **Arsenic in drinking water and obstetric outcome**: Arsenic exposure during pregnancy can adversely affect several reproductive endpoints. Several studies have examined the association between arsenic exposure and adverse pregnancy outcome, including spontaneous abortion, preterm birth, stillbirths, low birth weight and neonatal and perinatal mortality (56, 61). All these parameters were compared to those observed in the control women group from a non-arsenic exposed district (Medinipur East and Medinipur West) of West Bengal. Adverse obstetric effects were observed in our detailed studies with village women from Murshidabad district, West Bengal.

Arsenic body burden: sub clinical effects: Arsenic concentration in hair and nails plays an important role in evaluating the arsenic body burden. We measured inorganic arsenic and its metabolites in urine and total arsenic in hair, nail and skin scale samples from the villages where we had identified arsenical patients. Around 40-50% samples were collected from those already having skin lesions and rest from the persons who had not but living in the arsenic affected villages. So far we have analyzed 13325 hair, 13468 nail, 12831 urine and 1000 skin scale samples from arsenic affected villages in West Bengal. The results demonstrate that 91% of the hair, 97% of the nail, and 92% of the urine samples in West Bengal contained arsenic above the normal levels for urine and nails and toxic levels for hair. These results indicate that though many villagers may not be suffering from skin lesions but have elevated levels of arsenic in their biological; samples thus may be sub-clinically affected. Table 4 shows the parametric presentation of the arsenic concentration of the biological samples collected from arsenic affected areas of West Bengal and those from control samples collected from arsenic safe areas.

Table 4: Parametric presentation of the arsenic concentration in biological samples.

Parameters	Biological samples (Contaminated areas)			Biological samples (Arsenic safe areas)		
	Hair	Nail	Urine	Hair	Nail	Urine
Sample no.	13325	13468	12831	75	75	75
Mean	2427	4845	368	341	748	16
Minimum	70	80	5	217	540	10
Maximum	31770	44890	9375	499	1066	41
Standard Deviation	1823	4157	374	103	107	10.5
% of samples above normal/toxic levels	91	97	92	0	0	1

Note * Normal level of arsenic in hair is 80-250 µg/kg.
* Normal level of arsenic in nail is 430 – 1080 µg/kg.
** Normal level of arsenic in Urine is 5 – 40 µg/1.5L/day.
*** Toxic level of arsenic in hair is 1000 µg/kg

Arsenic affected children: Furthermore, plight of children in the arsenic affected regions of West Bengal and Bangladesh is remarkably similar. Infants and children are often considered more susceptible to the adverse effects of toxic substances than adults (106). In one of our studies on an arsenic affected population in Bangladesh we have found that second metabolic step in arsenic metabolic pathways is more active in exposed children in comparison with exposed adults (107).

Social Problems Due to Arsenic Contamination

The common social problems due to arsenic toxicity as we have noticed from West Bengal, India are as follows:

1) Affected wives are sent back, sometimes even with their children, to their parents.
2) Marriage of people of either sex from the affected villages is difficult.
3) Often jobs / service are denied / ignored to the arsenic affected persons.
4) When a husband or wife is singled out as an arsenic patient, the social problems crop up and may destroy the social fabric.
5) Due to ignorance, the villagers sometimes view it as a case of leprosy and force the arsenic patients to follow an isolated life.

Arsenic in food chain:

In arsenic affected areas of West Bengal and Bangladesh arsenic contaminated water is not only used for drinking and cooking but also for agricultural irrigation. Thus arsenic comes into the food chain. In the affected areas villagers also consume arsenic from Pantavat[1] and water added to food preparations like rice, soup, curry and tea. This aspect has been currently highlighted in a few publications (108-110). As we have described about an arsenic affected village, Kolsur Gram Panchayet (GP) in Deganga block of North 24 Parganas District in West Bengal, in one of our publications (108), "From the results of total amount of arsenic consumed (drinking water + rice + vegetables + pantavat + water added for food preparation) the body burden to North Kolsur villagers (1185.0 μg for per adult per day, 653.2 μg for per child per day), as the amount of arsenic coming form rice, vegetables, and water added for Pantavat[1] and food preparation is 485 μg, i.e., 41% of the total for adults and 253.2 μg, i.e., 38.8% for children and from rice and vegetables 285 μg, i.e., 24% of total for adults and 153.2 μg i.e., 23.4% for children. Our findings show that most of the arsenic coming from food is inorganic in nature."

DISCUSSION

Geological reasoning of incidence of arsenic in groundwater and possible temporal variability.

Lateral and depth-wise variation in the disposition of unconsolidated litho units (cobbles, pebbles, gravels, sand, silt, clay and their admixtures) in the subsurface quaternary sequence play major roles in the incidence and distribution of varied concentration of arsenic in groundwater.

150-250m thick granular zone occurring as alluvial fans in the extreme northern part of West Bengal acts as the recharge zone for the unconfined aquifers with high permeability. This zone receives on an average 3000mm of rainfall annually. This granular zone gets separated in most of the areas by 2 to 10 m thick clay layers within a depth of about 300m where confined groundwater occurs. These aquifers at depth to the south of the fan zone are hydraulically connected to the recharge zone and contain groundwater mildly affected by arsenic. The recent flood plain deposits of Maldah district, however, recorded high concentration of groundwater arsenic (111).

The subsurface geological picture of the southern part of West Bengal to the east of the Achaeans shield area is nearly similar to its northern counterpart except the absence of cobbles and pebbles in the sequence and the Pleistocene sediments covering almost one-half of the area to the east of the shield area. Eastward it is followed by Holocene deltaic sediments which by nature are characterized by frequent change in facieses from sand to clay and vice-versa at short distances both laterally and vertically. At the delta head

[1] Pantavat: This is common breakfast food in some part of rural West Bengal and Bangladesh. Pantavat is rice mixed with water. Normally they pour water on rice coked the previous night and have it as their breakfast. Normally villagers take it with vegetables/mashed potatoes/chili and onion.

located in Murshidabad and Nadia districts, 150-250m thick granular zone containing groundwater with high concentration of arsenic under unconfined condition occurs. It forms the recharge zone for the deeper aquifers down south. Like the Northern part, here also this thick granular zone gets separated by several clay layers, the thickness of which gradually increases southward. Beside, a clay layer appears at the top of the sequence with thickness gradually increasing southward from 2 to 30m precluding direct rainfall recharge to the group of aquifers below the top clay. These aquifers constitute the confined aquifer system receiving water from the recharge area to the north as well as to the west formed by the weathered sections within the crystalline rocks in the shield area.
In and around Kolkata beside the top clay layer, another 20-30m thick clay layers occurs at around 150m depth, the thickness of which increases to 50-60m further south. It is followed by alternating sequence of sand and clay layers down to a depth of about 300m (111).

In the delta and flood plains due to attenuation of intervening clay layers, the group of aquifers at depth gets interconnected at some places giving avenues for polluted groundwater to travel at deeper depths (111).

When groundwater flow path is obstructed by the presence of finer material groundwater arsenic is expected to increase. Similarly, at places, where such barriers are absent, arsenic content might remain same or show decrease or slight increase depending upon the complex recharge-withdrawal processes. This complex phenomenon seems to be responsible for variation in arsenic content in ground water within short distance tapping the same aquifer in the delta and flood plain deposits. Moreover, travel time required for transmission of arsenic contaminated groundwater from the recharge zones to the deeper aquifer system down south depends on the variation in composition of material through which groundwater moves. All these factors cause variations in arsenic concentration in groundwater from one location to the other. Seasonal change and/or temporal variation in arsenic concentration in groundwater are therefore, not an unexpected phenomenon.

Estimation of population at risk: the uncertainties involved

The magnitude of arsenic calamity seems to be severe from the overall study of groundwater arsenic contamination and its health effect in Murshidabad. Only in Murshidabad district we reported (60) that 2.6 million and 1.2 million people are at risk of drinking arsenic contaminated water above 10μg/L and 50μg/L respectively. Extrapolating the data we generated we found that about 9.5 and 4.6 million people may be at risk of drinking arsenic contaminated water above 10 and 50 μg/L respectively and, an estimated 0.8 million above 300 μg/L.

One of our assumptions for the estimation of population at risk was that, people have been drinking from the same contaminated tubewell all along from the time of analysis. But during last 10 years lot of awareness campaigns were launched in the affected areas to teach people vices of arsenic contamination and to test their tubewell for arsenic before use. Also different alternative safe water options have been made available to affected population like purified surface supply water, deep tubewells, dugwells, arsenic removal plants etc. Due to this gradual switchover to safe options actual population drinking arsenic contaminated water (> 50 μg/L) may be less than the predicted ones.

Temporal variability of arsenic concentrations

During our last 10 year survey of the arsenic affected districts of West Bengal, we noticed (112, 113) that within a span of 3-7 years in some villages, tubewells that had initially been safe (arsenic<10 μg/L) became contaminated (arsenic>50 μg/L) in course of time. Furthermore, the arsenic concentration in many tubewells had increased by as much as 5-20 folds (112,113).

Increasing exploitation of groundwater

West Bengal is village dominated and in remote villages more than 95% people drink private or public hand tubewell water. In urban and semi urban areas drinking water source is usually purified surface water or deep tubewell (above 100m depth) supplied through pipe line by public authorities though sometimes due to bacterial contamination (owing to underground pipeline leakage) people use hand tubewell water. There are districts in West Bengal like West Dinajpur, Jalpaiguri etc where due to plenty of available surface water and dugwell a decade before hand tubewells were few. At present due to lowering of water table people are switching to tubewells. This is a common practice allover the GMB plain including arsenic affected areas. Additionally since the launch of green revolution in India in 1960, due to gradual depletion of surface water resources and irregular monsoons, irrigation is one of the major sources of groundwater withdrawal. So exploitation of groundwater by tubewells continues unabated.

Mitigation approaches

1. **Surface water with proper watershed management and purification:**

Upto early 20th century the main sources of drinking water in West Bengal and Bangladesh, were ponds, lakes etc. and people would drink untreated water. With proper treatment against bacterial and other contaminations and proper management of available surface water may hold the key to safe potable water for West Bengal where per capita available surface water is huge (7,000 cubic meters in West Bengal), average annual rainfall in these regions is about 2,000 mm and the land known as "land of rivers" with huge wetland, flooded river basins, oxbow lakes. Below we present a specific instance of how surface water resources lay unutilized which could have been managed with proper planning.

A Canal named 'Dead Padma' popularly known as Mara (dead) Padma is one of the examples of vast unused water bodies of West Bengal, India. It is believed that once it was part of river Padma which is now in Bangladesh. Stretched over a span of around 90 kms, this canal is flowing through Nadia and 24 Parganas (North) districts and ultimately meets river Jamuna in 24 Parganas (North). A significant part (around 20 km) is situated in highly arsenic affected Deganga block. The canal is covered with water hyacinths. Throughout the year water is present in this canal. When water declines during winter, local people connect the canal with river Jamuna and cultivate "Boro" rice. There are several water bodies along side the canal, some privately owned. In absence of proper plan and management the canal lays almost unused except sporadic fishing by some localites. A proper plan to utilize this surface water resource in the following ways could provide safe water treatment and overall economic development for the people living on the banks:

(a) In Deganga block out of 15,886 tubewells we analyzed 13,000 tubewells for arsenic and found, 57% and 37.3% had above 10 and 50 μg/L concentration respectively. In this block out of 234142 people an estimated 7726 were drinking contaminated water having arsenic concentration above 300 μg/L. In our preliminary study with our medical group including expert dermatologist, obstetricians and neurologists we examined 11,780 people and 786 (6.6%) people were identified as patients (55). In these circumstances the water from this canal after proper treatment can be supplied to nearby areas. This can serve as a safe water option for the poor affected villagers.
(b) A planned fish culture program and duckary can be undertaken.
(c) The water can be directly used for irrigation instead of tubewells.

What we need is proper management of huge land-water body with people's participation using advanced water purification technologies.

2. **Deep tubewells free from toxins.**

It is well established that shallow tubewells in arsenic contaminated areas may not be safe. It is also observed that in the Gangetic plain As contamination in hand tubewells

has been observed to decrease after a certain depth (114) but in unconfined aquifers there appears to be no depth guarantee, even if the construction of tube well is done properly.
Based on our nineteen year long study over different parts of the GMB plain on groundwater arsenic contamination we observed that deep tubewells (>150m) may not always provide safe source of drinking water. Safety of deep tubewells depends on several factors: i) construction of the deep tubewell, ii) depth of the deep tubewell iii) presence of confined aquifer, and iv) the aquifer should be under a thick clay barrier.
However, a note of caution in West Bengal is, many tube wells that were safe (As < 10μg/l) became contaminated (above 50μg/l) over time (112-113). So periodic testing for water contaminants is important.

3. **Dugwells**.

With the advent of hand tubewells the use of dug wells subsided largely because of bacterial contamination of the dugwell water and consequent enteric diseases prevailing among the users. This called for wide scale abandoning of these dug wells. In this age of acute scarcity of water when it is predicted that toilet flush water would need to be recycled for use in future for potable water, this vast source of water should not at all be neglected. Proper management of dugwell would necessitate the following factors: i) Concrete structure with a storage tank. ii) Proper selection of location, iii) Preventing surface contamination, using a fine net / glass fiber screen over it, iv) Cleaning monthly with lime and sodium hypochlorite and removal of some amount of bottom sediment [During cleaning the dugwell water is to be stored in storage tank for supply] and v) If bacteria are even not detected after periodic cleaning we recommend a few drops of sodium hypochlorite (depending on water in dugwell) to be added at night everyday. If affordable a UV source (if electricity is available) after storage tank will help. Once a year removal of bottom sediment from dugwell is necessary and this will also take care of sand building.
In Betai region of Dangapara GP, block Tehatta, district Nadia a properly managed dugwell (photograph available on our website www.soesju.org) caters to drinking water need of 100 families.

4. **Rainwater harvesting**

In many states of India and southern parts of Bangladesh, the harvesting of rainwater is still a common practice. In present scenario if rainwater is harvested through clean roof top collection into storage tanks, and precautions are taken against bacterial contamination, the stored rainwater can be used for at least 4-5 months per year. In arsenic affected areas of Thailand this is a common practice. English people during their stay in Kolkata, a century ago, used to drink freshly collected rainwater.

5. **Arsenic removal plants**

One of the possible arsenic mitigation strategies was installation of Arsenic Removal Plant (ARP). Installation of ARPs in West Bengal-India started at the end of 1998. The West Bengal government and other organizations have already invested about 3 million dollars in installing ARPs purchased from both national and international manufacturers (1900 ARPs were set up at an average price of US$1500 for each ARP) in mainly 5 out of 9 arsenic affected districts of West Bengal, India.

Our preliminary investigations on the efficiency of ARPs in West Bengal began in late 1998. During last 7 years we evaluated the efficiency of 577 APRs in the districts of North 24 Parganas, Murshidabad, and Nadia of West Bengal till date and submitted our evaluation reports to the Government of West-Bengal, ARP manufacturers and other concerned NGOs for their information and follow-up action (115-119).

We conducted a two-year long systematic study in order to evaluate the efficiency of 19 ARPs from 11 different national and international manufacturers installed in Baruipur block of South 24 Parganas district under a project titled 'Technology Park Project'

implemented by All India Institute of Hygiene and Public Health (AIIH&PH), Govt. of India, Kolkata, in partnership with a number of NGOs under the financial support from India-Canada Environment Facility (ICEF), New Delhi. Ineffectiveness and poor reliability of the ARPs based on this study has been reported (120).

From our field experience we observed that in most cases authorities installed the ARPs abruptly without checking the ground realities. Lack of awareness and relevant information is one of the major hurdles in arsenic mitigation program (121). Though we noticed (120) none of the ARPs in Technology park project could achieve arsenic concentration below WHO provisional guideline value (10 μg/l) a few of them could limit arsenic below Indian standard 50 μg/l where the users were able to recognize the ARPs as an asset for the community and maintained it properly.

6. **Role of better nutrition**

We must understand that so far there is no available medicine for chronic arsenic toxicity; safe water, nutritious food, vitamins and physical exercise are the only preventive measures to fight the chronic arsenic toxicity. A recent study by Mitra et al. (122) covering 57 villages in South 24 Parganas in West Bengal highlighted that malnutrition could double the risk of skin lesions. Plenty of seasonal fruits and vegetables, which are very cheap, are available in arsenic affected villages around the GMB plain round the year. A large percentage of villagers are not aware that they can get better nutrition from local fruits and vegetables. They have to be trained how they can get nutritious food using cheap local fruits and vegetables. Cooking also destroys essential nutrients in vegetables and fruits.

7. **The Role of Community Involvement**

For successful arsenic mitigation community involvement especially of women is essential. The concept of community participation though a new paradigm is now become integral part of any successful social venture.
An awareness campaign should include the following points:

a) The danger of arsenic in drinking water
b) Different arsenic related health effects
c) The necessity of arsenic removal
d) Importance of keeping updated on quality of drinking water in terms of arsenic and other contaminants as found out from periodical testing. The results of periodical testing may be displayed near the source.
e) The role of better nutrition in fighting arsenic toxicity

Lack of awareness and relevant information is one of the major hurdles in any arsenic mitigation program.

CONCLUSION:

Though first case of arsenocosis was revealed in West Bengal in early 1980s the widespread contamination was not recognized until 1995. Similar pattern followed in the late recognition of groundwater arsenic contamination of Bangladesh. In Bihar, till date we found 12 districts by the side of Ganga arsenic contaminated and in 6 districts identified subjects with arsenical skin lesions since the discovery of arsenic contamination back in 2002 and more are coming to fore with the continuing surveys. We predict from our up-to-date preliminary survey from UP and Bihar 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. The areas of UP and Bihar, adjacent to arsenic contaminated Terai region, Nepal may also be affected.

In India before arsenic contamination problem surfaced in 1983, we knew about fluoride contamination in groundwater from 1937. At present only in India 62 million people are suffering from fluorosis, a crippling disease. The presence of uranium, boron, and

manganese in groundwater of Bangladesh above WHO prescribed limiting values has already been reported (123,124). Unless immediate measures for detailed water analysis are undertaken and awareness among all the sections of society (with especially involving women) about contaminants in drinking water is generated, toxins of higher toxicity may affect in course of time.

In Bangladesh and West Bengal, at present less people are drinking arsenic contaminated water due to growing awareness and access to arsenic safe water. But in Bihar, UP, Jharkhand, and Assam still the villagers are drinking contaminated water owing to non recognition of arsenic contamination as a problem requiring urgent action. The blunder committed in West Bengal and Bangladesh before should not be repeated.

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GEOGENIC ARSENIC CONTAMINATION TO GROUND WATER IN PARTS OF AMBAGARH CHOWKI BLOCK, RAJNANDGAON DISTRICT, CHHATTISGARH.

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INTRODUCTION

Arsenic, in very low concentration has its adverse effect on health. In India, 0.05 ppm (or 50µg/l) concentration of arsenic has been considered the upper safe limit in drinking water, though in the provisional guidelines (2001) of World Health Organisation (WHO), 0.01 ppm has been taken as the upper safe limit of Arsenic in drinking water which in 2003 has been endorsed by Bureau of Indian Standard (BIS).

The purpose of the present work is to document the status of the Arsenic contamination in ground water in Ambagarh Chowki block, Rajnandgaon district .The scope of work involves understanding the extent of Arsenic contamination in space and time and its variation with environmental conditions in the area. Attempts have also been made towards establishing various controls over the occurrence of Arsenic contamination in the area.

Ambagarh Chowki block of Rajnandgaon district is situated in the west central part of Chhattisgarh adjacent to Maharashtra . (**Fig.1**) The study area is situated in eastern part of Ambagarh Chowki block covering an area of about 330 sq.km, lying between the north latitudes 20°39'35" to 20°51'00" and east longitudes 80°38'50" to 80°49'28", as given in. **Fig**. **2**. The study area covers 92 villages where total population is 74604, mainly dominated by schedule tribes. The SC and ST community together constitutes 51% of population.

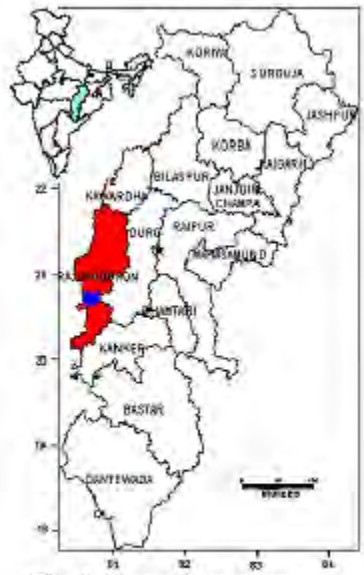


Fig 1 Location map

Fig 2 Location of Study area

The study area is located in the northern side of the regional water divide of the Godavari and Mahanadi basin. Area is drained by tributaries of the Mahanadi. Seonath is the major perennial tributary draining the area. The drainage pattern is generally sub-dendritic in nature. In areas of volcanic rocks the drainage density is high especially in the southern portion of the study area. The drainage density is poor to moderate in the area of granite terrain and laterite capping areas. The area experiences sub-tropical climate, characterized by extreme summer and extreme winter. The rainy season extends from June to September with well-distributed rainfall during southwest monsoon. During summer season, day temperatures often go above 46°C .During winter, the night temperatures may sometimes drop below 10°C. Evaporation is maximum in the month of May, which is more than 250 mm. In the district summer season humidity is the lowest, about 35% while it is higher during the monsoon period, about 86%.The long term average rainfall of 28 years (1978-2005) worked out to be 1225 mm for Mohala and 1187mm for the Ambagarh Chowki (Tewari,2003).

METHODOLOGY

Determination of Arsenic in natural water is a skillful job. The collection of samples, time between collection and analysis, analytical process all are very significant in determination of Arsenic in aqueous phase, which mainly occurs in ppb (parts for billion) level. In absence of prescribed sampling Protocol in the country, the conventionally followed sampling procedure has been adopted to collect ground water samples from the Arsenic affected area. 250 ml samples were collected for Arsenic analysis in polyethylene bottle (Tarson made) after filtering through membrane filter of 0.04 micron made of Cellouse nitrate (Sagitarious make) using hand operated vacuum pump (Tarson make). The bottle was filled up to top by sample water, rinsed thoroughly by distilled water first and then by sample water. Two ml of ultra pure HCl (1:1) was added for bringing the pH <3 and the cap was placed.

The dug well samples were collected at least 20 cm below the water surface by rope and bucket. The water samples from hand pumps were collected after running hand pumps for 5 minutes by putting the sample bottles directly below the tap. Samples from borewells and water supply system bores were collected directly after running the pump for 5 minutes. Samples from exploratory wells drilled in the area for delineation of Arsenic free zones was first collected by running the air compressor against the respective zone, and after completion of drilling by lowering of submersible pump and rejecting the first 20 minutes sample from each Piezometer.

40 wells were selected representing all the geological formations of the area for monthly monitoring after the first random sampling of 72 wells from 36 villages. The samples were tested at the site by Arsenic kit (Merck. 1.17927.0001 Arsenic kit, strip type, semi quantitatively by visual comparison) and subsequently in the CGWB regional laboratory. Arsenic analysis was done by ECIL make Atomic Absorption Spectrometer (AAS) using hydride generation technique. The detection limit of the method is 0.001 ppm. Further detailed sampling (July 2006) was carried out in five villages where Arsenic contamination beyond 0.050 ppm level was reported through monthly monitoring. Sampling stations were randomly selected within these villages. Drinking water supply scheme if present were invariably taken as sampling point. Samples were also collected from 40 identified wells in one liter plastic bottle for major ion determination in December 2005. The major ion determination for 40 samples was done following the standard procedure at Regional chemical laboratory of CGWB, NCCR, Raipur. EC & pH were analysed by EC and pH meter. Ca, CO3, HCO3 and Cl were analysed using volumetric methods The field measurement of quality parameters for all the monthly monitoring points was determined in November 2005 and July 2006. EC and pH were measured by calibrated pocket type portable instruments (Hanna made). Coordinates of all the sampling points were determined through GPS for plotting of sample location on map. Reduced level of all the monthly sampling points were determined through surveying from nearest Survey of India

bench mark. Water level data were collected for each month during sampling by graduated steel tape..

GEOLOGICAL SET UP

The Chowki area of Rajnandgaon district is part of Indian shield and fall in the Central India Craton. Regionally the area forms part of Dongargarh- Kotri rift zone and is surrounded by Paleo Proterozoic Dongargarh Batholithic granites in west, Meso Proterozoic platform sequence of Chhattisgarh Supergroup in NE and Paleo Proterozoic Supra Crustal sediments of Iron ore series in South. The area is situated within one of the India's most significant mineralization province where Dalli Rajhra Iron ore deposit, Malajkhand porphyry copper deposit, Chandi-Dondri Fluoride- lead deposit, Kotri Gold prospect and Bodal Uranium prospects are already being exploited where as base metal prospecting in the near by area is under progress.

Arsenic occurrence in the area is controlled by lithology and structure. Therefore the geology, chronostratigraphic sequence, structural history is important to understand the behavior of Arsenic occurrence in the area. The geological relationship of the rocks within the area is complex and poorly understood. The available published geological map on 1:50,000 scale (Krishnamurthy et.al 1998, Ashyiya and Patel 1998, Yogesh Pandey et.al. 2002, Acharyya et.al 2005) of the area by GSI and AMD are having differences. The area needs to be mapped on 1:25000 scale for further detailed information.

The rocks in the area have regional strike in N-S to NW-SE direction with sub vertical-to-vertical dips suggesting antiform or synforms. The rock types represented here by rhyolite, rhyolite porphyries, basalts and thin sheets of mildly ultrabasic (tremolite schists) rocks. The Dongargarh granite batholith emplaced into or formed co-magmatically with rhyolite sequence. **(Fig 3)** .The metamorphism is of low-grade green schist to epidote-amphibolite facies. The sheared rock and metamorphism is considered due to emplacement of epizonal Dongargarh granite batholith, (Krishnamurthy et.al.1988) which during hydrothermal phase deposited the extremely fine veins containing disseminated uranium, fluoride and sulfide minerals.

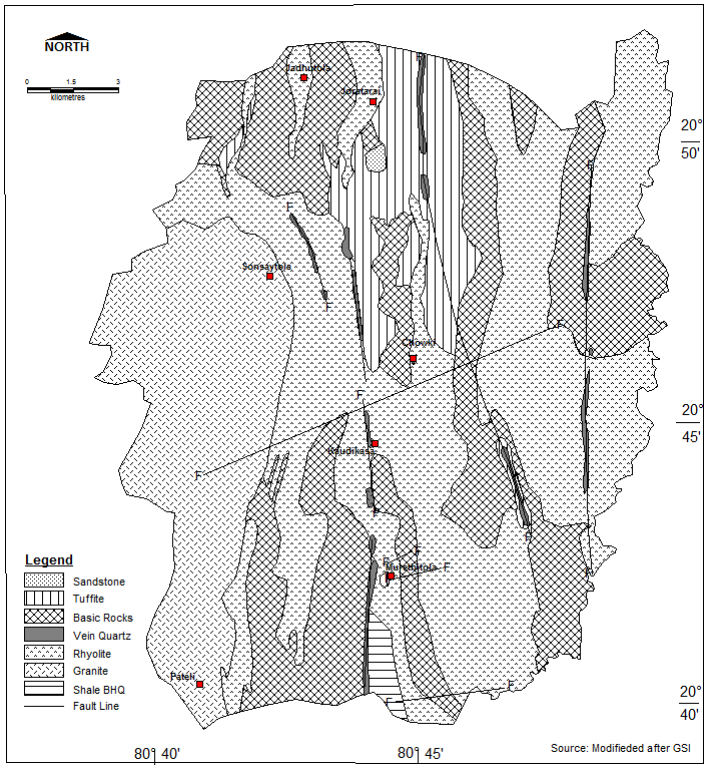


Fig. 3. Geological map of study area

HYDROGEOLOGICAL SET UP

Detailed hydrogeological study in the Arsenic affected area was carried out to establish hydrogeological relationship between geology and Arsenic concentration. During field investigation 40 key observation wells including both dugwell and bore well were established. Pumping tests were conducted in different formations to know the aquifer characteristics. Ground water level monitoring of all observation wells were carried out on

monthly basis and water samples were also collected to assess Arsenic concentration. Bore-wells constructed by CGWB and other agencies were studied.

Water bearing property of aquifer

Ground water occurs in weathered and fractured portion in hard rocks and in porous zones of laterite and alluvium in the area. Ground water occurs under phreatic condition in laterite, alluvium and weathered mantle of crystalline rocks and under semi confined to confined condition in deeper fractured zone. Ground water development in the area is done through dugwells, handpumps and bore wells. Maximum ground water development is observed through irrigation dug well and bore wells in flood plain area of Seonath alluvium. Ground water conditions in different rock formations are discussed below.

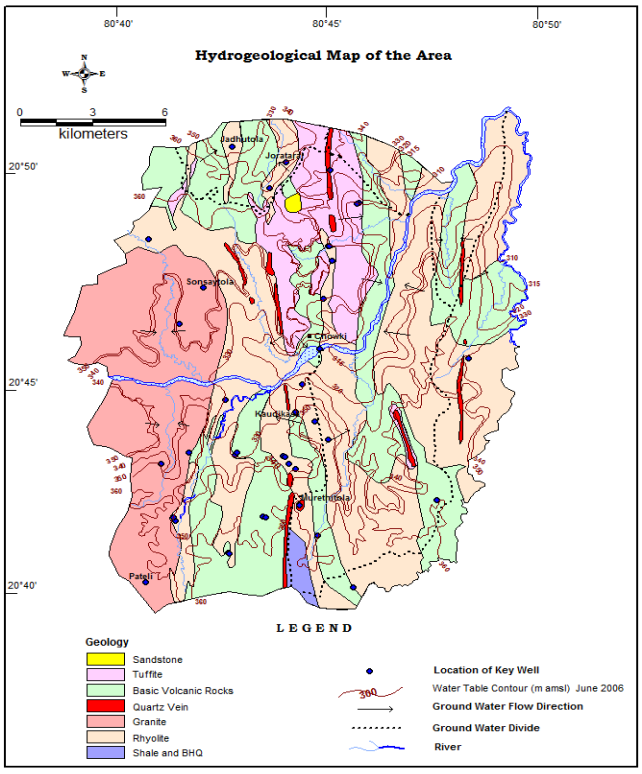


Fig 4 Hydrogeological Map of the study area

In Ferruginous shale and BHQ of the Iron ore Group exposed in southern boundary of the study area, in this formation Ground water occurs in the weathered portion under phreatic condition. In fractured zone (within depth of 100 mbgl) ground water occurs under semi confined to confined condition. Yield of the formation is poor due to their low secondary porosity. Depth to water level during post monsoon observed to vary from 1.5 to 5.00 mbgl and in pre monsoon from 7 to 13 mbgl. The gradient of water table contour in the area is steep. **(Fig 4).**

In Basic volcanics, secondary porosity are poorly developed. Weathering has developed permeable zones in weathered mantle of the formation. The thickness of the weathered mantle ranges from 9.9 m at Somatola to 22.57 m at Kumhli. Ground water in weathered mantle occurs in phreatic condition and in fractured aquifer under semi confined to confined condition. Yield potential of the fractured aquifer depends upon inter connectivity and dimension of fractures and the yield range has been recorded from 0.23 lps in Somatola to 12.39 lps in the well at Kumhli.Depth to water level during premonsoon was found to be shallowest at Taramtola (7.02 mbgl) and deepest at Devasur (17.70 mbgl). The post monsoon depth to water level ranges from 3.2 to 10.63 mbgl. Fluctuation of water level varies from 1.00 m at Bhagwantola to 7.72 m at Devasur. Four exploratory wells were constructed in basic rocks at Bhagwantola, Biharikhurd, Gaulitola and Murethitola. Bihrikhurd and Murethitola villages are situated on volcanic tuff where the tuff thickness varying from 13 to 16 m. Basic rock Andesite was encountered below the volcanic tuff and it extended down to maximum drilled depth i.e. 150 m bgl. In basic rock fractured zones are encountered at 32-38, 42-45 mbgl with yield ranges from 2 to 4.5 lps. Transmissivity and storativity of aquifers are moderate (Jogi,2001,Tewari. 2003).

Rhyolites predominate in the study area. In this formation groundwater occurs under phreatic and semi confined conditions and is more productive having potentiality higher than the granite. The thickness of the weathered mantle ranges from 5.6 m (Keshrtola) to 36.2 m(Telitola). The dug wells have a depth range from 6.79 mbgl (Biharikala, 64D/9) to 13.90 mbgl. (Devasur 64D/10). Premonsoon water level was shallowest (2.97 mbgl) at

Biharikala and deepest at Ambagarh Chowki (12.42 mbgl) .Seasonal water level fluctuation is in the range of 0.97 m to 6.12 m. The groundwater is under semiconfined conditions in the fractures and joints of rhyolite below the weathered zone. The Atargaon bore well-yielded a discharge of 0.47 lps and Iragaon has the maximum discharge of 15.68 lps. Eight exploratory wells were constructed in Rhyolite in the area, the villages are Kaurikasa, Arajkund, Biharikala, Atargaon , Keshritola, Borhanbhedi and Telitola. Telitola village is situated on volcanic tuffs, with the thickness of 36 m, rhyollite is encountered below volcanic tuff which extended down to the drill depth of 152 m bgl. Fractured zones recorded at 40-45, 58, 95-100, 135-140 m bgl. Yield of these borewells ranges from 1.5 lps to 12 lps. The Transmissivity and storativity of these wells are moderate. Salient features of the Borewell drilled in Rhyolite is given in **Table 1**

Table 1 : Salient features of the Bore-well drilled in the Rhyolites of the area

Location	Drilled depth (mbgl)	Casing (m)	Saturated Zone (m bgl)	Commutative discharge in lps	Draw down (m)	SWL (mbgl)	T (m^2/ day)	Sp. Capacity (m^3/m of dd/mint)
Telitola	137	36.4	60 to 65, 3.5 82 to 84, 87	7.9	6.48	6.52	25	73.15
Gotatola	137	38.2	27 to 31, 1.89, 121 to 135, 8.7, 127 to 130 to 10.45, 131 to 135,12.39	12.4	12.25	9.92	25	60.69

Ground water in granites occurs within weathered zone, joints and fractures, (deep aquifers) under phreatic to semi confined conditions. The thickness of the weathered zone ranges from 8.4 m at Ratanbhat to 26.78 m at Panabaras and the general thickness of the weathered overburden is 10 to 23 m. Four exploratory wells were constructed in the granitic terrain down to the depth range between 100 to 152 mbgl. The deeper fractures was encountered at 91.4 mbgl in Ratanbhat and 141.87 mbgl at Kaneri and Rangakatherea borewells . The maximum yield was recorded at Ratanbhat 11.39 lps. Most of the exploratory wells in granites have yielded meager discharge .

The depth of dug wells ranges from 4.95 mbgl at Hathea (64D/15) to 14.35 at Matiya (64D/13). Depth to water level ranges between 1.16 mbgl to 11.75 mbgl during premonsoon period and from 3. 1.16 mbgl at Dighwari to 8.20 mbgl at Kandadi (64D/11).in postmonsoon.. The seasonal water level fluctuation in observation wells in granite ranges from 0.22 m at Ghotia (64D/15) to 6.37 m at Markatola (64D/14).

Depth to water level

Depth to water level data of 40 observation key wells, for post monsoon (Nov 2005) indicates that in the major part of the area, depth to water level lies between 3 to 5 mbgl. The deepest water level of 19 m bgl was recorded at Devasur where as the shallowest, 1.94 mbgl was recorded at Dadhutola. About 10% of the wells show depth to water level ranges between 0-3 mbgl, 55% of well shows depth to water level in range of 3 to 5 mbgl and 35% of well shows depth to water level in the range of 5 to 10 mbgl **.**

Depth to water level for the premonsoon period indicates that in the major part of the area depth to water level is between 5 to 10 mbgl. The deepest water level of 18.35 mbgl was recorded at Devasur, whereas the shallowest 2.49 mbgl at Seonath river bank. In area about 2.5% the wells represented depth to water level between 0-5 mbgl, 67.5% shows 5-10 mbgl and remaining 30% well shows more than 10 mbgl.

Water level fluctuation

Seasonal water level fluctuation was calculated using depth to water of Nov 2005 and May 2006. Fluctuation indicates that more than 50% of the study area, the water level

fluctuation ranges between 3 to 5 m. The maximum fluctuation of 7.7 m is recorded at Devasur and the minimum of 1.25 m at Joratarai.

Ground Water Flow

To study the ground water flow during premonsoon June 2006, the reduced level of water levels recorded from 40 key wells were plotted and water table contours, with 10 m. interval was drawn. Water table ranges from 310 to 340 m amsl, (Fig 4). It is clear from the map that the ground water flows towards Seonath River from both side of river, The ground water more or less flow as per the surface drainage pattern. The gradient of ground water is steeper in north west of the Seonath River and is gentler in the south east of the study area. However, gradient of ground water varies from 3.0m /km to 0.3 m/km and the Seonath River is effluent type throughout the year.

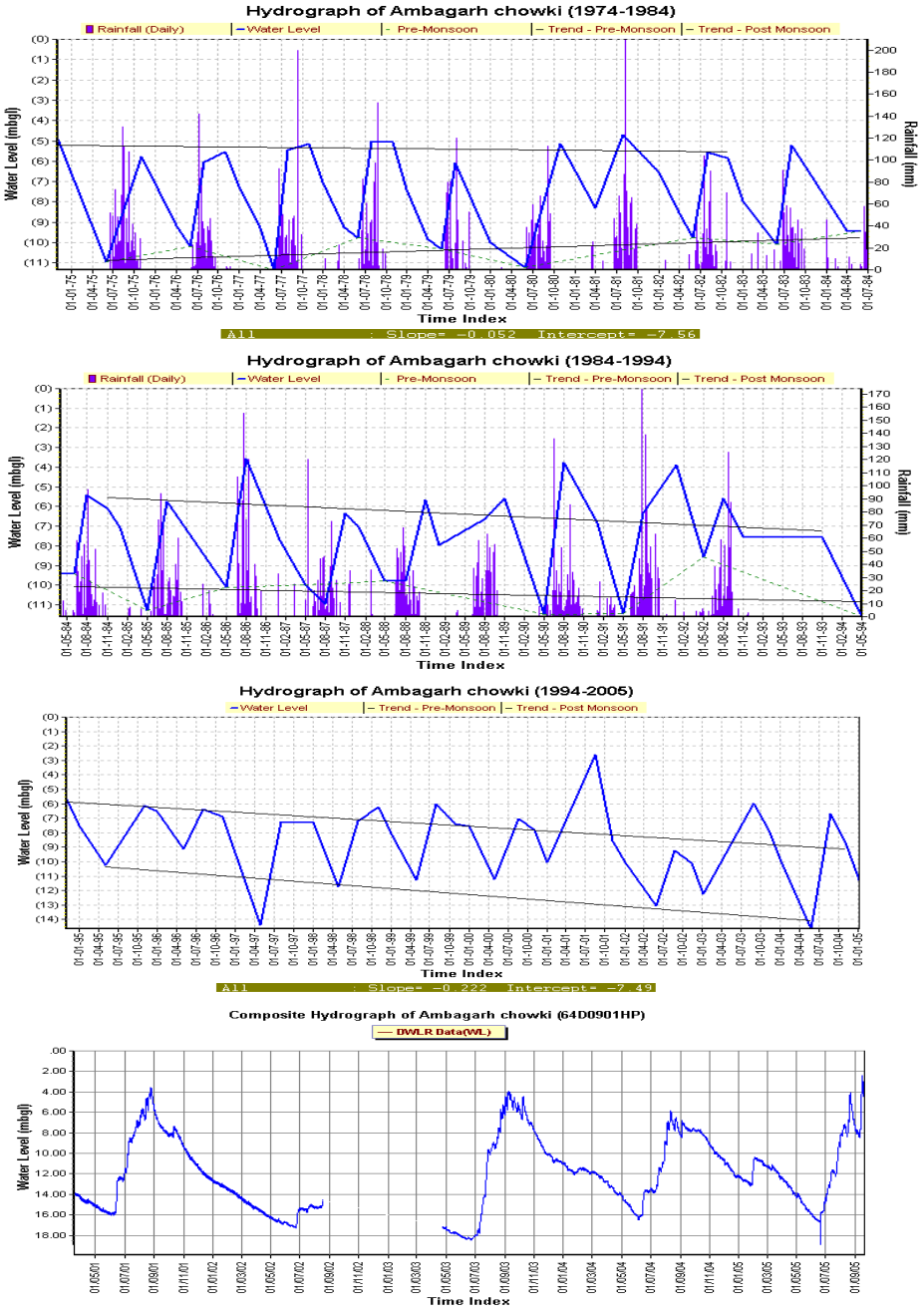


Fig 5 Long term hydrograph of Dug well (1974-2006) and Piezometer (2001-2005) of Ambagarh Chowki

Analysis of National Hydrograph Stations

There is one National Hydrograph stations in the study area and the NH station is situated at Ambagarh Chowki. Hence is considered to study long term behavior of water levels. This NH stations was monitored four times every year for study DTW, seasonal fluctuation and long-term fluctuation. To assess the long term behavior of the water level ,data of last 30 years of the station was analysed and hydrographs **(Fig 5)** prepared. The decadal trend was calculated separately.

Ground Water Resource

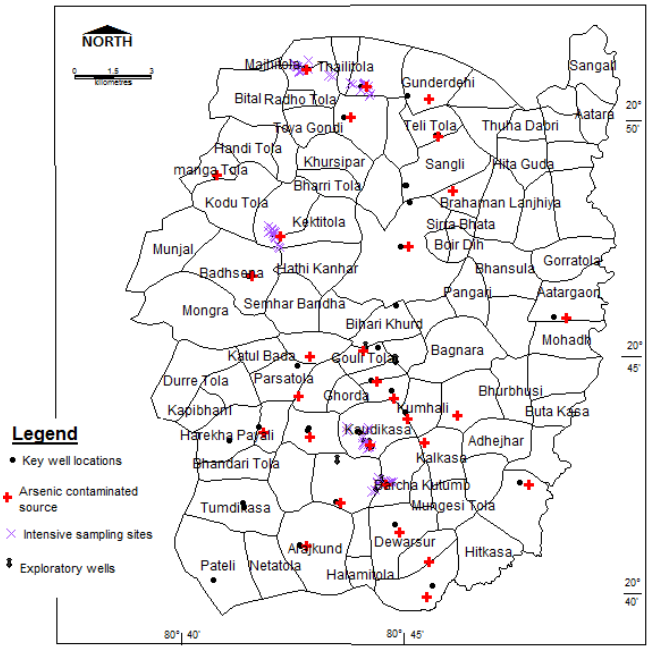
The Net annual Ground water availability in the study area as per the GEC-97 methodology is 4021.04 ham and the ground water draft for all uses is 969.12 ham. The stage of ground water development is only 24.10% and the area is categorized as safe from ground water development point of view.

ARSENIC IN GROUND WATER: SOURCE, EXTENT AND VARIATIONS

Sources of Arsenic in Study Area

The sources of Arsenic for the high Arsenic ground water in Chowki area is being established geogenic (Acharyya et.al 2001 and 2005, Y.Pandey et.al 2002, P.Pandey et.al 2002) and is related to Kotri-Dongargarh rift zone. All over the rift zone, insitu soil, weathered rocks and fresh rocks are found locally enriched with Arsenic. The volcanic and shear zone rocks (quartz ribs and vains) contain hydrothermal sulphide mineralization. The most common metal sulphide is pyrite, which many a time is Arsenic bearing. Acharyya et.al (2005) reported presence of 150 ppm Arsenic within the fresh pyrite, occurring in rhyolite from Joratari and 1.6% Arsenic from Dadhutola.

Fig. 6 Disribution of arsenic contaminated wells and sampling points



Baseline Concentration Of Arsenic In Ground Water

To know the baseline value of Arsenic in the ground water occurring in Chhattisgarh State ground water samples during May 02 were collected and analysed from 313 permanent monitoring National Hydrograph stations spread over on all 16 district of state (Tewari, 2003). Apart from this GSI Raipur has carried out intensive sampling of ground water all along the Kotri- Dongargarh rift zone. The state PHED through NEERI Nagpur has made village wise inventory of ground water of entire Chowki block to assess the value of Arsenic in ground water .

The results of 313 samples of Ground water of entire state (excluding Chowki block) by Central Ground Water Board shows that 68% of samples the Arsenic values are found below detection limit (i.e. <0.001 ppm). In other 32% sample the Arsenic values varies from 0.001 to 0.011 ppm. The maximum value observed in one well of Dongargarh (0.011 ppm). However higher Arsenic concentration is being reported by GSI in ground water from the Auriferous Kotri- Dongargarh rift zone extending over 80 km length from Kanker to Rajnandgaon district represented by bimodal volcanics, granite and Iron Ore Group rocks. Apart from the present study area, higher concentration (more than 0.05 ppm) of Arsenic is being reported from few other villages along the rift area are Gurwandi (0.250 to 0.680 ppm) Kaneri (0.060 ppm) Umarpal (0.058 ppm) Jabkasar (0.060 ppm). In other remaining samples the Arsenic concentration was found in the range of < 0.001 to 0.049 ppm. NEERI(2000) in their study have shown the ground water samples are having higher Arsenic concentration in the western part of Chowki block. However in other part of Chowki block ground water samples containing Arsenic concentration between 0.001 and 0.010 ppm.

Spatial And Temporal Extent Of High Arsenic Ground Water In Study Area.

Geogenic Arsenic contamination in ground water at different degree of severity occurs in eastern part of Ambagarh Chowki block, Rajnandgaon district, Chhattisgarh and is confined to the early Proterozoic rhyolitic rocks and granite along the N-S trending Kotri-Dongargarh rift zone. The high Arsenic ground water in the area is restricted to wells in small isolated area and in a cluster of few villages within widely place area of 330 sq.km which is 21.5 km long and 18.5 km wide (broadly 10 km radius area). This area lying between N latitudes 20°39 to 20°51 and E longitudes 80°40' to 80°49' and falling under 1:50000 toposheet 64D./ 9,10, 13 & 14. (**Fig.6) .**The village boundary in the map is as per Census report (1998).

Distribution of high Arsenic Ground water

The geographical distribution of high arsenic ground water is sporadic in the area. Five villages are found severely effected with high Arsenic ground water. These are Kaudikasa > Joratarai > Sonsaytola > Muletitola > Jadutola respectively in order of abundance. Even in the worst affected village -Kaudikasa not all ground water abstraction structures are found contaminated with high values of arsenic (i.e. >0.05 ppm). Only 10 to 70% of the ground water abstraction structures are found with high Arsenic value (>0.05 ppm) in the area.

Table- 2. Summarized details of Arsenic analysis in study area

Year and month	Nos of Ground water Sample analysed	**Nos of Ground water sample contain Arsenic in different Range**			**Village with no. of ground water structure Containing > 0.050ppm Arsenic**
		>0.050 ppm	0.010-0.049 ppm	< 0.010 ppm	
7/1999	28	3	Nil	25	Kaurikasa (2), Nichaghore (1)
12/2000 & 4/ 2001	72	12	19	41	Kaurikasa (10), Telitola (1), Bharsena (1)
6/2003	68	1	4	63	Kaurikasa (1)
June to July 2005-2006	625	76	79	470	Kaurikasa, Joratarai, Sonsaytola, Jadutola, Muletitola (See Table 3)

Year	**Surface water sample analysed number**	**Location**	**Range of Arsenic ppm**
1999	2	Bundaka nala,	BDL (below detection limit)
		Seonath River at Chowki	BDL
2002	1	Kotri River	0.0135
2003	1	Seonath River at Sirrabhata	0.00012
2005	4	Seonath River at Chowki,	BDL
		Seonath River at Mogradam	0.00096
		Sangli tank at Sangli	BDL
		Bhansula quarry pit	0.00014

While working in the Ambagarh Chowki block and all those villages of the block in which other organization have reported higher concentration of Arsenic have taken in to account. During investigations in the area from the year 1999-2006 total 793 ground water samples and 24 surface water samples were analyzed in laboratory (**Table-2**) and nearly 100 samples insitu at field by Arsenic testing kit and have conformed presence of high Arsenic ground water (>0.050 ppm) in 8 villages during one or the other time namely

Kaurikasa , Joratarai, Sonsaytola, Jadutola, Muletitola, Telitola, Bharsena, Nichakhore . Out of which first five are severely effected with high Arsenic ground water. The range of Arsenic values in the analysed samples varies from 0.0001 to 0.720 ppm.The surface water samples tested during this period are not found contaminated with Arsenic. (Table.2)

Analytical results: A study for continuous 14 months (June 05 to July 06) was conducted in selected 40 wells located in 29 villages to evaluate the arsenic concentration in ground water in different months, The ground water analysis results are presented in **Table 3**. The analysis results reveal the following facts.

1. The 40 wells (dug & bore wells) of 29 villages based on analytical results can broadly be divided into three major groups.

(a) Arsenic was never detected in any of the months of entire study period of 14 months in 9 wells.

(b) Arsenic is generally non detected but suddenly occurs for very few months (1 to 3 or 4 months) mostly during rainy season (June to August) and concentration is much below permissible limit of 0.050 ppm. i .e safe for drinking purpose as per BIS norm in 1-20 wells.

(c) Arsenic was detected in all 14 months in 6 villages viz- Jadutola , Joratarai , Sonsaytola , Kaurikasa , Mulethetola , Bhagwantola . The Jadutola and Joratarai occurs in Northern part of study area while Kaurikasa, Mulethetola and Bhagwantola is located in the southern part and the Sonsayatola is situated in western part (**Fig 6**). It was observed that in rest 5 villages only 8 wells (5 bore wells and 3 dug wells) content arsenic all through and out of 8 wells only in 5 wells arsenic occurs above permissible limit (>0.050 ppm). The maximum concentration of 0.720 ppm has been noted from a dug well located in house of Sh. Daulat Ram in Kaurikasa village and nearby bore well in market complex of same village content maximum of 0. 575 ppm arsenic.

2. The ground water structure of above 6 village which containt arsenic (more or less all the 14 months) are located in different rock types such as rhyolite (Kaurikasa and Joratarai), rhyolite tuff (Jadutola and Murethetola) and Granite (Sonsaytola) .
3. The concentration of arsenic varies widely in different months. The arsenic concentration of 0.190 ppm in July 2005 was found to reduced to 0.040 ppm in October 2005 and was found0.097 ppm in July 2006 in the same bore well in Joratarai .Similarly0. 575 ppm arsenic in June2005 remained much below permissible limit in all other months except in June 06 (0.169ppm) in bore well of Kaurikasa village.

Through no definite pattern in arsenic concentration, variation with respect to time has been noted. In certain cases, the concentration has been found to reduce gradually during rainy seasons with minimum concentration mostly during October/November followed by increased gradually in November-December and in rest of the months till May-June this increased values show some oscillating pattern instead of continuous increase. This variation in concentration had also been tried to correlate with monthly rainfall and depth to water level data but any definite conclusion could not be obtained with 14 months data (**Fig 7**). Perhaps long term data of 5 to 6 years may speak something definite

Causes of Temporal Variation

To establish the cause of temporal variation in the Arsenic concentration level in ground water, monthly water level data at the time of sampling were taken and monthly rainfall data from the nearby stations Chowki and Mohla were collected and plotted in graph. The analytical values clearly indicate a dilution of Arsenic concentration during monsoon (July to September when > 90% of annual rainfall occurs) and resultant ground water level remains shallowest during July to October (Fig 7)

Table 3 Seasonal variation in Arsenic concentration in monthly monitoring wells - 2005-06

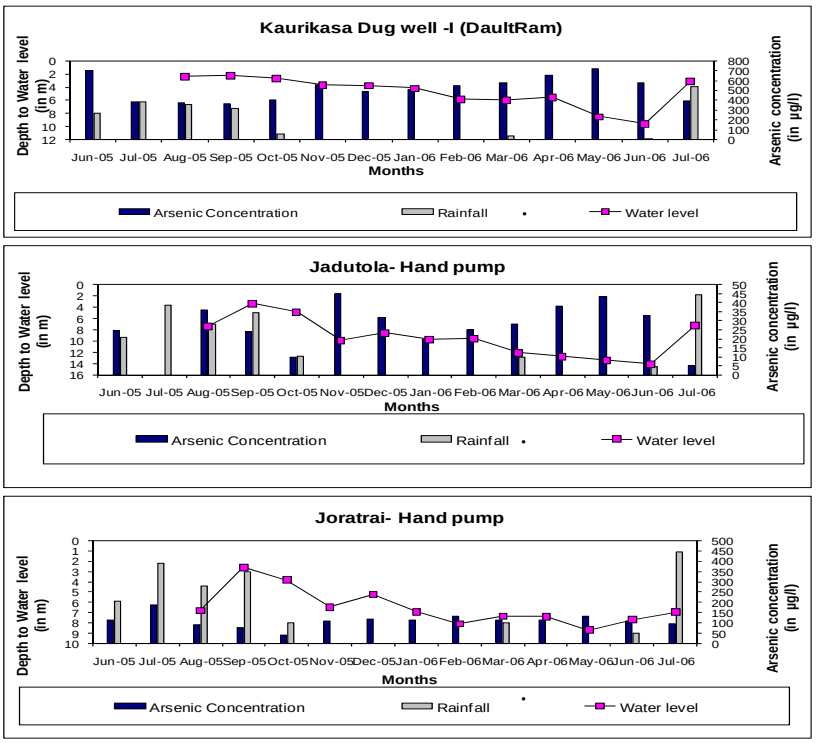
	Location	Lithology	Source	As in ppb (Analysis of sample at Chemica Lab. CGWB, NCCR, Raipur)													
				19-21 June 2005	25-26 July 2005	17-18 August 05	18-19 Sept 05	21-23 Oct 05	29-30 Nov 05	23-24 Dec05	Jan 06	Feb-06	30-31 Mar 06	April	22-23 May 06	23-24 June 06	21-24 July 06
1	Meregaon	Rhyolite	BW	nd	nd	4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
2	Sangali	Rhyolite	Talab	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
3	Sangali	Rhyolite	HP	nd	3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
4	Sangali	Rhyolite	DW	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
5	Telitola	Rhyolite	HP	nd	12	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
6	Telitola	Rhyolite	DW	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
7	Gunderdehi	Rhyolite	HP	nd	8	7	nd	13	8	9	7	nd	nd	nd	nd	nd	nd
8	Joratarai	Rhyolite	HP	113.74	190	90	80	40	110	120	115	132	115	114	132	108	97
9	Jadutola	Rhyollitic tuff	HP	24.31	49	36	24	10	45	32	20	25	28	38	43	33	5
10	Shivnath river bank, Cho	River alluvium	DW	0.964	snc	6	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
11	Atargaon	Rhyolite	Pump house	0.964	3	7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
12	Kursitikul(east)	Rhyollitic tuff	HP	1.218	9	4	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
13	Kumhali	Rhyolite	HP	0.457	3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
14	Muletitola	tuff	DW	56.8	60	52	46	3	57	61	62	65	78	86	104	64	65
15	Devasur	Rhyolite	HP	1.98	6		nd	nd	nd	9	12	17	nd	nd	nd	nd	nd
16	Taramtola	Gabbro	HP	1.472	5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
17	Bihari khurd	Tuff	DW	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
18	Metepar	tuffite	HP	0.711	nd	nd	10	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
19	Pandritarai	Rhyolite	HP	3.756	5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
20	Arajkund	Weathered Basic	DW	2.741	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
21	Arajkund	Rhyolite	HP	2.995	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
22	Pateli	Weathered granite	DW	nd	3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
23	Tumrikasa	Rhyolite	HP	nd	25	24	18	17	4	10	10	15	14	21	24	18	nd
24	Tumrikasa	Tuff/weathered rhyollite	DW	9.594	6	7	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
25	Harekhaphyali	Granite	DW	Snc	Snc	Snc	Snc	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
26	Kunderatola	Amphibolite	HP	Snc	Snc	Snc	Snc	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
27	Parsatola	Basic rock	HP	Snc	Snc	Snc	Snc	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
28	Bharsena	Weathered granite	HP	nd	11	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
29	Sonsaytola	Granite	HP	69.49	142	120	110	53	110	115	110	115	109	110	120	105	86
30	Mangatola	Rhyolite	HP	nd	5	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
31	Mangatola	Rhyolite	DW	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
32	Dhadutola	Rhyolite	DW	nd	nd	nd	8	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
33	Nichekohra	Rhyolite	HP	nd	15	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
34	Nichekohra	Rhyolite	DW	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
35	Bhagwantola	Gabbro	HP	14.42	17	19	nd	18	26	12	12	16	8	13	28	18	20
36	Bhagwantola	Gabbro	DW	5.025	9	8	nd	nd	9	4	5	10	7	11	13	9	4
37	Kaurikasa east	Rhyolite	HP 1	575.5	6	16	9	nd	21	18	20	15	14	40	20	169	6
38	Kaurikasa east (	Rhyollite	DW 1	707.2	385	380	365	400	560	490	510	550	580	660	720	580	394
39	Kaurikasa west (Near r	Rhyolite	HP 2	-	snc	nd	nd	nd	5	nd	nd	nd	nd	nd	40	9	6
40	Kaurikasa west (Towarc	Rhyolite	DW 2	-	18	19	21	9	15	8	12	8	7	25	13	7	6

snc= sample not collected, nd= not detected, HP= hand pump, DW= dug well, BW = bore well

Reasoning of occasional positive test of few well samples

The study reveals that dynamic ground water levels influence Arsenic concentration in ground water. The dynamic levels are results of recharge (mainly during monsoon) and discharge (draft and base flow) phenomenon due to hydro meteorological and climatic parameters and anthropogenic influence. Since the study area is mono-cropped and any ground water irrigational draft is mainly takes places during monsoon and just after monsoon and confined to Kharif crops only, the water level decline from post monsoon to pre monsoon is mainly due to evapo-transpiration (more than 15% area is forested) and steady base flow from the phreatic aquifer coupled with limited ground water draft. The high Arsenic ground water source show gradual enrichment in overall Arsenic concentration after monsoon and is found highest in pre monsoon. (Table 3). Leaching effects from Arsenic enriched soil and weathered rocks can be observed until first few showers. Therefore the wide change in values of Arsenic concentration in some wells in different year (**Table 4**) may be the result of variation in precipitation amount and pattern along with the availability/ expose of Arsenic source.

Fig 7 Correlation diagram for Rainfall,Water level and Arsenic concentration



The study in the area suggested presence of elevated arsenic concentration in wells is many a time caused by localized borehole interaction of air, water and sulfides. Although Arsenic contamination is caused by oxidation of naturally occurring sulfides, it is influenced by water level fluctuations caused by pumping wells or climatic change, which can shift geographic areas in which contamination occurs (Schrieiber et al, 2000, Smedley and Kinniburgh 2002).

The bore hole provides direct conduit for atmospheric oxygen to interact with water and sulfide minerals when due to pumping water level (draw down) goes below the presence of sulfide mineral in the aquifer material. The hydrogeological studies in the present area reveal drawdown of maximum 38 m in potential wells. However in poor yielding wells it will go further down. Further, deepest maximum water level in the area is noted around 18 mbgl in summer thus the exposed level of aquifer material during pumping can be around 60 mbgl or even more. All the hand pumps in this area are working in this depth range hence can exhibit high Arsenic if situation other wise is favorable/ source mineral is present.

Table : 4 Yearly variation of Arsenic values in individual wells*

(Arsenic values in ppm)

Year	1998	1999	2000	2001	2002	2003	2004	2005	2006
Kaurikasa DW (Daulatram)	0.180	0.256	1.050	0.330	0.510	-	-	0.470	0.570
BW Kaurikasa (New power pump PHED)	Not constructed	0.020	-	0.030	0.040	0.005	-	nd	0.048
Rainfall (mm)	898	1329	1163	1498	762	1768	1168	1465	

***** Data partly collected from various source (Pandey et.al 1999,Y. Pandey 2002,).

The borehole construction play important role in sulfide mineral oxidation. Schrieiber et al (2000) during their study in USA found in several heavily impacted wells a lag time occurred between well construction and initiation of sulphide oxidation. The current positive arsenic test in Joratari (0.210 ppm) and Sonsaytola (0.240 ppm) water supply bore well water and constant increase of Arsenic values in Kaudikasa water supply well **(**Table 4**)** may be an indication of lag time of sulfide oxidation and release of Arsenic in ground water. Therefore it can be stated that entire stretch of 80 km Kotri- Dongargarh rift zone where sulphide minerilization is in abandoned can be declared as "Arsenic Advisory area"

Arsenic concentrations in dug well and bore wells

Study in the area have established that though many dug wells are highly contaminated in the most affected five villages, still the Arsenic in dug wells are less than the bore wells. The dug wells in the area are maximum 15 m in depth and invariably tap the phreatic aquifer. Pandey P et al (1999, 2002) established negative correlation between diameter of dug well and Arsenic concentration. This relationship is obvious as per the chemical behavior of Arsenic. Due to better atmospheric interaction in dug wells arsenic get oxidized and removed from the aquous phase. Due to the same reason and dilution effect the base flow to surface water body have not effected the level of Arsenic in rivers and ponds. The contamination of nala (0.010 ppm) or some ponds (0.020 ppm) in Kaurikasa village (Acharyya et al. 2005) is probably due to direct pumping of ground water to ponds under Indira Gaon Ganga Yojna.

Relation of individual fracture zone and arsenic concentration

Detailed investigation to establish Arsenic free deeper aquifer in Chowki area has been taken up in the Rajnandgaon district. The exploratory drilling have proved occasional presence of potential deeper fracture which can yield water up to 7 lps. Deeper fractures have been encountered between 60 m and 150 m in number of wells in meta volcanic and granitic rocks in the district. (Tewari, 2003). Based on the findings of regional exploration detailed exploratory drilling programme has been taken up to construct specially design/ well nest in four villages in the area. Deploying DTH rig total 12 wells were constructed tapping individual fractures available in between 0-150 mbgl in a particular site eliminating others by cement sealing. The results of the exploration is summarized in the **table 5** and depth wise ground water sample collected while drilling by compressor and after drilling by deploying submersible pumps in the individual wells are analysed at field by Arsenic testing kit as well as in laboratory to find out depth wise Arsenic concentration.(table 5).

The depth wise exploratory wells constructed by tapping only a single water bearing fracture zone in 4 villages have not lead to any definite conclusion. In Mandirpara middle fracture (between 47-54 mbgl) is contaminated and shallow and deeper are free of Arsenic Table 5

Where as at Bihrikala the Arsenic concentration in well water collected by compressed air lifted sample, just after drilling shown constant increase in Arsenic level from BDL to0.027 ppm. However sample collected by lowering of pump have not found any arsenic in this deeper zone i.e. 135 mbgl. Importantly the exploration have provided two high discharge well of 4.5 and 6.3 lps at Bihiri khurd (Arsenic free) and Bihri kala (Arsenic0.027ppm) respectively. This relatively arsenic free source can be utilized for community supply of drinking water.

Table 5. Salient features of exploratory for arsenic free source

Location with geology		Type	Depth (m)	Casing (m)	Zone (mbgl)	Discharge (lps)	SWL* m bmp on 23-7-2006	mp (m agl)	Drawdown (m)	As test results ppm)	
										Sample on different date during drilling	Sample on 23-7-06
Mandirpara -Bhagwantola (Gabbro)	EW-I	BW	61.7	23.10	35	<1	7.48	0.51	5.75	0.007	nd
	EW-II	BW	54.1	47	51.5	0.78	7.84	0.20	6.75	0.053	0.045
		During the drilling a zone at 23.1 is found and tested nil and now is being sealed									
	EW-III	BW	152.9	62.5	62.5	Seepag	10.13	0.43	16.42	nd	nd
		During drilling a zone at 23.5 is found, water tested having 0.010 ppm arsenic and is now sealed.									
Muletitola (Basic rock)	EW	BW	40	21.2	23.7	1.57	6.73	0.50	5.14	0.025	0.030
Bihrikala (Rhyolite)	EW-I	BW	40	24.2	32-34	0.82	3.92	0.58	7.97	nd	0.007
	EW-II	BW	65.7	40.0	58	0.15	4.57	0.32	> 40	0.003	nd
	EW-III	BW	137	70.0	135.5	6.30	6.79	0.40	38.22	0.027	nd
Bihrikhurd (Basic rock)	EW-I	BW	48.5	39	42.9	4.55	8.35	0.37	18.05	nd	nd
	EW-II	BW	55.1	48	49	1.6	9.10	0.27	7.48	nd	nd
	EW-III	BW	150.9	70.5	dry	Seepage	56.32	0.42	--	Sample not collected	
Kaurikasa (Rhyolite)	EW-I	BW	150	70.00	98-100, 115-115.4	1.5	6.5	0.5	-	-	-
	EW-III	BW	150	69.75	70-75	0.50	3.00	0.6	-	-	-

Note : Different static water level in different wells at same place conforms the isolation of zone by cement sealing. nd - not detected, mbgl- m below ground level, magl-m above ground level, lps- liters per second, mp-measuring point

Lithological Control Over Arsenic Contamination

The high Arsenic ground water (>0.05 ppm) in the study area is preferably associated with acid meta volcanic and granitic rocks and is situated close to shear zone rocks. Ground water in the relatively younger metabasic, basic and pyroclastic rocks are having conspicuously low Arsenic level (below 0.050 ppm). These are very important observation for the area as basic rocks are occupied nearly 28% of the area and are closely associated with rhyolite. Some of the villages are situated over both the rock type. For example Muletitola, Deversur, Kalkasa, Sangli, Chowki, Arajkund etc, many of them are found one or other time with high arsenic contamination (i.e. > 0.05 ppm). Careful site selection on basic rocks in these villages can eliminate the high Arsenic source. There exists an urgent need of large scale geological mapping 1:25000 or even 1:10000 scale of the area. The occurrence of high Arsenic ground water preferably in rhyolite and granite is reported by Acharyya et al (2005) but they have not discussed the cause behind. Our search for arsenic free aquifer is mainly targeted to basic rocks of the area however large many numbers of villages situated on rhyolite are totally free of arsenic contamination in the area. The hydrothermal phase followed by acid magma intrusion has enriched the rhyolite-granite rocks with Arsenic. The basic rocks intruded after hydrothermal phase, this is the main cause of less abundance of Arsenic in these rocks. The limited occasional occurrence of Arsenic in basic rocks is due to assimilation of rhyolite rocks and enriched through remobilization of sulfide mineral. Because of the difference in the grain size, the glassy rhyolites probably have produced more fine ruptures than granite to host mineralization through moving hydrothermal solution.

Results Of Field Kit Test

Merck arsenic test kit (1.17927.001) is used for insitu field determination of Arsenic in ground water. In this when zinc powder, a solid acid, and- for the elimination of interfering sulfide irons- an oxidizing agent are added to compounds of arsenic (III) and arsenic (V), Arsenic hydride is liberated, which is turn reacts with mercury (II) bromide contained in the reaction zone of the analytical test strip to form yellow-brown mixed arsenic- mercury halogenides. The concentration of arsenic (III) and arsenic (V) are measured semi- quantitavely by visual comparison of the reaction zone of the analytical test strip with the fields of a colour scale. The field kit provides unreliable results regarding for arsenic concentration between 0.010-0.100 (ppm) (Md.Jakuriya et al 2000). During the present study results of kit test many time differ with lab test results, as summarized for few samples **Table 6.**

Table 6 Comparison of Arsenic values obtained from field kit test and laboratory analysis.

Sl.No	Location	Type	Results of (ppm)	
			Field test	Lab test *
1	Mandirpara	EW-I	0.010-0.025	0.007
2.	Mandirpara	EW-II, Ist zone IInd zone	0.010-0.025 0.025-0.050	0.010 0.053
3.	Mandirpara	EW-III, IInd zone	0.00-0.005	BDL
4	Muletitola	EW	0.005-0.010	0.025
5	Bihrikala	EW-I	0.010-0.025	BDL and 0.007
6	Bihrikala	EW-II	0.00-0.005	0.003
7	Bihrikala	EW-III	0.025-0.050	0.027
8	Bihri khurd	EW-I	0.000-0.005	BDL
9	Bihri khurd	EW-II	0.000-0.005	BDL
10	Muletitola	HP, S.No 45	0.050-0.100	0.039
11	Muletitola	BW,.46	0.025-0.050	0.023
12	Muletitola	HP, 47	0.050-0.100	0.011
13	Muletitola	HP, 48	0.025-0.050	0.025
14	Muletitola	HP, 49	0.010-0.025	BDL
15	Joratarai	DW, 73	0.050-0.100	0.168
16	Joratarai	HP, 74	0.010-0.025	0.222

* Sample analysis at CGWB, NCCR, Raipur Lab by AAS.

CHEMISTRY OF ARSENIC IN GROUND WATER OF CHOWKI BLOCK

Arsenic is the element of group V-A of the periodic table. Arsenic occurs in both organic and inorganic forms in water. In Inorganic arsenic systems the -3,0, +3 and the +5 oxidation states are common in aqueous systems. The +3 form is more toxic and has greater mobility compared to the other forms. Arsenic is known to readily participate in oxidation, reduction, methylation and acid base reaction. Aqueous arsenic in the form of arsenite, arsenate and organic arsenicale may result from mineral dissolution, industrial discharge or the application of herbicides. The toxicity of arsenic depends on its chemical form.

In previous para attempt has been made to discuss temporal and spatial variations of Arsenic content in ground water also discussed its geological control in various formations and different zones. Huge data had been collected to study arsenic in ground water of Chowki block. Apart form specific arsenic analysis, 39 ground water samples were analysed to determine chemical composition of ground water in the study area to understand the general characteristic of ground water in study area and the results are tabulated in **Table 7**

Discussion On Analytical Results

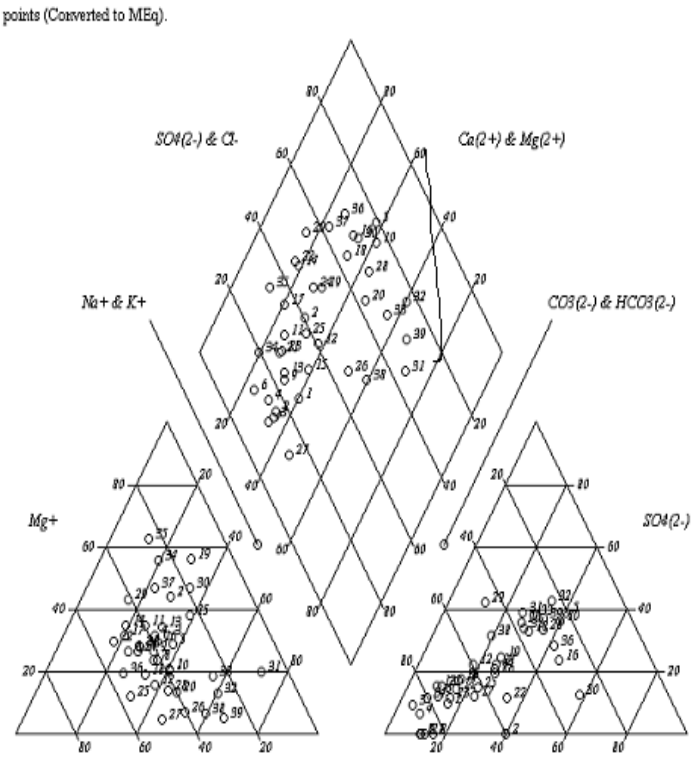


Fig 8 Piper tri linear plot

The results of chemical analysis of 39 samples from study area show that ground water in the area is generally fresh as EC values were found in the range of 201 µs/cm to 1388 µs/cm. EC values in excess of 1000 µs/cm were found in only 6 wells water. Water in the area is alkaline in nature as pH varies in the range of 7.6 to 8.2. All the major ions (cations and anions) including fluoride as minor ion were found in safe limit for drinking water use. Nitrate ion in excess of 45 ppm was found only in eight wells whereas more than 100 ppm was found in a well of Nichagoda Village where its concentration was 116 ppm. Plot of water quality data on tri-linear diagram **(Fig.8)** shows that calcium and magnesium ion together dominant over sodium and potassium, as such water is calcium and magnesium type in the area with regards to anions**.** Most of samples are carbonate and bicarbonate type. In some of the cases chloride and sulphate ions dominates.

An attempt has been made to find inter correlation been two ions. Some interesting features were noted from the results. As usual EC has positive correlation with all the major ions. Bicarbonates ions have better correlation of +0.61 with magnesium ion in composition to calcium ions (+ 0.27). This shows the dominance of $MgHCO_3$ in the area. Chloride ions have poor correlation of +.08 with bicarbonate. This shows higher the bicarbonate, lower is the chloride ions. Remaining correlations are normal and usual.

Table 7. Major ion concentration in ground water of study area (Dec.05),

Sl.No	Location	Type of sample	Date of collection	pH	Conc. In mg/l (Analysis at Chemical Lab, CGWB, NCCR, Raipur)												Con. of As In ppb	Lithlogy
					EC µs/cm at 25°c	TH	Ca	Mg	Na	K	CO_3	HCO_3	Cl	SO_4	NO_3	F		
1	Meregeon	BW	22/12/05	7.7	350	105	28	9	33	0.7	Nil	146	18	15	13	0.88	nd	Rhyollite
2	Sangali tank	Tank	23/12/05	7.6	49	25	4	4	3	3.4	Nil	18	7	ND	3	0.94	nd	Rhyollite
3	Sangali	HP	23/12/05	7.7	428	145	30	17	35	0.6	Nil	232	7	20	ND	0.94	nd	Rhyollite
4	Telitola	HP	24/12/05	7.8	353	135	30	15	27	0.7	Nil	195	11	12	3	0.92	nd	Rhyollite
5	Telitola	DW	24/12/05	8	1198	370	80	41	95	12	Nil	134	152	200	85	0.88	nd	Rhyollite
6	Gunderdehi	HP	24/12/05	7.7	261	105	28	9	15	0.8	Nil	140	11	ND	ND	0.88	9	Rhyollite
7	Joratarai	HP	23/12/05	7.6	201	70	18	6	16	0.5	Nil	92	7		10	0.84	**120**	Rhyollite
8	Jadutola	HP	23/12/05	8.1	269	100	26	9	25	0.3	Nil	128	14		5	0.9	**32**	Rhyollitic tuff
9	Seonath bank, Chowki	DW	24/12/05	7.7	273	105	26	10	23	0.8	Nil	122	11	15	9	0.4	nd	River alluvium
10	Atargaon	HP	24/12/05	7.9	988	290	76	24	91	0.9	Nil	140	135	165	17	0.86	nd	Rhyollite
11	Kursitikul	HP	24/12/05	8	420	170	36	19	26	0.3	Nil	183	25	30	7	0.86	nd	Rhyollitic tuff
12	Kumalhi	HP	24/12/05	7.9	686	210	62	13	58	0.8	Nil	220	39	65	31	1.4	nd	Rhyollite
13	Muletitola	DW	24/12/05	7.7	407	140	28	17	29	0.6	Nil	189	14	30	3	0.92	**61**	Rhyollitic tuff
14	Devasur	HP	24/12/05	7.8	715	290	66	30	31	0.6	Nil	201	57	62	44	0.9	9	Rhyollite
15	Taramtola	HP	24/12/05	7.7	615	200	30	30	57	1	Nil	256	35	52	9	0.88	nd	Gabbro
16	Biharikhurd	DW	23/12/05	7.7	349	125	28	13	26	1.1	Nil	49	43	30	40	0.8	nd	Rhyollitic tuff
17	Metapar	HP	23/12/05	7.6	418	165	40	16	19	0.7	Nil	165	35	24	ND	0.86	nd	Tuffite
18	Pandraitarai	HP	23/12/05	7.8	687	230	66	16	52	0.7	Nil	146	74	106	29	1.28	nd	Rhyollite
19	Arajkund	HP	23/12/05	7.8	605	220	18	43	43	0.9	Nil	171	53	67	19	0.98	nd	Basic rock
20	Arajkund	DW	23/12/05	7.9	745	215	64	13	84	1	Nil	171	74	130	2	0.96	nd	Rhyollite
21	Pateli	DW	23/12/05	7.7	468	170	42	16	28	0.4	Nil	207	18	34	ND	1.32	nd	Granite
22	Tumarikasa	HP	23/12/05	7.7	680	295	76	26	28	0.9	Nil	226	85	38	9	1.42	**10**	Rhyollite
23	Tumarikasa	DW	23/12/05	7.6	250	95	24	9	16	1	Nil	110	14	14	ND	0.88	nd	Tuff/ rhyollite
24	Harekhaphyli	DW	23/12/05	8.1	690	260	66	23	28	28	Nil	183	53	62	88	0.82	nd	Granite
25	Kunderatola	HP	23/12/05	7.7	380	140	46	6	30	0.3	Nil	128	28	24	33	0.96	nd	Amphibolite
26	Parsatola	HP	23/12/05	7.8	680	170	58	6	85	1.1	Nil	220	64	62	19	0.98	nd	Basic rock
27	Bharsena	HP	23/12/05	8	182	50	18	1	19	0.6	Nil	79	7	ND	4	1.38	nd	Granite
28	Sonsaytola	HP	23/12/05	7.7	527	150	46	9	53	0.6	Nil	85	57	72	36	1.28	**115**	Granite
29	Mangatola	HP	23/12/05	7.9	1113	470	92	58	40	0.7	Nil	281	43	205	72	0.94	nd	Rhyollite
30	Mangatola	DW	23/12/05	8.1	863	290	34	50	66	5.3	Nil	146	167	48	47	0.94	nd	Rhyollite
31	Dhadutola	DW	23/12/05	8.2	1330	195	24	33	150	120	Nil	262	113	230	60	0.96	nd	Rhyollite
32	Nichekohra	HP	24/12/05	8	1097	225	60	18	155	2	Nil	134	113	192	116	0.92	nd	Rhyollite
33	Nichekohra	DW	24/12/05	8	1249	275	64	28	124	63	Nil	220	121	205	85	0.96	nd	Rhyollite
34	Bhagwantola	DW	24/12/05	7.8	853	340	42	57	37	0.8	Nil	427	25	48	ND	1.38	**12**	Gabbro
35	Bhagwantola	HP	24/12/05	7.8	729	300	34	52	20	0.7	Nil	275	39	58	16	0.92	**4**	Gabbro
36	Kaurikasa	HP-I	24/12/05	8	689	250	74	16	39	1.5	Nil	104	85	77	52	0.9	**18**	Rhyollite
37	Kaurikasa	HP-II	24/12/05	7.9	942	365	58	54	42	13	Nil	201	92	145	45	0.86	nd	Rhyollite
38	Kaurikasa	DW-I	24/12/05	8.1	608	125	42	5	79	10	Nil	171	39	86	9	0.86	**490**	Rhyollite
39	Kaurikasa	DW-II	24/12/05	7.8	1388	390	56	6	100	84	Nil	226	152	225	84	0.84	**8**	Rhyollite

Relation Of Arsenic With Other Ions

An attempt has been made to establish a correlation between major and minor ions of the water samples together with arsenic. It has been observed that high arsenic is associated with low EC, low bicarbonates and comparatively high sulphate ions.

Quality of Ground Water For Drinking And Irrigation Use

As discussed above, it is inferred that arsenic free water if available; then ground water is the study area is safe for drinking water. In one cases nitrate concentration was found more than 100 mg/l this need to be monitored in future. Water quality data was plotted on US Salinity diagram **(Fig-9)** to assess irrigation quality of ground water. Ground water samples were found to fall in CS, C_2S, C_3S, class of irrigation quality classification. Since, there is no sodium hazard in the ground water and EC is below 1500 μs/cm, therefore, ground water in the area is safe for irrigation.

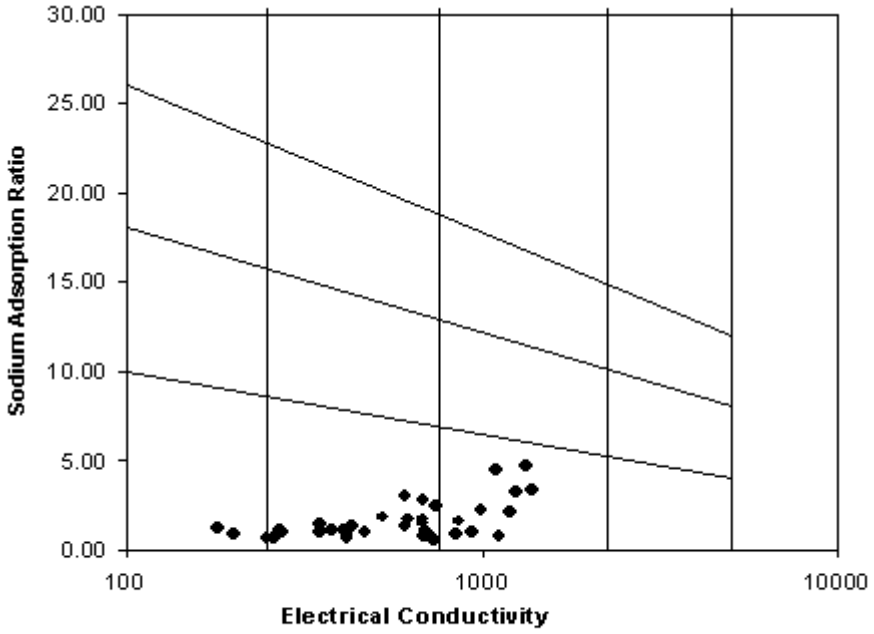


Fig.9 : Suitability of water for irrigation use. Adapted from U.S. Salinity Laboratory.

CONCLUSIONS

During the present investigation in high arsenic ground water area of Chowki block Rajnandgaon district detailed study have been made to (i) establish geological and hydrogeological relationship to high arsenic concentration in ground water, its variations and controls (ii) For source of arsenic free aquifer within the area by exploratory drillings. (iii) Inventory the present status of arsenic poisoning and possible remedial measures and alternative arrangements. The investigation carried out so far is able to understand many aspects of high Arsenic ground water in the area, these are summarized below.

The high arsenic ground water occurrence in eastern part of Chowki block, Rajnandgaon district, Chhattisgarh is confined to the early Proterozoic meta volcanic- granite rocks along the N-S trending Kotri-Dongargarh rift zone. The geographical extent of this high arsenic ground water occurrence is found in isolated clusters distributed over an area of 330 sq.km, nearly in a 10 km radius zone. The most severely affected villages are preferably situated on rhyolite and granite rocks close to shear zone. The relatively younger metabasic, basic and pyroclastic aquifers are less contaminated. This is an important since 28 % of the area is covered with basic rock closely associated as anasthomosing network with rhyolite, the dominant rock type of the area. The lithological control thus observed may contributes toward providing safe and alternative drinking and irrigation water. The intrusion of rhyolitic- granitic magma is followed by the hydrothermal phase which is responsible for arsenic enriched sulfide mineralization and Arsenic enrichment in bedrock. The emplacement of basic rocks took place after the hydrothermal

phase, the limited occurrence of Arsenic in basic rocks are due to assimilation and remobilization reaction only.

In this total 330 sq.km area 92 villages are situated where the present population (census 2001) is around 75000, mainly dominated by aboriginals (SC & ST). Ground water is the principal source for drinking water for the area including the five most arsenic affected villages. State PHED has nearly 780 HP and 20 power pumps in these villages for providing drinking water for people. Since 1997, State PHED has sealed nearly 25 hand pumps in 11 villages which were identified as high Arsenic ground water source. The alternative safe drinking water supply in the most Arsenic affected villages are still through ground water abstraction. During the present course of study, in two villages Sonsaytola & Joratarai it is found that the public water supply source (through ground water) is contaminated with high arsenic 0.240 and 0.210 ppm respectively .Regarding the irrigation water, the area is predominantly mono-cropped area. Kharif is the cropping season and mainly rain fed, supported by surface canal irrigation and occasional ground water irrigation. Second crop area is very scanty and is invariably based on ground water irrigation. The area is having limited ground water potential, which is restricted to the upper 150 m weathered and fractured zone . Present annual ground water draft for irrigation is 860 ham only and other industrial requirement is negligible**.** Overall ground water development of the area is 24% . Apart from the most arsenic affected five villages Kaurikasa> Joratari> Sonsaytola> Jadutola> Muletitola, the occurrence of high arsenic ground water in the remaining area is sporadic and occasional. Even in the most affected villages not all the ground water source are affected with high arsenic contamination. Bore wells and hand pumps are more affected than dug wells in general, and this is more particularly applicable to the area where arsenic contamination is less. However large numbers of dug wells are severely arsenic contaminated in most effected Kaurikasa, Sonsaytola, Joratarai village. During the ground water exploration in the area some arsenic free or limited arsenic contaminated (< 0.040 ppm) fractures were tapped through specially design wells by CGWB which can be utilized as alternative safe drinking water source. Geochemical control on occurrence of high arsenic ground water has been established. The ground water with more than 800 μs/cm EC are found invariably containing lower arsenic value, below 0.050 ppm.

Persons with arsenic toxicity manifestations are identified only in Kaurikasa and Sonsaytola village. Report says 400 persons (nearly 30% population) of village Kaurikasa are affected with high arsenic ground water poisoning and 130 people are critically affected. The clinical symptoms like palmoplanter keratosis can be frequently observed in the area. The critically affected patients are early adulthood or middle age group. Micro watershed management work under Rajiv Gandhi National Watershed Management Programme is going on in the area. Since the soil and weathered rocks are enriched with arsenic hence method of artificial recharge which can bypass the soil and weathered zone must be applied for the area. The Vadose zone available in the area for recharge to dilute the Arsenic contamination is calculated 41 MCM. Long term analysis of hydrograph of Ambagarh Chowki have shown significant decline in pre and post monsoon water level in last decade, where as in previous decade the level were either stable or rising in trend. This clearly indicates enhancement of draft during recent past, which gradually is exposing more and more aquifer material to oxidizing environment. The deepest static water level is at present around 18 m and maximum drawdown is recorded 38 m hence present zone of expose is around 60 m bgl which is the zone of hand pump operation in the area. Ground water in the Amabagarh Chowki block is otherwise geochemically fresh with low to medium salinity; therefore Arsenic free ground water is good both for drinking and irrigation use.

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GEOCHEMISTRY AND SPECIATION OF SOLID AND AQUEOUS PHASE ARSENIC IN THE BENGAL DELTA PLAIN AQUIFERS

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INTRODUCTION

Bengal delta plain (BDP), an integral part of the world's largest delta, is a major natural storehouse of high As groundwater where millions of people are now suffering from serious health hazards including arsenic induced cancer (Guha Mazumder et al., 1999). The unconsolidated alluvium of Pleistocene-Recent age is the source horizon that rests upon Tertiary rock sequence (Bhattacharya et al., 1997).

The scale of the problem is grave and unprecedented both in terms of human exposure (~ 60-80 million) and geographical area coverage (173x 10^3 km^2) (PHED, 1993; Bhattacharya et al., 1997; Smedley and Kinniburgh, 2002; Bhattacharya et al., 2003). The presence of As in groundwater, higher than the stipulated Indian standard (50 μg L^{-1}, drinking water quality standard for most countries) and WHO guideline value (10 μg L^{-1}) for human consumption was first reported from West Bengal, India during early 1980's with first diagnosed case of arsenicosis (Saha, 1984). Later on, within a span of decade, human suffering from natural dissolved inorganic As was widespread in the West Bengal part of BDP and with frequent cases of arsenicosis was reported from 72 blocks spread over nine districts covering ~ 3700 km^2 in West Bengal, starting from Malda in the north to the 24- Pargana (s) in the south (Bhattacharya et al., 1997; Bhattacharya, 2001). In west Bengal high As groundwater areas (barring Purbasthali, Bardhaman district and Balaghar, Hugli district) are confined to the west of Bhagirathi River. However, in the eastward extension of BDP (Bangladesh), the natural arsenic "hot spots" have much wider spatial distribution In those "hot spots" more than 90% of the shallow wells are shown to have elevated levels of arsenic compared to Bangladesh National Standard (50 μg L^{-1}), though the resultant health problem was first diagnosed only in 1993 (BGS and DPHE, 2001; Smedley and Kinniburgh, 2002; Ahmed et al., 2004).

In nature, arsenic (0, -3, +3, +5 oxidation states) exists in both inorganic as well as organic form. Dissolved forms of arsenic in the natural water includes arsenate (+5), arsenite (+3), mono-methyl arsonic acid (MMA) and di-methyl arsinic acid (DMA). However, the degree of toxicity solely depends on the form (inorganic/organic) and the oxidation state of the element. The inorganic forms (arsenate/arsenite) are more toxic

than organic forms (MMA/DMA). Among the inorganic forms, the trivalent form (AsO_3^{3-}) are likely to be more toxic than pentavalent ones (AsO_4^{3-}). Therefore, the precise concentration (chemical speciation) and chemical forms of dissolved inorganic arsenic (both aqueous and solid phases) are important because more toxic and labile As (III) is now globally identified as a major public health issue.

The understanding of the behavior and distribution of redox species in natural waters are essential to explain recently found large-scale groundwater contamination reported from various part of the world. Therefore, the present paper focuses on the hydrochemistry of high As groundwater as well as interaction between water and arsenic traps to understand the release of redox sensitive species into groundwater under local reducing condition (orthodox redox traps). Moreover, understanding the distribution of redox species in natural waters is also essential to explain the large-scale groundwater contamination in the BDP. The different forms of As (in both aqueous and solid phase) will also be identified to assess their roles in As mobilization as well as level of toxicity during human exposure. Attempts have also been made to visualize the geochemistry of the deltaic environment in relation with speciation of As.

GEOLOGY AND PHYSIOGRAPHY OF THE BENGAL DELTA PLAIN

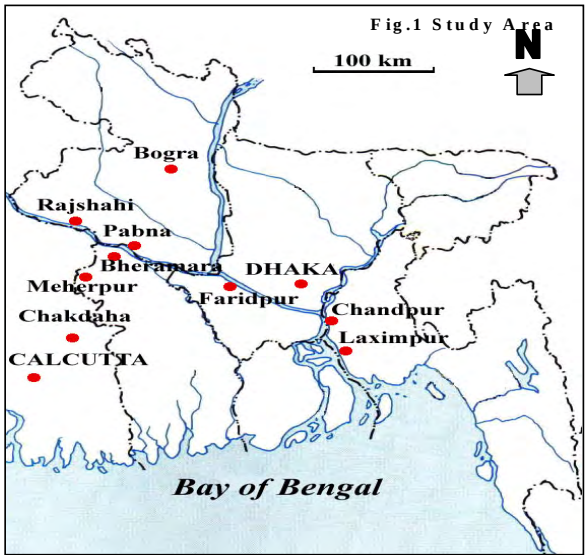
The Bengal basin is a large asymmetrical pericratonic basin and located in the north-eastern part of the Indian sub-continent and one of the largest sedimentary basins of the world. The BDP is an integral part of this basin, with an accumulation of fluvio-deltaic to deltaic-estuarine sediment. The West Bengal part is characterized by a long depositional history of sedimentation (Mesozoic to Recent) that was deposited on a Precambrian basement. The zone is demarked by subsurface domal structures of varying dimension bordering east by a row of enechelon faults. The BDP has characteristic topography, geomorphic and geologic features (through space and time) within the sediments. Throughout the Holocene period, the BDP seems to have acted as fluvial-estuarine-marine platform where both marine (lower part of delta) and non-marine (upper delta and valley margin fan) sedimentation took place. The BDP sediment constitutes dissected uplands with rolling topography and high alluvial plain above the regime of the present day river system. These sediments often disconformably overlie the older deposits, parts of which have been configured as low-lying swamp providing base for tidal inlets beyond the level of inundation of the rising sea-level at the beginning of the Holocene. Towards end of the mid-Holocene, the sea level has retreated to the south of Ranaghat-Khulna axis of the delta. The large inland swamp areas are often associated with vegetation cover, that could possibly be the source of Sedimentary Organic Carbon (SOC) that may have played as an active agent of metal deposition and isolation (Chatterjee et al., 2004).

The Bangladesh part of BDP, located at the head of the Bay of Bengal, occupies most of the Bengal basin. The basin is surrounded by the Indo-Burman range in the east, an uplifted block of Precambrian Shield (Shillong Plateau) in the north, and Precambrian basement complex (Indian Shield) in the west. More than 16 km thick syn-orogenic Cenozoic sediments are deposited in the basin derived from the Himalayan and Indo-Burman range (Uddin and Lundberg, 1998). Tertiary sediments in Bangladesh are represented mainly by sandstone and shale sequences, while Pleistocene sediments are represented mostly by clay, overlain by Holocene alluvium.

Various geomorphological units were mapped in the BDP (Morgan and McIntire, 1959; Umitsu, 1987; Brammer, 1996), which include piedmont plains, flood plains, delta plains and coastal plains. The geomorphological units in the Holocene landmasses within the Bangladesh part of delta include fan, flood plains, the moribund delta, the

Chandina plain and upland Pleistocene Terraces (Barind and Madhapur Tracts) (BGS and DPHE, 2001).

STUDY AREA



The study area (Nadia district, ~ 65 km north of Calcutta, West Bengal, India, Latitude 23°N and Longitude 88°E) forms an integral part of the Ganga-Brahmaputra-Meghna (GBM) fluvio-deltaic system (Figure 1). The vast alluvium plain spreading from Karimpur (north-east of Calcutta) down to the Bay of Bengal is characterized by succession of a fining upward sequence with occasional clay layers. The fluviatile-estuarine deposits has been influenced by grain size variation (reworked as well as distributed), mineral deposition, organic matter etc. Fluvio-marine deposits are also present in the near surface with organic matter and variable thickness of clay lenses are often observed in such environment. Overall formations are complex and interfingering in nature.

The geomorphology is characterized by a series of meander scars of varying wavelength and amplitude, abandoned channels, ox-bow lakes etc. Common land form features are natural levees, back swamps and inter-distributory swamps. The area has a natural southward slope with a relief difference of few meters (~ 2-5 m). The climate is tropical, hot and humid (temperature range 16-42°C, average relative humidity > 65%) with annual rainfall ranging between 1295-3945 mm (mostly concentrated during the monsoon, June – October).

The Bangladesh study area (Figure 1) is different from the West Bengal part in geomorphological aspects because Lower Delta Plain (LDP) was severely dissected in drainage pattern as well as relief. Climatically, Bangladesh is not much varied from West Bengal except heavy monsoon and high humidity. Groundwater development is almost similar to West Bengal. However, exploitation of shallow aquifers for irrigation are in much larger scale to sustain agriculture. Quaternary sediments provide good aquifers in West Bengal and Bangladesh but As-enrichment is mainly restricted to the Holocene alluvial aquifers at shallow and intermediate depths (Guha Mazumder et al., 1999; BGS and DPHE, 2001; Ahmed et al., 2001; Bhattacharya et al., 2002a). Quaternary sedimentation in the BDP is largely controlled by huge sediment supply, active tectonics and sea level changes (Goodbred and Kuehl, 2000).

METHODS

Sampling (both aqueous and solid phase)

Groundwaters were sampled from existing domestic tubewells in nine As affected districts of Bangladesh during January 1999 and 2001. The location of each tube well was determined using a hand held global positioning system (GPS). Groundwater pH, redox potential (Eh), temperature and electrical conductivity were measured in the field. pH was measured using a Radiometer Copenhagen PHM 80 instrument using a combination electrode (pH C2401-7). Redox potential was measured in a flow-through

cell using a combined platinum electrode (MC408Pt) equipped with a calomel reference cell. Water samples collected for analyses included: i) filtered (using Sartorius 0.45 µm online filters) for anion analyses; ii) filtered and acidified with suprapure HNO_3 (14 M) for the analyses of cations and other trace elements including arsenic (Bhattacharya et al., 2002b). Arsenic speciation was performed with disposable cartridges® (MetalSoft Center, PA) in the field, following the methodology described by Meng et al. (1998). The cartridges, strongly adsorbs As(V) while allowing As(III) to pass through. Similar protocols and methodology were practiced during groundwater sampling from number of affected villages of Nadia, West Bengal.

Bulk sediment was collected from various boreholes drilled during field investigation. Sediment samples were sealed in polythene bags under inert atmosphere and then stored in an airtight ice-cooled box (temp ~ 4°C). Details of sampling protocols, measurement techniques for both water and borehole sediment has been described in previous publications (Bhattacharya et al., 2003).

Analysis (both aqueous and solid phase)

Anions were analyzed by using ion chromatograph (Dionex 120/Metrohm 761), simultaneously Tecator AQUATEC 5400 analyzer was used to measure NO_3^- (540 ηm) and PO_4^{3-} (690 ηm). Cation analyses were done by ICP-MS (Varian/Jobin-Yvon/Perkin-Elmer). Arsenic [As_{tot} and As(III)] were determined using AAS (Perkin-Elmer) and a few bulk sediment samples were also analyzed by ICP-AES (Perkin-Elmer). Redox sensitive species were also analyzed spectrophotometrically (Perkin-Elmer, Lambda-20). During the measurement, ultra trace elements [mostly As(III)] were diluted in various ratios depending on their concentration and buffered (0.5M citrate buffer) for their selective measurement under controlled condition. Measured As(III) was also verified with disposable cartridge separation method and found that there was no significant difference in As(III) concentration (~ 5%). Dissolved organic carbon (DOC) in the water samples was determined on a Shimadzu 5000 TOC analyzer (0.5 mg L^{-1} detection limit with a precision of ±5 -10%). Certified standards, SLRS-4 (National Research Council, Canada) and GRUMO 3A (VKI, Denmark) and synthetic chemical standards prepared in the laboratory, and duplicates were analyzed after every 10 samples during each run. Trace element concentrations in standards were within 90-110% of their true values. Relative percent difference between the original and duplicate samples were within ±5 - 10%.

Chemical partitionings, using acid (7M HNO_3), oxalate (0.2M NH_4-oxalate, pH~3.5) and buffer (Na-acetate, pH~5.4), were performed in finer sediments (< 65 mm fraction) following the methodology detailed in Bhattacharya et al. (2001). Sequential extraction technique thus adopted to measure the specific solid phase (oxide/oxyhydroxide/carbonate), where As was associated. Extractant were analyzed for As_{tot} and associated elements (Fe, Mn, Al, P and S). Crystalline phases were also identified using an X-ray Diffractometer (Philips). Magnetic and non-magnetic fraction are separated by using a hand magnet. Sediments from different depths and individual mineral phases separated from each sample were then treated for As and associated elements analysis by using AAS. Organic carbon of the air dried borehole sediment samples are determined as discussed in Bhattacharrya et al. (2003).

RESULTS AND DISCUSSION

Groundwater chemistry and behavior of arsenic

Most groundwater are of Ca-/Ca-Mg- HCO_3 type, although Ca-Na-/Na-Ca- HCO_3^- type are also found in the saline tracts of Bangladesh where Cl^- concentration goes up to ~ 4000 mg L^{-1}. The characteristics chemical features of the natural high As groundwater of BDP (both West Bengal and Bangladesh) are low to very low dissolved oxygen (< 0.1 mg L^{-1}), high redox-sensitive metal species (Mn > 0.4 mg L^{-1}, As_{tot} > 1 µg L^{-1}, Fe > 0.2 mg

L^{-1}), HCO_3^- (> 300 mg L^{-1}), PO_4^{3-} (> 0.6 mg L^{-1}) and DOC (> 2 mg L^{-1}) and with low Eh (generally < 100 mV), NO_3^- (< 1.0 mg L^{-1}), SO_4^{2-} (< 3.0 mg L^{-1}) and nearly neutral pH (6.5-7.5). Therefore, the characteristic features of groundwater from BDP clearly demonstrate the typical anoxic nature of the aquifers (mostly shallow/intermediate). Major ion composition is HCO_3^- (300-620 mg L^{-1}) that varies with depth and lithology. Distribution of major anions (NO_3^-, SO_4^{2-}, PO_4^{3-}) indicates low variability, while mapping of groundwater PO_4^{3-} indicates that the high groundwater PO_4^{3-} areas are also arsenical (Figure 2a). Distribution of the major cations (Ca^{2+} ~ 21-184 mg L^{-1}, Mg^{2+} ~ 14-96 mg L^{-1}, Na^+ ~ 7-170 mg L^{-1} and K^+ ~ 1.5-20 mg L^{-1}) showed significant aerial variations with depth. Results of chemical analyses also showed large variation in the concentration of metal redox species [As_{tot} ~ 2.5-1020 µg L^{-1}, As (III) ~ 6-970 µg L^{-1}, Fe_{tot} ~ 0.2-15.7 mg L^{-1}, Fe (II) ~ 0.2-15.3 mg L^{-1}], thus indicating the presence of elevated levels of both As and Fe in groundwater. Arsenic (As_{tot}) concentration in the groundwater varies over 3-4 orders of magnitude in some of the shallow wells, and frequently exceeding the WHO guideline value. As concentrations showed little distinct regional trend with other measured water quality parameters and exhibits a significant short-range spatial variability. Speciation data indicate that the ratio of As(III)/(V) is varying largely over a large geographical area. However, the distribution of As_{tot} and As (III)/(V) ratio in the groundwater is largely fluctuating. There is a tendency of high As_{tot} and As(III) concentration (> 210 µg L^{-1}) of wells located in the low-laying areas (local sagging zones).

There is a positive correlation between As_{tot}, PO_4^{3-} and HCO_3^- whereas the correlation with Fe is not significant (Figure 2b). On the other hand in Bangladesh, Fe_{tot} indicates positive correlation with HCO_3^- (Figure 3a). This is commonly expected in BDP groundwater with reducing environment where dissolved Fe(II) concentration is largely controlled through precipitation/co-precipitation of iron carbonate/phosphate (e.g., siderite, vivianite etc.). The high alkalinity load in the groundwater is due to the breakdown of fresh organic matter during the activity of microbes that has been regulating the process. Groundwater temperature is relatively high (26-31°C) and elevated groundwater temperature further facilitating the microbial process that leads to increase in the local reducing condition. Partial pressure of CO_2 is also high in contaminated groundwater (log pCO_2 ~ 1-2.5) and calcite, dolomite, siderite and vivianite has been found in supersaturated phase. Hydrogeochemical model (Parkhurst, 1995), suggests that the dissolved As_{tot} and Fe_{tot} concentrations is depending on the dissolutions/precipitations of above mineral phases, therefore, it is unlikely to have a strong positive correlation between As and Fe in groundwater. On the other hand, elevated HCO_3^- levels are not only controlled by the dissolution of carbonates, where HCO_3^-concentrations shows overall positive correlation with DOC (Figure 3b). Thus favouring the breakdown of organic matter, and is important in controlling the thermodynamically favoured microbial reactions. Both SO_4^{2-} and NO_3^- does not show any correlation with As_{tot} and are generally in the low to very low concentration range in groundwater. Low NO_3^- concentration in groundwater is mainly due to consumption during microbial process before Fe reduction (de-nitrification process). There is a moderate to strong correlation between As(III) and NH_4^+ (r^2 = 0.57, Figure 3c) in Bangladesh groundwater where local reducing environments are more predominant and is observed because nitrogen (breakdown product of nitrification process) can be further reduced to NH_4^+ under strongly reducing condition. Therefore, such areas frequently show the presence of more toxic/labile As(III) in groundwater. This could be the reason of large number of patients have been identified from BDP hot spot areas (Guha Mazumder et al., 1999; Karim, 2000).

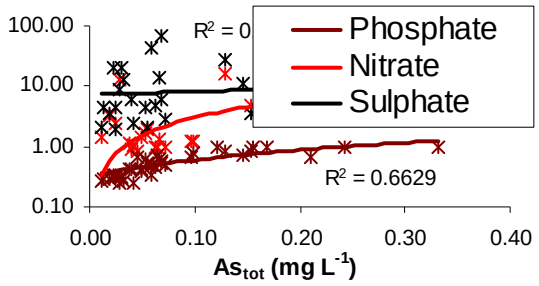


Figure 2a

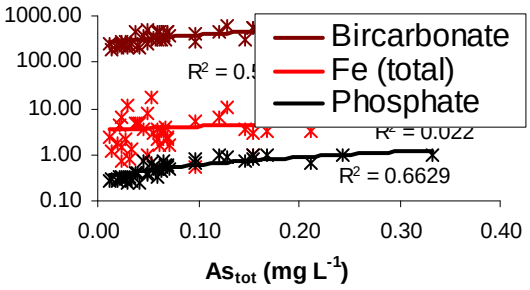


Figure 2b

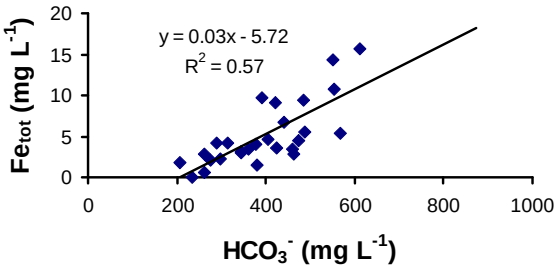


Figure 3a

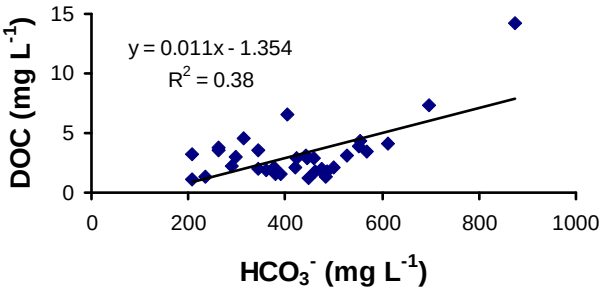


Figure 3b

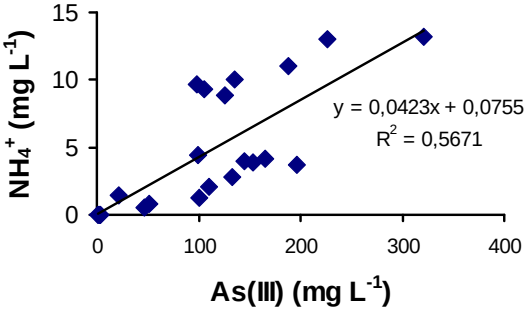


Figure 3c

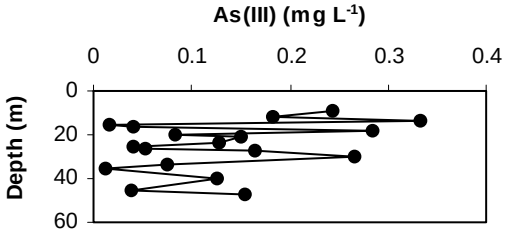


Figure 4a

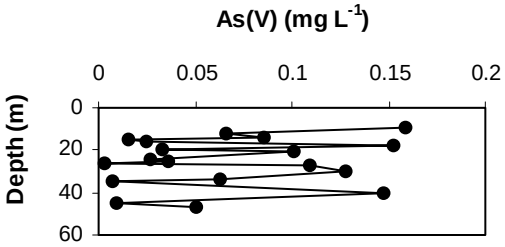


Figure 4b

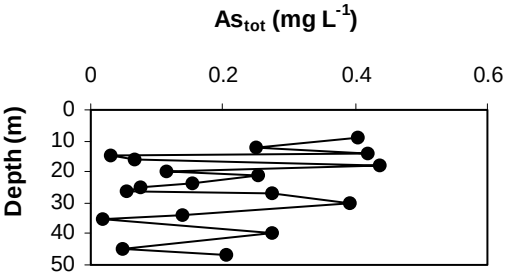


Figure 4c

Distribution of arsenic species

Groundwater As problem is serious in terms of both geographic distribution (discrete source) and scale of exposure (exposure risk from health point of view) even if within safe limits i.e. low As (<50ppb) groundwater. Speciation of As will provide better understanding (presence/absence) of the more toxic as well as labile As(III) which is important to protect human health. Depth distribution of groundwater As(III) concentration shows a high risk around the depth of 15 – 20 ±5 m (Figure 4a) and the As(III) concentration is in several orders of magnitude higher than the stipulated guidelines (WHO, India and Bangladesh). On the other hand, the depth distribution of groundwater As(V) does not show similar pattern (Figure 4b), while the depth distribution of As_{tot} exhibits a depth coverage of much wider areas (Figure 4c). Therefore, in many areas it appears that the tubewells having depth greater than 150 m (deep aquifer) can only provide low As water. The increasing concentration of As (III) is alarming due to the increased recognition of the significant outbreak of As induced cancers and internal health problems in BDP resulting from the extensive use of shallow groundwater which contains largely As(III) compared to As(V) (Bhattacharya et al., 1997). Therefore, aquifer mapping is essential to decipher the high- and low-As zones to ensure the level of As(III) in groundwater.

Sediment chemistry

The distribution of As (As_{tot} ~ 10-26.3 mg kg^{-1}), organic matter (SOC_{tot} ~ 4.2-9.5g kg^{-1}) and iron (Fe_{tot} ~ 0.5-1.6 g kg^{-1}) demonstrates that the fine grained sediments (silt/silty clay) were found to be associated with high groundwater As areas. A close examination of the chemical characteristic of sediment further reveals that there is a positive correlation (r^2 = 0.67) between elemental As and Fe, although the elemental As is absent in the structure of arsenic traps. On the other hand, there is a weak correlations (r^2 = 0.22) between elemental As and C, where average C content of the sandy sediment is often less as compared to silty/silty clay horizons.

Acid oxalate extractable fractions of Fe_{ox}, Mn_{ox}, Al_{ox}, P_{ox} and As_{ox} also reveal considerable variability with depth and lithology. The range of Fe_{ox}, Mn_{ox}, Al_{ox}, P_{ox} and As_{ox} varied between 0.4-5.9 g kg^{-1}, 0.005-0.45 g kg^{-1}, 0.1-1.32 g kg^{-1}, 5.1-144 mg kg^{-1} and 0.1-8.6 mg kg^{-1}, respectively. A positive correlation was observed amongst As_{ox} and Fe_{ox}, Mn_{ox} as well as Al_{ox} (Figure 5a-c). While the coarse-grained sediments indicated strong positive correlations between As_{ox} and P_{ox} (Figure 5d), their distribution in the fine-grained sediments (silty clay and clay) revealed an inverse trend (Figure 5d). Distinct negative correlation between As_{ox} and P_{ox} fractions suggests dissolution of secondary vivianite, rather than the release of PO_4 ions adsorbed onto the Fe-oxide surfaces in these fine grained sediments. Acetate extractable fractions Fe_{acet} (0.02-0.37 mg kg^{-1}), Mn_{acet} (0.002-0.27 mg kg^{-1}) and P_{acet} (0.7-73.7 mg kg^{-1}), account for a range of 2.1-80% Fe_{ox}, 15.8-97% Mn_{ox}, and up to 70% P_{ox}. Dissolution of minerals like siderite and rhodochrosite may account for the acetate extractable fractions of Fe_{acet} and Mn_{acet} in these sediments. However, high acetate extractable P fractions (P_{acet}) concomitant with high Fe (Fe_{acet}) indicate the possible dissolution of vivianite in these reducing aquifer sediments (Dodd et al., 2000). It is important to note that the hydrogeochemical speciation modeling also suggests that the groundwater are supersaturated with respect to these minerals, which act as sinks for Fe and Man as well as PO_4^{3-} and hence control their solubility in groundwater (Bhattacharya et al., 1998; Nickson et al., 2000). Oxalate extraction of the aquifer sediments demonstrate that the As and other associated elements (Fe , Mn , Al , P) were dominated the solid phase (Fe_{OX} ~ 0.2 -5.9 g kg^{-1}, Mn_{OX} ~ 0.005-0.45 g kg^{-1}, Al_{OX} ~ 0.02-1.32 g kg^{-1}, P_{OX} ~ 5.1-144 mg kg^{-1}, As_{OX} ~ 12-101 mg kg^{-1}), and the significant variability was observed with depth, topography, geomorphic and geologic features. It has also been observed that As_{OX} and P_{OX} showed positive correlation (Figure 5d) in coarser sediments rather than their distribution in the fine-grained sediments.

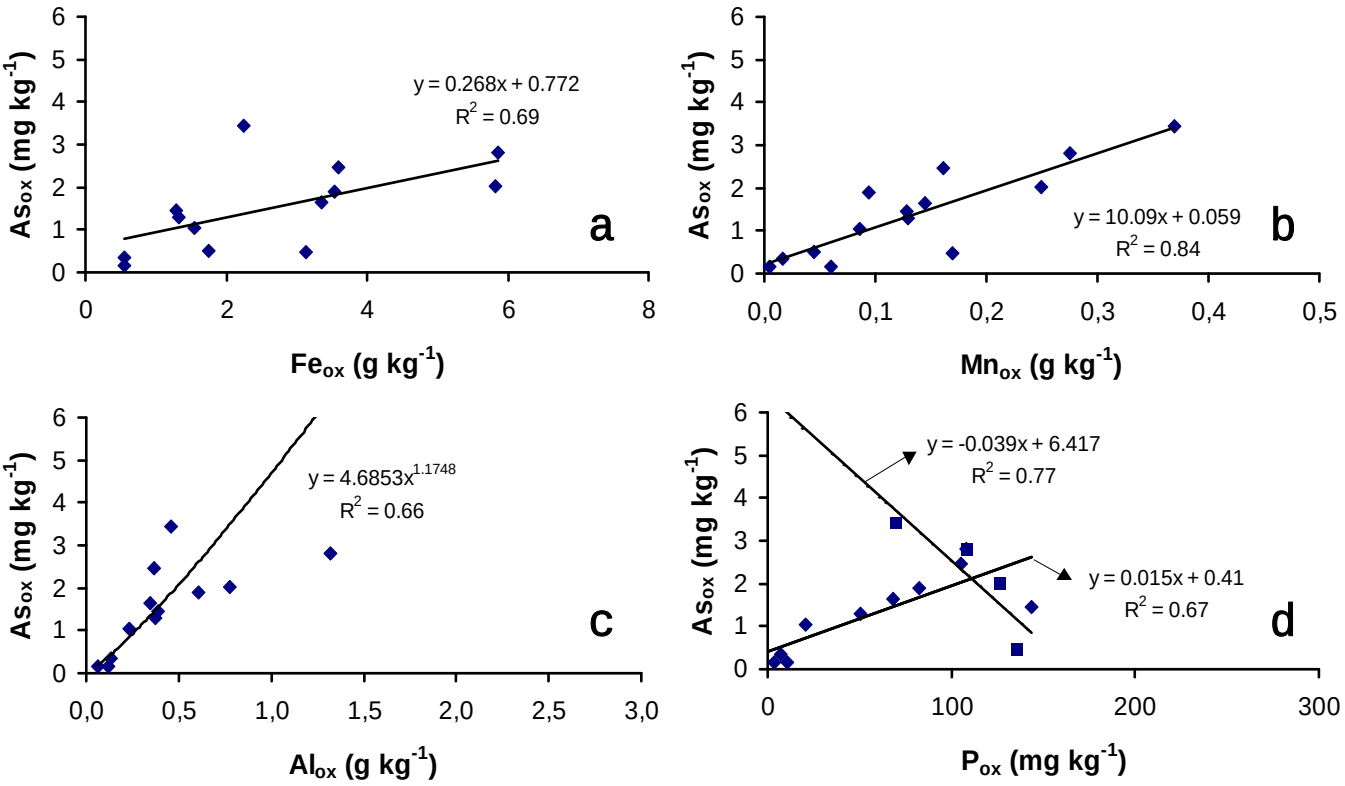


Figure 5 (a,b,c,d)

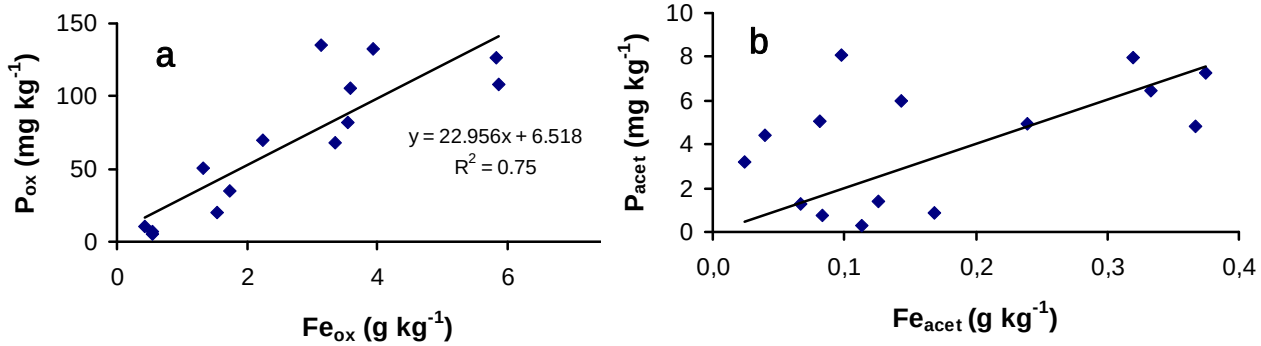
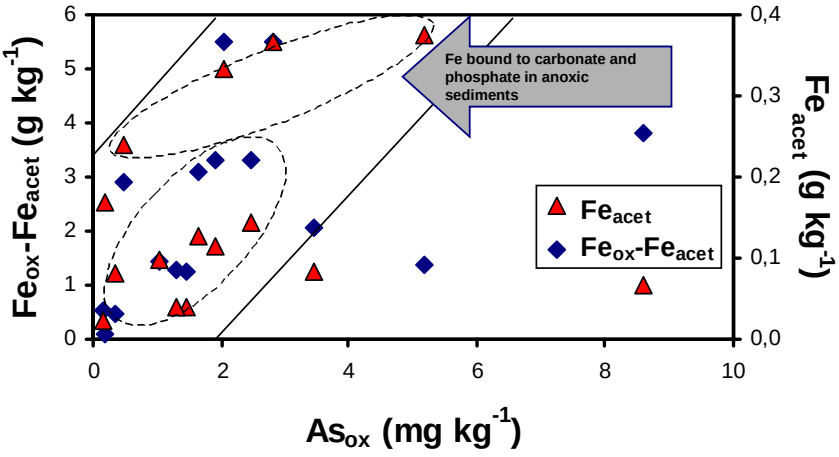


Figure 6 (a,b)

Furthermore relatively high acetate fraction (Fe_{acet} ~ 0.02 – 0.37 mg kg^{-1} in Fe_{ox} ~ 2.1 – 80%, Mn_{acet} ~ 0.002 – 0.27 mg kg^{-1} in Mn_{OX} ~ 15.8 –97%, P_{acet} ~ 0.7 – 73.7 mg kg^{-1} in P_{OX} ~ 70 %) confirms the possible dissolution of carbonate (siderire and rhodochrosite) as well as unstable phosphate mineral (vivianite) that has already been demonstrated by our speciation model during aqueous phase discussion. The study (hydrogeochemical and chemical partitioning modeling) further suggests that the groundwater were supersaturated with respect to carbonate and phosphate minerals which acted as sinks for Fe/Mn/PO_4^{3-}, and thereby, control their solubility in groundwater. Carbonate minerals were important components of mineralogy of the BDP sediments and dissolution/precipitation of As from such mineral phases controls groundwater chemistry. Therefore, reaction kinetics are important in understanding the local short range spatial variations. Moreover, correlation between Fe_{OX} and P_{OX} (r^2 = 0.74, Figure 6a) indicates reductive dissolution of the amorphous Fe–oxides together with surface bound PO_4^{3-}, whereas Fe_{acet} and $PO_4^{3-}{}_{acet}$ fraction do not exhibit such relationship. These suggest that the Fe-oxides – PO_4^{3-} pool is more significant than vivianite – PO_4^{3-} pool in BDP aquifers.

Fig. 7



Fairly high correlation between Fe_{ox} and P_{ox} (r^2 = 0.74; Figure 6a), indicates reductive dissolution of the amorphous Fe-oxides together with surface bound PO_4^{3-}, particularly in the coarse sediments. However, P_{acet} fractions do not exhibit a significant correlation with Fe_{acet} (Figure 6b). Further, P_{acet} fractions are in the order of magnitude lower than the P_{ox} fractions, which suggest that the pool of PO_4 related to Fe-oxides is more significant than the pool of PO_4 related to P-minerals like vivianite in the aquifers. Oxalate extractable As_{ox} plotted against Fe_{acet} and Fe_{ox}-Fe_{acet} as independent variables (Figure 7) reveals two distinct populations. The data sets plotted on this diagram, follow a linear trend for most of the analyzed sediments showing a clear association of As_{ox} with the Fe-oxide phases (Fe_{ox}-Fe_{acet}) in the coarse grained sediments. However, the reducing fine-grained aquifer sediments are characterized by high Fe_{acet} fractions plot separately. These results clearly demonstrate that siderite and vivianite are also present together with amorphous Fe-oxides with adsorbed As in the Holocene sedimentary aquifers.

Geochemistry and Arsenic affinity

The redox processes are important to understand the reduction reactions that occurs when aquifers behave anoxic (Langmuir, 1997). Among the processes, iron oxides/hydroxides (FeIII/II system) redox chemistry is important since the system has direct impact on the mobility of As under anaerobic environment. The major pathway of As release in aquous phase is the reductive dissolution of the "arsenic traps" (mostly sedimentary Fe-oxides/hydroxides) under local reducing condition (redox traps, SOC). Arsenic is released to groundwater during reduction (partially and/or completely) of these arsenic traps (Fe/Mn/Al oxides/hydroxides) and the process is regulated by

microbes (dissimilatory iron reducing bacteria, DIRB) where the oxidation of organic matter supplies necessary energy to drive thermodynamically favored redox processes via electron transfer reactions (Lovely and Chapelle, 1995). The redox ladder includes multiple steps and begins with consumption of dissolved oxygen available in the sub-surface water and an increase in dissolved bicarbonate ions due to the decomposition of organic matter. Next is the de-nitrification process and aqueous nitrate decreases rapidly with increase in dissolved bicarbonate ions. Sedimentary metal oxides/hydroxides are then reduced from insoluble phase to soluble phase [Mn (IV) (s) to Mn (II) (aq) and/or Fe (III) (s) to Fe (II) (aq)]. As a result, dissolved concentration of redox sensitive species along with bicarbonate ions are increased in the system and sulphate reduction, methanogenesis and finally ammonia production are the sequential steps that are also important to understand redox processes. The speciation of redox species (both solid and aqueous phase) and partitioning between sediment-water interaction are now important to understand the exact sequence of geochemical processes that leads to the elevated redox species concentration in the groundwater (Sracek et al., 2004).

Our studies revealed that significant amounts of amorphous Fe-oxides/hydroxides, carbonates as well as SOC are present in the aquifer sands/silts. Arsenic is released to groundwater during reduction of these mineral phases (arsenic traps) under local reducing conditions (~1% SOC) and the process is regulated by microbes (mostly by Dissimilator Iron Reducing Bacteria, DIRB) where oxidation of SOC supplies necessary energy to drive thermodynamically favoured redox processes. The sediment texture as well as the presence and distribution of SOC vary in space. The high concentration of redox sensitive species (As, Fe, Mn) along with high alkalinity and the absence of dissolved oxygen and low to very low NO_3^- in the groundwater indicates the geochemical processes (dentrification $\rightarrow$ iron reduction) that controls the groundwater chemistry of the high As aquifers (hotspot areas). However, the vertical and lateral variation in redox species concentration (geographical distribution of As and public health issues) and their heterogeneity (at least in the hot spot areas) are difficult to explain by the process of iron reduction by subsurface organic rich sediment.

In BDP, the subsurface geochemical process is activated through the presence of high redox sensitive species. It is suggested that the respiration of organic carbon via colloidal/pre-colloidal iron route plays an important role in As mobilization at best in shallow aquifers. However, mobilization may also be driven by reduction with organic carbon via carbonate/silicates dissolution during the paucity of colloidal/pre-colloidal iron oxides. This can be a possible explanation to understand the heterogeneity of the hotspot areas where iron concentration is very low or insignificant and As concentration is very high. Similar situation may also occur in deltaic/tidal/upland-inland basin areas where dissolved NH_4^+ and Ca^{2+} profiles follow the dissolved As concentration peak in natural groundwater and such observations are recently reported from various parts of BDP (Bhattacharya et al., 1997; Harvey et al., 2002; Akai et al., 2004; Sracek et al., 2004).

CONCLUSION

The present work suggests that the BDP groundwater is anoxic in nature and mostly calcium bicarbonate type. Sedimentary iron [Fe(III)/(II)] is the dominant mineral constituent that carry As might have deposited by the meandering river. Sediment mineralogy and texture along with organic matter play crucial role in release of As in groundwater. The possible geochemical pathways is Fe reduction at least in shallow aquifers. High redox sensitive species (As, Fe and Mn), high alkalinity and absence of dissolved oxygen and nitrates further demonstrate the microbial mediated and

thermodynamically favoured redox processes (denitrification→ iron-reduction). Aqueous speciation of As reveals that both As(III) and As(V) concentrations are varying largely and As(III) is significantly increasing in low lying areas. Stratigraphic distribution of As(III) and As(V) reveals that As(III) is more dominant in near-surface aquifers rich in organic matter. Chemical partitioning further supports the presence of amorphous Fe-oxide together with surface bound phosphates in hotspot areas.

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AN APPROACH TO MINIMISE THE DRINKING WATER PROBLEM THROUGH WETLAND MANAGEMENT AND ARTIFICIAL RECHARGE OF ARSENIC CONTAMINATED AQUIFER OF DASDIA MOUZA, HARINGHATA – I BLOCK, NADIA DISTRICT, WEST BENGAL

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INTRODUCTION

Dasdia 'mouza' of Haringhata-I, Block Nadia District of West Bengal is bounded by longitudes 88°35′23.16″ - 88°36′13.18″ and latitudes 22°57′7.85″ - 22°56′47.2″. Bamanbaria (J. L. No. 39) bound the village in the north, Dutta Para (J. L. No. 67) in the south and Jamuna river in the east and west (Fig. 1). The total area of the 'mouza' is 1.72 sq km.

Fig. 1 Location map of the study area

In the absence of any other sustainable water sources, groundwater is being used extensively for drinking, domestic, and agricultural purposes in Dasdia 'mouza'. With increasing population, the demand for water has increased manifold. This has led to continuous fall in the water table over the years. Apart from this, the groundwater is also contaminated with arsenic. As reported from local people three villagers have died recently due to arsenic contamination and many people are showing signs of arsenic contamination on their body. Therefore, this 'mouza' needs special attention from the point of view of groundwater. Thus a detailed study was carried out during the period 8th January, 2006 to 18th January, 2006 to recommend suitable methods for (i) supplying arsenic-free water to the local

people and, (ii) artificial recharge to groundwater for arsenic dilution and prevent further recession of the water table.

METHODOLOGY

Based on the 'mouza' map (scale 16" = 1 mile), the plot numbers were selected for measuring water level in selected network stations within the said plot. The plot numbers were selected in such a way that their spatial distribution covered the entire 'mouza'. Fifty eight network stations were selected for measuring the water level, reduced level and collecting water samples for chemical analysis of arsenic and iron. The water samples collected each day were sent to the laboratory for chemical analysis of arsenic and iron within twenty four hours. The data were used to prepare various thematic maps using GIS (ILWIS 3.3 Academic Version). To select suitable sites for artificial recharge of groundwater and supply of arsenic free water using cross and overlay operations of ILWIS 3.3 Academic Version was used.

BACKGROUND INFORMATION

The land use pattern of this area has undergone a pronounced change over years. The extensive plains lying adjacent to river Jamuna are agricultural land where cultivation is carried out through the year using either groundwater or surface water (river and pond). The northern and central parts of Dasdia 'mouza' are residential lands. On the other hand the eastern, western and southern parts are used for agriculture purpose throughout the year and groundwater is being tapped for irrigating the land through motorized shallow tubewells. The soil of the area consists mainly of sands, silts and clays deposited by the Jamuna river. The soil contains 50 - 56% sand, 20-40% clay, silt, and 4% organic matter. The pH value of this soil is generally 6.5. The climate is predominantly influenced by the northeast and southwest monsoons. The region enjoys a tropical rainy climate with a distinct dry season in December. The average annual rainfall of the area is around 2000 mm. January is the coldest month when temperature rarely goes below 10°C. Summer is hot and oppressive. May is the hottest month, when average temperature rises to 30°C. The area does not exhibit any marked topographical features. The landscape is mostly flat, the elevation varying between 7.26 and 9.14 m above mean sea level (Fig. 2). The area is drained by river Jamuna in both the east and west. There are numerous surface water bodies (ponds), spread over the area, which forms local topographic depressions. Most of these water bodies dry up during summer. The large ponds in the area are generally perennial in nature.

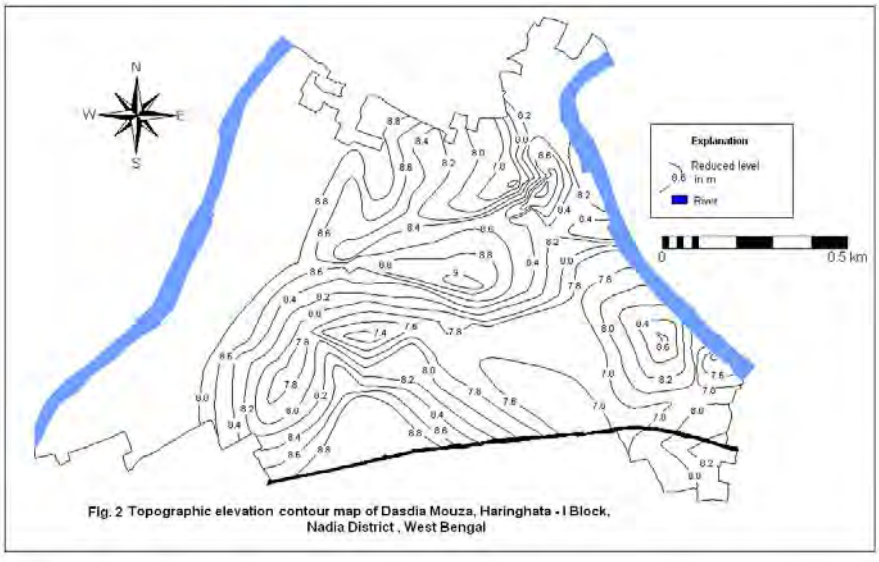

Fig. 2 Topographic elevation contour map of Dasdia Mouza, Haringhata - I Block, Nadia District , West Bengal

GENERAL GEOLOGY

The study area covers a very small part of the extensive Indo-Gangetic alluvial plain of Quaternary age, which is a part of the Bengal Basin. The Quaternary geology of the area consists of younger fluvio-deltaic plains. A fining upward sequence of the sediments indicates a fluvio-deltaic environment of deposition. Yellow to yellowish-brown colour sediments occurring within 35m - 52m depth indicate a fluvio-deltaic environment and deposition under oxidizing condition. Dark brown to grey coloured sand from 15m-35m depth was again found which indicate a reducing environment. The provenance of Bengal Delta is closely related with the tectonic history of this region. The geological sections through the Bengal Delta, of which Dasdia forms a small part, indicate the presence of various cycles of depositional environment. The basal deposits are marked by gravel and coarse sand followed upward by medium sand, fine sand, silt and clay.

The geological succession from the Mesozoic to Recent of Nadia district as suggested by Biswas (1959 and 1963) is presented in Table 1.

Table 1 General Stratigraphic Succession of Nadia District

Age	**Formations**	**Litho units**	**Thickness (m)**
Recent	-	Sand, silt and clay	
Pleistocene	-	Sand, silt and clay, kankar and gravel	91-189 (tentative)
Pliocene	Jalangi-7	Basal conglomerate followed by coarse sandstone grading upwards to grey siltstone and claystone	1007
Middle to late Miocene	Jalani-6	Upper: Poorly sorted mottled sandstone with a few lignitic shales and clays	358
Early Miocene		Middle: Well sorted sandstone with sparse massive fossils, with some lignitic streaks	146
Oligocene		Lower: Poorly sorted ocherous hematitic and lithomergic sandstones with lignitic alternations	119
Late Eocene	Jalangi-5	Upper: Dark grey shale calcareous in lower part	21
Middle Eocene		Lower: Nummulitic limestone	268
Upper most Cretaceous to Basal Eocene	Jalangi-4	Upper: Well sorted sandstone often glauconitic Middle: Sandy to lignitic and coaly shales with abundant pyrites, marcasite, resin and sparse asphalt Lower: Sandy bed with minor coaly and carbonaceous shaly layer	71
Late Cretaceous	Jalangi-3	Upper: Grey to dark grey shell limestones, dark grey to black organic shales and whitish sparsely shell-bearing current bedded sandstones	-
Lower Cretaceous to Upper Jurassic	Jalangi-2	Dull red hematitic sandstones and shales except for dark grey to black anhydrite bearing shales in the topmost 21m	
	Jalangi-1	Lava flows – Tholeitic plateau basalts	129.5

Formations belonging to Quaternary systems are the principal repository of the groundwater in the area under study. Although the lithological characters of these formations are fairly well known from the logs of the bore holes drilled in the area, the demarcation of the boundary between the Pleistocene and the Recent Series in vertical sequences has not been possible due to paucity of faunal and lithological evidences.

A generalized lithological succession as revealed from the study of lithological samples brought out during drilling of a shallow drinking water tubewell in the 'mouza' during the study period is given in Table 2.

Table 2. Subsurface lithological succession of Dasdia

Lithology	**Depth in meters**
Clay mixed with silt	0 - 15
Sand, fine to medium, grey, micaceous	15 - 30.50
Clay, bluish, plastic mixed with silt at places	30.50 - 33
Clay, yellowish brown, mixed with silt	33 - 36.50
Sand, medium to coarse, yellowish, micaceous	36.50 - 51.8

GROUNDWATER CONDITION

In Dasdia "mouza" groundwater occurs in a thick zone of saturation within the alluvial sediments and is unconfined in nature. Field investigation revealed the presence of a clay bed mixed with silt and fine sand at the top of the lithological column. This clay and silt bed is discontinuous in nature and is punctuated by a fine sand bed. This indicates that the groundwater in the area is in unconfined condition. Sand bodies, mainly medium to coarse texture, are the principal repository of groundwater.

In general three promising saturated granular zones of considerable thickness are present within the area. One is from 15 m to 30 m (consisting of fine to medium sands) the second is at a depth of 36 m to 60 m and the third one below 100m consisting of medium to coarse grained sand with gravels.

In general tubewells are being sunk to tap two different depth zones, one tapping the aquifer at the depth range of 15 to 60 m bgl and the other tapping the aquifer at depths greater than 100 m. Amongst the monitored wells, fifty one tubewells tap the shallow aquifer and only seven tubewells tap the aquifer at greater depths. The water level in both these depth ranges are similar, possibly indicating a hydraulic continuity between them and hence may be considered as a single aquifer system.

The transmissivity of the aquifer in this region varies from 3497 to 13951 m^2/day (Deshmukh et al., 1973). The tubewells constructed within 150m depth are capable of yielding 200 m^3/hr. The huge thickness of the alluvium with good aquifer material and effective recharge prospect makes the entire area one of the most developed well fields in the district. The whole region is suitable for construction of deep and shallow tube wells.

The depth to water table varies from 4.21m to 8.02 m below ground level (b.g.l.) with an average of 6.5m b.g.l. The spatial distribution map of the depth to water table is given in Figure 3 and is self-explanatory. The area occupied by various depths to water table class is given in Table3. It is observed from the table that the groundwater rest at a depth of 6-7 m below ground level in 67 % of the total area.

Table 3 Area occupied by various depth to water table class

Depth to Water Table Class	Area (sq km)
4-5 m	0.05
5-6 m	0.16
6-7 m	1.15
> 7 m	0.36
Total	1.72

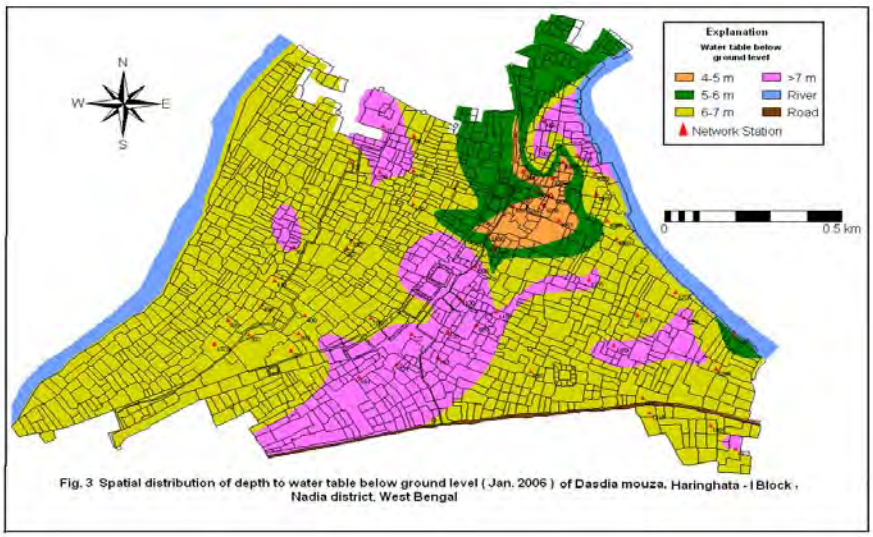

Fig. 3 Spatial distribution of depth to water table below ground level (Jan. 2006) of Dasdia mouza, Haringhata - I Block , Nadia district, West Bengal

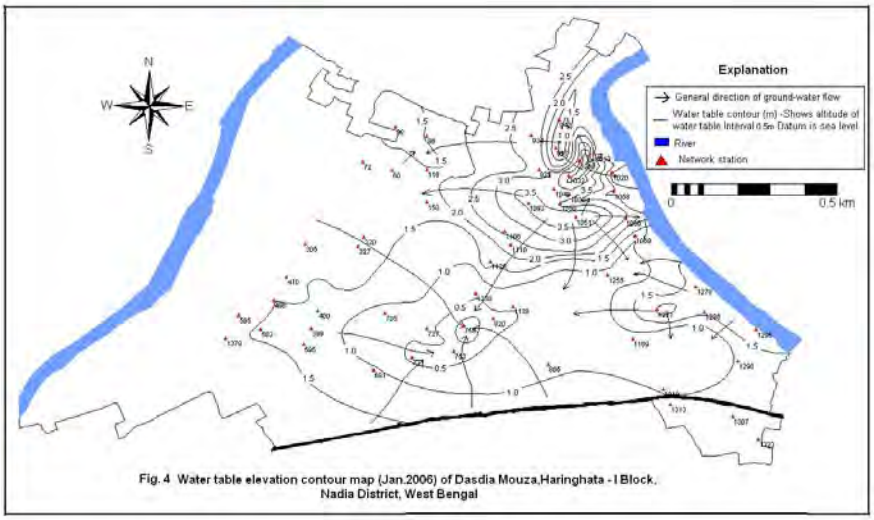

Fig. 4 Water table elevation contour map (Jan.2006) of Dasdia Mouza,Haringhata - I Block, Nadia District, West Bengal

The water table elevation above the mean sea level (msl) varies between -0.27 m to 4.4 m. The negative sign indicates that the water table is below the mean sea level. To determine the direction of groundwater flow and gradient of the water table a contour map depicting the elevation of the water table with respect to msl has been prepared (Fig. 4).

A perusal of the map reveals that there are three groundwater mounds in the eastern part of 'mouza' flanking the Jamuna river. The northernmost one is defined by the 4m contour. The groundwater flows in all directions from this mound towards the two troughs located to the northwest and east-southeast of the mound. The northwestern trough is defined by 1.0 m contour while the east-southeast one is defined by the 1.5 m contour. The easterly flow of groundwater indicates that the Jamuna river is effluent in nature, receiving water from the groundwater body. The second groundwater mound is located south of this mound and is defined by the 3.5 m contour. From this mound groundwater again flows in all directions. A part of the easterly flow is towards the Jamuana river and hence in this part the Jamuna river is also effluent in nature. Towards the southwest of this mound, in the extreme southern part of the 'mouza', there is a large groundwater

trough. The deepest part of this core lies about 0.27 m below msl. Groundwater flows from all directions towards this trough. The third groundwater mound lies in the southeastern part of the 'mouza' defined by the 2.0 m contour. The groundwater flow is again radial. South of plot no. 1066 along the Jamuna river the groundwater is at a higher elevation (around 1.5m a.m.s.l) and towards the west the elevation decreases. This indicates that the groundwater flows away from the river and hence this part of the Jamuna river has an influent character losing water to the aquifer.

Using the water table elevation data, trend surface analysis has been carried out using ILWIS 3.3 Academic Version to separate the local fluctuations in water levels from the major flow system by fitting a mathematical surface to the water table elevation data represented on a map. Fitting of trend surface is essentially a statistical technique involving non-orthogonal polynomials. The principle of least squares has been used to compute the surface of best possible fit. The computed surface is such that the sum of squares of the distances between the observed elevations of the water table and the corresponding point on the mathematically fitted surface is the least.

Polynomial trend surfaces of degrees1 to 4 have been fitted to the water table elevation data in order to separate the major component of the spatial variation of the variable from the less significant component. The goodness of fit and correlation coefficient increases with increase of degree of the computed surface, but so far as the present data are concerned, the degree-four surface is statistically highly significant and has been utilized for separating the local fluctuations from the major groundwater flow system in the aquifer underlying the study area.

The general equation of the trend surface of the water table is as follows:

$$Z = 1.440 + 0.002*X + 0.008*Y + 6.708e\text{-}007*X^2 + 3.940e\text{-}006*XY + 6.490e\text{-}006*Y^2 + (-)6.804e\text{-}009*X^3 + (-)2.523e\text{-}008*X^2Y + (-)2.323e\text{-}008*XY^2 + (-)4.575e\text{-}008*Y^3 + (-)1.476e\text{-}012*X^4 + (-)2.906e\text{-}011*X^3Y + (-)6.905e\text{-}011*X^2Y^2 + (-)1.400e\text{-}011*XY^3 + (-)1.507e\text{-}011*Y^4$$

where, X and Y are the Cartesian coordinates of the network stations and Z is the calculated elevation of the water table with reference to the mean sea level

A perusal of the degree-four trend surface map (Fig. 5) reveals that there is a WNW-ESE trending groundwater mound covering the northeastern part of the 'mouza'. Groundwater flows outward from this mound in all directions. A part of the groundwater flows towards a groundwater trough located in the southern part of the 'mouza'. The trough trends roughly parallel to the mound. Further south there is a tendency of the formation of another mound from where groundwater flows in to the trough. These mounds and

Fig. 5 Fourth degree trend surface map of Dasdia Mouza,Haringhata Block - I, Nadia district, West Bengal

the trough control the flow of groundwater in the aquifer underlying Dasdia 'mouza'. The local flow components indicated on the water table elevation contour map (Fig. 4) have been eliminated in the trend surface map, thus bringing out very clearly the major groundwater flow system. This major groundwater flow directions will help us in pinpointing sites for artificial recharge to groundwater in concomitant with other parameters.

HYDROGEOCHEMISTRY

Fifty eight groundwater samples were collected from different network stations for analysis of arsenic and iron. The summary of the results of the chemical analysis is presented in Table 4.

Table 4 Summary of the results of chemical analysis

Parameter	No. of Samples	Maximum concentration (mg/l)	Minimum concentration (mg/l)	Mean concentration (mg/l)	Indian Standard (BIS 10500: 1991) (mg/l)
Shallow aquifer					
Arsenic	51	0.602	0.023	0.095	0.05
Iron	7	1.24	0.38	0.68	0.3
Deeper aquifer					
Arsenic	51	0.610	0.038	0.205	0.05
Iron	7	1.20	0.62	0.80	0.3

A perusal of the results of chemical analysis reveals the following:

- Arsenic concentration of 32 water samples is below the standard.
- Arsenic concentration of only 2 water samples coincides with the standard
- 41 % of the samples have arsenic concentration higher than the standard of 0.05 mg/l.
- The highest concentration (0.61 mg/l) of arsenic is observed in plot no. 1323, located in the southern part of the 'mouza'.
- The lowest concentration (0.022 mg/l) of arsenic is observed in plot no. 1130, located in the southern part of the 'mouza'.
- Arsenic concentration of the deeper part of the aquifer i.e. > 100 m b.g.l. is also very high ranging from 0.038 to 0.61 mg/l. Therefore, the deep aquifer is also not safe to be tapped for drinking purpose.
- Iron concentration of all the samples is higher than the desirable level of 0.3 mg/l.
- 12% of the samples have iron concentration greater than the permissible limit of 1 mg/l.

To understand the spatial distribution of arsenic and iron in the groundwater of Dasdia 'mouza' two maps (Figs. 6 and 7) showing various concentration zones have been prepared. A perusal of the map showing spatial distribution of arsenic (Fig. 6) in groundwater reveals that the entire eastern part of the 'mouza' along the Jamuna river and in the southern part of the 'mouza' the groundwater has arsenic concentration above the permissible limit of 0.05 mg/l. The rest of the area the groundwater has concentration below the desirable limit except for four small pockets where the concentration is just above the desirable limit. Two of these pockets are located in the northern part of the 'mouza' and the other two are located in the southern part. The total area where arsenic concentration is <0.05 mg/l is 1.05 sq km i.e. 62 % of the total area (Table 5). In the south eastern part of the

'mouza' there is a gradual increase in arsenic concentration from 0.5 mg/l to 0.5 mg/l. In the extreme southeastern part the concentration ranges from 0.1 mg/l to 0.6 mg/l with plot no.1323 having the highest concentration of 0.61 mg/l.

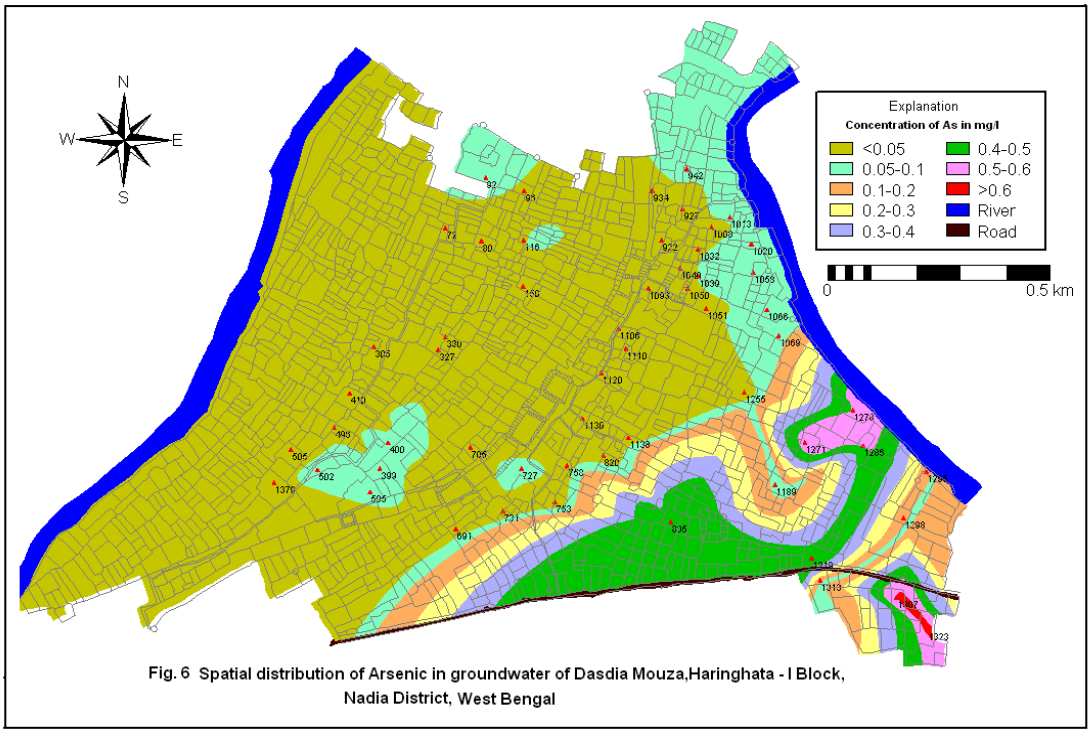

Fig. 6 Spatial distribution of Arsenic in groundwater of Dasdia Mouza,Haringhata - I Block, Nadia District, West Bengal

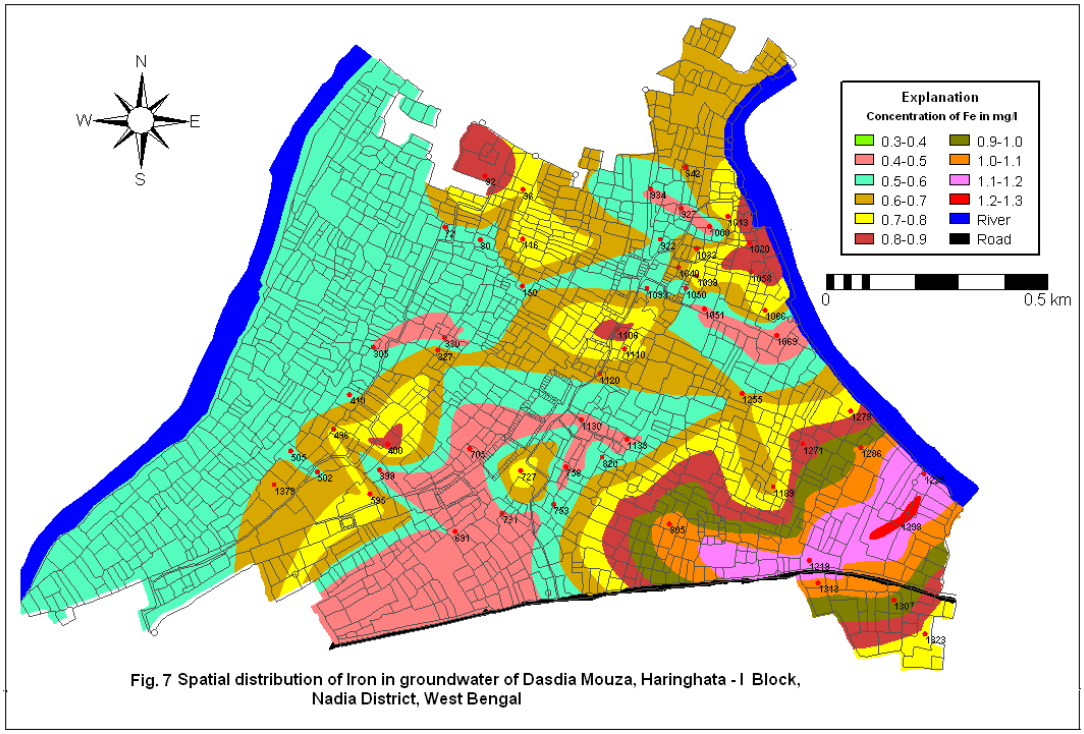

Fig. 7 Spatial distribution of Iron in groundwater of Dasdia Mouza, Haringhata - I Block, Nadia District, West Bengal

Table 5 Area occupied by various arsenic concentration class

Arsenic Concentration Class (mg/l)	Area (sq km)
<0.05	1.05
0.05 – 0.1	0.24
0.1 – 0.2	0.1
0.2 – 0.3	0.09
0.3 – 0.4	0.08
0.4 – 0.5	0.13
0.5 – 0.6	0.03
> 0.6	-
Total	1.72

The spatial distribution of iron in groundwater of Dasdia 'mouza' (Fig. 7) reveals that the area has concentration above the desirable limit of BIS 10,500, 1991. An area of about 0.13 sq km. in the southeastern part of the 'mouza' has iron concentration above the permissible limit of 1.0 mg/l (Table 6). The groundwater of plot no.1295 located in the south-eastern part of the 'mouza', just beside River Jamuna, has maximum iron concentration of 1.21 mg/l. On the other hand the minimum concentration of 0.38 mg/l is observed in plot no.705 located in the south-central part of the 'mouza'.

Table 6 Area occupied by various iron concentration class

Iron Concentration Class (mg/l)	Area (sq km)
0.3-0.4	-
0.4-0.5	0.2
0.5-0.6	0.69
0.6-0.7	0.36
0.7-0.8	0.19
0.8-0.9	0.09
0.9-1.0	0.06
1.0-1.1	0.07
1.1-1.2	0.06
1.2-1.3	-
Total	1.72

WATER RESOURCE DEVELOPMENT AND MANAGEMENT

In order to pinpoint the probable sites for tapping surface water after necessary treatment for arsenic free drinking water and artificial recharge of groundwater Cross Operation and Overlay methods of ILWIS 3.3 Academic Version has been used. At first the depth to water table map has been crossed with the spatial distribution map of arsenic. The area with arsenic concentration is <0.05 mg/l has been discarded. The rest of the area has been given colour to denote the water table depth vis-à-vis arsenic concentration. In the second step the fourth degree trend surface map has been overlaid on the crossed map. In the last step the plot map has been overlaid to get the final map (Fig. 8). From this map different locations have been pinpointed to supply arsenic free drinking water to the inhabitants of Dasdia "mouza" and artificially recharge the groundwater body through roof top rainwater harvesting. The locations are as follows:

Location A: The area in around this location has very high arsenic concentration (>0.2 mg/l). A wetland is located in Plot no. 1175. The wetland rests on a groundwater trough and hence groundwater will flow into the wetland and will keep

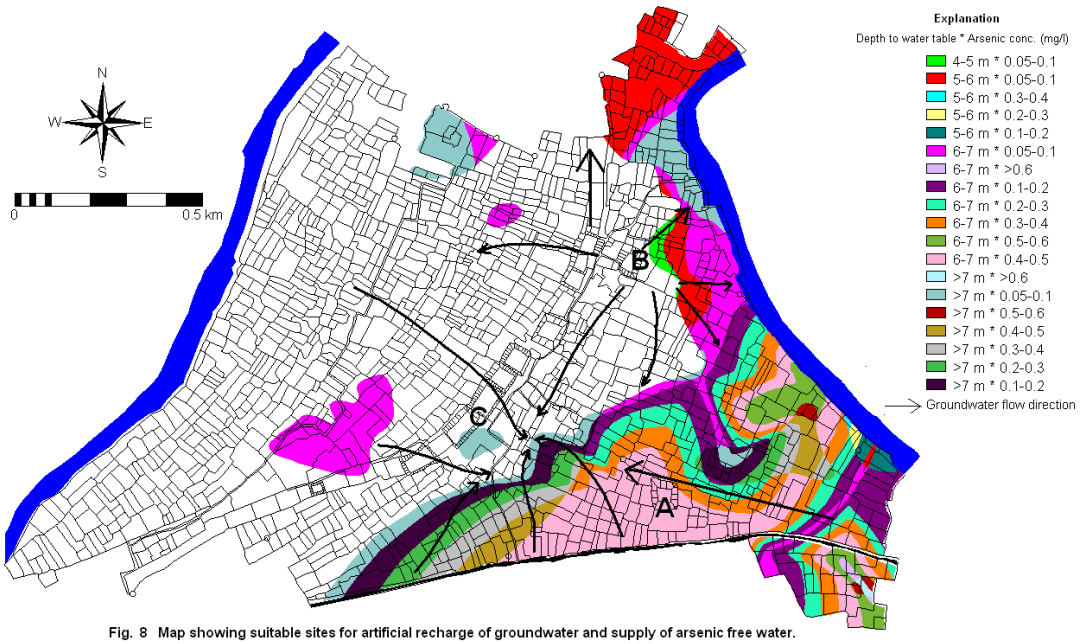

Fig. 8 Map showing suitable sites for artificial recharge of groundwater and supply of arsenic free water.

it perennial throughout the year. This wetland can be used to supply arsenic free water. Before using this wetland the following steps should be implemented:

1. The wetland water should be tested to determine the arsenic concentration arsenic at various places.
2. The wetland should be desilted.
3. The catchment area of the wetland should be kept free of activities such as bathing, washing of clothes and utensils, bathing and drinking of animals, dumping of household and other wastes.
4. The water from the wetland should be pumped into the primary tank where chlorine and alum should be added for primary treatment. This partially treated water should then be passed through a slow sand filter bed and then into a tertiary chamber where the water may again be treated with chlorine and alum. From this chamber, treated water can be taken for drinking purpose through a tap. It is necessary that the villagers pump water into the primary tank before taking water from the tertiary tank.

Location B: In and around this location Plot no 1049 is a wetland that can also be used to supply arsenic free water. Arsenic concentration in the area east of this wetland ranges between 0.05 and 0.1 mg/l. The wetland is located on a groundwater mound. Hence this wetland should be desilted or excavated up to a required depth to maintain water throughout the year or a shaft may be constructed in the wetland to tap the base flow. The other steps as mentioned for location A should also be strictly adopted.

Location C: This is the third alternative site located near the school (Plot no. 1120). Just beside the school there are a number of wetlands. One of them may be selected for providing arsenic free water. Here also steps 1 - 4 should be strictly adopted to ensure safe drinking water.

For artificially recharging the aquifer through roof top rainwater harvesting Plot no. 1051 near Location B is the only choice. In this plot, there is a concrete roof of about 850 sq ft. The arsenic concentration is between 0.05-0.1 mg/l and the depth to water

table is 4-5 m. Rainwater collected on the roof can be recharged into the aquifer through a bore well with strainers placed at depth of 50 m. The plot is located on the groundwater mound and hence the recharged water will move in all directions away from the mound and dilute the arsenic present in the aquifer in and around the area especially in the eastern direction. Piezometer may be installed and monitored continuously to understand the effect of the recharged water on the arsenic concentration.

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ARSENIC IN GROUND WATER IN PARTS OF MIDDLE GANGA PLAIN IN BIHAR- AN APPRAISAL

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INTRODUCTION

Ground water in different parts of the world has now been identified with unacceptably high concentration of arsenic, known for its carcinogenic health effects. The areas contaminated with arsenic in groundwater include Bangladesh and parts of India, China (including Taiwan), Myanmar, Nepal, Vietnam, Cambodia, Argentina, Chile, Mexico, South West United States, Hungary and Romania (Chatterjee et al 2005). In India, Bangladesh and some other developing countries, regulatory limit of arsenic in potable water is being considered as 0.05 mg/L. However, WHO (1993) has recommended a drinking water guideline value of 0.01 mg/L, which has also been endorsed by Bureau of Indian Standards (BIS 2003).

Arsenic groundwater contamination in Bihar was first detected in the year 2002. Subsequent investigations in the Gangetic Plain of Bihar revealed its wide occurrence, affecting 57 blocks in 15 districts of the state. The patches of high groundwater arsenic (>0.05 mg/L) zones are confined in Newer Alluvial belt along the river Ganga affecting both the active and the older flood plains. The contamination is confined within the top 50 m of the thick multi-cyclic sand, clay, sandy clay and silty clay sequence, jeopardizing the hand pump based rural drinking supply.

SPATIAL GROUNDWATER ARSENIC DISTRIBUTION

In Ganga Plain, in the upstream of Rajmahal Hills, groundwater arsenic exceeding 0.05mg/L was initially detected in 2002, from two villages, Semariya-Ojhapatti and Doodhghat, in Bhojpur district of Bihar, on the southern bank of the River Ganga (Chakraborty et al 2003). The villages are located on a monotonously flat, flood-prone tract of the Son-Ganga interfluve region. Investigations by CGWB, immediately after reporting of this, indicated maximum concentration as 0.178 mg/L. All the affected wells are hand pumps within a depth range of 20-35 m bgl. The dug wells (depth <8m) are found to be free from contamination.

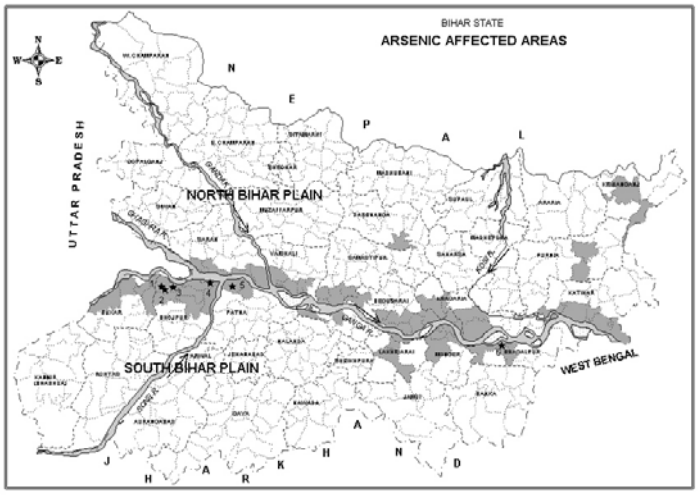

Fig. 1 Arsenic affected Blocks in the state of Bihar with few other highly contaminated specific locations: 1-Karnamepur, 2-Bharauli, 3-Semaria Ojhapatti and Bariswan, 4- Sinha Gram, 5- Maner, 6- Gosaindaspur

The Hydrogeological studies in Bhojpur district has revealed wide variation in concentration, resulting in patchyness in distribution. The hotspots (As >0.05 mg/L) are confined within the Newer Alluvium (CGWB 2006). With an understanding that the North Bihar belt adjoining the arsenic contaminated Tarai belt of Nepal (Tandukar et al 2001) is also affected, a detailed analyses has been carried out by UNICEF under technical guidance from CGWB. In nine districts of north Bihar bordering Nepal, the analysis (total sample ~3100) has revealed arsenic load below 0.05 mg/L. Subsequently a blanket survey

of the spot sources in a 20 km wide corridor along the course of the river Ganga has been carried out by PHED, Govt. of Bihar. Sampling from the reported hotspots, analyses and hydrogeological investigations renders an elaborate understanding on the spatial distribution of arsenic hotspots (CGWB and PHED 2005). Out of ~82000 samples analysed, 11% exceed 0.05 mg/L. Fifty seven blocks, in 15 districts, located on both the banks of Ganga are affected (Table 1, Fig. 1).

In a district-wise assessment, Bhojpur and Buxar are found to be relatively more affected, where 16-20% of the samples exceed 0.05 mg/L. Other districts following are Bhagalpur, Katihar and Samastipur where 11-15% of the samples are contaminated. The lesser affected districts are Saran, Begusarai and Vaishali where < 5% of the samples are found contaminated. Darbhanga, Lakhisarai, Purnea and Kishanganj are affected locally in one or two blocks.

Table1 Arsenic affected blocks in different district of Bihar with their population (2001 census)

Sl. No.	District	No. of blocks	Population (million)	Sl. No.	District	No. of blocks	Population (million)
1	Patna	4	0.86	9	Katihar	6	0.68
2	Bhojpur	6	1.20	10	Buxar	4	0.61
3	Begusarai	6	1.23	11	Vaishali	5	0.92
4	Khagaria	4	0.80	12	Darbhanga	1	0.23
5	Samastipur	4	0.50	13	Lakhisarai	2	0.29
6	Bhagalpur	3	0.79	14	Purnea	2	0.49
7	Saran	3	0.79	15	Kishanganj	2	0.39
8	Munger	4	0.67	**TOTAL**		**57**	**10.4**

GEOLOGICAL FRAMEWORK

About 90 % of the geographical area of the state is underlain by Gangetic alluvium laid during the Quaternary Period and forms a major part of the Middle Ganga Plain (MGP). In the west the MGP enters in Uttar Pradesh and in the east it merges with the Lower Ganga Plain/ Bengal Delta Plain in West Bengal and Bangladesh. The Precambrian Highlands in the south forms the southern border whereas in the north it merges with the Tarai belt, geographically located in Nepal along the foothills of lesser Himalayas. The Quaternary deposits in MGP having their provenance both in the Himalayas and the Peninsular craton, are conveniently divided into the Newer Alluvium (Holocene) and the Older Alluvium (Pleistocene) (Acharya 2005).

The Older Alluvium bordering the Precambrian Highlands in south is assigned Upper Pleistocene to Lower Holocene age by Chakraborty and Chattopadhyay (2001) whereas it occurs as discontinuous patches in the North Ganga Plain. The Younger (Newer) Alluvium is of Middle to Upper Holocene age and at many places the transition is marked with an erosional unconformity. Recent deposits are confined in the flood plains of the Ganga River and as wide patches in North Ganga Plain, in the flood-prone tract of the Ghaghra, Kosi, Gandak, Burhi Gandak and Baghmati Rivers which are perennial and carry substantial sediment load from the lesser and the upper Himalayas.

The thickness of the Quaternary sediments increases from a couple of meters along the fringe areas in south to > 700 m in the axial part of MGP and increases further towards north. Drilling by CGWB confirms the thickness of Quaternary sediments as > 450 m at Begusarai. The deposits are of fluvio-lacustrine origin, are made up of multi-cyclic sand, clay, sandy clay, in several fining upward sequence. The Older Alluvial deposits are yellowish to yellowish-brown in colour in contrast to gray coloured Holocene sediments.

ARSENIC CONTAMINATION SCENARIO AND QUATERNARY MORPHO-STRATIGRAPHY

The major rivers in the Ganga Plain in Bihar state exhibit narrow river valleys which are incised on to upland terraces (T2) developed on the Older Alluvium (Acharya 2005). The Newer Alluvial deposits along the river channels particularly the Ganga are incised as narrow terraces (T1). The T1 surface generally lies above the active flood plain (T0), which is subject to flooding, overtopping of banks during monsoon. The T1 surface is referred as older flood plain.

Arsenic in groundwater exceeding 0.05 mg/L is confined in the Newer Alluvial deposits along the Course of the River Ganga. The Pleistocene deposits exposed both in the South and the North Ganga Plains are low in groundwater arsenic load and nowhere the concentration has been reported to exceed 0.05 mg/L. A study in Sone-Ganga interfluve region covering Bhojpur district, maximum concentration in the Older Alluvium has been found as 0.007 mg/L (Saha et al 2009). About 59% (n=17) of the samples from Older Alluvium reported BDL. In the contiguous Newer Alluvial belt 61% and 41% of the samples (n=60) has exceeded 0.01 and 0.05 mg/L.

Earlier workers (Acharya 2005) opined that potential risk areas are confined to the active flood plains in the Newer Alluvium. Study by CGWB in parts of Bhojpur district reveals that arsenic exceeding 0.05 mg/L is affecting both the active and the older flood plains of the river Ganga. The pattern of arsenic distribution bears a sympathetic relationship with the Quaternary geomorphic and stratigraphic developments. Several sedimentary and stratigraphic facies have been identified and relation between arsenic groundwater contamination and shallow alluvial stratigraphy has been elaborated. The areas in and around the abandoned/cut-off palaeo-channels of Ganga are the arsenic hotspots, as has been observed in Bhojpur and Buxar districts. The cut-off palaeo-channels in the Older Flood Plain are filled and possesses a stratigraphic facies comprising flood plain/lacustrine (channel deep) mud/clay deposits rich in organic carbon (Facies 1, Fig.2) and are sympathetic to arsenic contamination. However, some of them still exist as curvilinear depressions, which hold water seasonally. Most of those in the Newer Flood Plain presently form enclosed water bodies in which sedimentation process is going on. High-arsenic groundwater has also been

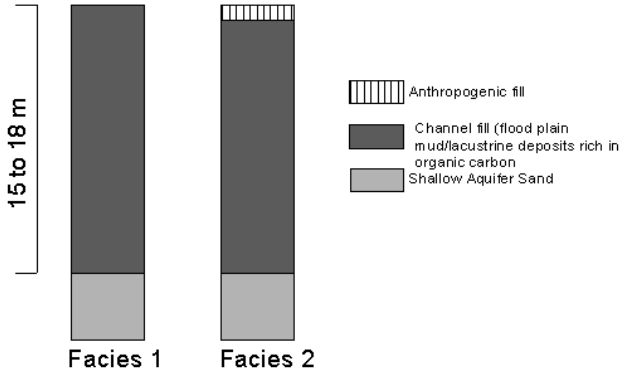

Fig 2: Stratigraphic facies in shallow arsenic contaminated aquifer of Bhojpur district.

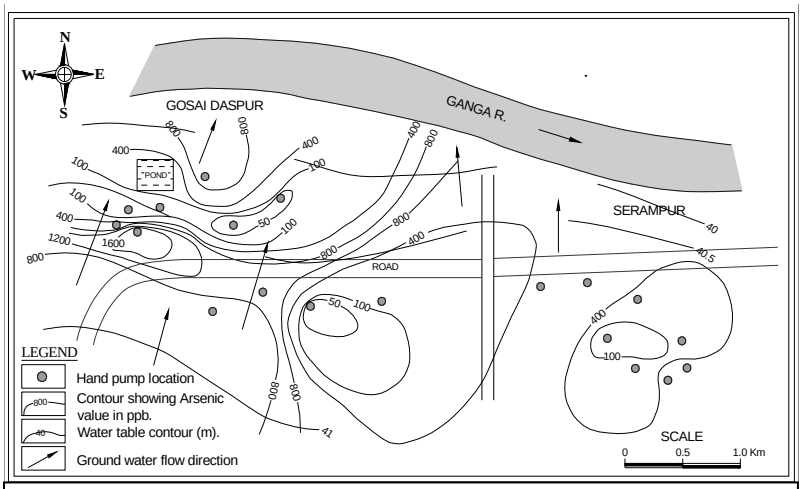

Fig 3: Location of wells in the newer alluvial plain in Gosaidaspur-Srerampur villages in Nathnagar block of Bhagalpur district showing wide spatial variation (> 50 times within 100m distance)

reported from the villages in and around these cut-off lakes. The settlements at Semaria Ojhapatti and Nargada that are within the span of cut-off palaeo-channels bear significantly high levels of groundwater arsenic. These settlements possess a stratigraphic facies comprising thick (15-18 m) flood plain mud/lacustrine deposits overlain by a reworked artificial fine sediment fill (Facies 2, Fig. 2).

Arsenic concentration shows wide spatial variation as also observed in the BDP (Bhattacharya et al 1997). In Semaria–Ojhapatti village in Bhojpur district the variation in concentration from hand pumps (depth 20-35 m) has been observed as 54 times. In the eastern part at Gosaidaspur village in Bhagalpur district, located in the active flood plain of the Ganga, the concentration in hand pumps (20-30 m) varies from <0.05 mg/L to > 1.8 mg/L within a distance of 800 m (Fig 3).

DEPTH DISTRIBUTION OF ARSENIC IN GROUNDWATER

Arsenic concentration in groundwater reduces with depth (Saha et al., 2010). In the BDP highest concentration and greatest spatial variability occurs in a few tens of meters below the ground surface and decrease rapidly below 100 m (Ravenscroft et al 2005). In the MGP in Bihar, because of availability of potential aquifers at shallow depth and shallow water level (generally < 10 m), hand pumps, which are the life-line for rural and semi-urban drinking water supply, have a depth range of 20-40 m. Arsenic sampling for this region is constrained beyond 40 m below ground because of non availability of deeper wells. To obtain groundwater samples from deeper zones, CGWB has drilled 54 aquifer-specific piezometers within 300 m bgl. Analyses of water samples from these piezometers indicate significant reduction in concentration beyond 50 m. The aquifers below 80 – 100 m bgl are contamination-free even considering WHO standard (1993). A depth vs arsenic concentration in Bariswan village reveals that the piezometer of 19 m depth has highest concentration (0.062 mg/L), which reduces to 0.013 mg/L at 62 m depth and further to 0.002 mg/L at 200 m below ground (Fig. 4). The dug wells (<10 m) exhibit low arsenic load (< 0.01 mg/L).

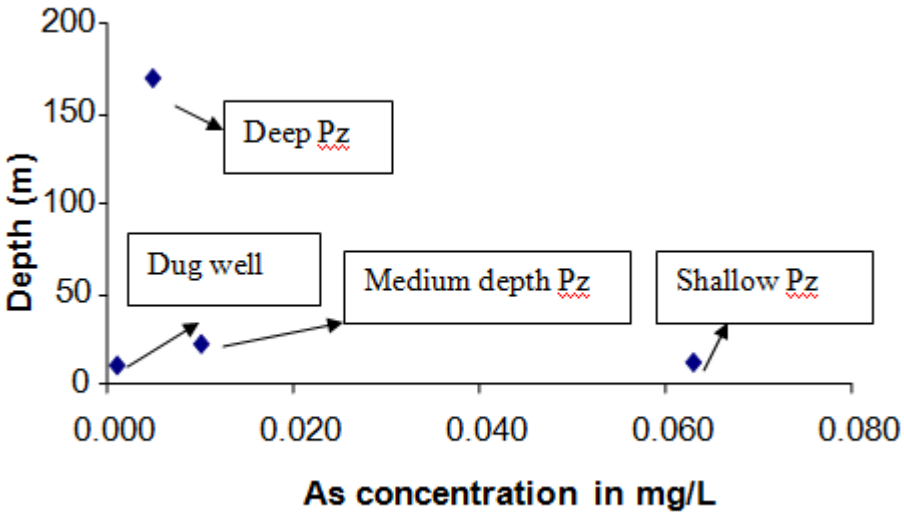

Fig 4: Depth-wise distribution of groundwater arsenic in Bariswan village

HYDROCHEMISTRY OF ARSENIC CONTAMINATED GROUNDWATER

Arsenic-contaminated groundwater is near-neutral to mildly acidic and dominated by alkaline earth (Ca^{2+} + Mg^{2+}) and weak acid (HCO_3^-). Hydrogeochemical characteristics of Newer Alluvium and those from low-arsenic Older Alluvial deposits in Bhojpur district have been studied (Saha et al 2009). Marginally higher load of HCO_3^- (av. 295 mg/L) is reported from samples in the Newer Alluvium compared to that of the Older Alluvium (av. 263.8 mg/L) while $SO4^{2-}$+Cl^- load is higher in the samples from Older Alluvium. The cation

chemistry in Older Alluvium is marked by dominance of Na^+ over Ca^{2+}, whereas in Newer Alluvium equal prevalence of Ca^{2+} and Na^+ exists (Table 2).

Table 2 Chemical quality of groundwater in Newer alluvium and Older Alluvium in parts of Bhojpur district (All constituents are in mg/L except As which is in µg/L)

Constituents	Newer Alluvium			Older Alluvium		
	Range	Av	SD	Range	Av	SD
pH	6.3-7.42	6.98	0.4	7.19-8.09	7.37	0.3
TDS	224.0-661.7	419.3	106.1	204.8-768.0	450.8	179.9
HCO_3^-	110.0-500.0	295.0	99.6	116.0-384.0	263.8	95.7
Cl^-	6.0-89.0	23.1	17.2	7.1-209	50.6	53.1
NO_3^-	0.06-13.4	2.5	2.7	1.0-1.9	1.4	0.3
SO_4^{2-}	0.3-190.4	21.8	29.9	0.5-162.3	50.7	56.6
Ca^{2+}	16.0-104.0	40.3	17.3	10-86	31.8	23.3
Mg^{2+}	3.6-67	25.2	14.4	12-43	23.7	9.8
Na^+	14-112.0	40.8	18.6	30-158	67.8	38.9
K^+	0.7-23.0	3.9	3.4	0.4-60	11.8	19.0
Fe (total)	0.037-7.55	1.4	1.8	0.03-1.11	0.3	0.3
As (total)	BDL-620.0	94.93*	124.6*	BDL-9.0	6.33*	2.2*

The groundwater in the contaminated belt are categorized based on Cl^-, $SO4^{2-}$ and HCO_3^- concentrations as normal chlorine (< 15 meq /l), normal $SO4^{2-}$ (<6 meq /l) and 92% samples are normal HCO_3^- (2-7 meq /l) types (Soltan 1998). NO_3^- ranges between 0.1 and 13.4 mg/L. Analysis in Piper diagram (Piper 1944) indicate dominance of alkaline earth (Ca^{2+}+Mg^{2+}) over alkalies (Na^++ K^+) and overwhelming dominance of HCO_3^- over Cl^-+ SO_4^{2-} (Fig 5). Twelve hydrochemical facies have been identified; Na-Ca-HCO_3 , Na-HCO_3 , Ca-Mg-HCO_3, Na-Mg-Ca-HCO_3, Ca-HCO_3, Ca-Na-HCO_3 , Mg-HCO_3 , Na-Mg-HCO_3, Mg-Ca-HCO_3, Na-Cl-HCO_3, Mg-Na-HCO_3, and a facies without dominance of any cation or anion.

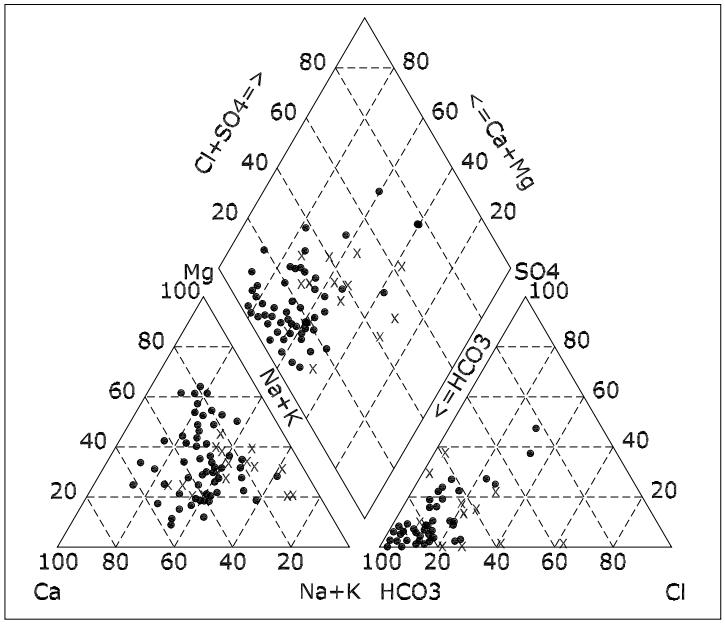

Fig 5: Piper plot (Piper 1944) showing dominance of alkaline earth (Ca+ Mg) and weak acids (HCO_3) in arsenic contaminated groundwater. Cross indicates samples from Older Alluvium and solid black dots represent Newer Alluvium affected by arsenic contaminated groundwater

Most frequently observed facies is Mg-HCO_3, followed by Ca-HCO_3 and Ca-Na-HCO_3. The Ca^{2+} and Mg^{2+} dominated facies exhibit frequent incidence of high arsenic (> 0.05 mg/L). Four facies are particularly found to be arsenic affected Ca-HCO_3 (BDL- 0.620 mg/L), Mg-HCO_3 (BDL- 0.227 mg/L), Ca-Mg-HCO_3 (BDL-0.550 mg/L) and Mg-Ca-HCO_3 (BDL-0.270 mg/L). The Older Alluvial areas are dominated by Na^+ dominated facies, viz, Na-Mg-HCO_3, Na-HCO_3 and Na-Ca-HCO_3.

Hydrogeochemical evolution of groundwater in arsenic contaminated Newer Alluvium part has been elaborated by Principal Component Analysis (PCA). The analysis involved varimax rotation to achieve rotated factor matrix. The rotation was used for better interpretation by maximizing the difference between the variables (Lee et al 2001). Principal Component1 (PC1) accounts for 29.08% of the variance and is contributed mainly by EC, HCO_3^- and Mg^{2+}, indicating infiltration of rainfall and seepage from surface water bodies (Table 3). High Mg^{2+} loading in PC1 indicate dissolution of ferromagnesian minerals and detrital dolomites. PC2 accounts for 20.01% of the variance and characterized by high positive loadings of Ca^{2+}, As (total) and Fe (total), revealing possible same mobilization path of As and Fe. Incidentally As and Fe shows strong positive correlation (r^2= 0.674)(Fig 6). Loading of HCO_3^- (0.364) indicates its role for releasing As and Fe in the aqueous phase.

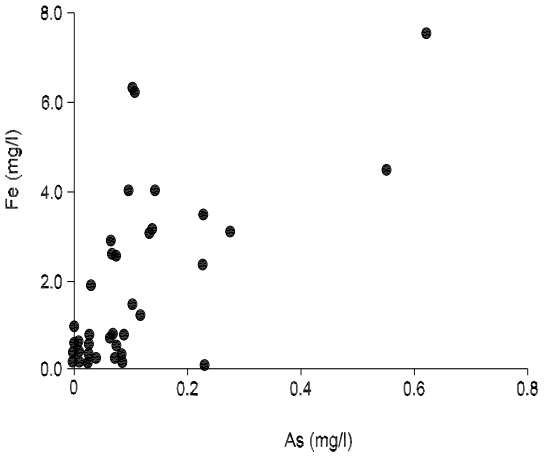

Fig 6: **Relation between Fe and As in newer alluvium samples**

Table 3 Results of Principal Component Analysis of groundwater samples from Newer Alluvial belt of Bhojpur district

Constituents	**Components**			
	1	**2**	**3**	**4**
EC	.792	.345	.411	-.046
HCO_3^-	.885	.364	-.147	-.118
Cl^-	.111	.012	.860	.252
NO_3^-	.084	-.133	-.038	-.732
SO_4^{2-}	-.359	.010	.776	.154
Ca^{2+}	.153	.741	.125	-.096
Mg^{2+}	.846	-.020	-.083	.226
Na^+	.136	.003	.805	-.287
K^+	.396	-.159	.063	.598
Fe (total)	.160	.862	-.052	.012
As (total)	.026	.832	-.034	.141
% Eigen value	*29.084*	*20.029*	*14.792*	*10.158*
Cum %	*29.084*	*49.113*	*63.905*	*74.063*

HYDROGEOLOGY OF ARSENIC CONTAMINATED AREA

Arsenic contaminated areas in the state lies in the upper part of high potential multi-group aquifer system. Visual analyses of drill-cut samples from 22 deep bore wells (~300 m) drilled by CGWB and 16"/64" electrical and self potential logging has helped understand the aquifer geometry. The litholog of Bharauli, an arsenic contaminated village in Bhojpur district, reveals a sequence of Quaternary fluvio-lacustrine deposits down to 250 m depth (Fig.7). At the top, a 13 m thick soil and clay sequence is followed by sandy clay, which grades to fine to medium sand up to 69 m bgl. A thick medium to coarse sand sequence underlies and continues till the appearance of light yellow colored clay and sandy clay (cumulative thickness 25 m). This clay and sandy clay layers appear to have less permeability and together have been referred as middle clay .

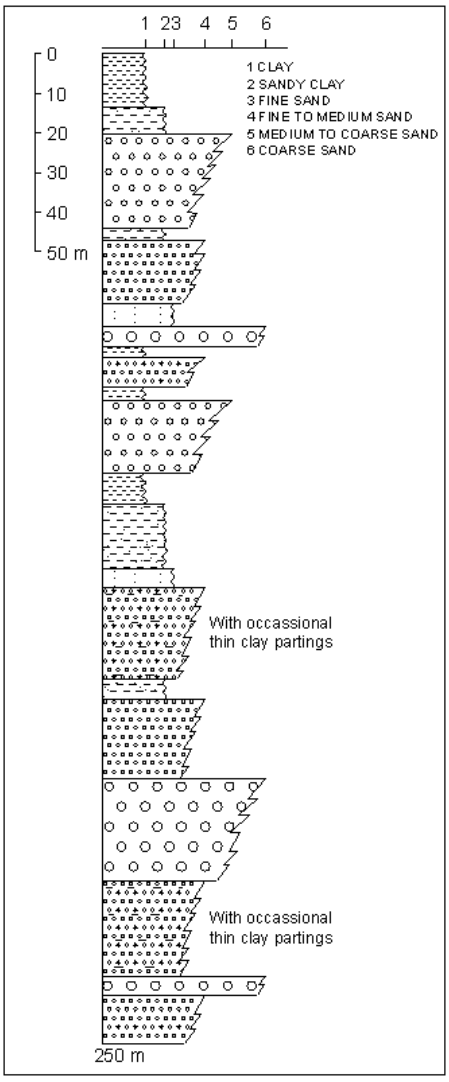

Fig 7: Litholog of Bharauli (Bhojpur district) in the southern bank of the Ganga River

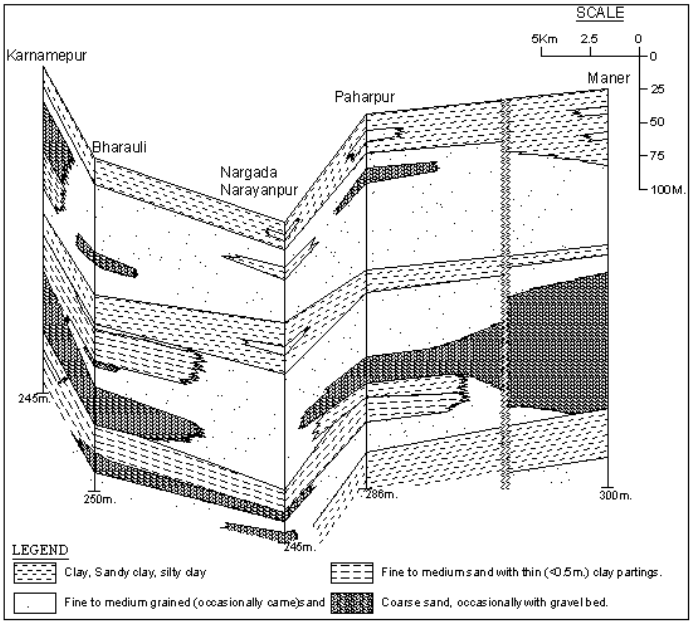

Fig 8: Geologic section, transect Karnamepur-Maner in Newer Alluvial area of Bhojpur and Patna district

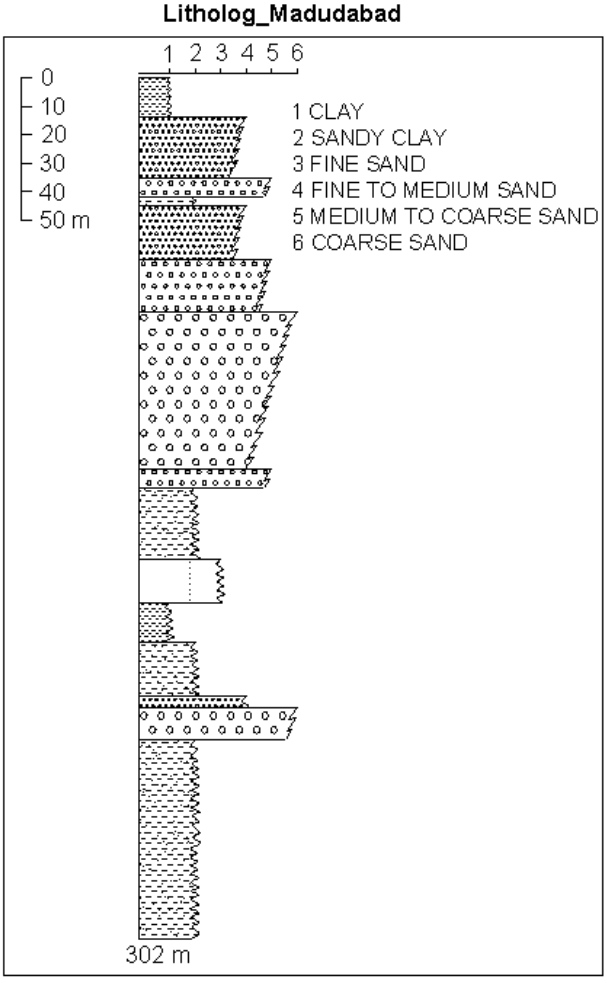

Fig 9: Litholog of Madudabad (Samastipur district), located on the northern bank of the Ganga River

A second sequence of fine to coarse sand appears below the middle clay and continues up to 250 m below ground, with occasional gravel beds confined at two depth zones; 183-209 m bgl and 230-238 m bgl. No significant clay bed appears within the second sand sequence, except thin clay partings (~10 cm thick) appeared in fine to medium sand layers, indicating temporary low energy conditions.

Various litho-units form a two-tier aquifer system separated by the middle clay. The upper aquifer ranges from 0 to 106 m bgl and lower aquifer starts at 130 m bgl. This two-tier aquifer system

prevails in the inter-stream region of the Sone and the Ganga, covering Bhojpur and Buxar districts. Hydrogeologic section between karnamipur to Maner reveals spatial continuity of the two-tier aquifer system separated by 15-33 m thick clay (Fig8). Aquifer configuration, however, is different in the northern part of the river Ganga to the east of Sone-Ganga interfluve. The litholog of Madudabad in Samastipur district reveals continuance of the upper aquifer upto 120 m bgl. Clay and sandy clay predominate the lithology at depth. Aquifers of 12-15 m thickness are found embedded within the thick argillaceous deposits (Fig.9)

Groundwater in the arsenic-contaminated shallow aquifers (within 50 m bgl) remains under unconfined condition. The hydrograph network station measurements reveal shallow hydraulic head indicating effluent nature of river Ganga in this part. During the pre-monsoon the water level remains between 5.0 and 10.0 m bgl, except in central parts in regions adjoining Ganga-Gandak confluence and parts of Buxar and Bhagalpur districts where it remains between 2.0 and 5.0 m bgl. During the post-monsoon the level ranges from 2.0 to 5. 0 m bgl except in few parts of Buxar, Bhojpur, Samastipur, Patna, Munger and Bhagalpur districts where it remains between 5.0 and 10.0 m bgl.

In the arsenic contaminated Newer Alluvium belt in Bhojpur district a detailed study indicates water levels of shallow contaminated aquifers found to vary between 5.1- 6.32 m (av 5.31m) and 3.2 to 4.43 m (av 3.78 m) during the pre and post monsoon seasons respectively. Groundwater flows towards the Ganga River with a gradient of $6x10^{-4}$ indicating sluggish movement. The head of the low-arsenic lower aquifer remains higher than the water levels representing shallow aquifer, 4.01–6.57 m during pre-monsoon and 2.56 -4.01 m during post-monsoon seasons.

Long-duration pumping tests have been carried out in 16 exploratory wells. In three wells (Maner, Bharauli and Karnamepur) in Bhojpur district tapping the lower aquifer long-duration pumping test data have been interpreted by curve-matching methods of Walton (1962) and Hantush (1955), considering aquifers as semi-confined. Transmissivity vary from 6009 to 6985 m^2/day (Table 4). Hydraulic conductivity ranges between 64.88 to 82.04 m/day. Storage coefficient values ($6.4x10^{-4}$ to $2.5x10^{-3}$) indicate semi-confined to confined nature of the aquifer.

Table 4 Aquifer hydraulic parameters determined by Walton (1962) and Hantush (1960) curve fitting methods

Location	Walton method		Hantush method		Average T (m^2/day)	Hydraulic conductivity (m/day)
	T (m^2/day)	S	T (m^2/day)	S		
Bharauli	6985.66	$6.4*10^{-4}$	6963.49	$2.5*10^{-3}$	6974.5	82.04
Karnamepur	6196.53	$9.4*10^{-4}$	4131.28	$1.3*10^{-3}$	5163.5	68.84
Maner	6009.00	$1.6*10^{-3}$	5151.27	$6.9*10^{-4}$	5580.0	64.88

The water level behavior and the aquifer configuration reveal unconfined mode of groundwater occurrence in arsenic-contaminated shallow aquifer. Hydraulic conductivity of the shallow zone has been determined based on the grain-size parameters using the established equations by Lambe (1958) and Breyer (1964) for Bharauli well. In Lambe's equation d_{10} is an important input whereas in Breyer's method U_c (uniformity coefficient) plays a significant role. Porosity is the most critical input in determining K by Lamb's method. Based on published values of porosity for different size-grades of sand (Morris and Johnson 1967; Driscoll 1986) values of 39% and 36% are considered suitable for medium to coarse sand and for very coarse sand (with occasional gravel) respectively. The hydraulic conductivity ranges between 37 and 92 m/day.

RECHARGE MECHANISM AND AGE OF GROUNDWATER IN DIFFERENT AQUIFERS

From the aquifer configuration it appears that the recharge paths are different for the shallow contaminated aquifers and the deep low-arsenic aquifers. The recharge mechanism has also a bearing on mobilization of arsenic in groundwater. Isotope analyses, both stable ($^{18}O/^{16}O$, ^{13}C) and radioactive (^{14}C, ^{3}H) have been carried out for aquifer-specific samples from Bharauli, Semaria-Ojhapatti, Bariswan and Sinha Gram in the arsenic contaminated area of Bhojpur district (CGWB and BARC, 2009).

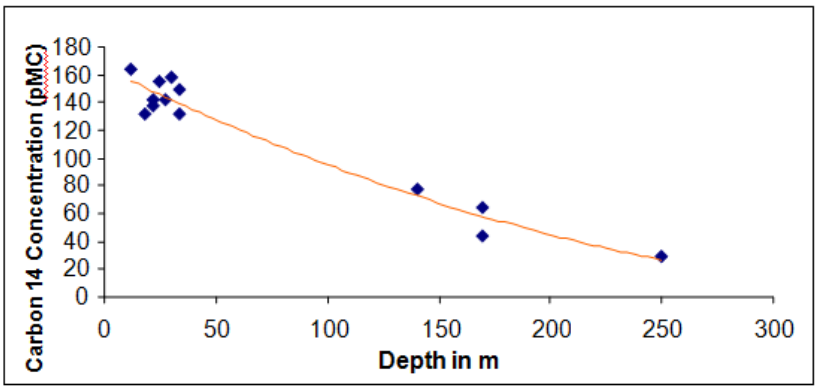

Fig 10: Depth Vs Carbon-14 activity

Tritium (^{3}H) concentration of the shallow groundwater (generally 3.42-10.13 TU) reveals a substantial component of modern recharge and the age has been estimated as less than 40 years. Carbon-14 concentration ranges widely, between 29.97 and 164 pMC, showing a positive correlation with depth of groundwater (Fig10). The deeper low-arsenic aquifer has ^{14}C concentration between 29.97 and 77.61 pMC. Based on ^{14}C concentrations, the age of the groundwater from deeper low-arsenic aquifers have been worked out as ~3000 years. The older age supports less permeable nature of the middle clay, holding the deeper aquifers under semi-confined to confined condition.

The $\delta^{18}O$ (‰ VSMOW) values vary from -7.69‰ to -5.52‰ whereas from shallow aquifers it remains in the range of -7.06‰ to -5.52‰. Three samples from lower aquifers exhibit a $\delta^{18}O$ range of -7.69‰ to -7.28‰ (Fig11), with an average value of -7.53‰, indicating that they are significantly depleted in ^{18}O than the upper aquifer. $\delta^{2}H$ (‰ VSMOW) varies in shallow aquifer from -46.96‰ to -36.52‰. Deeper aquifer samples represent still lower values (-47.95‰ to -43.14‰). The difference in $\delta^{18}O$ and $\delta^{2}H$ (‰ VSMOW) values between shallow and the deeper groundwater indicates difference in hydrostratigraphy and possibly the climatic regime under which the recharge took place. The plots of $\delta^{18}O$ vs $\delta^{2}H$ fall both above and below the Global Meteoric Water Line (GMWL) of Craig (1961) (Fig.11). Minor deviation from the GMWL indicates some evaporation of rainfall, prior to or during

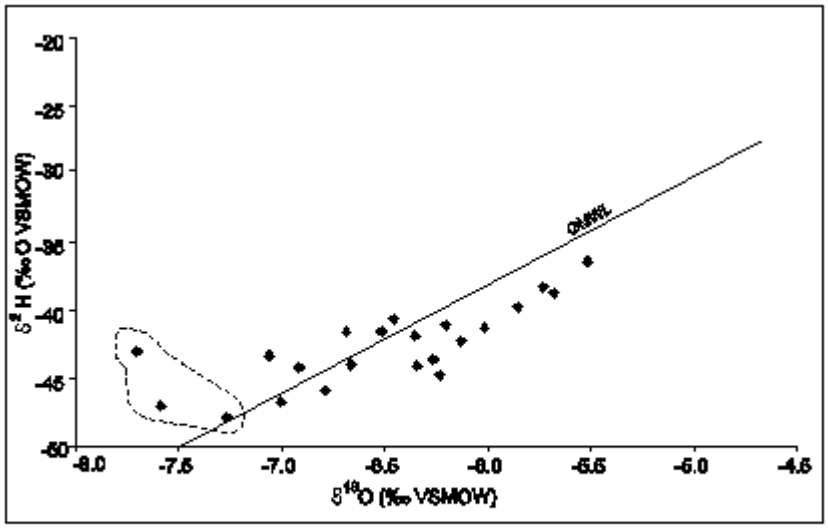

Fig11: Plots of $\delta^{2}H$ Vs $\delta^{18}O$ along with GMWL. Deeper ground water samples are shown as a separate group within a dotted line.

infiltration, or there might be some mixing of the infiltrating water with the pre-existing soil-moisture that has experienced several cycle of evaporation (Allison, 1982). A part of the recharge is contributed from natural surface water bodies, community tanks as well as recirculation of groundwater withdrawn for irrigation, which appears to be enriched in heavier stable isotopes due to evaporation.

CONCLUSIONS

Arsenic contamination in Groundwater beyond the regulatory limit of 0.05 mg/L is posing a challenge to the water supply in the state of Bihar. The contamination is affecting the shallow aquifer, within ~50 m bgl, which are the life line of hand pump based rural drinking supply.

Elevated arsenic load, are confined in the flood plain, both in the active (flood prone) and the older flood plain of the Ganga River. The Older Alluvium forming the Marginal Plain Upland Surface (Singh 2004) in South Ganga Plain and Dissected Upland Interfulve Surface in the North Ganga Plain have low arsenic load. In Bhojpur district maximum arsenic concentration in Older Alluvium has been detected as 0.007mg/L. However, localized high arsenic has also been detected in Darbhanga, Kishenganj far away from the present course of the Ganga.

Arsenic distribution is marked with wide spatial variability resulting in patchyness in distribution. No relation has been established between the concentration level of arsenic and groundwater flow direction. Depth wise there is a significant reduction in concentration beyond 40 m bgl. The aquifers at depth (> 80 m bgl), which appears to be of Pleistocene age are contamination free even considering the WHO (1993) guidelines.

The drill-cut samples from the arsenic contaminated Holocene deposits are gray coloured and rich in organic matter, indicating reducing environment. Deposition of organic matter is facilitated by numerous cut-offs, abandoned channels and back-swamps which hold water for a significant part of the post-monsoon period. Grain size distribution of sands reveals a fluvio-lacustrine depositional environment during the Holocene period.

Chemically the groundwater is mildly acidic and fresh with TDS generally remaining within 800 mg/L. The anionic chemistry is dominated by HCO_3^- while the cationic chemistry is marked by dominance of Ca^{2+} and Mg^{2+}. Groundwater with high arsenic load is marked with Ca-HCO_3, Mg-HCO_3 and Ca-Mg-HCO_3 facies. PCA of the major chemical constituents in Bhojpur district reveals high loadings of As (total), Ca^{2+} and Fe (total), and significant HCO_3^- loadings in PC2. Release of As and Fe in aqueous phase is related to same mobilization path, which is supported by positive correlation between them.
The arsenic contaminated Newer Alluvium belt exhibits flat topography with shallow water levels (<10 m bgl) and sluggish groundwater movement. Long-term water level analyses of Hydrograph Network Stations do not indicate any significant lowering of water level.

The main source of recharge of shallow aquifer is rainfall infiltration besides percolation from surface water bodies. Tritium concentration also reveals young age of shallow groundwater (<40 years). The abundance of organic carbon in the shallow alluvial stratigraphy allows a part of it to be carried downward with the percolating groundwater. The organic carbon stimulates microbial respiration and triggers reductive dissolution of As and Fe in solid phase. This process also generates HCO_3^- and so produce the relationship between AS and HCO_3^- in shallow groundwater

The deeper aquifers hold old water (> 3000 years) as indicated by ^{14}C activity and appear to have its recharge from far off places. Presence of sub-regional scale clay bed in Sone-Ganga interfluve region in Bhojpur and Buxar districts inhibits direct vertical percolation of arsenic contaminated water from shallow level to the deeper aquifer system beyond 120 m

bgl. In other affected areas of Middle Ganga Plain, the arsenic free deeper aquifers are of good potential, where T remains > 5000 m^2/day. Groundwater in these aquifers remains under semi-confined to confined condition and can be developed for community scale water supply through deep tube wells.

RECOMMENDATIONS

he spatial variation of arsenic concentration in groundwater, both horizontal and longitudinal, warrants detailed investigation. A clear understanding of the mobilization path of arsenic in groundwater in the Ganga Plain is yet to be established. The reasons for lesser degree of contamination in the flood plains of the other major rivers draining the Middle Ganga Plain, like Kosi and Gandak Rivers, as compared to the Ganga stem flood plain, also needs to be established. Sub-basin scale sustainable yield of the low-arsenic deeper aquifers for community-scale water supply is to be worked out. The recharge mechanisms in the contaminated shallow aquifers and low-arsenic deeper aquifers needs elucidation assimilating isotopic techniques both in the North and the South Ganga Plain.

Clinical manifestations of prolonged arsenic exposure through drinking sources are also reportedly not as severe in the Middle Ganga Plain, as has been documented in West Bengal and Bangladesh. Studies throwing light on the clinical aspects are also desired along with ascertaining the possibility of arsenic fixation in the food chain.

ACKNOWLEDGEMENT

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ARSENIC IN GROUND WATER OF NORTH 24 PARGANAS DISTRICT, WEST BENGAL

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INTRODUCTION

Arsenic Contamination in ground water used for drinking purposes is a severe health hazard in the state of West Bengal since late seventies. At present arsenic pollution in sporadic manner has been reported in ground water from eight districts of West Bengal in 79 administrative blocks and nearly 16.2 million people are in the risk zone. Epidemiological studies conducted so far by various organizations have established that intake of arsenic contaminated water over a long period results in arsenic poisoning in human body. Different Government / Non government Organizations / Institutions have come forward to identify the arsenic affected tube wells yielding arsenic contaminated water and also trying to monitor the magnitude and extent of the pollution to mitigate the problems. In this respect detailed studies have been Carried out by CGWB in North 24 Parganas district of West Bengal to understand the causes and mobilization of arsenic in ground water and suggestion on mitigation for suitable management of ground water.

STUDY AREA

The study includes in the arseniferous blocks (Bongaon, Bagdah, Gaighata, Habra I & II, Barasat I & II, Amdanga, Deganga, Rajarhat, Barrackpur I & II, Baduria, Haora, Swarupnagar, Basirhat I & II) of North 24 Parganas district. About 35.63 lakhs people out of the total population of 35.85 lakhs are in the risk zone of arsenic pollution. In total 253 number of Mouzas out of 1606 are arsenic affected.

HYDROGEOLOGY

Hydrogeologicaly the North 24 parganas district is mainly within the upper delta plain of Ganga-Bhagirathi river systems. Arsenic in ground water is mainly restricted in shallow aquifer (depth 15 to 70mbgl) which is mainly built up of sediments deposited by meandering streams and levees. The migration of the meander belts, lag front bars, levee back swamp with fining upward sequence in a vertical section depending upon the density of channel network the composition of sediments changes laterally across delta plain even within a few meter to several hundreds of metres. This may responsible for lateral variation of arsenic in ground water.

In the present study area, the main water bearing formations are Quaternary formations mainly Recent and Pleistocene alluvial deposits and the aquifer materials comprising of sand of varying grades and gravels. Ground water occurs within water table and in semi confined to confined conditions. It is also noticed that the nature of aquifer materials in horizontal extent is not uniform and it changes from place to place. This is due to the facies variation during the sedimentation.

From the periodical monitoring of arsenic in ground water from the shallow aquifers in time and space it is observed that arsenic content in ground water is maximum during pre monsoon period (April - May) and is minimum in monsoon period (Aug-Sept) which indicates the effect of dilution due to rainfall recharge during monsoon period. It is also interesting to note that arsenic content in ground water in same aquifer varies within a very short span of distance even within 100m and the extent of arsenic variation is very high to very low as (as 2.98 mg/l from a tube well at Adhata village of Amdanga block to 0.02mg /l in another tube well of same depth of 45m bgl at a distance of 100m). This leads to the problem for arsenic conc. contouring in space in a regional scale and is also difficult to demarcate the source of the arsenic in the area. As the source of arsenic

in ground water is geogenic, the actual nature of release of arsenic from geological horizon to ground water is still confusing which has been discussed later. The variation of arsenic concentration in space, from the same aquifer can be explained as (a) During the course of movement of arsenic water through the aquifer, local clay lenses may adsorb arsenic from the arsenic rich water (b) The nature of release of arsenic in ground water from the geological horizons may depend on local factors like presence of organic matter in the geological horizons, local geochemical conditions like radox potential (Eh), hydrothermal conditions and physico-chemical characters etc.

GROUND WATER EXPLORATION

Ground water exploration has been carried out (CGWB) for identification and delineation of arsenic free deeper aquifers. It has been observed that arsenic free aquifers are separated from the upper arseniferous aquifers by a thick clay bed. Construction of suitably designed tube well tapping the arsenic free deeper aquifer with cement sealing technique yields arsenic free water. The details of the exploratory drilling and arsenic free aquifer identified has been presented in Table 1.

Table 1 Ground water exploration in parts of North 24 Parganas district, West Bengal.

Sr. No	Block	Location	Depth drilled in m bgl	Zones tapped in m bgl	Well constructed in m bgl	Discharge in lps	Arsenic content in mg/l	Cement Sealing depth in m bgl
1	2	3	4	5	6	7	8	9
1.	Barasat I	Madhyamgram	349	223-241	262	20	BDL	221-223
			265	100-118	121	8.14	BDL	89-91
2.		Jagannathpur	351	261-276	279	6.2	BDL	248-251
3.	Habra I	Gobardanga	256	191-203	206	5	BDL	178-180
			164	127-152	155	20	BDL	107-110
4.		Nakpul	257	208-232	235	9.1	BDL	163-167
			160	123-147	150	10.2	BDL	108-112
5.		Badekhatura	350	260-278	281	22.7	BDL	206-209
6.	Habra II	Ashoknagar	253	168-174	204	4.3	BDL	158-160
				189-210				
7.		Ayera	250	191-209	212	25	BDL	187-190
8.		Chaitanya College(Habra)	250	187-205	208	16	BDL	180-183
9.	Bongaon	Banksipalli	251	201-207	236	8	BDL	189-192
				221-233				

Sr. No	Block	Location	Depth drilled in m bgl	Zones tapped in m bgl	Well cons-tructed in m bgl	Discharge in lps	Arsenic content in mg/l	Cement Sealing depth in m bgl
1	2	3	4	5	6	7	8	9
10		Nahata	219	207-213	216	5	BDL	189-192
11	Barrackpur I	Doda complex	350	175-199	202	15	BDL	157-160
12	Barrackpur II	Bhatpara	250	162-180	183	10.2	BDL	151-155
			120	100-118	120	8.8	BDL	67-69
13		Kanchrapara	233	132-150	153	11	BDL	126-128
14	Gaighata	Gaighata	245	197-215	218	12.48	BDL	189-192
15		Banigopalpur	246.2	133-139 142-154	157.5	0.3		123-126
16	Amdanga	Mirati	232	140-158 161-170 173-179	182	34		70-73
17	Bagda	Bagda	248.1	190-196 215-227	243	22		130-140
18	Salt Lake (Municipal)	IA park	352	130-142 171-177 190-196 200-206	209	12	BDL	

BDL : Below detection limit (<0.001), Source: CGWB

Based on the sub-surface lithological correlation diagram (Fig.1 & Fig 2) of the this district it has been observed that three aquifer systems exist in the area: The first aquifer system exists down to the depth of 80 m below ground level. The second aquifer system starts below 100m below ground level and extends up to the depth of 180m bellow ground level and the third aquifer system exists down the depth of 200- 335m bgl out of the explored depth of 350m bgl. Furthermore, each aquifer system is consisting of one or more aquifers which are interconnected within a short distance.

The first shallow aquifer system (within depth of 80 m bgl) consists of two to three aquifers in which thickness of individual aquifer (10m to 40m) varies from place to place and individual aquifers are separated by thin clay layers which are not extended regionally. The aquifer material is fine to medium grained sands in the upper part and coarser in the lower part. There is a lot of facies changes within this aquifer system. This

aquifer is potential enough to yield good quantity of ground water having sporadic occurrences of arsenic in ground water in this aquifer in most of the places.

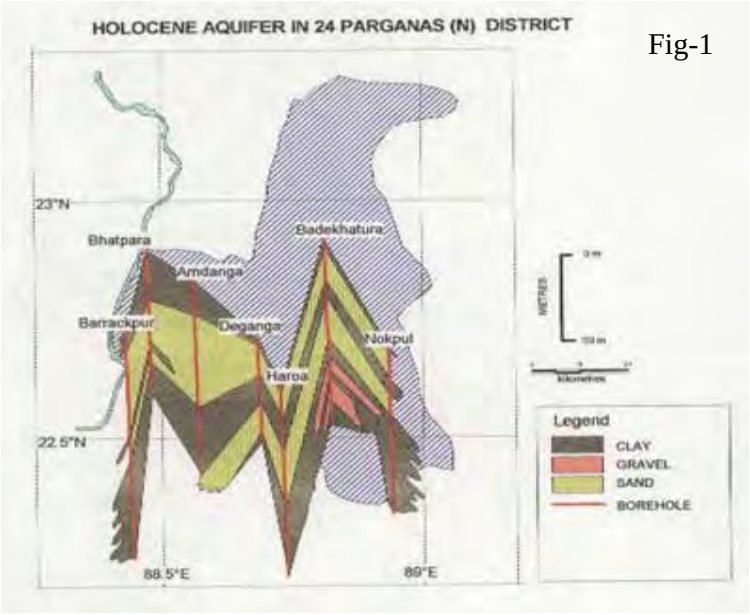


Fig-1

The second aquifer system (within the depth of 100 to 180 m bgl) is separated .from the upper shallow aquifer system by a thick clay layer of 10 to 30 m thick. This aquifer system consists mainly of one or two aquifers whose individual thickness varies from 5 m to 30 m in place to place and the aquifer are separated by thin clay layers which are also not extended regionally. The aquifer material is mainly medium to coarse grained sands and is of Pleistocene alluvial deposits. The aquifer is regionally extended and potential enough to contribute good quantity of arsenic free ground water.

The third deeper aquifer (within the depth range of 200 to 335 m bgl) is separated from the upper second deeper aquifer system by thick clay layer of 10 to 30 m. This aquifer system consists of one aquifer (5 m to 20 m thick) but the thickness varies from place to place. The aquifer material is medium to coarse grained sands in places enriched with gravels and of Pleistocene to Tertiary in age. The yield of this aquifer is relatively less than the upper aquifer systems. The regional extension of this aquifer could not be assessed in details due to insufficient data.

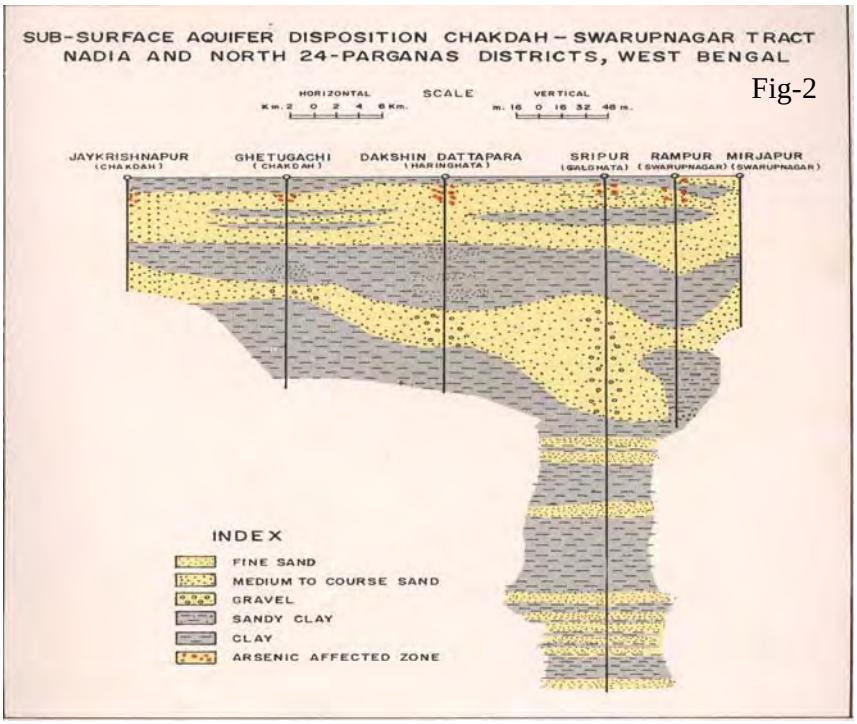


Fig-2

From the above table it is observed that arsenic free deeper aquifer exists in most parts of the district and properly designed tube well with cement sealing techniques can be capable of yielding sufficient quantity of safe potable and arsenic free ground water for drinking purposes. Transmissivity(T) of arsenic free deeper aquifers are determined as 2000-3000 m^2/d.

CAUSES & MOBILIZATION OF ARSENIC AND ITS MITIGATION

The studies have been carried out in different parts of the district to identify the causes and mobilization of arsenic:-

Arsenic in Vadose water zone

Arsenic water in most parts of the district is mainly used for irrigation purposes and there is a chance of arsenic rich zone in the top soil and in vadose water zone. Considering this view vadose zone (upto 3m b.g.l.) litho samples as well as vadose water samples have been collected through hand auger drilling and vadose zone sampler for arsenic, iron, phosphate and sulphate analysis. It is observed that in vadose zone water arsenic concentration is <0.001mg/l, iron concentration <0,1 mg/l, Phosphate concentration 0.025 to 1.25mg/l and sulphate concentration is low whereas in sediment samples iron concentration ranges between 8-112mg/kg and arsenic concentration 0.05 to 6.5 mg/kg. This indicates that irrigation through arsenic water does not increase the arsenic content in the vadose zone water. As soon as the arseniferous water is exposed to air and top soil, some of the arsenic may absorb by the plants & soils and rest may decomposes to arsine gas through bioorganic activity. Again, use of phosphatic fertilizer may not responsible for the release of arsenic in ground water as the vadose water contains very low phosphate. However, detailed works is essential to establish the fact.

Artificial Recharge Study

Experimental study has been conducted at Ashoknagar, Habra I block where recharge of arsenic free rain water from a recharge pit has been allowed through a small diameter shallow tube well (depth 16m) to recharge the shallow arseniferous aquifer (within depth of 20mbgl). The results indicates that initial arsenic concentration of 0.128mg/l could be diluted to 0.08mg/l in one month and < <0.001 mg/l in a span of 3 months during October to December. The rate of natural recharge in this case has been estimated as 7.11 liters/hr. The recharge rate has been increased to 115 liters/min by pumping of arseniferous water (dischage 0.5 lps for 180 minutes). This indicates that recharging of arsenic free water in arseniferous aquifer may reduce the arsenic concentration in ground water.

Arsenic and Iron concentration consequence to pumping of arsenic water from arseniferous aquifer:

The behaviour of arsenic concentration consequent to pumping has been studied from six locations in Barasat, Gaighata, Habra blocks .It has been observed that there is no definite relation of arsenic concentration consequent to pumping. However, arsenic concentration comes down in some of the pumped wells as 0.036 to 0.026 mg/l after 120 min in Gopalnagar, 0.128 to 0.069 mg/l after 180 min in Gajna (both the tubewells are of 22-24 m depth). Consequent with the pumping (pumping discharge 29 to 31 m^3/hr),in some places arsenic concentration fluctuates consequent to pumping as seen in Ashoknagar and Mayna. Arsenic concentration increases (0.65 to 0.87 mg/l) in the observation well located close to pumping well consequent to pumping as observed in Mayna.

The behaviour of iron concentration consequent to pumping has been studied and it has been observed that ferrous iron increases consequent to pumping (5.8 to 7.4 mg/l in Ashoknagar, 62.5 to 7.10 mg/l in Dhakuria, 15.4 to 23.4 mg/l in observation well of Moyna, 3.25 mg/l in Gopalpur).

In some places, iron concentration, are also decreases consequent to pumping (7.0 to 5.7 mg/l at Gajna, 10.28 to 10.02 at Mayna). Therefore, it can be concluded that iron concentration consequent to pumping does not reflect any linear trend and it fluctuates. It has been observed that Oxidation Reduction Potential (ORP –75 to –60 mv) has no definite trend consequence to pumping of arsenic rich water, pH increasing (pH 6.6 to

7.12 whereas EC & Dissolved Oxygen reducing (EC 620 to 281 micromhos/cm & DO 1.9 to 0.5 mg/l). This also indicates that release of arsenic from sediments to water is instantaneous and not from a distance sources.

Study of Arsenic rich litho sample :

Determination of arsenic content and other chemical constituents in lithological samples has done from the bore hole samples down to depth of 70.02 m drilled by CGWB at Joypur village, Barasat block and has been analysed in the laboratory of Geological sciences, London, U.K. (Ref .J.M. Mc Arthur of Geological sciences, UCL, London, UK) The lithogy of the bore hole is as follows:-

Depth Range in meter	Material
0.00 to 1.82	Top soil
1.83 to 5.48	Aquitard; silly grey clay
5.49 to 12.8	Aquitard; silly grey clay
12.81 to 29.2	Aquifer A; grey sand
29.21 to 29.87	Organic-rich clay
29.88 to 49.44	Aquifer B; grey sand
49.45 to 69.18	Aquiclude; freenish clay
69.19 to 70.02	Grey sandy clay

The 0.66 metre-thick unit between 29.21 and 29.87 metres depth contains 18% organic matter (7.2% TOC). The concentration of arsenic is high in clay rather than sand samples This value is very high compare to the values found in the aquifer sands. Concentrations of extractable-arsenic in the sediment profile are lowest in Aquifer B and show minima related to organic matter concentrations that confirm the operation of solubilization of arsenic via reduction of iron oxides. The concentration of arsenic is high in clay rather than sand samples. Concentrations of Zn, Cu, Ni, correlate well with each other and show an association with traces of sedimentary iron sulfide, which is authigenic in origin in stable in a reducing environment that is maintained as anoxic by the high concentrations of organic matter in the aquitards and organic-rich layer. As expected, concentrations of Arsenic show associations with both FeOOH and iron sulfides. These influence can be separated using measurements of TOS (total sulfur), which resides primarily in iron sulfides. Similar organic rich horizon has been identified in arsenic affected parts of North 24 Parganas district within the depth of 30m and it seems to play an important role for the release of arsenic in ground water.

The major element composition of the core lithological samples indicate differing proportions of mica, feldspar and quartz in the different aquiclude and aquifer units. Distinct differences are seen between the aquifer above organic-rich horizon (Aquifer A) and that below it (Aquifer B).

Arsenic rich aquifer constituted of grey coloured medium to fine sand, sub-angular to sub-rounded in shape with mineral assemblages of biotite, garnet, lignite, opaques indicating a provenance of dominantly metamorphic origin. Sand grains in the arsenic rich aquifer coated with iron and arsenic rich material. Presence of clay with enriched organic matter in the sediments having high iron and arsenic sulphides deposited in the reducing environment is the principal source of high arsenic concentration in ground water. Arsenic is released to solution by reductive dissolution of FeOOH and release of its sorbed arsenic to ground water.

Study of the Efficacy of Arsenic removal equipments :

The efficacy of different arsenic removal equipment installed by different agencies show results of different arsenic removal equipments. The results are presented in Table 2.

Table 2. Result of Performance of Different Arsenic Removal Plants in Study Area

Sl. No.	Technology/ Manufacture	Location/block	Arsenic Concentration (mg/l)		Iron concentration (mg/l)	
			Raw	Treated	Raw	Treated
1.	Paul Trockner	Nayana, Barasat-I,	0.82 1.07 1.12	BDL BDL BDL	12.0 7.74 10.28	0.02 <0.01 1.26
2.	Water System International (WSI)	Joypur, Barasat-I	0.238 0.310 0.126	BDL 0.16 BDL	5.45 5.55 8.00	0.31 0.07 0.96
3.	APIRON	Sibalaya, Barasat-I	1.035 0.290 0.360	BDL BDL BDL	10.76 11.17 15.98	0.60 0.01 1.12

Back wash samples from three locations of different community plants have been collected and analysed for arsenic, iron an aluminium concentration. The results are presented in Table 3A.

Table 3A Concentration of Arsenic, Iron, and Aluminium in shallow Ground Water.

Type of Plants/ filters	Location	Arsenic (mg/l)	Iron (mg/l)	Aluminium (mg/l)
1. Community based plants	1. Moyna (Pal Trockner)	1.11	32.54	-
	2. Joypur (WSI)	0.184	0.56	0.21
	3. Sibalaya (APIRON)	136	28.02	0.22

Thus it can be stated that-

1. All the arsenic removal equipments installed in Joypur Moyna and Sibalaya village, are capable of removing arsenic as presented in Table 3B.

Table 3B. Arsenic removal Capacity

Arsenic and Iron Concentration	Pal trockner	Apiron	WSI
Arsenic	1.12 mg/l	2.34 mg/l	0.238 mg/l
Iron	12.0 mg/l	11.17 mg/l	8.0 mg/l

The values presented above, have been arrived from the maximum arsenic concentration, each technology has been able to remove at the available input water concentration. Sometimes treated water contains arsenic as in Joypur (0.16 mg/l), this may be attributed to poor maintenances and any inherent weakness in the technology itself.

2. The concentration of both arsenic and iron is high in the backwash samples that were analyzed. It is recommended from 'research and Development study for their safe disposal otherwise back washing may form a secondary source of contamination.

3. Parameters of general chemistry of both raw and treated water (table 31) fall within the normal prescribed limit

Heavy metal analysis :

To study the correlation of arsenic concentrations with the heavy metals in the study area, samples have been collected and analysed. The data on heavy metal analysed is presented in Table 4.

Table 4 Concentration of heavy metals in the ground water of arsenic rich aquifer.

Location	AL	Cd	Cr	Cu micrograms	MN/Litre	Pb	Zn	Arsenic mg/l
Joypur	19	1	3	2	817	Nd	416	0.125
Sibalaya	34	1	5	Nd	1339	Nd	3	0.360
Moyna	52	Nd	11	Nd	65	8	9	1.12

Nd= Not detected

Concentration of heavy metal in the ground water of shallow aquifer is within the range and desirable limit of drinking water standards.

Arsenic in Food grains and cooked food:

To understand the mobilization of arsenic in food items irrigated by arsenic rich water (As concentration 0.06 and 0.40 mg/l, 13 numbers of food items of Joypur Village, Barasat I block have been collected and analyzed. Food items include spinach, Bean, Tomato, Cabbage, Potato, Chilli Brinjal, Pumpkin, Papaya, Banana, wheat and mustard).

The determination of Arsenic in food chain was done by hydride generation method using sodium boro hydride and GBC atomic absorption spectrophotometer. And results are presented in Table 5

Table 5 Results of arsenic content of some raw food item (Irrigated by Ground water having in Arsenic concentration 0.06 to 0.40 mg/L)

Sl. No.	Location	Food Chain Samples	Results mg/kg
1.	Joypur, N 24 Parganas	Spinach	0.9
2.	"	Bean (F)	0.5
3.	"	Tomato	2.0
4.	"	Cabbage	1.65
5.	"	Potato	1.8
6.	"	Chilli	1.3
7.	"	Brinjal	0.5
8.	"	Pumpkin	1.3
9.	"	Papaya	1.45
10.	"	Banana	1.50
11.	"	Corianeon (Seed)	Nd
12.	"	Wheat	0.4
13.	"	Mustard	0.65

On perusal of the results obtained it is observed that almost all the food items do contain arsenic in appreciable amount. The average arsenic level in the food items are likely to be variable depending upon the level of element in the soil. Krishnamurti (1987) has reported a range of 0.02-0.3 mg/kg of arsenic in vegetables. The values obtained varies from 0.4 to 2.0 mg/kg which is much higher than normal value.

Arsenic enters in the human body through the biogeochemical and biochemical pathways. If the soil contains significant levels of arsenic content then the food items may be directly affected by that (Buat Menard, 1987). Animals feeding on the arsenic contaminated vegetables and other food items might accumulate this element in them, which could then be transferred to human being. This is the area which requires more attention.

Arsenic is similar to phosphorus in chemical behaviour therefore; it is likely to compete with phosphorus in normal metabolic process. The toxicity of arsenic is due to the inhibition of critical sulfhydryl (SH) group of proteins, complextion with coenzymes and uncoupling of phosphorylation (Peer, 1973). Organo-arsenic compounds like Arsenobetain or Arsenocholine have been found in some cases and it has been

demonstrated that arsenic replaces the phosphorus in the phosphate group of DNA (Lepp, 1981). These might have links with the problems of arsenic toxicity which definitely needs extensive research.

MITIGATION OF ARSENIC PROBLEM IN THE STUDY AREA

Considering the seriousness of the problem several mitigation practices have been introduced by different organization/institutions/private companies. There are two types of mitigation practices in the study area as (i) Short-term measures includes identification of arsenic free tube wells in arsenic affected areas and installation of arsenic removal equipments to remove arsenic from arsenic rich ground water and (ii) The long term measures includes (a) identification of deep arsenic free aquifer and construction of suitable designed tube well and (b) supply of purified surface water.

From the Ground Water Exploration, it is clearly observed that arsenic free deeper aquifers are present in the arsenic infested study area. Isotope studies carried by Bhaba Atomic Research Centre, Mumbai in a collaborative project with Central Ground Water Board in Ground water of North 24 Parganas district reveals that the age of the ground water of shallow aquifer (within 80m) is of modern age i.e. within 50 years. On the other hand the age of the ground water of deeper aquifer (l00-350m) is about 500 years. Thus the upper shallow aquifer is completely different from the deeper aquifer. The deeper arsenic free aquifers is separated from upper arseniferrous aquifer by a thick clay bed. Proper designing of tubewells by putting cement sealing against appropriate thickness of clay bed.

Proper designing of tubewells (Fig 3) by putting cement sealing against appropriate thickness of clay bed can prevent vertical percolation of arsenic rich water from shallow aquifer into deeper aquifer. The leakage of arsenic water from the shallow aquifer should be prevented adopting proper cement sealing techniques. The cement sealing is an effective sealing for separation of upper aquifer from the deeper aquifer. The aim of this technique is to place thoroughly mixed cement slurry against the impervious layer between the casing and the wall of the borehole either by gravity or under pressure through pump. Practically it is the filling up of openings principally to retain the impervious character so that there is no percolation from the upper aquifer to the lower aquifer. The cement slurry consists of ordinary /quick settling cement and water. A little clay is added in cement water mix to improve the flowing properties. 40 kg of cement should be mixed with 20-25 liters of water with a specific gravity of 1.8. About 2 to 6 per cent of bentonite is added to this slurry to improve its workability. About 30 cm of fine sand layer should be placed at the top of the gravel packing before the cement grouting operation. Settling time of 72 hrs for ordinary cement and 30 hrs for quick settling cement may be allowed and no work is to be done till the cement is fully set.

In North 24 Parganas district, ground water from exploratory tube wells constructed by Central Ground Water Board few years back has been monitored for change in concentration of arsenic in deeper aquifer. It is worth mentioning that all these wells are not contaminated by arsenic as on date. This also indicates that proper cement techniques can be prevent the percolation of arsenic from upper arseniferous aquifer and the deeper aquifer is still arsenic free after several years.

It is noticed from few places of the study area that deeper aquifer has been contaminated with arsenic after few years of construction. This may be due to the faulty construction of the tube well with out using proper cement sealing techniques. Apart from this, some of the deep tube wells were constructed in this area tapping both the shallow aquifer and deep aquifer cumulatively and this situation leads to the leaking of arsenic from upper shallow aquifer to the deeper aquifer. Therefore, no tube well should be constructed in future tapping both shallow and deep aquifers without cement sealing.

Fig3

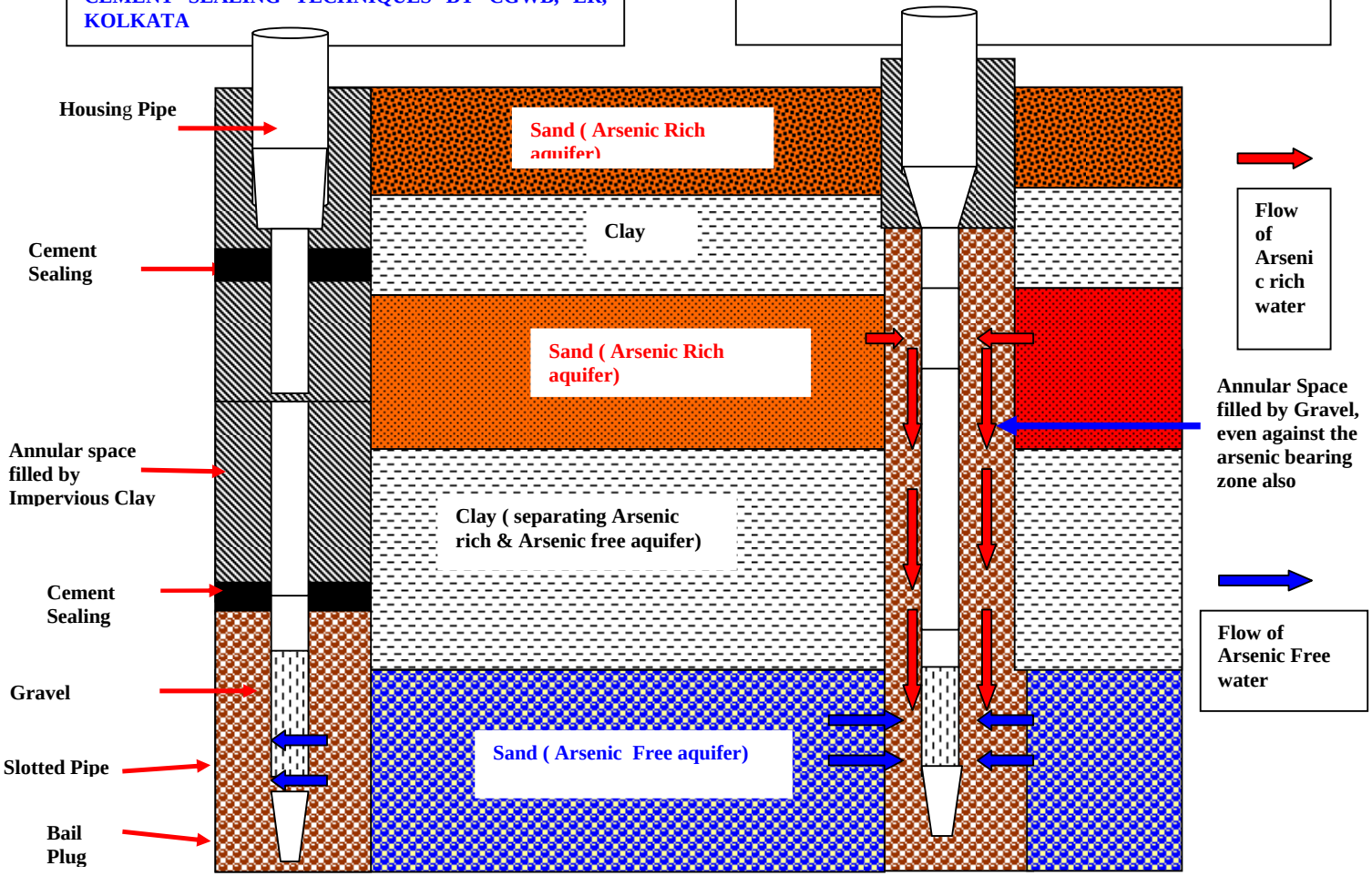
TUBE WELL DESIGN IN ARSENIC INFESTED AREA

PROPER CONSTRUCTION OF TUBE WELL TO GET ARSENIC FREE WATER

TUBE WELL YIELDING ARSENIC FREE WATER IN ARSENIC INFESTED AREA- WELL DESIGN USING CEMENT SEALING TECHNIQUES BY CGWB, ER, KOLKATA

FAULTYCONSTRUCTION OF TUBE WELL

DEEP TUBE WELL YIELDING ARSENIC RICH WATER IN ARSENIC INFESTED AREA AS IT WAS CONSTRUCTED IN ARSENIC FREE AQUIFER WITHOUT USING CEMENT SEALING



Considering the average yield of the arsenic free water from each constructed tube well, the number of tube wells required for the supply of arsenic tree water to the entire population for drinking purpose only has been assessed for some of the blocks of the study area which has been presented in Table 6 (Considering 10 liters per capita per day consumption for drinking purposes). It has been observed that in total 48 tube wells in North 24 Parganas district can meet the supply of safe arsenic free water in all affected inhabits of seven arsenic infested blocks.

Table 6 Number of tube wells required for the supply of arsenic free water to the entire population of some blocks of North 24 Parganas district

Block	Average expected yield in litre per Second	Supply of arsenic free water by running 8 hrs of pumping in litre per day	Population in arsenic risk zone	Total water required in drinking purposes in litre per day	No. of Tube well required to construct to crater the demand of arsenic free drinking water
Barasat I	13	3,74,400	2,38,000	23,80,000	6
Habra I	17	4,89,600	1,88,000	18,80,000	4
Habra II	15	4,32,000	1,50,000	15,00,000	4
Bongaon	8	2,30,400	3,44,000	34,40,000	15
Barrackpore I	15	4,32,000	1,57,000	15,70,000	4
Barrackpore II	10	2,88,000	1,59,000	15,90,000	6
Gaighata	12	3,45,600	3,00,000	30,00,000	9
Total		25,92,000	15,36,000	1,53,60,000	48

Similarly arsenic problem in rest of the district can be meet up with construction optimum number of deep tube tube wells using proper cement technique. The deep exploratory wells constructed by Central Ground Water Board has ultimately handed over to Public Health Engineering Department/municipalities for safe drinking water supply. Apart from deep tubewells Public Health Engineering Department, Govt. of West Bengal also implemented some surface water schemes for arsenic free drinking water supply.

CONCLUSIONS

- The causes of arsenic in ground water of the study area of North 24 Parganas district is geogenic and the it is observed that with the presence of an effective clay barrier, the deeper arsenic free aquifer can meet up the demand of arsenic free water for the present drinking water requirement. The tube well construction should be properly designed by cement sealing techniques against the impervious clay separating the upper arsenic rich and deeper arsenic free aquifers. In this regard, age of ground water has been detected which indicates that arsenic rich younger water from shallow aquifer has no hydraulic connection with the arsenic free old water from the deeper aquifer.
- Proper cement sealing will prevent vertical percolation of arsenic rich water from the upper arsenic contaminated aquifer into the deeper arsenic free aquifer. The water quality should be monitored periodically to assure arsenic free water supply. Sometimes it is also reported that some of the deep tube wells are contaminated with arsenic, due to not properly designed with cement sealing Techniques or both the upper contaminated & deeper arsenic free aquifers to get higher discharge.
- Arsenic treatment units (mainly as short term mitigation measures) which are community based and can cater to the needs of 200 persons, have been installed

in different arsenic infested areas to provide arsenic free water to the people. Most of the Arsenic Treatment Units work effectively, provided they are monitored and maintained effectively.

- Recharging of arsenic free water in arseniferous aquifer can reduce the arsenic concentration in ground water. Large scale artificial recharge projects can be undertaken specially in areas of high arsenic ground water to bring down the level of concentration of arsenic and its impact assessment in time.
- Arsenic content in some of the food items have been determined. However, whether the arsenic is in organic or inorganic form and whether there is any adverse impact of these arsenic containing food items on human health or not, is yet to be established

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ARSENIC CONTAMINATION IN GROUND WATER IN MAJULI ISLAND, JORHAT DISTRICT, ASSAM

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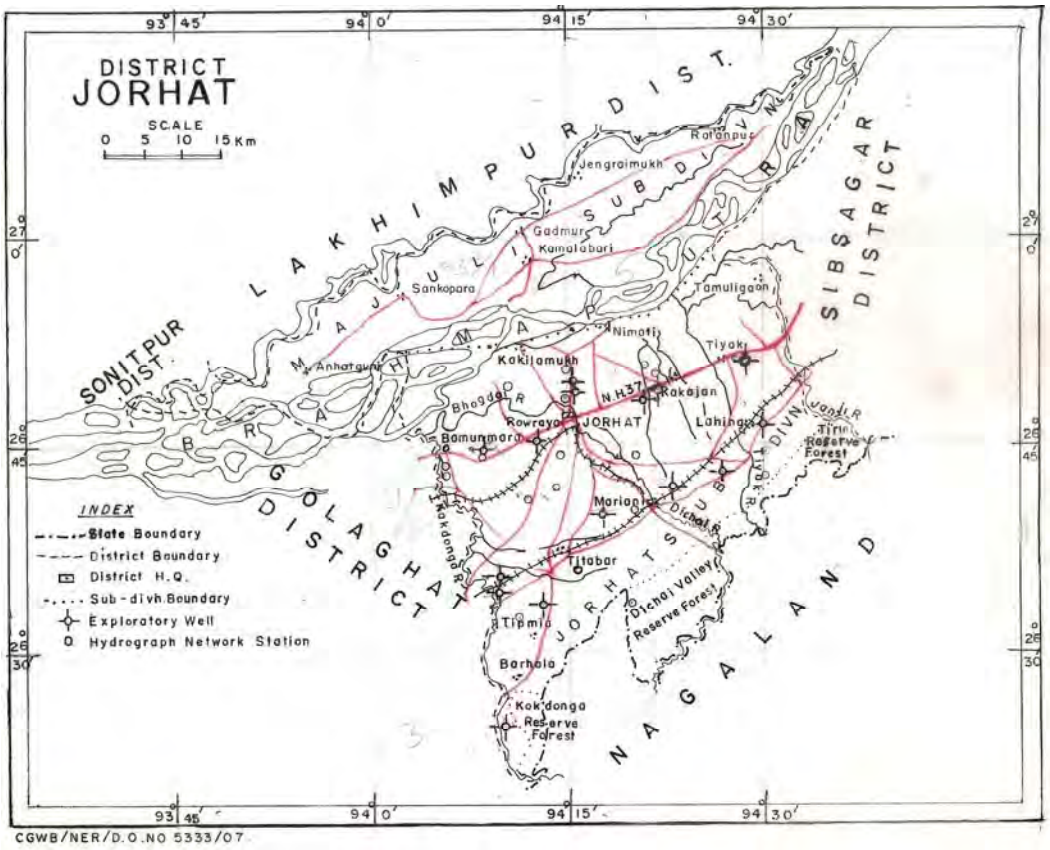
INTRODUCTION

Located on the middle of the mighty Brahmaputra River, Majuli Island is regarded as the largest fresh water river island in the world. The island is formed with the confluence of Brahmaputra and Lohit rivers. The island also termed as the cultural capital of Assam.

Fig. 1 Majuli Island in Jorhat district



The area is bounded by the N Latitudes 26° 39' 57.6'' and 27° 16' 19.2'' and E Longitudes 93° 34' 12'' and 94° 42' 3.6'' and is covered by the Survey of India toposheet no. 83 F/13, I/4, I/8, I/12, J/1, J/5, J/6 and J/9 (Fig. 1). The river Brahmaputra and its tributary, the Subansiri River forms the boundary of the island on three sides and the Kherkutia Suti, a distributary of Brahmaputra River, forms the fourth side.

AREA AND ACCESSIBILITY

The island was severely affected by erosion since the occurrence of 1950 earthquake. It is reported that the original size of 1,245 sq km is reduced to 577.65 sq km (as evidenced by the study from the IRS satellite imagery of 1998) due to erosion. At present, the area of the

island is reported to be about 422 sq. km. The frequent floods and the consequent erosion have shattered the Majuli Island (Fig. 2).

It is approachable both from the northern side as well as southern side. The easiest way to approach the island is from Jorhat, which is very well connected by road (NH - 37), rail and air to Guwahati and other parts of the country.

The climate is characterized by highly humid atmosphere, abundant rainfall and general coolness. Average annual rainfall recorded at the Majuli Island is about 1,922 mm. The altitude ranges from 40 to 120 m a MSL.

Fig.2 Erosion of Majuli Island by mighty Brahamputra River

GEOLOGICAL SETTING

Geologically, the Majuli Island is occupied by unconsolidated alluvial sediments of Quaternary age. The island forms a part of the vast alluvial plain of Brahmaputra River valley. It was developed by foreland depression lying in between the Himalayan orogenic belt in the north and southern crystalline massifs. The sediments owe its origin and development with the different phases of upliftment, glaciations and erosion of the Himalayas and basement tectonics of crystalline massifs. The newer alluvium is generally confined to topographical lows following the stream courses. These deposits are distinguishable by their characteristic grey colour and generally well sorted alternate layers of clays, silts, sands and gravels.

SUB- SURFACE GEOLOGY

The drilling carried out by ONGC and Oil India Limited for oil and gas in nearby area of the island in the Brahmaputra valley revealed the thickness of sediments ranges from 4 km to as much as 6.5 km. The bore hole logs of ONGC at Rudrasagar and Lakwa which are about 50 km south-east of the island indicate the thickness of Quaternary alluvium as 714 m and 1,250 m respectively and the basement at Rudrasagar is 4,098 m bgl .The nature and thickness of sediments encountered in these two locations are given in Table-1.

Table1 Depositional Thickness of Sediments

Age	Formation	Depth Range (m bgl)	
Pleistocene to Recent	Newer and Older alluvium	Rudrasagar	Lakwa
		G.L. – 714	G.L. – 125
Mio-Pliocene	Namsang formation	714-1,250	-
Miocene	Tipam Group	1,250-2,800	-
Oligocene	Barail group	2,800-4,098	-

In the Island, the CGWB has not carried out any ground water exploration due to the problems of approachability. Truck mounted rig cannot be transported through water route to Majuli Island. As such, the disposition of granular zones to the depth of about 300 m bgl has been confirmed based on exploratory well data of CGWB constructed in Jorhat sub-division under similar hydrogeological condition. The granular zones delineated from the exploratory data of the drilling are as follows.

a) Shallow Aquifer Zones (0-50 m b.g.l.)
   20-40 m b.g.l., 20 m. (Average thickness)
b) Deeper Aquifer zones (50-200 m b.g.l.)

60-90	=	30	
106-123	=	17	cumulative thickness of 91 m
135-156	=	21	
162-185	=	23	

HYDROGEOLOGY

Based on the data available in adjacent area, behavior and occurrence of ground water beyond the Island i.e. south of Brahmaputra River bordering the Island, the regional ground water condition of the area have been grouped under two categories.

a) Shallow aquifer occurring within the depth of 50 m.
b) Deeper aquifer beyond a depth of 50 m and down to 200 m below ground level.

a) Shallow Aquifer

The shallow aquifer occurring within a depth of 50 m from the land surface consists of a mixture of sand, clay and silt. The thickness of aquifer is about 20 m and ground water occurs under unconfined condition. Open wells and shallow tube wells are feasible to develop ground water for domestic as well as irrigation purposes.

The water table is shallow and rests within 2-4 m b.g.l. during pre-monsoon period and the general fluctuation of water table during pre and post monsoon period is about 2 m. The flow of ground water almost follows the general topography of the area and towards River Brahmaputra. The hydraulic conductivity of 15 to 20 m/day may be expected.

b) Deeper Aquifer

The aquifer occurring in the depth range of 50 to 200 m below ground level is grouped in this category. The aquifers consist of fine to medium grained sand with clay intercalation. The exploration data revealed presence of four to five major aquifer zones. Ground water occurs under confined to semi-confined conditions. The piezometric level rests around 5 m below ground level as revealed from the exploratory well at Brahmingaon and Kakajan. The hydraulic conductivity value of aquifers as 50 m/day may safely be taken for design criteria of deep tube wells.

CHEMICAL QUALITY OF GROUND WATER

Arsenic Study in Majuli River Island, Jorhat district, Assam

Higher concentration of arsenic (As) in groundwater in the northeastern states of India has become a major cause of concern in recent years. Arsenic (As) in ground water has been reported from a few parts of Assam and adjoining areas. These areas mostly fall in the vast riverside tracts of the Brahmaputra River. However, reports have also come from Barak River valley areas. North-Eastern Regional Institute of Water and Land Management (NERIWALM), based on their own study, claimed that most of the districts of Assam are affected. Public Health Engineering Department has conducted its own study partly in collaboration with UNICEF, however, detailed findings are yet to be published. Thus, Assam has been identified as one of the states with As contamination. However, physical manifestation of '*arsenicosis'* has not been observed till date among the people living in the area.

As per advice of Ministry of Water Resources, a programme was chalked out for sampling in Majuli Island for determination of arsenic content in ground water. As deep tube wells do not exist in Majuli Island at present, it posed a constraint for determination of arsenic content in ground water in deeper aquifer. Water samples were collected from shallow tube wells/hand pumps within 50 m depth. These samples were analyzed in the Regional Chemical Laboratory, CGWB, ER, Kolkata.

Source, Cause and Toxicity of Arsenic

Arsenic may occur in ground water as a result of mineral dissolution and industrial discharges containing Arsenic or by the application of Arsenic based pesticides used for agricultural purposes. In Assam, the arsenic contamination problem is mainly due to geological reason. Ground water may contain varying amount of Arsenic compounds of As (III) or As (V). In oxidizing environmental conditions, pentavalent species are more stable and predominant. Whereas in reducing environmental conditions, trivalent species are predominant. The trivalent compounds are generally more toxic than pentavalent compounds. The most common compound of Arsenic is the sulphides in the reduced form and Arsenate is in the oxidized form.

The occurrence of Arsenic in ground water is mostly due to leaching of geological minerals, dissolution of unstable Arsenic minerals, chemical transformation within the formation etc.

Alluvial environments are mostly characterized by reducing conditions (anaerobic), which cause high Arsenic concentrations in ground water. In these environments, aquifer sediments do not allow air to enter the aquifer and coupled with the fact that recent sediments contain organic matter which uses available oxygen, result in the development of reducing conditions. Reducing conditions result in increased concentrations of Arsenic in solution, which are dominated by trivalent Arsenic species. Arsenic contamination may also be caused by oxidation of pyrite, arsenopyrite that is present in aquifer sediments, by atmospheric oxygen, which enters ground water. Iron also plays an important role in the release of arsenic in groundwater. Another factor that can affect arsenic concentrations is the presence of anions such as bicarbonate, phosphate and sulphate.

However, no specific source of Arsenic has been identified yet. Arsenic fluxes in ground water depend on redox processes (anaerobic and aerobic). The transport behaviour of Arsenite (As III) and Arsenate (As V) varies significantly on redox condition. In an anaerobic aquatic environment, relatively high Arsenic concentration may occur depending on the local geochemical controls.

Trivalent arsenic can be toxic, consequently causing cell damage. Arsenic can interfere with essential enzymatic functions and transcriptional events in cell. Arsenite is known to inhibit more than 200 enzymes in the body. Because Arsenate has a similar structure as phosphate, it can substitute for phosphorus in the body, which can lead to replacement of phosphorus in the bone for many years. Arsenate prevents subsequent transfer of phosphate to adenosine diphosphate (ADP) to form adenosine triphosphate (ATP, the energy currency of the cell) and thus depletes the cell of its energy. It is also known that Arsenic decreases DNA repair process and hence enhances susceptibility to cancer and noncancerous diseases. Prolonged consumption of arseniferous ground water may result in large-scale health hazard in the concerned region due to symptoms of arsenicosis, skin lesions, hyperkeratosis, melanosis as well as other types of carcinogenic manifestations.

RESULTS AND DISCUSSION

Twenty-four ground water samples were collected from shallow ground water abstraction structures mainly tube wells and were analyzed for arsenic concentration. Results of the chemical analysis of the samples are given in Table-2. The location of the sampling stations and arsenic content has been shown in Plate-I. The range of arsenic in the area is from 6-90 ppb. Concentration of arsenic has been found beyond permissible limit (Permissible limit-10 ppb, BIS, 2007) at all locations except the locations of Kamalabari Ghat and Gutiamari.

However physical manifestation of arsenic effect has not been reported in the area. Some salient points regarding chemical analysis of water samples are given below.

- The pH of the analyzed samples varies from 6.86 to 8.08. In general, pH of water samples was neutral to slightly alkaline in nature.
- EC values vary from 179 to 1000 μScm^{-1} at 25 ^0C.

- Bicarbonate contributes an average of 89% to the total anions followed by chloride (7%) with minor contribution from nitrate, sulphate and fluoride.
- The phosphate concentration varied between 0.1 to 1.09 mg/l. The average phosphate value was 0.34 mg/l.
- The range of Iron in the area is from 0.012-6.16 mg/l. The analytical data shows that Fe exceeds the safe limit in about 50% of the sample.

Geochemical characteristics of ground water collected from Majuli Island are shown in Table 3.

Map (Not in Scale)

Fig-3

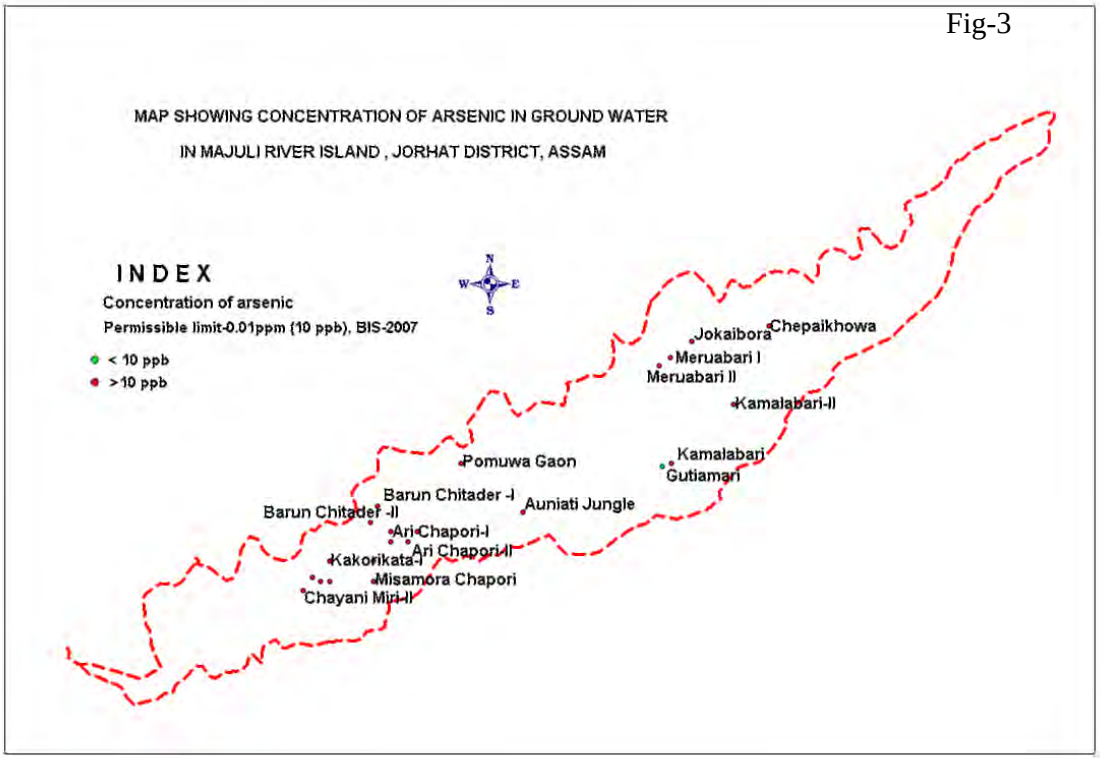


Table-2, Concentration of Arsenic in Ground Water in Majuli River Island, Jorhat District, Assam

Sl. No.	Location	Name of village	Latitude	Longitude	GW Abstraction Structure	Depth (Feet)	Location	Concentration of As (ppb)
1	Pokajora Gp	Jokaibora	27°02′00″	94°17′00″	Single Hand Pump(SHP)	80	In the compound of Rajen Deo residence	**52**
2	Pokajora Gp	Meruabari I	27°01′00″	94°15′30″	Mark III	120	3 km from point 1 towards Kamlabari	**50**
3	Pokajora Gp	Meruabari II	27°00′30″	94°14′45″	Tera Pump(TP)	120	In the compound of Meruabari LP School	**80**
4	Chilakola Gp	Barun Chitader -I	26°52′00″	93°55′30″	Tera Pump(TP)	80 to 90	At Chitader Bokora LP School	**90**
5	Chilakola Gp	Barun Chitader -II	26°51′00″	93°55′00″	Single Hand Pump(SHP)	67 to 88	At Sri Nityanand Bhuyan's place	**50**
6	Chilakola Gp	Barun Chitader -III	26°48′55″	93°55′30″	Hand Pump(HP)	26	At Sri Someswar Tamuli's compound	**56**
7	Chilakola Gp	Kakorikata-I	26°49′00″	93°55′30″	Hand Pump(HP)	40	At Sri Sarkar's compound	**46**
8	Chilakola Gp	Kakorikata-II	26°48′30″	93°52′30″	Hand Pump(HP)	150	At Kakorikata Hari Mandir	**42**

9	Karatipar GP	Auniati Jungle	26°52′20″	94°06′15″	Single Hand Pump(SHP)	60	Near Auniati Satra gate	**12**
10	Karatipar GP	Auniati Jungle	26°52′15″	94°06′00″	-	-	Near point no. 9 (Auniati Satra gate)	**-**
11	Kamalabari -I	Kamalabari	26°55′30″	94°16′00″	Tera Pump(TP)	120	In the compound of AEE,PHED	**16**
12	Ahatguri GP	Kamalabari	26°47′40″	93°51′00″	Tera Pump(TP)	90	At Member Doley Compound	**88**
13	Ahatguri GP	Chayani Miri-II	26°4′.00″	93°51′30″	Hand Pump(HP)	46	At Kamader Patir compound	**40**
14	Karatipar GP	Misamora Chapori	26°48′30″	93°56′00″	Tera Pump(TP)	120	Kuli Chapori LP School	**54**
15	Karatipar GP	Misamora Chapori	26°49′00″	93°56′50″	Tera Pump(TP)	120	Amguri MV School	**30**
16	Karatipar GP	Misamora Chapori	26°50′55″	93°57′00″	Single Hand Pump(SHP)	120	At Amguri Namghar Compound	**68**
17	Karatipar GP	Ari Chapori-I	26°51′20″	93°57′55″	Hand Pump(HP)	100	At Samouguri Locality	**34**
18	Chepaikhowa	Chepaikhowa	27°02′55″	94°22′15″	Single Hand Pump(SHP)	72	At Chepaikhowa locality	**72**
19	Karatipar GP	Ari Chapori-II	26°50′40″	93°58′20″	Single Hand Pump(SHP)	47	At Khatoriaper Namghar palace(Near SSA School)	**22**
20	Karatipar GP	Misamora Chapori	26°51′10″	93°59′40″	Hand Pump(HP)	63	At Misamora LP School	**62**
21	Pomuwa Gaon	Pomuwa Gaon	26°55′30″	94°02′10″	Hand Pump(HP)	76	In the compound of Pamuwa gaon LPS	**30**
22	Rawanper GP	Potia gaon	27°04′55″	94°28′30″	Single Hand Pump(SHP)	72	At Hokonarmukh locality	**44**
23	Kamalabari -II	Kamalabari	26°59′50″	94°20′30″	Hand Pump(HP)	64	In the compound of Majuli College	**10**
24	Kamalabari -II	Kamalabari	26°01′50″	94°23′00″	-	26	In the compound of Sericulture Department.	**16**
25	Kamalabari -Ghat	Gutiamari	26°54′25″	94°14′56″	Hand Pump(HP)	36	2 Km from Ghat towards Kamlabari	**6**

Table 3 Geochemical characteristics of ground water collected from Majuli Island

Parameter	**Min.**	**Max.**	**Avg.**	**Parameter**	**Min.**	**Max.**	**Avg.**
pH	6.86	8.08	7.34	Mg	4	75	28
EC	179	1000	437	Na	1.6	5.6	5
TDS	116	650	278	K	3	7	5
F	0.12	0.76	0.33	TH	95	605	242
Cl	4	18	10	MH	19.29	52.73	39.75
HCO_3	116	677	273	RSC	0.01	0.59	0.22
NO_3	1	47	14	%Na	2.87	16.83	6.95
SO_4	1	40	7	SAR	0.04	0.43	0.12
Ca	24	120	57	PI	31.3	86.01	51.15
Fe	0.1	6.16	0.86	As	6	90	44.58

[Units concentration in mg/l, except As (ppb) pH, EC (µS/cm), SAR, RSC, PI, and MH. MH - magnesium hazard, RSC - residual sodium cacrbonate, SAR - sodium adsorption ratio, PI - permeability index]

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

From the analysis of ground water samples collected from shallow depth (50 m), it is found that out of 24 samples analyzed, all have shown Arsenic content more than 10 ppb except one sample. Highly silty nature of sediments prevails in shallow depth. Arsenic content in ground water in deeper aquifers could not be assessed because no deep tube well exists in the Island. There is not a single case of physical manifestation in the human body contrary to be observation in the neighboring states. The reason may be attributed to the practice of local people to use indigenous filters to filter ground water before drinking and domestic use. Arsenic probably precipitates out along with iron to some extent in the above process.

Recommendations

i. Deeper aquifers should be explored.
ii. Ground water of deeper aquifers should be analyzed for assessment of hazardous element like arsenic, fluoride etc.
iii. Alternate sources of drinking water should be studied and prioritized.
iv. Awareness campaigns about health hazards due to intake of excessive Arsenic are the need of the time.
v. Geophysical resistivity survey to determine the sub-surface lithology.
vi. Sampling of lithology (through manual boring) up to 50 m depth should be done for studying the correlation and depositional trend of sediments.
vii. Role of pesticides used for agricultural activity should be carefully observed.

Acknowledgement

The authors are thankful to Chairman, Member (SML), Member (SAM), Regional Director (NER), Central Ground Water Board for kindly permitting the authors to publish this paper.

ARSENIC CONTAMINATION IN GROUND WATER: AN ALARMING PROBLEM AND ITS REMEDIAL MEASURES IN BALLIA DISTRICT (U.P.)

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INTRODUCTION

The risk management of geoenvirnment and its impact on the ground water is the present day concern all over the world. Evaluation of the vulnerability of human population has a special significance in designing area specific appropriate mitigation measures. The present study deals primarily with the arsenic contamination in parts of Ballia district : an alarming problems and its remedial measures.

The Ballia district is eastern most part of Utter Pradesh State lies between 25^0 33' and 26^0 11' north latitude and 83^0 38' and84^0 39' east longitude. It is in Central Ganga Alluvial Plain situated in doab of river Ganga and Ghaghra. For the administrative function district is divided into seventeen blocks and six tehsils. (Figure 1)The total geographical area of the district is 3168 Sq Km. The average annual rainfall is 947 mm. People are depend on handpumps for drinking water.

Observations have revealed high concentration of Arsenic (> 50 ppb) in ground water of phreatic aquifer in younger alluvium of Ganga and Ghaghra rivers along meandering course. People of village Rajpur Ekauna, Chain Chhapra, Tiwai Tola, Sughar Chhapra, Chaube Chhapra are suffering from various stages of arenicosis. The exploration programme has been taken up (CGWB) in view to accelerate potable water and study of horizontal and vertical distribution of arsenic in different aquifer system in the area and to control the health hazard due to arsenic in ground water.

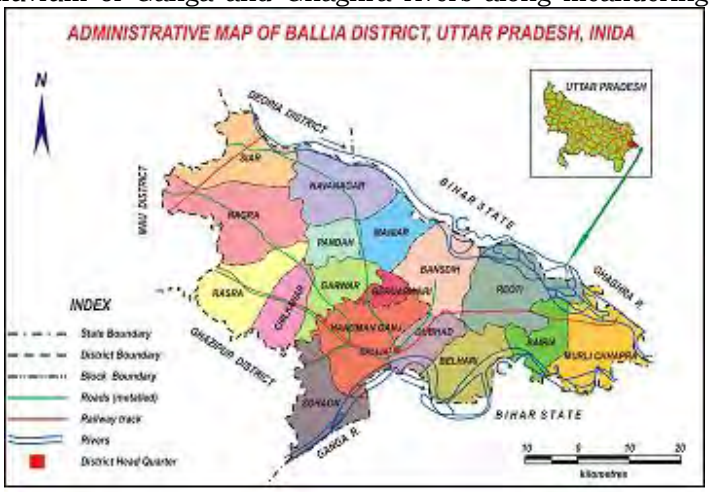


Figure 1 : Showing administrative division of Ballia district, U.P

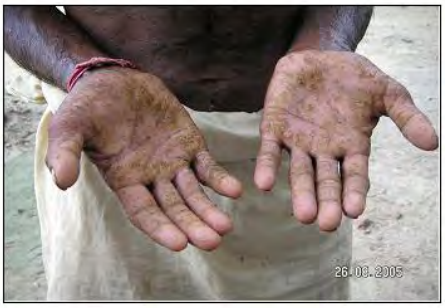


Figure 2: A man affected from Keratosis

Figure 3: A man lost his finger due to arsenicosis

HYDROGEOLOGICAL ENVIRONMENT

The area falls in Central Ganga Plain underlain by thick sequence of Quaternary sediments comprising Clay, Sand, Silt and Kankar. Geomorphologically area is divided into Younger and Older alluvium. The ground water exploration (C.G.W.B) in the district (down to 750 m bgl) reveals three tier system of aquifer. The ground water occurs under unconfined condition in phreatic aquifer and confined condition in deep aquifer. The depth to water level in pre monsoon period varies from 3.50 m to 9.8 mbgl. In post monsoon period it varies from 1.8m to 8.0 mbgl. The different grades of sands are the main granular zones in the area. The yields of the tubewells tapping shallow aquifer vary from 35-100 lps with draw down between3.0 to14.0 m. The yields of the deep tube wells range between 30 to 50 lps with draw down ranges between 2.0 to11.0 m. The water table contours shows flow of ground water towards Ghaghra in northern parts and towards Ganga in southern part of the district. Hydrological map of the area is given in *Figure 4.*

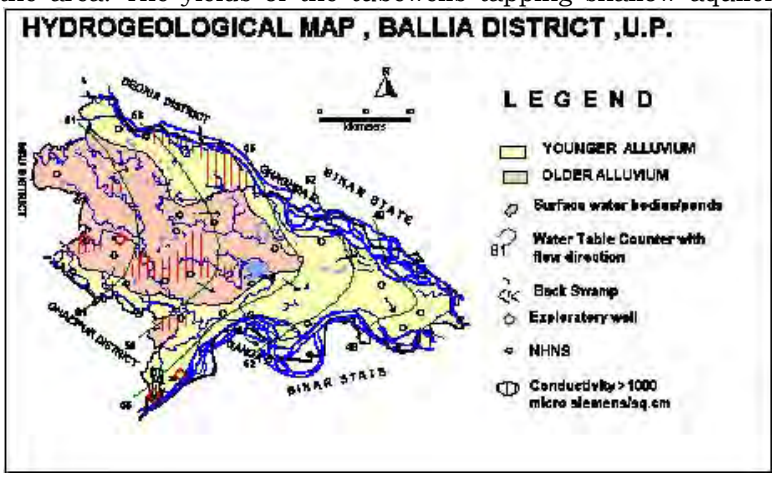
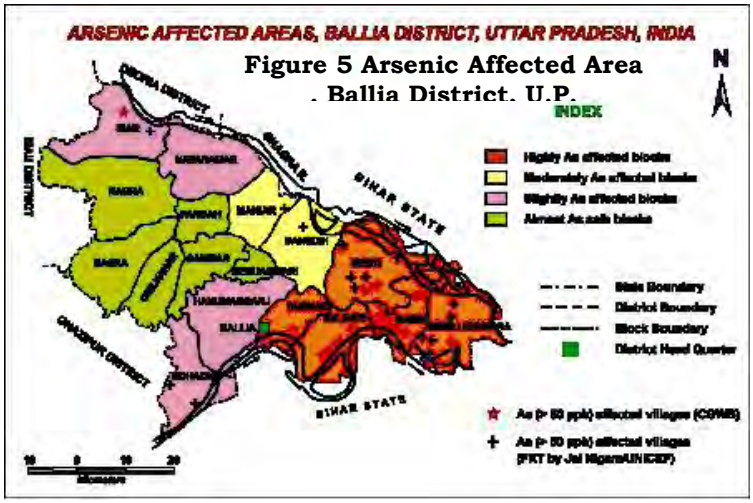


Figure 4 Hydrogeological Map of Ballia District, U.P.

OCCURANCE AND DISTRIBUTION OF ARSENIC IN GROUND WATER:

In September 2004, presence of high arsenic symptoms in human body of the people from Rajpur Ekauna, Chain Chapra , Ramgarh Dhala,Sughar Chhapra villages in Ballia district has been reported . The blood sample of Sh. Dina Nath Singh of Rajpur Ekauna village had ***34.4 ppb*** of arsenic where as the reference limit is mere 1.4 ppb. The presence of high Arsenic in blood can only be possible in case of chronic exposure.

In September 2004, water samples were collected from different abstraction structures i.e. dugwell, handpump State & CGWB tubewell and Ganga River . Out of 144 samples 65 have Arsenic concentration above 50 ppb. No Arsenic concentration has been reported from all three exploratory existing tubewell of CGWB. The maximum occurrence of arsenic is reported from handpumps (depth Range 27 –66 m bgl). All the arsenic affected handpumps are located in younger alluvium in Belhari ,Baria, Dubhad, Murli Chchapra,Reoti, Sohaon, Maniar and Siar Bloicks.The highly arsenic infested villages are Rajpur Ekauna , Chain Chchapra , TiwariTola, Choube Chchapra (Belhari Blocks)and Sughar Chapra, Ramgarh (Bairia Block) .Maximum arsenic



concentration observed at Choube Chchapra is 1310 ppb. Figure 5 and Table 1 &2 illustrates the vertical and horizontal distribution of arsenic in ground water in the study area.

Table –1 Arsenic Concentration in Different Ground Water Structures with respect to Depth

S.No.	Name of Village/Blocks	Type & No of GW Structure	Depth Range m bgl	Arsenic Concentration (ppb)
Block	**Belhari**			
1	Rajpur Ekauna	DW 1 HP Pvt 8 HP IM II 17	13 31-35 31-49	242 27-200 14-146
2	Chain Chhapra	HP Pvt 3 HP IM II 1	18-32 32	70 -258 68
3	Choube Chhapra	DW 2 HP Pvt 3 HP IM II 2 HP IM II 2	13 16-23 16-32 61-64	107-154 243-1310 238-239 56-95
4	Rikini Chhapra	DW 1 HP Pvt 2 HP IM II 2	13 16-23 32-63	62 37-178 75-136
5	Tiwari Tola	DW 1 HP Pvt 2 HP IM II 6 HP IM II 1	13 25-27 27-35 66	86 330 -665 130-685 29
6	Ramgarh Dhala	HP Pvt 1 HP IM II 4	22 34-35	345 130 -190
7	Ramgarh	DW 1 HP Pvt 3	13 23-25	12 13-260
Block	Bairia			
8	Sughar Chhapra	DW 2 HP Pvt 4 HP IM II 2	13- 14 18-38 25-32	3-4 2-195 35-74
9	Balihar	HP IM II 1	38	195

Table – 2 Concentration of Arsenic in Different Ground Water Abstraction Structure

Source	No of Sample Analyzed	No of Sample with As Concentration (ppb)				Range of As Concentration (ppb)
		ND	<10	10 -50	>50	
Dug Well	09	0	2	2	5	Nd -242
Hand Pump Pvt	48	0	10	12	26	2-685 (1310*)
Hand Pump IM II	69	8	7	22	32	Nd-345
State TW	15	1	2	10	2	Nd -45
CGWB TW	03	3	0	0	0	
Total	144	12	21	46	65	

As per analysis of ground water samples and distribution pattern that high concentration of As is observed in phreatic aquifer in younger alluvium along meandering course of Ganga and Ghaghra River.

Permissible Limit

Earlier maximum permissible limit of arsenic for drinking water was 50 ppb. Recently World Health Organisation has reduced its permissible limit to 10ppb for drinking water purpose. In India, Department of Drinking Water Supply Ministry of Rural Development has yet its 50ppb to be used for time being.

MOBILIZATION OF ARSENIC

As per occurrence and distribution of arsenic in different part of India and abroad (West Bengal and Bangladesh). There are three main theories for mobilization and occurrence of arsenic in ground water.

Reductive dissolution of iron oxihydraoxide (FeOOH) and release of sorbed arsenic to ground water (Bhattacharya et al 1997, Nickson 1998,2000,2005)

1 Arsenic was naturally transported by river system of Himalaya and adsorbed on to fine-grained iron and manganese hydroxide. These are deposited in the flood plain. And buried in the sedimentary pile of sediments.
2. Microbial oxidation of organic carbon due to occurrence of peat deposits depleted the dissolved oxygen in the ground water thus creating a strongly reducing environment.(Mc Authur etal 2001)

Oxidation of Arsenical Pyrite (Acharya et al 1997)
1 Arsenic is released by oxidation of arsenical pyrite in alluvial sediments since pumping drawdown permits atmospheric oxygen to invade the aquifer.
2 As the water level rise due to recharge during monsoon arsenic leaches out of sediments into aquifer.

Anion (Competitive) Exchange of sorbed arsenic with Phosphate from fertilizer : (Acharya et al 1997)
1 Arsenic anions sorbed to the aquifer minerals are displaced into solution by competitive exchange of phosphate anion derived from over application of fertilizer.
2. Withdrawl of ground water for irrigation may have mobilized the phosphate in fertilizer and also from decay of natural organic matter in shallow aquifers.

On the basis of analysis of the ground water samples it is suggested that arsenic is released in the reducing environment in the study area. (Chauhan et al 2009)

REMEDIAL MEASURES

1) The problem of Arsenic pollution in ground water in Ballia district has to be immediately addressed to. The first and the foremost task is to identify the villages where Arsenic concentration is above the maximum permissible limit defined by BIS (IS 10500 – 91). Arsenic field-testing kit could prove to a very useful instrument to commence the detailed investigations in these areas. The spot analysis of arsenic by field Kit and high concentration of arsenic samples are analyzed by AAS in CGWB and Jal Nigam
2) The hand pumps yielding water with higher Arsenic concentration may be demarcated like being painted red etc. These markings would indicate that these pumps are not fit to be used for catering to human or livestock needs.
3) Alternative sources of ground water may be identified and recommended for use. The exploratory wells in different aquifer at different places in arsenic affected area of the district has been constructed by CGWB to know the arsenic concentration in different aquifer. These exploratory well which are free from arsenic may be utilized by Jal Nigam as production well for drinking water. Till date 10 nos of deep tube well (down to 350 m bgl) were constructed by CGWB.(Fig. 7) Arsenic free aquifer is separated from other aquifer by cement sealing within clay layer to check mixing of ground water of different aquifers. Hydrogeological tests were conducted at different exploratory well and it was found that no effect was observed on other observation when main well was pumped. It shows that there is no link between different aquifer and cement sealing technique is properly working. Figure 6 show detail of litholog, cement sealing position

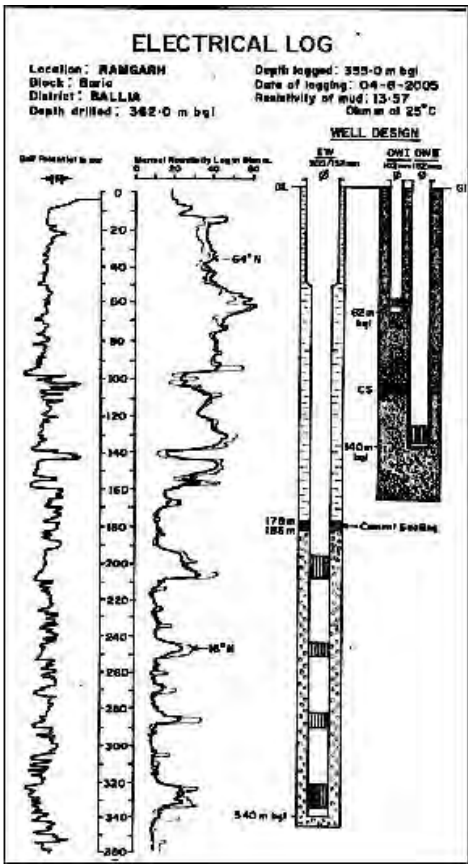


Figure 6 Well Design of Main Well and Observation At Ramgarh, Ballia District, U.P.

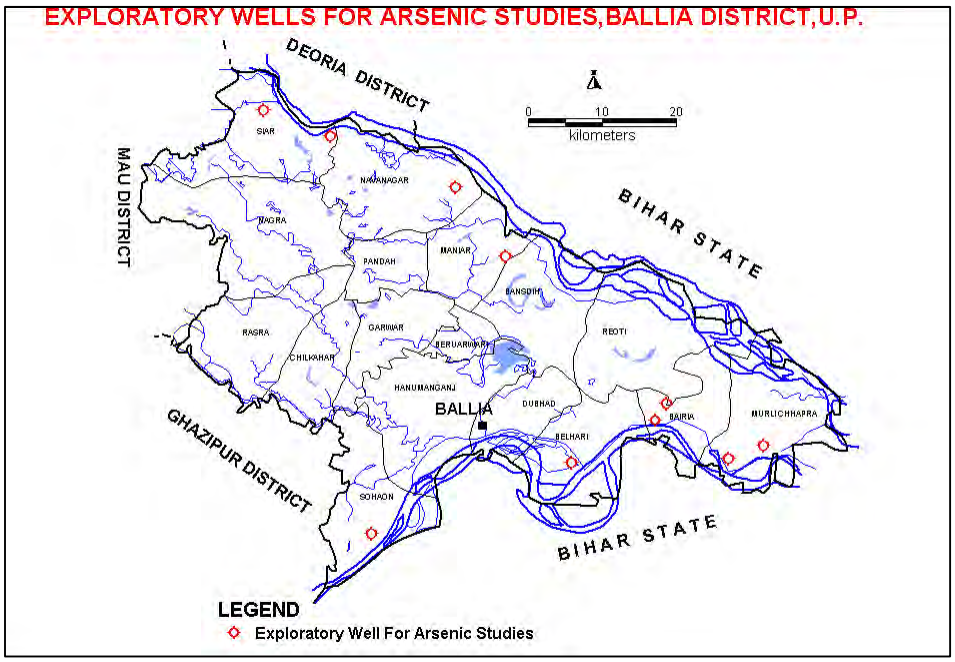


Figure 7 Location of exploratory wells constructed for arsenic studies by CGWB in Ballia district, U.P.

4) The most important aspect of any pollution study is *not to scare but make people aware*. It is imperative to make people aware of the groundwater structures having high concentration of arsenic. The objective is to educate them – to use and/or avoid groundwater structures according to arsenic content in water.

Acknowledgement

The authors express sincere gratitude to Chairman, Member, CGWB & Regional Director, CGWB, NR Lucknow for giving permission to publish this paper.

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TECHNOLOGY OPTIONS FOR UTILISATION OF ARSENIC CONTAMINATED GROUND WATER

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INTRODUCTION

A 'SAFE' water supply can be defined as one that provides water that is free from chemicals injurious to human body including Arsenic and biological contamination. The onus of supplying safe drinking water meeting primary health based standards lies with the water management authorities. The contamination of ground water by geogenic leached out Arsenic has assumed an alarming proportion in several countries including India and Bangladesh. It has been proved that continued and prolonged ingestion even at a very low level (WHO limit is 0.01 mg/L) can lead to serious arsenic related diseases. Though literature abounds in occurrence of ground water contamination by Arsenic and its removal from ground water by different technological options, millions of people continue to suffer particularly in the developing countries.

The most important remedial action is prevention of further exposure by providing safe drinking water. The cost and difficulty of reducing arsenic in drinking water increases as the targeted concentration lowers. In India earlier the desirable limit of Arsenic was 0.05 mg/L which has been reduced to 0.01 mg/L by BIS).It also varies with the arsenic concentration in the source water ,the chemical matrix of the water including interfering solutes, availability of alternative sources of low arsenic water ,mitigation technologies and amount of water to be treated .

The control of arsenic in drinking water is more complex where drinking water is obtained from many individual sources (such as hand pumps and wells) as is common in rural India. Low Arsenic water is only needed for drinking and cooking. Arsenic rich water can be used to limited extent for laundry and bathing.

TECHNOLOGY OPTIONS FOR THE SAFE WATER SUPPLY IN THE ARSENIC AFFECTED AREA

The technology options for the safe water supply in the arsenic affected area could be one of the following

(i) Using surface water sources such as ponds, dug wells, rivers etc.
(ii) Tapping alternate aquifer for arsenic free ground water.
(iii) Artificial recharge
(iv) Removal of Arsenic from ground water

i) Supply of Surface Water

Supply of surface water sources such as ponds, dug wells, rivers etc. through pipe net work system after purification by conventional method of treatment viz. coagulation, flocculation, rapid sand filtration and disinfection. Horizontal roughing filter with slow sand filter may also be adopted using pond water.

ii) Tapping Alternate Aquifer For Arsenic Free Ground Water

Installation of deep tube well is one of the best options depending upon the feasibility as Arsenic contamination has been found mainly in shallow aquifers.

This will depend upon the local geo hydrological condition as for safe arsenic free supply; the upper arseniferous aquifer has to be cement sealed if proper impervious layer is available to prevent percolation of arsenic contaminated ground water from the top aquifer, as concerns about cross-examination of the deeper aquifers by arsenic seeping from shallow aquifers remain significantly important. The isotopic studies carried out in West Bengal by CGWB with BARC has proved that there is a wide difference between the age of shallow contaminated ground water and deeper arsenic free aquifers.

The two options are being adopted wherever possible notwithstanding the huge financial requirements for the river water passed piped water scheme or deep tube wells.

(iii) Rain Water Harvesting

Rainwater harvesting may be adopted if an appropriate roof is available to facilitate collection with introduction of line filter and intermittent disinfection. . Rainwater harvesting can also be utilized in some areas where sufficient rainfall is available for most the time and the subsurface geology is suitable for the same. Rain water harvesting can potentially suffer from microbiological contamination and may require some treatment to ensure acceptable quality.

(iv) Removal of Arsenic from Ground Water

The treatment of tube water for removal of Arsenic has not been applied in a big way. Though the number of Indian institutes and organization from abroad has developed technologies for removal of arsenic, the community at large and water supply professional are not adequately informed for the same.

SUITABILITY OF ARSENIC REMOVAL PLANTS

Before attempting to use any of Arsenic removal plants ,one has to ensure the following points:

1. The plant should have high efficiency as far as removal of Arsenic is concerned
2. The technology to be used should be safe
3. It should be cost effective
4. It should produce minimum residual mass.
5. Sufficient life operation and
6. It must be users friendly.

TECHNOLOGIES AVAILABLE FOR REMOVAL OF ARSENIC

There are several technologies available by which Arsenic is removed from drinking water . The principle of such processes for on surface and in-situ removal include Co-precipitation, ion exchange, adsorption, membrane separation ,bioremediation and oxidation of Arsenic (III) and Iron (II). There are considerable applications of theses methodologies in up gradation of water quality. In this connection, it would be appropriate to explore thoroughly all the possible methods for removal of arsenic from drinking water and to arrive at An appropriate technology which could be effectively used for up gradation of water quality in Arsenic affected areas besides, appropriate technology must be economically viable and socially acceptable.

The following are the different techniques available for removal of Arsenic from drinking water.

(i) Oxidation of Arsenic (III)
(ii) Coagulation-flocculation-Sedimentation-filtration (Co-precipitation)
(iii) Ion exchange
(iv) Adsorption on different media
(v) Reverse Osmosis and electro dialysis
(vi) Bioremediation and
(vii) In- situ remediation
(viii) Passive sedimentation
(ix) Solar oxidation
(x) Iron coated sand
(xi) Low pressure Nanofiltration

(i) Oxidation of Arsenic (III)

The common valency of Arsenic in raw water sources are + 3 (Arsenite) and +5 (Arsenate) as are evident in the inorganic hydrolysis species such as $H_3\ AsO_3$, $H_2\ AsO_3$, $HAsO_3^{-2}$, and AsO_3^{-3} and $H_3\ AsO_4$, $H_2\ AsO_4$, $H_2\ AsO_4^{-2}$ and AsO_4^{-3}.

In geogenic Arsenic the above mentioned 2 valance forms mainly concern. The chemical behaviours of the two forms are different and as such during removal of arsenic concentration each redox species need to be estimated. Different studies indicate that Arsenic (III) can not be removed from water effectively.

Oxidation of As(III) by dissolved oxygen in water is a very slow process . But effective removal of arsenic from water requires complete oxidation of As(III). The redox reaction is,

$H_3\ AsO_4 + 2\ H^+\ 2e \quad = \quad H_3\ AsO_3 + H_2O \quad E_0 = 0.56\ V$

Accordingly selection of appropriate oxidizing agent is very important. The following criteria are required to be considered for selection of appropriate oxidizing agent.

(i) Residual effect
(ii) Oxidation by product
(iii) Oxidation of other in organic and organic constituents
(iv) Reaction kinetics

The following oxidizing agent could be used for conversion of arsenite to arsenate

(a) Oxygen : Aeration process may help in oxidizing arsenite but the process is very slow(Clifford et.al 1983)
(b) Powdered active carbon as dissolved oxygen catalytic oxidation: The process require very high quantum of powdered active carbon need to be removed.
(c) UV radiation: Requires high pressure mercury lamp the process is quite fast organic compounds if present in water may get oxidized. Application of the process in domestic unit as well as community models is not feasible in rural area
(d) Chemicals: Free chlorine, Hypochlorite, Bleaching powder, , Permanganate and hydrogen peroxide can be used. Bleaching powder solution or sodium hypochlorite could be used for oxidation which is readily available..Potassium permanganate is very effective for oxidation of arsenite but it may develop some faint colour.(Viraghvan and Pokhrel,2006)

(e) Ozone: Ozone dose of approximately2000 micro gram /L is suitable for 70mg/L of Arsenic prior to filtration (Kim and Nriag 1999). Application of Ozone would be costly

(f) Sunlight: In the presence of sunlight and natural occurring high absorbing minerals the rate of oxidation of Arsenic(III) by oxygen can be increased.

(ii) Coagulation-Flocculation-Sedimentation & Filtration (co precipitation)

In water treatment aluminum or ferric salts are used for coagulation of particles and colloids in the water . Arsenic removal by metal ions is the best known and most frequent.As such for the removal of arsenic from water Aluminium or ferric salts are added. Both metal salts undergo hydrolysis to various products, but can be reduced to very low residual if the poorly soluble hydroxides are formed at the proper pH and can be filtered off completely. For removal of Arsenic (V) ferric salt is slightly more effective than aluminium salt. While the arsenic removal efficiency with application of aluminium salt is 90 to 95 %, whereas with ferric salts it may be 95 to 99%.(Heringet.al. 1997)

(iii) Ion Exchange

Ion exchange resins can be used to remove As (V). During flow through resin As (III) is passed through column of anion exchange resin whereas As(V) is found effectively on resin. It works best when As (III) got oxidized to As (V) and performs simultaneous removal of arsenic,iron and bacteria from water.The orocess is normally used for removal of specific undesirable cation or anion from water. As the resin becomes exhausted ,it needs to be regenerated. The arsenic exchange and regeneration equations with common salt solution as regeneration agents are as follows

Arsenic exchange

$2R\text{-}Cl + HAsO_4^- = R_2 HAsO_4 + 2 Cl^-$

Regeneration

$R_2 HAsO_4 + 2 Cl^- + 2Na^+ = 2R\text{-}Cl + HAsO_4^- + 2 Na^+$

The frequency of regeneration or replacement of resin depends upon the quantum of iron present in water. The arsenic removal capacity is dependent on sulphate and nitrate contents of raw water as sulphate and nitrate are exchanged before arsenic.The efficiency improves by pre oxidation As (III) to As(V) and process is less dependent on pH of water.

(iv) Adsorption

Effective arsenic removal could be obtained by using activated alumina. As (V) is adsorbed effectively by activated alumina whereas arsenic (III) remains unabsorbed. However if iron is present in ground water along with arsenic which is very common, than considerable amount of arsenic (III) may be removed during filtration through activated alumina bed . The best removal is possible between pH 5.5 to 9.0. (Gifford et.al.1983)The mechanism which is one of the exchanges of contaminants anions for surface hydroxide on aluminum is generally called adsorption. The typical activated alumina used in water treatment is 0.3 to 0.6 mm size. These are mixture of amorphous and gamma aluminium oxide prepared by low temperature 9300-600 ^oC) dehydration of Al $(OH)_3$. By using the model of hydroxylated alumina surface subject to protonation and deportation. The following legend –exchange reaction can be written to arsenic adsorption in acid solution alumina exhaustion in which Al represents the alumina surface and over bar denotes solid surface

$\overline{Al.OH} + H^+ + H_2AsO_4 \quad \overline{Al.H_2AsO_4} + HOH$

The equation for arsenic desorption by hydroxide , Alumina regeneration is

$$\overline{\text{Al. } H_2AsO_4} + OH^- \quad \overline{\text{Al.OH}} + H_2AsO_4$$

Activated alumina processes are sensitive to pH and anions are best adsorbed below pH 8.5 ,a typical pH corresponding to zero point of charge(ZPC) below which the alumina surface has a net positive charge. Above pH_{zpc} alumina is predominantly a cation exchanger.

Cement based stabilization is suitable for the disposal of arsenic containing sludge. Attempt have been made to stabilize arsenic laden sludge with cement and sand. Activated carbon can adsorb arsenic if water is passed through fixed bed. The performance of activated carbon is not that satisfactory as the regeneration of the bed is very difficult.

Granulated ferric hydroxide has been used widely but iron should be preferably removed before subjecting water to ferric hydroxide treatment .Granular ferric hydroxide is prepared from ferric chloride solution by neutralization and precipitation with sodium hydroxide. It is poorly crystallized - FeOOH with a specific surface of 250-300 m^2/g and a porosity of 75-80%. The grain size ranges from 0.2 to 2.0 mm. As no drying procedure is included in its preparation, all the pores are completely filled with water, leading to a high density of available adsorption sites And thus to a high adsorption capacity. Phosphate competes strongly with arsenic. So its presence in raw water may reduce the arsenate adsorption capacity.

The residue is a solid waste with an arsenic content of 1-10 g/kg. The spent adsorption being non toxic and its volume being small its disposal is less problematic .Both domestic and community based plants are available.

A highly efficient process technology for simultaneous removal of arsenic and iron in ground water has been designed by C.G.C.R.I. based on the principle of adsorption using suspended media in colloidal form and efficient cross-flow microfiltration by ceramic membranes.
A simpler and less expensive form of arsenic removal using 3 pitchers containing cast iron filling and sand in the first pitcher and wood activated carbon and sand in the second has been developed known as Sono arsenic filter. Plastic buckets can also be used .

(v) Reverse Osmosis & Electro dialysis

Both reverse osmosis and electro dialysis process can be used but it has been found that As (V) is effectively removed (95-98%) while As (III) is only partially separated (46-75%) due to neutral form of As (III) as $H_3 AsO_3$.

(vi) Bioremediation

Artificial stimulation of metabolism of indigenous sulphate reducing bacteria (SRB) has the potential to remediate the ground water loaded with arsenic./ This sulphate reducing technology takes advantage of anaerobic heterotrophic bacteria already present, though it requires nutrients to stimulate metabolism. Soluble organic carbon is required for the purpose.

(vii) **In situ remediation**

The subsurface removal of arsenic has been practiced in some countries. It is usually linked to artificial recharge. This relies on the strong adsorption of As especially As (V) by iron (III) oxides that are formed when reduced near neutral sediments and ground water are oxidized. The oxidation zone created by aerated water boosts the activity of the arsenic oxidizing microorganism which can oxidize arsenic fromAs (III) to As(V).The oxidation can be brought about by the injection of air or an oxidizing agent such as hydrogen peroxide. In Vyredox method for removal of iron a ring of wells injects aerated water around a central supply well . The iron precipitates, thus arsenic also in outer part of the aquifer furthest from the supply well . Clogging of the aquifer is generally not a problem in the life time of the plant. In-situ oxidation of arsenic and iron in the aquifer has also been tried. The aerated tube well water is stored in a tank and released back in to the aquifers through the tube wellby opening a valve in a pipe connecting the water tank to the tube well pipe under the pump head. The dissolved oxygen in water oxidized arsenite to less mobile arsenate and also the ferrous iron in the aquifer to ferric iron ,resulting in reduction of arsenic and iron both.

(viii) Passive sedimentation

It is one of the easiest method for removal of Arsenic in ground water. Oxidation of water during collection and subsequent storage in houses may cause a reduction in arsenic concentration in stored water. The concentration can be reduced to even zero by passive sedimentation.The use of naturally occurring iron precipitates in ground water which helps in removing arsenic by adsorption. Although no good correlation between concentration of dissolved iron and arsenic has been derived. Iron and arsenic have been found to co exist in ground water. Arsenic reduction by sedimentation appears to be dependent on water quality particularly the presence of ferrous iron. Ahmed et.al. 2000.

(ix) SOLAR Oxidation

SORAS is a simple method of solar oxidation of Arsenic in transparent bottles to reduce arsenic content of the drinking water Weglin et.al. 2000. Ultra violet radiation can catalyze the process of oxidation of arsenite in presence of other oxidants like oxygen.

Water treatment with coagulants such as aluminium alum $Al_2(SO_4)_3.18\ H_2O$, ferric chloride,$FeCl_3$ and ferric sulphate $Fe_2(SO_4)_3.7$ are effective in removing arsenic from water. H_2O

(x) Iron Coated Sand

Iron coated sand based treatment units for removal of arsenic has been attempted. It is prepared as suggested by Joshi and Choudhuri1996. The iron content of iron coated sand was found to be 25 mg/g of sand. Raw water having 300 micro gram /L of arsenic when filtered through iron coated sand becomes essentially arsenic free. As such iron coated sand is equally effective in removing both As (III) and As(V).(Jiang,2001)

The removal of As (III) by haemetite (particle size around 200mm) has also been tried but the maximum capacity has been found about 2.6 mmol/kg Feldspar has also used for removal of arsenic. These studies indicate the possible application of natural oxides for removal of arsenic but their small specific surface are limits their capacity of adsorption.

(xi) Low pressure Nanofiltration

Nano filtration membrane process for the treatment of arsenic contaminated water applying low pressure has been found suitable. This works better with As (V) hence pre oxidation of As (III) is recommended(Oh et.al.2000).BARC has also developed ultrafiltration (UF) based membrane technology for water decontamination .

Issues related to management of the arsenic contaminated waste generated by these technologies has not fully resolved yet. It may be understood that no process can make arsenic zero in the environment and requires extensive research to tackle the sludge produced.

CONCLUSION

The supply of safe and arsenic free water to the population in the affected area is a serious challenge to the planners and the water management people specially for those who are responsible for community water supply.

It is important to point out each of the safe water options have some challenges in its implementation on a large scale. The capital costs and the cost associated with effective operation and maintenance of each option has to be carefully weighed. Water supply experts recently recommended that piped water supply should be deemed as the eventual target, but any of the other options can be utilized locally in accordance with the persisting local conditions.

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BLOCKS/LOCATIONS OF ARSENIC IN GROUND WATER
(> 0.05 mg/litre)