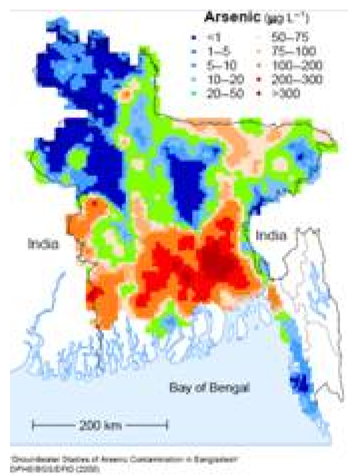
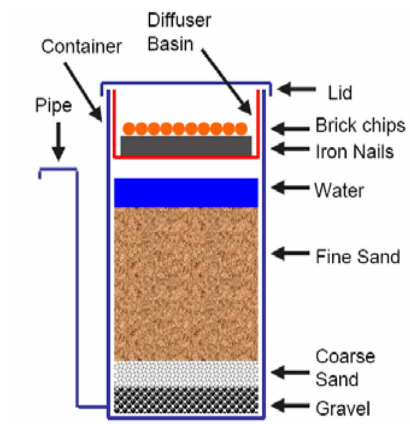
Bangladesh Technology Verification Application

Kanchan Arsenic Filter

Tom Mahin - MIT/CAWST

Tommy Ngai - CAWST





Presented at the Centre for Affordable Water and Sanitation Technology (CAWST) Learning Exchange – Calgary, Canada June 2008

World Health Organization

EXECUTIVE BOARD
118th Session
Provisional agenda item 5.4

EB118/14
24 May 2006

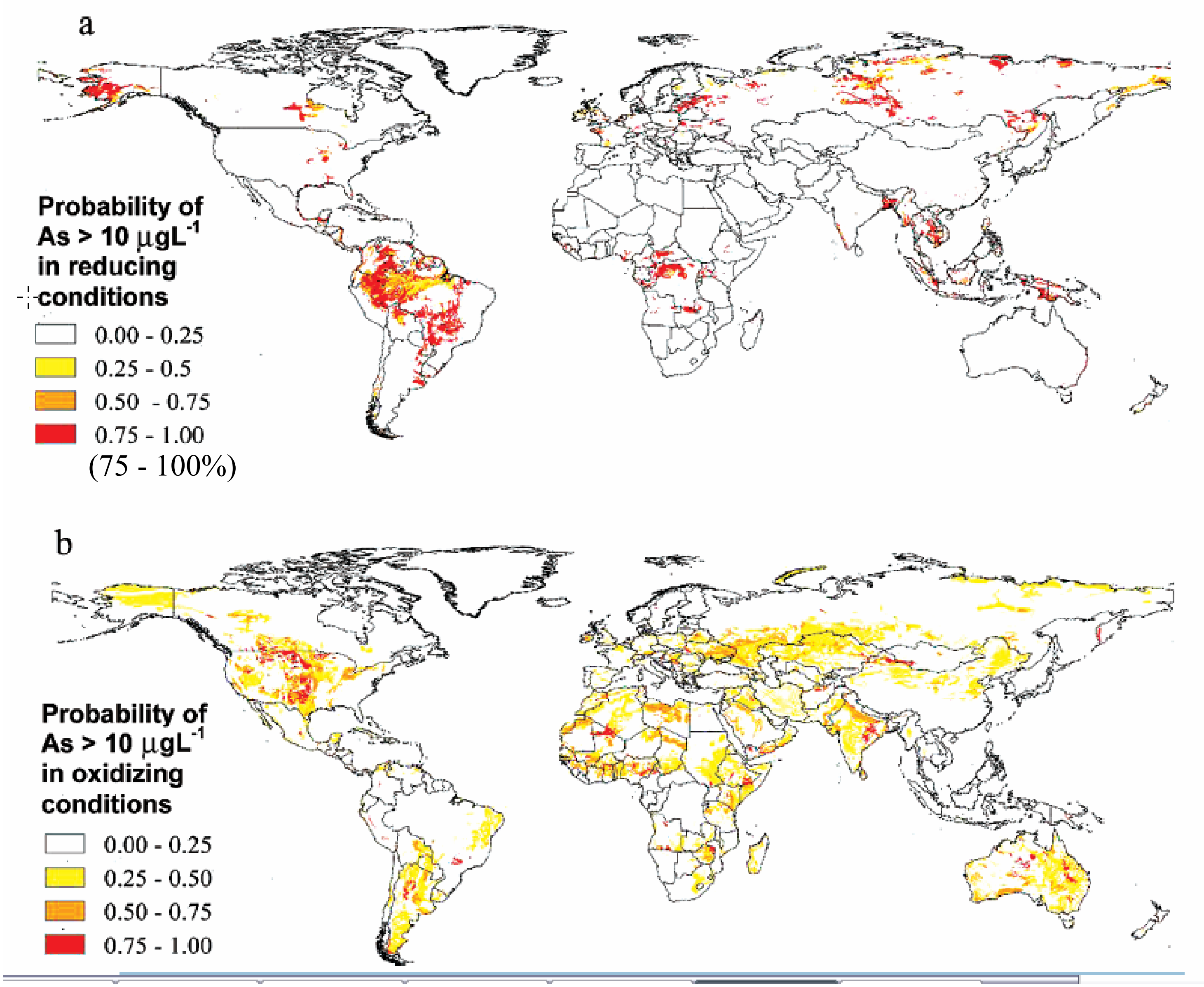
Arsenic mitigation for safe groundwater

Report by the Secretariat

- 12 countries in Asia currently ….are exceeding permissible levels, with at least 50 million people exposed to levels exceeding 50 µg/l."

- "In Latin America it is estimated that at least four million people are exposed to high concentrations of arsenic in drinking-water, primarily rural dwellers consuming water from wells in affected countries, including Argentina, Bolivia, El Salvador, Mexico, Nicaragua and Peru".

Modeled global probability of arsenic contamination in groundwater for (a) reducing groundwater conditions, and (b) high-pH/oxidizing conditions.



(75 - 100%)

From Amini et al., *E, S & T* (March 2008)

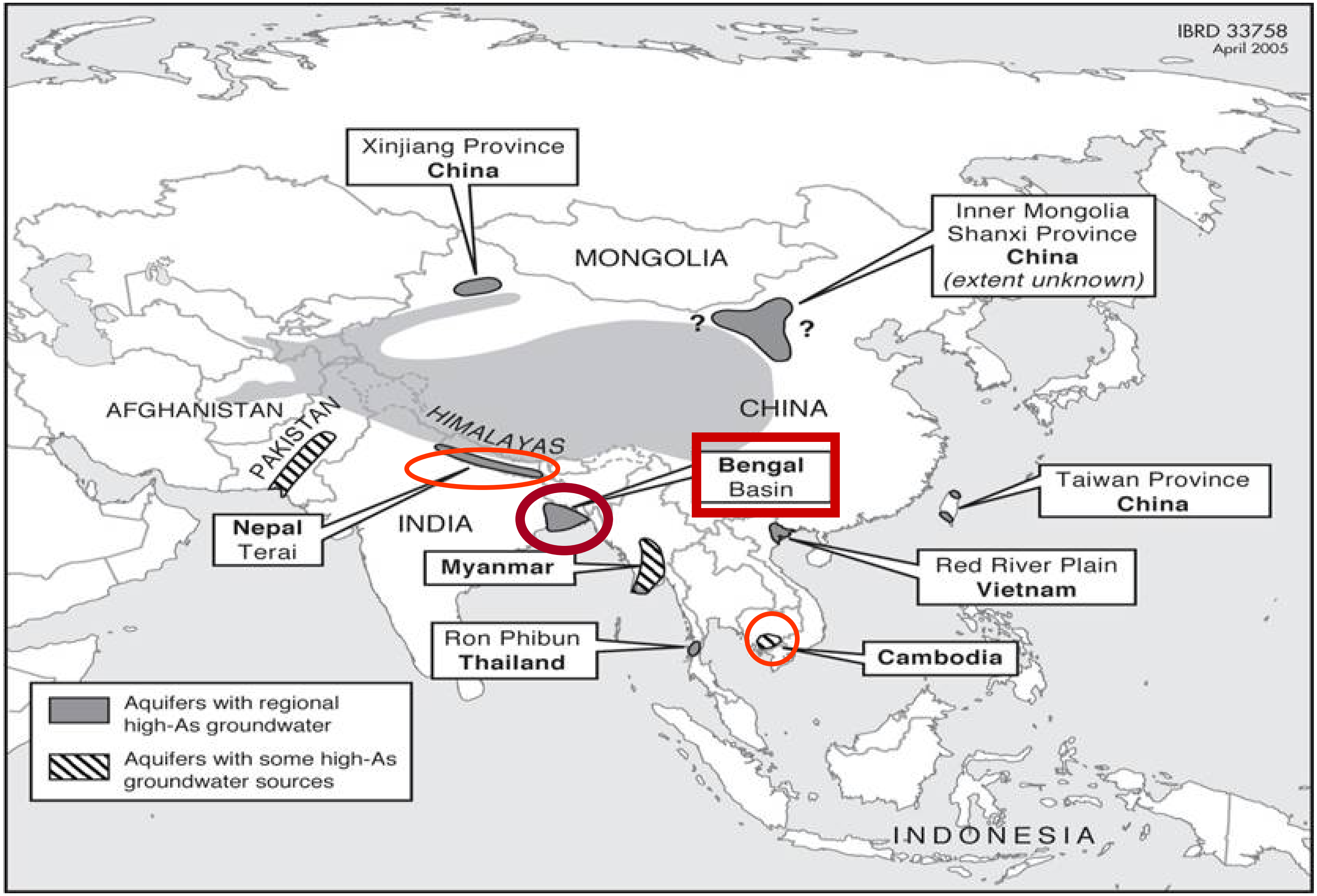
TABLE 4. State of Arsenic Contamination in Groundwaters in Different Countries of the World

predicted contaminated regions with reported contamination			predicted contaminated regions with no measurements or reported contamination		
country	condition	% area[b]	country	condition	% area[b]
Bangladesh (*2*)	reducing	35.4	Estonia	reducing	37.2
Cambodia (*25, 26*)	reducing	45.8	Amazon basin[a]	reducing	32.6
Vietnam (*8, 9, 25*)	reducing	15.8	Lithuania	both	35.0
Taiwan (*27*)	reducing	8.2	Congo	reducing	30.1
Nepal (*28*)	reducing	3.2	Russia	both	14.8
Romania (*29*)	reducing	3.5	Myanmar	both	9.2
USA (*7, 10, 23*)	both	8.3	Poland	both	8.8
Argentina (*30*)	oxidizing	4.9	Cameroon	both	14.0
India (*31*)	both	6.4	Ukraine	oxidizing	7.0
China (*4, 32*)	both	2.5	Byelarus	oxidizing	3.3
Hungary (*29*)	reducing	7.4	Zambia	oxidizing	7.0
Finland (*33*)	unknown	34.7	Nigeria	oxidizing	9.0
Greece (*34*)	unknown	0.1	Angola	oxidizing	5.5
			Kenya	oxidizing	2.4
			Ethiopia	oxidizing	5.3

[a] Average values for Peru, Brazil, and Colombia. [b] % Area in each country with probability of arsenic contamination >0.75.

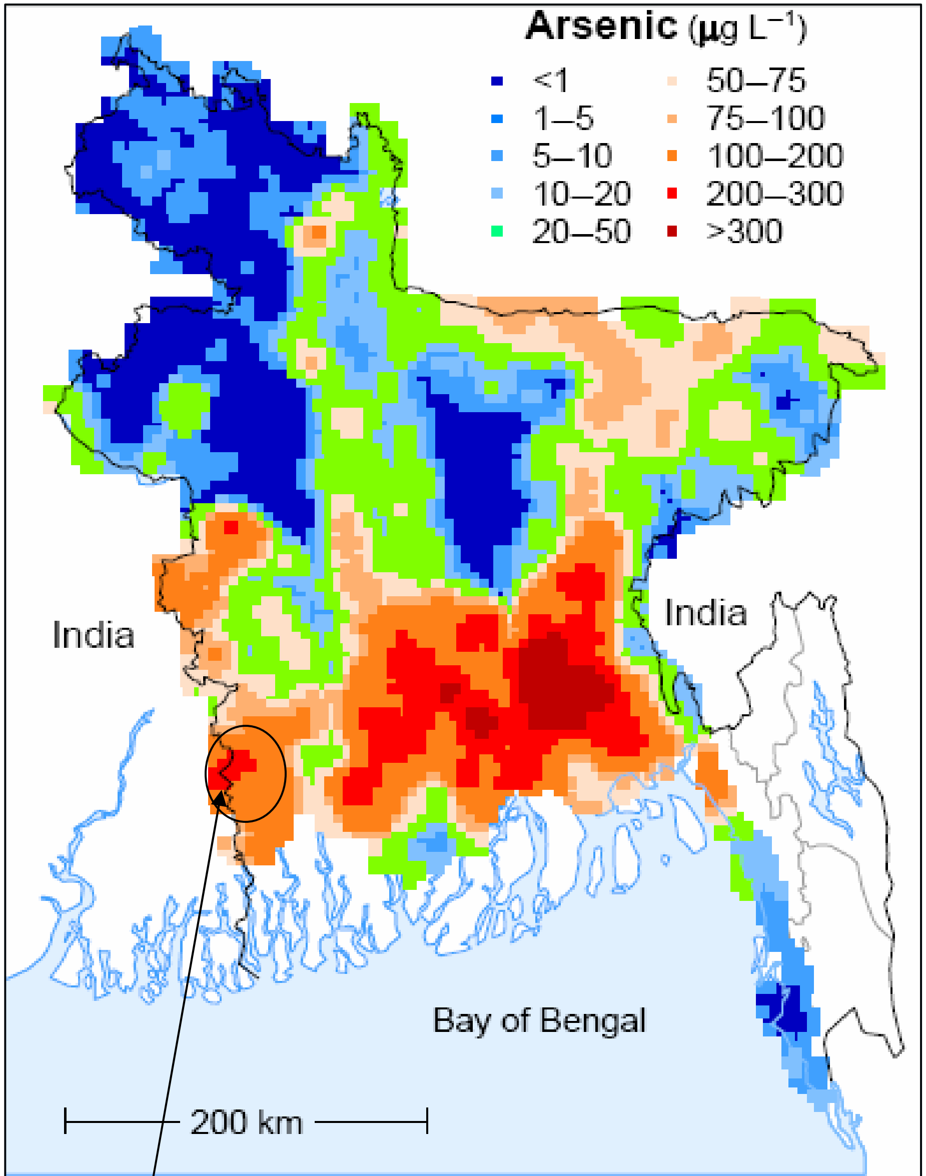
From Amini et al., *E, S & T* (March 2008)

Arsenic in Asia



From: World Bank "Study: Arsenic Contamination of Groundwater in South and East Asian Countries" 2005

Arsenic Levels in Groundwater in Bangladesh



'Groundwater Studies of Arsenic Contamination in Bangladesh'
DPHE/BGS/DFID (2000)

Project area

Drinking Water Standards

Bangladesh – 50 ug/L

WHO – 10 ug/L

Government of the People's Republic of Bangladesh
Ministry of Local Government, Rural Development and Cooperatives
Department of Public Health Engineering

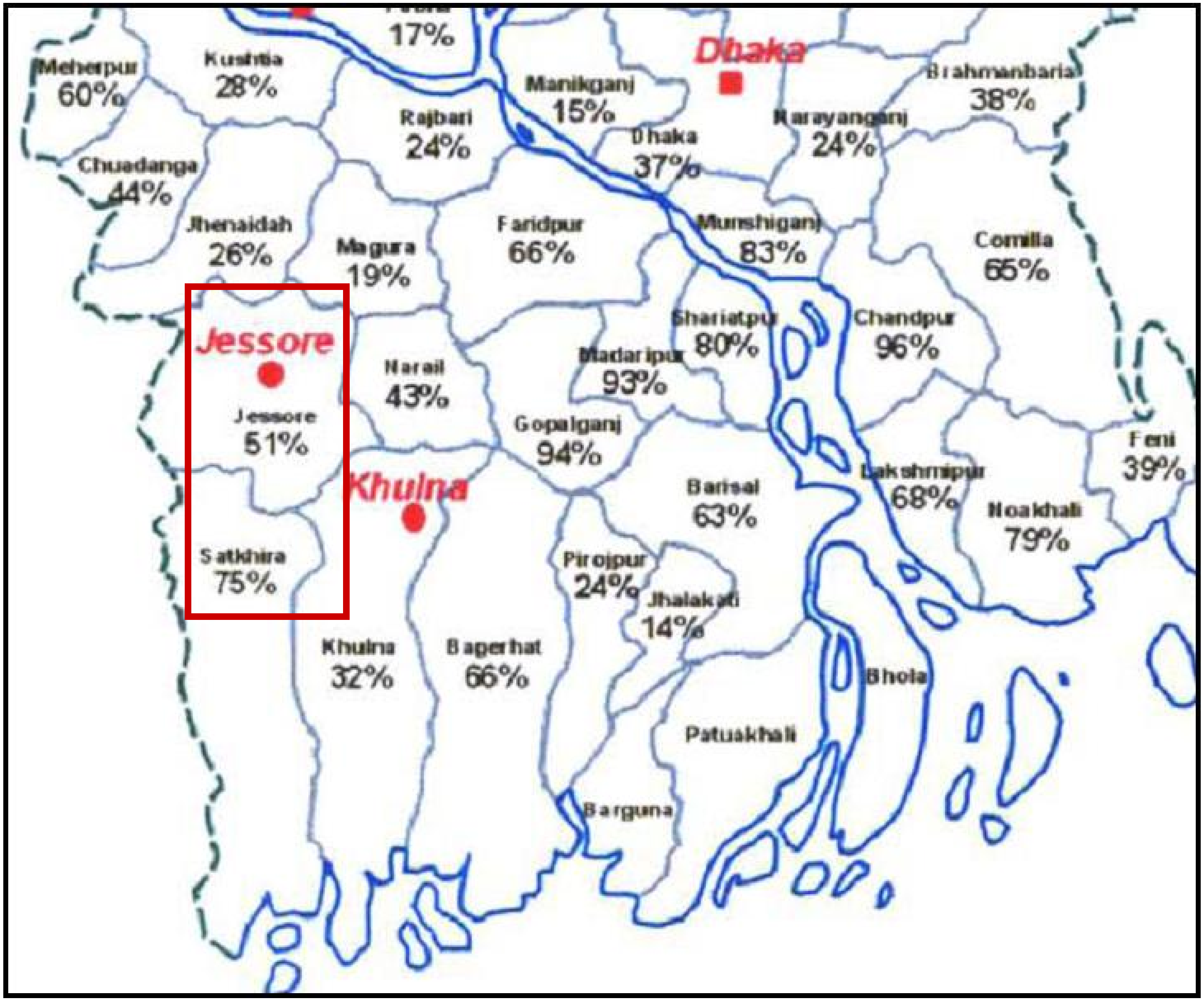
ARSENIC IN GROUNDWATER IN BANGLADESH

Groundwater Studies of Arsenic Contamination in Bangladesh
British Geological Survey

Funded by
Department for International Development, UK

March 2000

Percent of Wells > 50 ug/L of Arsenic (Bangladesh Standard)



BGS AND DPHE, 2001
Arsenic contamination of groundwater in Bangladesh
KINNIBURGH, D G and SMEDLEY, P L (Editors)
Volume 1: Summary
British Geological Survey Report WC/00/19
British Geological Survey, Keyworth.

Average Arsenic Concentrations in Wells by District

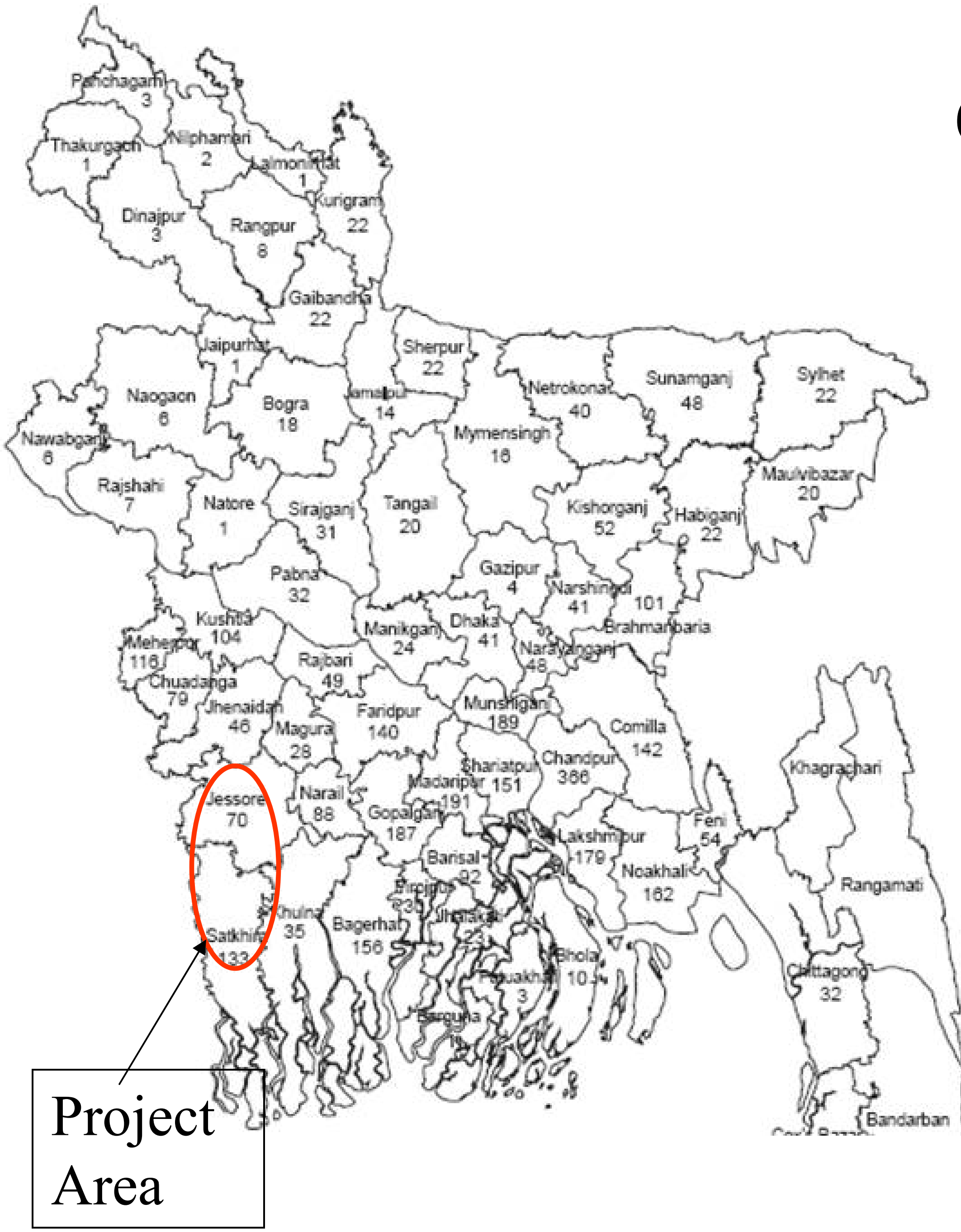


Figure 4. District-wise average arsenic concentration (in µg L^{-1}) found from the DPHE/BGS National Hydrochemical Survey

BGS AND DPHE, 2001
Arsenic contamination of groundwater in Bangladesh
KINNIBURGH, D G and SMEDLEY, P L (Editors)
Volume 1: Summary
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British Geological Survey, Keyworth.

Contamination of drinking-water by arsenic in Bangladesh: a public health emergency

Allan H. Smith,[1] Elena O. Lingas,[2] & Mahfuzar Rahman[3]

Bulletin of the World Health Organization, 2000, **78** (9)

The contamination of groundwater by arsenic in Bangladesh is the largest poisoning of a population in history, with millions of people exposed. This paper describes the history of the discovery of arsenic in drinking-water in Bangladesh and recommends intervention strategies. Tube-wells were installed to provide "pure water" to prevent morbidity and mortality from gastrointestinal disease. The water from the millions of tube-wells that were installed was not tested for arsenic contamination. Studies in other countries where the population has had long-term exposure to arsenic in groundwater indicate that 1 in 10 people who drink water containing 500 μg of arsenic per litre may ultimately die from cancers caused by arsenic, including lung, bladder and skin cancers. The rapid allocation of funding and prompt expansion of current interventions to address this contamination should be facilitated. The fundamental intervention is the identification and provision of arsenic-free drinking water. Arsenic is rapidly excreted in urine, and for early or mild cases, no specific treatment is required. Community education and participation are essential to ensure that interventions are successful; these should be coupled with follow-up monitoring to confirm that exposure has ended. Taken together with the discovery of arsenic in groundwater in other countries, the experience in Bangladesh shows that groundwater sources throughout the world that are used for drinking-water should be tested for arsenic.

"1 in 10 people who drink water containing 500 ug/L of arsenic may ultimately die from cancers caused by arsenic including lung, bladder and skin cancers" - WHO

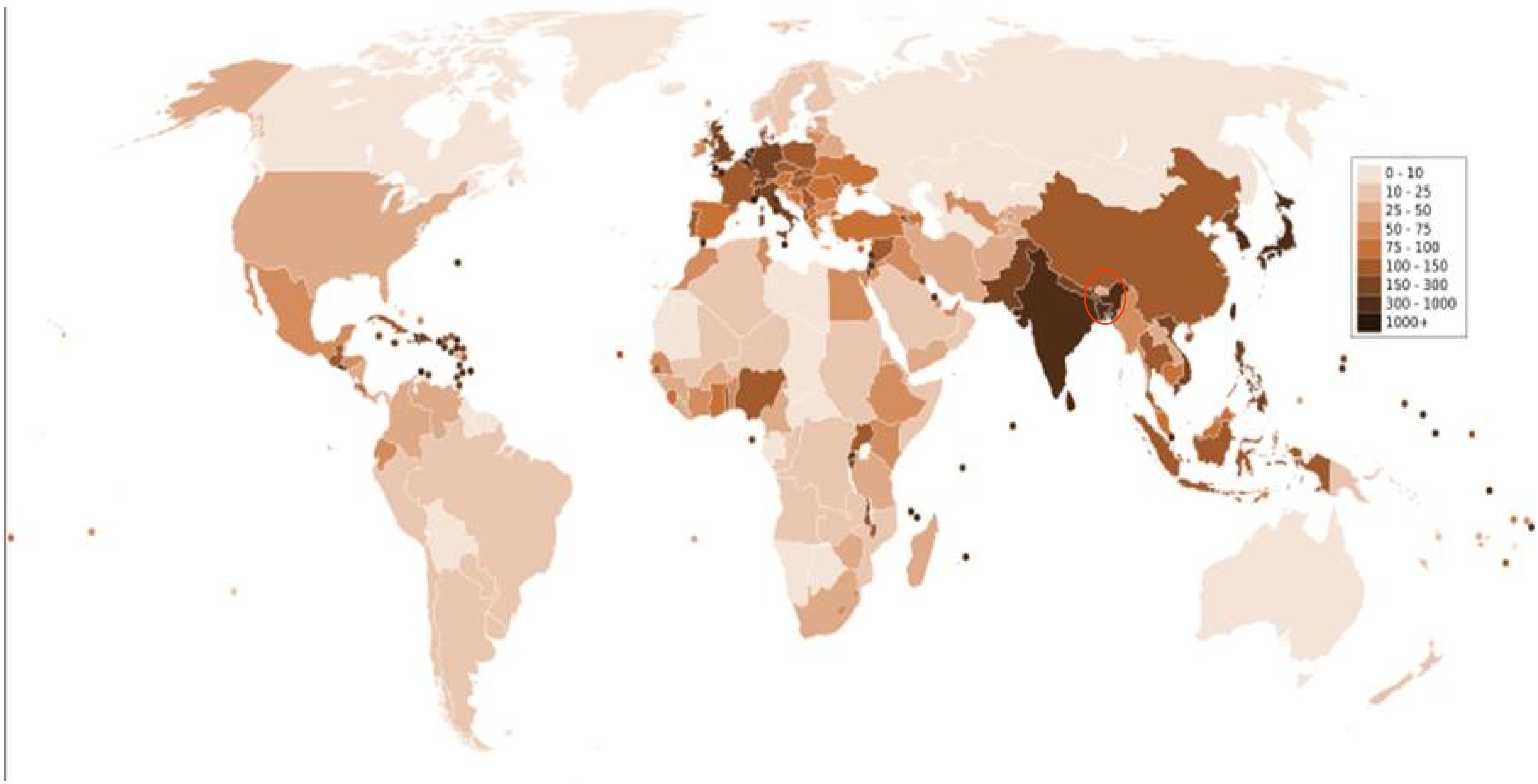
Box 2. **Long-term health effects of exposure to arsenic**

- Skin lesions
- Skin cancer
- Internal cancers
  - Bladder
  - Kidney
  - Lung
- Neurological effects
- Hypertension and cardiovascular disease
- Pulmonary disease
- Peripheral vascular disease
- Diabetes mellitus

Scale of the Arsenic Problem in Bangladesh

- Bangladesh Drinking Water Standard – 50 ug/L (ppb).
- Approximately 8 million drinking water wells (tubewells) in Bangladesh.
- 20 million people potentially impacted (current UNICEF estimate).

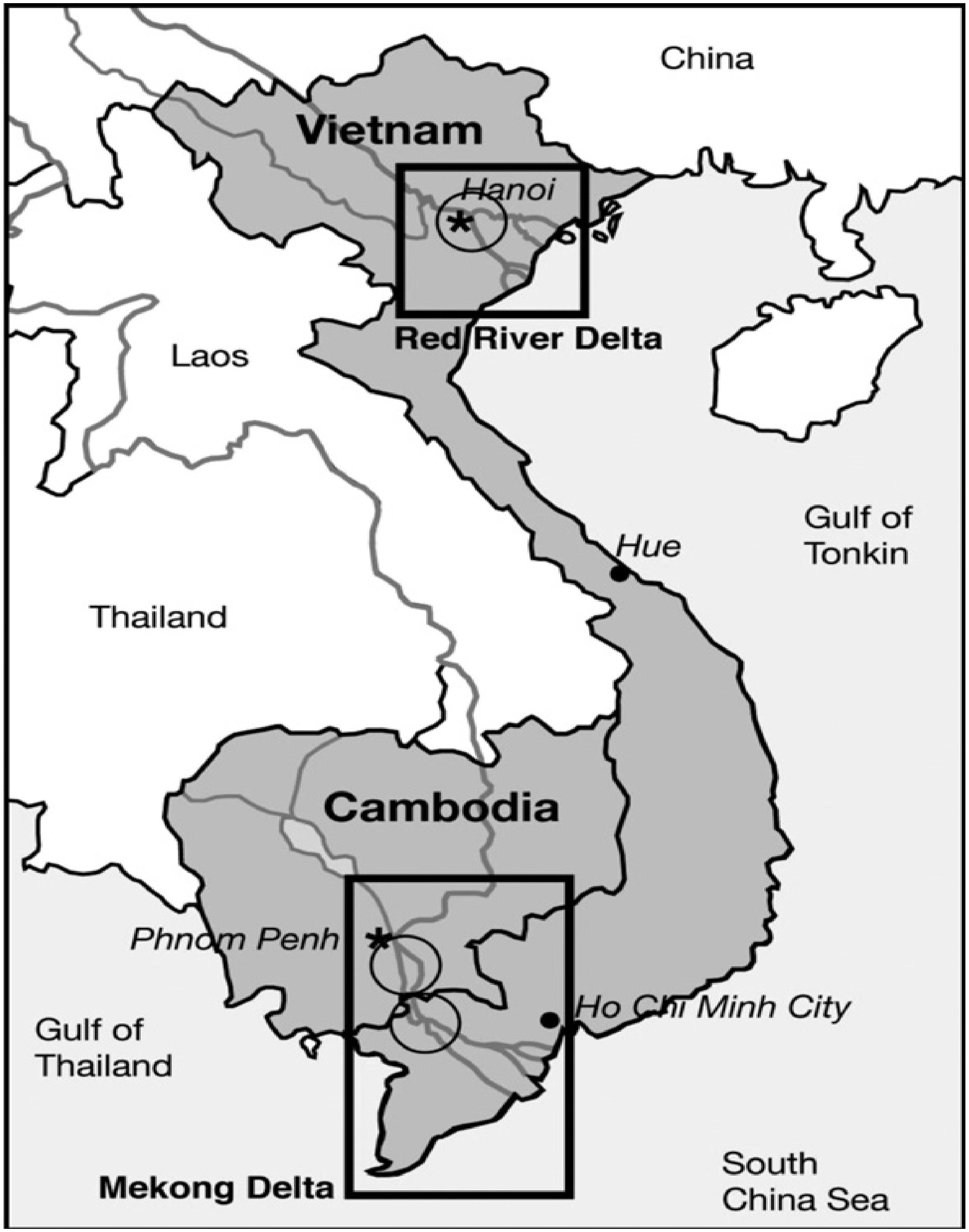
Countries by Population Density



From Wikipedia

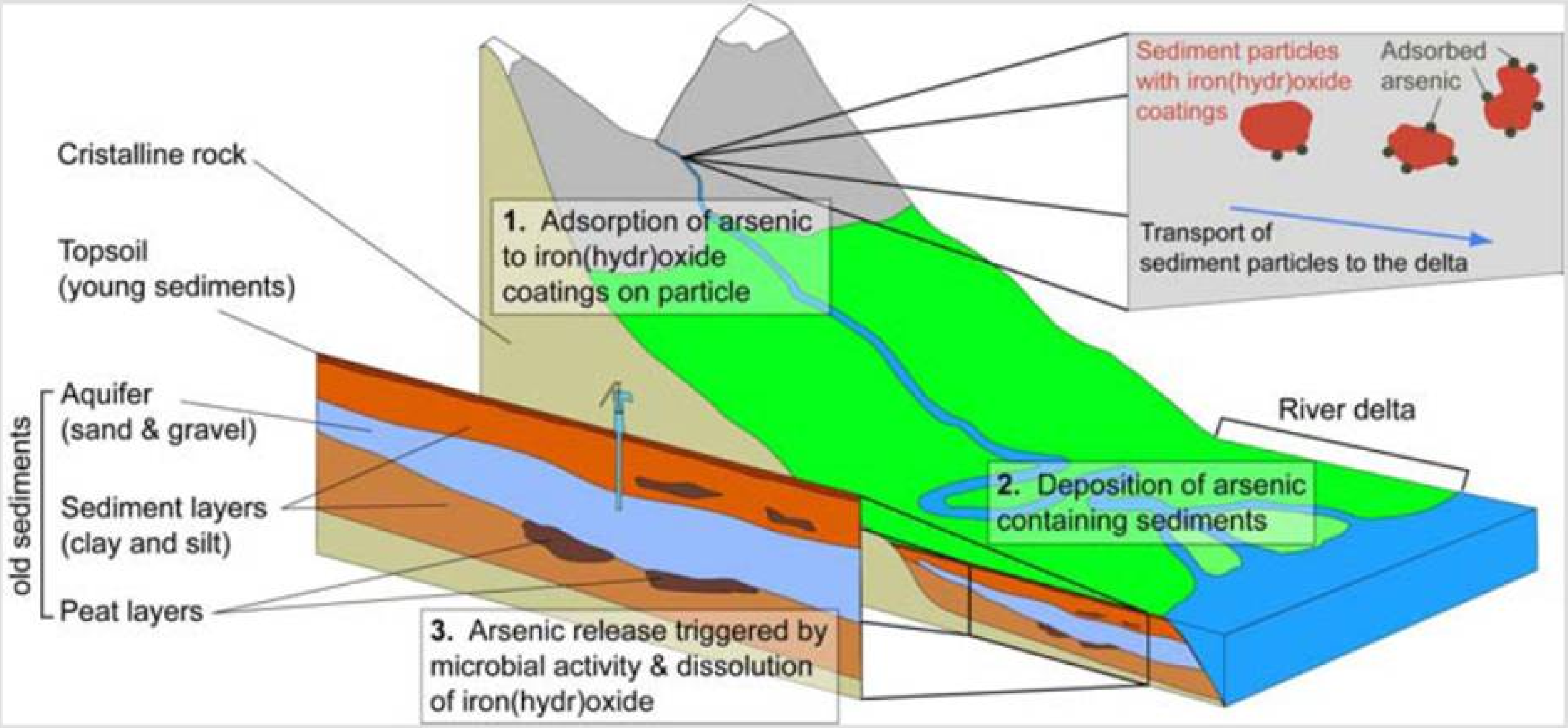
The World's Largest River Delta

Most of Bangladesh lies within the world's largest river delta formed by 3 rivers (Ganges, Brahmaputra, and Meghna) and is subject to annual flooding during the monsoon season. Large quantities of fertile soil is deposited by the floodwaters. Most of the land in Bangladesh is extremely flat and low-lying.

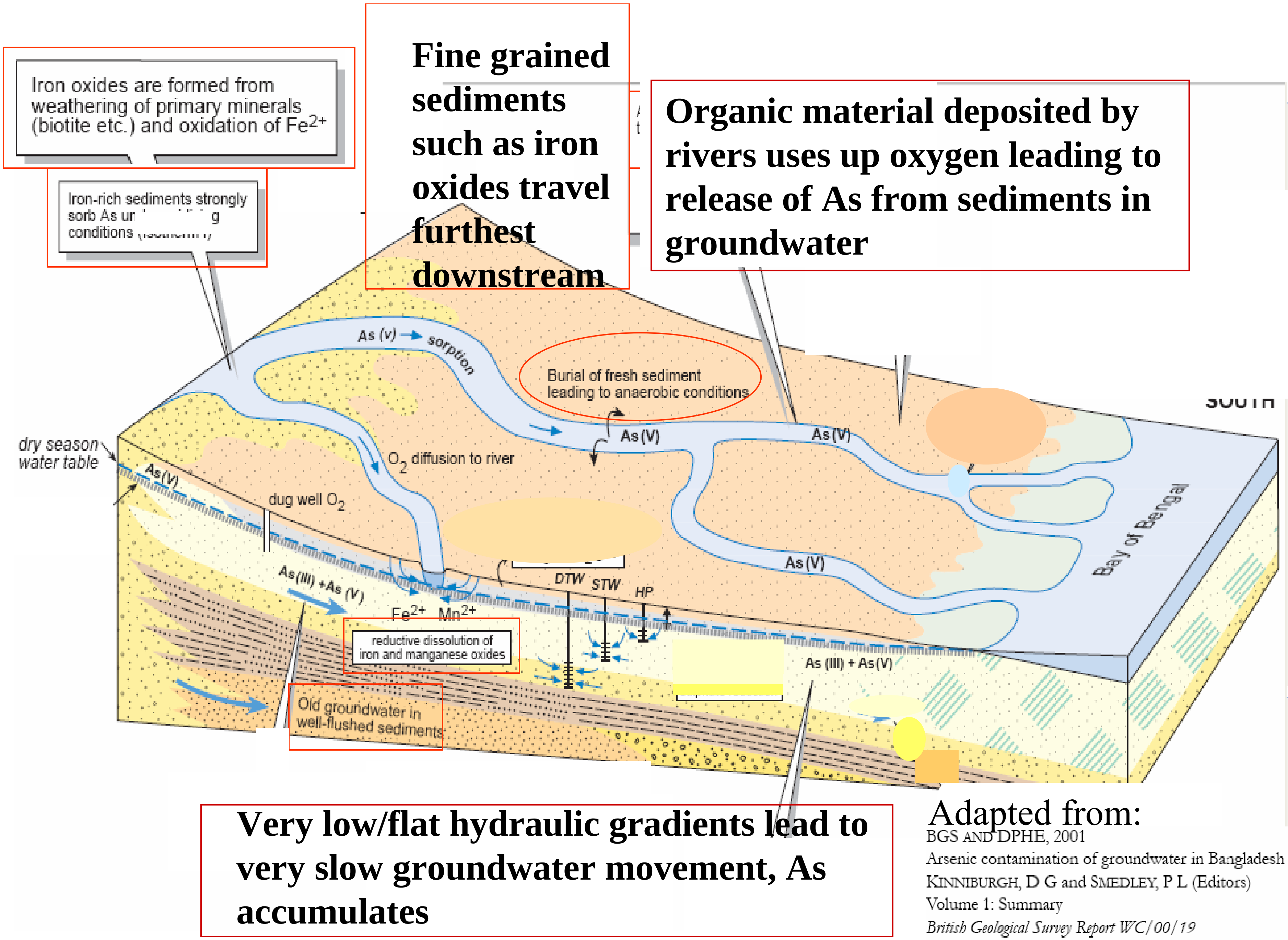


From Berg et al. Science of the Total Environment (2007)

Figure 3. Illustration of the widely accepted theory on the origin of arsenic in groundwater of tropical and subtropical river deltas



From: Technical Report Household Sand Filters for Arsenic Removal by EAWAG 2004



Adapted from:
BGS AND DPHE, 2001
Arsenic contamination of groundwater in Bangladesh
KINNIBURGH, D G and SMEDLEY, P L (Editors)
Volume 1: Summary
British Geological Survey Report WC/00/19
British Geological Survey, Keyworth.

Why Are Arsenic Levels So High in Bangladesh Wells?

• High arsenic levels in groundwater in Bangladesh are a function of hydrogeology & groundwater chemistry of Bengal Basin not the levels of As in sediments.

• Levels of As in sediments are similar to many other parts of the world.

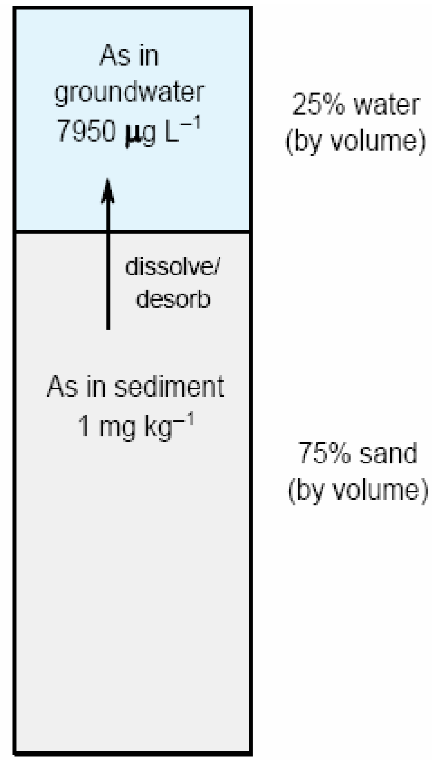
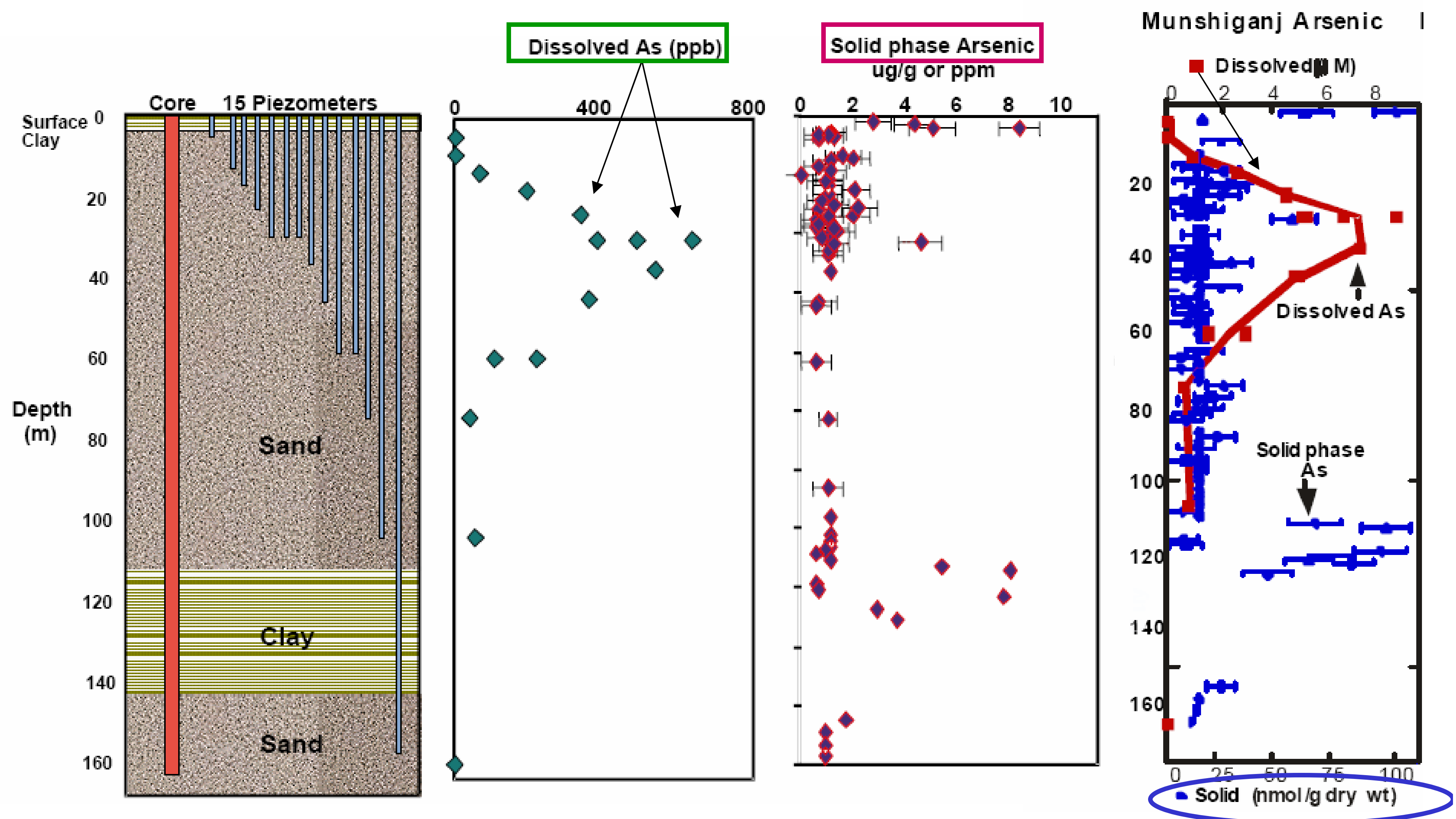


Figure 12.7. Schematic diagram showing how the consequences of a high solid/solution ratio on pore water arsenic concentrations. Complete dissolution of even small amounts of arsenic (1 mg kg^{-1} here) from a sandy Bangladesh aquifer sediment would give rise to extremely high concentrations of arsenic in the groundwater.

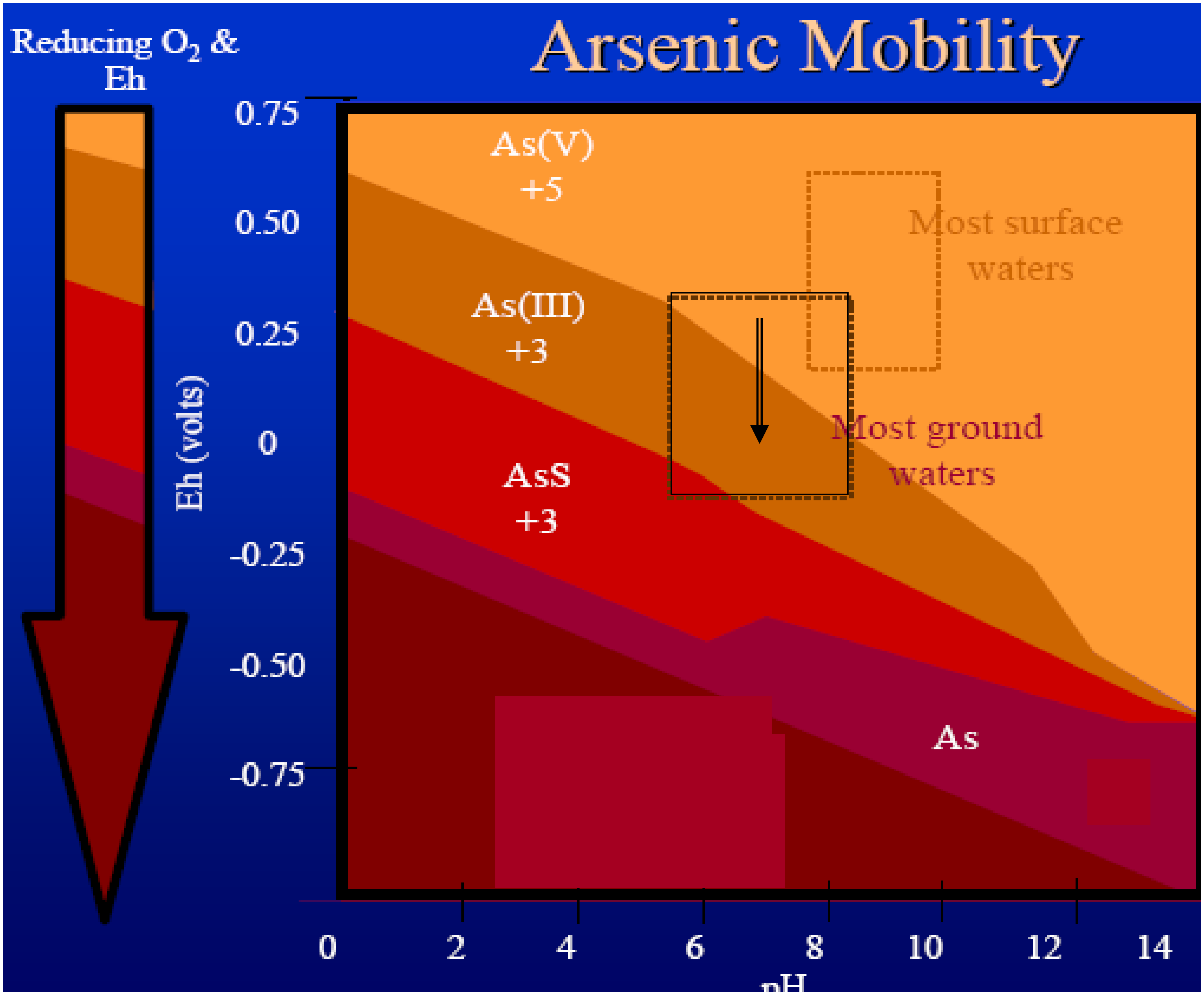
Figure 12.7 above from:

BGS AND DPHE, 2001
Arsenic contamination of groundwater in Bangladesh
KINNIBURGH, D G and SMEDLEY, P L (Editors)
Volume 1: Summary
British Geological Survey Report WC/00/19
British Geological Survey, Keyworth.

Comparison of Dissolved As in Groundwater vs. As in Solid Phase (sediments in the aquifer)



From Harvey – MIT OpenCourseWare at http://dspace.mit.edu



= Reduction in oxygen in groundwater causes As^{+5} to be converted to As^{+3} which is the more mobile form..

From: "CHRONIC ARSENIC TOXICITY *Environmental Health, Natural History and Chemical Assessment*" *by* José A. Centeno U.S. ARMED FORCES INSTITUTE of PATHOLOGY

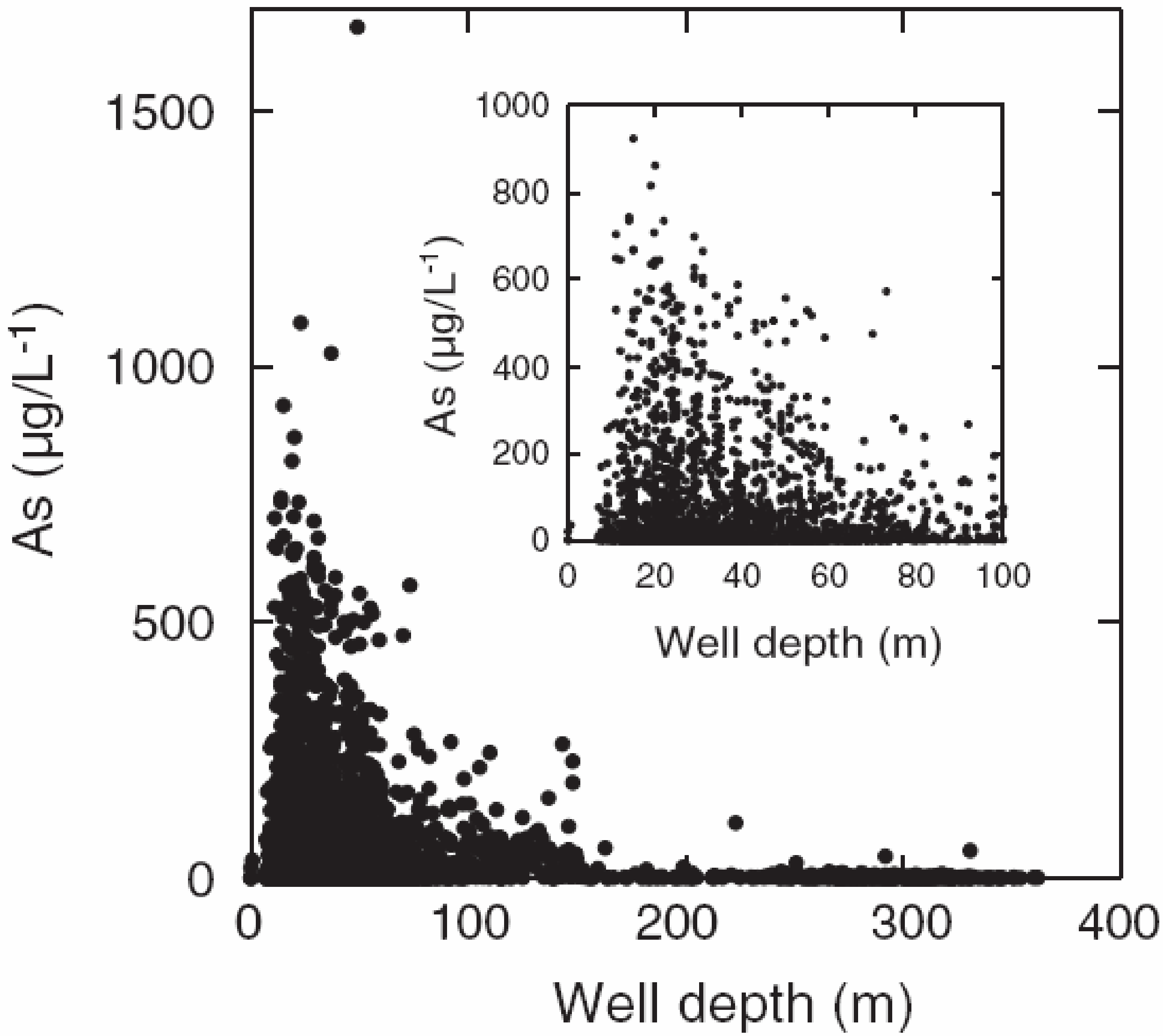


Figure 2.3 Arsenic concentration of groundwater in tube-wells from the DPHE/BGS National Hydrochemical Survey plotted as a function of tube-well depth (Kinniburgh & Smedley 2001)

Arsenic Removal Technology Verification Bangladesh

- The Governments of Canada and Bangladesh established a technology verification project to help Bangladesh develop and implement a scientifically defensible method for validating arsenic removal performance claims by technology proponents.

- The Bangladesh Council of Scientific & Industrial Research (BCSIR) was designated as the verification authority.

- The Ontario Centre for Environmental Technology Advancement (OCETA) in Canada is working with BCSIR.

Basic Technology Verification Concepts

Technology verification for water treatment for chemical contaminants is based on:

1. Field testing under actual field use conditions (not laboratory conditions) by a neutral third party.

2. Identifying the range of situations under which a technology will work as designed (maximum pH, maximum phosphate levels, etc.).

Project Partners for Field Testing of Kanchan Arsenic Filter (KAF) for Certification Application in Bangladesh

- LEDARS – Highly motivated NGO from SW Bangladesh.
- CAWST (Centre for Affordable Water & Sanitation Technology).
- Massachusetts Institute of Technology (MIT).
- ENPHO – Provided supporting activities such as training & initial plastic filters.

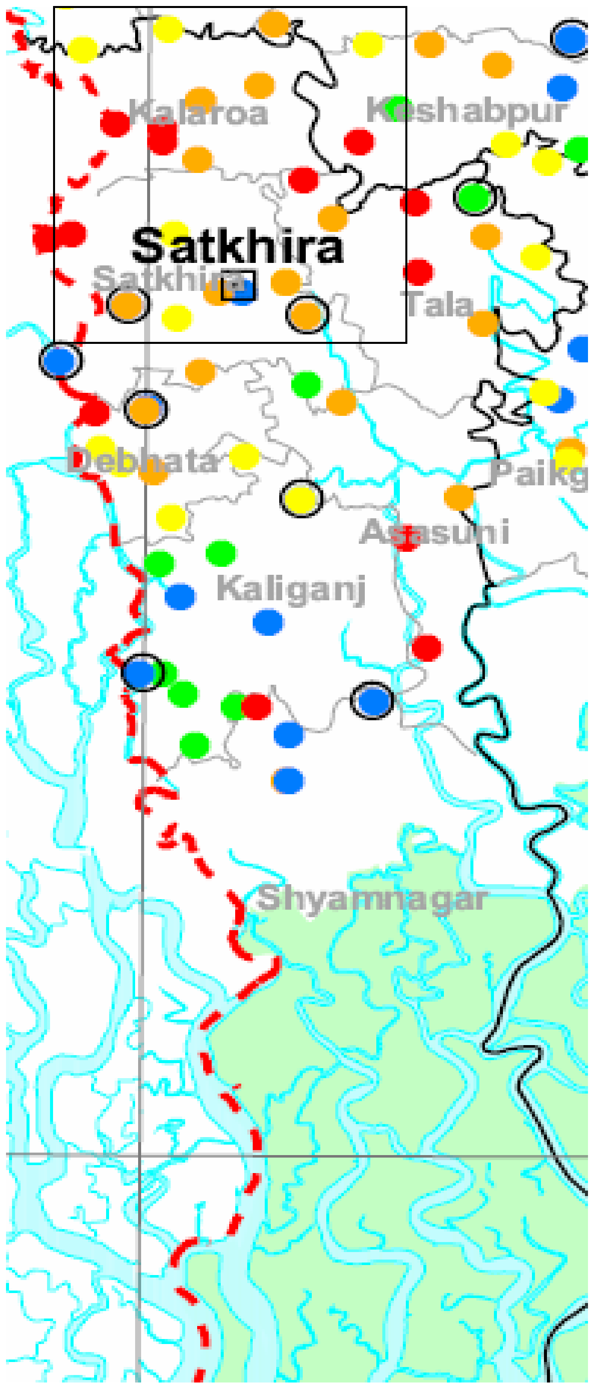
Overview of Kanchan Arsenic Filter Pilot Study Bangladesh

- 8 KAF filters tested in 2 different districts in Bangladesh prior to submittal of certification application.
- Some sampling was done by test kits but most all of the samples were by laboratory analysis by AAS at Asia Arsenic Network (AAN) lab in Jessore. Split lab sample taken to AAN and DPHE lab (Khulna).
- 5 sampling rounds (March – Dec. 2007).
- Certification testing expected to start in August 2008.

Bangladesh Project Team

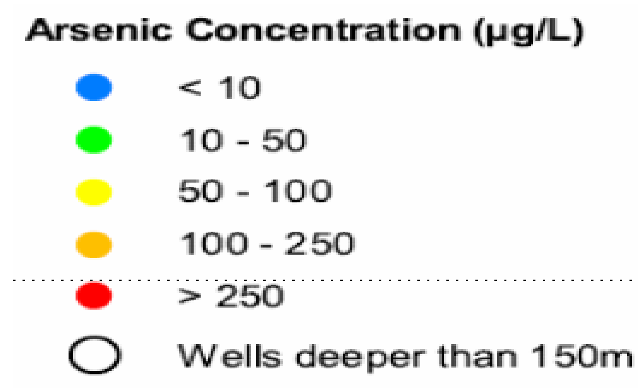
- Mohon Mondal (LEDARS-Bangladesh) – Responsible for filter construction, logistics and project oversight.
- Rachel Peletz – (CAWST) International Technical Advisor & lead trainer for KAF construction trainings.
- Tommy Ngai (CAWST) –Advisor & developed KAF with ENPHO while grad student at MIT.
- Susan Murcott (MIT) – Advisor & project financial support for LEDARS.
- Bipin Dongal (ENPHO & UN HABITAT) –Involved in developing KAF & provided KAF training in Nepal.
- Tom Mahin (MIT/CAWST) - Project coordinator.

= Portion of Satkhira District included in CAWST/MIT pilot study



Arsenic Levels in Satkhira District

(BGS/DPHE data)



Government of the People's Republic of Bangladesh
Ministry of Local Government, Rural Development and Cooperatives
Department of Public Health Engineering

ARSENIC IN GROUNDWATER IN BANGLADESH

Groundwater Studies of Arsenic Contamination in Bangladesh
British Geological Survey

Funded by
Department for International Development, UK

March 2000

District: Satkhira Upazila: Kalaroa

Example of Part of Satkhira District Where We Work

	Tubewell Survey					
		# of Village	Total TW	# of Arsenic Safe TW	# of Arsenic Conta. TW	% of TW Conta.
1	Chandanpur	12	2127	116	2011	94.55
2	Diara	8	2046	179	1867	91.25
3	Helathala	13	1453	19	1434	98.69
4	Jallabad	11	1537	44	1493	97.14
5	Joynagar	11	1476	38	1438	97.43
6	Jugikhali	13	884	17	867	98.08
7	Kaila	5	756	16	740	97.88
8	Keragachhi	12	1658	180	1478	89.14
9	Keralkata	20	1769	144	1625	91.86
10	Kushadanga	15	1069	16	1053	98.50
11	Nangaljhara	8	642	20	622	96.88
12	Sonabaria	8	1586	100	1486	93.69
Upazila summary:-		136	17003	889	16114	**94.77**

Data from Bangladesh Water Supply Program Project

% Drinking Water Wells Contaminated with Arsenic (> 50 ppb)

The Daily Star

Today's issue 28 page

Committed to People's Right to Know

Dhaka Monday March 31, 2008 • www.thedailystar.net • Chaitra 17, 1414 BS • Rabiul Awal 22, 1429

ARSENIC CONTAMINATION

Number of patients soars for want of safe water

Jasim Uddin Khan

The number of severe arsenic contaminated patients is three times higher than the previous estimation done around two years ago, says a joint study of the government and JICA.

The study shows the number of arsenicosis patients are increasing alarmingly due to want of safe water sources in affected areas.

The study conducted under the project titled "Sustainable Arsenic Mitigation under Integrated Local Government Systems (SAM-ILGS)" also finds many identified patients died in last five years without proper treatment.

"The actual number of patients in the country could be even more than triple than that was identified previously if the contaminated areas are surveyed again," Kazuyuki Kawahara, project manager, said.

The first government arsenic project titled Bangladesh Arsenic Mitigation and Water Supply Project (BAMWSP) started in January 1998 and continued until June 2006.

Kawahara said they found 799 patients in Chowgachha upazila in Jessore while the previous BAMWSP found only 275 patients there.

"The main reason of increasing number of patients is that previously the patients were identified by the field workers under BAMWSP whereas the patients have been identified under the new (SAM-ILGS) project by health assistants and confirmed by doctors," Kawahara added.

He said BAMWSP identified around 38,000 arsenicosis patients in 268 upazilas across the country. But if the areas are surveyed again and doctors confirm the patients, the number would cross even 1 lakh.

He emphasised initiating a fresh survey on the most vulnerable areas in Comilla, Chandpur, Chapainawabganj and Faridpur.

According to the previous project, 4,036 patients were identified

SEE PAGE 15 COL 5

Arsenic

FROM PAGE 16

alone in Comilla, 2,600 in Chandpur, 2,321 in Chapainawabganj and 903 in Faridpur.

The number of patients is drastically increasing due to lapse in constant vigilance in mitigating contamination and because many abandoned the instruments supplied by the government and donors.

Admitting the rising trend of arsenic contamination, SAM-ILGS Project Director and Deputy Secretary (Water Supply) of Local Government Division M Shafiqul Islam said the users abandon water-purifying devices due to lack of maintenance, thus affecting more people.

"People must use purified water in the contaminated areas. There's no way left to get rid of the diseases as most of the contaminated areas have high level of arsenic existence," he added.

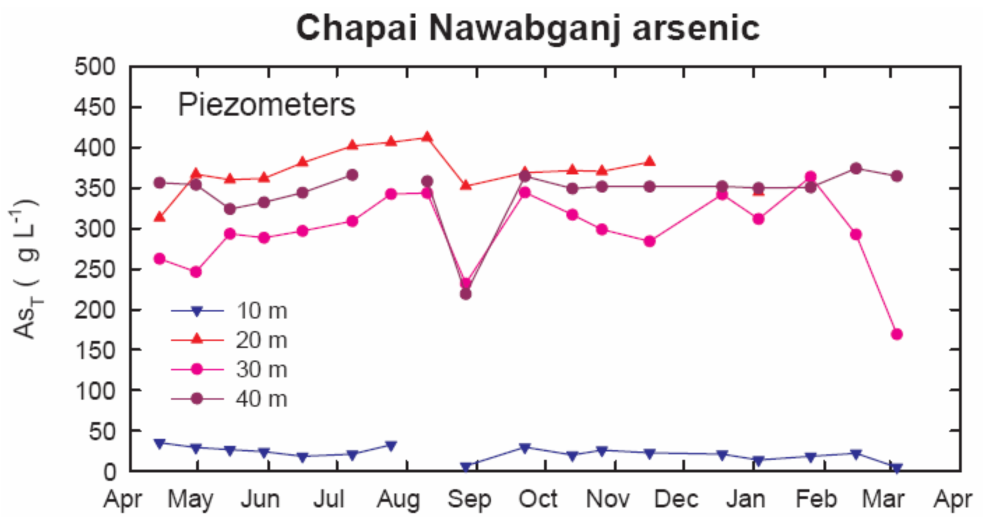
The project consultant suggests community initiative to raise

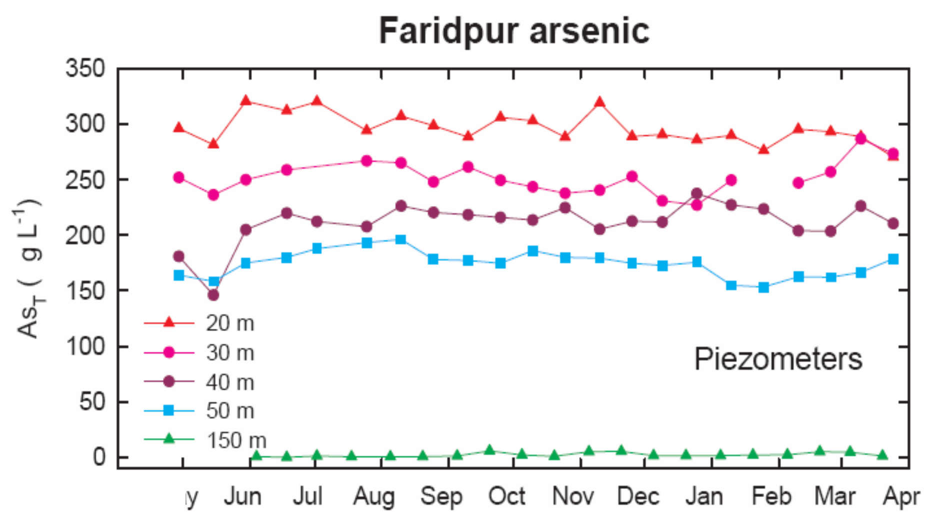
Arsenicosis Patient - Cambodia

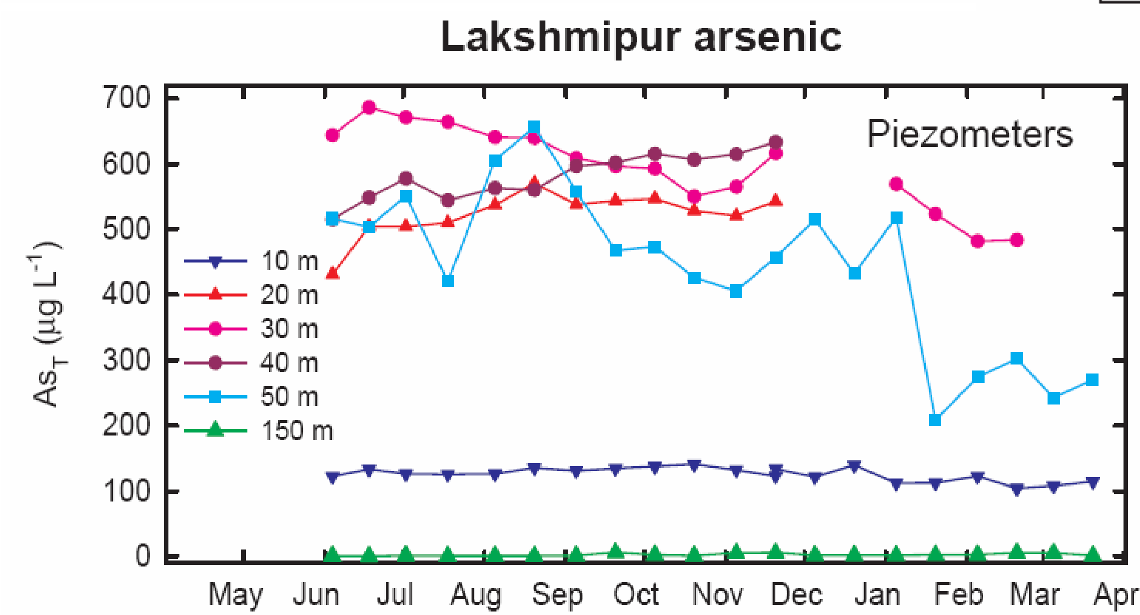
Photo by T. Mahin

Variation of Arsenic Over Time

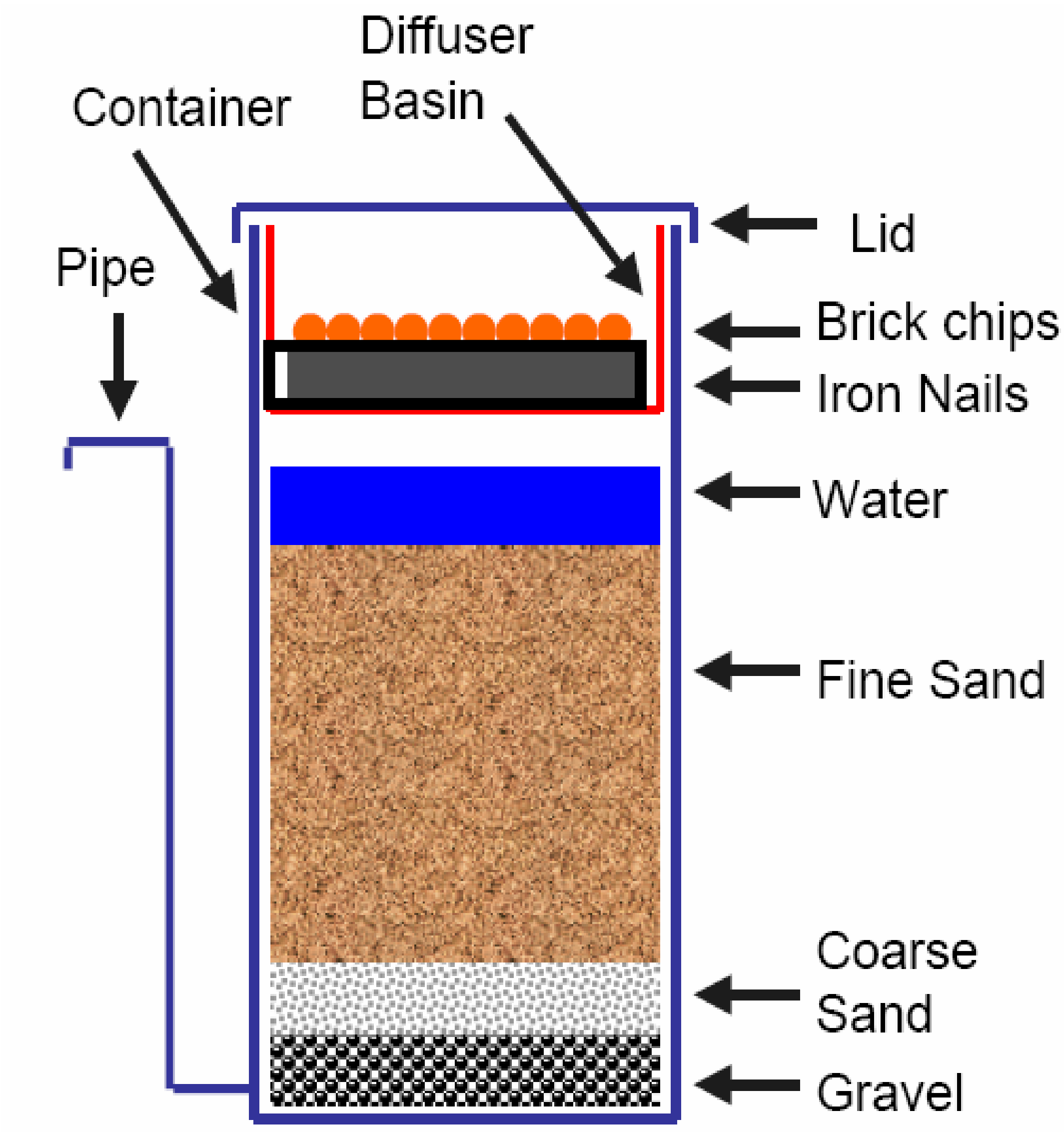
(Charts from British Geological Survey)







Kanchan Arsenic Filter



Kanchan Arsenic Filter Performance*

*based on 1000+ filters in use for 1 year across Nepal

Parameters	*Typical values*
Arsenic	85-90% reduction
Iron	90-95% reduction
Phosphate	80-85% reduction
Turbidity	80-95% reduction
Total coliforms	85-99% reduction
pH	0.35-0.40 increase

Recommendation: Arsenic <= 0.5 mg/L (500 ppb)
Phosphates as PO4 <= 5.0 mg/L
pH <= 7.5

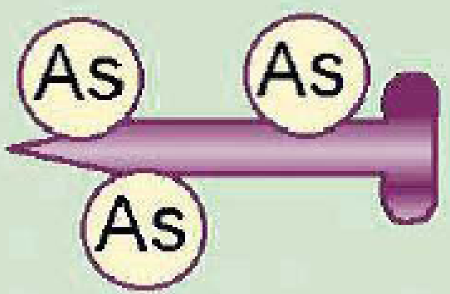
Reference:
Ngai, T.K.K., Murcott, S., Shrestha, R.R., Dangol, B., Maharjan, M. Design for Sustainable Development – Household Drinking Water Filter for Arsenic and Pathogen Treatment in Nepal. *Journal of Environmental Science and Health*, Part A. Vol A42 No 12 pp1879-1888, 2007.

Kanchan Arsenic Filter
Arsenic Removal Mechanism

- After contact with water and air, iron nails in the diffuser basin will quickly rust

- Iron rust (ferric hydroxide) is an excellent adsorbent for arsenic

- Arsenic may stay in the diffuser box (i.e. adsorbed to the surface of the rusted nails in the box), or the arsenic-loaded iron particles can be flushed down and trapped on top of fine sand



Arsenic (As) particles are effectively adsorbed on the rusted iron nails surface.

Selecting Filter Locations for CAWST/MIT/LEDARS Pilot Study

- Reviewed published data on arsenic levels in Bangladesh.
- Met and reviewed data with JICA staff in Bangladesh who were very helpful.
- Met with Asia Arsenic Network staff and discussed data sources.
- Met with DPHE (Department of Public Health Engineering) officials and discussed existing data.
- Talked with UNICEF about the worst contaminated areas in SW Bangladesh.
- Conducted preliminary field testing.

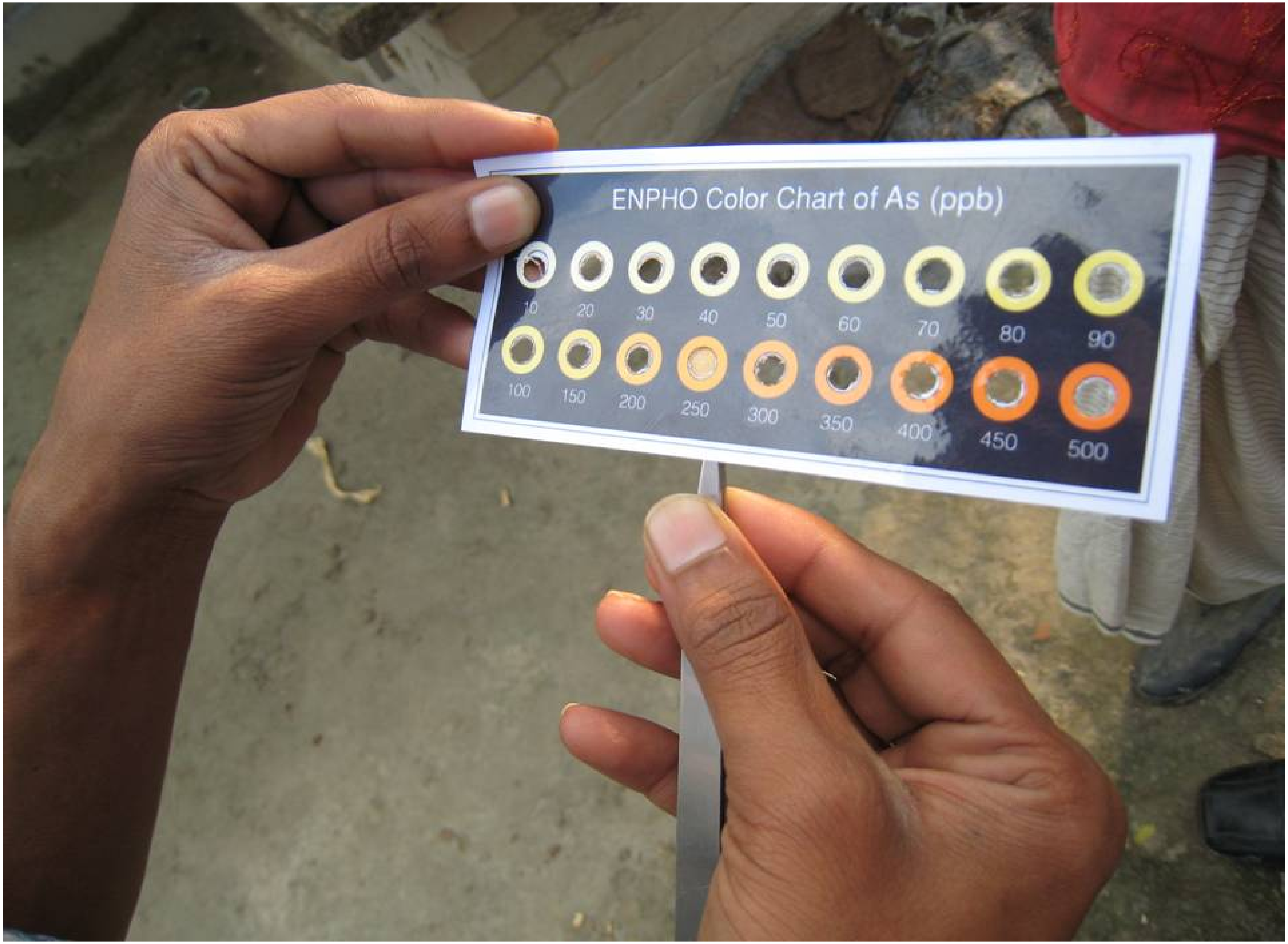


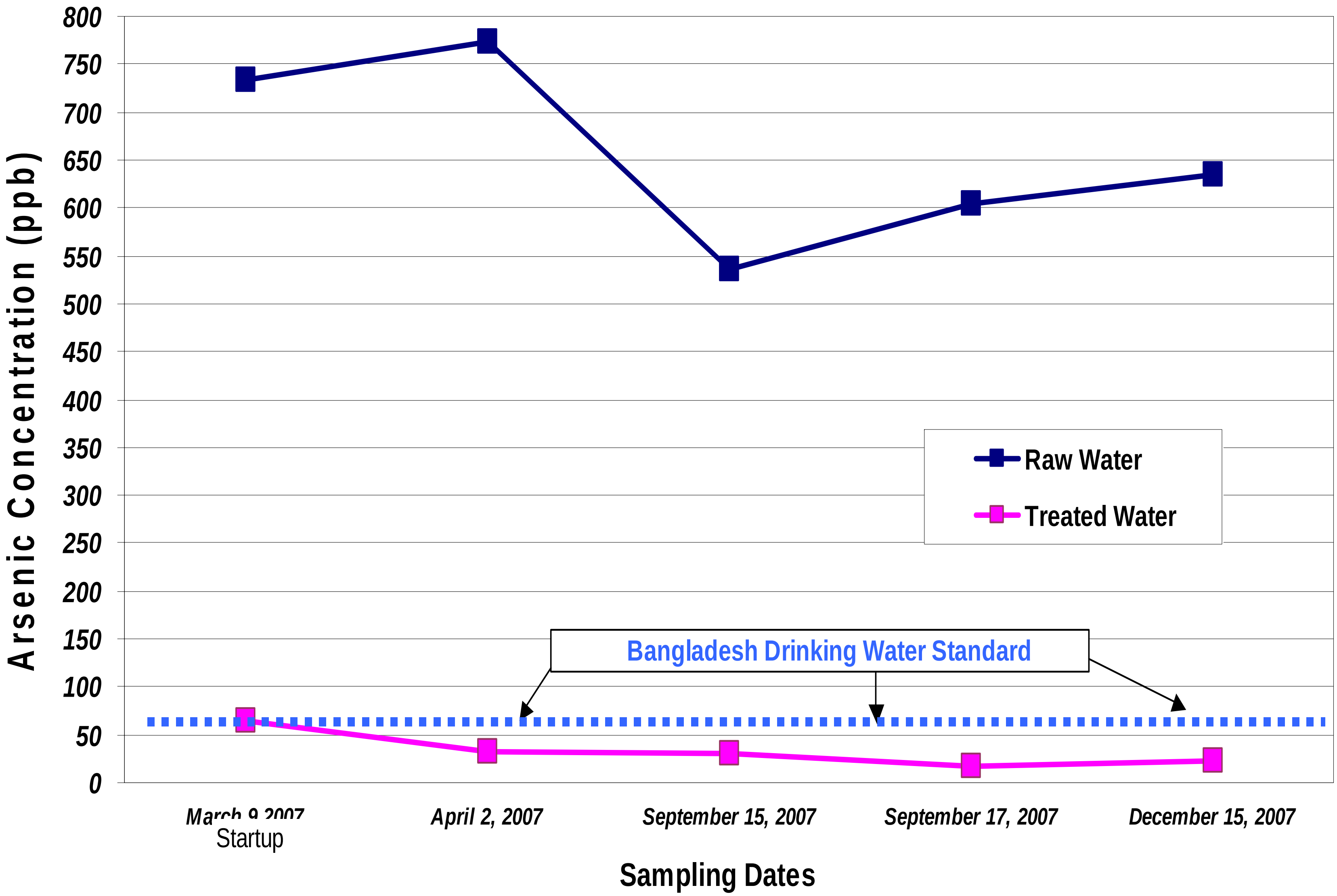
Photo by T. Mahin

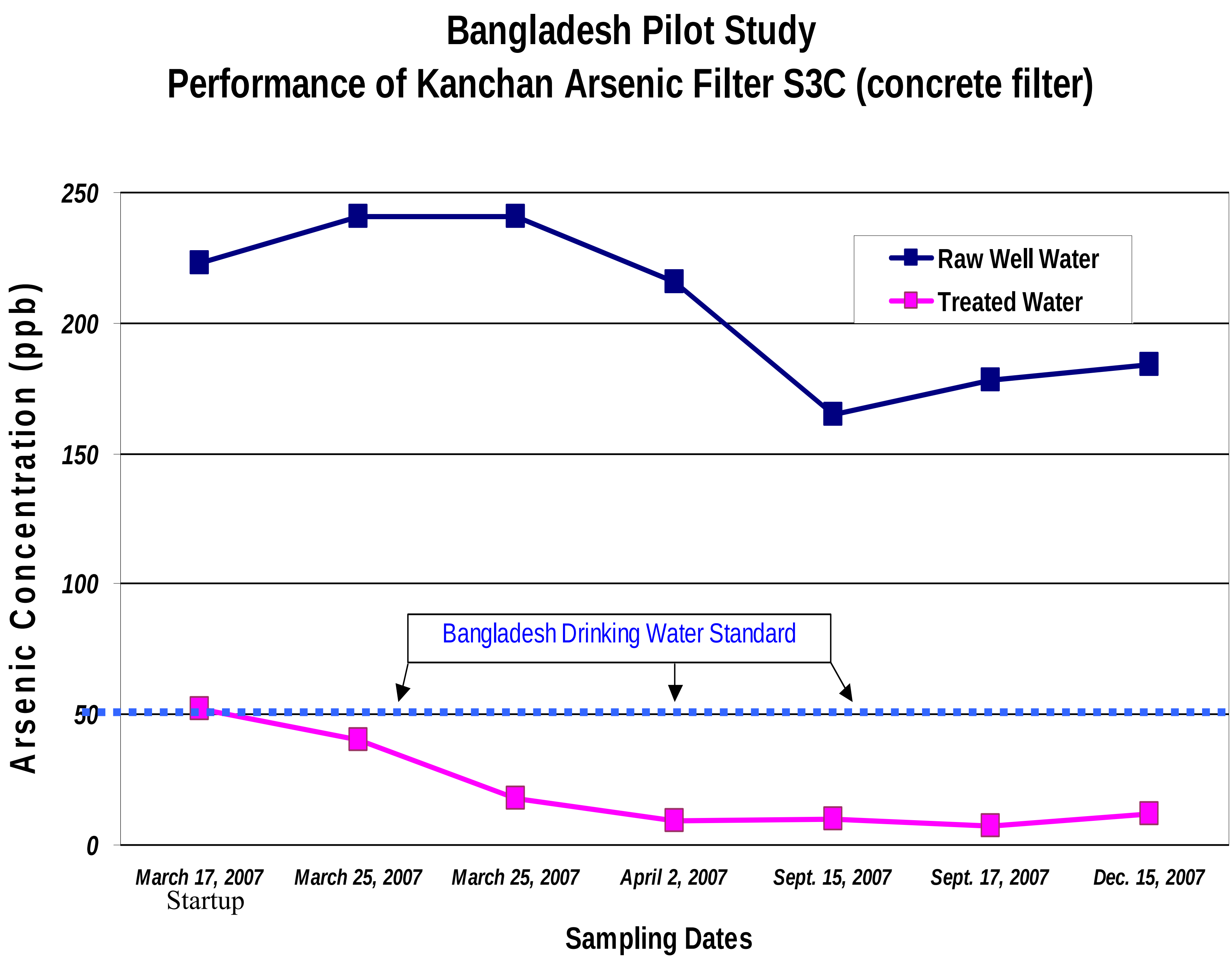
Photo by T. Mahin

Asia Arsenic Network Lab
Jessore, Bangladesh

Photos by T. Mahin

Bangladesh Pilot Study
Performance of Kanchan Arsenic Filter S4B (plastic filter)




Bangladesh Pilot Study
Performance of Kanchan Arsenic Filter S3C (concrete filter)
Arsenic Concentration (ppb)
250
200
150
100
50
0
Raw Well Water
Treated Water
Bangladesh Drinking Water Standard
March 17, 2007
Startup
March 25, 2007
March 25, 2007
April 2, 2007
Sept. 15, 2007
Sept. 17, 2007
Dec. 15, 2007
Sampling Dates

3 Parameters That Impact Arsenic Removal & Vary Tubewell by Tubewell

- **Phosphate** levels of in raw water. Bangladesh groundwater has relatively high phosphate levels Higher **phosphates** reduce arsenic % removals.
- **pH** above 7.5 can reduce arsenic % removal by reducing positive charge of iron. High pH significantly impacted performance of 1 of 8 filters during pilot study.
- Higher naturally occurring **iron** levels increase arsenic % removals.

Impact of Phosphates on Arsenic Removal by Adsorption Systems

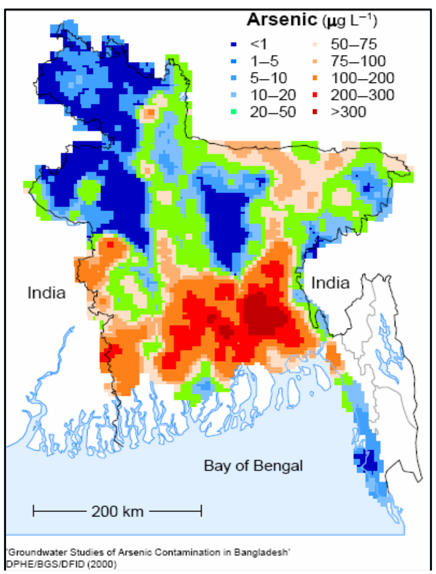
- Numerous studies have shown that phosphates can have a significant impact on the % arsenic removed by iron-based treatment systems.
- Because phosphates have similar chemical structure to arsenate (As^{+5}) they compete with arsenic for adsorption sites on iron oxides.
- For the same sample a phosphate result of 3 mg/L PO_4 = approximately 1 mg/L reported as P or PO_4-P.

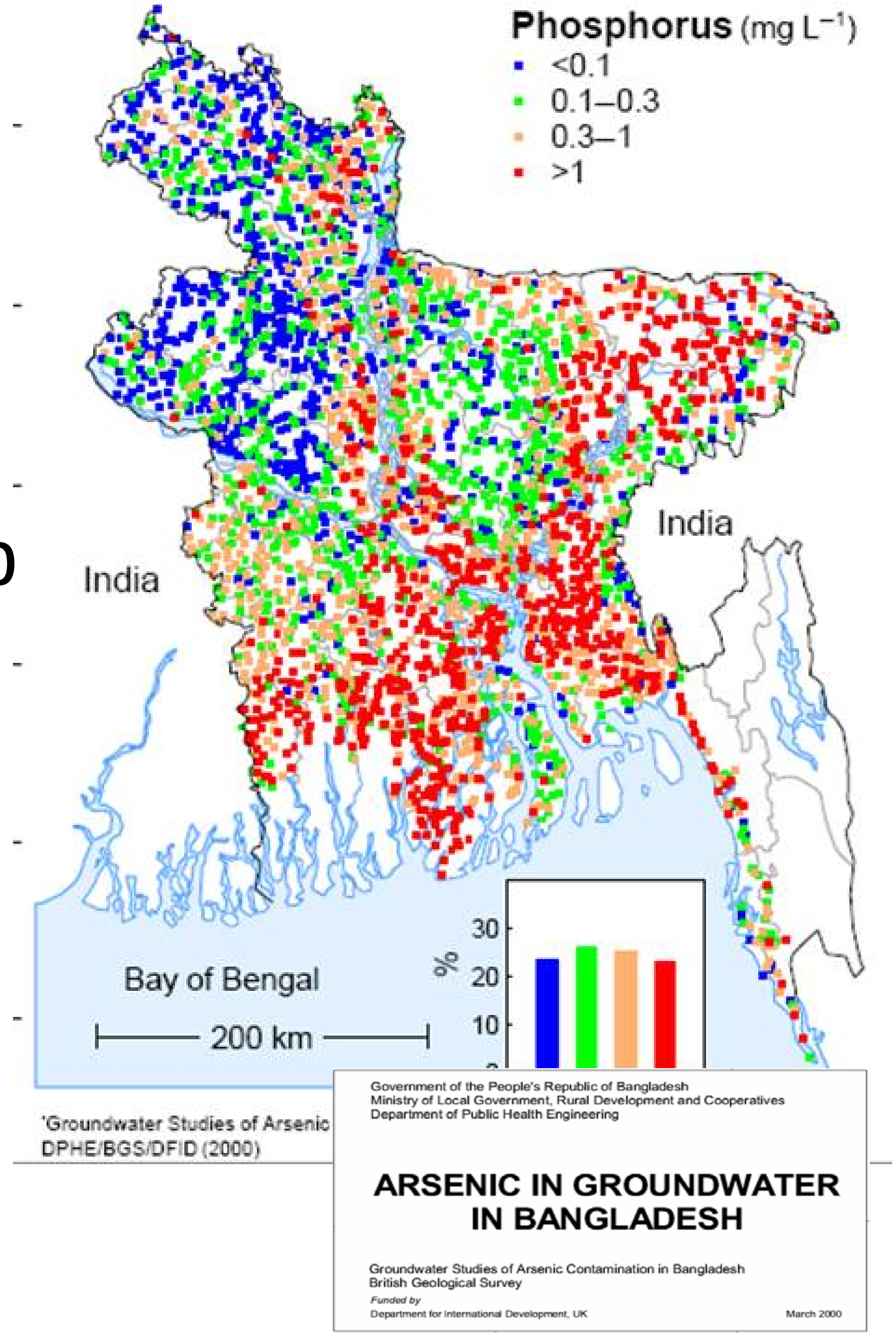
Origin of Phosphates in Ground Water

- The likely sources of phosphates are decomposition of organic matter and weathering of minerals.
- Similar to arsenic in Bangladesh, phosphates appear to be concentrated in high iron (hydr)oxides (often as coating on sediments) and are released naturally by the dissolution of iron (hydr)oxides initiated by reducing (low dissolved oxygen) conditions.
- Fertilizers can potentially also contribute phosphates at shallower groundwater depths but in Bangladesh there often is clay layer near the surface minimizing such impacts from the surface.

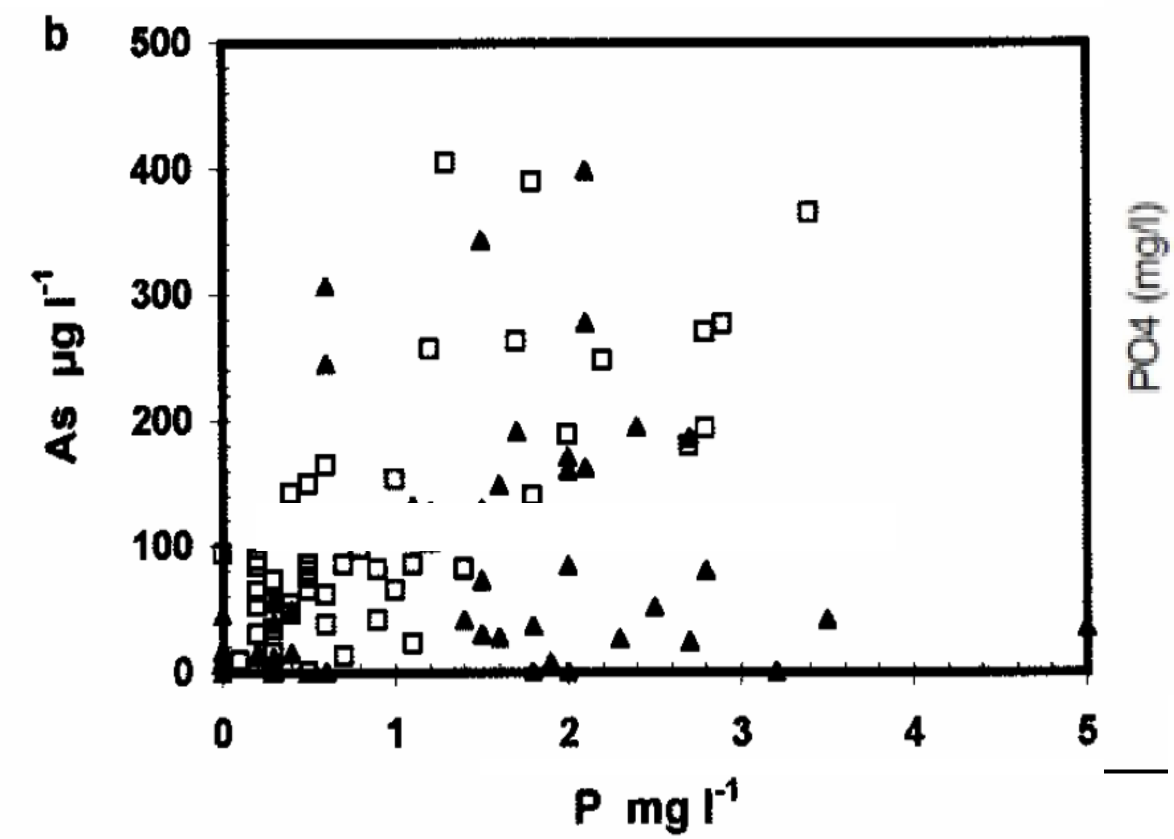
Bangladesh Phosphate Results (DPHE/BGS)

- 0.3 mg/L P (median) for 3,530 samples
- But when As > 50 ppb P averaged 1.5 mg/L (median - 1 mg/L)

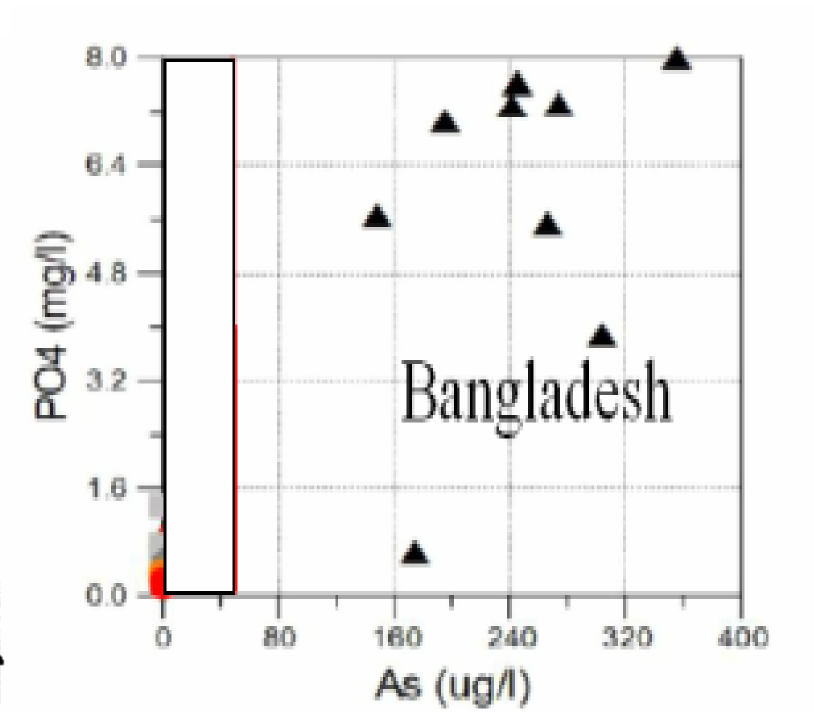




In High Arsenic Areas of Bangladesh Phosphates Are Often Elevated Though Levels Can Vary Significantly



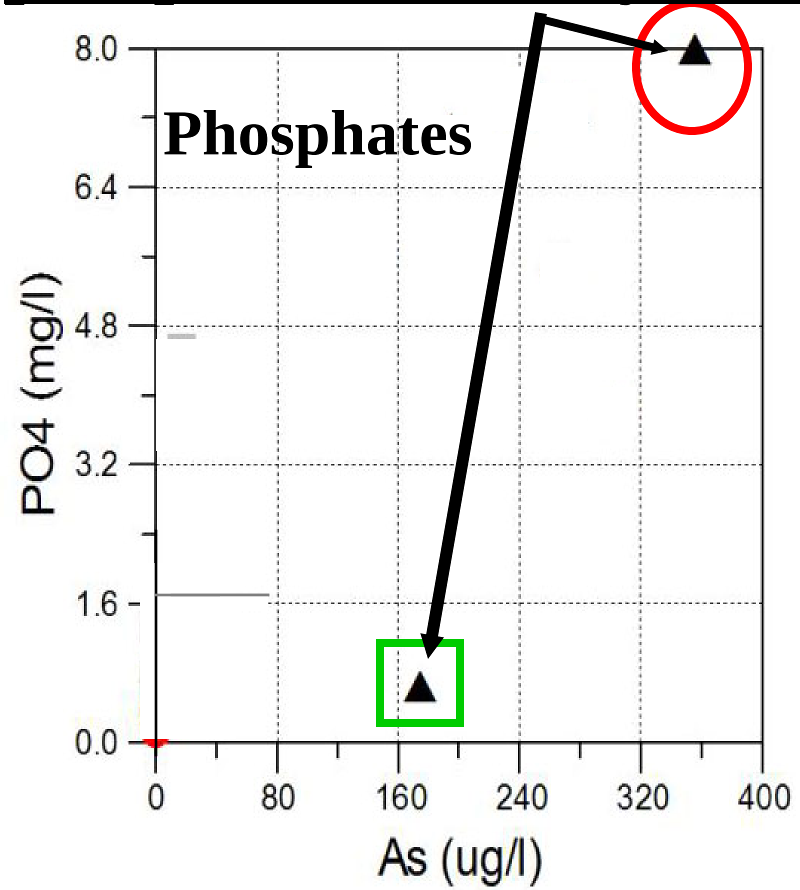
From McArthur et al. WATER RESOURCES RESEARCH (JANUARY 2001)

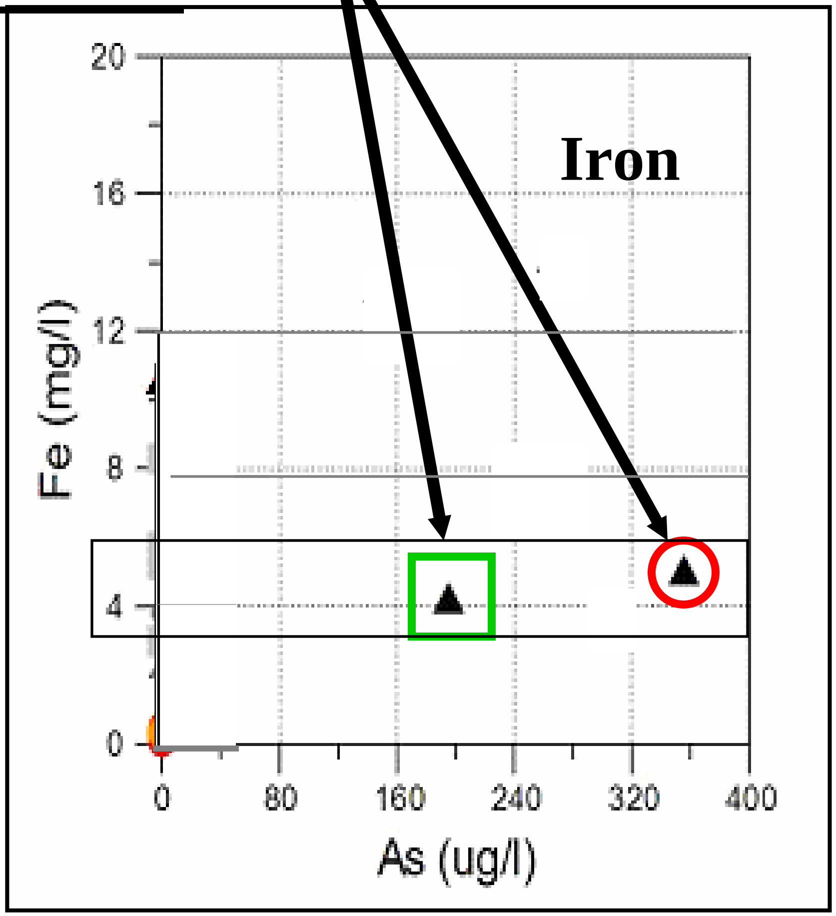


From "Targeting safe aquifers in regions with arsenic-rich groundwater in Bangladesh Case study in Matlab Upazill"a - Jonsson and Lundell (2004) Swedish University of

Ratio of Phosphates to Iron Vary by Individual Wells in Bangladesh Making Some Wells More Difficult to Treat Than Others

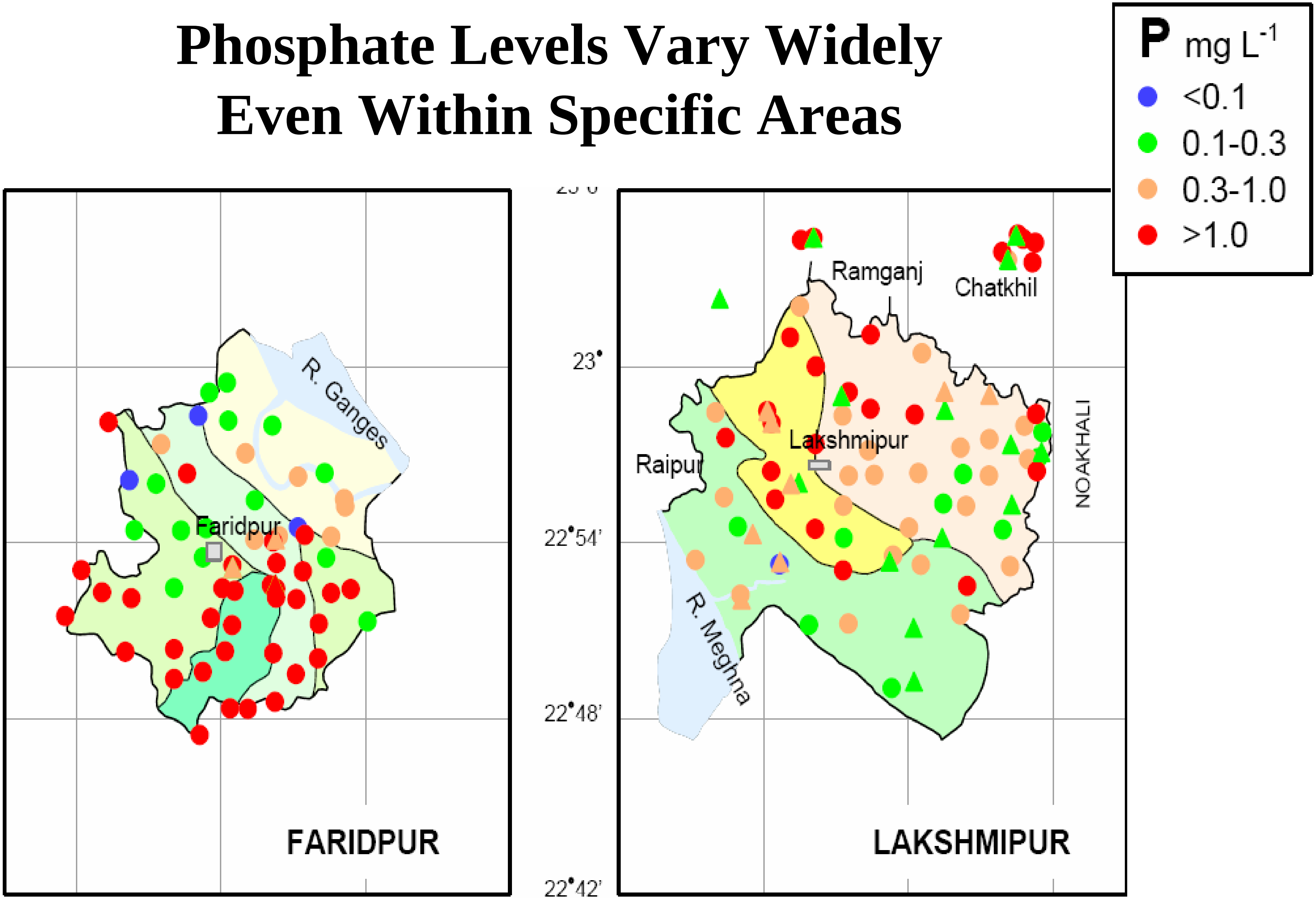
For ***Well # 1*** ***and*** ***Well # 2*** **iron levels are very similar** but **phosphates differ by a factor of 10**





Adapted From: Targeting safe aquifers in regions with arsenic-rich groundwater in Bangladesh Case study in Matlab Upazila - Jonsson and Lundell (2004) Swedish

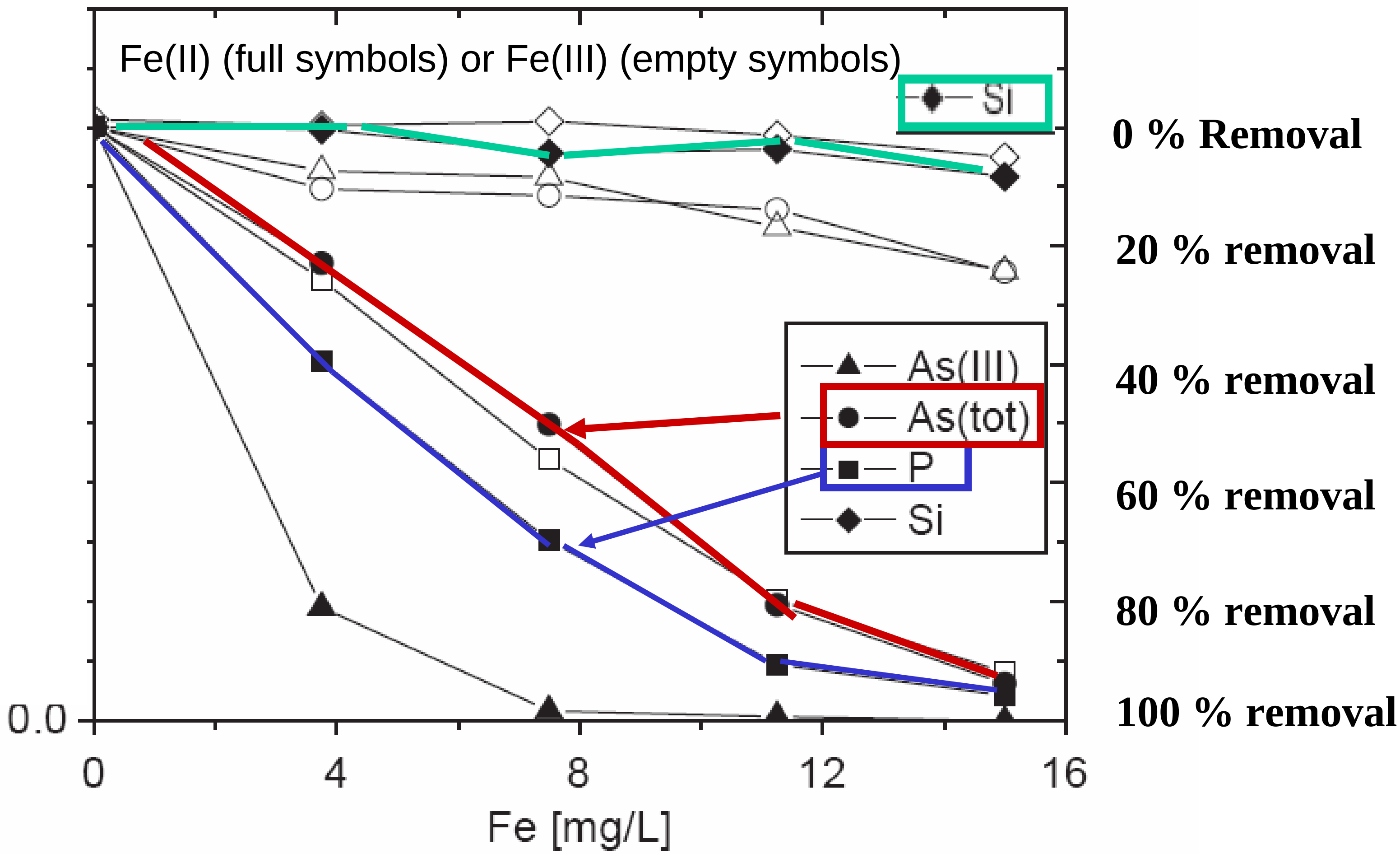
Phosphate Levels Vary Widely Even Within Specific Areas



Adapted from British Geological Survey/DPHE 2000

With Increasing Iron, Phosphates (P) & Arsenic Removal Increases

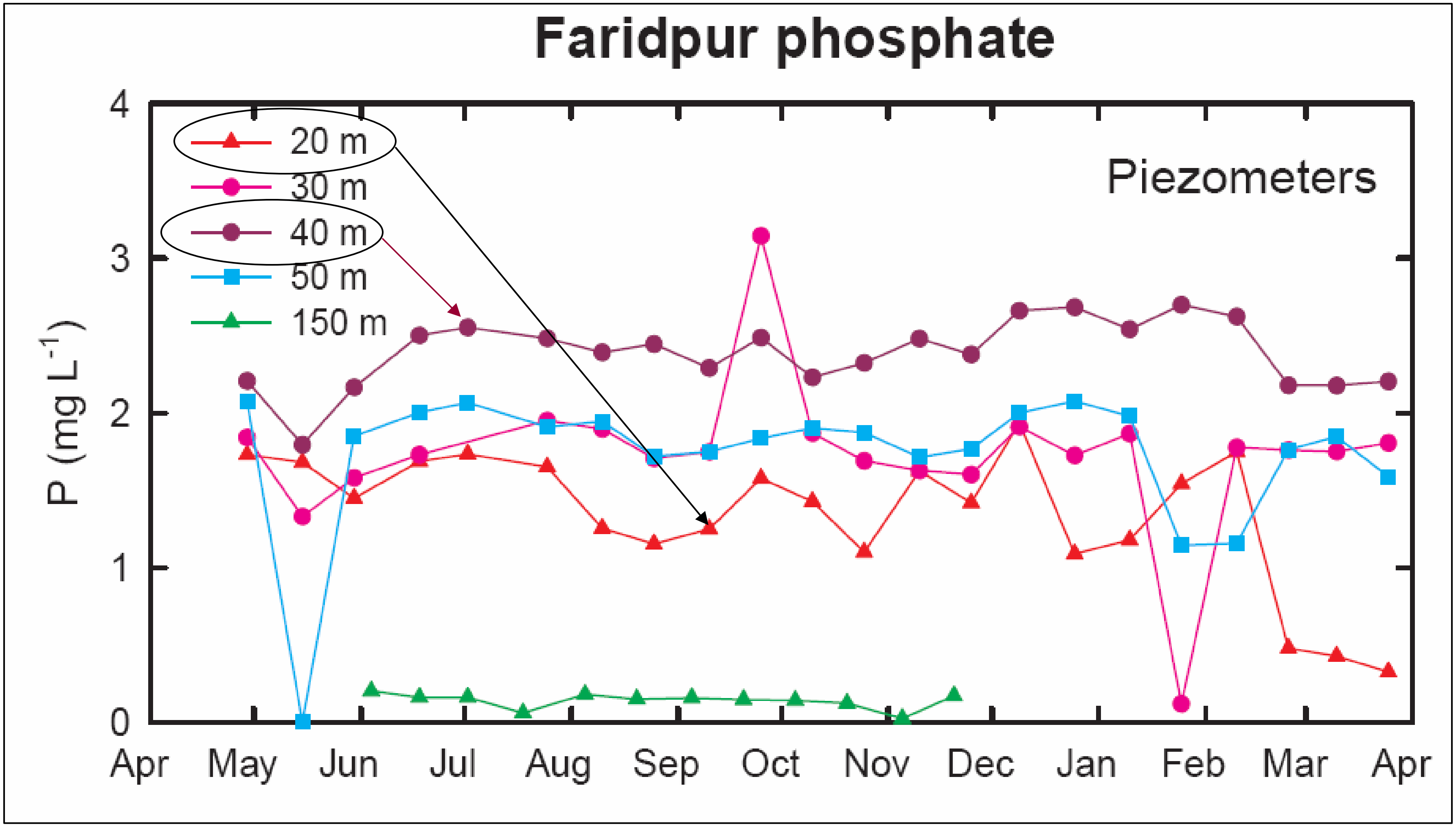
O.X. Leupin, S.J. Hug / Water Research 39 (2005)



Adapted from *O.X. Leupin, S.J. Hug / Water Research 39 (2005)*

Variation of Phosphates By Depth and by Month

(Charts from British Geological Survey – Bangladesh data)



Note - phosphate levels at 40 meters greater than phosphates at 20 m

Impact of High Phosphates on As Removal in 2 Sets of Wells with Similar Iron levels (sand filter no nails)

Arsenic (As) In well ug/L	As - filtered water	**% As removed**	Natural Iron in well ppm (no nails)	**Phosphates** (as PO_4-P) mg/L
Vietnam (high naturally occurring iron)				
223	21	91%	11	0.05
137	49	***64%*** --- ***cause*** →	11	***2.8***
70	9	87%	7	0.2
55	44	***20%*** → ***cause*** →	6	***3.7***

<u>Solution – Use 6 kg Nails to Increase Fe Levels & to Compensate for PO_4</u>

Bangladesh

171	25	85% **with nails**	8 + <u>iron from nails</u>	2.3

Raw Data from: Berg et al. "Arsenic Removal from Groundwater by Household Sand Filters – Comparative Field Study, Model Calculations, and Health Benefits"– *E S & T*

The Impact of Phosphates on % Removal of Arsenic by Sand Filters

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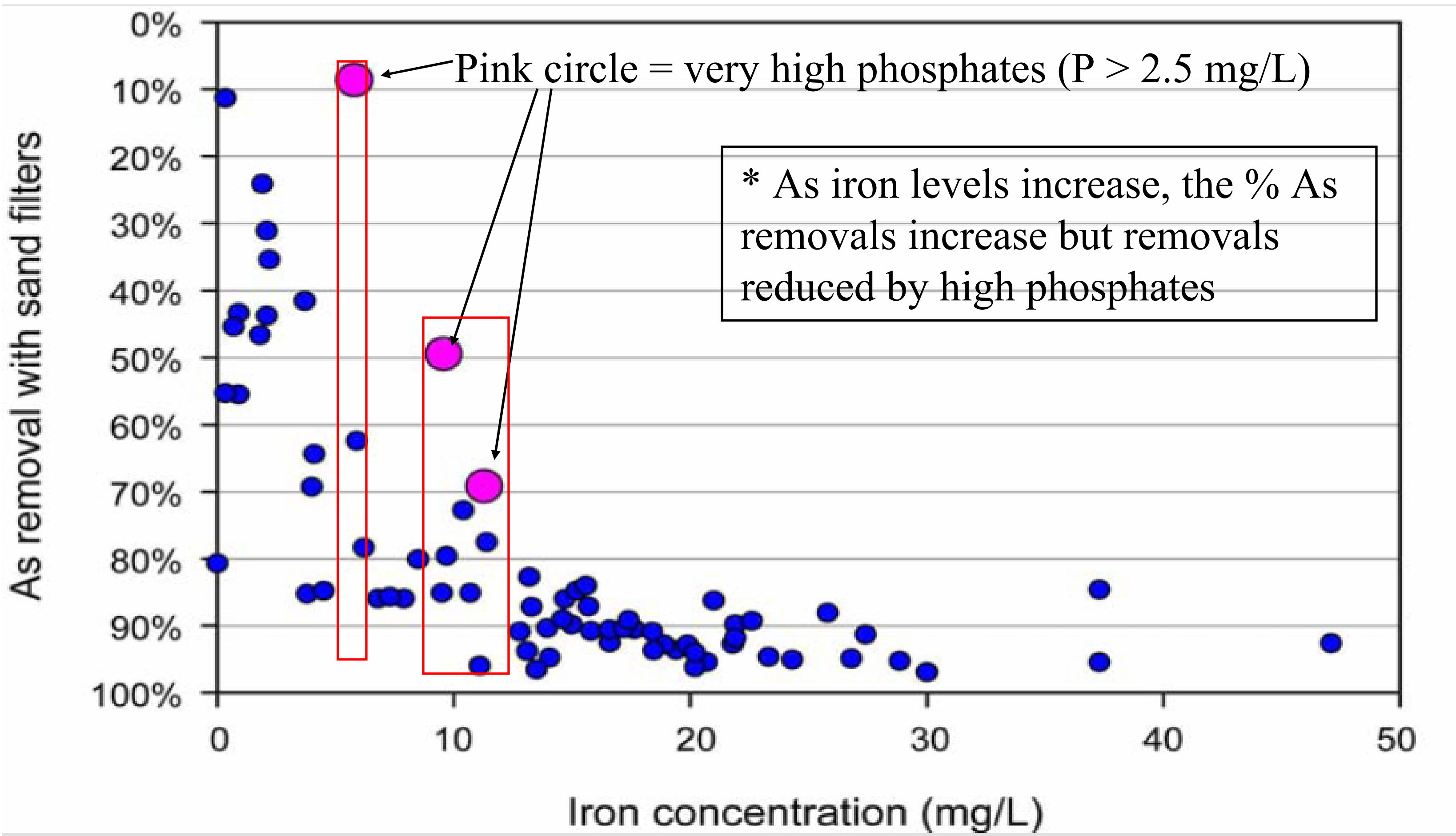
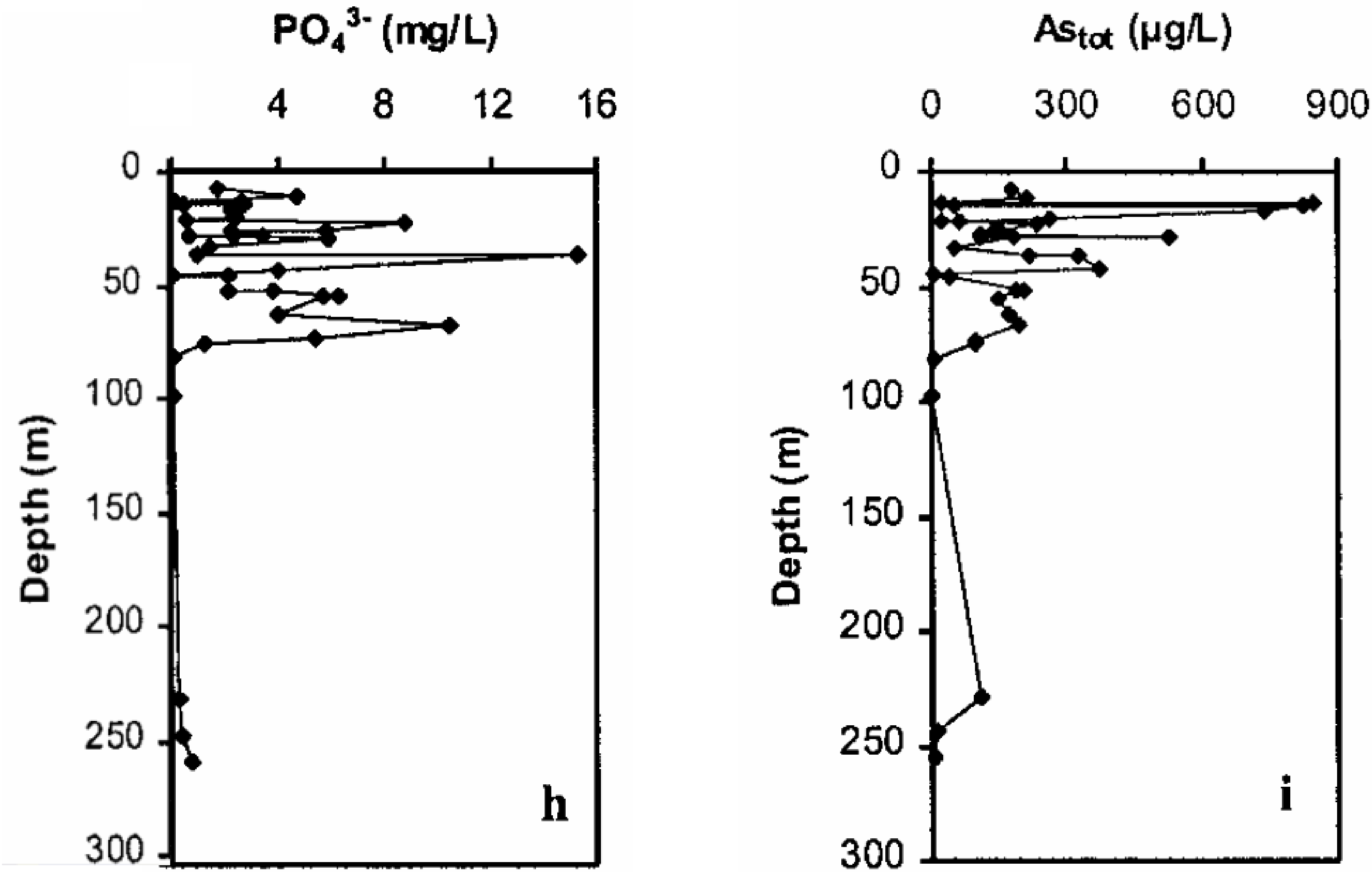


Adapted from graph by Berg et al., “Household Sand filters for Arsenic Removal – Technical Report” – EAWAG 2004

Comparison of Phosphates vs. Arsenic in One Area of Bangladesh

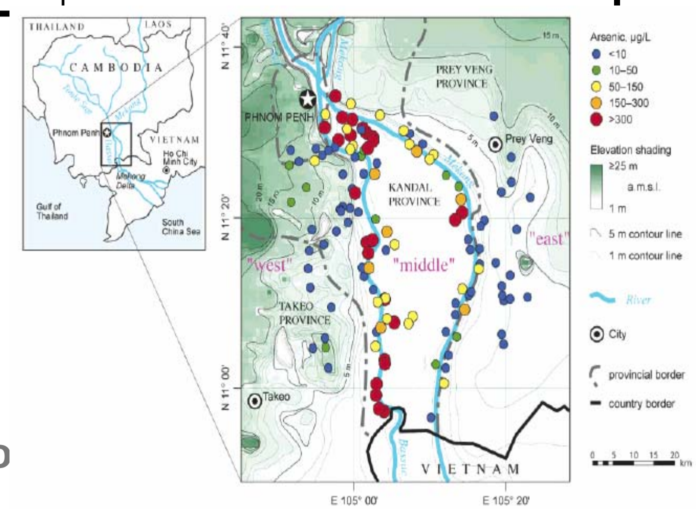


From: Bhattacharya et al., Bull. Environ. Contam. Toxicol. (2002)

<u>High Arsenic Area of Cambodia (Kandal Province)</u>

Generally has high Phosphate (PO_4-P) levels
& moderate Iron (Fe) levels

PO_4-P (mg/L)*	As (ug/L)*	Fe (mg/L)*
Average - 0.66 Range:<0.2–3.14	Average – 233 Range:1 -1340	Average – 2.8 Range<0.05-16



* - Data from Swiss Institute of Aquatic Science and Technology, Eawag, as published in Environ. Sci. Techno
2007, 41

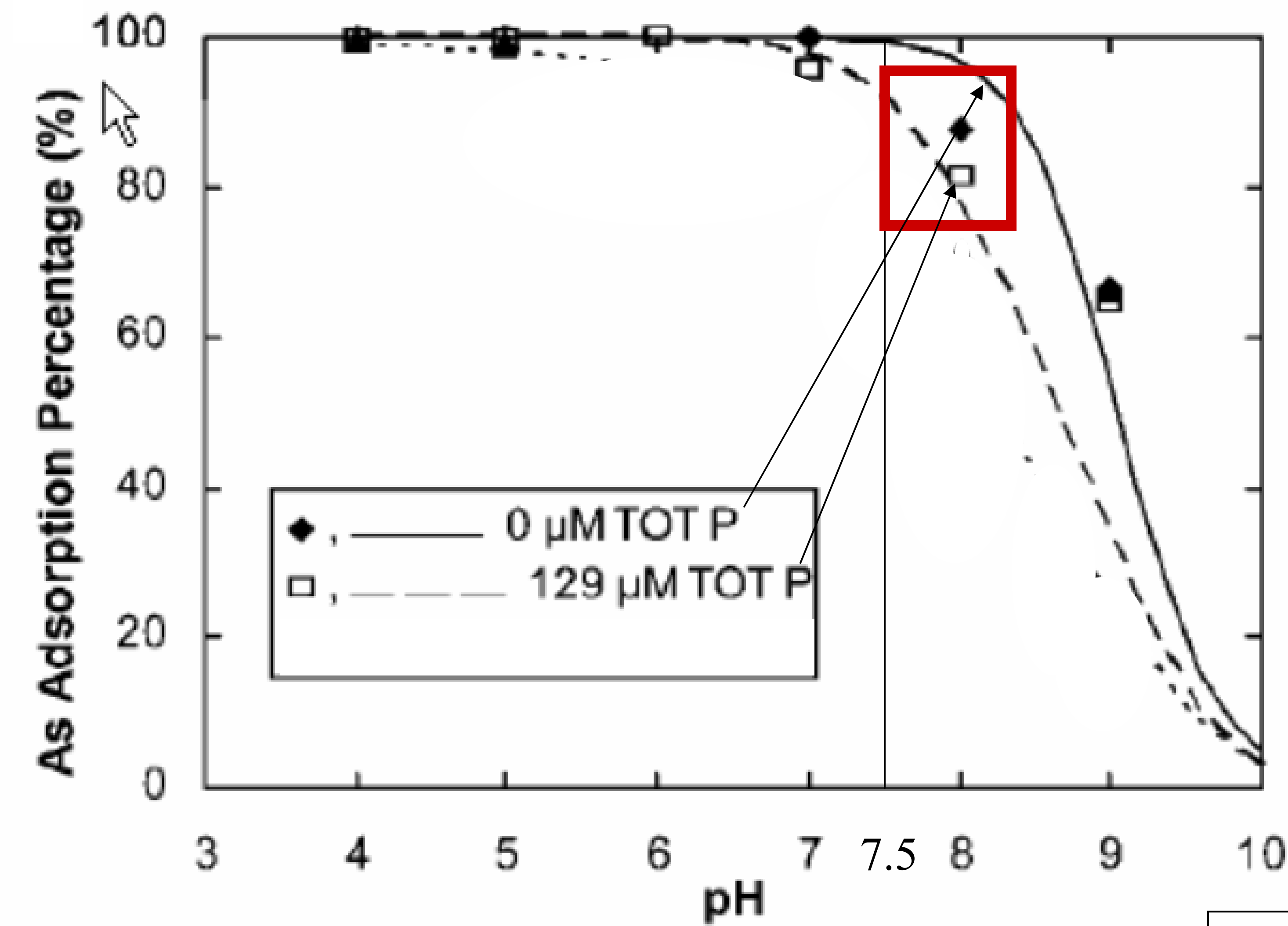
Summary - Impact of Phosphates

KEY POINTS

- Elevated phosphate levels decrease arsenic removal efficiency.
- In the pilot study this was compensated for by increasing the amount of nails from 5 to 6 kg. Of the wells tested in the pilot study none had performance problems caused by phosphates.

Impact of pH on Arsenic Removal

Example of Impact of Raw Water pH on % As Removal, Impact Increases when Phosphates Very High



If phosphates are high then tubewells with pH > 7.5 have reduced arsenic removal efficiency

From Zeng et al. 2008 in *E, S & T*

High pH Reduces + Charge of Iron Reducing % As Removal

(critical pH varies by type/form of iron)

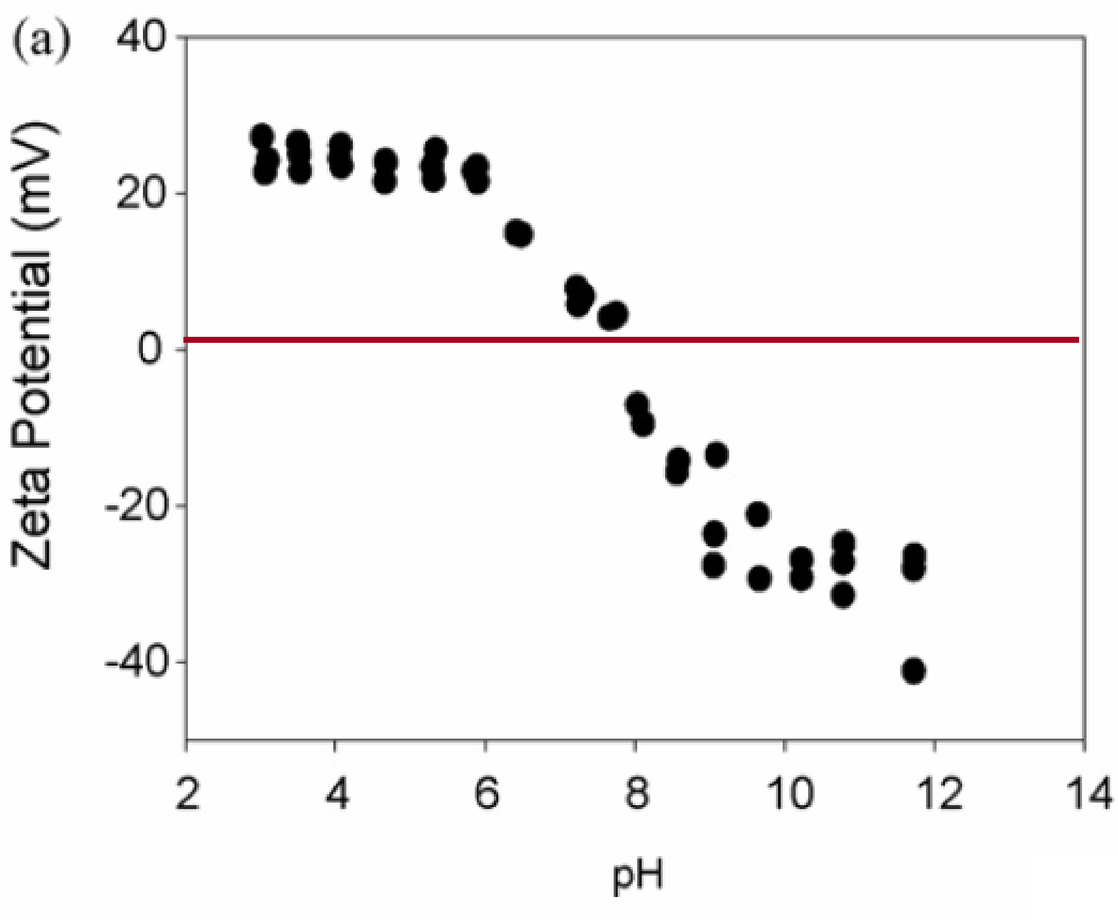
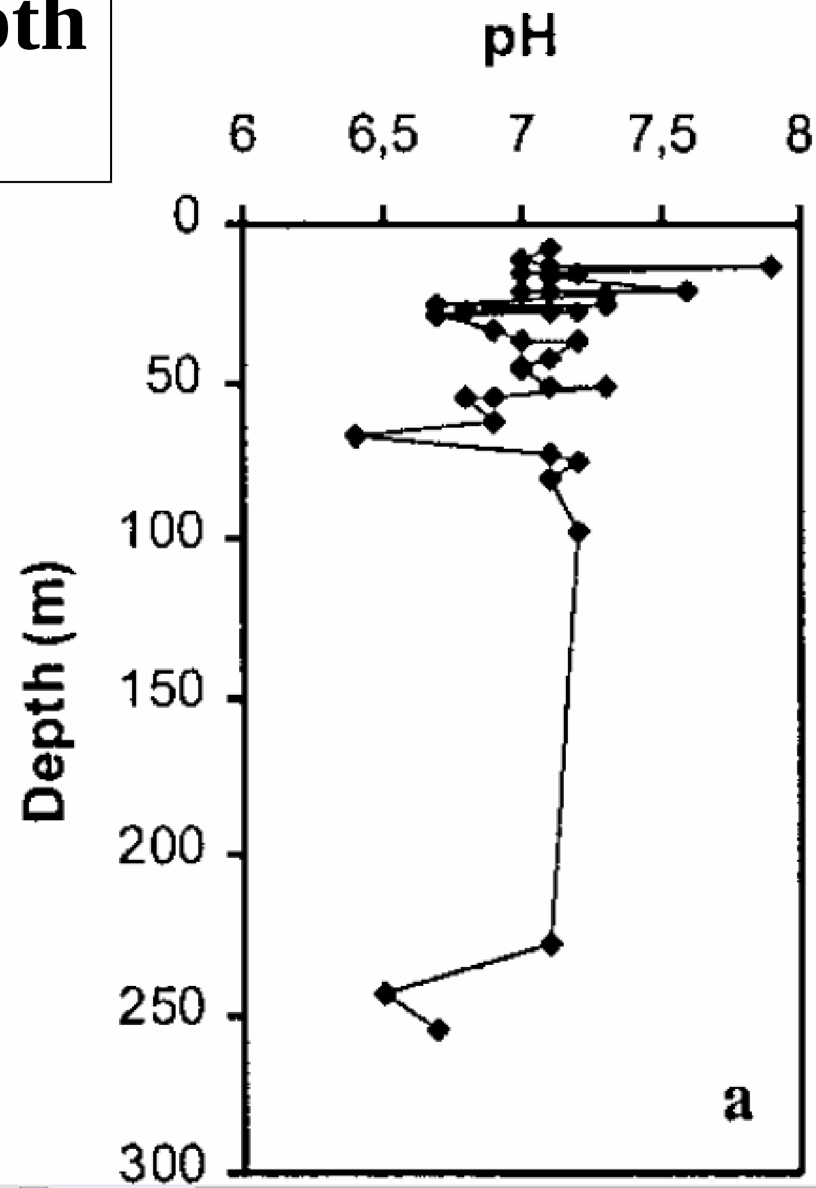


Fig. 1. (a) Zeta potential of GFH as a function of pH

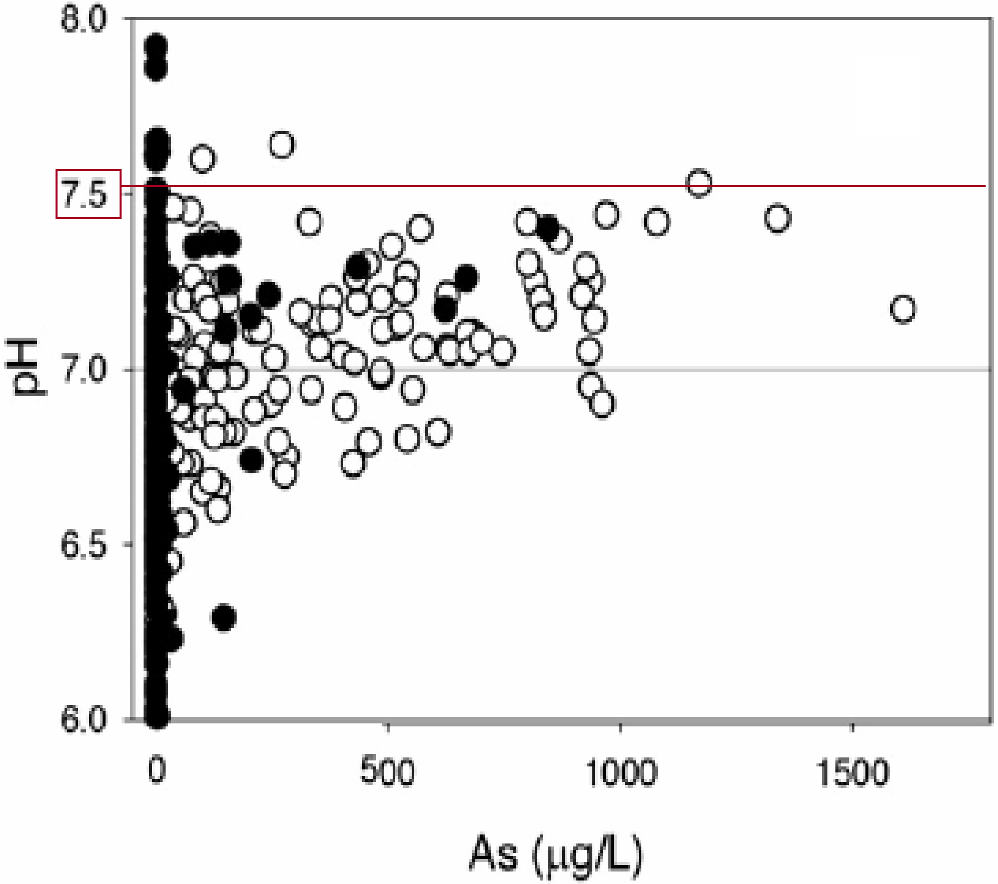
From: Guan et al. "Removal of arsenic from water using granular ferric hydroxide: Macroscopic and microscopic studies" Journal of Hazardous Materials 2008

Example of pH vs. Depth Bangladesh



From: Bhattacharya et al.
Bull. Environ. Contam. Toxicol. (2002)

pH Data from 207 Wells in Cambodia



Cambodia Data White Circles

Fig. 3. Bivariate plots of arsenic and selected parameters measured in groundwater samples of the upper Mekong Delta, Cambodia and Vietnam. Open circles (○) are samples from Cambodia (n = 207), black dots- (●) from southern Vietnam (n = 112). a) redox potential–arsenic, b) pH–arsenic, c) ammonium–arsenic, d) dissolved organic carbon–arsenic.

Data from Cambodia is non-filled in circles " O " (207 samples). From "Magnitude of arsenic pollution in the Mekong and Red River Deltas — Cambodia and Vietnam" by Berg et al. in Science of the Total Environment 2007

Example of pHs in High Arsenic Area - Nepal

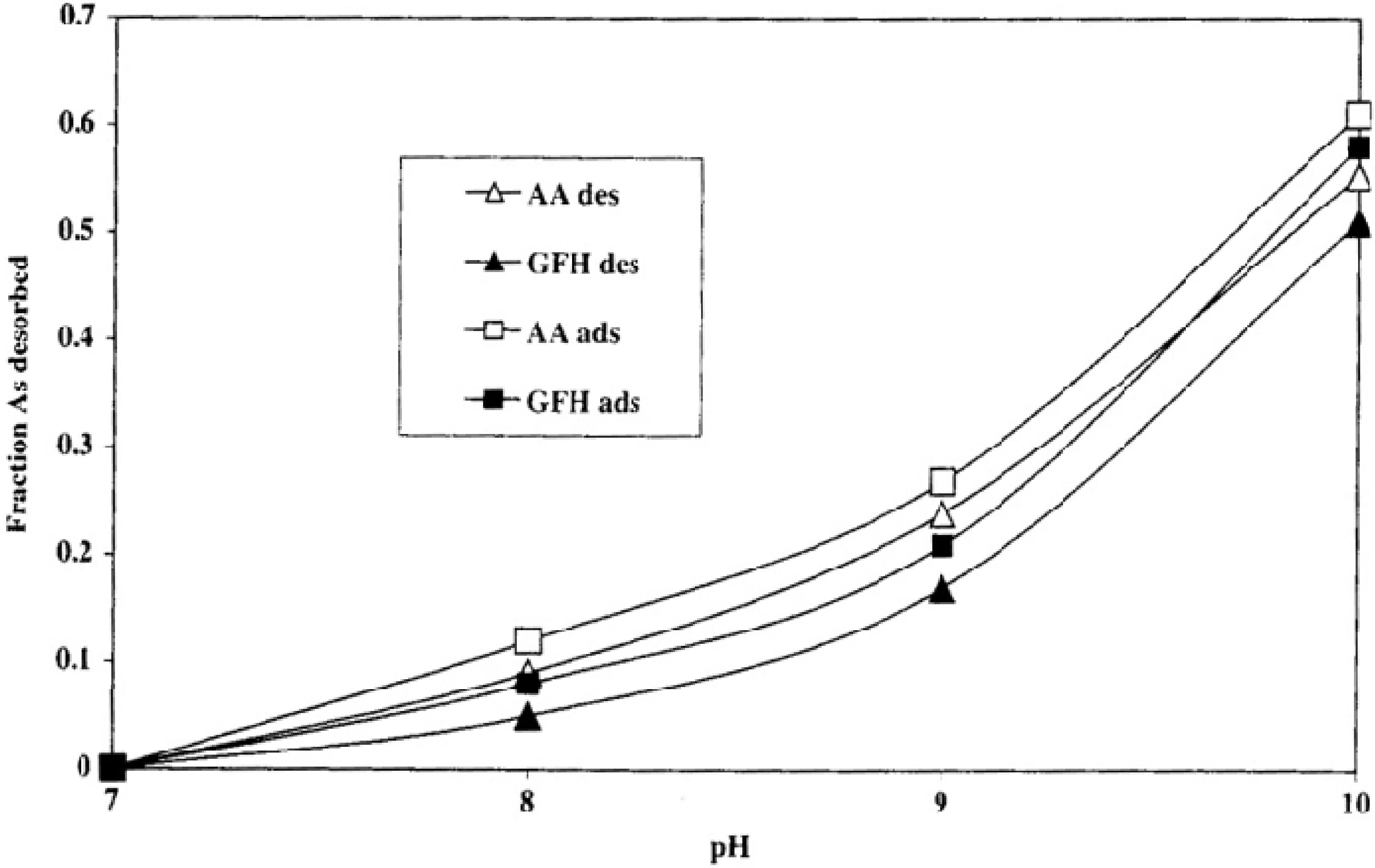
Table 5 Results from water analyses, Nawalparasi Nepal

Sample ID	As conc. (ppm)		Fe conc. (ppm)		pH
	AAS	Field kit	AAS	Field kit	
NP-1	0.35	0.35	4.5	3	7.2
NP-2	0.43	0.40	2.7	2	7.1
NP-3	< 0.01	0.15	4.1	3	7.1
NP-4	0.43	0.40	4.3	4	7.3
NP-5	0.74	0.50	2.0	1	7.5
NP-6	0.27	0.30	2.6	7	7.0
NP-7	0.24	0.30	2.9	3	7.2
NP-8	0.73	0.40	4.3	3	7.4
NP-9	0.29	0.35	7.5	3	7.0
NP-10	0.46	0.30	1.9	4	7.2
NP-11	0.31	0.30	19.5	4	7.3
NP-12	0.26	0.35	6.1	3	7.2
NP-13	0.41	0.40	12.1	4	7.4
NP-14	< 0.01	0.02	0.3	0.2	7.2

ND not detected

From Gurung et al. *Environmental Geology* (2005)

In Some Parts of the World High Arsenic is the Result of High pH GW That Causes Desorption of As From Iron Oxides



From: Gosh et al., Science of the Total Environment 2006

Impact of pH

Key Points

- High pH of tubewell water decreases percent removal of arsenic.

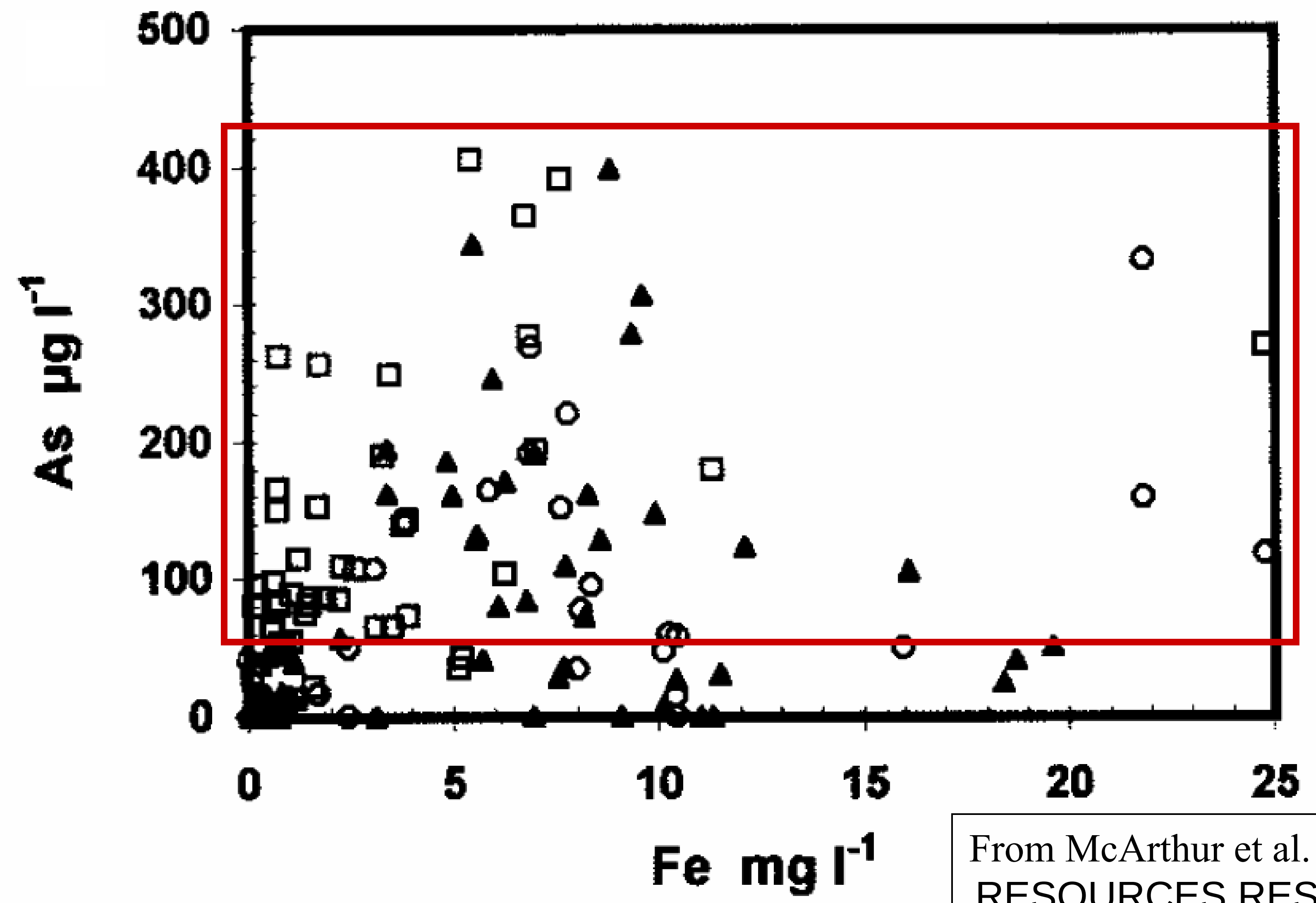
- While 1 well in Bangladesh had reduced arsenic removal (approx. 60% removal) due to high pH, the great majority of wells in Bangladesh (and it appears Cambodia) are near neutral and for these wells pH shouldn't be a problem.

- In countries with arid high pH areas (Argentina, Inner Mongolia, etc.) pilot testing would need to be performed to evaluate significance of high pH.

Impact of Iron

Photo by T. Mahin

Bangladesh
Iron Varies Greatly in High Arsenic Wells



From McArthur et al. WATER RESOURCES RESEARCH (JANUARY 2001)

Impact of Tubewell Iron Levels on Arsenic Treatment Efficiency

- Iron levels in tubewells vary from arsenic levels.
- Naturally occurring high iron levels increase % removals of arsenic and can help compensate for high phosphate levels.
- Even with high iron levels in raw water (tubewell) KAF effectively removes iron.