



British  
Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



[www.bgs.ac.uk](http://www.bgs.ac.uk)

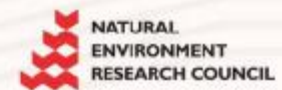
# Arsenic in groundwater – natural sources, mobilisation controls and the question of human influences

Pauline Smedley

British Geological Survey, Wallingford, UK

Maclean Building  
Crowmarsh Gifford  
Wallingford OX10 8BB  
Tel 01491 838800

© NERC All rights reserved





# Arsenic in rock-forming minerals

Mineral	As concentration range (mg kg <sup>-1</sup> )
<b>Sulphide minerals:</b>	
Pyrite	100–77,000
Pyrrhotite	5–100
Marcasite	20–126,000
Galena	5–10,000
Sphalerite	5–17,000
Chalcopyrite	10–5000
<b>Oxide minerals:</b>	
Haematite	up to 160
Fe oxide (undifferentiated)	up to 2000
Fe(III) oxyhydroxide	up to 76,000
Magnetite	2.7–41
Ilmenite	<1
<b>Silicate minerals:</b>	
Quartz	0.4–1.3
Feldspar	<0.1–2.1
Biotite	1.4
Amphibole	1.1–2.3
Olivine	0.08–0.17
Pyroxene	0.05–0.8
<b>Carbonate minerals:</b>	
Calcite	1–8
Dolomite	<3
Siderite	<3
<b>Sulphate minerals:</b>	
Gypsum	<1–6
Barite	<1–12
Jarosite	34–1000
<b>Others:</b>	
Apatite	<1–1000

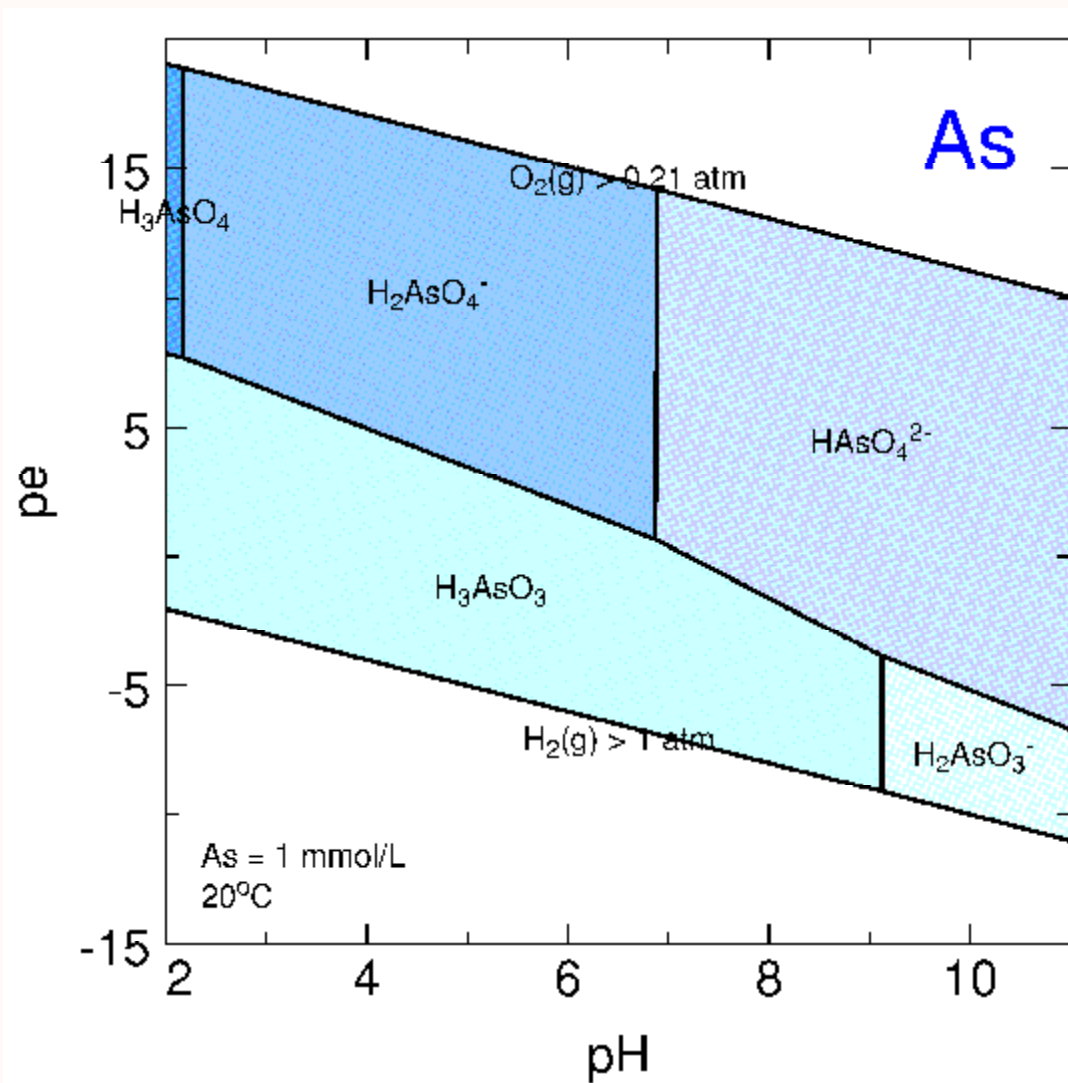


British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



www.bgs.ac.uk



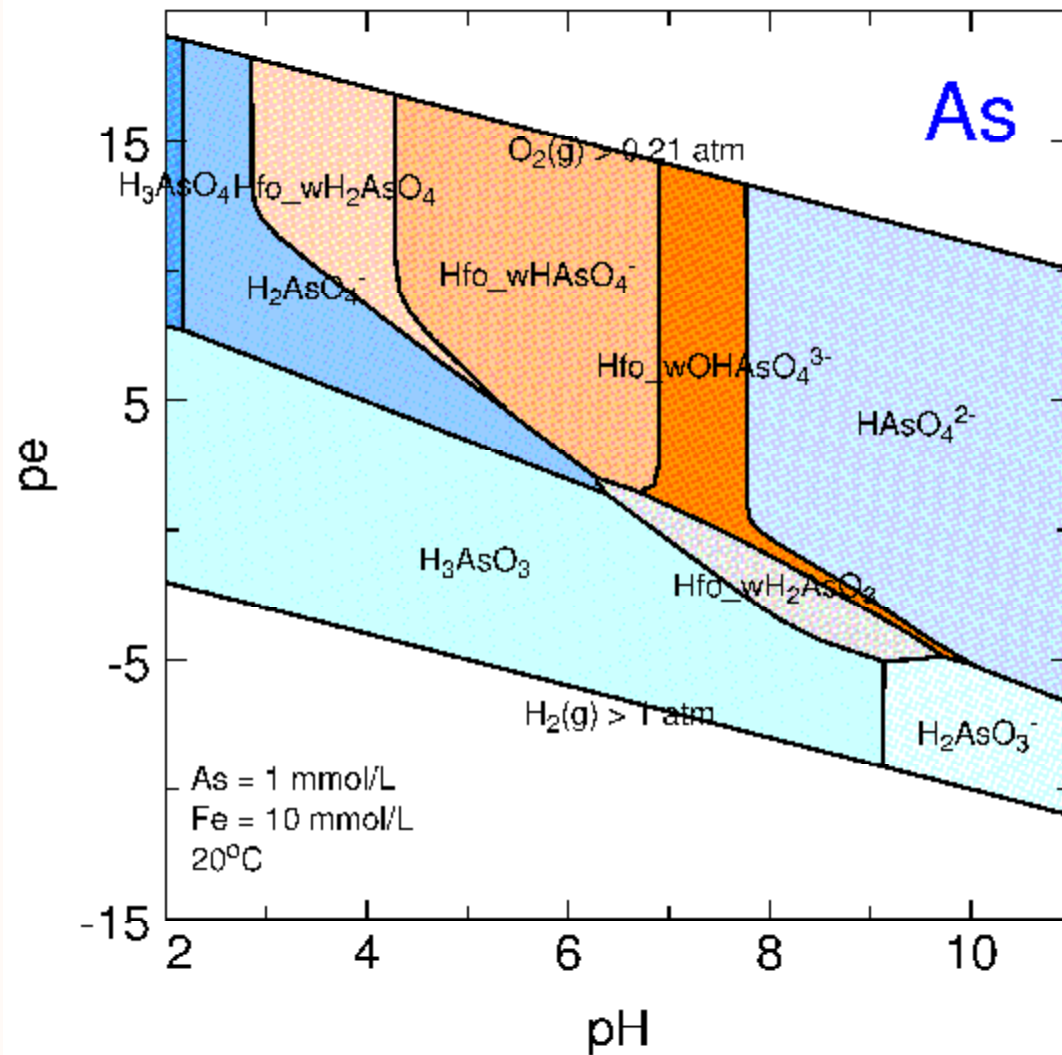


British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



www.bgs.ac.uk





**British Geological Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL



[www.bgs.ac.uk](http://www.bgs.ac.uk)





British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



www.bgs.ac.uk



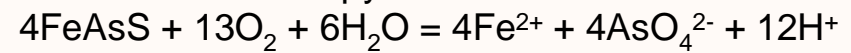
Mine workings



Mine drainage

## Mining-related arsenic problems: Obuasi (Ashanti), Ghana

Oxidation of arsenopyrite:





British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



www.bgs.ac.uk

## Obuasi, Ghana



Mine tailings pond



Downstream of effluent discharge:  $350 \mu\text{g L}^{-1}$

Tailings effluent  $1.8 \text{ mg L}^{-1} \text{ As}$



British  
Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



www.bgs.ac.uk

## Obuasi (Ghana) drinking water

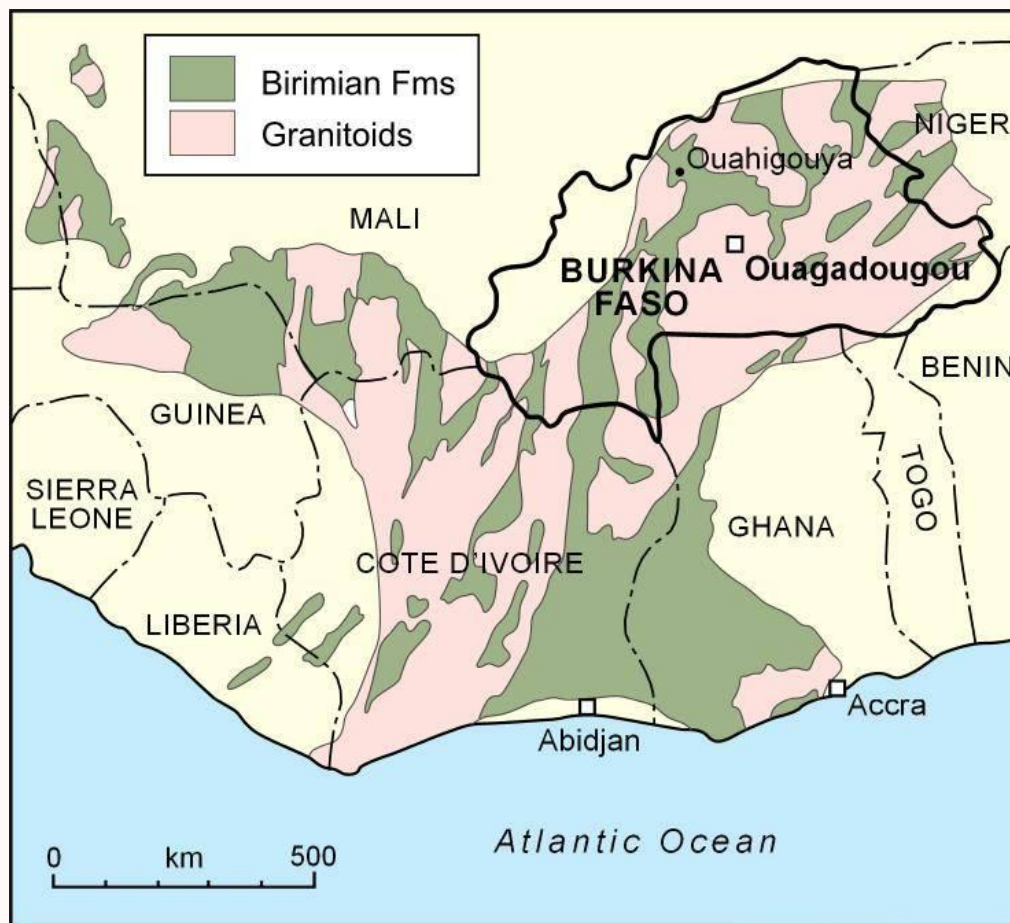


Streamwaters:  $<2-175 \mu\text{g L}^{-1}$

Groundwaters: median  $<2 \mu\text{g L}^{-1}$  (up to  $64 \mu\text{g L}^{-1}$ )



## Precambrian formations of West Africa





British  
Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



[www.bgs.ac.uk](http://www.bgs.ac.uk)



## Artisanal mining, Burkina Faso



British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



[www.bgs.ac.uk](http://www.bgs.ac.uk)

## Drinking water, Burkina Faso

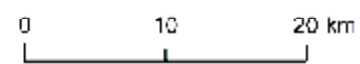
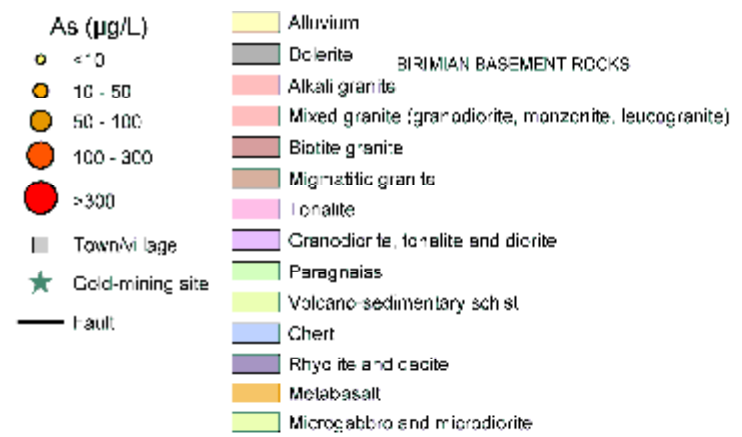
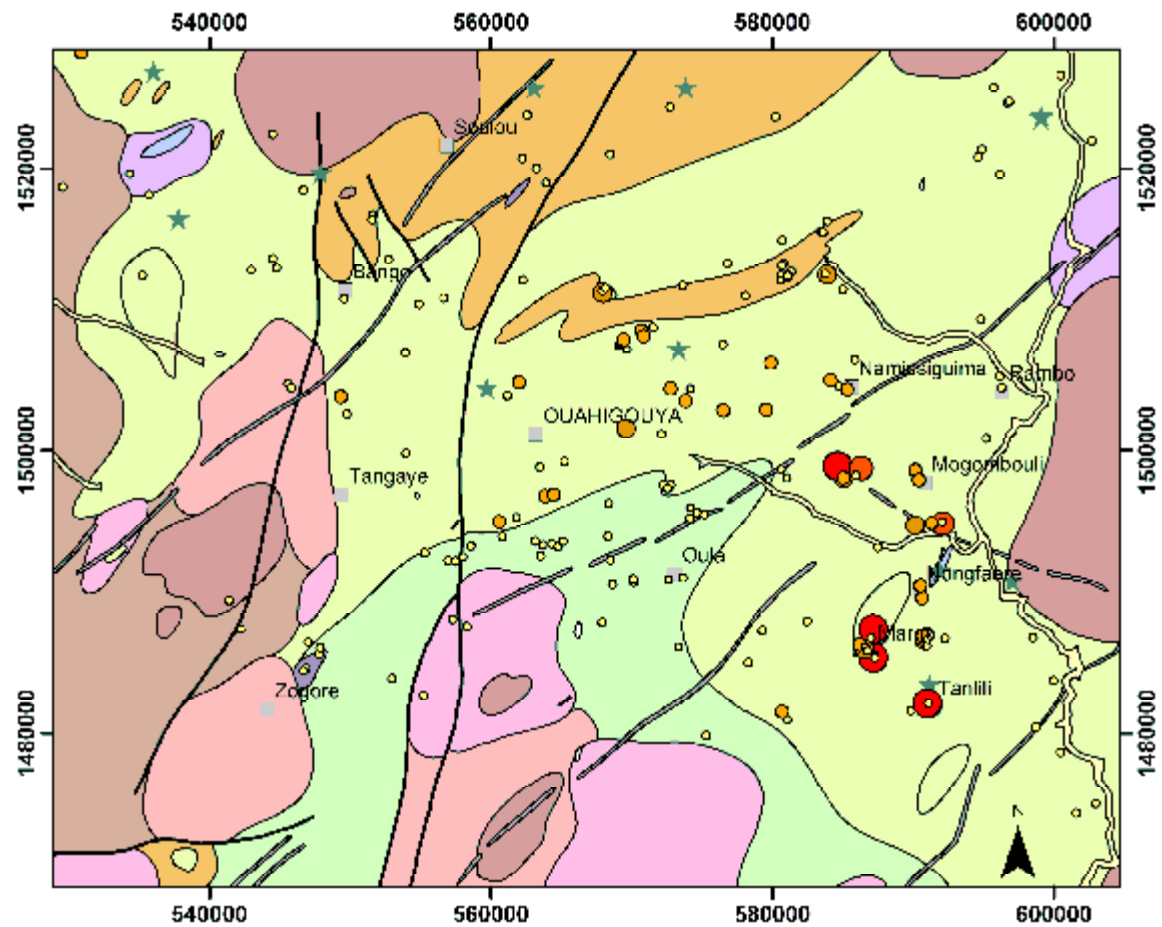




## Burkina Faso groundwater

Parameter	Units	Range	Median	Range	Median
		N=9		N=36	
		Wells		Boreholes	
pH		5.2 – 7.0	5.7	5.8 – 7.8	7.1
DO	mg L <sup>-1</sup>	1.4 – 4.5	3.3	<0.1 – 5.8	0.8
SEC	μS cm <sup>-1</sup>	40 - 201	65	54 – 1770	369
SO <sub>4</sub>	mg L <sup>-1</sup>	<0.2 – 33	0.38	<0.2 – 657	6.8
NO <sub>3</sub> -N	mg L <sup>-1</sup>	<0.05 – 5.5	2.1	<0.05 – 22	1.05
Fe	mg L <sup>-1</sup>	0.009 – 0.11	0.03	0.005 – 0.69	0.008
Mn	μg L <sup>-1</sup>	1.5 – 1450	18	0.2 – 99	1.1
As	μg L <sup>-1</sup>	<0.5 – 6.1	1.5	<0.5 – 1630	15







British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



[www.bgs.ac.uk](http://www.bgs.ac.uk)



## Skin lesions, Burkina Faso



# Arsenic in young sediments

Aquifer/sediment	As range (average) (mg kg <sup>-1</sup> )
Average sedimentary rocks	5-10
Continental margin sediments	2-8
Lake sediments	2-40
Loess (USA)	8-12
Marine shale	3-15
Non-marine shale/mudstone	3-12
Stream and lake silt (Canada)	<1-72 (6)
Loess silts (Argentina)	3-18
Alluvial sands/silts (Bangladesh)	2-12
Alluvial clay/silt/sand (Nepal Terai)	2-31 (9)
Alluvial/lake silts (Inner Mongolia)	3-29 (12)
Alluvial sands/silts (Vietnam)	2-33 (7)



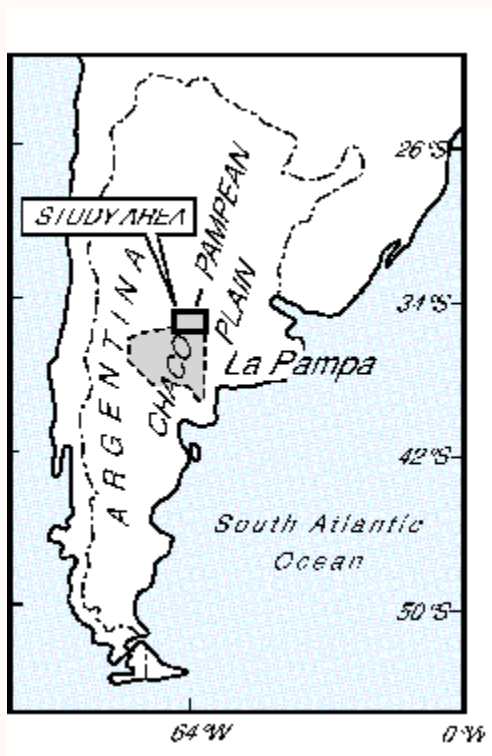
British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



www.bgs.ac.uk

# Arid inland basins: La Pampa, Argentina





Quaternary loess deposits

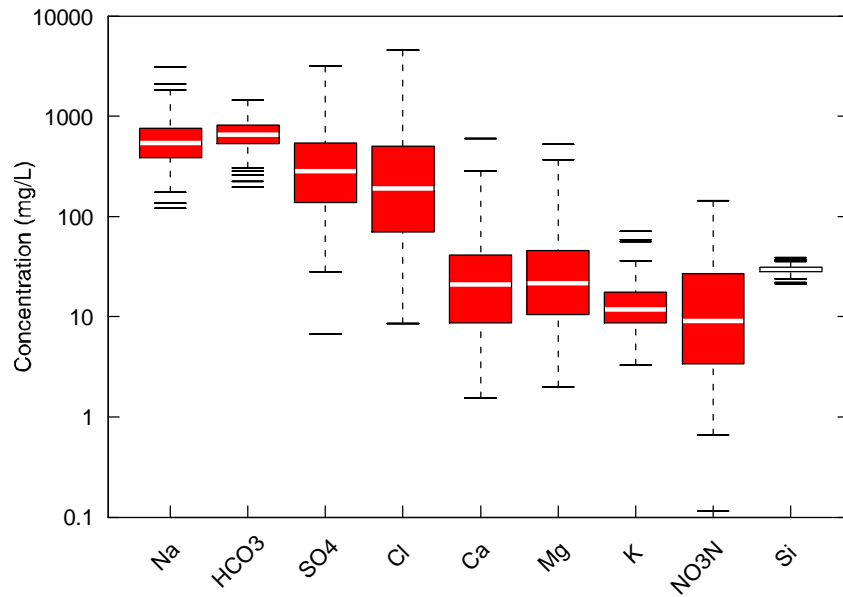


La Pampa, Argentina

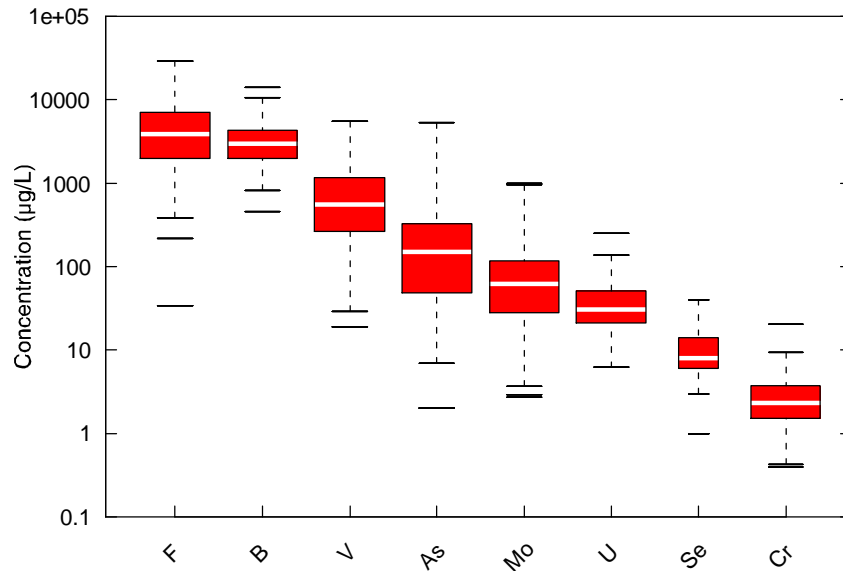


Evaporating ponds (semi-arid)

### Major elements



### Trace elements



## La Pampa groundwaters (n=108)

Parameter	Units	Min	Max	Median
pH		7.0	8.7	7.9
SEC	µS cm <sup>-1</sup>	773	17500	2610
DO	mg L <sup>-1</sup>	0.8	9.9	6.1
Cl	mg L <sup>-1</sup>	8.5	4580	192
HCO <sub>3</sub>	mg L <sup>-1</sup>	195	1440	653
SO <sub>4</sub>	mg L <sup>-1</sup>	6.8	3200	290
As <sub>T</sub>	µg L <sup>-1</sup>	<4	5300	150
As(III)	µg L <sup>-1</sup>	<3	110	4.2
Fe	mg L <sup>-1</sup>	<0.006	1.1	0.055
Mn	µg L <sup>-1</sup>	<1	79	2
F	mg L <sup>-1</sup>	0.03	29	3.8

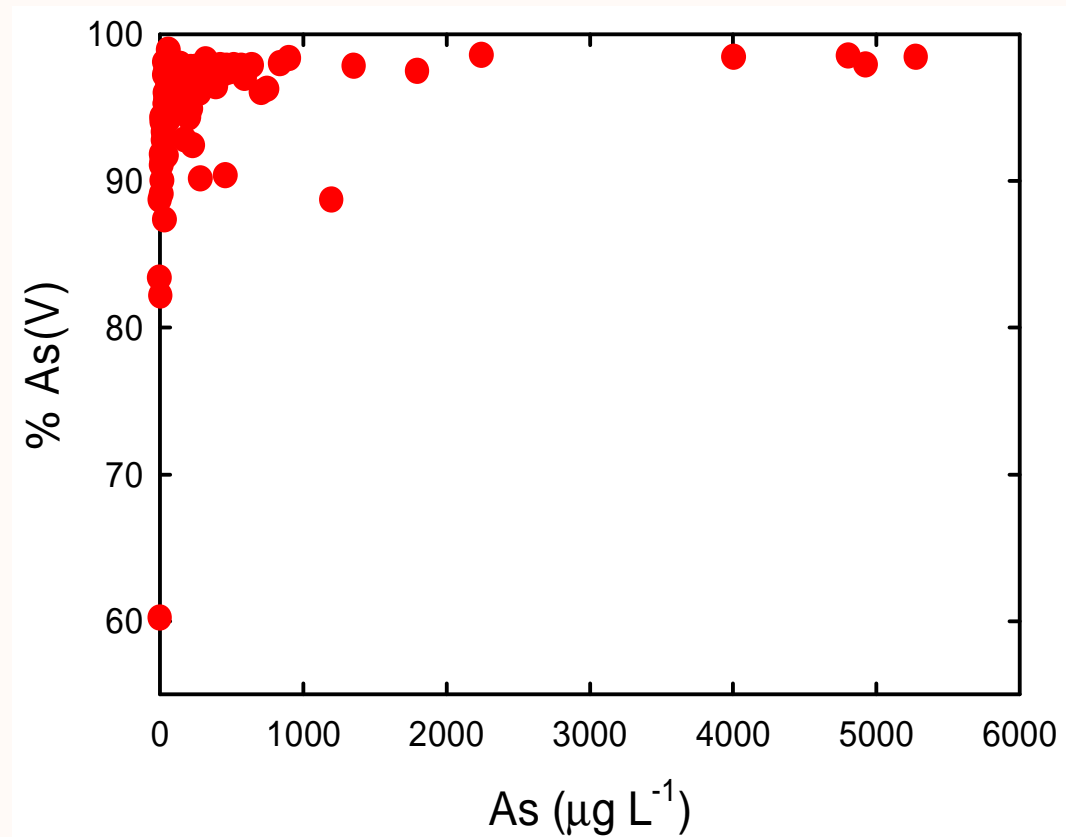


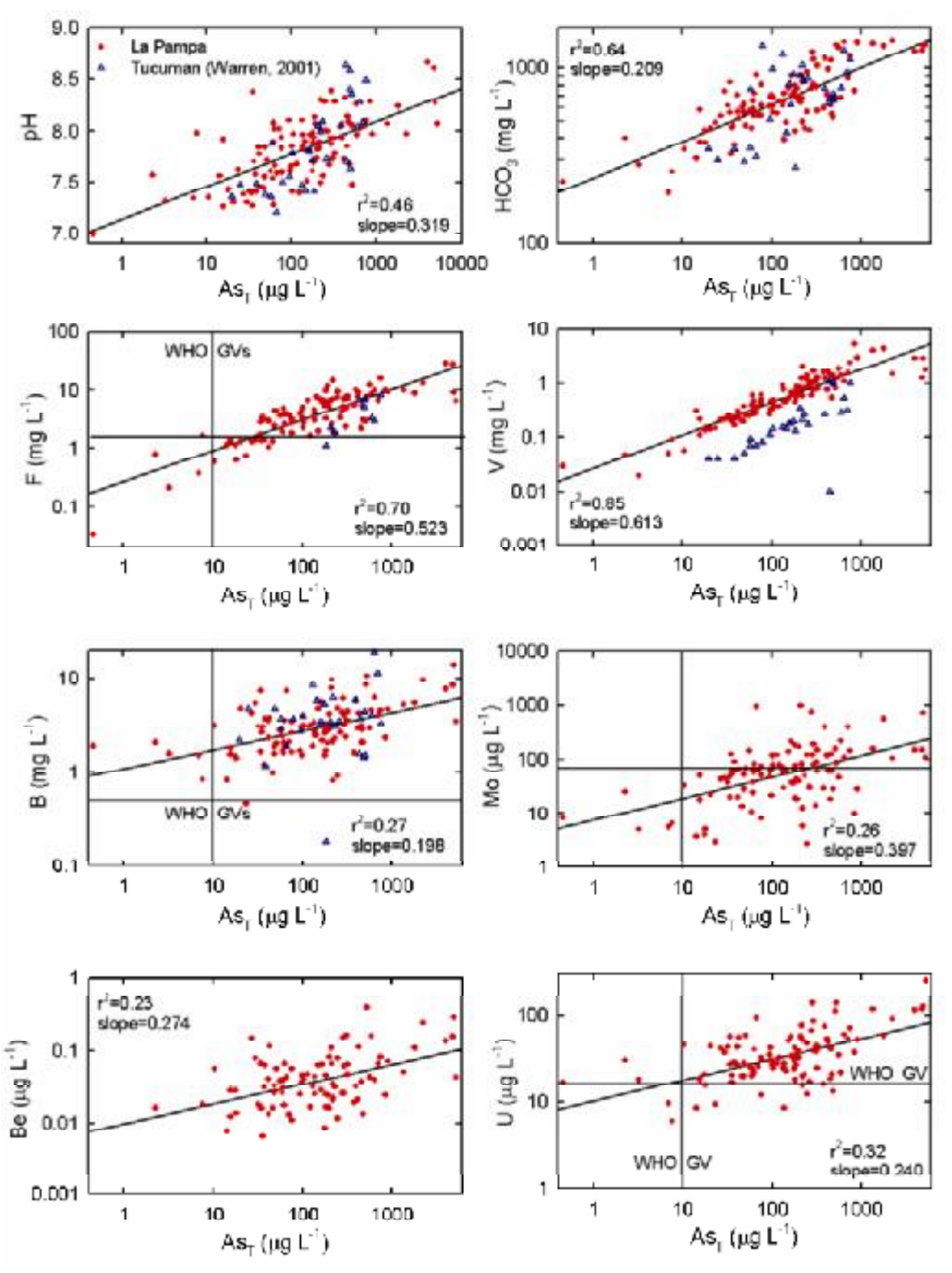
British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



[www.bgs.ac.uk](http://www.bgs.ac.uk)





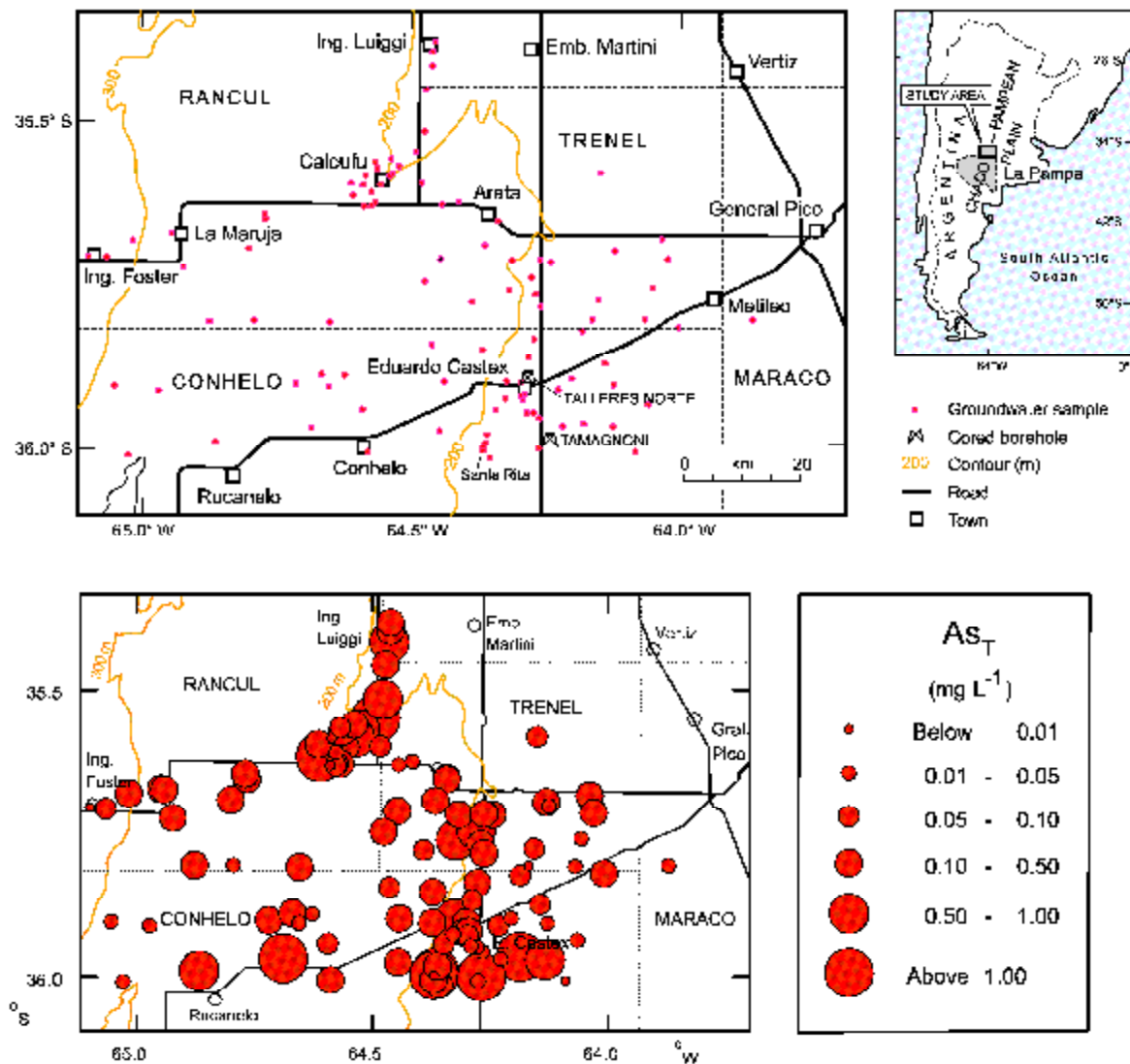


British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



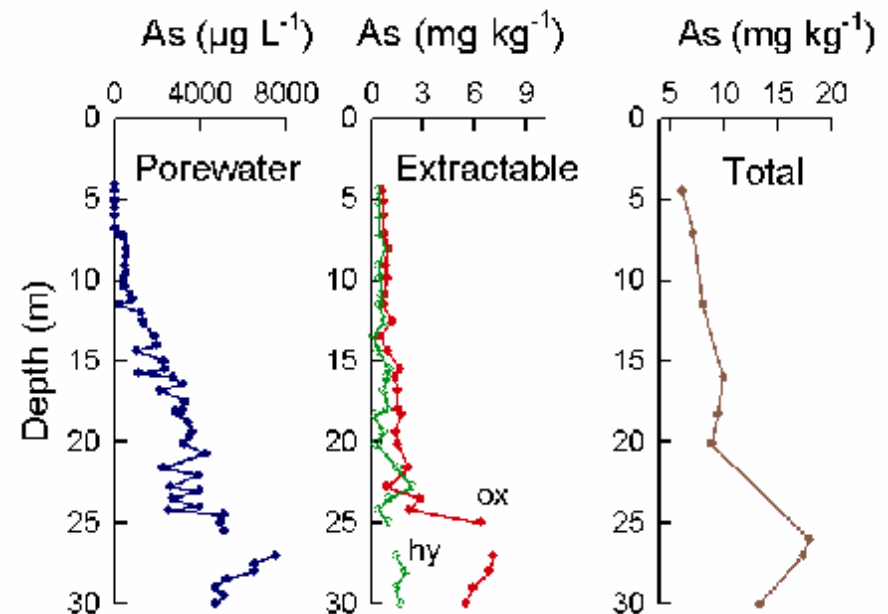
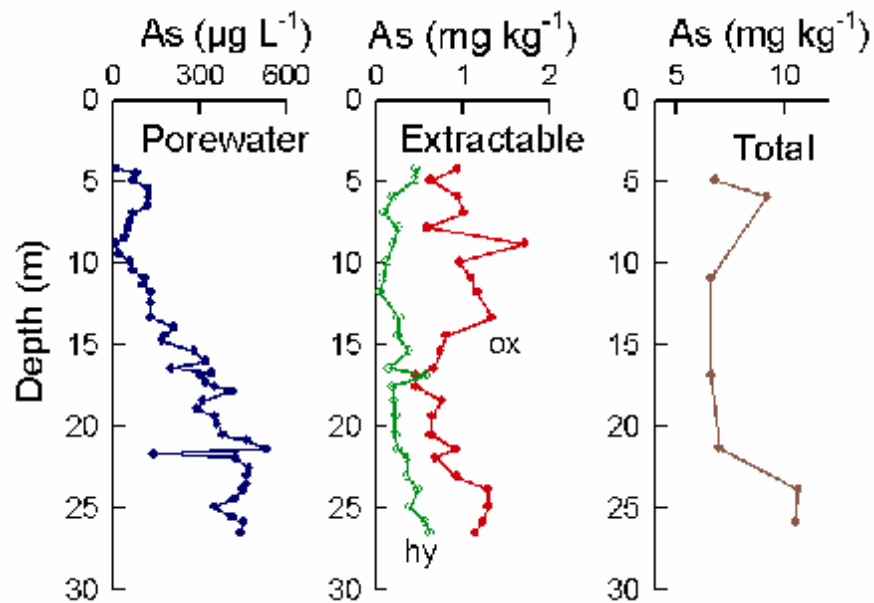
www.bgs.ac.uk





### Talleres Norte (flat-lying area)

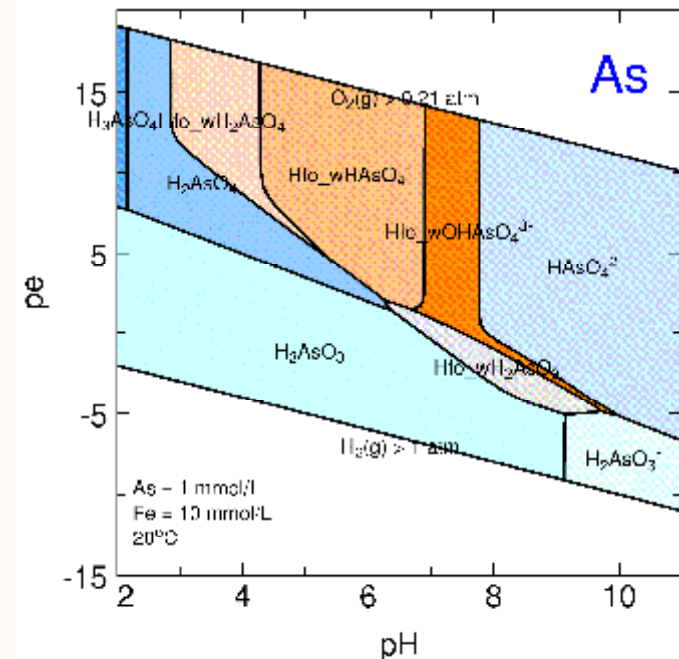
### Tamagnoni (topographic depression)





# As release – Argentina

- Increase in pH – silicate weathering
- Desorption of As(V) from iron oxides
- High As concentrations in topographic depressions – lack of flushing
- High concentrations of other oxyanions (V) – competition for binding sites





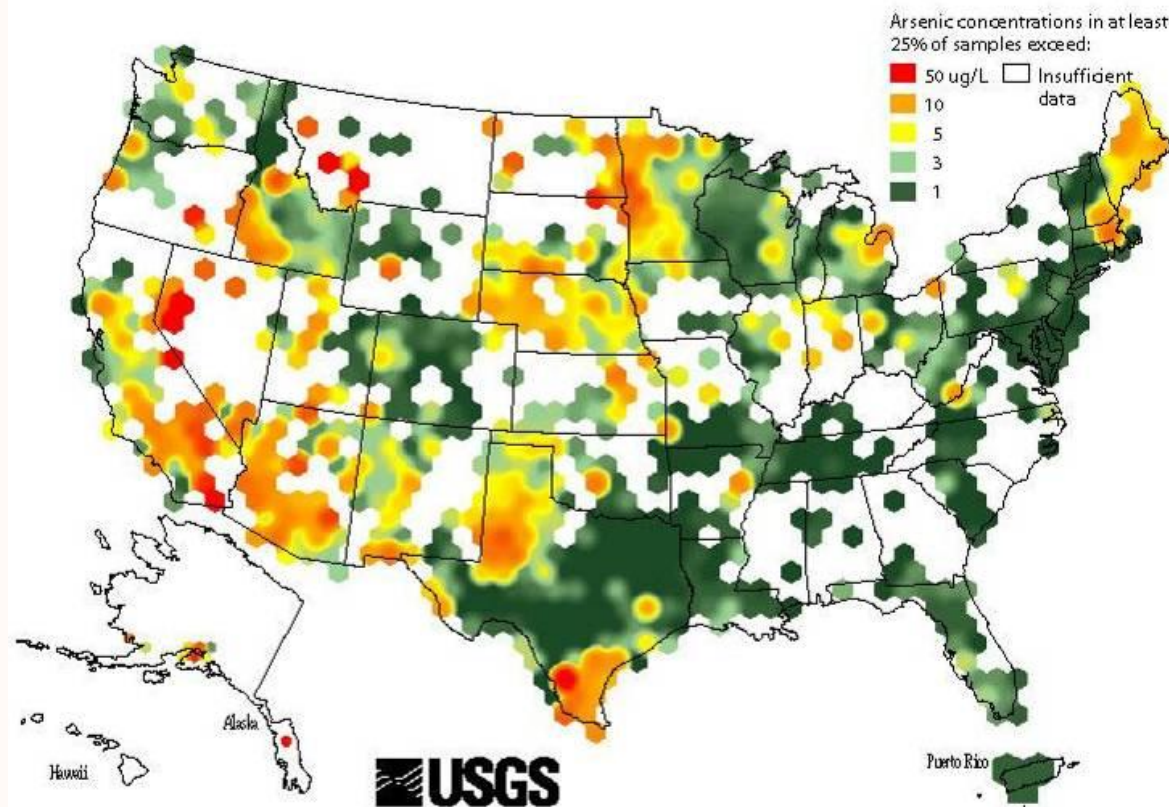
British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



www.bgs.ac.uk

# Arid inland basins: south-west USA

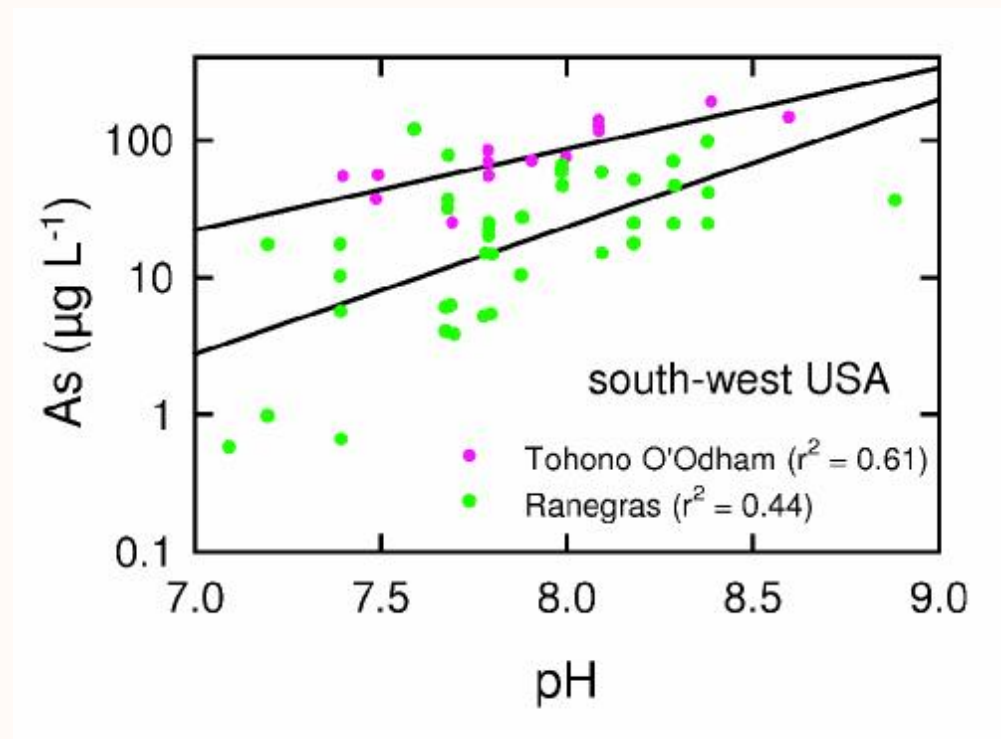


From Ryker (2001)



- **Basin & Range, Arizona (Robertson, 1989)**

- Quaternary sediments (closed basins)
- Arsenic in groundwater <math>10-1300 \mu\text{g L}^{-1}</math>
- Aerobic groundwater
- High pH (7.0-8.9)
- Arsenic mainly As(V)
- Correlations As – V, F, Mo





British  
Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



[www.bgs.ac.uk](http://www.bgs.ac.uk)

# Alluvial / delta plains: Bangladesh





**British  
Geological Survey**

NATURAL ENVIRONMENT RESEARCH COUNCIL



[www.bgs.ac.uk](http://www.bgs.ac.uk)



Paddy fields on the Bengal alluvial plain



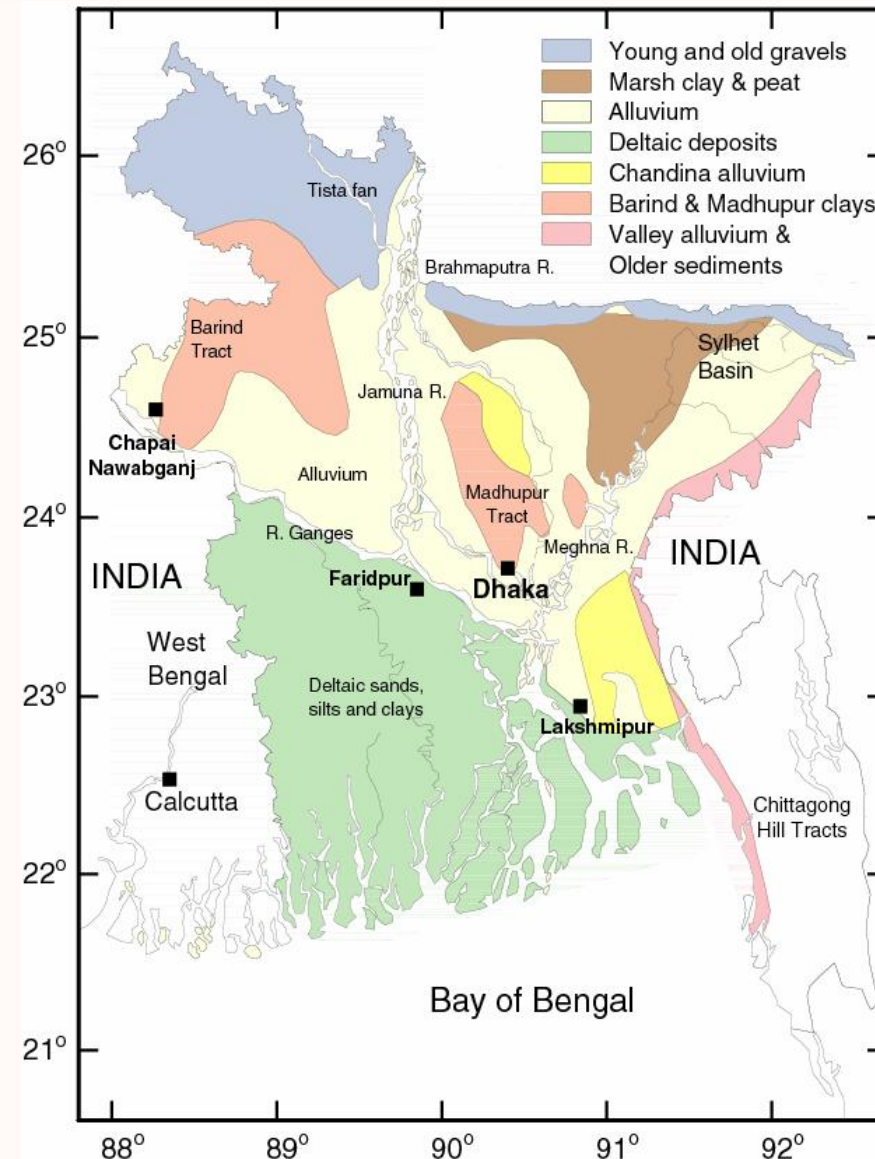
British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



www.bgs.ac.uk

## Simplified geological map of Bangladesh





British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



www.bgs.ac.uk

## BGS and DPHE (2001) survey

3534 groundwater samples

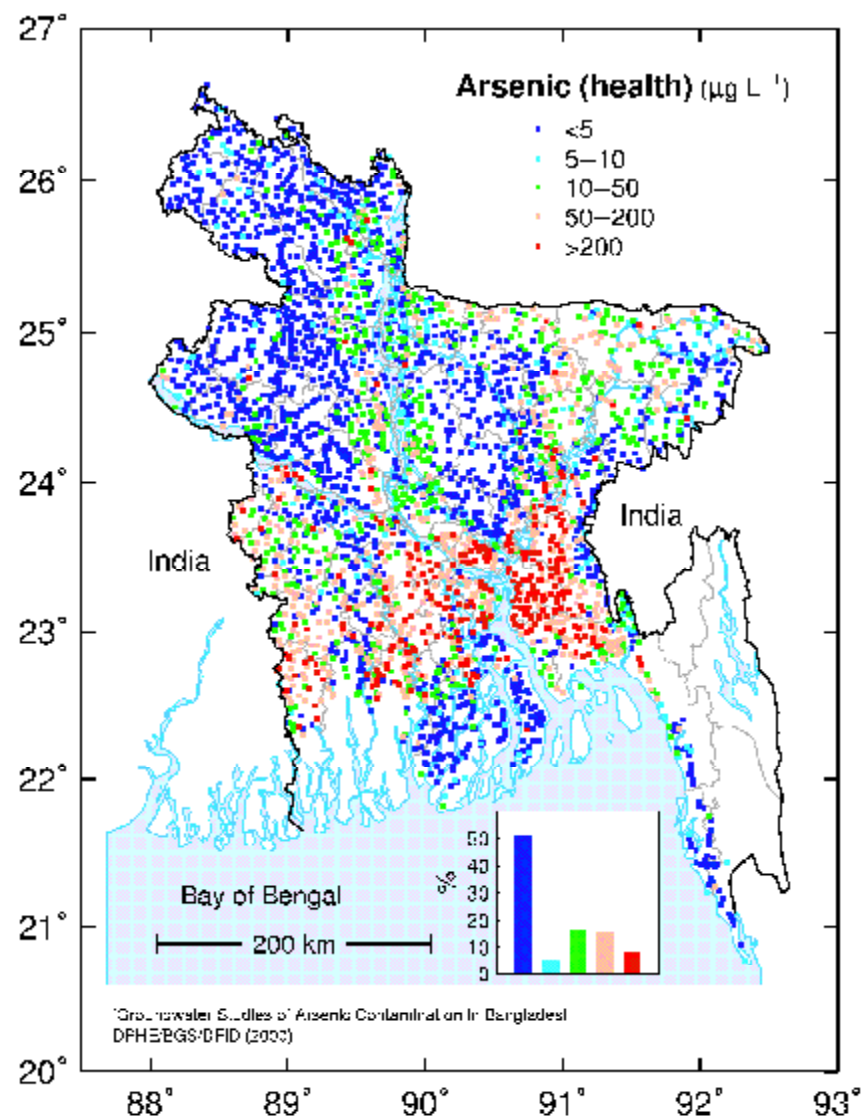
Range  $<0.25$ - $1670 \mu\text{g L}^{-1}$

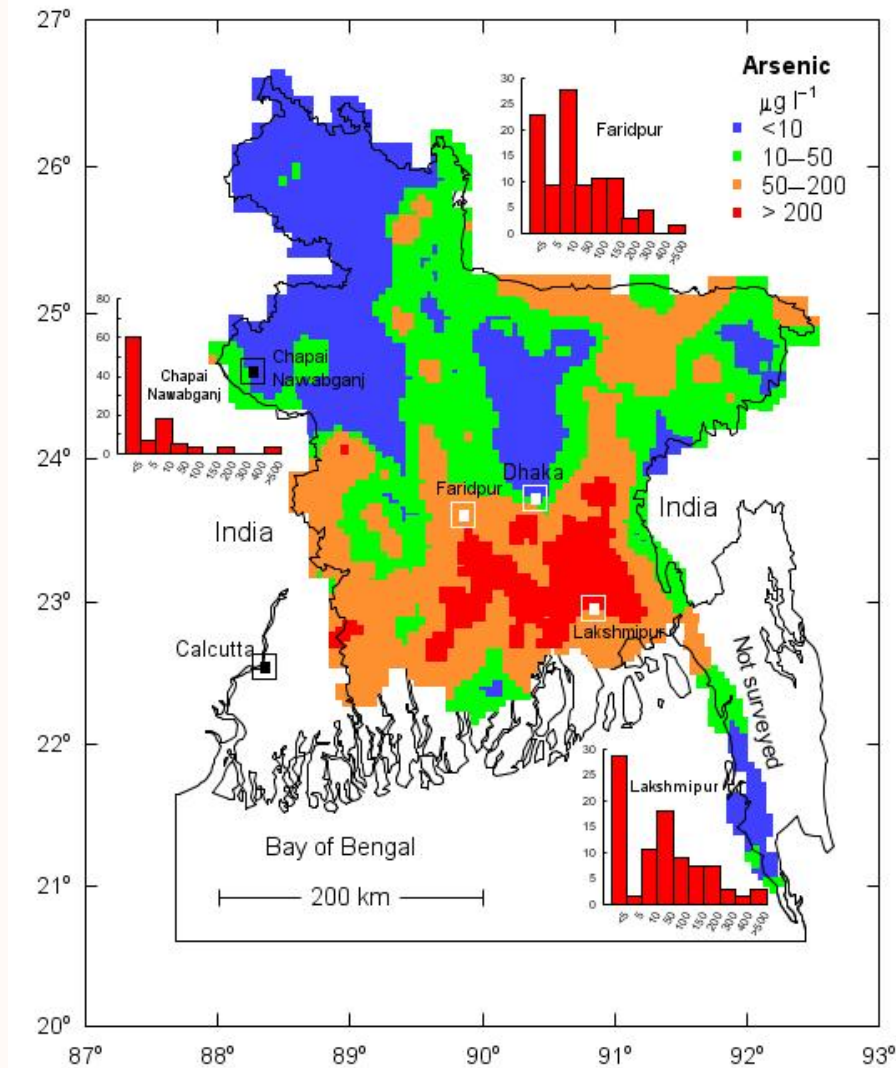
42%  $>10 \mu\text{g L}^{-1}$

25%  $>50 \mu\text{g L}^{-1}$

9%  $>200 \mu\text{g L}^{-1}$

[www.bgs.ac.uk/arsenic/bangladesh](http://www.bgs.ac.uk/arsenic/bangladesh)





Population exposed:

>50  $\mu\text{g L}^{-1}$ : 35 million people

>10  $\mu\text{g L}^{-1}$ : 57 million people

(1999, based on 125 million population)

Shallow groundwaters (n=3208)

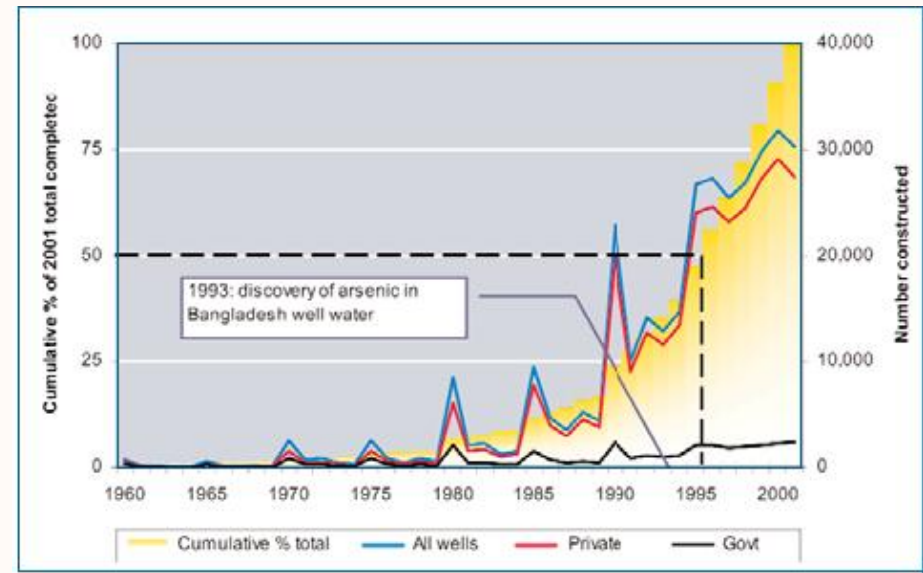
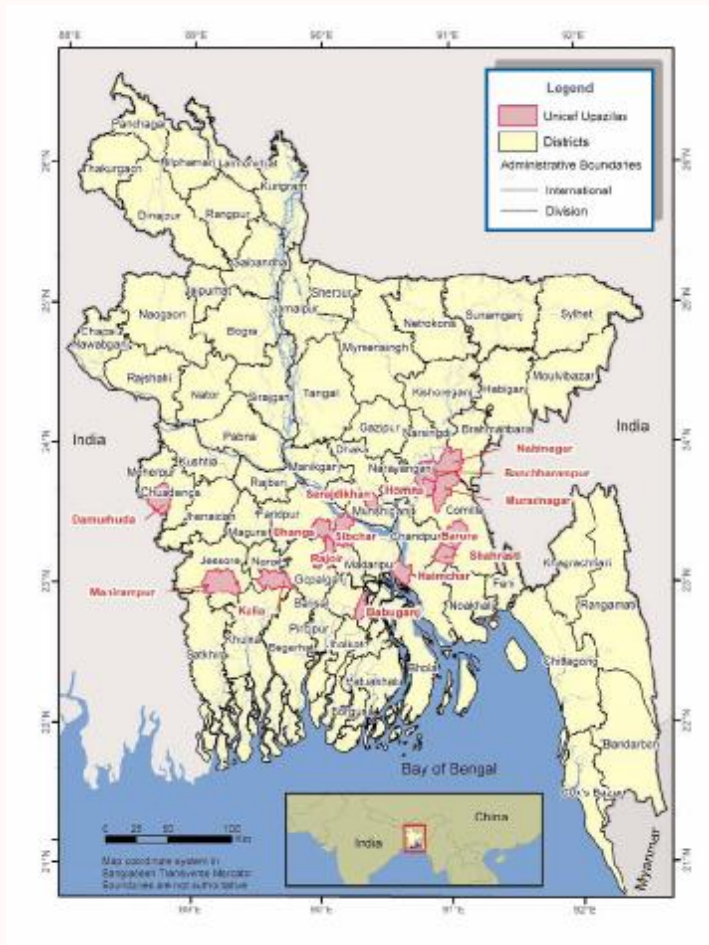


British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



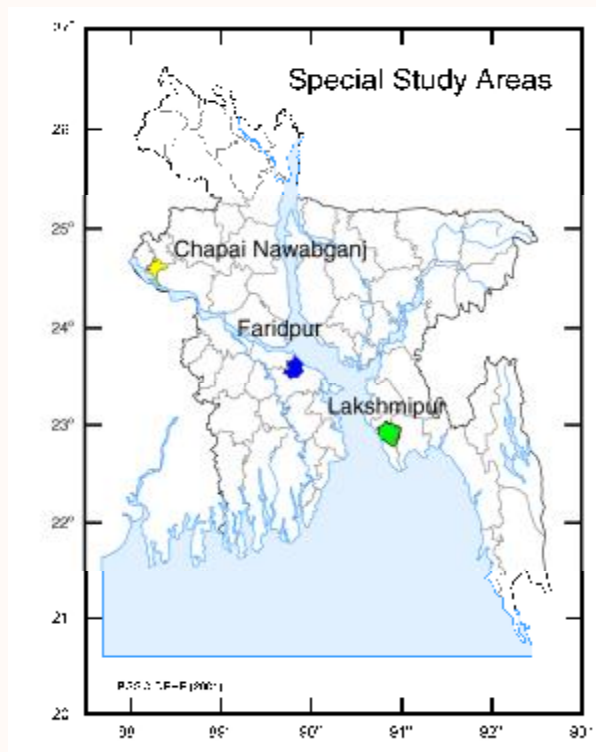
www.bgs.ac.uk



Source: Rosenboom (2004) APSU report



## Faridpur tubewells (<100 m depth) (n=59)



Parameter	Units	Range	Median
pH		6.4 – 7.4	6.9
DO	mg L <sup>-1</sup>	<0.1 – 1.4	<0.1
SEC	μS cm <sup>-1</sup>	344 - 1400	749
SO <sub>4</sub>	mg L <sup>-1</sup>	<0.2 - 64	<0.2
HCO <sub>3</sub>	mg L <sup>-1</sup>	200 - 848	536
NO <sub>3</sub> -N	mg L <sup>-1</sup>	<0.3 – 4.9	<0.3
Fe	mg L <sup>-1</sup>	0.05 – 20	5.6
Mn	mg L <sup>-1</sup>	0.04 – 4.2	0.69
P	mg L <sup>-1</sup>	<0.2 – 5	1.5
As	μg L <sup>-1</sup>	<0.5 - 1460	39

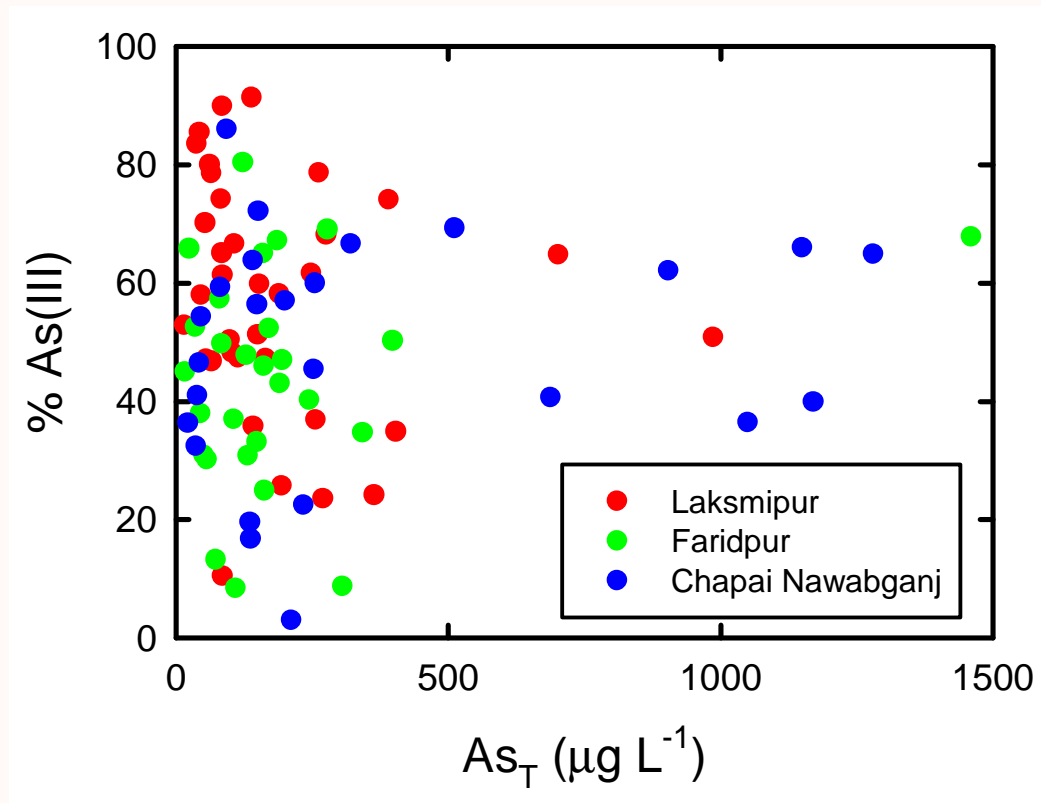


British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



www.bgs.ac.uk



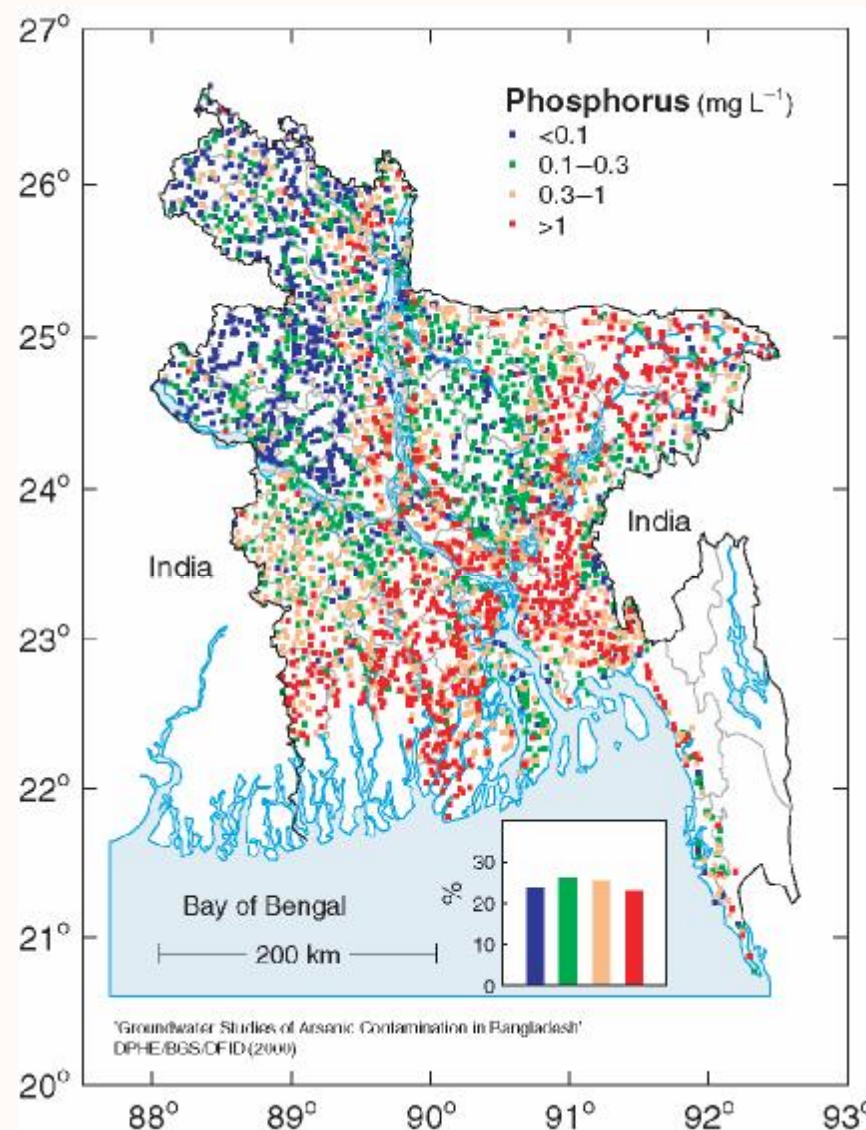
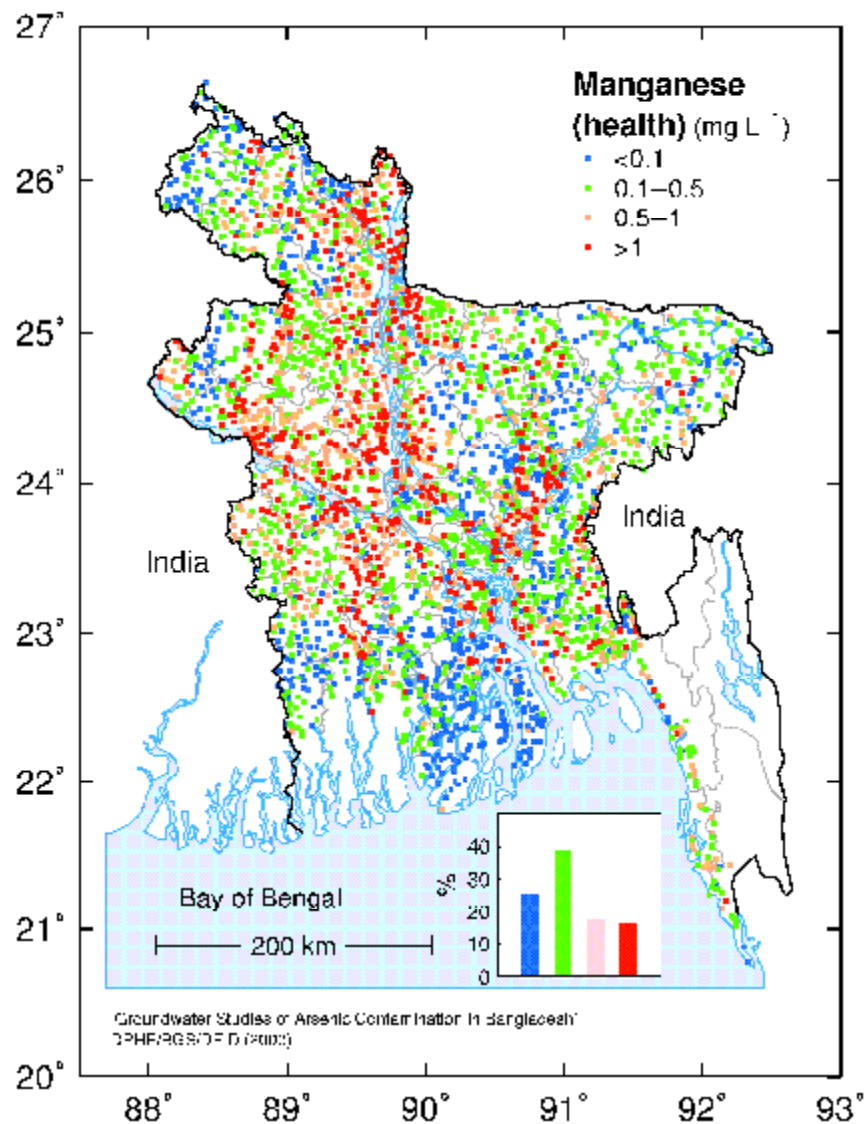


British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



www.bgs.ac.uk



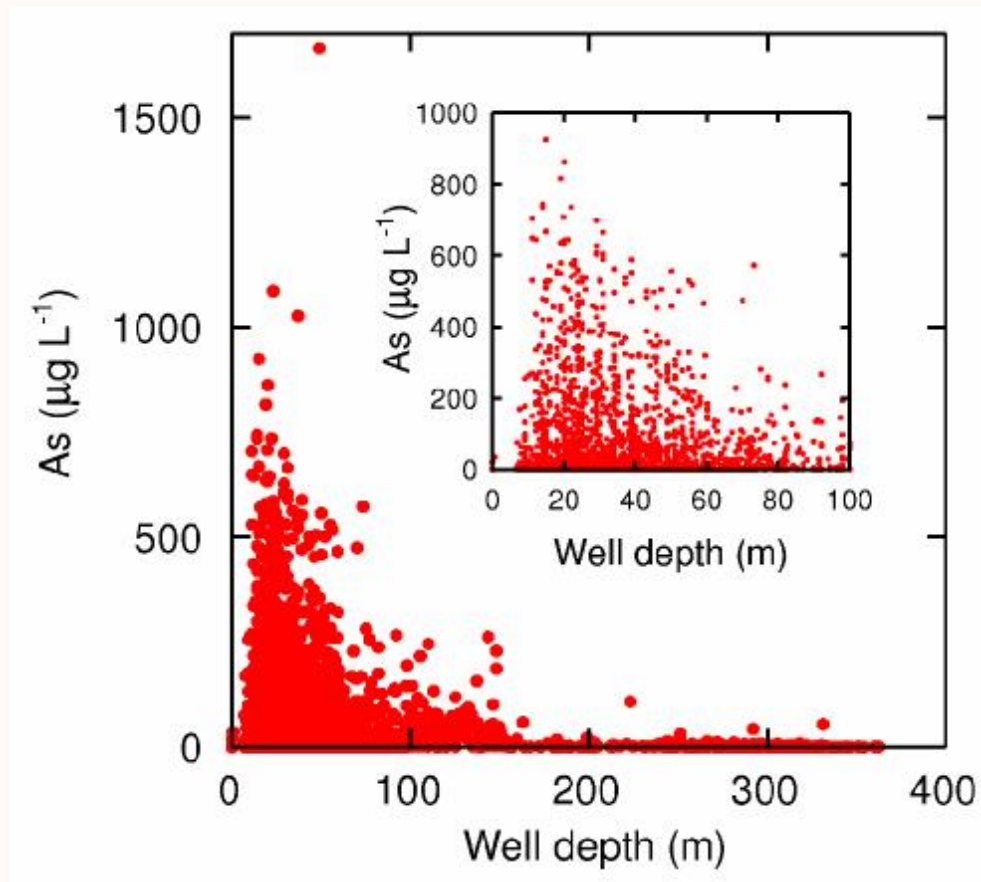


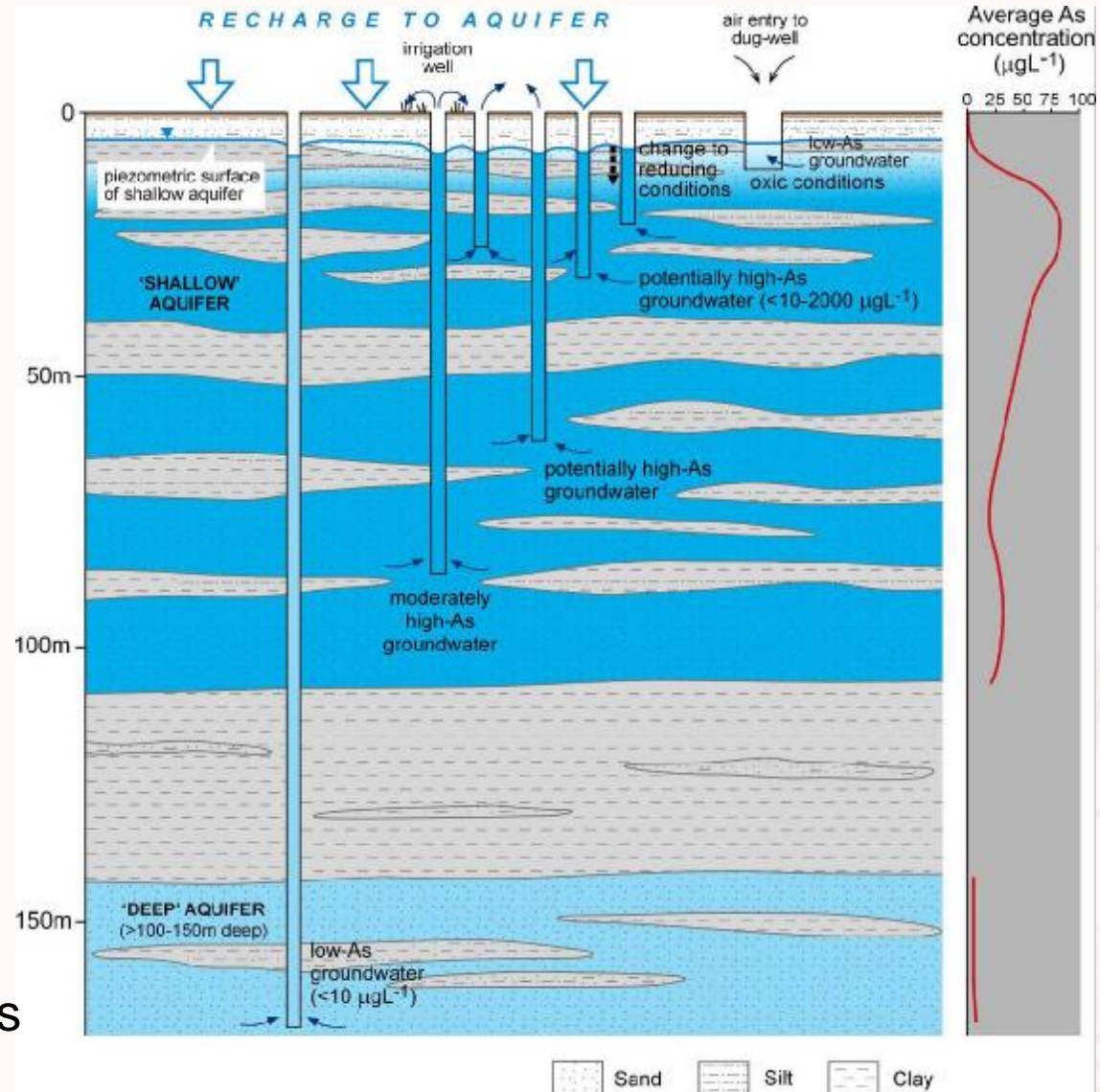
British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



[www.bgs.ac.uk](http://www.bgs.ac.uk)

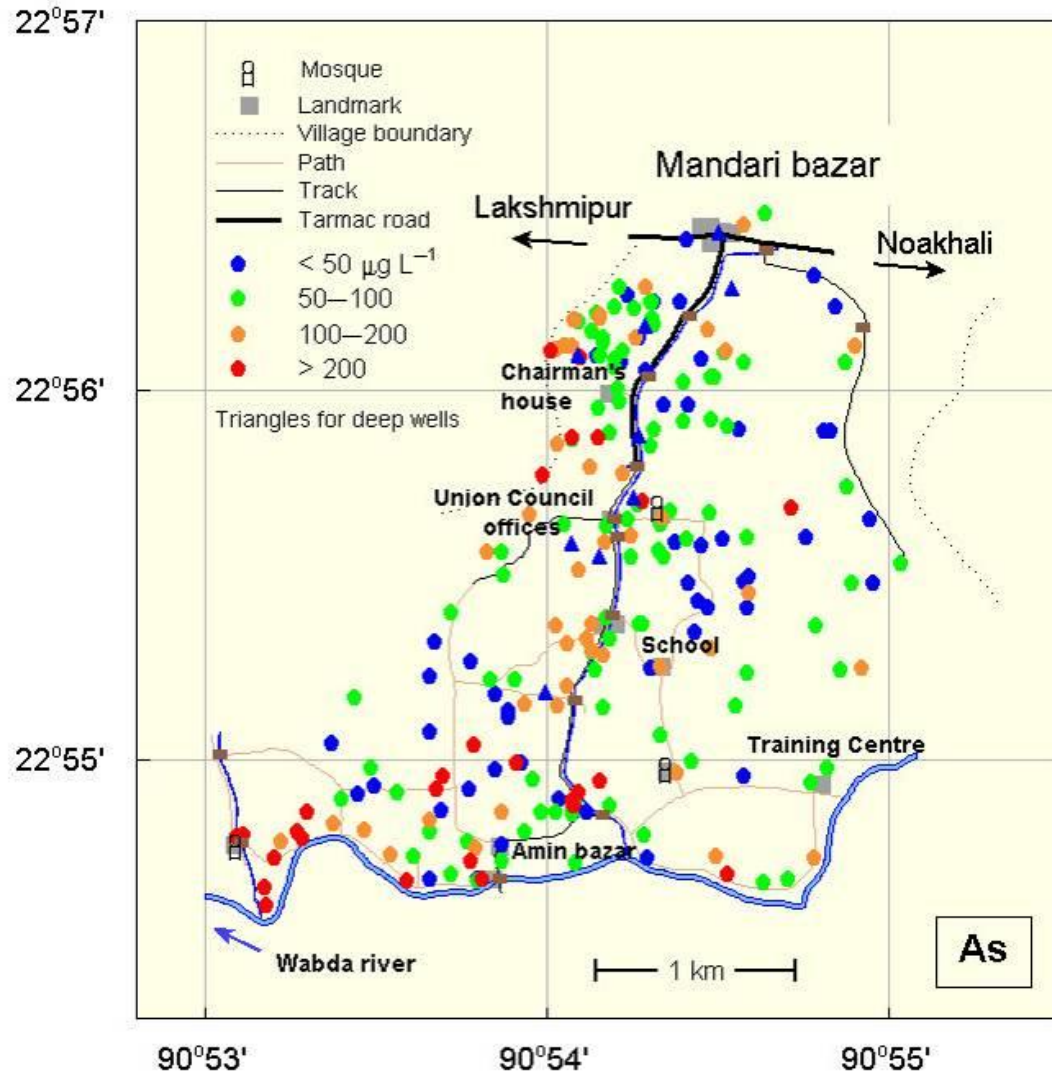




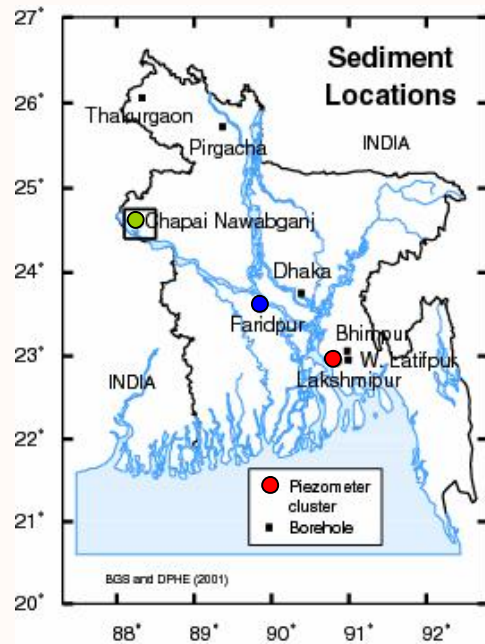
Schematic section of Bangladesh aquifers

Large spatial  
variability

Mandari

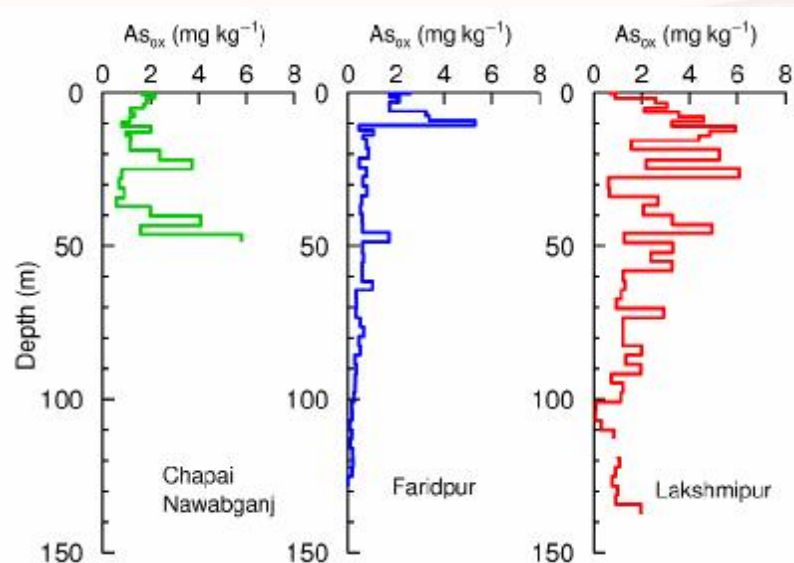
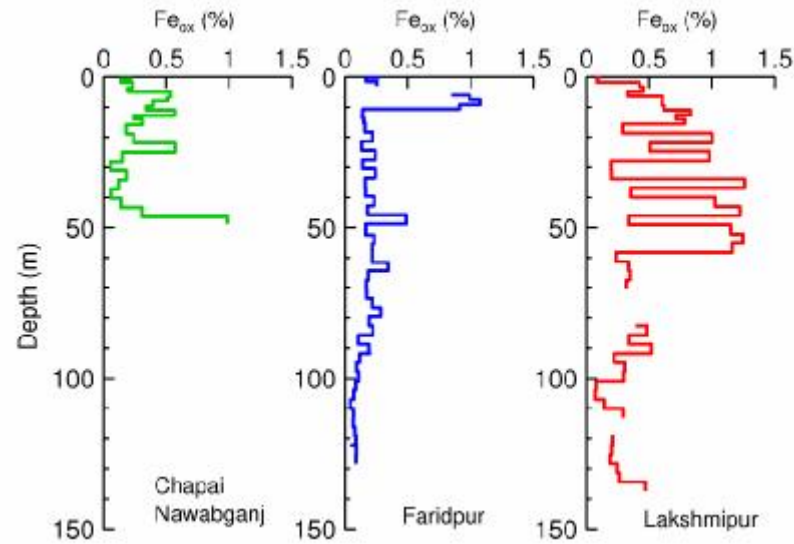


1ft sections



## Bangladesh sediments

### Oxalate-extracts



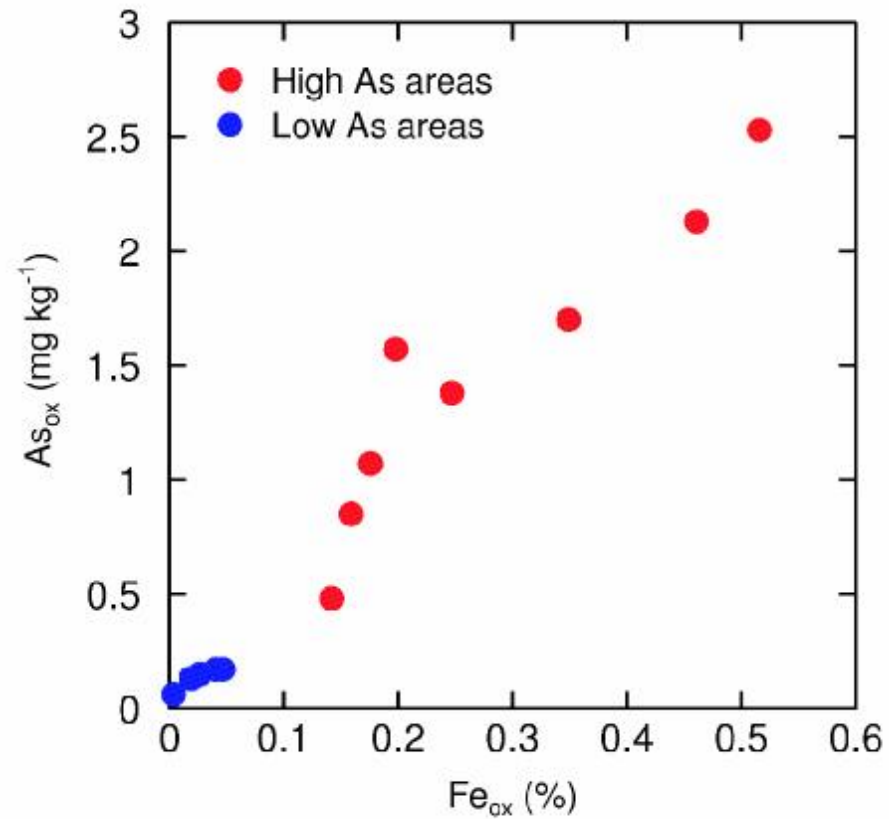


British Geological Survey

NATURAL ENVIRONMENT RESEARCH COUNCIL



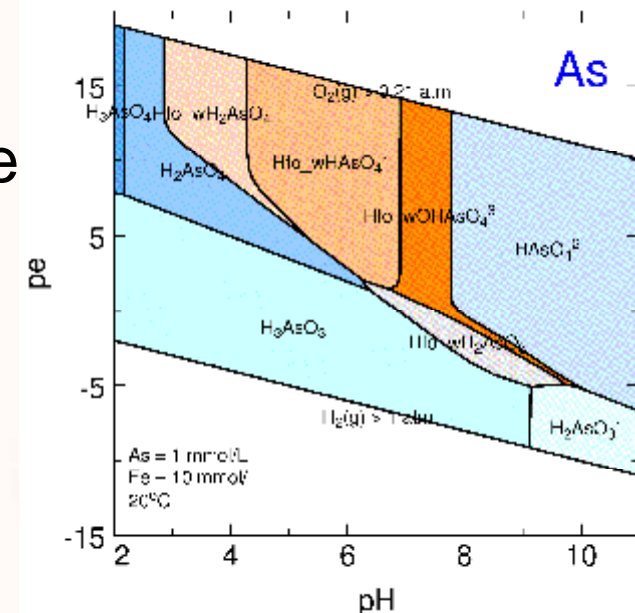
[www.bgs.ac.uk](http://www.bgs.ac.uk)





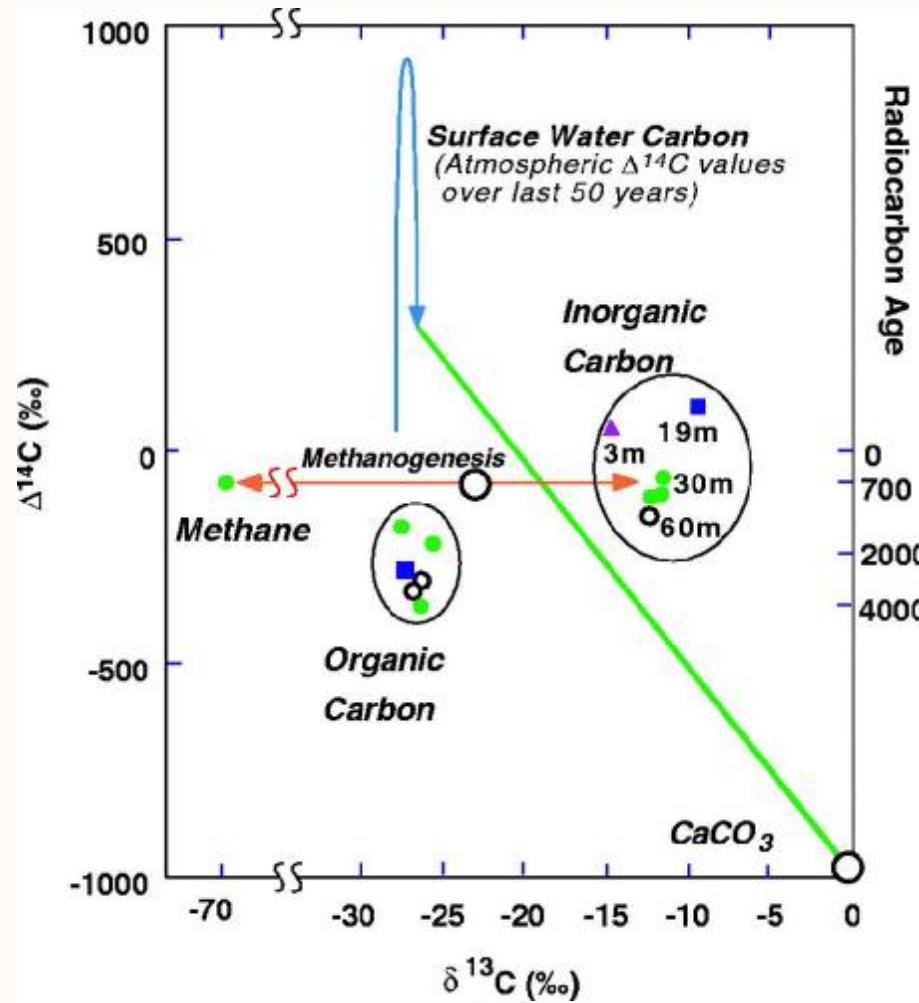
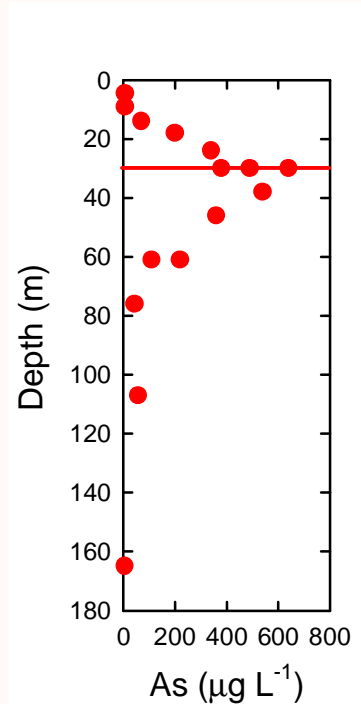
# As release - Bangladesh

- Rapid burial of sediment and organic matter:
  - Change to reducing conditions (microbial mediation)
  - Reductive desorption - As(V) to As(III)
  - Dissolution of Fe oxides
  - Diagenesis of Fe oxides – change in structure/surface area
  - Competition for binding sites on Fe oxides –  $\text{PO}_4$
  - Lack of flushing





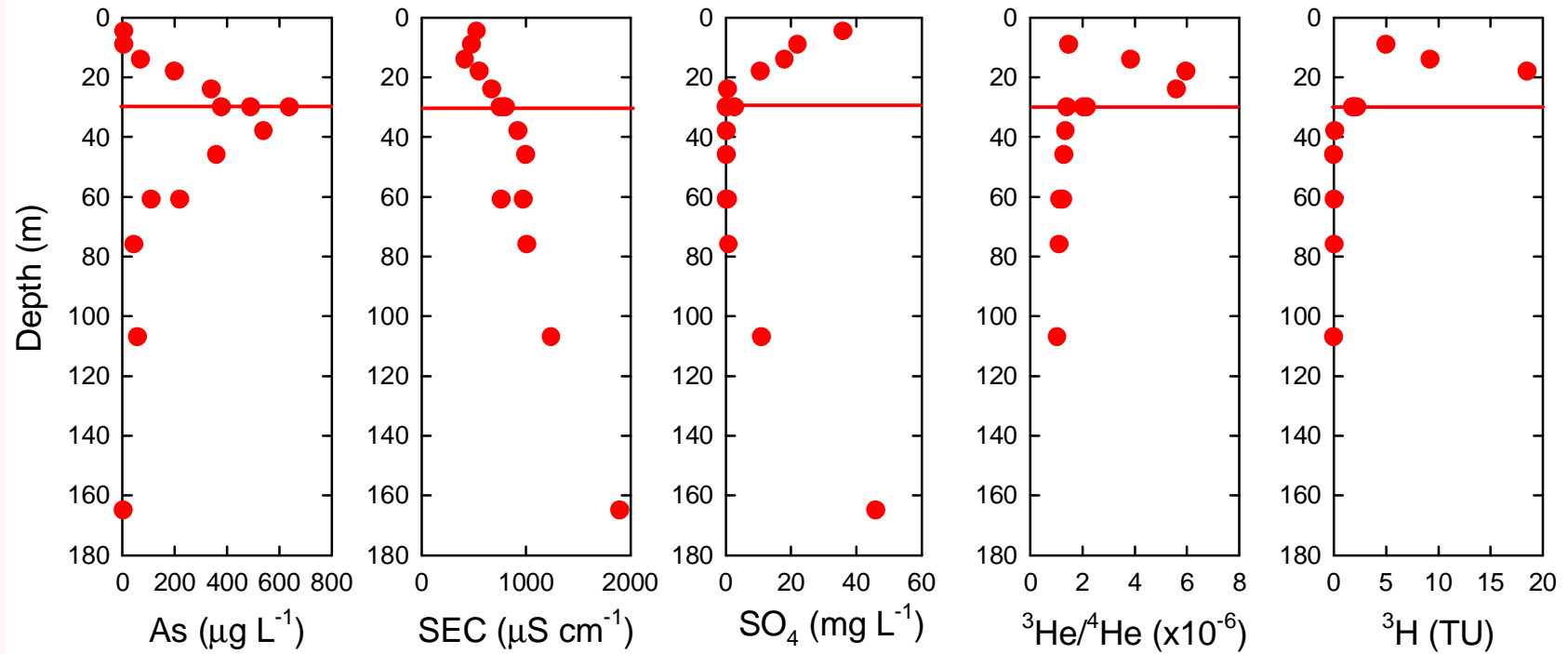
# Munshiganj, Bangladesh



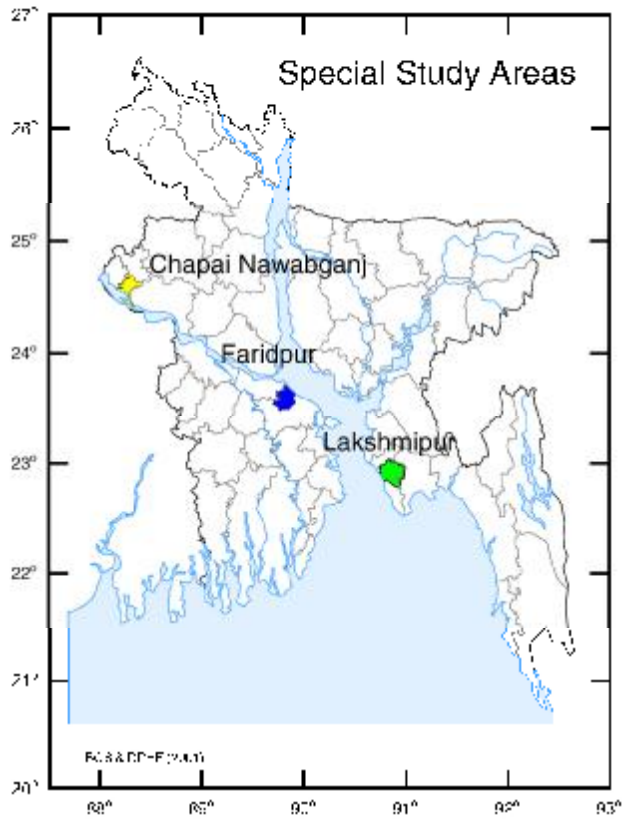
Source: Harvey et al. (2002), Science, 298, 1602-1606



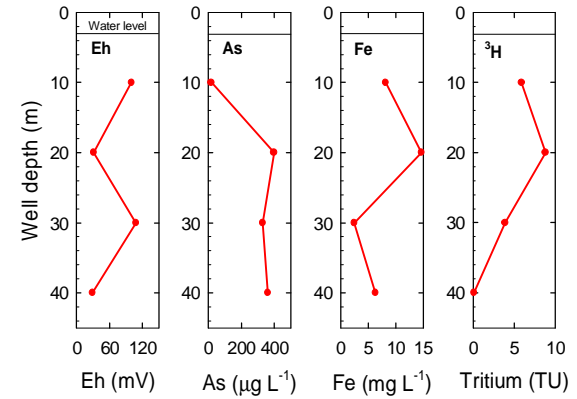
### Munshiganj District, Bangladesh



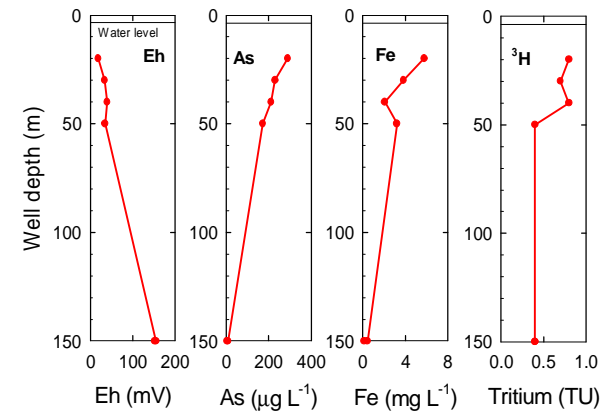
Sources: Swartz et al. (2004), GCA, 68, 4539;  
Klump et al. (2006), ES&T, 40, 243



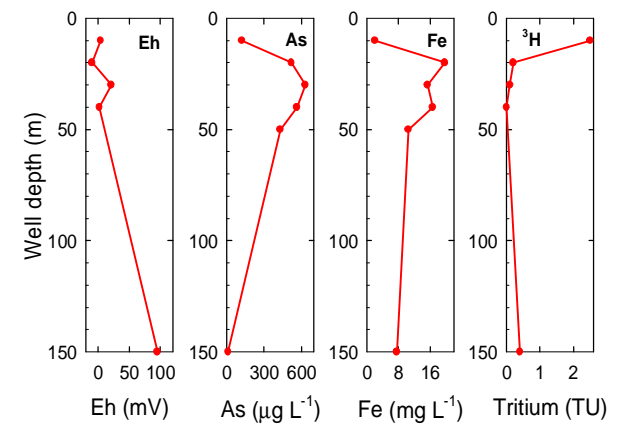
### Chapai Nawabganj piezometers



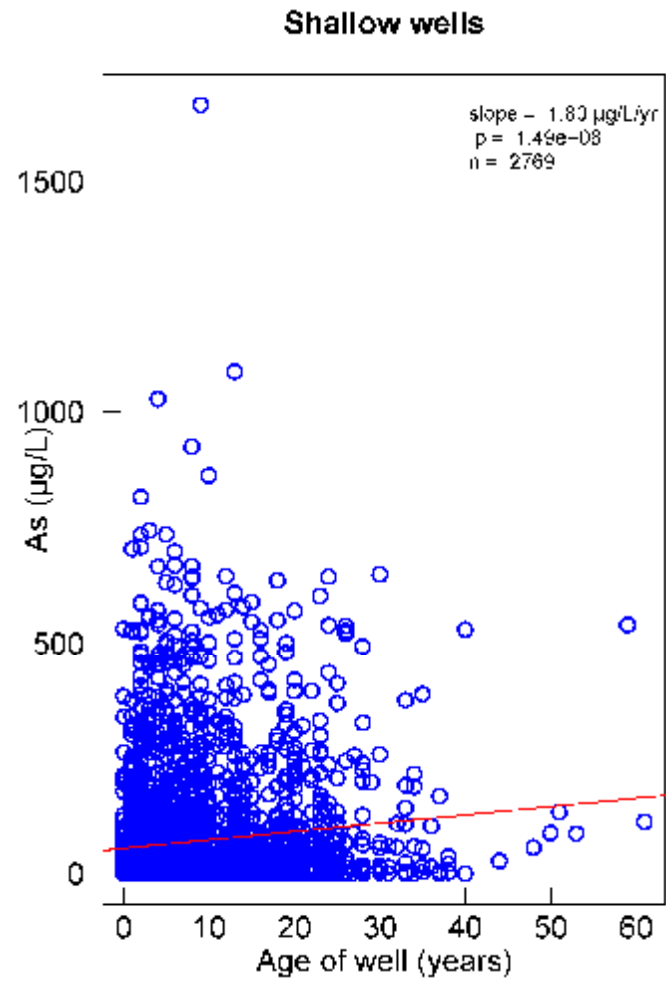
### Faridpur piezometers



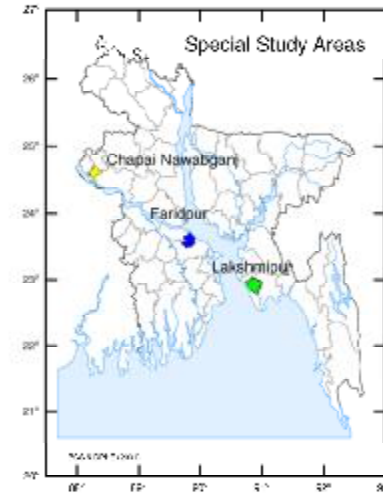
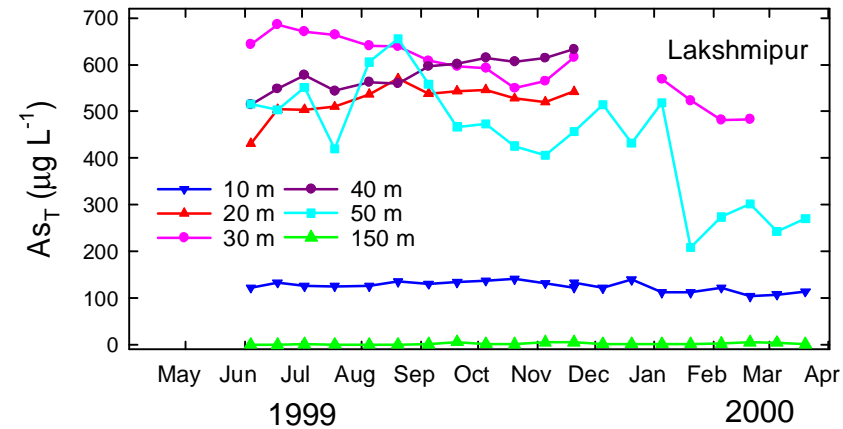
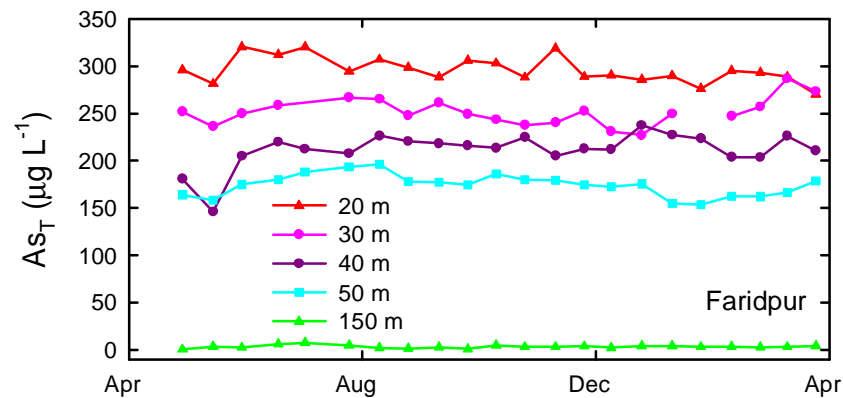
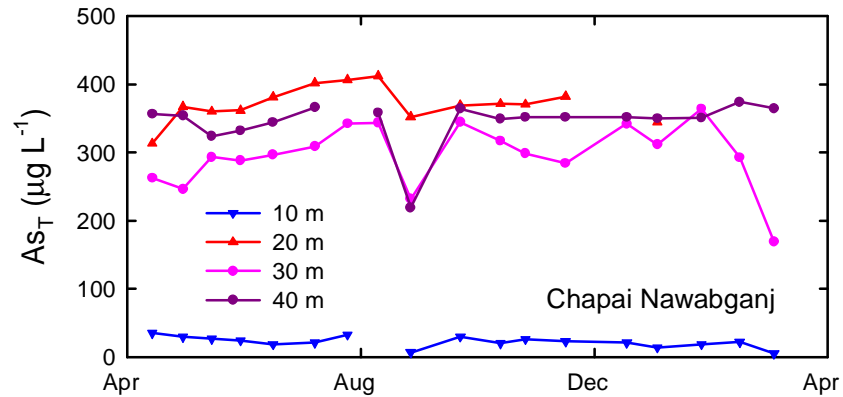
### Lakshmipur piezometers



# Bangladesh: As vs well age



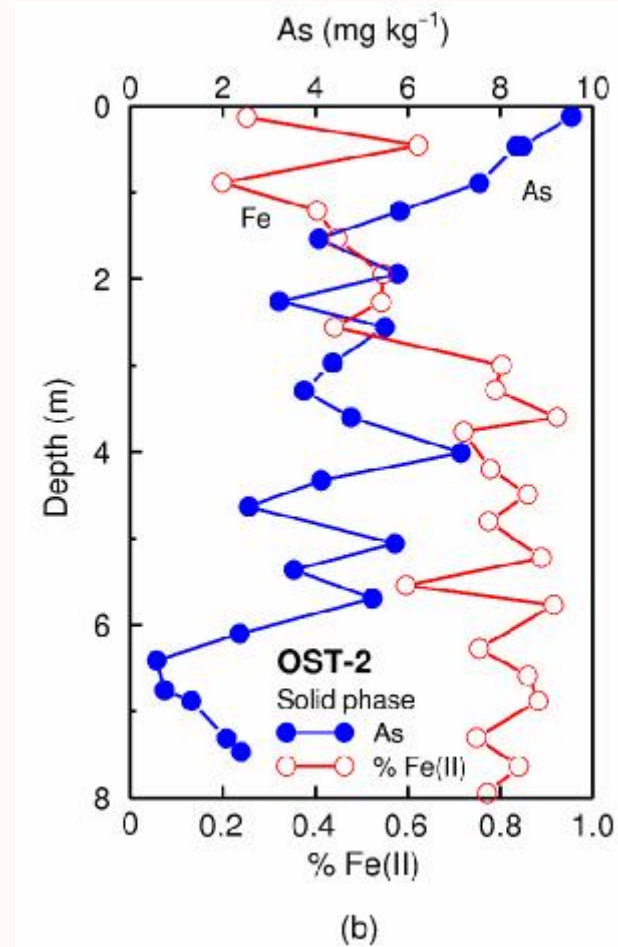
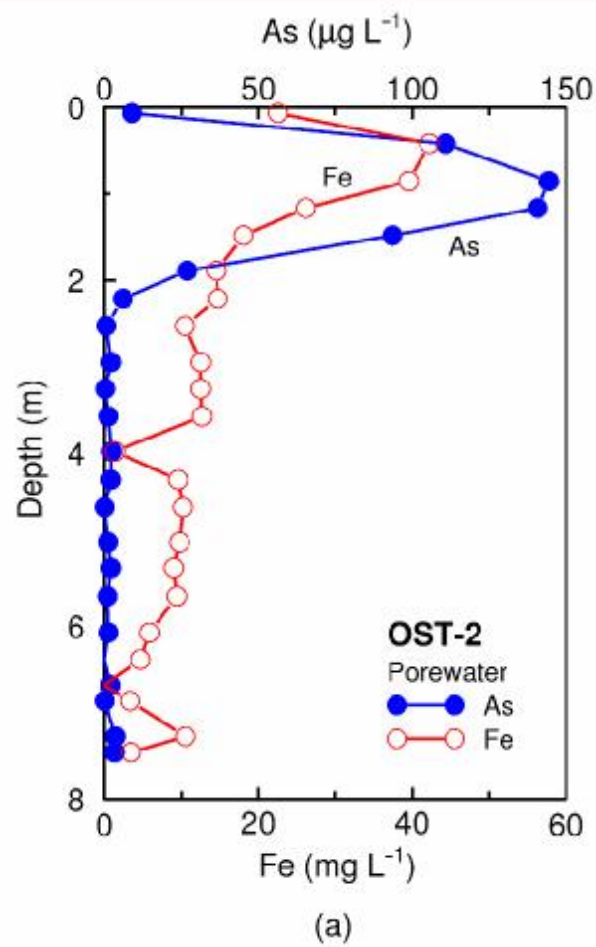
## Special Study Areas, Bangladesh



BGS and DPHE (2001)



# Amazon shelf



Source: Sullivan and Aller (1996), GCA, 60, 1465-1477



# Conclusions

- **High-As sources:**
  - Geothermal
  - Mineralised/mining areas – sulphide oxidation
- **‘Average-As’ sources - young sedimentary aquifers:**
  - Increase in pH (arid, oxic conditions) – e.g. Argentina
  - Change to reducing conditions – e.g. Bangladesh
  - Slow groundwater flow – lack of flushing
- **Impact of man?**
  - Mining areas – localised
  - Groundwater movement/mixing due to pumping