CE 435 (January 2018 Semester)

Environmental Pollution and Management:

Water Pollution

CN-6: Water Quality Problems in Bangladesh

Dr. M. Ashraf Ali
Professor of Civil Engineering, BUET

Water Quality Problems in Bangladesh

- Widespread surface water pollution from industrial and domestic discharges
- Arsenic contamination of groundwater
- Salinity (both surface and groundwater) in coastal areas
- High manganese (Mn) in groundwater
- High iron (Fe) in groundwater
- Detection of fecal contamination in tubewell water

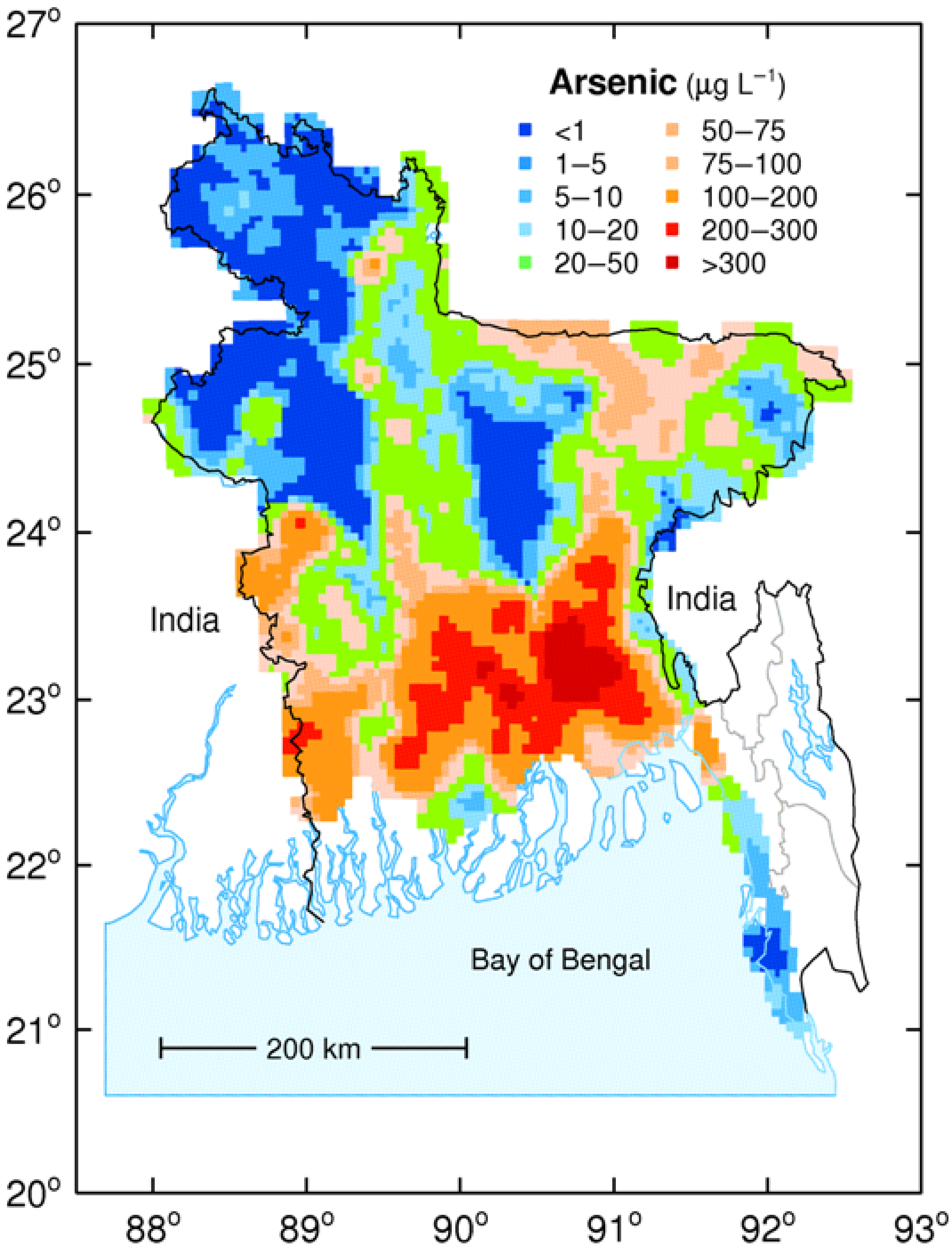
Arsenic Contamination of Groundwater

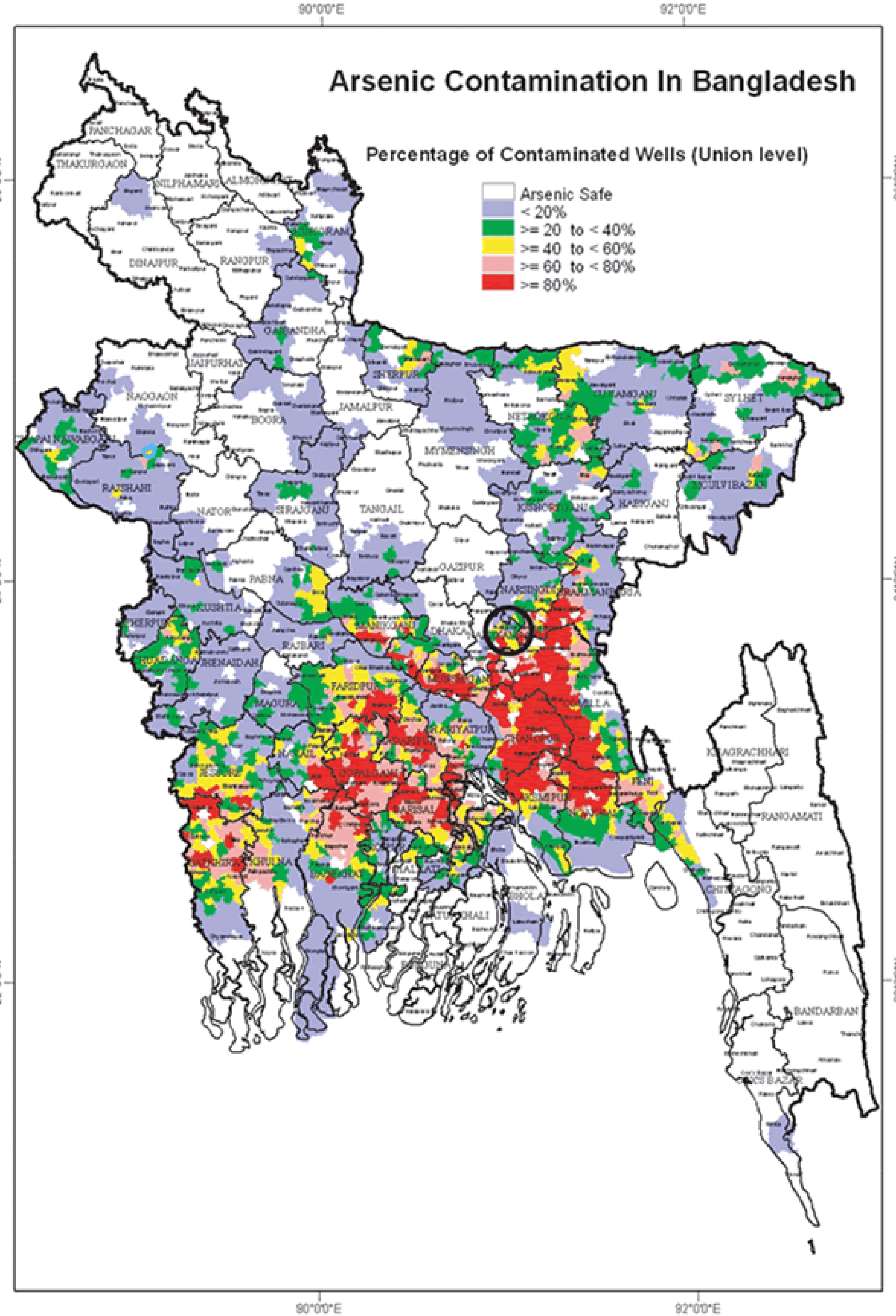
Arsenic Contamination of Groundwater

- Arsenic (As) in groundwater was first detected in late 1993 in the district of Chapai Nawabganj bordering the West Bengal district of India.
- The shallow aquifer, which has been extensively exploited for both water supply and irrigation, is the principal source of Arsenic. Very shallow (< 10 m depth) and deeper (> 150 – 200 m) aquifer appear to be less contaminated by As.
- Discovery of Arsenic reduced water supply coverage dropped to **74%** from **97%.**

Global Arsenic Occurrence

Distribution of As in Groundwater of Bangladesh





Distribution of As in Groundwater of Bangladesh

Arsenic Contamination of Groundwater ….

- **Arsenic problem is complicated because:**
  - It is tasteless, colorless, and odorless
  - Its effect on population is delayed
  - Occurrence of As appears to be highly scattered
  - It is difficult to detect its presence in water

- Currently, about **12.4 per cent of the population are exposed to As conc. exceeding Bangladesh Standard of 50 ppb**; 24.8% are exposed above WHO guideline value of 10 ppb.

- **Arsenic is still is the most significant obstacle that is preventing us from increasing “safe water coverage”.**

Toxicological Effects of Arsenic

Non-carcinogenic Effects:

- ✓ Cuteneous Effects:
  - o Hyperpigmentation (dark spots on the skin)
  - o Hypopigmentation (white spots on the skin)
    (these two are collectively referred to as "melanosis")
  - o Keratosis (skin hardened and develops raised wart-like nodules)
- ✓ Others: Nausia, abdominal pain, vomiting; Hypertension; Diarrahoea; Anemia; etc.

Carcinogenic Effects:

- o Skin cancer
- o Lund cancer
- o Bladder cancer
- o Liver cancer

Toxicological Effects of Arsenic …..

Most Likely Source As and Mechanism of its Mobilization in the Subsurface

- The original source of arsenic can most likely be traced back to the oxidation of sulfide minerals, principally pyrite derived from the granitic and metamorphic source regions of the Himalayas.

- Pyrite oxidation probably occurred during weathering at the source in the Himalayas and that arsenic was transported and deposited in the Ganges delta in association with resulting iron oxides.

Most Likely Source As and Mechanism of its Mobilization in the Subsurface

- In Bangladesh arsenic-rich iron oxyhydroxides appear to be a major source of arsenic, from which arsenic is released by reductive dissolution (of iron oxyhydroxides) ~~or~~ and perhaps by desorption.

- There is some evidence to suggest that increased pumping (for irrigation) is drawing "nutrient-~~rich~~ organic-rich" water to depths (may be up to ~100 ft), and this is promoting reducing environment and consequent release of arsenic from sediment.

Role of "Reduction" in As Mobilization:

(A) Mobilization of Arsenic & Reduction

- Under reducing environment, iron oxyhydroxides undergo "dissolution" and release Arsenic associated with it.

- Reducing environment may be created by the presence of organic matter in the sediment and their decomposition.

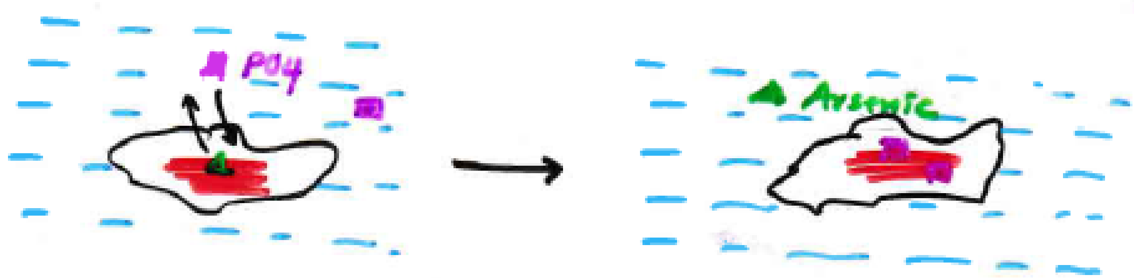
$$Fe(OH)_3(s) + \tfrac{1}{4}CH_2O + 2H^+ \rightarrow Fe^{2+} + \tfrac{1}{4}CO_2 + \tfrac{11}{4}H_2O$$

dissolved iron

- microbial processes appear to play an important role in the reductive dissolution of iron solids and consequent mobilization of Arsenic.

Role of "Phosphate" (e.g., from Phosphate fertilizer) in As Mobilization:

Arsenic adsorbed on iron-oxyhydroxide solids in the aquifer may undergo desorption in the presence of a competing anion such as PO_4^{3-}.



Thus application of phosphate fertilizer has the potential to increase arsenic concentration in groundwater.

Possible Alternatives to Arsenic-affected Groundwater

(A) Arsenic Avoidance

1) Groundwater Development:
   - o Arsenic-free tubewell water (where available)
   - o Dug well (shallow groundwater)

2) Surface Water Development
   - o Pond Sand Filters (PSFs)
   - o Ultra-filtration systems

3) Rainwater Harvesting

(B) Treatment of groundwater for As Removal

(C) Managed Aquifer Recharge (MAR): Emerging technology; involves recharge of aquifer with pond/rainwater

Treatment of Groundwater:
Important to understand basics of As Chemistry

Principal Forms of (Inorganic) Arsenic in Water:

Arsenite, As(III):

- Dominant form in anaerobic conditions **(e.g., in groundwater)**
- Depending on pH can exist as: H_3AsO_3, $H_2AsO_3^-$, $HAsO_3^{2-}$, AsO_3^{3-}
- In pH range 6-9, dominant form: H_3AsO_3
- *Note:* **As(III) is about 10 times more toxic than As(V)**

Arsenate, As(V):

- Dominant form in aerobic conditions
- Depending on pH can exist as: H_3AsO_4, $H_2AsO_4^-$, $HAsO_4^{2-}$, AsO_4^{3-}
- In pH range 6-9, dominant forms: $H_2AsO_4^-$, $HAsO_4^{2-}$

Other forms:

(1) Elemental Arsenic (As): Least toxic, minor importance
(2) Arsine : Most toxic, minor importance
(3) Organic Arsenic : Much less toxic

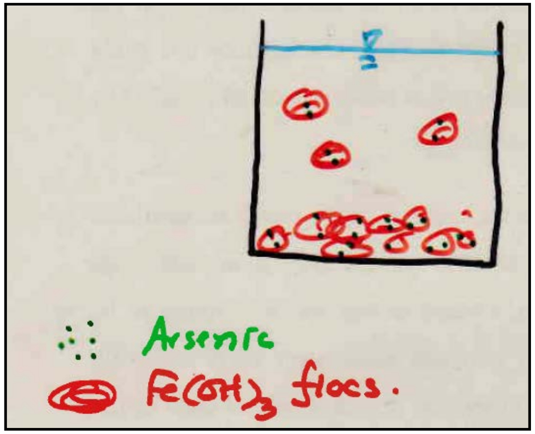
In general, As(III) is more difficult to removal from water than As(V). Therefore, many treatment technologies involve oxidation of As(III) to As(V).

Principles of Arsenic Removal Technologies:

(A) Oxidation:

Involves oxidation of As(III) to As(V), with concomitant oxidation of insoluble Fe(II) to Fe(III), facilitating removal of As

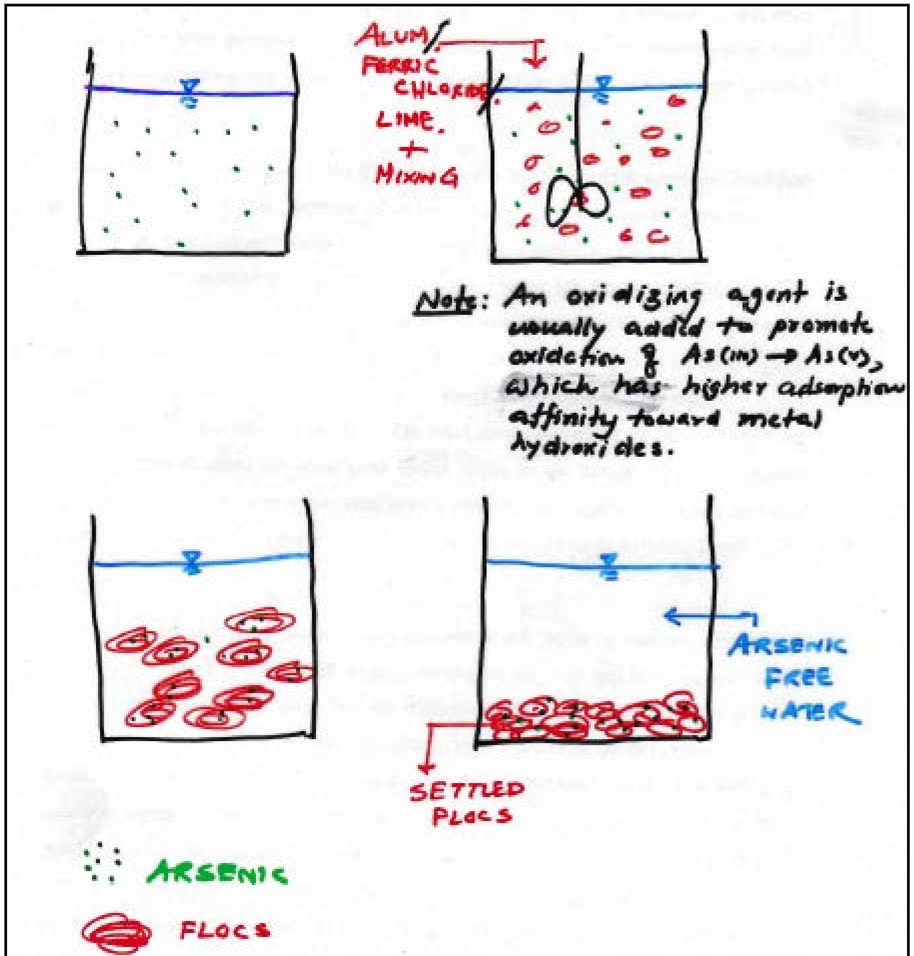
- **Passive sedimentation**
- **Chemical oxidation**
- **Solar oxidation**



- **<u>Passive Sedimentation:</u>**
- Arsenic-bearing tubewell water kept in a vessel (e.g., Kolshi) overnight.
- Part of As(III) converts to As(V); Fe(II) converts to Fe(III) and forms Fe(OH)3 percipitates.
- Arsenic is removed by adsorption onto iron hydroxide flocs.

Principles of Arsenic Removal Technologies:

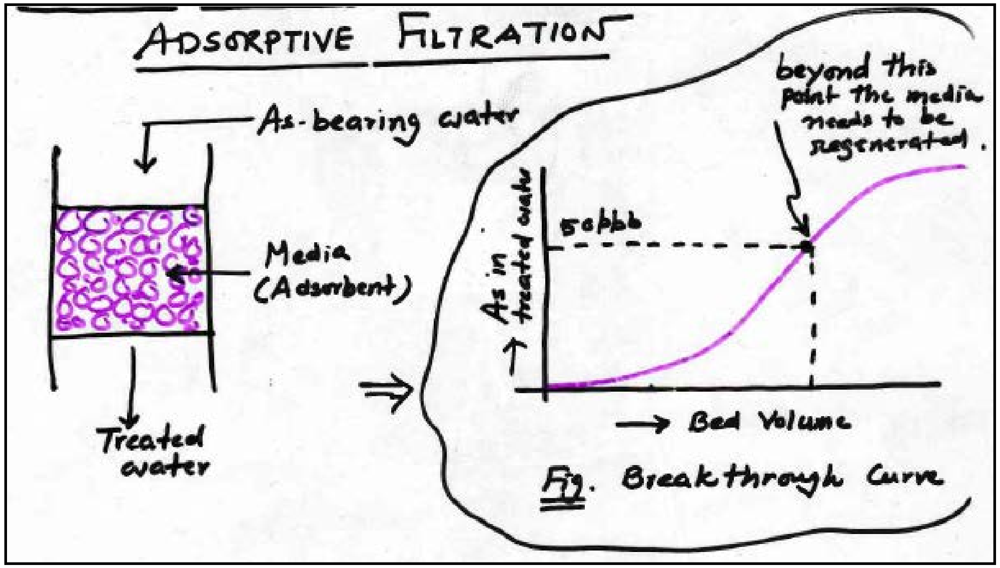
(B) Coagulation-Adsorption-Coprecipitation:



- ❑ Commonly used coagulants include Alumium and Iron Salts (e.g., Alum and Ferric Chloride).
- ❑ Presence of Phosphate in groundwater reduces removal efficiency, by competing with As for adsorption sites.
- ❑ Presence of Iron is groundwater is likely to improve removal efficiency by facilitating adsorption.

Principles of Arsenic Removal Technologies:

(C) Adsorption:

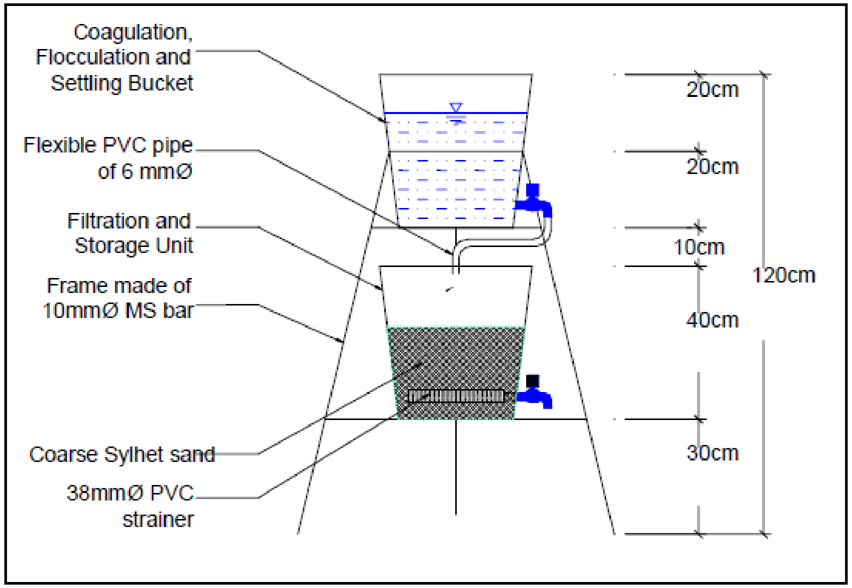


- ❑ Commonly used adsorption media include: Activated alumina; Activated carbon; Iron-coated sand/brick chips; Granular ferric hydroxide; etc.
- ❑ Presence of Phosphate in groundwater reduces removal efficiency, by competing with As for adsorption sites.
- ❑ Presence of Iron is groundwater also adversely affect the system performance by clogging the filter media.

(D) Membrane Techniques

Technologies used for As Removal in Bangladesh

(1) Household Units:

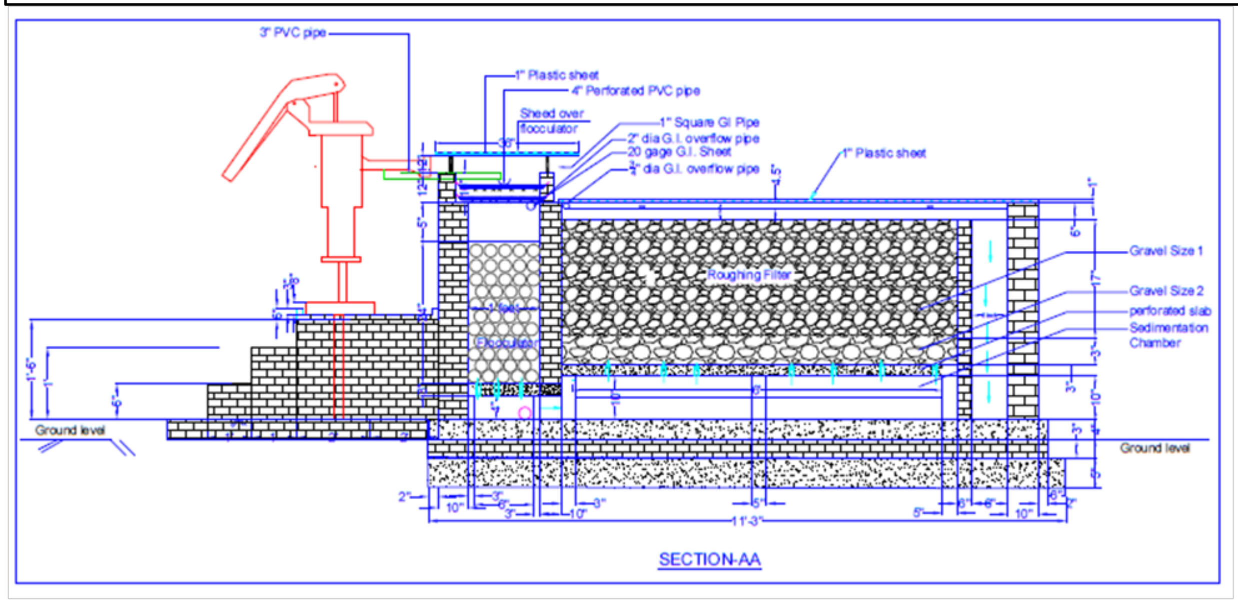


Household Arsenic Removal Unit (ARU) based on **Alum coagulation** and Bleaching Powder disinfection

Commercially available **Sono Filter**

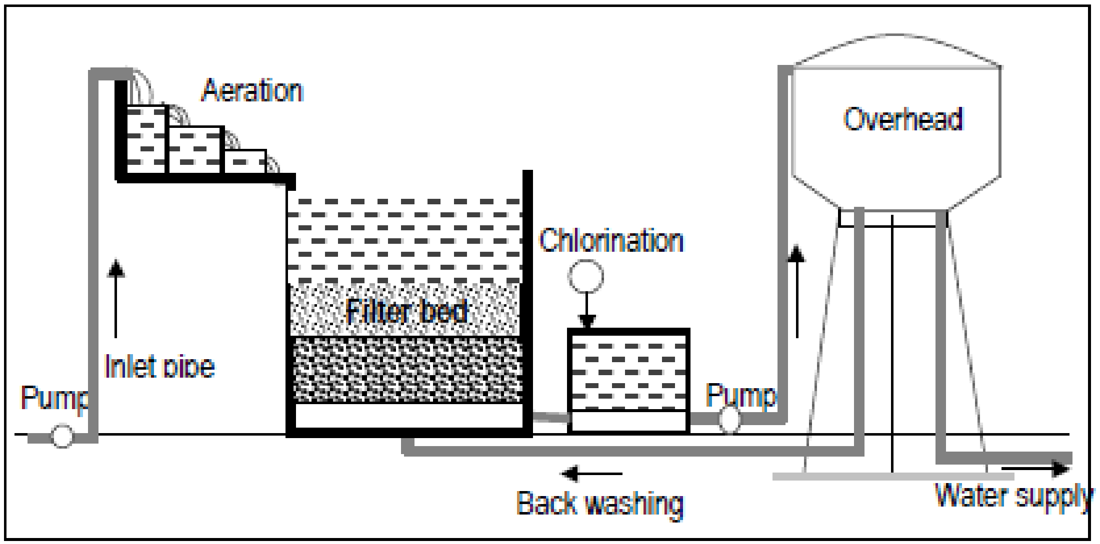
Technologies used for As Removal in Bangladesh …

(2) Arsenic Iron Removal Plants (AIRPs): Community Scale



Technologies used for As Removal in Bangladesh….

(3) Arsenic Iron Removal Plants (AIRPs): Municipal Scale



Technologies used for As Removal in Bangladesh

(4) Commercially Available SIDKO Plant: Community Scale

Questions?

- Water from a tubewell with high arsenic concentration also has an iron concentration of 10.0 mg/L. You have two options for removal of arsenic from this water: (a) coagulation (e.g., with ferric chloride) and (b) filtration system (e.g., using iron-coated sand). In your opinion, which option is more appropriate for this particular water? Explain.

Arsenic in Food Chain

- Groundwater widely used for irrigation during dry season, primarily for growing "boro" rice.

- Groundwater irrigation covers about 80% of total irrigated area of about 4.88 million ha; about 65% covered by shallow tubewell. Over 1.2 million shallow tubewell and about 30 thousand deep tubewells operated in 2006-07 season.

- Like shallow drinking water wells, a significant fraction of shallow irrigation wells is likely to be contaminated by Arsenic

Arsenic in Food Chain ……..

- An estimated ~~1000~~ 1360 metric tons of As is cycled each year through irrigation water.
- Higher accumulation of Arsenic in irrigated soil and in crops (primarily rice) grown with As-contaminated groundwater is a major concern.
- Higher As concentrations in vegetables grown in As-contaminated areas is also a concern.
- Arsenic in food items could significantly increase overall As exposure.

Arsenic load on Agricultural Soil:

If As in irrigation water = 1000 µg/L

Irrigation water = 1000 mm/season (typical for boro rice)

Arsenic load on Soil = 1 kg/ha

Arsenic in Irrigated Soil

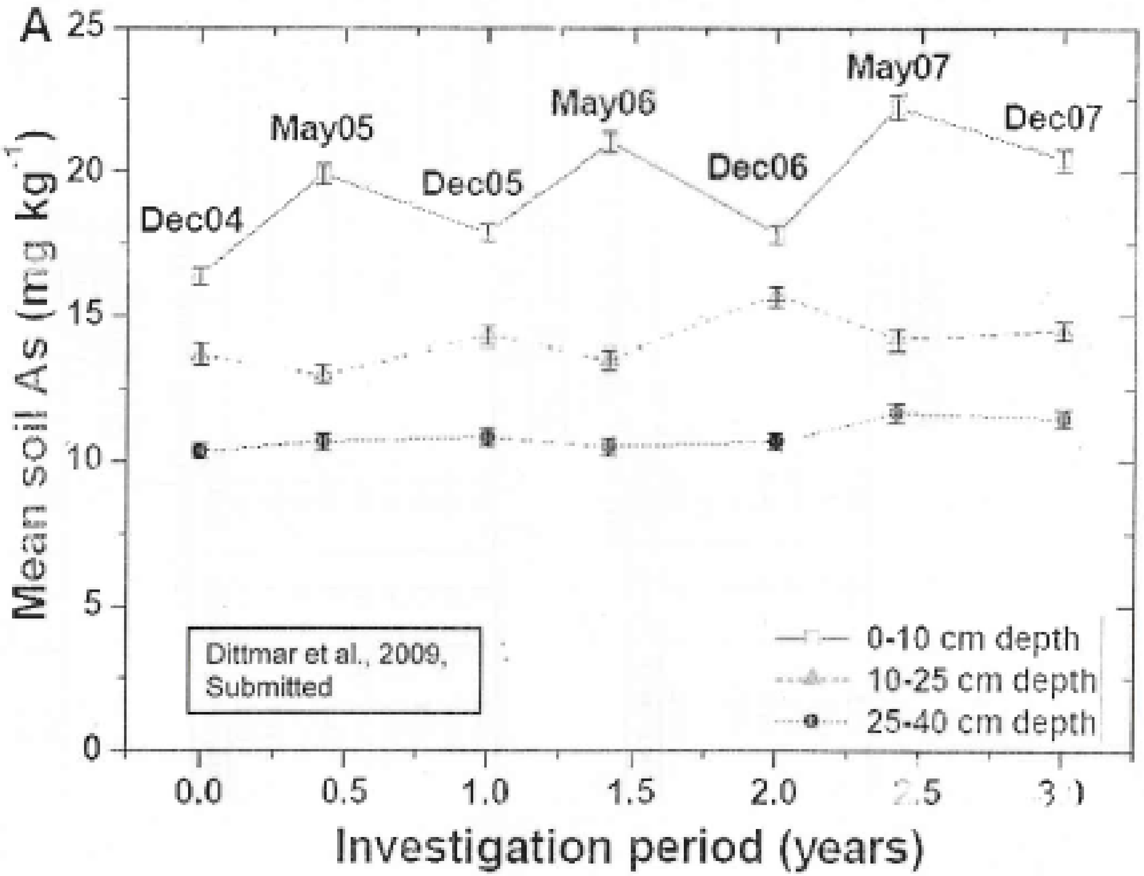
- Data on As in soils in Bangladesh indicate that 5-10 mg/kg is the background level.
- Reports indicate that soil concentrations are increasing because of As input via irrigation water
- Available data suggest significant accumulation of As in top layer (~0-10 cm) of irrigated soil; reported soil As concentrations vary from about 10 to 70 mg/kg.
- There is significant spatial and temporal variation of As concentration in irrigated soil.

Arsenic in Irrigated Soil ……..

- Fe (III) oxides present in soil and those produced by oxidation of Fe (II) in irrigation water promote adsorption and retention of As in soil. However, desorption and dissolution of Fe-solids (e.g., during flooding) may reduce As accumulation in soil.

- As a result, As concentration in top layers of irrigated soil typically increases at the end of irrigation season (May, for boro rice), and then decreases after flood by December.

Area-weighted Soil As Concentration between December 2004 – December 2007



- Higher As in irrigated soil in May, compared to December;
- Gradual; build-up of As in irrigated soil

Arsenic in Irrigated Soil ……….

- Presence of As in irrigation water leads to elevated levels of As in soil, with significant spatial and temporal variation.
- Since floodwater removes significant quantities of accumulated As from agricultural soil, areas without pronounced monsoon flooding may be at greater risk of soil As accumulation than seasonally flooded fields.
- Long-term accumulation of As in soil is likely to result in a concomitant long-term decline in rice yields in arsenic affected areas.

Arsenic in Rice and Food Items

- Reported As concentrations in rice grains range from 0.03 to 1.24 mg/kg.

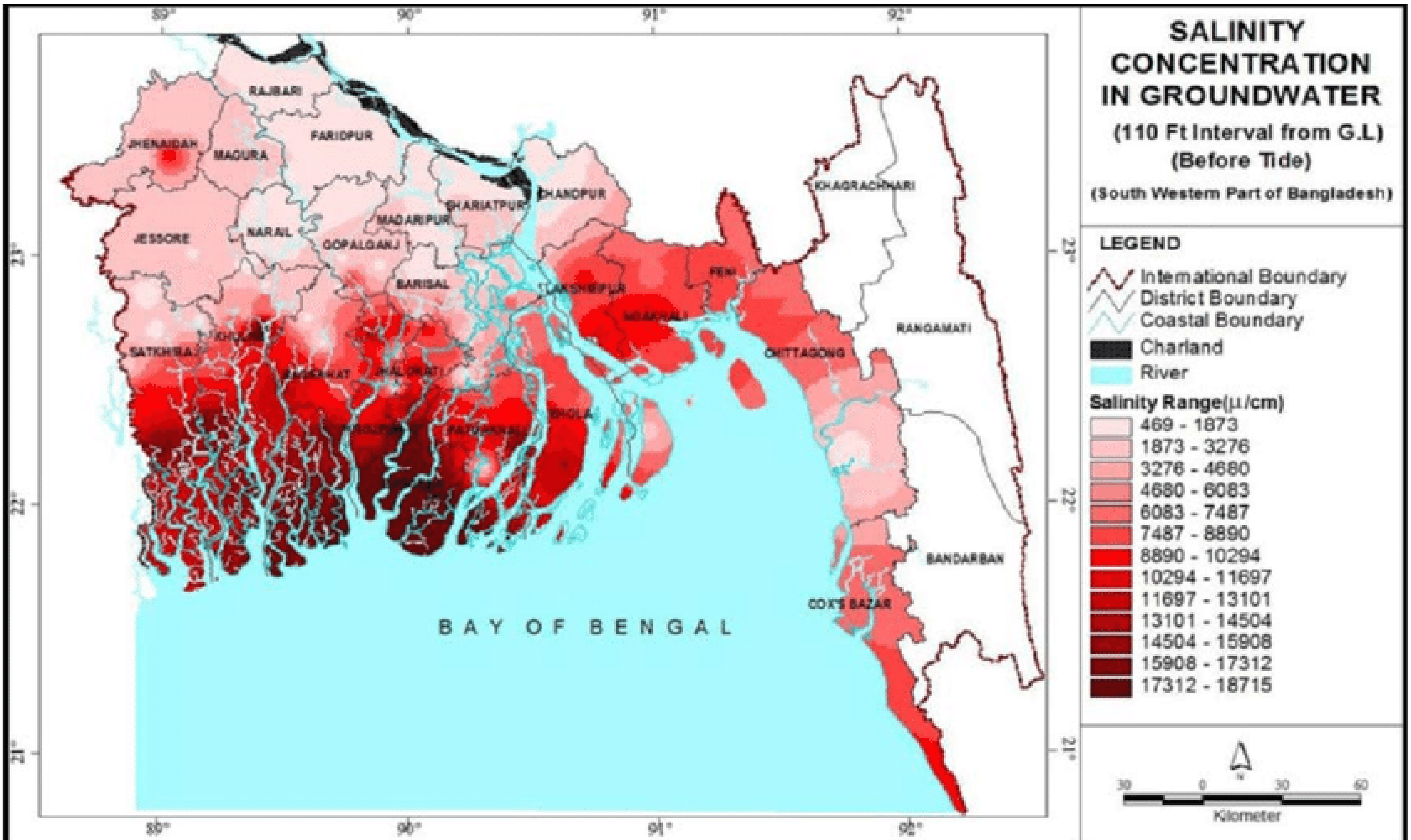
- Compared to other countries, rice from Bangladesh and India had the highest percentage of inorganic As (about 80%), against 42% in rice from the USA.

- Arsenic concentration in straw and grain of rice appear to be strongly correlated with As in soil.

Arsenic in Rice and Food Items ....

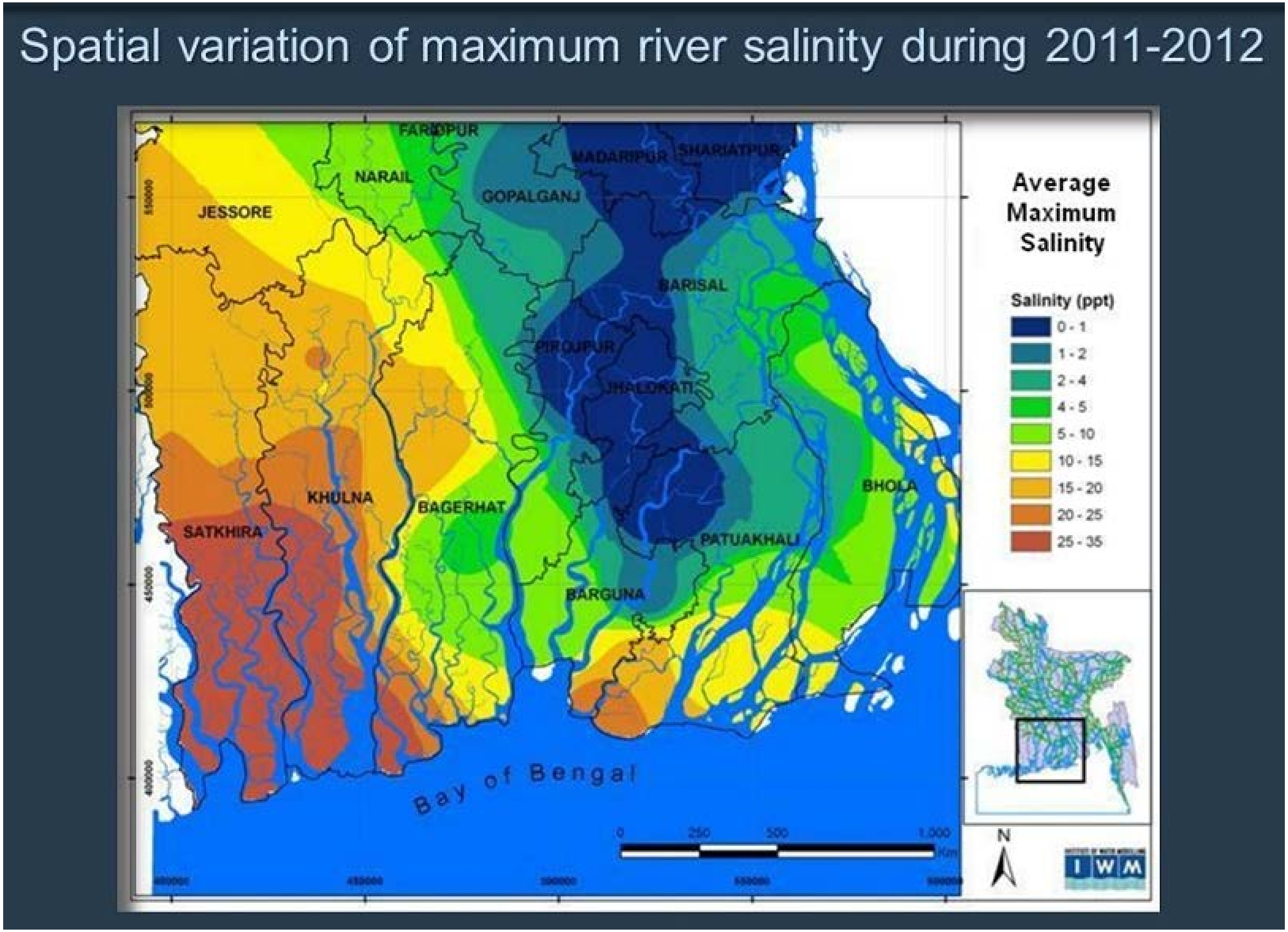
- Relatively high concentrations of As have been found in common vegetables grown with As-contaminated groundwater.
- All As ~~present~~ in vegetables, pulses and spices is reported to be present in more toxic inorganic form.
- Human As uptake via rice and vegetables (i.e. food) may represent a major As uptake pathway, especially where As intake via drinking water is limited (e.g., by provision of low-As drinking water).

Salinity Problem in Coastal Areas



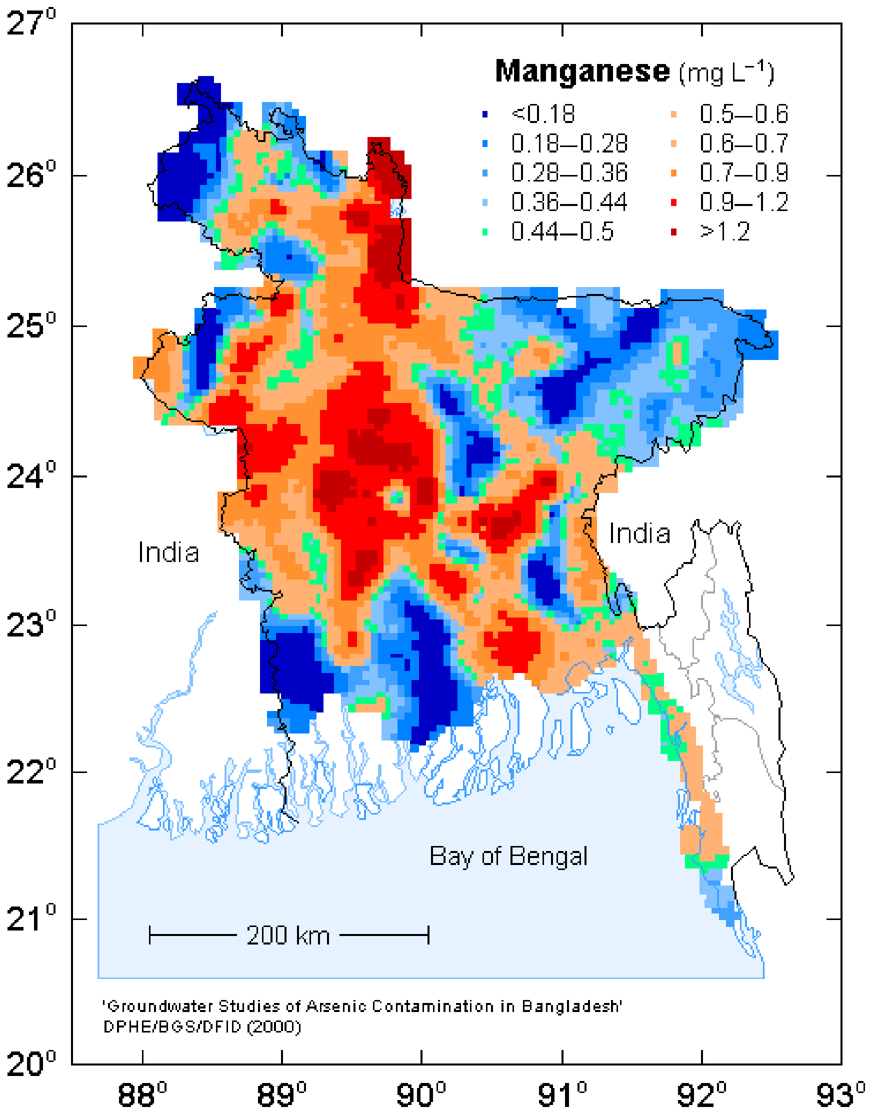
Source: Glass (2013).

River Salinity in Southwest Coastal Region (*IWM, 2013)*

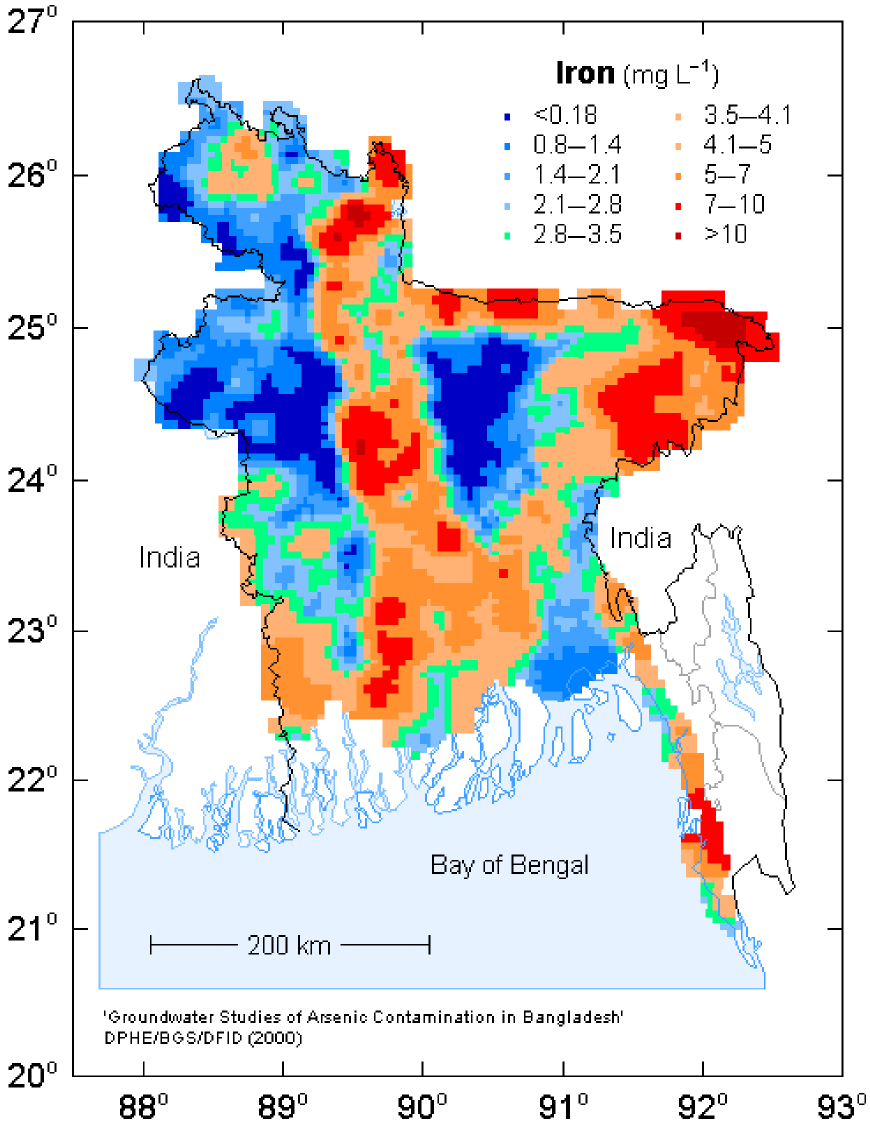


Common Water Options in Coastal Areas

- Pond sand filters (PSF),
- Rainwater harvesting systems (RWHS),
- Reverse osmosis (RO) plants (for treatment of saline water),
- Ultra-filtration systems
- Tubewell (saline and arsenic free),
- Ringwells (saline and arsenic free)



Distribution of Mn in Groundwater of Bangladesh



Distribution of Fe in Groundwater of Bangladesh