ARSENIC IN VEGETABLES AND ITS IMPLICATIONS ON HUMAN ARSENIC EXPOSURE

by

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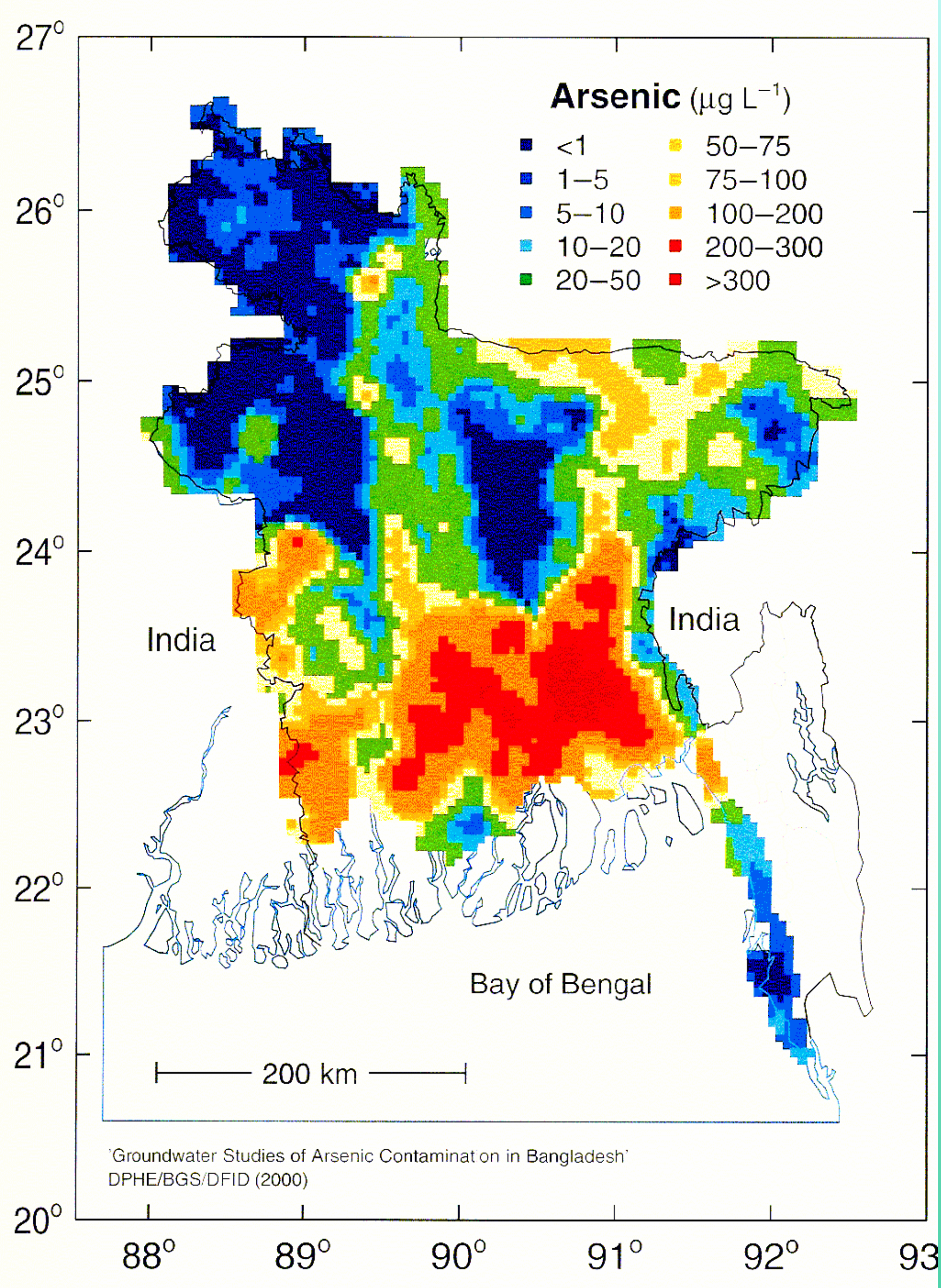


Arsenic Contamination of Groundwater in Bangladesh:

- **Shallow aquifer (< 100 m) primarily affected, which is widely used for domestic purpose through use of hand tubewells**
- **Out of 465 *upazilas* (sub-districts), 270 seriously affected**
- **Over 30 million people exposed to As above 50 ppb**

Groundwater Irrigation in Bangladesh

- Groundwater is widely used for irrigation during dry season (December-April), primarily for growing dry season paddy, called *boro;* and also wheat. Some vegetables also receive groundwater irrigation

- Groundwater irrigation covers about 75% of the total irrigated area; shallow irrigation wells covers about 60% of total irrigated area.

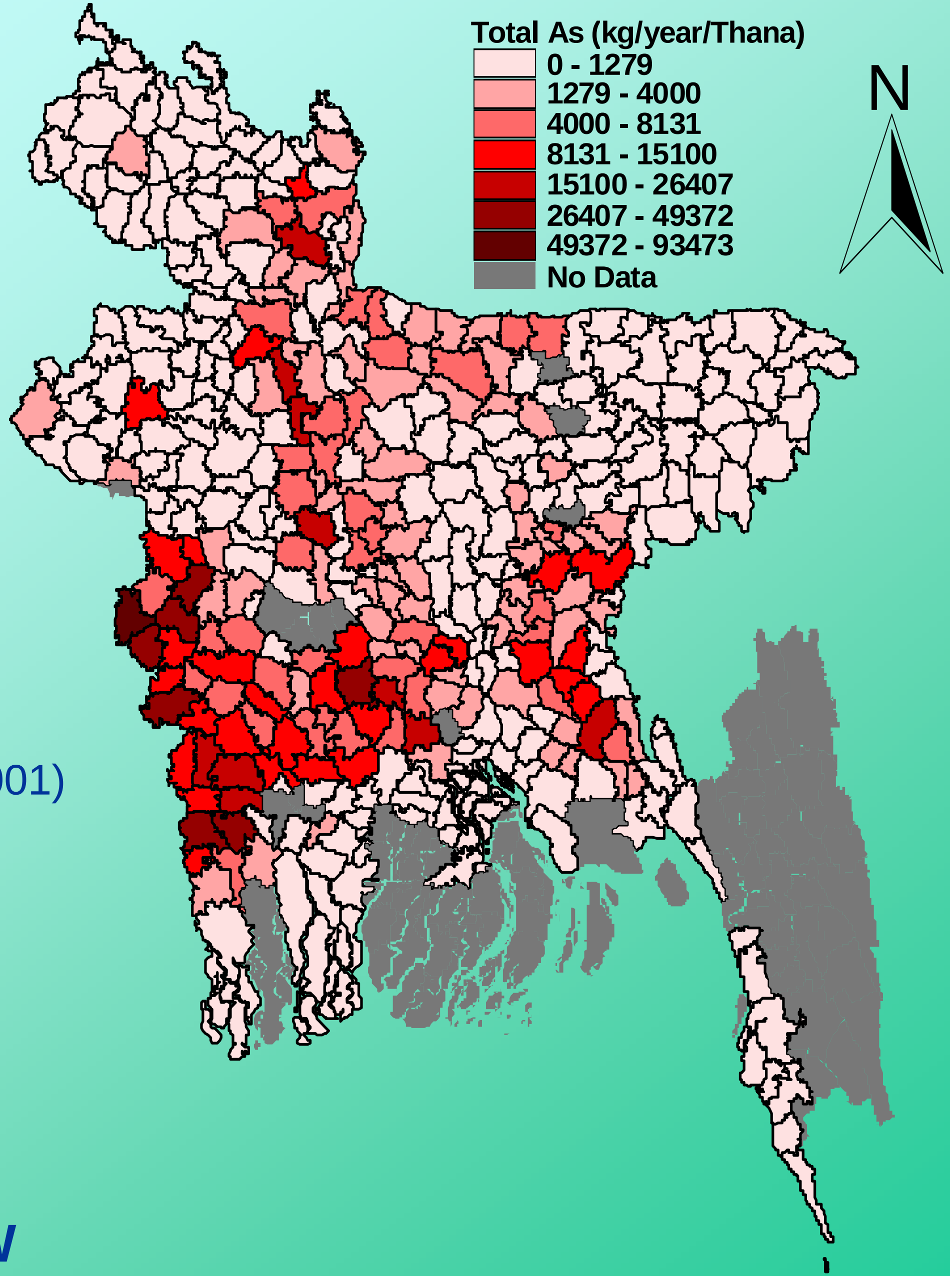
- Widespread use of groundwater for irrigation suggests that ingestion of irrigated crops could be a major exposure route for As, along with drinking water.

- About 40% of about 40,000 Arsenicosis patients identified so far are actually drinking water with As concentration within safe (0-50 ppb) range, possibly indicating As exposure from other sources

HOW MUCH ARSENIC IN PUMPED WITH "STW" IRRIGATION WATER ?

Estimation:

- Area under STW: BADC (2001-2005)
- Irrigation requirement: 1000 mm
- Average As conc: From DPHE/BGS (2001)



➢ **Total As cycled through Irrigation water:**

About 970 tons per year

➢ **Higher cycling of As in SW and SC regions**

Food Consumption Pattern

- **Average food consumption in "g/capita/day"**
  Hels et al. (2003)

- Rice	**: 450**
- Vegetables	**: 178**
- Roots & Tubers	**: 61**
- Fish	**: 39**
- Other animal products	**: 31**

- **In rural areas, the main meal usually consists of boiled rice served with cooked vegetables.**
- **Reported vegetable consumption varies from 130 to 500 g/capita/day (wet/fresh weight)**

Arsenic in Food & Vegetables

- Relatively more research/data on As in rice
- Most available data on As concentration in vegetables are based on random sampling and not accompanied by As concentration in the irrigation water.
- Recent findings (Williams et al., 2006) suggesting that all As in vegetables, pulses and spices exist in the more toxic “inorganic” form is a cause of concern

Objectives of the Study

Effect of As concentration in irrigation water on As accumulation in vegetables and its implications on human As exposure

Specific objectives:

In selected areas, determine/estimate

- **Arsenic concentration in irrigation water**
- **Corresponding As accumulation in topsoil**
- **Arsenic uptake by different parts of some common vegetables**
- **Implication on As exposure**

Study Areas

❖Three different areas selected

Two As affected areas:

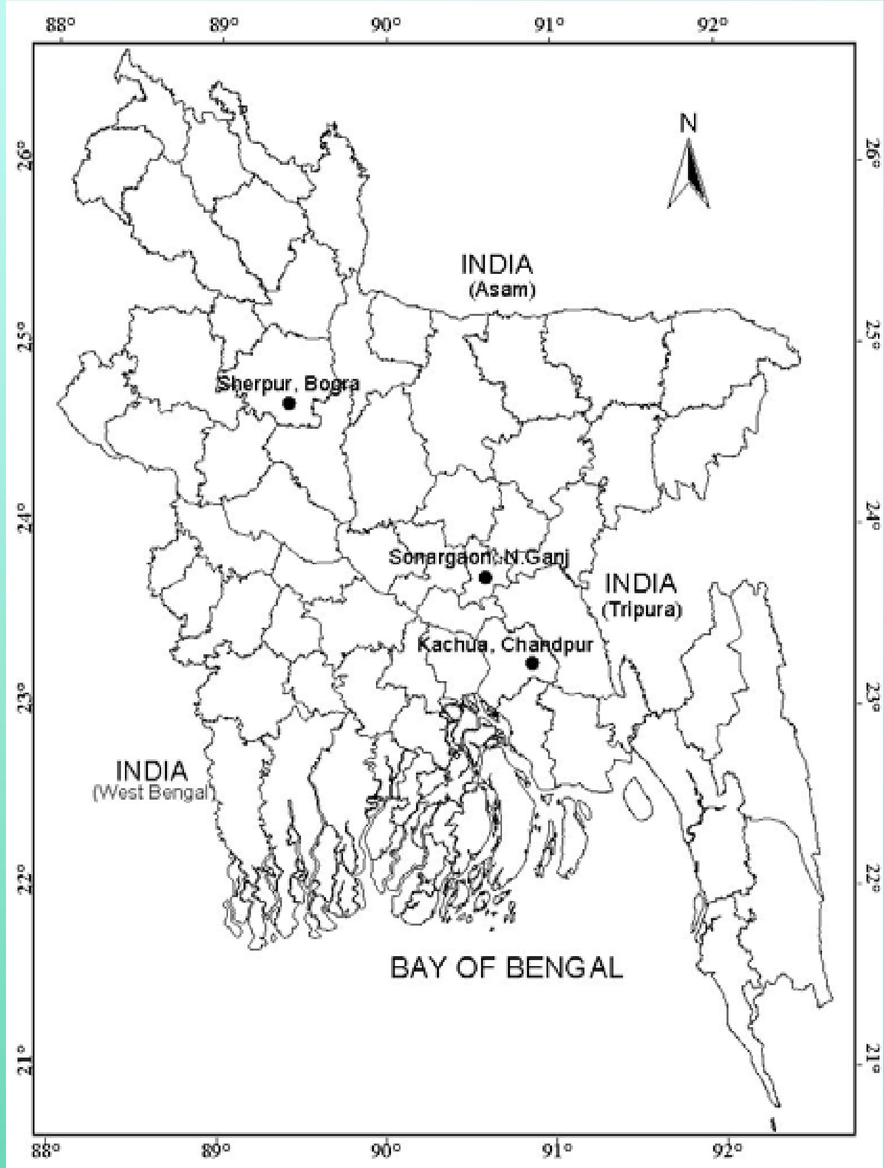
- Sonargaon, Narayangonj
- Kachua, Chandpur

One unaffected area:

- Sherpur, Bogra

❖Selected Vegetables

Potato, Tomato, Stem Amaranth, Red Amaranth, Cabbage and Cauliflower



Sample Collection and Analysis

- Collection of Irrigation Water Sample:

- Groundwater samples were collected directly from wells and surface water samples were collected from respective ponds / canals.

- Collection of Soil Samples:

- From each vegetable field, 3 soil core samples were collected with a 37.5 mm dia, 750 mm high PVC pipe sampler.

- Collection of Vegetable Samples:

- Three different vegetable plant samples (of each of the 6 types of vegetables) including root and root- soil were collected from each field.

Laboratory Analysis

- **Division of Soil Core Samples:**
  - 0 - 75 mm; 75 - 150 mm; 150 - 300 mm; 300 - rest
  - "Root-soil" (soil associated with root) was also collected by washing with deionized water

- **Division of Plant Samples:**

  (i) root, (ii) stem, (iii) leaf, (iv) edible part

- **Analysis of Soil Sample:**

  Digested with aqua-regia and analyzed for total As using GF-AAS (Shimadzu, AA6800)

- **Analysis of Plant Samples:**

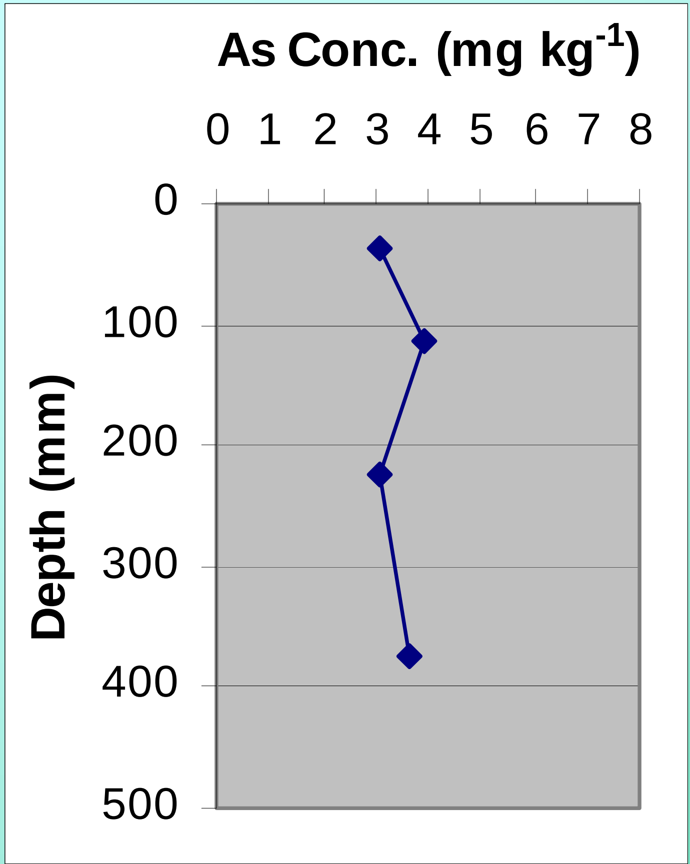
  Digested using nitric acid and perchloric acid and analyzed for total As using HVG-AAS (Shimadzu, AA6800)

Arsenic in Irrigation Water

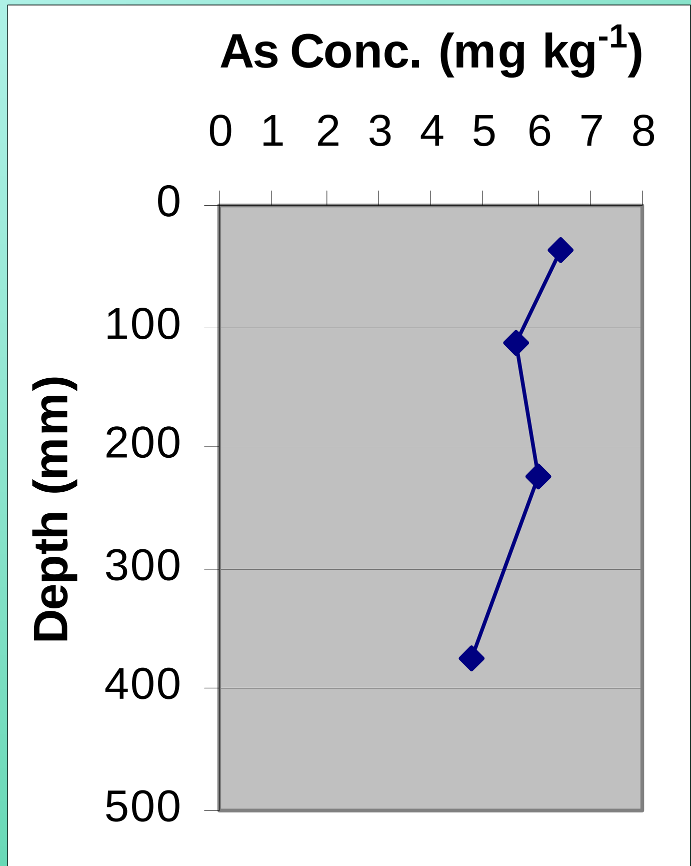
- As concentrations in groundwater:
  - Borga : < 1 ppb
  - Chandpur : 73 to 132 ppb
  - Narayanganj : 63 to 266 ppb

- As concentrations surface water:
  - Bogra : < 1 ppb
  - Chandpur : up to 6.7 ppb
  - Narayanganj : up to 25.3 ppb

Arsenic Profile in Cauliflower Field Soil Cores (Narayanganj)

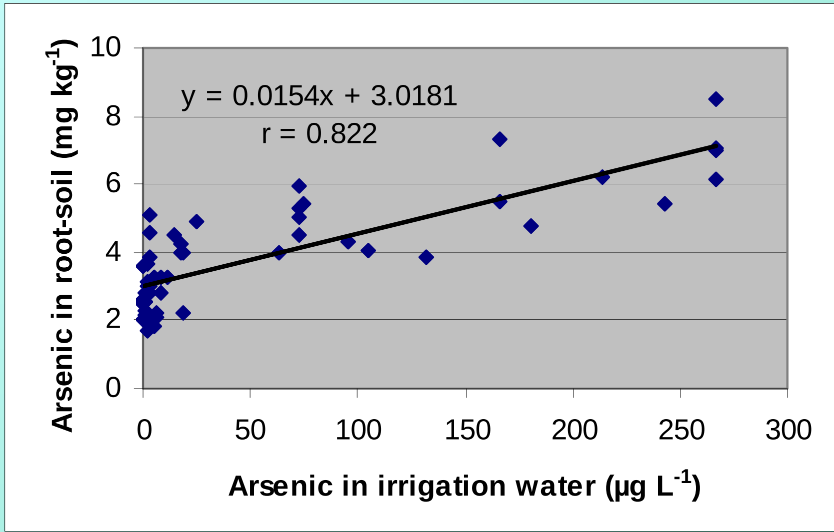


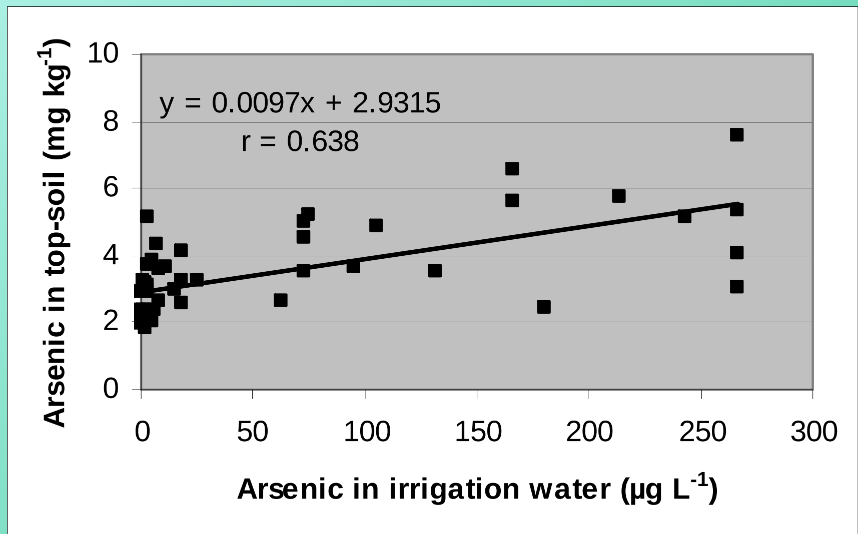
Surface water
As =15-18.1 ppb



Groundwater
As: 166 ppb

Arsenic in Irrigation Water and Soil





Arsenic in Vegetable Samples: Potato

Groundwater Irrigation						
Sampling Location	As in Water (µg/l)	As in Root Soil Mean ± SD (mg/kg)	As in Root Mean ± SD (mg/kg)	As in Stem Mean ± SD (mg/kg)	As in Leaf Mean ± SD (mg/kg)	As in Edible Part Mean ± SD (mg/kg)
Bogra (n=6)	**< 1.0**	2.55 ± 0.28	0.16 ± 0.04	0.09 ± 0.03	0.07 ± 0.03	**0.02 ± 0.01**
Chandpur (n=6)	**95 – 132**	4.09 ± 0.23	1.78 ± 0.57	0.34 ± 0.15	0.25 ± 0.10	**0.23 ± 0.12**
Narayanganj (n=6)	**214 - 243**	5.82 ± 0.93	2.62 ± 0.60	1.45 ± 0.32	2.06 ± 0.41	**1.15 ± 0.31**
Surface Water Irrigation						
Sampling Location	As in Water (µg/l)	As in Root soil Mean ± SD (mg/kg)	As in Root Mean ± SD (mg/kg)	As in Stem Mean ± SD (mg/kg)	As in Leaf Mean ± SD (mg/kg)	As in Edible Part Mean ± SD (mg/kg)
Bogra (n=3)	**< 1.0**	2.59 ± 0.51	0.35 ± 0.12	0.12 ± 0.05	0.25 ± 0.11	**0.04 ± 0.01**
Chandpur (n=3)	**1.6**	3.12 ± 1.08	0.45 ± 0.09	0.24 ± 0.10	0.25 ± 0.08	**0.10 ± 0.03**
Narayanganj (n=3)	**25.3**	4.90 ± 1.67	1.58 ± 0.46	0.85 ± 0.25	1.03 ± 0.45	**0.51 ± 0.20**

Arsenic in Vegetable Samples: Tomato

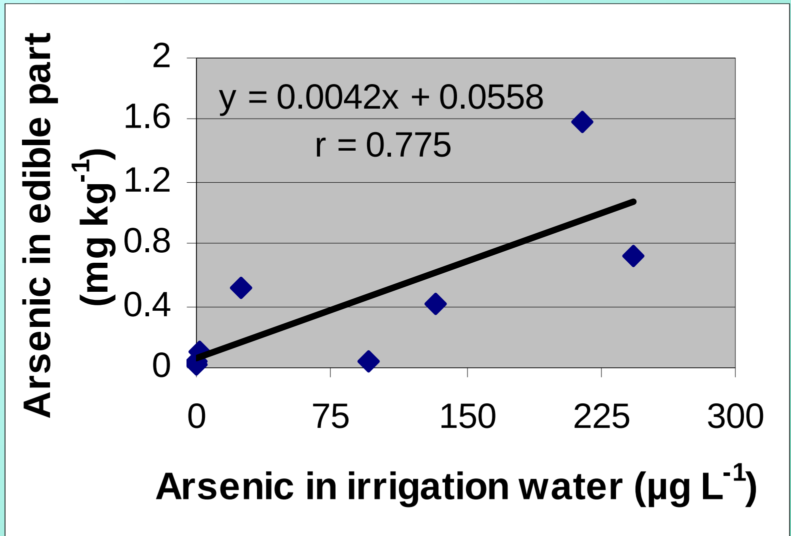
Groundwater Irrigation						
Sampling Location	As in Water (µg/l)	As in Root Soil Mean ± SD (mg/kg)	As in Root Mean ± SD (mg/kg)	As in Stem Mean ± SD (mg/kg)	As in Leaf Mean ± SD (mg/kg)	As in Edible Part Mean ± SD (mg/kg)
Bogra (n=6)	**<1.0**	3.03 ± 0.57	0.33 ± 0.28	0.13 ± 0.04	0.39 ± 0.16	**0.27 ± 0.05**
Chandpur (n=3)	**73**	4.53 ± 0.51	1.69 ± 0.47	0.99 ± 0.24	0.85 ± 0.21	**1.05 ± 0.29**
Narayanganj (n=6)	**63 - 166**	5.63 ± 1.68	1.99 ± 0.11	1.15 ± 0.35	2.82 ± 0.23	**1.70 ± 0.15**
Surface Water Irrigation						
Sampling Location	As in Water (µg/l)	As in Root soil Mean ± SD (mg/kg)	As in Root Mean ± SD (mg/kg)	As in Stem Mean ± SD (mg/kg)	As in Leaf Mean ± SD (mg/kg)	As in Edible Part Mean ± SD (mg/kg)
Bogra (n=3)	**2.5**	3.67 ± 0.76	1.72 ± 036	0.55 ± 0. 13	0.33 ± 0.09	**0.47 ±0.08**
Chandpur (n=6)	**2.0 - 3.2**	3.53 ± 1.46	0.48 ± 0.16	0.23 ± 0.08	0.36 ± 0.07	**0.78 ± 0.31**
Narayanganj (n=3)	**18.2**	2.21 ± 0.51	1.03 ± 0.38	1.09 ± 0.27	0.93 ± 0.35	**0.99 ± 0.25**

Arsenic in Vegetable Samples: *Stem Amaranth*

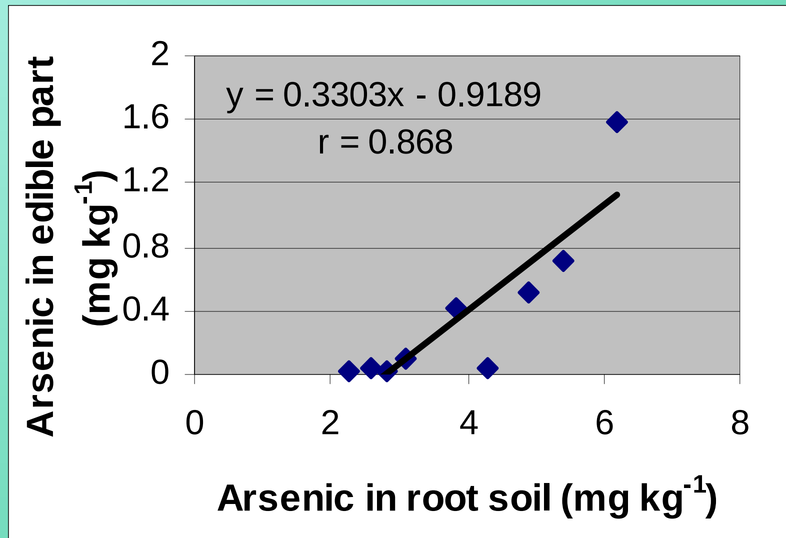
Groundwater Irrigation						
Sampling Location	As in Water (µg/l)	As in Root Soil Mean ± SD (mg/kg)	As in Root Mean ± SD (mg/kg)	As in Stem Mean ± SD (mg/kg)	As in Leaf Mean ± SD (mg/kg)	Mean As in Edible Part (avg. of stem and leaf) (mg/kg)
Bogra (n=6)	**5.0**	2.55 ± 0.71	1.08 ± 0.21	0.99 ± 0.08	0.62 ± 0.06	**0.80**
Chandpur (n=3)	**73**	5.03 ± 2.05	2.04 ± 0.51	1.70 ± 0.42	0.87 ± 0.18	**1.28**
Narayanganj (n=3)	**166**	5.52 ± 1.08	1.55 ± 0.43	1.41 ± 0.26	1.40 ± 0.68	**1.41**
Surface Water Irrigation						
Sampling Location	As in Water (µg/l)	As in Root soil Mean ± SD (mg/kg)	As in Root Mean ± SD (mg/kg)	As in Stem Mean ± SD (mg/kg)	As in Leaf Mean ± SD (mg/kg)	Mean As in Edible Part (avg. of stem and leaf) (mg/kg)
Bogra (n=3)	**1.1**	2.54 ± 0.33	1.27 ± 0.38	0.24 ± 0.09	0.56 ± 0.18	**0.40**
Chandpur (n=6)	**6.2 - 6.7**	2.16 ± 0.17	0.81 ± 0.21	0.25 ± 0.11	0.42 ± 0.14	**0.33**
Narayanganj (n=6)	**15 - 18.2**	4.23 ± 0.27	2.40 ± 0.60	1.00 ± 0.24	1.47 ± 0.45	**1.24**

Arsenic in Vegetables: Correlation with Water and Soil Arsenic

Potato



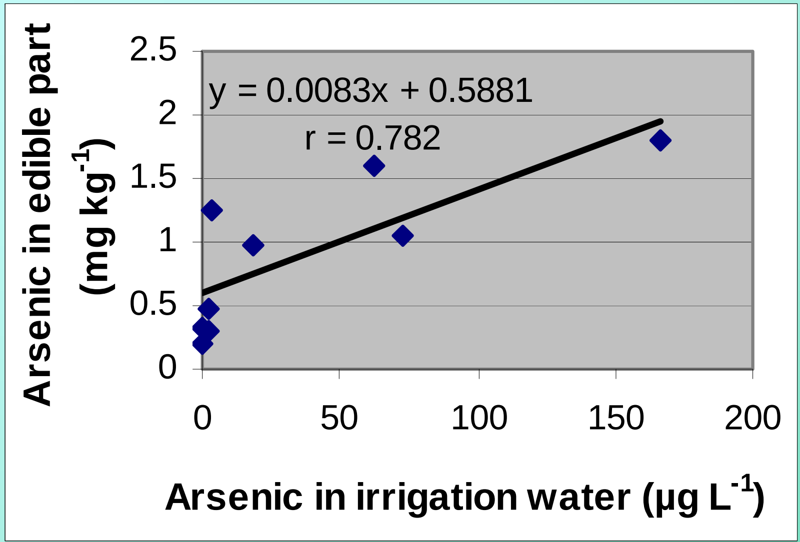
($p < 0.05$)



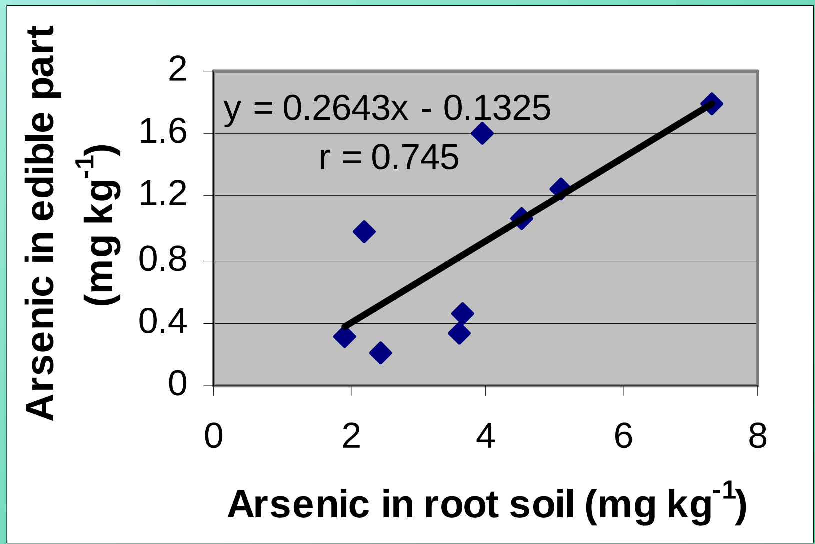
($p < 0.01$)

Arsenic in Vegetables: Correlation with Water and Soil Arsenic

Tomato



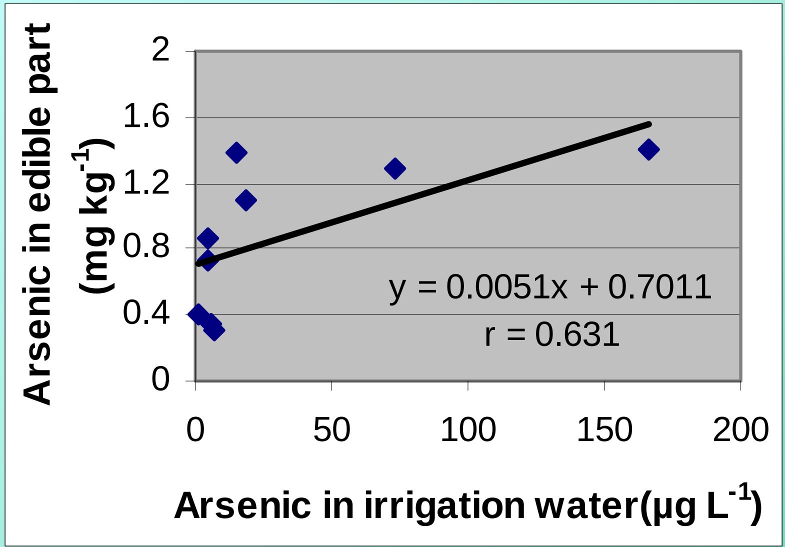
($p < 0.05$)



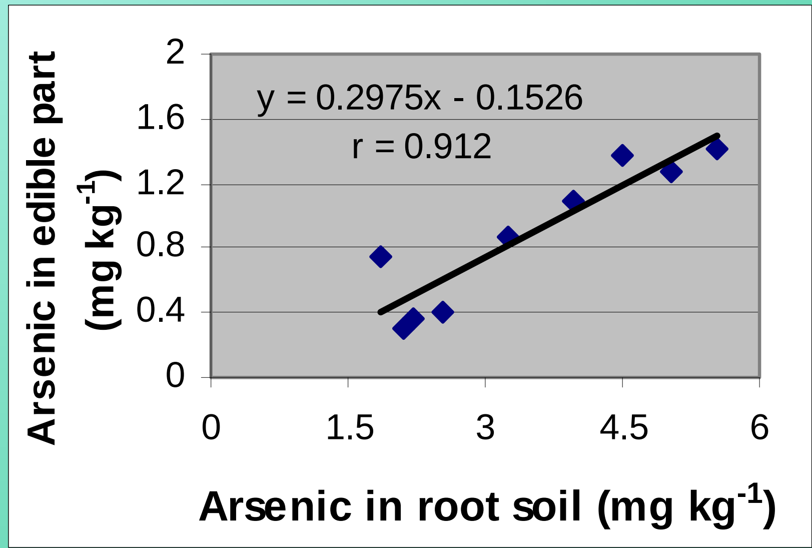
($p < 0.05$)

Arsenic in Vegetables: Correlation with Water and Soil Arsenic

Stem Amaranth



($p = 0.068$)



($p < 0.01$)

MAJOR OBSERVATIONS

- The As concentrations in edible parts of the vegetables are strongly correlated with As concentrations in both irrigation water and root-soil.

- Among the selected vegetables, mean As concentrations have been found to be relatively higher for stem amaranth, red amaranth (both leafy vegetable) and tomato.

- Total As concentrations in most vegetables irrigated with As contaminated groundwater exceeded the Chinese food safety standard of 0.05 mg/kg inorganic As (wet weight basis) by a large margin.

Exercise: Dietary Intake of Arsenic from Rice & Vegetables (μg/day)

Vegetable Consumption (g/capita/day)	Bogra Vegetable Mean As: 0.074 mg/kg	Narayanganj Vegetable (SW irrigation) Mean As: 0.185 mg/kg	Narayanganj Vegetable (GW irrigation) Mean As: 0.33 mg/kg
130	5	12	21
178	6	16	29
500	18	46	82

- WHO's Provisional Maximum Tolerable Daily Intake: 126 μg/day (60 kg adult)
- Intake from rice with As=0.2 to 0.5 mg/kg (450 g/capita/day): 72-180 μg/day
- Intake from vegetables: 12-82 μg/day

Thus, depending on As in irrigation water, vegetables could be an important source of inorganic As from food source, along with rice, in the As-affected areas.

Exercise: Dietary Intake of Arsenic from Drinking Water and Food Sources (μg/day)

Source and Consumption (g/capita/day)	Bogra Vegetable Mean As: 0.074 mg/kg	Narayanganj Vegetable (SW irrigation) Mean As: 0.185 mg/kg	Narayanganj Vegetable (GW irrigation) Mean As: 0.33 mg/kg
Vegetables (178 g/capita/day)	6	16	29
Rice (450 g/capita/day) As: 0.4 mg/kg*	144	144	144
Water from food (1.3 l/capita/day) As: 100 ppb	--	130	130
Drinking Water (3.0 l/capita/day) As: 100 ppb	--	300	300
As from Food	157	290	303
As from Drinking water	--	300	300

*80% inorganic As

Conclusions

- While it is generally agreed that rice is the predominant source of inorganic As from food sources, vegetables grown with As contaminated groundwater could significantly increase As exposure in As-affected areas.

- In some As affected areas, As exposure from food (cooked rice, vegetables) could be comparable to that from contaminated drinking water.

- Current focus of “National As Policy” and “Implementation Plan” on providing safe drinking water may not be enough to limit As exposure of population in the affected areas.

- Among other measures, efforts may be made to identify vegetables that are more prone to As accumulation and to encourage use of surface water in vegetable cultivation, which requires much less irrigation (that could be available for surface water sources in many areas).

Research Areas/Ideas

ARSENIC IN FOOD CHAIN:

- **Assessment of As exposure from different sources (food, water, others)**
- **Assessment of As cycling in irrigated agricultural lands**

Research Areas/Ideas

WATER TREATMENT

- Development of water treatment technologies for simultaneous removal of Fe, Mn and As

- Ammonia and algae removal from water in surface water treatment plant [Vietnam]

Research Areas/Ideas

WASTEWATER TREATMENT

- **Development of low-cost technologies for treatment of textile dyeing wastewater [Japan]**

Thank You Very Much