

Bangladesh and Vietnam: Different groundwater compositions require different approaches to arsenic mitigation

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Supporting Information

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Table S1. Overview of key data of Bangladesh and Vietnam. Sources: The world fact book of the CIA (<http://www.cia.gov/cia/publications/factbook/>) and (<http://www.nationmaster.com/>)

	Bangladesh	Vietnam
Area	total: 144,000 sq km land: 133,910 sq km water: 10,090 sq km	total: 329,560 sq km land: 325,360 sq km water: 4,200 sq km
Land use	arable land: 55.39% permanent crops: 3.08% other: 41.53% (2005)	arable land: 20.14% permanent crops: 6.93% other: 72.93% (2005)
Irrigated Land	47,250 sq km (2003)	30,000 sq km (2003)
Fertilizer used (kg per ha)**	156.3	285.3
Population	147,365,352	84,402,966
Population growth rate	2.09% (2006 est.)	1.02% (2006 est.)
Life expectancy at birth	total population: 62.46 years male: 62.47 years female: 62.45 years (2006 est.)	total population: 70.85 years male: 68.05 years female: 73.85 years (2006 est.)
Literacy (definition: age 15 and over can read and write)	total population: 43.1% male: 53.9% female: 31.8% (2003 est.)	total population: 90.3% male: 93.9% female: 86.9% (2002)
GDP (purchasing power parity):	\$304.3 billion (2005 est.)	\$232.2 billion (2005 est.)
GDP - real growth rate:	5.7% (2005 est.)	8.4% (2005 est.)
GDP - per capita (PPP):	\$2,100 (2005 est.)	\$2,800 (2005 est.)
Unemployment rate	2.5% (includes underemployment) (2005 est.)	5.5% (2005 est.)
Population below poverty line:	45% (2004 est.)	19.5% (2004 est.)

The exact number of people with arsenic related diseases is still an issue of intense debate. Yu et al. (S1) estimated that long-term exposure to arsenic in Bangladesh would result in approximately 1,200,000 cases of hyperpigmentation, 600,000 cases of keratosis, 125,000 cases of skin cancer, and 3000 fatalities per year from internal cancers. Exposure to arsenic was also shown to adversely affect the mental development of children (S2).

Table S2. Concentrations and relevant numbers for arsenic removal in Bangladesh

District	As (µg/L) (mean±std)	Fe (mg/L) (mean±std)	P (mg/L) (mean±std)	(Fe- 1.8P) (M/M)	As >50 µg/L	As>50 µg/L (%)	As removal OK	As removal OK (%)	Popula- tion (Mio)
Bagerhat *	175±172	6.78±5.33	1.42±0.90	17	37/55	67%	17/55	31%	1.516
Barguna	5±6	1.18±1.00	5.37±1.45	-4668	0/3	0%	0/3	0%	0.838
Barisal *	189±202	4.08±3.31	2.11±2.21	-19	26/40	65%	4/40	10%	2.331
Bhola **	201±54	4.45±4.57	1.10±0.28	6	2/2	100%	0/2	0%	1.677
Bogra	18±70	3.13±6.66	0.26±0.61	168	8/90	9%	48/90	53%	2.989
Brahamanbaria	103±159	3.31±4.89	0.98±1.31	2	21/52	40%	19/52	37%	2.989
Chandpur **	410±178	4.45±3.29	2.17±1.74	-8	52/52	100%	2/52	4%	2.210
Chittagong	39±80	4.80±8.81	2.28±4.11	-91	6/32	19%	12/32	38%	6.545
Chuadanga	82±124	2.55±2.07	0.33±0.24	24	13/31	42%	11/31	35%	0.987
Comilla *	150±152	2.58±2.81	1.27±1.41	-14	68/101	67%	18/101	18%	4.587
Cox'sBazar ^g	4±13	6.45±7.03	0.54±0.84	1541	1/27	4%	18/27	67%	1.757
Dhaka	51±71	5.51±5.86	0.86±0.75	71	14/36	39%	17/36	47%	8.576
Dinajpur	3±8	1.41±2.70	0.13±0.14	466	2/94	2%	42/94	45%	2.618
Faridpur *	149±155	4.29±3.40	0.92±0.76	12	41/59	69%	10/59	17%	1.719
Feni	62±87	3.59±5.76	1.10±1.86	0	16/44	36%	19/44	43%	1.196
Gaibandha ^g	22±87	5.36±7.08	0.35±0.41	258	5/67	7%	45/67	67%	2.118
Gazipur	4±24	0.51±0.90	0.14±0.09	16	1/42	2%	11/42	26%	2.026
Gopalganj **	229±153	6.98±4.24	1.46±0.85	13	32/34	94%	8/34	24%	1.132
Habiganj ^g	23±47	8.02±6.78	1.04±0.84	274	6/56	11%	40/56	71%	1.757
Jaipurhat ^g	1±2	1.71±3.19	0.07±0.06	1415	0/40	0%	30/40	75%	0.845
Jamalpur	15±35	4.33±5.17	0.37±0.40	285	4/61	7%	39/61	64%	2.089
Jessore	76±81	2.99±2.18	0.70±0.75	13	32/61	52%	11/61	18%	2.441
Jhalakati	54±144	1.93±2.30	5.00±2.75	-356	2/14	14%	0/14	0%	0.696
Jhenaidah	49±91	2.82±2.66	0.36±0.27	46	13/49	27%	26/49	53%	1.555
Khulna	52±89	2.82±3.19	1.40±1.60	-45	16/49	33%	5/49	10%	2.334
Kishoreganj	55±96	2.68±3.42	0.94±1.12	-9	27/96	28%	24/96	25%	2.525
Kurigram	21±57	6.95±8.65	0.40±0.43	357	7/76	9%	48/76	63%	1.782
Kushtia	115±311	2.66±2.94	0.39±0.44	17	13/42	31%	14/42	33%	1.713
Lakshmipur **	323±279	3.35±3.97	1.66±2.04	-8	13/16	81%	1/16	6%	1.479
Lalmonirhat	1±3	2.61±4.37	0.19±0.35	1841	0/39	0%	23/39	59%	1.089
Madaripur **	255±193	4.10±3.49	2.03±2.36	-13	25/27	93%	1/27	4%	1.137
Magura	25±53	1.48±2.22	0.33±0.38	21	4/29	14%	6/29	21%	0.811
Manikganj ^g	23±25	4.71±4.56	0.70±0.59	140	6/42	14%	28/42	67%	1.275
Maulvibazar ^g	17±39	7.36±7.06	0.56±0.61	445	3/48	6%	34/48	71%	0.580
Meherpur	115±145	2.95±1.93	0.42±0.30	18	8/13	62%	3/13	23%	1.604
Munshiganj *	198±146	4.80±4.29	1.19±0.73	6	37/43	86%	9/43	21%	1.294
Mymensingh	17±35	1.41±3.19	0.28±0.33	41	14/100	14%	24/100	24%	4.439
Naogaon	6±30	1.32±2.62	0.10±0.12	227	2/92	2%	54/92	59%	2.377
Narail	92±99	3.65±4.56	1.01±0.88	5	10/23	43%	5/23	22%	0.689
Narayanganj	52±97	2.91±5.56	0.47±0.39	36	7/28	25%	7/28	25%	2.138
Narsingdi	43±64	1.98±3.08	0.43±0.65	18	15/54	28%	15/54	28%	1.891
Natore	1±3	0.42±1.02	0.09±0.08	130	0/51	0%	11/51	22%	1.521
Nawabganj	7±14	0.96±1.58	0.14±0.19	100	2/45	4%	14/45	31%	1.420
Netrokona	30±43	3.05±4.40	0.67±0.77	39	14/64	22%	16/64	25%	1.938
Nilphamari ^g	2±5	3.05±4.63	0.14±0.22	1521	0/47	0%	34/47	72%	1.551
Noakhali **	231±167	1.36±1.60	1.81±2.12	-26	30/32	94%	1/32	3%	2.533
Pabna	32±90	2.26±4.30	0.23±0.32	63	13/78	17%	33/78	42%	2.154
Panchagarh ^g	3±6	2.54±6.50	0.17±0.36	1047	0/39	0%	27/39	69%	0.829
Patuakhali	7±6	5.02±0.49	2.35±2.33	-473	0/2	0%	1/2	50%	0.507
Pirojpur	42±74	3.04±2.72	3.03±2.54	-217	8/33	24%	2/33	6%	1.444
Rajbari	50±91	3.35±4.78	0.32±0.40	62	8/33	24%	17/33	52%	1.127
Rajshahi	8±18	0.73±1.57	0.15±0.20	43	5/78	6%	17/78	22%	0.940
Rangpur	8±33	4.46±6.19	0.28±0.34	559	1/83	1%	44/83	53%	2.262
Satkhira *	156±130	4.80±2.79	1.30±0.78	5	38/48	79%	13/48	27%	1.843
Shariatpur *	184±166	4.40±3.48	1.58±1.38	-5	32/40	80%	6/40	15%	1.057
Sherpur	23±36	5.06±8.07	0.27±0.31	248	6/50	12%	30/50	60%	1.247
Sirajganj	31±53	7.69±8.63	0.58±0.47	254	20/87	23%	55/87	63%	2.707
Sunamganj	41±62	5.61±7.49	1.67±2.03	6	2/13	15%	6/13	46%	1.969
Sylhet ^g	19±28	10.52±11.5	1.40±1.45	419	12/67	18%	46/67	69%	2.570
Tangail ^g	20±33	5.20±5.31	0.48±0.45	240	8/89	9%	60/89	67%	3.254
Thakurgaon	1±1	1.01±1.74	0.13±0.17	844	0/46	0%	19/46	41%	1.196
Over 200 **	301 ± 200	4.20 ± 3.80	1.88 ± 1.83	-8	154/163	94 %	13/163	8 %	10.17
Over 149 *	207 ± 183	4.28 ± 3.83	1.50 ± 1.48	-4	433/549	79 %	90/549	16%	14.35
> 90 m deep	5 ± 21	1.12 ± 2.11	0.30 ± 0.46	-	1/81	1.2 %	-	-	-
> 90 m deep	10 ± 33	1.00 ± 2.38	0.32 ± 0.37	-	9/173	5.2 %	-	-	-

Table S2. Concentrations of As, Fe and P and relevant numbers for arsenic removal in all districts of Bangladesh. Calculated from the BGS-DPHE (2) database with wells from 10-90 m depth (2988 of 3534) with reported values for As, P and Fe (2984). Non-numerical entries with "< detection limit" were replaced with numerical values (detection limit/2). The districts are marked and color-coded as follows: **As>149 µg/L ***, **As>200 µg/L ****, **Arsenic removal possible for > 65% of wells**⁹. In each of the worst affected districts of Bhola, Chandpur, Gopalganj, Lakshimpur, Madaripur, and Noakhali (marked red), more than 80% of the wells are affected by [As] >50 µg/L, and less than 6% of the wells could be treated by passive removal or sand filters (except in Gopalganj where 24% could be treated. The criterion for treatment with natural iron is based on the numbers of Meng et al., who reported that after oxidation of As with NaOCl, Fe:As ratios of >40 (mgL⁻¹/ mgL⁻¹) or > 53.6 (M/M), added as FeCl₃, are need to remove As to less than 50 µg/L (12). This criterion is in principal agreement with our laboratory and field study on passive removal with natural iron (13). In the red marked districts combined, the mean As-concentration is 301 µg/L, around 94 % of the wells have over >50 µg/L As and only about 8 % can be treated by precipitation with natural iron. In the orange (yellow in the maps) and red marked districts combined, the mean As-concentration is 207 µg/L and 79 % of the wells have >50 µg/L As and 16 % can be treated by passive removal. Over 24.5 million people live in these districts. As a comparison, the corresponding numbers from wells deeper than 90 m (92-362 m deep) in the marked districts are listed in the last two rows. (District populations from: <http://www.statoids.com/ybd.html> with 2001-01-23 census provisional data from Bangladesh Bureau of Statistics).

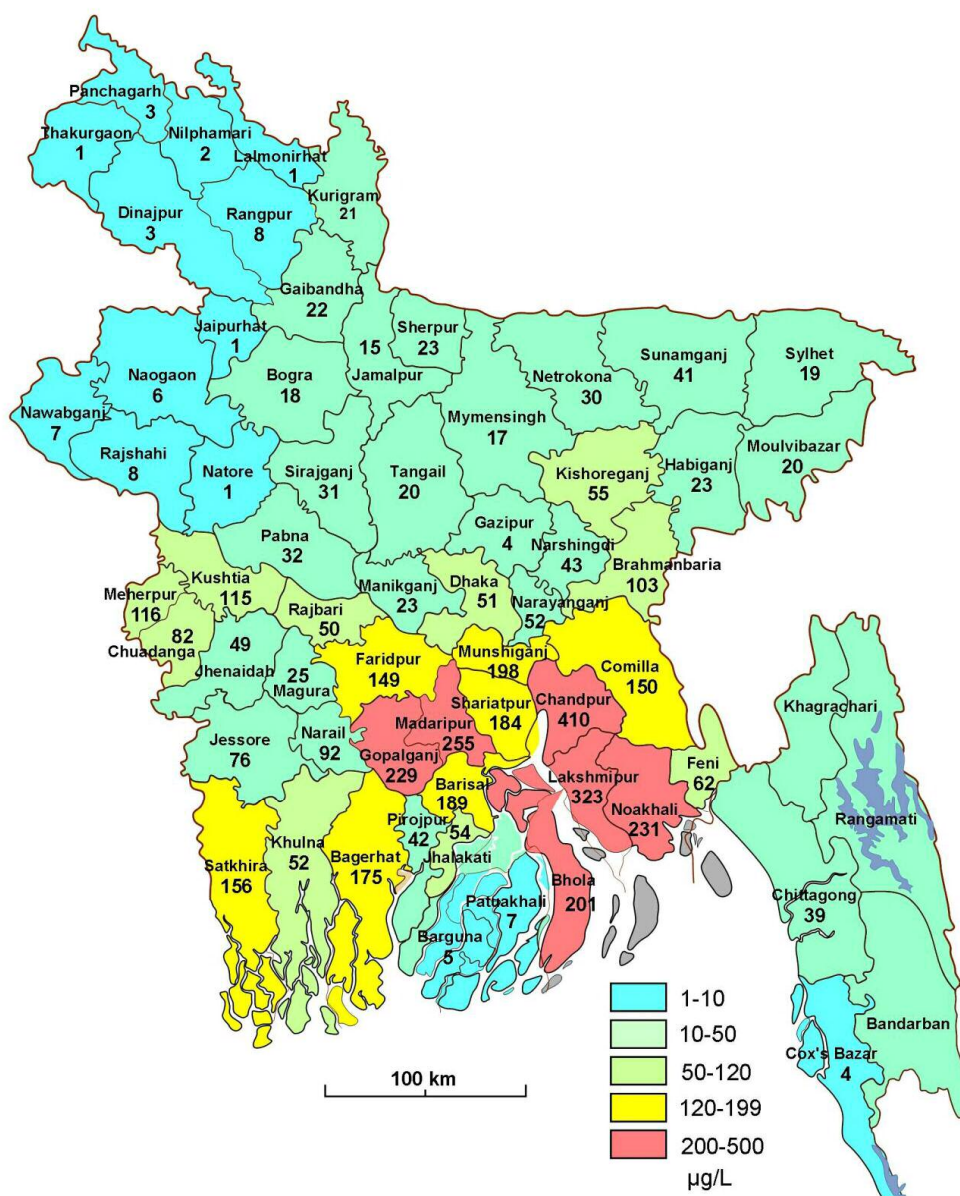


Figure S1. District map of Bangladesh with mean As-concentrations in 10-90 m deep tubewells, as explained in Table S2. Insufficient information was available in the regions marked grey.

Literature Cited

- (S1) Yu, W. H.; Harvey, C. M.; Harvey, C. F. Arsenic in groundwater in Bangladesh: A geostatistical and epidemiological framework for evaluating health effects and potential remedies. *Water Resour. Res.* **2003**, 39, (6).
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