Assessment of the impact of arsenic-containing irrigation water on soil contamination and plant uptake

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Abstract

Ground water, the main source of drinking and irrigation water, is contaminated by naturally occurring arsenic (As) in 61 out of 64 districts of Bangladesh. A study was conducted to assess the quality and impact of As contaminated irrigation water on agricultural soils and crops uptake and to know the spatial variability of As in soil, water and rice. More than hundred shallow tube wells (STW) were selected in Tala thana of Satkhira district in southwestern Bangladesh during boro (winter rice) season, 2002. As content in water, soil and plant parts were determined by hydride generation-atomic absorption spectrophotometer (HG-AAS). The mean value of As in the irrigation water samples was 150 ?g/l. Water As content was moderately correlated with electrical conductivity (EC), P, K, Mg, Na and Mn content in water. The mean soil As content was 19.3 mg/kg. The As build up in the soils was influenced by water-As, P, Na, Ca, Mg and Fe and soil organic carbon, clay, exchangeable K, Ca and Mg contents. The mean As concentration in rice grain was 0.328 mg/kg, which was much below the maximum permissible limit (1 mg/kg). The contents of As in straw were several folds higher than in grain and increased with increasing As contents in water and soil. Contents of organic carbon, exchangeable Mg and silt in soil and Fe in water significantly influenced the uptake of As by rice. A well-developed pattern of spatial variability in As content in irrigation water, soil and rice grain was observed in the studied area resulting from differences in soil and land type.

Media summary

The arsenic (As) status of agricultural soil is influenced by As content in irrigation water. The content of As in rice straw is much higher than that in grain.

Introduction

The extensive use of As-contaminated ground water for irrigating the crop fields produces high risk of contamination of the food chain. Rice (*Oryza sativa*), the staple food crop of Bangladesh, occupies about 75% of the total cropped area in the country. It is estimated that 83% of the total irrigated area of Bangladesh is used for rice cultivation (Dey et al. 1996). The availability of As for rice plant is influenced by differences in geographic location, soil properties, redox condition, cropping season and rice cultivar (Meharg and Rahman, 2003). Little is known about the impact of arsenic contaminated irrigation water on rice yield and grain quality and, ultimately on the health of the millions of rice consumers in Bangladesh. The objective of the study was a) to assess the quality of As-contaminated irrigation water and its impact on soil contamination and plant uptake and b) to determine the spatial variability of As concentration.

Materials and Methods

A total of 105 STWs were randomly selected from all over the Tala thana of Satkhira district representing land types used for irrigated rice during Boro season, 2002. All selected locations were geo-referenced by a GPS. Water samples were collected through membrane filter (0.45 ?m) and were acidified with 0.2M HCl. Parameters such as pH, EC and dissolved oxygen were determined on the spot. The water samples were brought to the laboratory and immediately analyzed for required parameters. Soil samples (0-15 cm) were collected from the STW command area at harvest and then processed and analyzed using standard analytical method. The concentration of As was determined by a flow-injection hydride generation AAS (FI-HG-AAS) after reducing the sample in potassium iodide and conc. HCl. Hydride of As (AsH_3) was generated using sodium borohydride. Rice straw and grain samples were also analyzed for the required properties using similar methods used for soil. Statistical analysis was performed using standard statistical software. To evaluate the spatial variability of the soil properties, semivariogram was prepared using GS+ 5.3.2 (Gamma design software, 2002).

Result and Discussion

The mean value of As of 105 water samples was found 150 ?g/l with a large range of 5 to 457 ?g/l (Table 1). Out of 105 samples, the As concentration ranged from 25 -75 in 31 samples and 125-225 ?g/l in 62 samples, respectively and only 12 samples had a relatively high As content of >225 ?g/l.

Table 1. Summary statistics for water arsenic and some selected water parameters of irrigation water collected from different locations of Tala Thana, Satkhira District.

?Parameters	Unit	Min	Max	Mean	SD	Skewness	Kurtosis
Arsenic	?g/l	5.280	462.38	150.53	88.79	0.88	0.96
EC	ds/m	0.27	4.16	1.49	0.87	1.04	0.41
Diss. O_2	mg/l	0.27	1.40	0.79	0.22	0.28	-0.06
pH	-	6.90	7.90	7.10	0.13	2.20	12.49
Boron	mg/l	0.06	0.47	0.15	0.09	0.85	0.11
Sulfate	mg/l	0.59	33.63	2.81	5.76	3.79	14.28
Phosphate	mg/l	0.31	2.08	1.09	0.36	0.16	0.02
Potassium	mg/l	1.61	15.46	7.20	3.22	0.55	-0.47
Magnesium	mg/l	14.48	104.42	40.01	16.86	1.20	2.12
Calcium	mg/l	69.22	244.12	124.57	37.96	1.05	0.74
Sodium	mg/l	9.10	32.15	23.81	7.20	-0.62	-0.91
Manganese	mg/l	0.03	0.91	0.11	0.14	4.39	21.24

Iron	mg/l	1.78	14.27	5.28	2.13	1.13	2.29

Pearson correlation coefficients among the various chemical properties indicate that water arsenic is weekly to moderately correlate with EC, P, K, Mg, Na and Mn content (Table 2).

Table 2. Pearson correlation coefficient among the chemical properties of irrigation water.

Property	EC	pH	Dis.O_2	P	K	Mg	Ca	Na	Mn	Fe
EC	1	?	?	?	?	?	?	?	?	?
pH	-0.47**	1	?	?	?	?	?	?	?	?
Diss. O_2	-0.10	0.43**	1	?	?	?	?	?	?	?
P	0.17	-0.35*	-0.20	1	?	?	?	?	?	?
K	0.62**	-0.23	-0.06	0.50**	1	?	?	?	?	?
Mg	0.79**	-0.33*	-0.03	0.47**	0.83**	1	?	?	?	?
Ca	0.83**	-0.57**	-0.07	0.01	0.23	0.51**	1	?	?	?
Na	0.84**	-0.37**	-0.06	0.22	0.70**	0.73**	0.58**	1	?	?
Mn	-0.21	0.23	0.06	-0.04	-0.27	-0.29*	-0.04	-0.29*	1	?
Fe	0.55**	-0.81**	-0.20	0.32*	0.17	0.36*	0.74**	0.39**	-0.03	1
As	0.35**	-0.14	-0.21	0.57**	0.41**	0.36*	0.26	0.34*	0.44*	0.21

* Correlation is significant at the 0.05 level (2-tailed)
** Correlation is significant at the 0.01 level (2-tailed)

The soils are neutral to alkaline in reaction, having a medium to high organic C- range from 0.53 to 3.90% with mean value 1.29% (Table3). Soils collected from low land showed high organic C contents. The mean As content in the soil was 19.3 mg/kg with a range of 5.17 to 48.75 mg/kg (Table 3). In 45 out of 105 samples, the As content was found to be below 20 mg/kg, and 56 samples had a As content from 20 to 30 mg/kg. Only 4 samples had relatively high As content of >30 mg/kg.

Table 3. Summary statistics of total and extractable arsenic and some selected parameters of Wetland rice soils collected from different locations of Tala Thana, Satkhira District.

?Parameters	?Units	Min	Max	Mean	SD	Skewness	Kurtosis
Total soil As	mg/kg	5.17	48.75	19.37	7.31	0.49	1.28
P-extractable As	mg/kg	0.77	14.80	4.48	2.29	1.11	2.93
$NaHCO_3$-As	mg/l	0.13	4.26	0.97	0.66	2.14	7.62
Soil pH	-	7.65	8.70	8.25	0.22	-0.48	0.18
EC	dS/m	27.83	403.47	125.30	75.11	1.37	2.08
Clay	%	16.24	74.99	45.98	13.30	-0.03	-0.62
Sand	%	4.91	36.26	11.88	4.81	2.04	6.65
Silt	%	16.25	70.10	42.14	11.71	-0.10	-0.59
Organic C	%	0.54	3.90	1.30	0.48	1.86	7.44
Total N	%	2.42	38.28	14.43	7.91	0.95	0.58
Olsen-P	mg/kg	0.05	0.24	0.13	0.04	0.46	-0.05
Exchangeable K	me/100g	0.21	1.13	0.45	0.14	1.02	3.54
Exchangeable Ca	me/100 g	10.01	29.07	15.58	3.77	0.95	1.08
Exchangeable Mg	me/100 g	5.47	17.40	12.65	2.62	-0.66	-0.14
Exchangeable Na	me/100 g	0.05	5.45	1.90	1.56	0.66	-0.77

The statistical distribution of soil arsenic slightly skewed from normal curve (skewness < 1), and it's mean and median is 19 mg/kg. The data set were divided into two groups - a) the soils (n=24) received low As content (<100 ?g/l) and b) the soils (n =43) received high arsenic content (>100 ?g/l) irrigation water. All of the parameters (mean, range, and variance) of the high As receiving soils showed higher value and also statistically significant variance than did low arsenic receiving soils (Table 4). This indicates that irrigation with high arsenic content water (> 100 ?g/l) increases the arsenic content in wetland rice soils.

Table 4. Summary statistics for total arsenic content of two soil groups having high and low arsenic from irrigation water.

Soil	N	Min.	Max.	Mean value	Std. error	SD	Variance
High	43.00	7.37	48.78	22.25	1.14	7.46	55.61
Low	24.00	5.17	28.52	14.13	1.18	5.79	33.48

Arsenic concentration in grin ranges from 0.087 to 1.013 mg/kg with a mean value of 0.328 mg/kg and only two samples exceed the maximum permissible limit (Table 5). The As concentration in rice straw were much higher than those in the grain. The range of straw As was 0.338-13.49 mg/kg with a mean of 5.482 mg/kg. Water and soil arsenic content significantly influenced the straw As content (Table 6).

Table 5. Summary statistics of total grain and straw arsenic and phosphorous of wetland rice. Samples collected from different locations of Tala Thana, Satkhira District.

Parameters	Unit	Min	Max	Mean	SD	Skewness	Kurtosis
Grain As	mg/kg	0.087	1.013	0.328	0.151	1.616	4.625
Straw As	mg/kg	0.338	13.496	5.481	3.138	0.502	-0.548
Grain P	%	0.015	0.797	0.604	0.098	-2.378	12.308
Straw P	%	0.001	0.343	0.128	0.057	0.681	1.344

Pearson correlation coefficient value in Table 6 also shows the significant influence of water Fe, soil silt, organic C content and exchangeable Mg on rice arsenic uptake. The semivariogram parameters i.e., the range, nugget variance, sill and Q value for selected water and soil chemical properties were estimated using the fitted model with the greatest r^2 value (Table 7).

Table 6. Pearson correlation coefficient among the selected water and soil parameters related to the plant arsenic content.

?Properties	Grain As (mg/kg)	Straw As (mg/kg)
Grain As (mg/kg)	1	
Straw As (mg/kg)	0.1999**	1.0000
Water P (mg/l)	0.1078	0.1818
Water Fe (mg/l)	0.2641**	-0.0516
Water Arsenic (?g/l)	0.1690	0.2158*

Soil Total As (mg/l)	0.1219	0.3898**
P-extract. As (mg/l)	0.0652	0.3612**
Silt (%)	-0.1988*	-0.2633**
Organic C (%)	0.2599**	0.3404**
Soil K (meq/100 g soil)	0.1026	0.2604**
Soil Ca (meq/100 g soil)	0.0500	0.0713
Soil Mg (meq/100 g soil)	0.1963**	0.3182**

Table 7. Geostatistical parameters of arsenic content in water, soil rice and grain collected from 105 locations of Tala thana, Satkhira district.

Model parameters	Water As (?g/l)	Soil As (mg/l)	Grain As (mg/l)
Model	Exponential	Spherical	Spherical
Nugget (Co) (mg/kg)	10.000	26.900	0.00065
Sill (Co+C)	8716.0	59.160	0.02260
Range parameters (A_0)	2450.0	12460.0	2680.00
Q $\{C/(C_0+C)\}$	0.999	0.545	0.971
r^2	0.952	0.659	0.220

The degree of spatial dependence varied among the water, soil and grain arsenic content. The Q value of 0.999 and 0.971 for water, and grain arsenic content, respectively suggesting a highly developed spatial structure for arsenic in water and rice grain at Tala Thana. The value for soil arsenic was 0.545 indicating a moderate development of the spatial structure. The ranges for water and grain arsenic are much shorter than soil arsenic content, indicating much longer spatial dependency of soil arsenic content than that of water and grain arsenic content. Considerable spatial variability was clearly observed for arsenic content in irrigation water, soil and rice grain.

Conclusions

Accumulation of As in rice grain was limited, and was less than the maximum permissible limit of 1 mg/kg. The As status in rice varies widely from place to place. This variation probably results from differences in As availability depending on soil and land types. Irrigation with high–As water increased the As content in all plant parts including edible parts such as grains and straw. High concentrations of As in rice straw may pose a potential health hazard to the cattle population and finally to the human health because rice straw used as cattle feed in Bangladesh and in other countries.

References

Dey MM, Miah NMI, Mustafi BAA, Hussain M (1996). In ‘Rice research in Asia: Progress and priorities’.(Ed. RE Evenson et al.) pp 179-191. CABI-IRRI.

Gamma design software, 2002. GS+ Geostatistics for the Environmental Sciences version 5.3.2. Gamma Design Software, Michigan, USA.

Meharg AA and Rahman MM (2003). Arsenic Contamination of Bangladesh Paddy Field Soils: Implications for Rice Contribution to Arsenic Consumption. Environ. Sci. Technol. 37, 229-234.