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Arsenic contamination through food-chain in *Gangetic* delta of West Bengal – looking beyond drinking water pollution menace

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ABSTRACT

The widespread arsenic contamination in groundwater in different parts of West Bengal has been detected to be distributed over 111 blocks, with dietary exposure of arsenic to nearly 35 million people. Rice (Oryza sativa L.) is the major food crop of the endemic area which accounts for withdrawal of more than 50 per cent of the total contaminated groundwater drifted for irrigation. An effort has been made, through the present study, to take an account of arsenic accumulation in rice over seasons along with possibilities of mitigating the toxicity hazard, in the arsenic affected villages of Chakdaha block, Nadia district, West Bengal, India having an arsenic concentration of irrigation water drifted from the shallow tube wells in the range of 0.03-0.32 mg l^{-1}. The unique waterlogged rice rhizosphere was also contaminated by arsenic to the tune of 10.24-19.17 mg kg^{-1}. Accumulation of the toxin in rice grain were observed to the tune of 0.42^{-1}.33 (pre-kharif rice), 0.32-0.62(kharif rice) and 0.46^{-1}.69 (summer rice). Consumption of rice straw containing considerable amount of arsenic (4.56-17.18 mg kg^{-1}) by cattle could potentially lead to increased arsenic levels in livestock and products. A risk assessment of dietary arsenic intake of arsenic through rice revealed that maximum tolerable daily intake (MTDI) of arsenic for an adult of 60 kg body weight being 0.12 mg, a daily consumption of rice of 300 g day^{-1} would indulge a risk of daily arsenic intake of 0.507 mg which is > 400 % of MTDI. Use of relatively uncontaminated surface water (below detection level-0.03 mg l^{-1}) or soil amendment through organic manures like vermicompost, phosphocompost, FYM, municipal sludge etc. were observed to offload arsenic accumulation in rice grain.

Keywords: Arsenic, dietary, organic and rice

Rice (*Oryza sativa* L.) is the most important crop of India and second principal food crop of the world. In India, rice is predominantly grown in the Indo-Gangetic plains, over an area of 13.5 million ha which is 85 per cent of the cultivated land area where ground water is the principal source of irrigation. Most of the shallow aquifers of groundwater in southern Bangladesh and eastern part of West Bengal, India, is geogenicaly contaminated with arsenic (As), exposing more than 40 million people at risk of As in drinking water (World Bank, 2005). Arsenic contamination in groundwater in the state of West Bengal has assumed the proportion of 12 endemic districts, 111 endemic blocks and above 50 million people exposed to threats of arsenic related health hazard (School of Environmental Science, J.U, 2006). It is only the agricultural sector which enjoys the major share (> 90%) of such contaminated groundwater as source of irrigation and received attention for quantifying the influence of arsenic in soil-plant system (Abedin, 2002, Mukhopadhyay and Sanyal, 2004). Arsenic contamination of water and soil can also adversely affect food safety. A global normal range of 0.08 to 0.2 mg As kg^{-1} has been suggested for rice (Zavala and Duxbury, 2008), but values as high as 0.25 mg As $kg.^{-1}$ have been found in rice (Mandal *et al.*, 2007). The average daily intake of As from rice for an Indian adult is approximately 100 mg As (400 g dry wt × 0.25 mg As kg^{-1}), which is 5 times higher than 20 mg As intake from consumption of 2 L of water as the WHO limit of 10 ugL^{-1} (WHO, 1993). Rice is the major food crop of the endemic area which accounts for withdrawal of more than 50 per cent of the total contaminated groundwater drifted for irrigation. An effort has been made, through the present study, to take an account of arsenic accumulation in rice over seasons along with possibilities of mitigating the toxicity hazard, in the arsenic affected villages of Chakdaha block, Nadia district, West Bengal, India having an arsenic concentration of irrigation water drifted from the shallow tube wells in the range of 0.03-0.32 mg^{-1}.

MATERIALS AND METHODS

The experiment was conducted in the Village-Ghentugachhi, dictrict Nadia, West Bengal, India; Geographical location: N $23^0$02′7.1′′, E$88^0$35′4.8′′, Details of crop management: Crop – Rice, Variety – GS3, MTU-7029 and IET- 4786. Organic manure application : Farm yard manure @10 t ha^{-1}, Vermicompost @ 03 t ha^{-1}, Municipal sludge @ 10 t ha^{-1}, Mustard cake @ 0.5 t ha^{-1}. and green leaf manure @10 t ha^{-1} scheduled as per recommendation of Department of Agriculture, Government of West Bengal. The soils were mostly

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neutral to slightly alkaline in reaction (pH values ranging from 6.64 to 7.78). The cation exchange capacity of these soils ranged from 16.5 to 24.1 c mol (p^+) kg^{-1} soil. Generally two types of textural variations were noted in these soils *i.e.* silty clay loam and silty clay. The soils were found low in available nitrogen content (ranging from 136 to 220 kg ha^{-1}) moderate in available phosphate (ranging from 43.0 to 57.0 kg ha^{-1}) and moderate in available potassium (ranging from 156 to 190 kg ha^{-1}). The total arsenic content varied from 12.6 to 20.4 mg kg^{-1} soil. Arsenic content in shallow-tube well water of experimental site varied from 0.12 to 0.32 mg L^{-1}, while arsenic content of pond water varied from 0.005 to 0.30 mg L^{-1}.The important physico-chemical properties of the experimental soils are shown in the table-1.

Popular rice cultivars namely GS3, MTU-7029 and IET-4786 were selected for conducting experiments during pre-*kharif*, *kharif* and *boro* seasons respectively. Field experiments were conducted to study the uptake of arsenic by the crop and corresponding release from the soil both in absence and presence of soil amendments. The soils were treated with well decomposed FYM, vermicompost, municipal sludge, mustard cake and green leaf manure (incorporated in all the treatment except control). The recommended doses of N, P, K fertilizers were applied to the soils irrespective of each treatment. The soils and plant samples were collected at different growth stages and arsenic content was measured by atomic absorption spectrophotometer (PerkinElmer AAnalyst 200) coupled with flow injection system (FIAS-400). The experiments were laid out in a factorial randomized block design and conclusions were drawn with the software package of SPSS 12.0 version (www.spss.com).

Soils were collected, tagged and packed in brown polythene packets and taken to the laboratory. The soil samples were air-dried, ground and sieved through 2 mm sieve and packed in air tight polythene containers. The plant samples were oven dried for 24 hours at 105°C, ground and packed in air tight polythene container. Soil samples were analyzed for detailed characterization with respect to the important physico-chemical properties (pH, organic carbon, available N, P_2O_5 & K_2O, total and extractable arsenic) following the standard methods (Page, 1982). Available N content of soil was determined by the Kjeldahl method (Subbiah and Asija, 1956), available P by 0.5 M $NaHCO_3$ (pH 8.5) (Olsen SR and Sommers LE 1982, Methods of soil analysis, part 2) exchangeable K by 1M NH_4OAc (pH 7.0) (Knudsen *et al*. 1982), oxydizable organic C (Walkley and Black, 1934), texture (Dewis and Freitas, 1984), olsen extractable As by 0.5 M $NaHCO_3$, pH 8.5 (Olsen SR and Sommers LE 1982, Methods of soil analysis, part 2) and total As by tri-acid digestion (Sparks, 2006). Plant samples were digested with a mixture of acids *i.e.* HNO_3, $HClO_4$ and H_2SO_4 in a proportion of 10:4:1 (v/v) for total As measurement. Olsen extractable P was analyzed colorimetrically, ammonium acetate extractable K was analyzed by flame photometry. Sodium bicarbonate extractable, total soil As and plant As were determined through atomic absorption spectrophotometer (PerkinElmer AAnalyst 200) coupled with flow injection system (FIAS-400).

Risk assessment in terms of percent MTDI (Maximum tolerable daily intake)

Risk associated with the consumption of contaminated rice has been computed in terms of percent MTDI.

Risk (%MTDI) = As concentration in rice grain (mg kg^{-1}) × standard consumption of rice by an adult (kg) ×100/ [MTDI (mg kg^{-1}) × standard body weight of an adult]

Where, MTDI (mg kg^{-1}) = 0.002 (WHO, 1993)

Standard adult body weight was considered 60kg

Standard rice consumption by an adult was considered 300g day^{-1}

Instrumentation and analytical conditions of AAS

The leachate from soil or the digest of soil and plant samples was diluted to 50 ml. 10 ml of the aliquot was taken in 50 ml volumetric flask, 5 ml of concentrated HCl and 1 ml of mixed reagent [5% KI (w/v) + 5% Ascorbic acid (w/v)] were added to it, kept for 45 minutes to ensure complete reaction and the volume was made up to 50 ml The resultant solution was analyzed in a PerkinElmer Atomic Absorption Spectrophotometer with Flow Injection Analysis System (FIAS 400) @ λ_{max}≅193.7 nm where the carrier solution was 10% v/v HCl, the reducing agent [to ensure all As species be reduced to AsH_3 and to be measured against a calibration with standard As^{+3} solution in 10% (v/v) HCl] was 0.2% $NaBH_4$ in 0.05% NaOH. The spectrometer technique is AA, integration time 15 sec, peak height- smoothing- 0.5 sec/19 points, lamp- EDL, slit- 0.7 nm, cell temperature- 900^0C.

RESULTS AND DISCUSSION

In the present study, samples of irrigation water, agricultural field soil were collected from the arsenic affected village of Chakdaha block and analyzed. The results clearly indicate that the agricultural soil of the study area has remained highly contaminated with arsenic (20.17mg/kg) due to the excessive use of arsenic rich groundwater (0.32mg/l) for irrigation. Long term use of arsenic contaminated groundwater for irrigation may result in the further increase of arsenic concentration in the agricultural soil and eventually in rice plants.

Table 1: Physicochemical properties of experimental site

Properties	Observation
pH	6.64-7.78
EC(dsm^{-1})	0.008-0.12
Organic C (%)	0.41-0.56
Textural class	Silty clay
Sand (%)	3.5-5.9
Silt (%)	46.7-48.55
Clay (%)	49.8-55.43
CEC c mol(p+) kg^{-1}	16.5-24.1
Available nitrogen (kg ha^{-1})	136.0-220.0
Available Phosphate (kg ha^{-1})	43.0-57.0
Available potassium (kg ha^{-1})	156.0-190.0
Total arsenic (mg kg^{-1})	12.6-20.4
Available arsenic (mg kg^{-1})	0.62-7.50
Arsenic in pond water (ppm)	0.005-0.03
Arsenic in shallow water (ppm)	0.12-0.32

The results of table-5 revealed that maximum accumulation of arsenic in rice grain and straw was observed in *boro* rice (0.46^{-1}.69 mg $kg^{-1}$and 10.52-18.63 mg kg^{-1}), followed by pre *kharif* (0.42^{-1}.33 mg kg^{-1} and 7.46-17.18 mg kg^{-1}) and *kharif* rice (0.32-0.62mg/kg and 3.21-9.17 mg kg^{-1}). Such results have been further substantiated with the findings of variability of arsenic content in irrigation water over different rice growing season (Fig.1).

The results recorded in tables 2, 3, 4 clearly indicated that incorporation of organic manures has marked effect on reduction of arsenic accumulation in different plant parts of rice. It was observed that incorporation of organic manures significantly reduced the arsenic uptake (13.1-54.9%) by different plant parts of rice over the control counter part under both the irrigation regimes shallow tube well water (STW) and pond water (PW). Such beneficial role exerted by different organic sources has been found to be most pronounced and consistent with FYM and compost. Das (2007) also observed 18.30 and 14.01per cent decrease in 0.5 M NaHCO3-extractable soil As form the control counterpart when the soil was amended with vermicompost and well-rotten FYM, due to formation of organo-As complexation. The magnitude of such decreases, however, varied with sources and levels of applied organic matter while such decrease remained most pronounced with vermicompost, which might be due to formation of insoluble arseno-organic complexes and its adsorption on to organic colloids.

Organic amendments such as composts and manures which contain a high amount of humified organic matter can decrease the bioavailability of heavy metals through adsorption and by forming stable complexes with humic substances. (Chen *et al.*, 2000). Precipitation and flocculation of humic acids by heavy metals were observed in both acidic and calcareous soils (Clemente and Bernal, 2006). Humic acids have great capacity to retain and bind metals. Their molecular structure is usually larger than the soil pore size resulting in the low mobility and little leaching through soil profile. (Halim *et al.*, 2003).

Observations recorded in the tables-2, 3, 4 also revealed that rice raised with irrigation from surface water (PW) accumulated significantly less arsenic than those supported by ground water (STW) irrigation in all the seasons. Such changes in arsenic accumulation in rice manifested either through using surface water as irrigation source or through organic amendments, may be attributed to similar changes in soil available arsenic under similar situations, as reflected in significant correlations drawn between total arsenic uptake by rice at harvest and available arsenic in post-harvest soil of rice (Table 2, 3, 4).

Rice, being a main staple food of the territory, the health risks associated with arsenic ingestion through consumption of rice by people in the contaminated region may be of considerable dimension. The risk associated with exposure to contaminated rice grain has been classically computed in terms of percent MTDI for standard consumption of pre-*kharif*, kharif and boro rice and the magnitudes ranged from 80.0-422.5% MTDI of an adult (Table 5). The efficiencies of organic interventions evaluated in the present study remained capable of minimizing such risks to the tune of 54.9 per cent from the control counterparts (through administration of vermicompost as soil amendment)

Table 2: Arsenic content (mg kg^{-1}) in soil-plant under pre-*kharif* rice (var. GS-3) grown with different irrigation sources and organic intervention

Irrigation (I)	Treatment (T)	Arsenic accumulation in mg kg^{-1}		
		Grain	Straw	Soil
Shallow tube-well water	C	1.33	17.18	4.46
	O_1	0.76	16.13	4.19
	O_2	1.08	7.46	4.01
	O_3	**0.60**	**11.89**	**3.97**
	O_4	0.67	13.50	4.28
	Mean	**0.89**	**13.23**	**4.18**
Pond water	C	1.17	10.84	3.93
	O_1	0.64	9.36	3.66
	O_2	0.48	8.54	3.03
	O_3	**0.44**	**7.53**	**3.31**
	O_4	0.51	9.39	3.51
	Mean	**0.65**	**9.13**	**3.49**
CD (P = 0.05)				
I		**0.01**	**0.11**	**0.05**
T		**0.02**	**0.18**	**0.09**
I × T		**0.03**	**0.26**	**NS**
Correlation		**0.703****	**0.793****	**1.00**

C = Control, O_1 = Mustard cake@1t ha^{-1}, O_2 = Farm Yard Manure @10t ha^{-1}, O_3 = Phospho-compost @3t ha^{-1} and O_4 = Municipal sludge@10t ha^{-1}, As content of STW-0.32mg l^{-1}, As content of pond water-0.03mg l^{-1}

Table 3: Arsenic content (mg kg^{-1}) in soil-plant under *kharif* rice (var. MTU- 7029) grown with different irrigation sources and organic intervention

Treatments		Grain arsenic (mg kg^{-1})	Straw arsenic (mg kg^{-1})	Soil arsenic (mg kg^{-1})
W_1	O_1	0.62	7.76	1.98
	O_2	0.51	6.23	1.41
	O_3	0.36	5.49	**0.96**
Mean		**0.50**	**6.49**	**1.39**
W_2	O_1	0.54	6.40	1.19
	O_2	0.46	5.58	0.76
	O_3	0.32	4.38	**0.62**
Mean	**0.44**	**5.45**	**0.85**	
CD (@ 5%)				
W	0.011	0.020	0.011	
O	0.013	0.021	0.010	
W × O	0.020	0.023	0.014	
Correlation	0.860**	0.953**	**1.00**	

W_1- Shallow tube well, 0.16 to 0.24 mg L^{-1} As; W_2- Pond water, 0.05 to 0.12 mg L^{-1} As); O_1- Control, O_2- Green manuring @ 10 t ha^{-1}, O_3- Vermicompost @ 2.5 t ha^{-1});

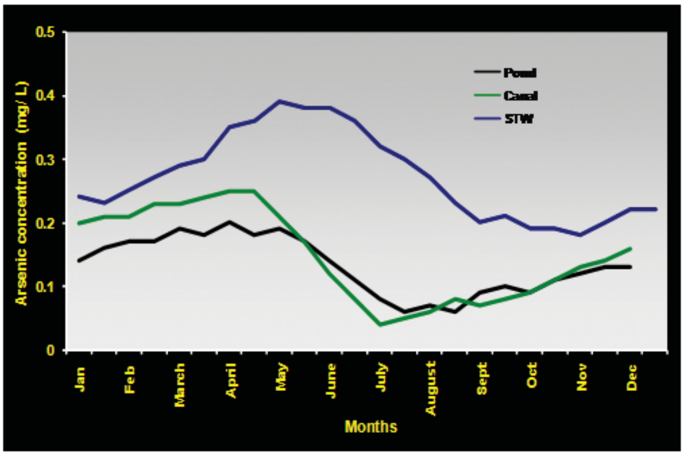

Fig.1: Seasonal variation in arsenic content of water sources

Table 4: Arsenic content (mg kg^{-1}) in soil-plant under *boro* rice (var. IET-4786) grown with different irrigation sources and organic intervention

Irrigation (I)	Treatment (T)	Arsenic accumulation in mg kg^{-1}		
		Grain	Straw	Soil
Shallow tube-well water	C	1.69	18.63	7.50
	O_1	1.28	11.29	5.76
	O_2	1.56	13.43	5.66
	O_3	1.60	12.90	5.81
	O_4	1.59	10.55	6.35
	Mean	**1.54**	**13.36**	**6.22**
Pond water	C	1.27	11.72	5.13
	O_1	0.90	9.85	4.22
	O_2	0.96	10.81	3.55
	O_3	1.11	9.51	4.45
	O_4	1.04	10.23	4.77
	Mean	**1.06**	**10.42**	**4.42**
CD (P = 0.05)				
I		**0.01**	**0.04**	**0.06**
T		**0.02**	**0.06**	**0.09**
I × T		**0.02**	**0.09**	**0.13**
Correlation		**0.915****	**0.783****	**1.00**

C = Control, O_1 = Farm Yard Manure @10 t ha^{-1}, O2 = Vermicompost @ 3t ha^{-1}, O_3 = Municipal sludge @10 t ha^{-1} and O_4 = Mustard cake @1t ha^{-1}

*** indicates significant at 1 % level of significance*

Table 5: Arsenic accumulation in rice

Cultivars	Source (STW water) Mg L^{-1}	Arsenic accumulation (mg kg^{-1})			Risk (% MTDI)
		Sink (soil) (0.5 M $NaHCO_3$ extractable)	Grain	Daily intake (mg)	
GS-3 (Pre-*kharif*)	0.28-0.32	3.03-4.46	0.42^{-1}.33	0.12-0.39	105-332.5
MTU-7029 (*kharif*)	0.16-0.24	0.62^{-1}.98	0.32-0.62	0.09-0.18	80-155.0
IET-4786 (*boro*)	0.22-0.26	3.55-7.50	0.46^{-1}.69	0.13-0.50	115-422.5

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REFERENCES

Abedin, M. J. and Meharg, A. A. 2002. Relative toxicity of arsenite and arsenate on germination and early seedling growth of rice (*Oryza sativa* L.). *Pl. Soil*, **243** : 57- 66.

Chen, Z.S., G.J. Lee and J.C. Lin, 2000. The effect of chemical remedial treatments on the extractability and speciation of Cd and Pb in contaminated soils. *Chemosphere*, **41** : 235-42.

Clemente, R. and M.P. Bernal, 2006. Fractionation of heavy metal and distribution of organic carbon in two contaminated soils amended with humic acid. *Chemosphere*, **64** : 1264-73.

Das, D. K. 2007. Effects of arsenic-contaminated irrigation water, zinc and organic matter on the mobilization of arsenic in soils in relation to rice (*Oryza sativa* L.) *Trace Metals and other Contaminants in the Environment*, **9** : 331-54.

Dewis, J. and Freitas, F.1984. Physical and Chemical Methods of Soil and Water Analysis. Oxford and IBH Pub. Co., New Delhi, pp. 51-106.

Halim, M., Conte, P. and Piccolo, A. 2003. Potential availability of heavy metals to phytoextraction from contaminated soils induced by exogenous humic substances. *Chemosphere*, **52** : 265-75.http://www.soesju.org/arsenic/wb3.htm

Knudsen, D., Petterson, G.A. and Pratt, P.F. 1982. Lithium, Sodium and Potassium. Methods of Soil Analysis, Part 2: Chemical and Microbiological Properties, Page, A.L., R.H. Miller and D.R. Keeney (Eds.). ASA and SSSA,. Madison, WI., pp. 225-46.

Mandal, S.M., Mondal, K.C., Dey, S. and Pati, B.R. 2007. Arsenic biosorption by mucilaginous seeds of Hyptis suaveolens (L) poit. *J. Sci. Indus. Res.*, **66**: 577- 81.

Mukhopadhyay, D. and Sanyal, S.K. 2004. Complexation and release isotherm of arsenic in arsenic-humic/fulvic equilibrium study. *Australian J. Soil Res*., **42**: 815-24.

Olsen, S.R. and Sommers, L.E. 1982. Phosphorus. pp. 403-430 In. Page et al. (Eds). *Methods of Soil Analysis*, part 2, Americam Soc. Agron. Inc., Madison, Wasington, USA.

Page, A.L. 1982. *Methods of Soil Analysis*. 2nd Edn. American Society of Agronomy, Madison, WI., USA.

Schnitzer, M. and Skinner, S.I.M. 1966. Organo-metallic interactions in soils: 5 Stability constants of Cu^{2+}, Fe^{2+} and Zn^{2+} fulvic acid complexes. *Soil Sci*., **102**: 361-65.

Sparks, D.L. 2006. Methods of Soil Analysis. Part 3, Chemical Methods. *Soil Sci. Soc. America Inc.*, Madison, Washington, USA., pp: 639-64.

Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the determination of available nitrogen in soils. *Curr. Sci*., **25:** 259- 60.

Walkley, A.J. and Black, C.A. 1934. Estimation of soil organic C by the chromic acid titration method. *Soil Sci*., **37**: 29-38.

WHO 1993. Guidelines for drinking water quality. 2nd Edn., Geneva.

Williams, P.N., Islam, M.R., Adomako, E.E., Raab, A., Hossain, S.A., Zhu, Y.G., Feldmann, J. and Meharg, A.A. 2006. Increase in rice grain arsenic for regions of Bangladesh irrigating paddies with elevated arsenic in groundwaters. *Environ. Sci. Technol.*, **40** : 4903- 4908.

Zavala, Y. and Duxbury, J.M. 2008. Arsenic in rice: I. Estimating normal levels of total arsenic in rice grain. *Env. Sci. Technol.*, **42**: 3856-60.