

Arsenic content in irrigation water and impact on soils of the Indo-Gangetic Plain of West Bengal

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Abstract

The present investigation was conducted in a part of Chakdah block of Nadia district, West Bengal representing the Indo-Gangetic Plain. Spatial variability of arsenic concentration indicated that the area can be divided into high, medium and low arsenic contaminated zones. Arsenic content of soils showed that the Ap horizon contained the maximum concentration of extractable arsenic with a concomitant decrease down the depth. The average amount of total arsenic withdrawn from the deep tubewell water was around 76 kg per year and is being distributed in the command area of about 25 ha.

Additional keywords : Spatial variability, soil-arsenic build up

Introduction

Arsenic contamination of groundwater and the sufferings of the people of West Bengal have been reported by Saha (1985). At present in West Bengal 5 million people in 978 villages of 67 blocks from 9 districts, viz. Malda, Murshidabad, Nadia, North 24-Parganas, South 24-Parganas, Howrah, Hooghly, Bardhaman and southern part of Kolkata (Chakraborti *et al.* 1999) are drinking arsenic contaminated water above the prescribed safe limit of 0.01 mg As/l (WHO 1996). Many people are suffering from arsenical skin lesions, hyperkeratosis, and edema.

The information regarding mechanism of groundwater contamination by arsenic is quite scanty. According to Nickson *et al.* (1998), As derives from reductive dissolution of arsenic-rich iron oxyhydroxides, which in turn was derived from weathering of base-metal sulphides. The Fe oxyhydroxide exists in the aquifer as dispersed phase in the form of coatings on sedimentary grains. As dissolved iron is oxidized it precipitates as iron oxyhydroxides which is instrumental in scavenging the As from solution. Iron pyrites may be responsible for As contamination of groundwater (Chakraborti *et al.* 1992). Arsenic is possibly associated with pyrites formed due to chemical combination of sulphur with iron containing minerals brought along by rivers as a part of the alluvial sediment or formed *insitu* under reducing conditions. The pyrites undergo oxygenated decomposition due to excessive withdrawal of groundwater especially during the summer period resulting in formation of Fe(II) and Fe(III) sulphate and sulphuric acid, which in turn, are responsible for As-mobilization. According to Acharyya *et al.* (1999) the widespread withdrawal of groundwater may have mobilized phosphate derived from fertilizers and from the decay of natural organic materials in shallow aquifers. The increase in phosphate concentration

could promote the growth of sediment biota and the desorption of arsenic from sediments. These combined microbiological and chemical processes might have increased the natural mobility of arsenic. Though the exact mechanism of groundwater contamination with arsenic is not clear, the increase in the affected areas corresponds with the increased groundwater utilization for irrigation. Deeper aquifers, previously found to be free from contamination, show arsenic contamination with time (Muralidharan 1998).

In view of the above consideration, the present investigation attempts to generate a map of the study area delineating high, medium and low zones of arsenic levels based upon the As content of the irrigation water, and then to study the effect of arsenic containing irrigation water on As build - up in the soils.

Materials and methods

The study area, comprises of the Ghentugachhi mouza (533ha) which lies between latitudes $23^{\circ}1'19''$ to $23^{\circ}2'48''$ N and longitude $88^{\circ}33'37''$ to $88^{\circ}35'25''$ E in Chakdah block, district Nadia, West Bengal.

Water samples were collected from the shallow and the deep tubewells, located in Ghentugachhi (Fig. 1) mouza during May-June, 1998 and January-February, 1999 and tested for arsenic content in the laboratory with the help of Atomic Absorption Spectrophotometer coupled with hydride generator, model: GBC 932B (APHA-AWWA-WPCF 1975).

Arsenic withdrawn from deep tubewell water was calculated based on the total amount of water withdrawal in a year (Mandal *et al.* 1996). The flow rate of this tubewell was 1.5×10^5 litre per work hour. During the month of December to April, the tubewell worked for 15 hours per day and during the period from May to November and the rest of the year the tubewell ran for 2 hours per week. As a whole the tubewell worked for about 2306 hours per year.

Detailed soil survey was conducted on 1:4,000 scale using cadastral map of the mouzas. Three representative soil profiles were studied in different arsenic contaminated zones and horizonwise soil samples were collected (Soil Survey Staff 1951). Soils were correlated and classified as per soil Taxonomy (Soil Survey Staff 1998). Besides the profiles, sixty-five surface (0-20 cm) soil samples of grids (200 metre interval) were collected and analysed for the physical and chemical properties *viz.* pH (1:2.5 water), EC (1:2.5 water), organic carbon, particle size class, CEC using the standard methods (Jackson 1973). Dithionite - extractable iron (Fe_d) was determined by the method of Mehra and Jackson (1960). Amorphous Fe (Fe_o) was determined by acid ammonium oxalate method (McKeague and Day 1966). Olsen extractable P was determined by 0.5 M $NaHCO_3$ adjusted to pH 8.5 by following the method of Watanabe and Olsen (1965). Arsenic was extracted by 0.5 M $NaHCO_3$ (pH 8.5) by following Johnston and Barnard (1979) and was measured after reduction with KI and HCl.

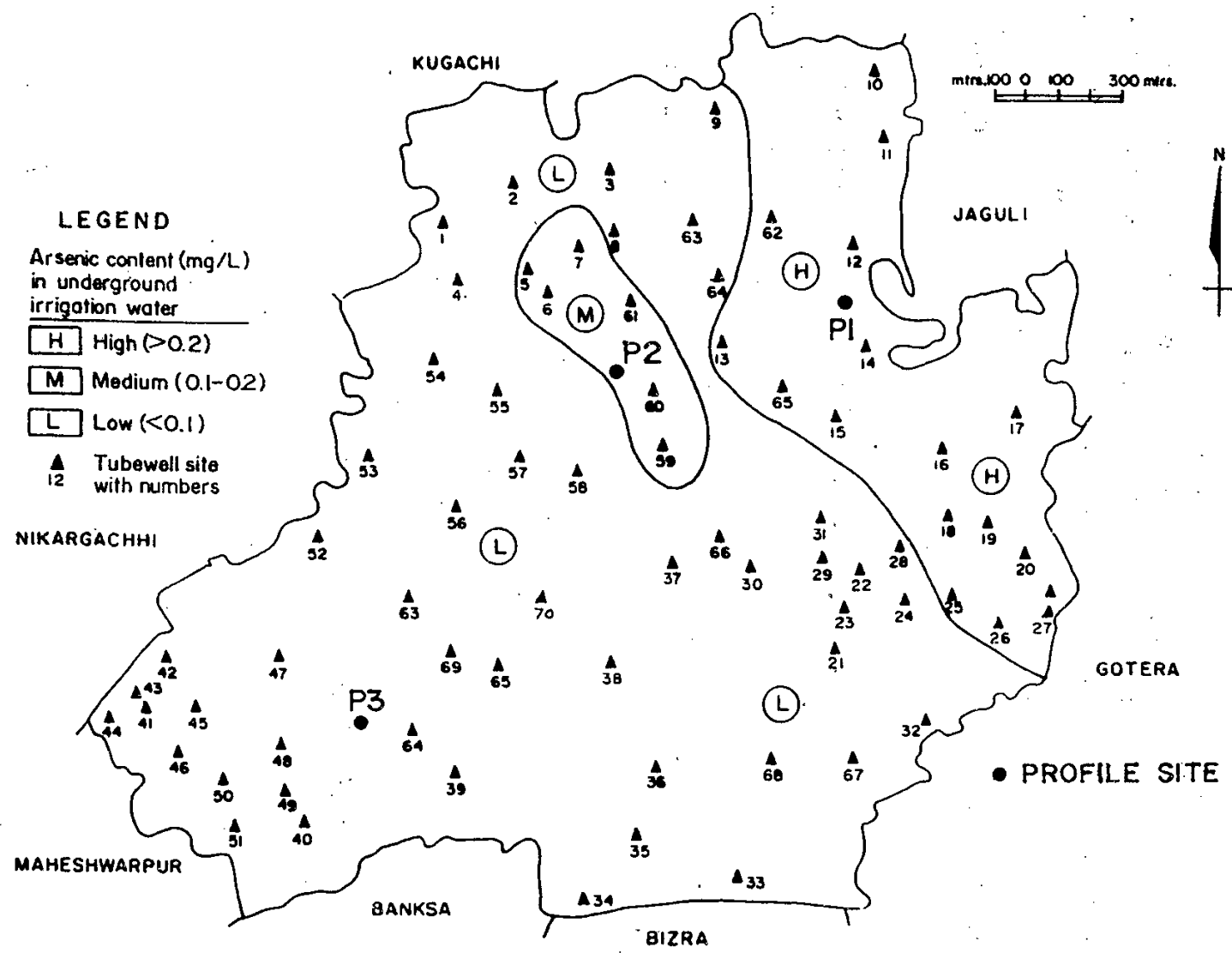


Fig. 1. Areas representing Ghentugachhi Mouza receiving irrigation for groundwater with various degrees of arsenic contamination.

Results and discussion

Morphological properties : Data on soil resources indicated that soils were very deep (>100 cm) and very dark greyish brown to dark brown in colour (10 YR/ 2.5 Y hue) in the surface and dark grey to light olive brown in the subsurface horizons (Table 1). The texture of the series control section of pedon P1 (collected from high As contaminated zone) varied from loam to silty clay, whereas soils of the series control section of pedon P2 (collected from medium As contaminated zone) and P3 (collected from low As contaminated zone) were heavy throughout (clay content 49.8 to 59.8%). Structurally soils were mainly subangular blocky in nature. Soils were friable in moist condition and were very sticky and plastic in wet condition. Few very fine iron-manganese concretions were observed in pedons P1 and P3 only. A well developed structural B horizon indicative of cambic diagnostic sub-surface horizon was observed in all the pedons.

Table 1 : Morphological characteristics of the soil of Ghentugachhi Mouza, District Nadia, West Bengal

Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistence		Nodules
					M	W	
Pedon P1 : Typic Haplustepts (Low land, slope 0-1%)							
Ap	0-18	10YR3/3	sic	m	fi	vs, p	vf, f
Bw1	16-38	10YR3/3	sic	m3 sbk	fr	vs, p	vf, f
Bw2	38-60	2.5YR4/2	sicl	m2sbk	fr	s, p	vf, f
Bw3	60-90	2.5YR5/4	l	m1sbk	fr	ss, ps	f, f
Bw4	90-125	25YR5/4	l	m1sbk	fr	ss, ps	f, f
Bw5	125-147	2.5YR5/4	sil	m1sbk	fr	ss, ps	f, f
Pedon P2 : Vertic Haplustepts (Medium land, slope 1-3%)							
Ap	0-21	10YR3/3	sic	m	vfi	vs, sp	-
Bw1	21-45	10YR3/3	sic	m3sbk	fi	vs, p	-
Bw2	45-79	2.5Y4/2	sic	m2sbk	fi	s, p	-
Bw3	79-114	2.5Y4/3	sic	m2sbk	fi	vs, vp	-
Bw4	114-145	2.5Y4/4	sic	m2sbk	fi	vs, vp	-
Pedon P3 : Vertic Endoaquepts (Medium land, slope 1-3%)							
AP	0-20	10YR3/2	sic	m	vfi	vs, vp	-
Bw1	20-46	10YR3/2	sic	m2sbk	vfi	vs, vp	-
Bw2	46-82	2.5Y4/2	sic	m3sbk	fi	sp, p	vf, f
Bw3	82-127	2.5Y4/0	sic	m2sbk	fi	vs, p	vf, f
Bw4	127-150	2.5Y5/2	sic	m3sbk	fi	vs, p	-

Physical and chemical properties : Soils of pedon P1 were slightly acidic to moderately alkaline in reaction (pH 6.5-8.0). The pH of pedon P2 and P3 ranged from 7.3 to 7.9. Electrical conductivity of pedon P1 ranged from 0.1 to 1.0 dS/m whereas the pedon P2 and P3 showed a constant value of 0.2 dS/m. The surface soils contained maximum organic carbon (1.1-1.6%) which decreased with depth. Soil texture ranged from silt loam to silty clay. The clay content in the surface horizon of the profiles was high and varied from 44.9 to 59.9 %. The CEC of the soils varied between 7.8 and 39.6 cmol(p+)kg⁻¹. Acid ammonium oxalate extractable iron (Fe_o) decreased down the profile with values in surface soils ranging from 0.45 to 0.68% and in sub-surface soils it ranged from 0.10 to 0.53%, and dithionite-citrate-bicarbonate extractable iron (Fe_d) did not show any definite distribution pattern. Olsen extractable P was maximum in the surface horizon and it ranged between 15.0 and 28.0 mg P/kg and decreased with depth.

The pH of the grid soil samples ranged between 6.5 and 8.7 whereas the EC values ranged between 0.1 and 1.4 dS/m (Table 4). Organic carbon content varied from 5 to 22 mg/kg and oxalate extractable iron (Fe_o) varied from 0.3 to 0.7 %. Olsen P was in the range 7.8 to 47 mg/kg and clay content varied from 16.9 to 59.9 %.

Table 2. Physical and chemical properties and sodium bicarbonate extractable arsenic of soil profiles in Ghentugachhi mouza, District- Nadia, West Bengal

Hori. zon	Depth (cm)	pH	EC (dS/m)	Org. C (%)	Clay (%)	Tex. class	CEC cmol (p+)kg ⁻¹	Fe _o (%)	Fe _d (%)	Ext. P (mgkg ⁻¹)	Ext. As (mgkg ⁻¹)
P1: Soils of High arsenic contaminated zone : (Typic Haplustepts)											
Ap	0-16	6.5	0.2	1.1	59.9	sic	32.8	0.64	0.21	28.0	15.8
Bw1	16-38	6.9	0.2	0.6	57.3	sic	30.5	0.53	0.13	12.0	1.5
Bw2	38-60	7.5	0.4	0.4	38.0	sicl	21.0	0.35	0.08	12.0	1.0
Bw3	60-90	7.6	1.0	0.3	27.0	l	13.5	0.17	0.18	16.0	0.9
Bw4	90-125	7.9	0.2	0.2	28.1	l	8.0	0.15	0.28	11.0	1.0
Bw5	125-147	8.0	0.2	0.2	22.5	sil	7.8	0.10	0.46	8.0	1.0
P2: Soils of Medium arsenic contaminated zone : (Vertic Haplustepts)											
Ap	0-21	7.3	0.2	1.4	44.9	sic	33.8	0.68	0.57	15.0	3.6
Bw1	21-45	7.6	0.2	0.6	42.9	sic	35.3	0.40	0.86	5.0	3.0
Bw2	45-79	7.4	0.3	0.6	46.9	sic	35.3	0.51	0.69	3.0	1.7
Bw3	79-114	7.9	0.2	0.5	42.9	sic	36.1	0.32	0.87	2.0	0.8
Bw4	114-145	7.3	0.2	0.4	40.9	sic	28.7	0.30	0.90	1.0	0.8
P3 : Soils of Low arsenic contaminated zone : (Vertic Endoaquepts)											
Ap	0-20	7.5	0.3	1.6	56.0	sic	39.6	0.45	0.50	15.0	2.4
Bw1	20-46	7.6	0.2	0.8	59.8	sic	39.0	0.32	0.98	2.0	0.9
Bw2	46-82	7.9	0.2	0.5	49.8	sic	26.5	0.30	0.96	10	0.9
Bw3	82-127	7.8	0.2	0.5	58.8	sic	35.9	0.24	0.43	1.0	1.0
Bw4	127-150	7.6	0.1	0.4	58.4	sic	29.6	0.27	0.46	5.0	0.6

Arsenic content of water and spatial variability: The arsenic levels of Ghentugachhi mouza ranged from trace to 0.80 mg As/l. Based on the arsenic content of water samples a map of the mouza was prepared (Fig. 1) depicting the various areas receiving irrigation from groundwater with various degrees of arsenic contamination. The map was delineated into three zones, viz. high (>0.2 mg/l), medium (0.1-0.2 mg/l) and low (<0.1 mg/l) receiving contaminated irrigation water. The map helps in identification of high risk zones located in the study area. The high contaminated zone represented 97.9 ha (18.3% of the total area) whereas medium and low contaminated zones accounted for nearly 57.3 ha (10.7%) and 378.8 ha (70.9%) respectively.

Table 3 : Estimation of arsenic withdrawn from deep tubewell water

Mean arsenic concentration of deep tubewell water (mg/l)	Flow rate (l/hr)	Total working hours of the tubewells (hr/yr)	Volume of water extracted (l/yr)	Total arsenic withdrawn from deep tubewell water (kg/yr)	Estimated arsenic in the soils (kg/ha)
0.22	1.5×10^5	2306	3.46×10^8	76.17	45.25

* Data of the present investigation

Arsenic content of soils : The sodium bicarbonate extractable As decreased with depth in all the pedons of Ghentugachhi mouza. Arsenic content was the highest in the surface horizon of P1 (15.8 mgAs/kg) and the lowest in P3 (2.4 mgAs/kg) (Table 2) which might be due to the fact that P1 received irrigation water containing highest amount of As content while P3 received irrigation containing lowest amount of As. Similar relationship between the arsenic content of irrigation water and extractable As content of the surface soil was exhibited by pedon P2. The Olsen extractable As of the 65 grid soil samples ranged from 0.1 to 30.0 mg/kg. The data of table 2 indicates a sharp decrease in the As content between the surface and sub-surface horizons of all the pedons. This may be probably due to the slow mobility of As in the soils. Similar observation was made by Lund and Fobian (1991). It was observed that there was an abrupt fall in As content in sub-surface horizons in Ghentugachhi mouza as that Fe_o and clay content. The large specific surface area of the clay minerals and amorphous iron tends to sorb As on their surfaces. It can be inferred that amorphous Fe (Fe_o) and clay content are the most important soil properties which are responsible for the sorption of As. This is in agreement with the observations of Manning and Goldberg (1997).

Oxalate extractable iron (Fe_o) was significantly correlated with As ($r = 0.34^{**}$). The large specific surface area of Fe_o was instrumental in sorbing As on their surfaces. Olsen P was also significantly correlated with As ($r = 0.40^{**}$). Phosphorus, because of its chemical and physical similarities to As, generally competes for As fixation sites in the soil and thus affects As availability. Clay percent was significantly and negatively correlated

with As ($r = -0.26^*$). This may be due to the fact that clay bind more As and make them unavailable.

Table 4. Physical and chemical properties of the soil samples
(Range values are given for the 65 soil samples)

pH	EC dS/m	Organic carbon (g/km)	Fe _o (%)	P (mg/kg)	clay (%)	As (mg/kg)
6.5-8.7	0.1-1.4	5-22	0.30-0.70	7.8-47	16.9-59.9	0.1-30.0

In the present investigation an attempt was also made to estimate the total As withdrawn from deep tubewell water of the command area (about 25 ha) under the deep tubewell (DTW 216), located in Gotera Mouza, adjacent to the Ghentugachhi, Nadia district (Table 3). The mean extractable As in the surface soil of the command area was 45.2 kg As/ha. It was calculated that the total arsenic withdrawn from the deep tubewell water was around 76 kg per year. Due to slow mobility of As, major portions of it are retained by the soils and a sizeable amount of As build up was observed as reflected by the As content of the surface soils.

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