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An evaluation of arsenic contamination status and its potential health risk assessment in villages of Nadia and North 24 Parganas, West Bengal, India

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Abstract
The present study was conducted to evaluate the arsenic (As) contamination and possible associated health hazards to exposed population in four villages of two districts (Nadia and North 24 Parganas) of West Bengal, India. The study included two villages each from Nadia (Jaguli and Kugacchi) and North 24 Parganas (Chamta and Byaspur) districts. Groundwater, surface water, soil, rice grains and rice-based food samples were collected from these villages. The results revealed the presence of As in high concentrations in groundwater (35.00 to 186.00 μg L^{-1}), surface water (30.00 to 61.00 μg L^{-1}), soil (46.17 to 66.00 mg kg^{-1}), rice grains (0.017 to 1.27 μg g^{-1}) and rice-based food products (0.012 to 0.40 μg g^{-1}). The maximum As levels were recorded in all types of samples collected from Kugacchi village. The rice grain samples included high-yielding and local varieties, and the level of As in high-yielding varieties was found to be higher (0.72 to 1.27 μg g^{-1}) than in local varieties (0.25 to 1.06 μg g^{-1}). The data of As concentrations was used for understanding the hazard quotient (HQ) and incremental lifetime cancer risk (ILCR) to the As-exposed population, and significant non-carcinogenic and carcinogenic risks were revealed considering consumption of rice grains at 400 g per day. The study demonstrates the severity of As contamination in the surveyed villages, which may pose a hindrance to attainment of sustainable development goals (SDGs) by 2030 and proposes the implementation of requisite safety measures.

Keywords Arsenic · Groundwater · Incremental lifetime cancer risk · Surface water · Rice grains

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Introduction

Arsenic (As) contamination of the bio-resources, i.e., water, soil and air, is a serious persistent issue (Pal et al. 2023). The presence of As in high concentrations in the environment, especially in severely affected areas, leads to As accumulation at threatening levels in vegetables, crop plants, grains, mushrooms, animals and also in humans (Khanam et al. 2022; Li et al. 2020). Water and soil health is a crucial parameter specially in developing nations affecting various sustainable development goals (SDGs) directly or indirectly. It can also hinder the attainment of various SDGs including zero hunger (SDG 2), good health and well being (SDG 3), clean water and sanitation (SDG 3), life on land (SDG 15) and other indirect goals.

In India, the regions falling in Gangetic and Brahmputra basin including Uttar Pradesh, Bihar, Punjab, West Bengal and Assam are among the severely impacted areas with As (Chakraborti et al. 2016; Sharma et al. 2017; Kumar and Singh 2020; Singh et al. 2022a). The chronic exposure to heavy metals including As in humans for prolonged duration over the years leads to several health issues including cardiovascular, kidney problems, skin-related problems and cancers (Rahman et al. 2022; Rashid et al. 2019, 2021). The scale of problem needs continued efforts and regular monitoring in already-known As contaminated regions. Identification of newer regions under As contamination is also equally important to understand the dynamic nature of As contamination.

West Bengal is the worst affected state by As contamination in India, where currently nine out of total 19 districts are facing the problem of As contamination, and it is expected to reach to other areas too as estimated via modelling approaches (Kumar et al. 2022; Shukla et al. 2020). Researchers, non-governmental organisations and government agencies have surveyed the area and found the problem of As to exist from cities to remote villages (Shrivastava et al. 2017; Upadhyay et al. 2019). It has been found that even after so many years, the awareness about the problem is lacking and there are numerous apprehensions and misconceptions in the people's mind (Singh et al. 2022a). The major routes through which humans get exposed to As in the contaminated area include drinking water, food and air (Awasthi et al. 2017; Singh et al. 2022b). Among food items, rice grains and rice-based food products have been identified as the major sources of As to humans around the globe (Tyagi et al. 2020; Khanam et al. 2022). Rice plants and grains are reported to accumulate higher levels of As than any other crop plants (Wang et al. 2015). Moreover, rice is the most consumed food item in West Bengal region, and people often eat rice in all three meals of the day from breakfast to dinner; total rice intake by a person can reach to as high as 300–400 g in a day (Srivastava 2020). West Bengal is also a humid region forcing people to drink more water especially during summer months, making the problem of As exposure even worse (Biswas et al. 2014).

The 2030 Agenda for Sustainable Development by United Nations provides 17 SDGs, which are an urgent call for action by all countries—developed and developing in a global partnership. Soil and water health in developing countries is a prime concern for attainment of SDGs. Hence, it is very important to monitor the water and soil health in developing nations including India with respect to local conditions to facilitate the attainment of SDGs by 2030. The present study was planned to understand the status of As contamination in groundwater, surface water, soil and rice grains in four remote villages of West Bengal and two each from of Nadia and North 24 Parganas districts and to evaluate their health implications on the exposed population.

Material and methods

Study area

For the present study, four villages were selected belonging to two different districts, Nadia and North 24 Parganas of West Bengal. Both the districts are considered to be As-contaminated. The studied villages from Nadia district were Jaguli and Kugacchi. The villages from North 24 Parganas district were Chamta and Byaspur. The details of the location are presented in Fig. 1. All the four villages studied in this work are remote villages of West Bengal, and the population living here is mostly dependent of agriculture.

Water and soil collection

Groundwater samples were collected from 15 tube wells (S1 to S15) in triplicates from each of the four studied villages. The pumps were started and allowed to run for about 15 min, and then, water was collected. Surface water samples were collected from small ponds commonly present in the villages; a total of ten surface water samples (S1 to S10) were collected from each of the four villages. The location of tube wells and small ponds was 50–100 m from each other. For each tube well and pond sampling, 5 samples were collected, mixed thoroughly, and considered as one composite sample. All the water samples were collected in pre-washed polyethylene containers with the addition of 0.1% (v/v) concentrated nitric acid solution. The water samples were placed in a cooled ice box for transportation and stored at 4 °C prior to As estimation. All the sampling was done in triplicate. The pH, electrical conductivity (EC) and oxidation reduction potential (ORP) were measured in samples freshly after the collection by using Aquasol Digital Meter. Then, the samples were kept in washed polyethylene containers (100 ml), and few drops of concentrated nitric acid were added for bringing the samples to laboratory (Upadhyay et al. 2019).

For soil sampling, agricultural field soil was collected from five locations (S1 to S5) in a village representing the whole area. S1 and S5 sampling locations are the start and end points respectively to the particular village. S2, S3 and S4 are the points at different agricultural fields inside the particular village. At each agricultural field, composite sample was taken from five different spots of the field and was considered as representative sample. Soil cores 20 cm in length were collected from the fields using PVC pipes. Soil samples were then taken out of the core segments and were air-dried, grounded and passed through 2-mm sieve and homogenized to make a representative sample. All

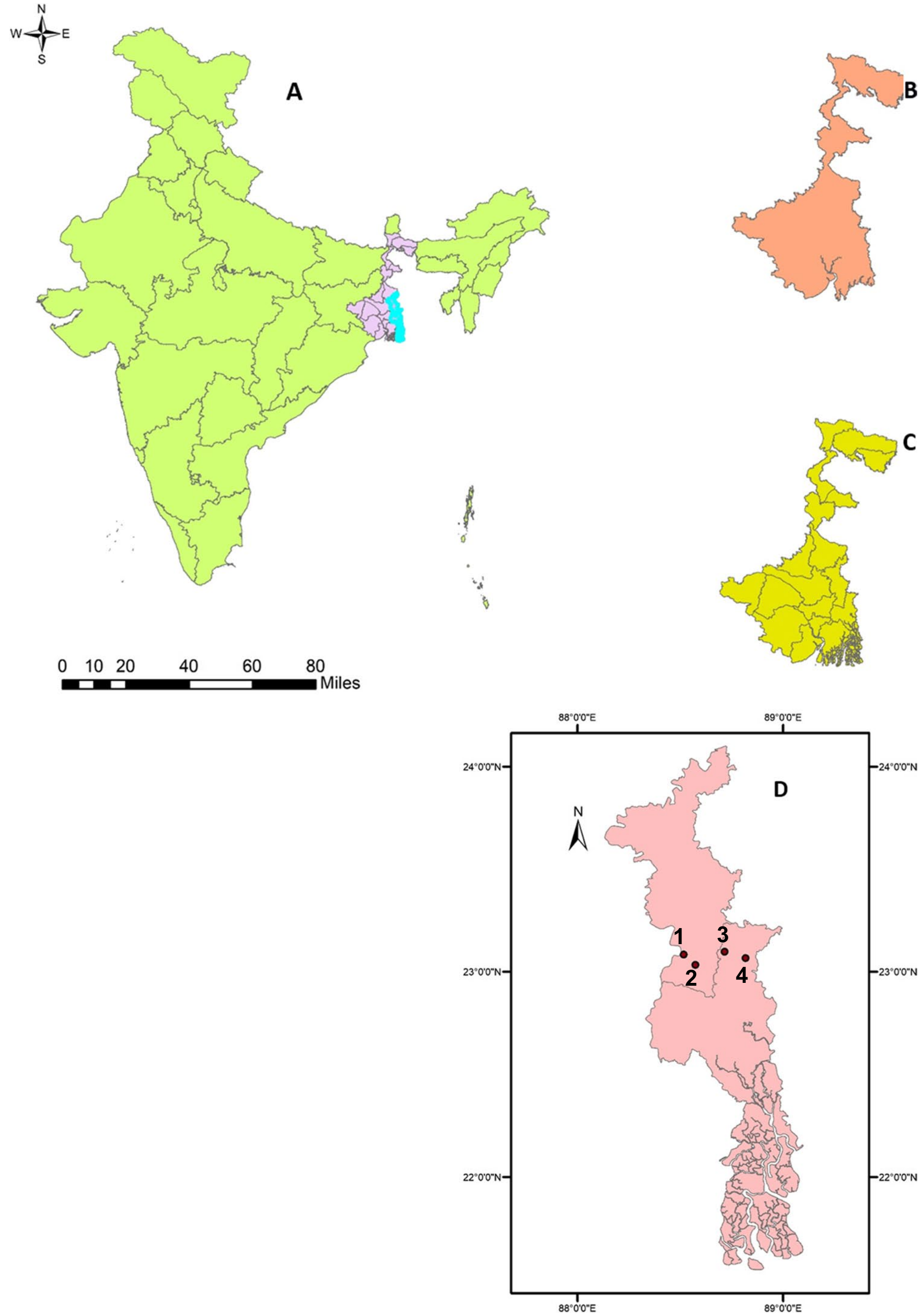


Fig. 1 Map showing **A** India, **B** West Bengal state, **C** West Bengal district, and **D** Nadia in the north and North 24 Parganas in the south showing location of sampling villages: (1) Jaguli, (2) Kugacchi, (3) Chamta and (4) Byaspur

samples were in triplicate. The soil samples were taken in two layers of polythene bags and were analysed in laboratory for pH, EC, ORP and organic carbon (OC) by following Upadhyay et al. (2019).

The study also included collection of raw rice grains (10 varieties) and rice-based food products (puffed rice, parched rice and beaten rice) from the local villagers in individual sterile zip locks (approx. 100 g). The collected rice grain varieties included Ratna, Gotra Bidhan, Satabdi, IR-50 and Triguna belonging to high-yielding varieties (HYVs) and Tulsa, Megi, Kerala sundari, Megha dambur and Tulaipanji belonging to local varieties (LVs).

Arsenic analysis

For As analysis in water, soil and rice samples, procedures detailed in Upadhyay et al. (2019) and Tyagi et al. (2020) were followed. The content in the samples was determined using graphite furnace atomic absorption spectrometry (GFAAS Zeenit 350P Analytikjena, Germany). The instrument was calibrated using SRM (3103a), and spike recovery test was carried out. Analytical data quality of As was ensured through repeated analysis ($n = 6$) of EPA quality control samples in water, and the results were found to be within 2.15% of certified values. The analysis was carried out after calibrating the instrument in the working range with coefficient of determination ($R2$) = 0.995. The blanks were run in triplicate to check the precision of the method with each set of samples. A series of aqueous standards in the range of 30 to 200 μg L^{-1}, prepared by serial dilution from a stock standard solution of 1000 mg L^{-1}, were used for calibration of the instrument. The As stock solution of 1000 mg L^{-1} was obtained from Inorganic Ventures and traceable to SRM 3103a. The analytical method was validated by spike recovery experiments.

Contamination and health indices

Contamination factor

The soil contamination was assessed in terms of contamination factor (CF), which was calculated by dividing the concentration of As in the soil by its reference level (6.83 mg kg^{-1}) (Antoniadis et al. 2019).

$$CF = CS/C_{Ref}$$

where CS is total soil element content (mg kg^{-1}) and C_{Ref} is reference content in pristine soils (mg kg^{-1}). Soil can be categorized as less contaminated (CF < 1), moderately contaminated ($1 \leq CF < 3$), considerably contaminated ($3 \leq CF < 6$) and highly contaminated ($CF \geq 6$) on the basis of CF values (Antoniadis et al. 2019).

Human carcinogenic health risk assessment

Health risk assessment for carcinogenic effects was evaluated by assessing estimated average daily intake (ADI), which was used to calculate hazard quotient (HQ) and incremental lifetime cancer risk (ILCR) as per method given in Khanam et al. (2022).

ADI in μg kg^{-1} body weight day^{-1} was calculated by the following equation:

$$ADI = C_{iAs} \times IR \times EF \times ED/BW \times AT$$

where C_{iAs} is the concentration of inorganic As (μg kg^{-1}), taking 86% of total as inorganic; IR is ingestion rate (taken as 400 g day^{-1} for rice grains and 100 g day^{-1} for rice-based products) (Brahman et al. 2016); EF (exposure frequency) was taken as 365 day $year^{-1}$ (Tyagi et al. 2020); BW is average specific body weight, which was taken as 60 kg; and AT was average time ($365 \times 60 = 21{,}900$ days) (USEPA 2011).

HQ values were calculated by following the equation:

$$HQ = ADI/RfD$$

where ADI is the average daily intake and RfD is the reference dose 0.3 μg kg^{-1} bw day^{-1} (USEPA 2011).

ILCR values for As were calculated with the help of following equation.

$$ILCR = ADI \times SF$$

SF is slope factor; it was described to be 1.5 for As (USEPA 2011). The safe range of the ILCR value is recommended between 10^{-6} and 10^{-4} (USEPA 2005).

Statistical analysis

All the sampling was done as per proper methodology and in triplicate for each sampling location. Soil sampling was done as composite sample, and these were also in triplicate. Standard deviation was calculated from triplicate values for all the data. One-way ANOVA was performed in all the data and found to be significant at $p \leq 0.01$.

Results and discussion

Arsenic in groundwater, surface water and soil and physico-chemical properties

A total of 15 groundwater and 10 surface water samples were analysed from each of the four villages. In ground water, the range of As was found to be 35 to 185 μg L^{-1} in Jaguli, 80 to 182 μg L^{-1} in Kugacchi, 41 to 126 μg L^{-1} in Chamta and 42 to 183 μg L^{-1} in Byaspur (Fig. 2A). Thus, all the villages have high As contamination of groundwater, and most of the samples collected from these four villages have shown levels of As higher than the drinking water permissible limits (50 μg L^{-1}) (WHO 2011). Groundwater from only one location has shown As level within permissible limit in Jaguli and Byaspur, while in Chamta, groundwater from two locations have shown As level < 50 μg L^{-1}. However, at Kugacchi village, all the samples have shown As levels > 50 μg L^{-1}. Out of 15 ground water samples collected, 5, 11, 6 and 8 samples have shown As levels > 100 μg L^{-1} from Jaguli, Kugacchi, Chamta and Byaspur respectively, which is quite alarming.

The ranges of surface water As were 34 to 44 μg L^{-1} in Jaguli, 40 to 61 μg L^{-1} in Kugacchi, 30 to 45 μg L^{-1} in Chamta and 32 to 48 μg L^{-1} in Byaspur (Fig. 2B). Thus, surface water in all the villages had As concentration at

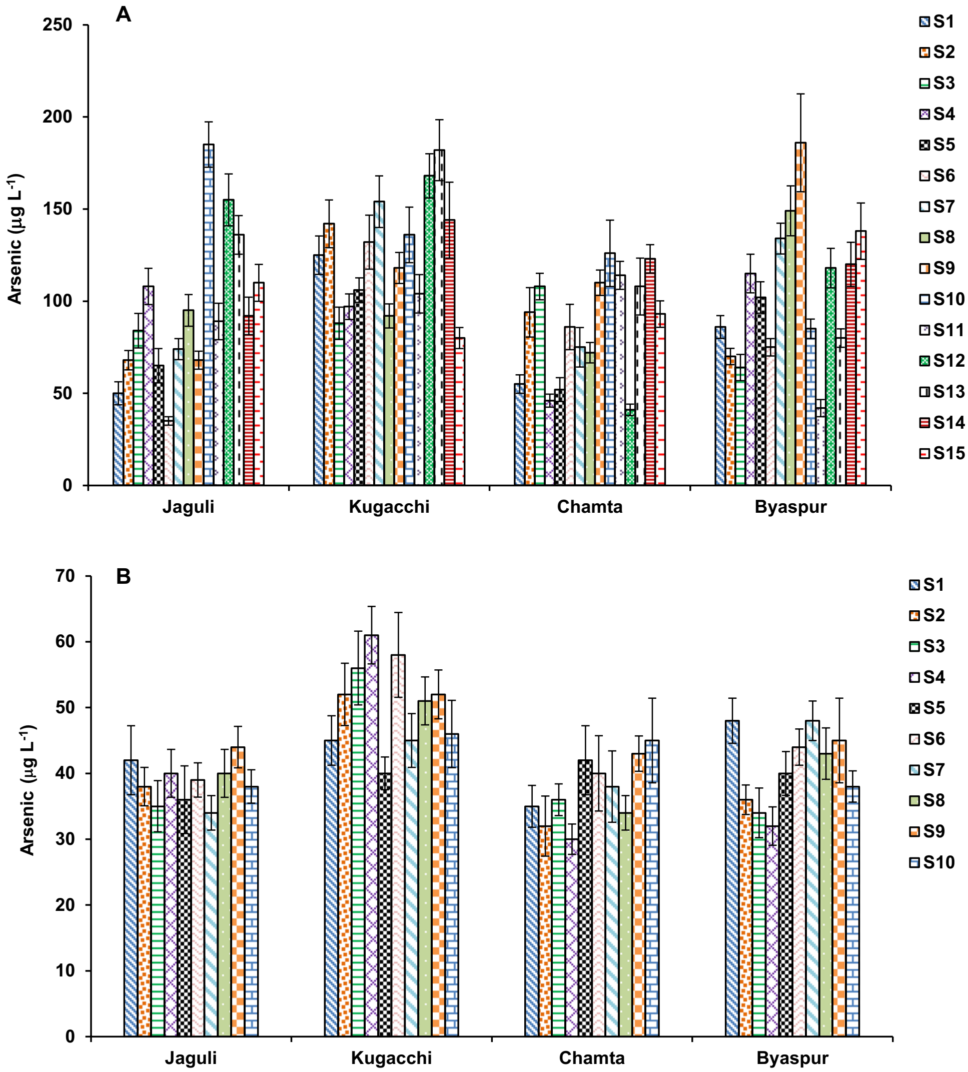


Fig. 2 Arsenic level in groundwater of fifteen locations (S1–S15) (**A**) and surface water of ten locations (S1–S10) (**B**) collected from each village. The values represent triplicate mean. One-way ANOVA was found to be significant at $p \leq 0.01$

alarming level being close to the maximum permissible limit. The range of pH in ground water samples was found as 7.51–8.12, 7.74–8.11, 7.75–8.11 and 7.74–8.11 in Jaguli, Kugacchi, Chamta and Byaspur villages respectively (Table 1). ORP in the same sample sets was recorded as 140–185, 138–175, 137–168 and 140–186, while EC was recorded as 314–328, 340–360, 302–320 and 325–348 in Jaguli, Kugacchi, Chamta and Byaspur villages respectively (Table 1). Globally, potentially toxic elements including As pose health hazards and genotoxicity in the groundwater aquifer. Rashid et al. (2019, 2021, 2023) have recorded metal contamination in the groundwater samples of Lower Dir, Mardan and Malakand (Pakistan), and physicochemical parameter ranges (pH, EC, ORP) were in line with the present study dealing with As contamination in groundwater samples of West Bengal, India. They have also studied metal concentration, carcinogenic and noncarcinogenic health hazards, groundwater quality indexing (GWQI-model), source provenance and fate distribution in the groundwater of Hindukush ranges, Pakistan, and reported that EC, turbidity, TSS, PO_4^{3-}, Na^+, Mg^{2+}, Ca^{2+}, Cd, Co, Fe and Pb have exceeded the World Health Organisation (WHO) guidelines (Rashid et al. 2022).

Similarly for surface water samples, pH was found in the range of 8.05–8.22 in Jaguli, 8.04–8.21 in Kugacchi, 8.04–8.23 in Chamta and 8.04–8.22 in Byaspur villages (Table 2). ORP in the surface water samples collected from these villages was recorded as 95–114, 120–137, 82–98 and 110–125; however, EC was found in the range of 242–265, 272–310, 236–248 and 252–270 in Jaguli, Kugacchi, Chamta and Byaspur villages respectively (Table 2). Thus, in surface water, pH ranged from 8.04 to 8.23 while EC and ORP showed the range of 82 to 138 and 236 to 310 respectively in all the four villages studied here (Table 2).

A total of five soil samples were collected from each village from evenly separated agricultural fields. The ranges of As were found to be 46.17 to 63.23 mg kg^{-1} in Jaguli, 52.96 to 66.00 mg kg^{-1} in Kugacchi, 47.87 to 61.93 mg kg^{-1} in

Table 1 Physico-chemical properties of groundwater samples collected from four villages of Nadia and North 24 Parganas. EC: μS cm^{-1}; ORP: mV

	Jaguli			Kugacchi			Chamta			Byaspur		
	pH	ORP	EC	pH	ORP	EC	pH	ORP	EC	pH	ORP	EC
S1	7.54 ± 0.72	155 ± 15	320 ± 30	7.92 ± 0.75	165 ± 16	345 ± 33	8.02 ± 0.76	140 ± 13	315 ± 30	7.96 ± 0.76	148 ± 14	332 ± 32
S2	7.71 ± 0.67	175 ± 15	328 ± 28	7.95 ± 0.71	160 ± 14	348 ± 30	7.95 ± 0.69	162 ± 14	315 ± 27	7.95 ± 0.69	150 ± 13	336 ± 29
S3	8.08 ± 0.90	181 ± 20	315 ± 35	8.05 ± 0.90	148 ± 16	355 ± 40	7.92 ± 0.88	165 ± 18	320 ± 36	7.84 ± 0.86	186 ± 21	331 ± 27
S4	7.51 ± 0.95	178 ± 23	326 ± 41	7.94 ± 1.01	155 ± 20	359 ± 45	8.05 ± 1.02	137 ± 13	314 ± 40	8.04 ± 1.02	175 ± 22	325 ± 41
S5	8.06 ± 0.64	164 ± 13	314 ± 25	7.88 ± 0.62	165 ± 13	340 ± 27	8.11 ± 0.64	170 ± 17	308 ± 24	7.95 ± 0.63	144 ± 11	342 ± 27
S6	8.11 ± 0.87	144 ± 15	319 ± 34	7.85 ± 0.84	152 ± 16	352 ± 38	7.93 ± 0.85	156 ± 17	309 ± 33	7.92 ± 0.85	155 ± 17	348 ± 37
S7	7.86 ± 0.78	145 ± 14	320 ± 32	7.82 ± 1.01	175 ± 17	356 ± 35	8.04 ± 0.80	152 ± 15	320 ± 32	8.08 ± 0.80	168 ± 17	339 ± 34
S8	7.95 ± 1.01	160 ± 20	322 ± 44	7.86 ± 0.77	156 ± 20	351 ± 44	7.96 ± 1.01	145 ± 18	314 ± 40	8.11 ± 1.03	154 ± 20	341 ± 43
S9	7.92 ± 0.68	167 ± 14	326 ± 28	8.11 ± 1.00	168 ± 14	348 ± 30	7.91 ± 0.68	152 ± 13	310 ± 27	7.82 ± 0.67	140 ± 12	340 ± 29
S10	7.65 ± 0.73	185 ± 18	324 ± 31	7.94 ± 0.74	148 ± 14	342 ± 32	7.99 ± 0.76	168 ± 16	307 ± 29	7.98 ± 0.76	165 ± 16	348 ± 33
S11	8.12 ± 0.62	145 ± 11	318 ± 34	7.92 ± 0.77	140 ± 11	340 ± 26	8.02 ± 0.61	150 ± 11	316 ± 24	7.74 ± 0.59	149 ± 11	342 ± 26
S12	8.02 ± 0.55	140 ± 10	319 ± 22	7.74 ± 0.60	138 ± 9	356 ± 32	7.96 ± 0.55	158 ± 11	314 ± 25	7.92 ± 0.51	158 ± 13	336 ± 23
S13	7.59 ± 0.69	148 ± 14	327 ± 30	8.11 ± 0.53	159 ± 15	358 ± 26	7.92 ± 0.72	148 ± 14	310 ± 28	7.83 ± 0.71	154 ± 15	338 ± 31
S14	7.62 ± 0.60	155 ± 12	325 ± 26	7.84 ± 0.74	142 ± 13	360 ± 24	7.86 ± 0.62	164 ± 15	302 ± 24	8.05 ± 0.63	162 ± 13	340 ± 27
S15	7.93 ± 0.66	160 ± 13	320 ± 27	7.96 ± 0.66	158 ± 16	347 ± 33	7.75 ± 0.65	152 ± 16	308 ± 26	7.96 ± 0.66	150 ± 17	348 ± 29

Table 2 Physico-chemical properties of surface water samples collected from four villages of Nadia and North 24 Parganas. EC: μS cm^{-1}; ORP: mV

	Jaguli			Kugacchi			Chamta			Byaspur		
	pH	ORP	EC	pH	ORP	EC	pH	ORP	EC	pH	ORP	EC
S1	8.11 ± 0.77	104 ± 10	258 ± 25	8.06 ± 0.77	136 ± 13	278 ± 26	8.23 ± 0.78	85 ± 13	236 ± 30	8.15 ± 0.96	112 ± 14	252 ± 30
S2	8.15 ± 0.71	98 ± 8	249 ± 22	8.15 ± 0.71	130 ± 11	284 ± 25	8.06 ± 0.70	88 ± 16	245 ± 27	8.11 ± 0.99	110 ± 13	258 ± 27
S3	8.08 ± 0.90	110 ± 12	244 ± 27	8.04 ± 0.90	124 ± 14	298 ± 33	8.15 ± 0.91	92 ± 19	248 ± 36	8.05 ± 0.78	125 ± 21	264 ± 36
S4	8.22 ± 1.04	114 ± 14	264 ± 33	8.09 ± 1.02	129 ± 21	310 ± 39	8.20 ± 0.88	84 ± 11	239 ± 40	8.12 ± 1.09	118 ± 22	269 ± 40
S5	8.09 ± 0.64	95 ± 11	248 ± 20	8.21 ± 0.65	131 ± 10	288 ± 23	8.18 ± 0.65	96 ± 17	240 ± 24	8.04 ± 0.94	114 ± 11	257 ± 24
S6	8.05 ± 0.87	105 ± 15	265 ± 28	8.16 ± 0.88	137 ± 15	282 ± 30	8.15 ± 0.85	82 ± 18	248 ± 33	8.22 ± 0.85	120 ± 17	269 ± 33
S7	8.14 ± 0.81	111 ± 14	248 ± 25	8.21 ± 0.81	125 ± 12	291 ± 29	8.16 ± 0.89	98 ± 14	246 ± 32	8.16 ± 0.80	115 ± 17	264 ± 32
S8	8.16 ± 1.03	112 ± 13	250 ± 32	8.14 ± 1.03	120 ± 15	296 ± 38	8.23 ± 0.91	87 ± 18	238 ± 40	8.19 ± 1.04	116 ± 20	261 ± 40
S9	8.21 ± 0.77	96 ± 10	242 ± 21	8.06 ± 0.71	138 ± 12	297 ± 26	8.18 ± 0.98	90 ± 18	240 ± 27	8.06 ± 0.68	122 ± 12	270 ± 27
S10	8.12 ± 0.79	105 ± 14	255 ± 24	8.15 ± 0.77	135 ± 132	272 ± 26	8.04 ± 0.86	94 ± 16	238 ± 29	8.16 ± 0.76	119 ± 16	268 ± 29

Chamta and 52.50 to 57.87 mg kg^{-1} in Byaspur. Thus, agricultural soil collected from all the four villages has shown high level of As contamination, while Kugacchi village (Nadia) had the maximum As content in soil among four villages studied here, which is in line with high As levels in water samples collected from this village (Fig. 3A). The analysis of CF values depicted a range of 6.75 to 9.66 in all four villages that indicated highly contaminated agricultural soil in the study area (Fig. 3B). The range of pH, EC (μS cm^{-1}), ORP (mV) and OC (%) were found to be 8.22 to 8.62, 618 to 692, 208 to 253 and 0.95 to 1.33 respectively (Table 3).

The soil and water resources of West Bengal are known to be contaminated with As for past few decades, and it is known that the contamination has affected the health and well-being of people living there (Upadhyay et al. 2019; Sarkar et al. 2022). There exists wide variability in As contamination of water and soil even in close distances, and therefore, monitoring and regular evaluation of various samples is necessary to understand the current status of As contamination. Although Kugacchi was found having greater As contamination in general in groundwater, surface water and soil samples, all villages had very high levels of As and the contamination factor indicated “very high soil As contamination” (Fig. 2).

Recently, agriculture soil contamination by potential toxic elements (PTEs) has been increased and become the focus of environmental scientist in recent decade worldwide

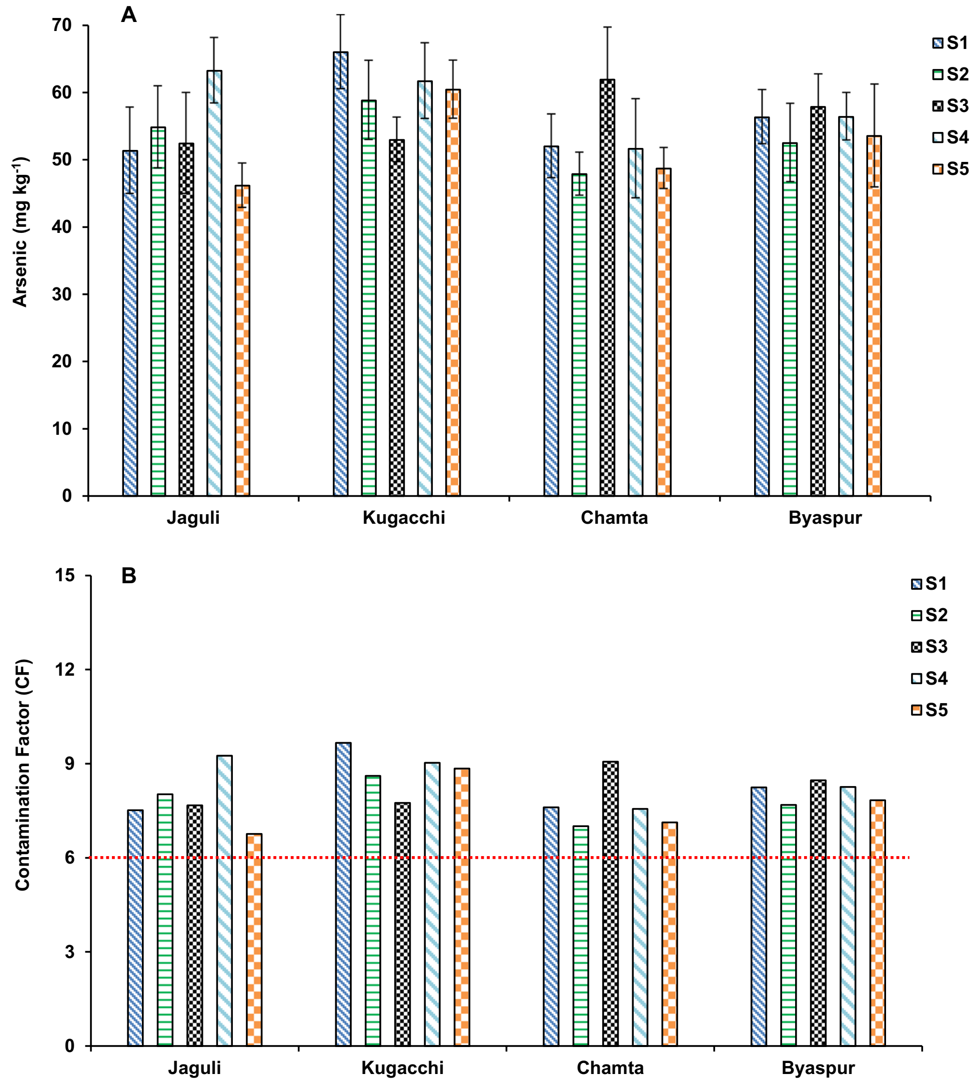


Fig. 3 Arsenic level of soil samples collected from five locations (S1–S5) of each village. Composite soil sampling was performed. The values represent triplicate mean (**A**). One-way ANOVA was found to be significant at $p \leq 0.01$. The panel (**B**) presents contamination factor (CF) calculated by using observed data and reference value of arsenic for uncontaminated soil

(Ali et al. 2019). Arsenic contamination recorded in the agricultural soils collected from rural areas of West Bengal is alarming. West Bengal is known for intensive rice cultivation with two crops a year, and this subjects the soil to repeated irrigation and rapid changes in physico-chemical conditions of the soil. Water usage and changes in physico-chemical properties of the soil are connected to microbiological functions, and this has been implicated in high As contamination of soil in West Bengal (Majumdar et al. 2021). Irrigation-induced As build-up in soil was also demonstrated in earlier work of Upadhyay et al. (2019) who found higher As concentrations in top soil layers than in lower soil layers. The physico-chemical properties of soil and water indicated generally alkaline pH conditions and positive ORP ranges that would favour presence of As in the arsenate form than arsenite form (Strawn 2018; Barla et al. 2017; Raju 2022). The ORP values of soil change as per the water saturation and development of reducing conditions during rice crop growth cycle, and therefore, ORP in reducing range is detected. In the present study, the observed positive ORP values are due to the fact that sampling was done after crops were harvested that allowed collection of rice grains also from villagers. OC was generally less than 1.4%, and it is known to influence microbial community and functions to influence subsequently the As release into the soil (Raju 2022).

Arsenic in rice grains and rice-based food products

Apart from the As-contaminated water, rice grain is the prime source of As for the rural population of West Bengal (Rahman and Hasegawa 2011). West Bengal is well known as one of the major rice-producing states in India, and rice grain accumulates high amount of As owing to use of As-laden groundwater for irrigation and its cultivation practices (Singh et al. 2022b). Rice grain contributes a significant amount of As to the daily diets through consumption of cooked rice and rice by-products and poses potential

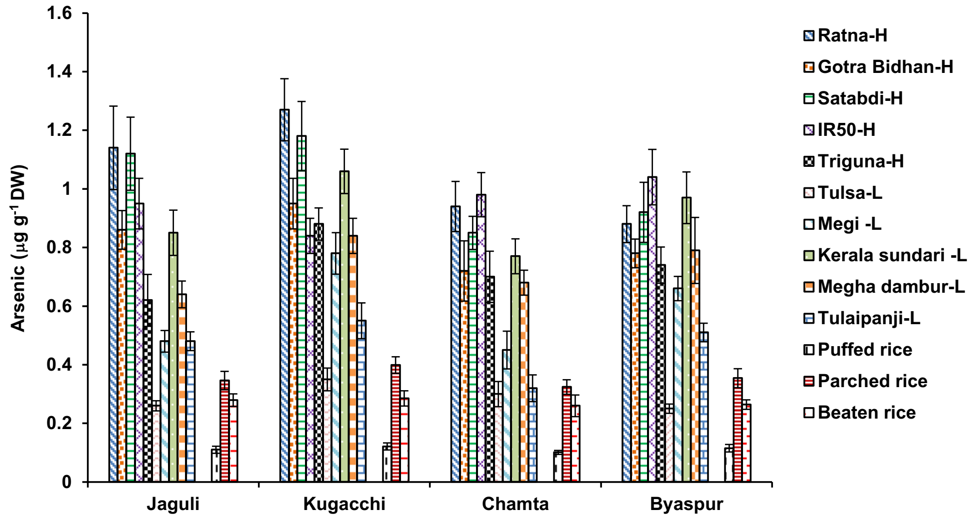
Table 3 Physico-chemical properties of soil samples collected from four villages of Nadia and North 24 Parganas. EC: μS cm^{-1}; ORP: mV, OC: %

	Jaguli				Kugacchi				Chamta				Byaspur			
	pH	EC	ORP	OC	pH	EC	ORP	OC	pH	EC	ORP	OC	pH	EC	ORP	OC
S1	8.33±0.73	679±58	241±16	1.08±0.10	8.62±0.77	632±60	216±15	1.07±0.10	8.37±0.59	684±65	249±23	1.22±0.09	8.38±0.73	646±61	224±19	1.14±0.08
S2	8.43±0.89	688±86	253±25	0.94±0.08	8.45±0.68	618±53	225±23	1.11±0.10	8.30±0.85	680±58	249±21	1.04±0.11	8.45±1.06	624±53	238±29	1.11±0.17
S3	8.34±0.91	675±49	224±26	0.98±0.11	8.34±0.88	627±70	226±26	1.13±0.13	8.22±0.96	682±76	234±31	1.33±0.16	8.34±0.62	641±71	222±16	1.02±0.13
S4	8.42±1.07	688±54	247±21	1.14±0.14	8.54±1.13	619±78	210±18	1.12±0.14	8.34±0.74	669±84	242±26	1.32±0.12	8.39±0.67	626±79	222±17	1.29±0.09
S5	8.29±0.66	692±77	234±22	0.97±0.08	8.51±0.74	623±49	208±19	1.05±0.08	8.38±0.82	672±53	248±24	1.06±0.18	8.33±0.96	640±50	222±24	1.18±0.16

threat to several families residing in the different As-exposed areas (Biswas 2019; Rokonuzzaman et al. 2022; Tyagi et al. 2020). Rice by-products such as puffed rice, parched rice and beaten rice are very popular among the rural population of West Bengal as snacks, and these are prepared from parboiled rice grain. They also act as an additional source of As to the people of rural Bengal.

The present study included the collection and analysis of rice grains and rice-based food products from the homes of local villagers to assess the risk faced by them as the villagers used to consume the stored crop produce. The range of As in rice grains and rice-based food products was found to be 0.26–1.14 μg g^{-1} and 0.11–0.35 μg g^{-1} respectively in Jaguli, 0.35–1.27 μg g^{-1} and 0.12–0.40 μg g^{-1} respectively in Kugacchi, 0.30–0.98 μg g^{-1} and 0.10–0.32 μg g^{-1} respectively in Chamta and 0.25–1.04 μg g^{-1} and 0.12–0.35 μg g^{-1} respectively in Byaspur. The range of As also varied to some extent in high-yielding (0.72–1.27 μg g^{-1}) and local varieties (0.25–1.06 μg g^{-1}), local varieties showing lower As levels in rice grain (Fig. 4A). In both the villages of Nadia distict, Jaguli and Kugacchi, the highest accumulation of As in rice grain was recorded in var. Ratna (high yielding). In Chamta and Byaspur villages of North 24 Parganas district, var. IR50 (high yielding) showed the highest As level in grain. Chowdhury et al. (2018) reported As concentration in rice grain from Deganga block, North 24 Parganas district as 1120 g kg^{-1}, which is in agreement to our findings specially in Ratna and Satabdi varieties. Rice var. Tulsa (local) showed the lowest level of As in grains than other rice varieties studied here across all the 4 villages; nonetheless, As levels were still higher than the maximum permissible limit of 0.2 μg g^{-1} As (Sohn 2014). The presence of As in rice by-products might be due to the fact that those were prepared from the contaminated rice grains locally cultivated in the exposed areas; however, they had slightly lower As levels, which might be due to loss of As during processing steps like washing and heating. The variety-specific differential response of As accumulation in rice grains (in 10 varieties) was observed in the present study. The varietal differences in As accumulation in rice grains occur due to environmental factors, agronomic practices and microbiological profiles affecting the extent of As accumulation in rice grains (Awasthi et al. 2017; Kumari et al. 2018; Duan et al. 2017; Yadav et al. 2021). Similar findings have been reported by other researchers showing varietal difference in As accumulation in rice plant parts including grain (Bhattacharya et al. 2013; Samal et al. 2021). The different potential of hybrid rice varieties, local aromatic varieties and hybrids in As accumulation in plants and grains has been recorded in a recent study by Khanam et al. (2022) who found local aromatic rice varieties to have less As accumulation in rice grains than that of hybrids and HYVs. The authors attributed this to the higher root biomass and higher iron plaque

Fig. 4 Arsenic level of rice grains of high-yielding and local varieties and rice-based food products collected from each village. The values represent triplicate mean. One-way ANOVA was found to be significant at $p \leq 0.01$



formation, and to the presence of higher number of nodes and internodes due to greater height in local varieties as compared to that in hybrids and HYVs. Rice consumption-based risk analysis also depicted lower human health risks associated with local varieties (Khanam et al. 2022).

The calculation of ADI, HQ and ILCR values indicated significant chronic toxicity and carcinogenic risks particularly owing to rice grain consumption (Table 4). The consumption of As owing to rice grains was estimated to range from 3.55 to 7.28 µg kg^{-1} bw day^{-1} in HYVs and 1.43 to 6.08 µg kg^{-1} bw day^{-1} in local varieties. The ADI levels of As with respect to rice-based food products were 0.14 to 0.57 µg kg^{-1} bw day^{-1}. The provisional tolerable daily intake (PTDI) limit for inorganic As through food stuff is 3.0 µg kg^{-1} bw day^{-1} (WHO 2011). Hence, all HYVs and some local rice varieties contributed more than PTDI limit to As exposure to people, while rice-based food products contributed As in range lower than PTDI. However, consumption of various rice-based snacks is an additional input to daily diet of people. HQ values were found to range from 11.85 to 24.27 for HYVs, 4.78 to 20.26 for local varieties and 0.48 to1.91 for rice-based

Table 4 Values of the estimated average daily intake (ADI; µg kg^{-1} bw day^{-1}), incremental lifetime cancer risk (ILCR) and hazard quotient (HQ) of As for rice grains collected from four villages of Nadia and North 24 Parganas, West Bengal, India

Name of rice variety/ rice-based food product	Jaguli			Kugacchi			Chamta			Byaspur		
	ADI	ILCR*	HQ	ADI	ILCR*	HQ	ADI	ILCR*	HQ	ADI	ILCR*	HQ
High-yielding varieties												
Ratna-H	6.54	8.40	21.79	7.28	9.36	24.27	5.39	6.93	17.96	5.05	6.49	16.82
Gotra Bidhan-H	4.93	6.34	16.44	5.45	7.00	18.16	4.13	5.31	13.76	4.47	5.75	14.91
Satabdi-H	6.42	8.26	21.40	6.77	8.70	22.55	4.87	6.27	16.24	5.27	6.78	17.58
IR50-H	5.45	7.00	18.16	4.82	6.19	16.05	5.62	7.22	18.73	5.96	7.67	19.88
Triguna-H	3.55	4.57	11.85	5.05	6.49	16.82	4.01	5.16	13.38	4.24	5.45	14.14
Local varieties												
Tulsa-L	1.49	1.92	4.97	2.01	2.58	6.69	1.72	2.21	5.73	1.43	1.84	4.78
Megi -L	2.75	3.54	9.17	4.47	5.75	14.91	2.58	3.32	8.60	3.78	4.87	12.61
Kerala sundari -L	4.87	6.27	16.24	6.08	7.81	20.26	4.41	5.68	14.72	5.56	7.15	18.54
Megha dambur-L	3.67	4.72	12.23	4.82	6.19	16.05	3.90	5.01	13.00	4.53	5.82	15.10
Tulaipanji-L	2.75	3.54	9.17	3.15	4.05	10.51	1.83	2.36	6.12	2.92	3.76	9.75
Rice-based food products												
Puffed rice	0.16	2.03	0.53	0.17	2.23	0.58	0.14	1.86	0.48	0.16	2.12	0.55
Parched rice	0.50	6.38	1.65	0.57	7.35	1.91	0.46	5.97	1.55	0.51	6.52	1.69
Beaten rice	0.40	5.14	1.33	0.41	5.25	1.36	0.37	4.79	1.24	0.38	4.87	1.26

*For all rice grains, ILCR values are in the order of 10^{-3}; for rice-based food products, ILCR values are in the order of 10^{-4}

food products. HQ values of more than one are considered to be indicative of significant non-carcinogenic health risks, and all rice grains and parched and beaten rice had higher than one HQ values (Table 4). ILCR values were 1.84×10^{-3} to 9.36×10^{-3} for rice grains and 1.86×10^{-4} and 7.35×10^{-4} for rice-based food products (Fig. 4B). Thus, ILCR due to rice-based food products was in the safe range as prescribed by USEPA, while ILCR due to rice grains was in high risk range of 10^{-3}. Recently, similar effects have been reported by Rokonuzzaman et al. (2022) on human health owing to consumption of rice and vegetables grown in As-contaminated areas of Chandpur, Bangladesh.

The health effects of As-laden crop plants are dependent on the consumption amount and metabolism of As in humans. The present study evaluated possible non-carcinogenic and carcinogenic health risks in terms of HQ and ILCR values respectively with the assumption of complete As bioavailability to humans after consumption and found rice grains to pose high level of non-carcinogenic and carcinogenic threat. The consumption rate of rice-based food products is generally low, and therefore, it fell in safe range. Rice-induced carcinogenicity has been implicated in a number of studies (Karagas et al. 2016; Palma-Lara et al. 2020).

Conclusion

The present study demonstrated the presence of high level of As contamination in groundwater, surface water and soil in studied villages of West Bengal. The rice grains and rice-based food products also had significant amount of As that might impose high non-carcinogenic and carcinogenic risks to people. The local varieties showed lower As in grains and consequently lower ADI, HQ and ILCR values as compared to high-yielding varieties. The authors propose the popularisation of local varieties among people considering the safety to be the foremost priority. The government may provide subsidy to the farmers to cover for their loss due to lower yields of local varieties and HYVs. This work highlights region-specific environmental challenges (rural areas of West Bengal, India) posing hindrance to SDGs. The suitable mitigatory measures should be developed for local conditions to facilitate the attainment of SDGs by 2030.

Author contribution S.S.1 (Shraddha Singh) and V.P.V. conceptualized the idea. S.S.1 and P.K.P. selected sites and performed sample collection. S.S.1, A.S. and S.S.2 (Sudhakar Srivastava) carried out analysis and prepared manuscript draft. S.S.1, S.S.2 and V.P.V. reviewed and finalized the manuscript. All authors have read and agreed to the published version of the manuscript.

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Declarations

Ethical approval Not applicable.

Consent to participate Not applicable.

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