RESEARCH ARTICLE

Arsenic in the foodstuffs: potential health appraisals in a developing country, Bangladesh

Md. Saiful Islam[1,2] · Ramal Ahmed Mustafa[3] · Khamphe Phoungthong[2] · Abu Reza Md Towfiqul Islam[4] ·
Tofazzal Islam[5] · Tasrina Rabia Choudhury[6] · Md. Humayun Kabir[7] · Mir Mohammad Ali[8] · Abubakr M. Idris[9,10]

Abstract

The presence of highly poisonous arsenic (As) elements in food concerns humans and animals. In Bangladesh, arsenic-contaminated groundwater is frequently utilized for agricultural irrigation. This is a significant source of arsenic pollution in the human food chain. For the first time, we investigated the presence of total arsenic in various foodstuffs obtained from 30 distinct agricultural eco-zones of Bangladesh to understand human exposure to arsenic through the food chain in Bangladesh. The greatest and lowest As concentrations were reported in fish among the examined dietary items (0.55 mg/kg, fw) and fruit (0.0068 mg/kg, fw), respectively. The results show that arsenic consumption from daily diet and food with drinking water was estimated to be 0.0352 mg/day for rural residents and 0.2002 mg/day for urban residents, respectively. The highest target hazard quotients (THQ) of arsenic in the fish samples surpassed the allowable limit (> 1), proving that fish are the primary dietary items influencing the possible danger to health. However, the target cancer risk (TR) from nutritional arsenic consumption was likewise higher than tolerable. A value of 10^{-4} indicates that Bangladeshi people are continuously exposed to arsenic, which has carcinogenic and non-carcinogenic dangers. Overall, our results highlight that people in Bangladesh are exposed to hazardous levels of arsenic throughout the food chain, which should be addressed to ensure the country's food safety.

Keywords Ago-ecological zone · Arsenic · Bangladesh · Foodstuffs · Health risk

Introduction

Arsenic (As) is a well-known hazardous contaminant that threatens water resources in developing countries (Islam et al. 2019). Because of its pervasiveness, it has the potential to modify soil, water, and plants, as well as other ecosystem components, and is detrimental to human health (Bundschuh et al. 2012; Proshad et al. 2017; Moulick et al. 2021). Arsenic enrichment in Bangladeshi groundwater is regarded as one of the most concerning environmental disasters (Reza et al. 2010). Groundwater As pollution with concentrations over the Bangladesh regulatory limit (0.05 mgL^{-1}) has

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Responsible Editor: Philippe Garrigues

✉ Md. Saiful Islam
  msaifulpstu@yahoo.com

1   Department of Soil Science, Patuakhali Science
    and Technology University, DumkiPatuakhali 8602,
    Bangladesh

2   Environmental Assessment and Technology for Hazardous
    Waste Management Research Center, Faculty
    of Environmental Management, Prince of Songkla
    University, Songkhla 90112, Thailand

3   University of Garmian-College of Education,
    Kalar City 46021, Iraq

4   Department of Disaster Management, Begum Rokeya
    University, Rangpur 5404, Bangladesh

5   Institute of Biotechnology and Genetic Engineering,
    Bangabandhu Sheikh Mujibur Rahman Agricultural
    University, Gazipur, Bangladesh

6   Analytical Chemistry Laboratory, Chemistry Division,
    Atomic Energy Centre Dhaka, Bangladesh Atomic Energy
    Commission, Dhaka 1000, Bangladesh

7   Department of Environmental Science and Resource
    Management, Mawlana Bhashani Science and Technology
    University, Tangail, Bangladesh

8   Department of Aquaculture, Sher-E-Bangla Agricultural
    University, Dhaka 1207, Bangladesh

9   Department of Chemistry, College of Science, King Khalid
    University, Abha 62529, Saudi Arabia

10 Research Center for Advanced Materials Science (RCAMS),
    King Khalid University, Abha 62529, Saudi Arabia

afflicted 59 of Bangladesh's 64 administrative districts, causing arsenicosis sickness in the local population (Islam et al. 2021a). Terrestrial and aquatic biota can uptake arsenic from As-contaminated water and soil and enters the human body through foodstuffs (Bundschuh et al. 2012; Bhattacharya et al. 2009, 2013; Santra et al. 2013a, b; Islam et al. 2017a). Therefore, human exposure to arsenic found in food must be monitored because humans are one of the top consumers in the food chain.

Although arsenic is the most commonly found hazardous element in food, there is no indication that it is required for human health (Ahmed et al. 2016). Arsenic, both inorganic and organic, is found in foods, water, and other environmental components, and humans are exposed to it. In Bangladesh, foods such as rice, wheat, lentils, eggplant, carrot, potato, tomato, banana, beans, chili pepper, mango, onion, jackfruit, and different fish and meats are frequently used up by the people habitually (Islam et al. 2014a, 2015a, b). Inhalation can have a substantial impact in severely arsenic-contaminated areas, but for most individuals, food consumption is the predominant cradle of arsenic exposure (Kabir et al. 2021a, b). Arsenic's entrance into the human body via food chain routes is widely documented worldwide (Zhang et al. 2011). The binding of numerous biological ligands to inactivate an enzyme system is the utmost collective practice of arsenic poisoning in humans (Shen et al. 2013). In contrast, chronic arsenic exposure causes cancers, diabetes mellitus, hyperkeratosis, peripheral vascular disease, restrictive lung disease, melanosis, hypertension, ischemic heart disease, and gangrene (Argos et al. 2010; Ahsan et al. 2006; Samal et al. 2013, 2021). Several of these health conditions are now affecting people in South and Southeast Asia, most notably in Indonesia, Pakistan, and Taiwan. Arsenic is a dangerous substance linked to skin and lung cancer in humans. (WHO 2001). Furthermore, eating arsenic-contaminated food can deplete the body's critical nutrients and create significant health difficulties (Samal et al. 2010; Islam et al. 2014b). It should be emphasized that, while arsenic may alter chemical forms, it cannot be decomposed or eliminated.

The human repercussions of arsenic contamination of groundwater in Bangladesh are substantially inferior to those in any other country, as evidenced by exposure to drinking water and food. At its highest, about 26 million individuals drank water with a concentration of more than 50 $\mu g L^{-1}$, while at its lowest, around 49 million people drank water with > 10 $\mu g L^{-1}$ (Hasan et al. 2019). In Bangladesh, people (97%) have dug hundreds of wells to collect fresh groundwater for drinking, irrigation, fish culture in hatcheries, and domestic use (Ahmed et al. 2004, 2021; Bhattacharya et al. 2020). As a result, natural processes in the groundwater and excessive groundwater withdrawal due to overpopulation, the individuals who consume this contaminated water face a major detrimental threat. Approximately 27%

of Bangladesh's wells are seriously contaminated with elevated amounts of As (> 0.05 mgL^{-1}) (Anawar et al. 2002). In Bangladesh, arsenic-enriched groundwater is the focal point of As amassing in the food chain through the water-soil-crop-food system (Das et al. 2004; Rahman et al. 2012, 2013; Islam et al. 2017b).

Inadequate surveillance of input routes, lack of knowledge of hazard measures, limited knowledge of regulatory frameworks, and poor administration of manufacturing effluents are the leading causes of hazardous trace element pollution of the environment and food in Bangladesh (Rahman et al. 2012, 2013; Islam et al. 2017a). However, legislative flaws relating to arsenic contamination are not a top concern in Bangladeshi research. The evaluation of daily dietary arsenic exposure and health hazards based on daily food ingesting research is critical for Bangladesh (FAO 2006; Williams et al. 2006; Islam et al. 2017a, b, 2019). Although a few publications have explored the presence and toxicity profile of arsenic in Bangladesh's food chain, soil, water, and other environmental compartments (Ahmed et al. 2019; Islam et al. 2018, 2021a,b), the primary concerns in terms of risk factors, policy, and research gaps have received little attention. Arsenic pollution and associated biogeochemistry are an extensive study topic regarding exposure and health consequences worldwide. Furthermore, arsenic poisoning, exposure lethality, gaps in updated research and coordination among the government and public, and factors responsible for increasing food security in Bangladesh are seldom investigated, and toxicity data of arsenic from foods is inadequate to estimate health hazards in Bangladesh. Hence, the purposes of this study were to (i) quantify the concentration of arsenic in foodstuffs consumed by both rural and urban people of Bangladesh living in 30 agro-ecological zones of the country; (ii) estimate the highest target hazard quotients (THQ) of arsenic in the food items; and (iii) estimate target cancer risks (TR) from ingesting dietary arsenic. Our study, for the first time, facilitated well-being and excellent valuations of the local food chain for predicting the potential fitness risk concerning dietary consumption, non-carcinogenic, and target cancer risk for the urban and rural adult inhabitants of Bangladesh.

Materials and methods

Study area

Bangladesh forms the world's largest delta at 88o10′ to 92o41′ East and 20o34′ to 26o38′ North. The great delta is flat from the Himalayas in the north to the Bay of Bengal in the south. The Meghna, Padma, Jamuna, Karnafuli, and tributaries wash the plain. Monsoon rains soak the land and rivers. Summer rains overflow their banks, flooding

low, and outlying areas annually. Two elevated tracts, Modhupur and Barind, and rows of hilly forests relieve the monotony of flatness inland. The great plain is nearly sea level along the southern coast and rises gradually northward. Rangamati Hill district's Keocradang Hill is 4034 feet above sea level. Topography can be divided into five classes.

Bangladesh's agro-ecological zones are based on physiography, soils, floods, and agro-climatology. Bangladesh's agro-ecological zones total 30. These 30 zones are organized into 88 agro-ecological sub-regions and 535 units (Banglapedia 2014). Physiography is the mix of soil geology and landscape. It defines Bangladesh's agro-ecological regions. The agroecological zone's water resource system is determined by its relationship to the Ganges–Brahmaputra-Meghna (GBM) basin and the Bay of Bengal. These zones have a humid subtropical climate. The average maximum and lowest temperatures are 43 °C and 3.6 °C, with an average annual rainfall of 2400 mm (Das and Islam 2021). The GBM delta's Pleistocene and Holocene alluvial deposits constitute the world's most prolific aquifer. Annual monsoons and floods refresh much of the delta system.

Sample collection and preparation

A total of 325 samples of rice and wheat grains; nine vegetables such as lentil, eggplant, carrot, bean, potato, tomato, onion, and chili pepper; three different fruits like banana, mango, and jackfruit; three different fish species like rui, pangas, and tilapia; and chicken eggs, cow milk, and chicken meat were gathered from the country and urban markets throughout Bangladesh's 30 agro-ecological zones (AEZ) (Fig. 1). The sample took place between January and December of 2017. Collected samples were labeled properly and wrapped in polythene bags and brought to the University of Dhaka's Institute of Nutrition and Food Science (INFS). Each food item was thoroughly washed in the laboratory using deionized water. The moisture contents in plant components were calculated by recording the fresh and dried weights. In a food processor, a composite

Fig. 1 The distribution of the 30 agro-ecological zones of Bangladesh from where food samples of this study were collected
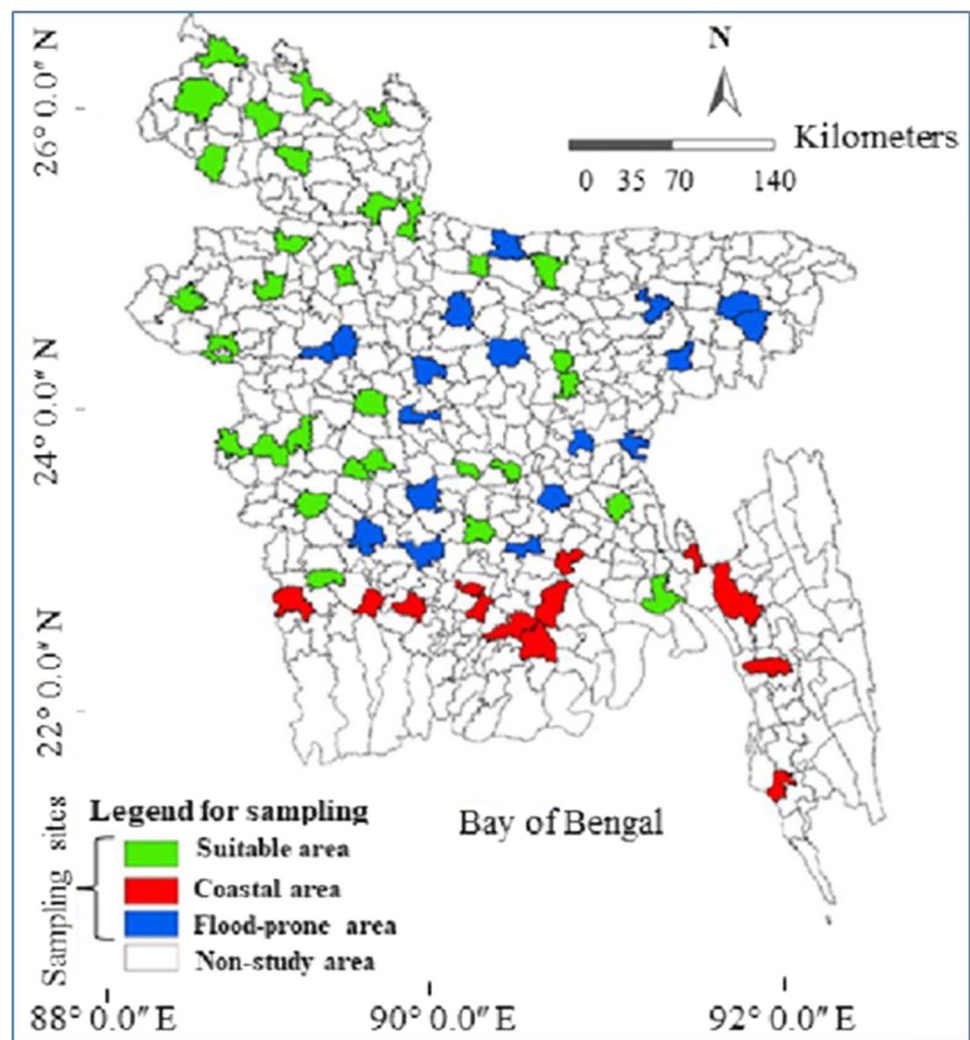
sample for each food item was prepared and homogenized, and 50 g test samples were collected and dried at 65–75 °C to achieve a consistent weight. The pre-processed samples were then sent to Yokohama National University in Japan, where they were kept in an airtight, clean zip-lock bag in the freezer until chemical analysis.

Sample extraction procedure

Ultrapure water and analytic reagent-grade compounds were used to make all of the solutions. A microwave (Bergh of Microwave MWS-2, Germany) was used for sample digestion. 0.2 g of dried powdered material was processed with 6 mL of 69% HNO_3 and 2 mL of 30% H_2O_2 for extraction (Wako Chemical Co, Japan) in a Teflon vessel (DAP-60 K) of microwave digestion system (Islam et al. 2022a). Three-step digestion procedures were used: step 1, 180 °C temperature and 85% power were held constant for 15 min; step 2, 200 °C temperature with 90% power for 15 min; and step 3, 100 °C temperature and 40% power for 10 min to lower the temperature. After digestion, Teflon containers were dipped in cold water to alleviate any leftover pressure within the vessel. The samples were moved to a Teflon beaker, and the total volume was increased to 25 mL using MilliQ water (Elix UV5 and MilliQ, Millipore, USA). After filtering (with a DISMIC®—25HP PTTF syringe filter with a pore size of 0.45 mm), the digest solution was maintained in a plastic crew cap tube (Islam et al. 2022b,c,d).

Instrumental analysis and quality control

An inductively coupled plasma mass spectrometer was then used to test the samples for arsenic (ICP-MS, Agilent 7700, USA). Spex Certi Prep® USA supplied standard solutions covering 10 g/L of internal standards such as indium, yttrium, beryllium, cobalt, and titanium were used to construct the standardization curve. For calculating concentration, calibration curves with an $R^2 > 0.999$ were allowed. Working standards were generated and utilized daily in 5% (v/v) HNO_3 at 69% ultrapure grade. If all test batches satisfied the stated internal quality controls, they were examined and verified using an internal quality methodology (IQCs). To check the accuracy of the instrument analysis and standard reference material of INCT-CF-3, corn flour was analyzed for arsenic concentration, and data for certified value (0.01 mg/kg) and measured value (0.0098 ± 0.001 mg/kg) was checked. The recovery percentage of the arsenic estimation was

98%, indicating that the instrumentation procedure was accurate for estimating arsenic from the samples.

Data calculations

Estimated daily intakes of arsenic

Estimated daily intakes (EDI) for arsenic were calculated by the following formula:

$$EDI = \frac{FIR \times C}{BW} \quad (1)$$

where FIR denotes the food intake rate (g/person/day), C denotes the arsenic amount in samples (mg/kg, fresh weight (fw)), and BW is the body weight considered to be 60 kg for adult occupants in the current study (FAO 2006). On a fresh weight basis, the adult population's daily food intake rate was determined (HIES 2017).

Non-carcinogenic risk

The non-carcinogenic risk {(target hazard quotient (THQ)} of arsenic was calculated using the USEPA region III risk-based concentration table (USEPA 2010) as follows:

$$THQ = \frac{EFr \times ED \times FIR \times C}{RfD \times BW \times AT} \times 10^{-3} \quad (2)$$

$$TotalTHQ (TTHQ) = THQ_{metal1} + THQ_{metal2} + \cdots\cdots\cdots + THQ_{metaln} \quad (3)$$

where EFr is the frequency of exposure (365 days per year); ED is the length of exposure (70 years), which corresponds to the average human life time (USEPA 1991); and RfD is the oral reference dosage (mg/kg/day); BW is the average body weight (adult, 60 kg); and AT is the averaging time for non-carcinogens (365 days per year number of exposure years, assuming 70 years). Arsenic's oral reference dosage was 0.0003 mg/kg/day (USEPA 2010). If the THQ is less than one, arsenic exposure is unlikely to influence the exposed population's health negatively. The THQ value is one or above that indicates a possible health concern (Wang et al. 2005), and treatments and preventative measures to reduce arsenic exposure in meals would be implemented.

Carcinogenic risk

The carcinogenic risk of arsenic was used to assess the incremental likelihood of an adult developing cancer as a result of lifetime exposure to that likely carcinogen (i.e., incremental or excess individual lifetime cancer risk; USEPA 1989). The

following formula (USEPA 1989) was adopted to calculate the target carcinogenic risk:

$$TR = \frac{EFr \times ED \times FIR \times C \times CSFo}{BW \times AT} \times 10^{-3} \qquad (4)$$

According to the USEPA (2010), the TR for arsenic was 1.5 (mg/kg/day)$^{-1}$, where TR denotes the objective carcinogenic risk or lifelong cancer risk and CSFo denotes the oral carcinogenic slope factor.

Statistical analysis

Microsoft Excel 2016 computed arsenic levels' averages and standard deviations in food samples. Arsenic datasets are tested for normality using the Kolmogorov–Smirnov test.

Results and discussion

Arsenic in foods

The study's major focus is on Bangladesh's rural and urban inhabitants' total exposure to arsenic from food and consumption of water, as well as their health effects from consuming arsenic-contaminated foods. Cumulative arsenic levels (mg/kg fw) in foods widely consumed by Bangladeshi people are evaluated in this study, and the results are shown in Table 1. On a fresh bulk basis, the mean arsenic contents in the dietary groups were 0.0133 (cereals), 0.0072 (vegetables), 0.0068 (fruits), 0.557 (fish), 0.012 (egg), 0.0489 (milk), and 0.0426 (meat). Rahman et al. (2014) observed that the total arsenic concentration in different varieties of Australian rice was 0.270 and Bangladeshi rice was 0.073 mg/kg dw, which was identical to the present study (Table 1). Total arsenic concentration in Brazilian rice was 0.212 mg/kg dw (Batista et al. 2011; Ciminelli et al. 2017); Indian rice was 0.094 mg/kg dw; Chinese rice was 0.128 mg/kg dw (Chen et al. 2018); and Pakistan was 0.083 mg/kg dw and other countries (Table 1) which was in line with the current study. In this study, arsenic concentration in wheat was 0.055 mg/kg which was comparable with the other studies such as in China 0.050 mg/kg (Adomako et al. 2011); India 0.027 mg/kg (Kumar et al. 2016); Spain 0.086 mg/kg (Matos-Reyes et al. 2010); Scotland, UK 0.030 mg/kg (Williams et al. 2007); and Cornwall, UK 0.070 mg/kg (Williams et al. 2007) (Table 1). In the current study, As concentration was observed in wheat as 0.055 mg/kg, which was slightly higher than the previous study conducted by Adomako et al. (2011) in China (0.050 mg/kg); Kumar et al. (2016) in India (0.027 mg/kg); Cubadda et al. (2016) in Italy (0.009 mg/kg); Williams et al. (2007) in Scotland, UK (0.030 mg/kg) and lower than the study by Islam et al. (2017a, b) in Bangladesh (0.26 mg/kg), Bhattacharya et al. (2010) in India (0.129 mg/

kg), and Matos-Reyes et al. (2010) in Spain (0.086 mg/kg) (Table 1).

The fish (0.557 mg/kg, fw) and fruits (0.0068 mg/kg, fw) had the highest and lowest levels of arsenic, respectively. Food intake could be a crucial pathway for arsenic bioaccumulation in fish (Zhang et al. 2011). The overall arsenic quantities in seafood, such as fish, are slightly higher in Cambodian meals than in other cuisines (Wang et al. 2013), the UK (Al Rmalli et al. 2005), China (Li et al. 2011a, b), and other studies in Bangladesh (Ohno et al. 2007; Das et al. 2004). As concentration in fish in the present study was comparable to the previous studies conducted by Ciminelli et al. (2017) in Brazilian fish at 0.233 mg/kg dw, in China at 0.038 mg/kg dw) (Wu et al. 2014), and in Bangladesh at 2.18 mg/kg dw (Ali et al. 2022) (Table 1).

In general, the mean arsenic concentrations of the dietary items studied were in the following order: fish > milk > meat > cereal > egg > vegetable > fruit. Arsenic concentration varied among the analyzed foodstuffs. This might be owing to variances in arsenic absorption and accumulation capacities, and changes in the development periods and rates of the dietary items (Islam et al. 2014b), and climatic variations for the vast areas of food production in Bangladesh (Santos et al. 2004). All cereals, vegetables, fruits, fish, eggs, milk, and meat samples tested had mean arsenic amounts below the acceptable limit (0.5 mg/kg) (Codex 2001; Table 1). On a dry weight basis, previous investigations have revealed arsenic concentration in eggplant of 0.2 mg/kg and potato of 0.01 mg/kg (Alam et al. 2003). Another study in Bangladesh depicted the arsenic concentration as 0.0545 mg/kg in some vegetable species (Al Rmalli et al. 2005). In Bangladesh, two investigations found mean arsenic concentrations in vegetables of 0.2 (0.009–7.9 mg/kg dw) (Islam et al. 2015a) and 0.05 (0.01–0.2 mg/kg dw) (Rahman et al. 2013). In previous studies, arsenic concentrations were reported on as dry weight basis, which showed slightly higher than the present study. If those studies could convert the concentration of arsenic in foods, then it would be identical to the present study.

Human health implications

Estimated daily intake of arsenic

The nutritional occurrence approach for arsenic from popular meals is a trustworthy instrument for examining a public meal in terms of nutrients, bioactive chemicals, and pollutant ingestion, supplying vital information on potential nutritional shortages or sufficient (exposure) to dietary contaminants such as arsenic (WHO 1985). This study assesses dietary arsenic consumption through commonly consumed daily products in the Bangladeshi population's daily diet, including rural and urban residents.

Table 1 Arsenic concentrations (mg/kg fw) in the commonly consumed food items collected from 30 agro-ecological zones of Bangladesh and comparison with the food items in the world

Sample type	Country	Mean (mg/kg dw)	References
Rice (*Oryza sativa*)			
Rice (different varieties) (*n* = 30)	Bangladesh	0.0816 ± 0.0219 (fw)	This study
Rice (Kaligira)	Bangladesh	0.77 ± 0.30	Islam et al. (2022b)
Rice (Basmati)	Bangladesh	1.04 ± 0.50	Islam et al. (2022b)
Rice (different varieties)	Australia	0.270*	Rahman et al. (2014)
Chinigura (aromatic)	Bangladesh	0.073*, 0.068**	Rahman et al. (2014)
Rice (white, parboiled white)	Brazil	0.212*	Batista et al. (2011)
Grain, market samples	Brazil	0.212*, 0.102**	Ciminelli et al. (2017)
Wild rice	Canada	0.019**, 0.028*	Rahman et al. (2014)
Rice	China	0.128**	Chen et al. (2018)
Basmati rice	India	0.094**	Rahman et al. (2014)
Italian white rice	Italy	0.155*, 0.102**	Tenni et al. (2017)
White rice	Japan	0.141*, 0.131**	Naito et al. (2015)
Rinse-free white rice	Japan	0.125*, 0.119**	Naito et al. (2015)
White rice	Malaysia	0.103*	Nookabkaew et al. (2013)
Basmati	Pakistan	0.083**	Rahman et al. (2014)
Rice semolina	Spain	0.145	Matos-Reyes et al. (2010)
White sticky rice	Thailand	0.093*	Nookabkaew et al. (2013)
Rice	USA	0.13	Williams et al. (2007)
White rice	Vietnam	0.136*	Nookabkaew et al. (2013)
Wheat (*Triticum aestivum*)			
Wheat (*n* = 10)	Bangladesh	0.055 ± 0.0010 (fw)	This study
Wheat	Bangladesh	0.26 (fw)	Islam et al. (2017a, b)
Wheat grain	China, USA	0.050	Adomako et al. (2011)
Wheat grain	India	0.129	Bhattacharya et al. (2010)
Wheat	India	0.027	Kumar et al. (2016)
Durum wheat	Italy	0.009	Cubadda et al. (2016)
Wheat semolina	Spain	0.086	Matos-Reyes et al. (2010)
Wheat grain	Scotland, UK	0.030	Williams et al. (2007)
Wheat grain	Cornwall, UK	0.070	Williams et al. (2007)
Vegetables			
Lentil (*Lens esculenta*) (*n* = 10)	Bangladesh	0.0032 ± 0.0008 (fw)	This study
Lentil (*Lens esculenta*)	Bangladesh	0.040	Williams et al. (2006)
Lentil (*Lens esculenta*)	Bangladesh	0.29 fw	Islam et al. (2017a, b)
Lentil (*Lens esculenta*)	India	0.096	Bhattacharya et al. (2010)
Lentil (*Lens esculenta*)	India	0.029	Matos-Reyes et al. (2010)
Brinjal (*Solanum melongena*) (*n* = 30)	Bangladesh	0.006 ± 0.001 (fw)	This study
Brinjal (*Solanum melongena*)	Bangladesh	0.96 ± 0.42 (dw)	Islam et al. (2022b)
Brinjal (*Solanum melongena*)	Bangladesh	0.17 (fw)	Islam et al. (2017a, b)
Brinjal (*Solanum melongena*)	Cambodia	0.010 (fw)	Wang et al. (2013)
Brinjal (*Solanum melongena*)	India	0.492	Kumar et al. (2016)
Carrot (*Daucus carota*) (*n* = 20)	Bangladesh	0.0063 ± 0.0005 (fw)	This study
Carrot (*Daucus carota*)	Bangladesh	1.04 ± 0.55	Islam et al. (2022b)
Carrot (*Daucus carota*)	Bangladesh	0.25 (fw)	Islam et al. (2017a, b)
Carrot (*Daucus carota*)	Brazil	0.007 (fw)	Ciminelli et al. (2017)
Carrot (*Daucus carota*)	Cambodia	0.037 (fw)	Wang et al. (2013)
Carrot (*Daucus carota*)	Spain	0.241	Matos-Reyes et al. (2010)
Bean (*Phaseolus vulgaris*) (*n* = 20)	Bangladesh	0.0184 ± 0.0066 (fw)	This study
Bean (*Phaseolus vulgaris*)	Bangladesh	0.31 (fw)	Islam et al. (2017a, b)

Table 1 (continued)

Sample type	Country	Mean (mg/kg dw)	References
Bean (*Phaseolus vulgaris*)	Bangladesh	0.030	Williams et al. (2006)
Bean (*Phaseolus vulgaris*)	Brazil	0.050 (fw)	Ciminelli et al. (2017)
Bean (*Phaseolus vulgaris*)	India	0.044	Roychowdhury et al. (2003)
Potato (*Solanum tuberosum*) (*n* = 10)	Bangladesh	0.0063 ± 0.0006 (fw)	This study
Potato (*Solanum tuberosum*)	Bangladesh	0.79 ± 0.48	Islam et al. (2022b)
Potato (*Solanum tuberosum*)	Bangladesh	0.27 (fw)	Islam et al. (2017a, b)
Potato (*Solanum tuberosum*)	Brazil	0.009 (fw)	Ciminelli et al. (2017)
Potato (*Solanum tuberosum*)	India	0.654	Bhattacharya et. al. (2010)
Tomato (*Solanum lycopersicum*) (*n* = 10)	Bangladesh	0.0059 ± 0.0017 (fw)	This study
Tomato	Bangladesh	0.67 ± 0.34 (dw)	Islam et al. (2022b)
Tomato	Brazil	0.005 (fw)	Ciminelli et al. (2017)
Tomato	Bangladesh	0.25	Islam et al. (2017a, b)
Tomato	India	0.084	Bhattacharya et al. (2010)
Onion (*Allium cepa*) (*n* = 20)	Bangladesh	0.0077 ± 0.0016 (fw)	This study
Onion (*Allium cepa*)	Bangladesh	0.95 ± 0.37 (dw)	Islam et al. (2022b)
Onion (*Allium cepa*)	Bangladesh	0.29 (fw)	Islam et al. (2017a, b)
Onion (*Allium cepa*)	Spain	0.039	Matos-Reyes et al. (2010)
Onion (*Allium cepa*)	India	0.162	Bhattacharya et al. (2010)
Chili (*Capsicum annuum*) (*n* = 20)	Bangladesh	0.0038 ± 0.0015 (fw)	This study
Chili (*Capsicum annuum*)	Bangladesh	0.26 (fw)	Islam et al. (2017a, b)
Fruit			
Banana (*Musa acuminate*) (*n* = 30)	Bangladesh	0.0005 ± 0.0002 (fw)	This study
Banana (*Musa acuminate*)	Bangladesh	0.39 (fw)	Islam et al. (2017a, b)
Banana (*Musa acuminate*)	Cambodia	0.013 (fw)	Wang et al. (2013)
Banana (*Musa acuminate*)	India	0.027	Roychowdhury et al. (2003)
Mango (*Mangifera indica*) (*n* = 10)	Bangladesh	0.0129 ± 0.0003 (fw)	This study
Mango (*Mangifera indica*) (*n* = 10)	Bangladesh	0.17 (fw)	Islam et al. (2017a, b)
Jackfruit (*Artocarpus heterophyllus*) (*n* = 5)	Bangladesh	0.0069 ± 0.0008 (fw)	This study
Jackfruit	Bangladesh	0.16 (fw)	Islam et al. (2017a, b)
Fish			
Rui (*Labeo rohita*) (*n* = 10)	Bangladesh	0.082 ± 0.014 (fw)	This study
Pangas (*Pangasius pangasius*) (*n* = 10)	Bangladesh	0.077 ± 0.009 (fw)	This study
Tilapia (*Oreochromis mossambicus*) (*n* = 10)	Bangladesh	0.086 ± 0.004 (fw)	This study
Fish	Brazil	0.233	Ciminelli et al. (2017)
Fish (different species)	Bangladesh	2.18	Ali et al. (2022)
Fish	China	0.038	Wu et al. (2014)
Bivalves	China	3.47	Wu et al. (2014)
Prawn	Norway	54	Julshamn et al. (2004)
Egg			
Chicken (*Gallus bankiva murghi*) (*n* = 20)	Bangladesh	0.0120 ± 0.0067 (fw)	This study
Egg (chicken)	Bangladesh	0.11	Islam et al. (2017a, b)
Egg (duck)	Bangladesh	0.076	Islam et al. (2017a, b)
Egg	Brazil	0.013	Ciminelli et al. (2017)
Milk			
Cow (*Bos primigenius*) (*n* = 10)	Bangladesh	0.0489 ± 0.0038 (fw)	This study
Milk (cow)	Bangladesh	0.041	Islam et al. (2017a, b)
Meat			
Chicken leg (*Gallus bankiva murghi*) (*n* = 20)	Bangladesh	0.0426 ± 0.0013 (fw)	This study
Chicken breast (*Gallus bankiva murghi*) (*n* = 20)	Bangladesh	0.0415 ± 0.0010 (fw)	This study
Meat (chicken)	Bangladesh	0.033	Islam et al. (2017a, b)

Table 1 (continued)

Sample type	Country	Mean (mg/kg dw)	References
Meat (duck)	Bangladesh	0.038	Islam et al. (2017a, b)
Chicken	Brazil	0.021	Ciminelli et al. (2017)
Maximum allowable concentration		0.50 (fw)	FAO/WHO (2011)

As concentration in dry weight (dw) but some data is in fresh weight (fw)

*Total As (tAs). **Inorganic As (iAs)

Table 2 displays arsenic content, rates of food consumption, and anticipated arsenic intakes for the studied food items. The amount of arsenic consumed through food was 0.0352 mg/day in rural and 0.0427 mg/day in urban populations, respectively (Alam et al. 2003; Steinmaus et al. 2005). The total arsenic consumption estimates were based on the sum of arsenic absorbed from a range of meals and drinking water consumed by an adult resident (average body mass of 60 kg) during 24 h. Assuming a daily water consumption of 3 L and an arsenic concentration of 0.055 mg/L (DPHE 2001), the total daily consumption of arsenic would be 0.2002 and 0.2077 mg/day for the rural and urban residents, respectively (Table 2), by a factor of two over the FAO limit, suggesting a considerable risk. Our research found that urban residents' daily arsenic exposure to foods was substantially higher than that of rural residents. The EDI for urban residents at 0.2077 mg/day/ person was much greater than the WHO benchmark dose (BMDL0.5 = 0.118 mg/day/person), suggesting an interim tolerated intake value (JECFA 2011). According to this analysis, high daily arsenic consumption in urban dwellers was primarily attributable to the increased consumption of fish, meat, milk, and fruits, all of which contain significant levels of arsenic. The estimated daily intake of arsenic from foods of the current study is compared with some other studies in Bangladesh and other countries in the world as presented in Table 3. The results showed that EDI of arsenic of the present study was slightly higher than the studies in Bangladesh (Islam et al. 2017a), Mexico (Del Razo et al. 2002), Japan (Tsuji et al. 2007), and Ghana (Adomako et al. 2011), whereas slightly higher than other studies in the world, i.e., Bangladesh (Rahmana et al. 2008), India (Samal et al. 2011, 2021), Iraq (Mustafa 2023), China (Fu et al. 2007), and Spain (Martí-Cid et al. 2008) (Table 3).

Table 2 The concentrations of food consumption rate and estimated daily intake of arsenic in different food groups commonly consumed by the rural and urban people of Bangladesh

Food group	Concentration of As (mg/kg)	Consumption rates (g/day)**		Estimated daily intake (EDI) (mg/day)	
		Rural	Urban	Rural	Urban
Cereal	0.0683	464.99	377.89	0.0318	0.0258
Vegetable	0.0072	170.04	154.95	0.0012	0.0011
Fruit	0.0068	42.73	50.59	0.0003	0.0004
Fish	0.082	45.67	59.91	0.0037	0.0049
Egg	0.0120	5.80	11.32	0.0001	0.0002
Milk	0.0489	31.78	39.16	0.0016	0.0019
Meat	0.0421	9.01	17.42	0.0004	0.0007
Drinking water*	0.055 mg/L	3 L		0.165	0.165
Daily intake of arsenic via food consumption				0.0391	0.035
Daily intake of arsenic via food and drinking water				**0.2041**	**0.200**
Maximum tolerable daily intake (MTDI)				0.126 mg/day (FAO, 2006)	

*Ahmed et al. 2015; **HIES 2017

Note: Bold indicate that daily intake of arsenic from foods and water was higher than the maximum tolerable daily intake (MTDI)

Table 3 Comparison of daily intake of arsenic from foods for adult inhabitants of the current study and other studies in the world

Countries	EDI (mg/day)		References
	Rural	Urban	
Bangladesh	0.0391	0.035	This study
Bangladesh	0.032	0.0281	Islam et al. 2017a
Mexico		0.0156	Del Razo et al. 2002
India	0.018	0.050	Mondal et al. 2010
India		0.04 (mg/kg-day)	Samal et al. 2021
Bangladesh	0.20–0.35		Rahman et al. 2008
Southeast, China	0.222		Fu et al. 2008
Ghana	0.0015		Adomako et al. 2011
Japan	0.0037		Tsuji et al., 2007
Iraq		0.220	Mustafa et al. 2022
West Bengal, India	0.560		Santra et al. 2013a, b
India	0.126		Samal et al. 2011
Spain		0.261	Martí-Cid et al. 2008

Table 4 Target hazard quotient (THQ) and target carcinogenic risk factor (TR) of arsenic for both rural and urban residents of Bangladesh

Food groups	Target hazard quotient (THQ)		Target carcinogenic risk (TR)	
	Rural	Urban	Rural	Urban
Cereals	**1.76**	**1.43**	**2.4E-02**	**1.9E-02**
Vegetables	0.07	0.06	3.1E-05	2.8E-05
Fruits	0.02	0.02	7.3E-06	8.6E-06
Fish	0.208	0.273	**2.8E-03**	**3.7E-03**
Egg	0.001	0.01	1.7E-06	3.4E-06
Milk	0.09	0.11	3.9E-05	4.8E-05
Meat	0.02	0.04	9.5E-06	1.8E-05
Total	**2.169**	**1.943**	**2.7E-02**	**2.3E-02**

Bold indicates THQ > 1 and TR > 10^{-4}

Non-carcinogenic and carcinogenic risks

Table 4 displays the non-carcinogenic risk (THQ) and carcinogenic risk (TR) of arsenic in the examined food items in Bangladesh. Based on comprehensive data on dietary arsenic in the daily diet, the predicted THQ and TR standards effectively indicate the health hazard below actual sites. The result showed that the maximum THQ of As in fish samples for both rural and urban residents was above the safe level (> 1) by a factor of two (2), indicating that fish is the principal dietary item causal to the possible health risk. Considering all examined food items, THQ standards of arsenic for rural and urban inhabitants were 1.95 and 2.37 (> 1.0), showing a possible non-carcinogenic danger to individuals in Bangladesh. As a result, the health concerns posed by inorganic arsenic exposure in everyday consumable foods are a source of anxiety in Bangladesh.

The target carcinogenic risk factors (TR) ranged from 8.3 per 10,000 to 9.5 per one million people (Table 4). The highest safe criterion for cancer risk is one per 10,000, while the lowest is one per one million. All of the expected target cancer hazards from eating arsenic have been confirmed exposure exceeded 10^{-6}, and urban persons had a greater risk than rural residents. According to Table 4, inhabitants of metropolitan areas may be exposed to high levels of dietary arsenic through fish eating, resulting in lifetime risk of cancer. Human consumption of arsenic-contaminated farmed fish poses health hazards, according to Kar et al. (2011). Li et al. (2011a, b) stated the lowermost cancer risk of 123 per 100,000 persons and the uppermost cancer risk of 201 per 100,000 persons due to arsenic exposure from low land and upland rice.

The toxic properties of arsenic depend on the species and chemical form. Chronic arsenic poisoning indications appear gradually and rely on the dose quantity and the exposure length (Banerjee et al. 2011; Sarkar 2009). Numerous studies have indicated clinical signs such as nausea, diarrhea, anorexia, and abdominal pain (Smith et al. 2000). Cumulative arsenic poisoning has been related to several pathways that induce DNA damage. According to a study conducted in West Bengal, India, defects in DNA repair ability, alteration of methylation of the promoter regions of the p53 and p16 genes, and genomic methylation change may all play a role in arsenic-induced disease manifestation in humans. Arsenic-induced keratosis has been linked to an increased prevalence of arsenic-induced keratosis. Among the numerous genes involved in the control of arsenic metabolism, purine nucleoside phosphorylase single-nucleotide polymorphisms were associated with an increased frequency of arsenicosis (Mazumder and Dasgupta 2011). Arsenic acts as a cancer promoter rather than a starter, causing cancer, and cancer risk in the human body is dose-dependent. Bowen's disease, basal cell carcinoma, and squamous cell carcinoma are all arsenical skin cancers induced by arsenic exposure (Santra et al. 2013a, b). The great bulk of Bangladeshi individuals continues to use water with high arsenic content for household activities, putting them at risk of developing arsenic skin lesions and cancer due to their overall dietary consumption of arsenic through food.

Fig. 2 Share of different food groups in the daily dietary intake of arsenic by the people of Bangladesh
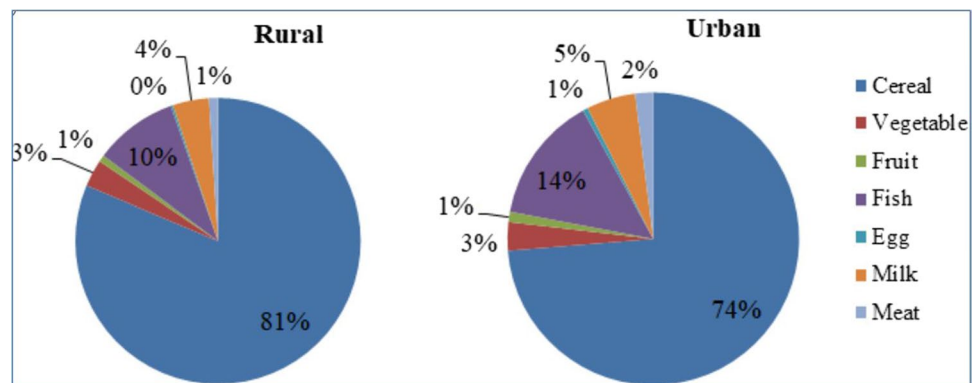
Contribution of arsenic exposure from food items.

Figure 2 highlights the dietary contributions of arsenic from various food sources consumed. In both rural (72%) and urban (78%) areas, fish consumption accounted for the highest share of total arsenic ingestion. This may be because fish contain substantially higher levels of arsenic than other foods (Tables 1 and 2). Our findings were consistent with prior research, which found that fish contributed 75–90% of cumulative arsenic consumption from dietary sources (Das et al. 2004; Hughes 2006; Borak and Hosgood 2007). Cereals accounted for the second greatest amount of complete arsenic consumption in both rural (18%) and urban (12%) areas (Fig. 2). A previous study has reported that higher arsenic levels in rice (Ma et al. 2008; Xu et al. 2008) may be linked to high arsenic levels in agricultural field soil and substantial use of arsenic-contaminated irrigation water for rice agriculture.

Das et al. (2004) found 16.676.61 mg/kg of arsenic in Bangladesh soil, which was greater than the global average of 10 mg/kg. They also discovered a good association between arsenic in polluted water and arsenic on soils ($r = 0.74$, $p = 0.01$). In the current study, the proportion of arsenic food consumption across several food groupings was equivalent to that of Cambodia, where the significant amount originated in fish, trailed in cereal (Wang et al. 2013). In the current study, vegetables, fruits, meat, milk, and eggs supplied a minor amount of arsenic during food ingestion, consistent with previous investigations by Wang et al. (2013) in Cambodia and Munoz et al. (2005) in Chile.

According to the ecosystem approach, the Bangladeshi population lives in complicated food chain pathways that are, of course, interconnected. Figure 3 displays the many food chain channels that expose Bangladeshis to arsenic poisoning, from source to food. Humans are one of the principal consumers of arsenic from rice, vegetables, fish, milk, and meat, and arsenic buildup in humans may occur via other sources of the environment such as soil–plant-human's and/or plant-animal-human's and/or soil–water-animal's food chain pathways (Fig. 3).
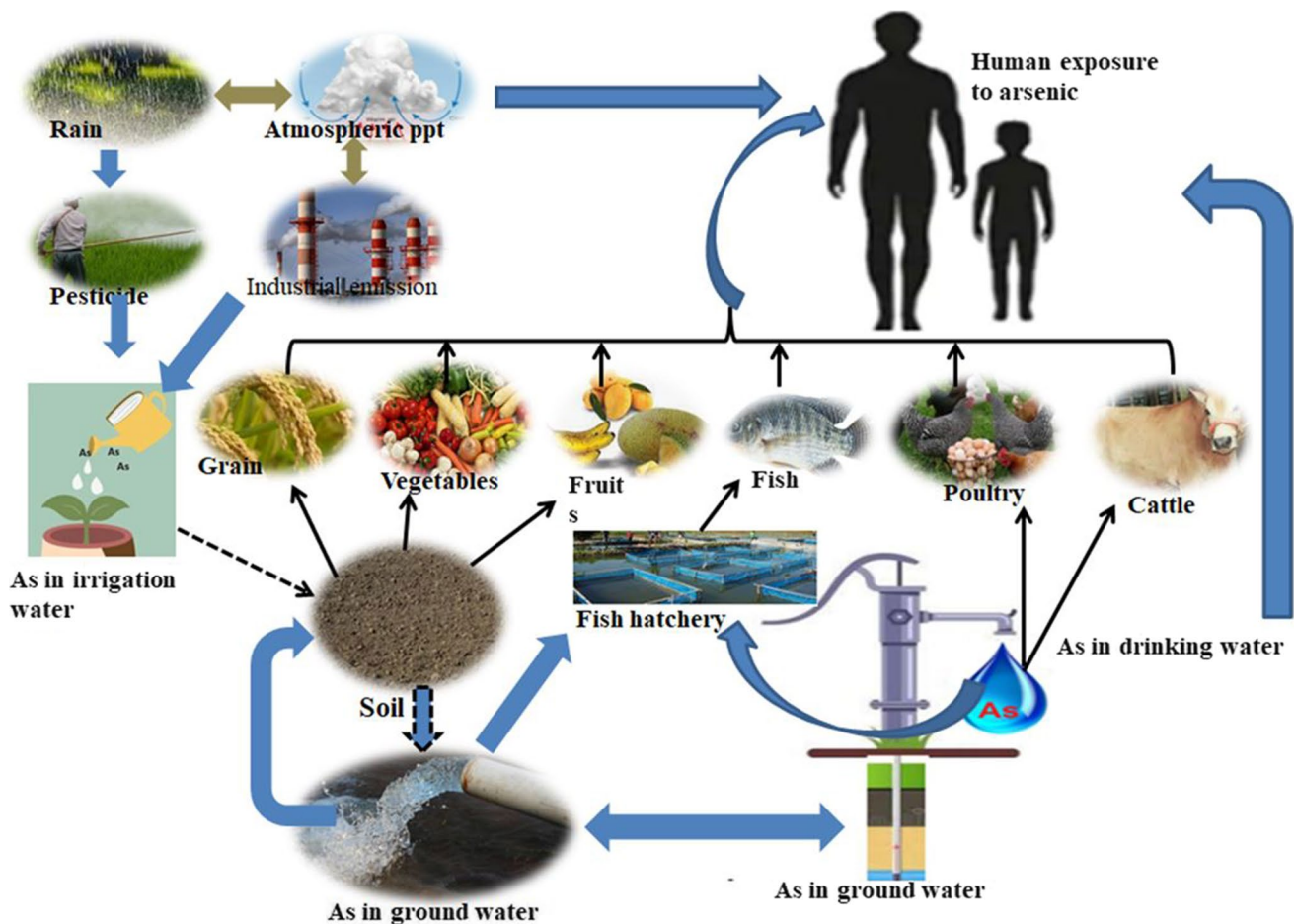
Fig. 3 Putative food chain pathways of arsenic exposure to humans. This illustration shows the possible food chain pathways of arsenic exposure to the people of Bangladesh

Limitations and environmental implication

The authors of this study believe that there are several limitations associated with arsenic exposure through food, which may add to the risk assessment ambiguity. We could not distinguish between different types of arsenic in the foods included in our investigation. Apart from seafood (essentially non-toxic organic arsenic forms readily removed by urine) (Fattorini et al. 2004), inorganic arsenic may be the principal source of arsenic exposure from various foods. Furthermore, the current study only looked at a few of the most widely eaten foods and beverages and drinking water. Foods were usually boiled before being consumed in Bangladeshi families. Cooking and drinking water are generally done with the same water. As a result, more dietary arsenic would be present in their final diet, which we did not account for in our study. Despite certain limitations, we believe the findings of this study will be significant in conducting future in-depth epidemiological research that will cover population contact with numerous arsenic species and organic and other inorganic contaminants.

Conclusions

This study determined the concentrations of As in the commonly used foodstuffs covering 30 AEZ in Bangladesh. It estimated the highest (THQ) and target cancer risks (TR) from ingesting dietary arsenic. Our work showed that an elevated concentration of arsenic in the fish meal exceeded the maximum permitted limit in food. The mean arsenic concentrations of the dietary items studied were in the following order: fish > milk > meat > cereal > egg > vegetable > fruit. The total daily intake of arsenic from some of the studied food items was more than the (MTDI), indicating a significant risk to human health. The total THQ and TR values for arsenic from all food items surpassed the threshold values (THQs > 1, TR > 10^{-4}), suggesting that people in Bangladesh have both non-carcinogenic and carcinogenic health hazards due to dietary arsenic exposure. A comprehensive management strategy for the entire arsenic contamination scenario is required, which includes surface water conservation and custom, rainfall collection, and the prudent use of pure groundwater for farming, aquaculture, and home needs. Because of the prolonged use of arsenic-contaminated groundwater for crop production, the soil is expected to increase the quantity of arsenic in foods through bioconcentration. To fix the unexpected problem of arsenic contamination in Bangladesh, there needs to be a regular monitoring system for the whole food chain.

Author contribution Md. Saiful Islam, Ramal Ahmed Mustafa, and Abu Reza Md Towfiqul Islam collected the water samples from the study area. Khamphe Phoungthong, Abu Reza Md Towfiqul Islam, Md. Saiful Islam, and Tofazzal Islam designed the total experiment. Tasrina Rabia Choudhury, Md. Saiful Islam, Md. Humayun Kabir, Mir M. Ali, and Abubakr M. Idris analyzed the data and wrote, revised, and improved the manuscript. All authors reviewed and approved this manuscript.

Data availability Not applicable.

Declarations

Ethical approval Not applicable.

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Consent to publish Not applicable.

Conflict of interest The authors declare no competing interests.

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