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Assessment of Arsenic in Rice and Cooked Rice in Meherpur, Bangladesh: Associated Health Risks Implications

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Abstract

Arsenic is a toxic element. Chronic exposure to arsenic can pose a variety of health problems including cancers, lung disease, skin lesions, diabetes, gangrene, reproductive disorders, hypertension, and heart disease. Globally the concern of arsenic is growing day by day. Addressing this concern, the study aimed to assess the arsenic level in raw rice grain and rice cooked with tubewell water and rainwater. The study was conducted at the Sholotaka Union of Gangni Upazila in Meherpur District of Khulna Division, Bangladesh in 2023. For this purpose, seven raw samples including rice grain, rainwater and tubewell water samples and six cooked rice samples were analyzed. Rice and water samples were digested using the USEPA method-3050B in Arsenic Center Jashore, under Asia Arsenic Network, Japan. The arsenic level in the samples was tested using the HG-AAS method using a Shimadzu model AA7000 (Japan) Atomic Absorption Spectrophotometer. The study's findings revealed that arsenic concentration in rainwater samples consistently displays 0 mg/l indicating the absence of arsenic in this sample. Three (03) tube well water samples and three (03) raw rice grain samples showed a significant variation in arsenic concentration. The mean value of tubewell water samples T1, T2, and T3 was found 0.53 ± 0.003 mg/l, 0.31 ± 0.003 mg/l, and 0.65 ± 0.002 mg/l, respectively. Whereas raw rice grain samples RG1 showed a mean of 0.607 ± 0.007 mg/kg, RG2 at 0.458 ± 0.008 mg/kg, and RG3 at 0.7145 ± 0.001 mg/kg. The study found that rice cooked with tubewell water contained a higher arsenic concentration than rice cooked with rainwater. The most prominent finding of this study was that cooked rice using rainwater had a lower amount of arsenic than the raw rice grain. So, it is clearly said that using rainwater can minimize the amount of arsenic. Furthermore, the study indicates that the health risks associated with arsenic exposure have increased. Estimated daily intake (EDI) values for cooked rice samples ranged from 3.07 to 5.47 μg/kg body weight/day, exceeding safe limits. Target Hazard Quotient (THQ) values varied from 10.2 to 18.2, indicating significant potential for non-carcinogenic health effects. Lifetime Cancer Risk (LCR) values ranged from 0.461% to 0.821% exceeding the U.S. Environmental Protection Agency's acceptable risk threshold of 0.01%, which reflects a heightened cancer risk. The study suggests that people in the study area should use rainwater instead of tubewell water for their cooking purposes. Furthermore, rainwater harvesting should be prioritized in this area to address arsenic issues.

Keywords

Arsenic, Rice grain, Atomic Absorption Spectrophotometer, Cooked Rice, Health Risks

1. Introduction

Arsenic is the 20th utmost predominant element in the Earth's crust and exists in two forms such as inorganic and organic. It poses significant health risks due to its extreme toxicity and persistence in the environment (Sharma et al., 2014). It is a strong endocrine disruptor that alters hormone-mediated cell signaling even at low concentrations (Bhattacharya et al., 2012). Chronic exposure to toxic inorganic arsenic can lead to arsenicosis and has been accompanied by a lot of health issues, including various cancers, gangrene, lung disease, skin lesions, reproductive disorders, hypertension, diabetes, and heart disease (Sharma et al., 2014; Chen et al., 2009; Das et al., 2004; Shankar et al., 2014; Shazzadur Rahman et al., 2022; Vahter, 2009).

In Bangladesh, rice serves as the primary staple food making it the main component of the people's diet and provides a modest amount of protein. During dry season, irrigation is necessary for the cultivation of rice and ground water is used for this purpose (Rahman & Hasegawa, 2011; Williams et al., 2006). If the groundwater is arsenic contaminated, then there is a chance of accumulation of arsenic in rice grain. Rice grains from arsenic-endemic regions contain around ninety percent of inorganic arsenic, with only a small percentage of less toxic organic arsenic. This suggests that rice is an essential dietary source of arsenic (Kumarathilaka et al., 2019; Bae et al., 2002; Rahman et al., 2006). Rice produced on arsenic-contaminated soils can also absorb it. Over 150 million people worldwide are threatened by arsenic-contaminated groundwater, especially in Bangladesh and India (Rahman et al., 2023; Mondal et al., 2010; Shankar et al., 2014). Bangladesh has been concerned about arsenic since 1992. Over 27.2% of tube wells had arsenic levels greater than 50 mg/L in 1996, and 42.1% surpassed 10 mg/L, indicating widespread contamination (Chakraborti et al., 2010; Mukherjee et al., 2006; Rahman et al., 2009; Rahman et al., 2011). Human exposure to arsenic (As) primarily occurs through two main routes. Firstly, by consuming arsenic-contaminated groundwater and food crops grown in soils polluted with arsenic and secondly, through the use of contaminated irrigation water for farming (Islam et al., 2017b).

Arsenic exposure from rice can be significant, with the intake of inorganic arsenic posing a major health risk, particularly for populations that rely heavily on rice as a dietary staple. Elevated arsenic levels have been found in rice across several Southeast Asian countries, further increasing the risk to consumers (Islam et al., 2017b). To evaluate associated health risks, Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Lifetime Cancer Risk (LCR) are employed that offer insights into the non-carcinogenic and carcinogenic effects of arsenic exposure through dietary intake. Studies demonstrate that the EDI of arsenic from rice often exceeds safe thresholds, particularly in regions with high rice consumption. For instance, research in Kunming, China, revealed an EDI of 3.52×10^{-4} mg/kg body weight/day, underscoring significant exposure among adolescents (Liao et al., 2018). Similarly, a study in Bangladesh indicated elevated arsenic levels in rice, correlating with high EDI values and emphasizing a public health risk (Shawon et al., 2021). Research from Chinese urban populations highlighted THQ values exceeding the safety threshold for many consumers due to high arsenic exposure from rice (Zhou et al., 2020). Likewise, a study on local rice in Nigeria demonstrated THQ values above 1 for certain demographics, indicating a considerable non-carcinogenic risk from prolonged rice consumption (Olaleye et al., 2022). An LCR exceeding 1×10^{-4} is considered unacceptable by regulatory standards. For instance, research in Pakistan found that despite most rice samples being below arsenic limits, the LCR values were high enough to warrant concern, particularly for vulnerable populations (Sarwar et al., 2020). Similarly, a study in the Bahamas found that 79% of tested rice samples had LCR values indicative of carcinogenic risks (Watson & Gustave, 2022).

The quantity of arsenic in cooked rice is proportionate to the quantity of arsenic in raw rice grains which may differ depending on the cooking procedure and cooking water. Consuming rice cooked in arsenic-contaminated water will greatly raise the inorganic arsenic concentration, and doing so may put human health at risk if the raw rice has more arsenic than is safe (Jansen et al., 2018; Pal et al., 2009; Signes-Pastor et al., 2012; Kumarathilaka et al., 2019; Smith et al., 2006; Mondal et al., 2010; Rahman et al., 2006). Cooked rice has 10% - 35% more arsenic compared to raw rice, due to processes like chelation or evaporation. Traditional cooking methods using low arsenic water resulted in a 57% reduction in arsenic levels in cooked rice (Rahman & Hasegawa, 2011). Over the past decade, Physico-chemical and biological techniques have been researched to reduce rice grain arsenic. Harvesting rainwater for cooking is the most effective way to lower the potential risk of arsenic-contaminated rice consumption (O'Neill et al., 2013). Rainwater can be used for rainfed agriculture in arsenic-contaminated areas or for home water in water-scarce areas (Helmreich & Horn, 2009; Islam et al., 2010; Naddeo et al., 2013). Hygienically preserved rainwater is safe for arsenic mitigation in places with an average precipitation of 1600 mm/year or more in Bangladesh, making it a preferable option (Sharma et al., 2014).

In the study area, most of the populaces rely on rice for their regular caloric intake and they use arsenic-contaminated tubewell water for their cooking purpose. As a result, cooked food including rice may have a great chance of being contaminated by arsenic from the water source. Thus, preparing rice with arsenic-contaminated water may be a significant source of arsenic, and the cooking procedure may further affect the concentration of arsenic in cooked rice. Various studies have measured arsenic in tubewell water and food (Ahmad et al., 2018; Adomako et al., 2009; Bhattacharya et al., 2009; Laparra et al., 2005; Rasheed et al., 2018). However, there has been little research on the estimation of arsenic concentration in rice grain and cooked rice. This study intends to assess arsenic levels in rice grains and cooked rice. In addition, the study had been undertaken to make a comparison between cooked rice prepared with tubewell water and rainwater in the study area. This research works to raise awareness among the local population and highlight the importance of harvesting rainwater for cooking.

2. Materials and Methods

2.1. Delineation of Study Area

The study took place in a village named Bholadanga under the Sholotaka Union of Gangni Upazila, located in the Meherpur District of the Khulna Division in Bangladesh. Bholadanga has an area of 0.17016118 square kilometers. The coordinates of Bholadanga village are 23.85˚N latitude and 88.86˚E longitude. About 489 households are present in the village with a total population of 2358, among them 1156 are male and 1202 are female (BBS, 2022). The study area map is presented in **Figure 1**.

2.2. Sample Collection and Preparation

To conduct this study, a total of seven raw samples were collected from the study area during the year 2023. The raw samples included three Boro rice grain samples, three tube well water samples, and one rainwater sample. After the raw samples were collected, six cooked rice samples were prepared using a traditional rice cooking method. The proper labeling of the different samples collected from the study area and the prepared samples is represented in **Table 1**.

About 2 L of rainwater was collected in a plastic bottle prewashed with concentrated nitric acid (1:1) from a particular collection point in the study area. 1.5 L of rainwater was used for cooking purposes and the rest of it was sent to the laboratory for further analysis. Three water samples were collected from three different households and about 1 L of tube well water from each household was collected without filtering (Rahman et al., 2011). To ensure consistent water discharge, all tube wells were pumped for 5 - 10 minutes before sampling. Water samples were stored in polypropylene bottles pre-washed with 1:1 concentrated nitric acid. Post-collection preservation included 0.1% v/v nitric acid (Rahman et al., 2009). Three samples of Boro rice, weighing approximately 750 grams in total, were collected from the study area.

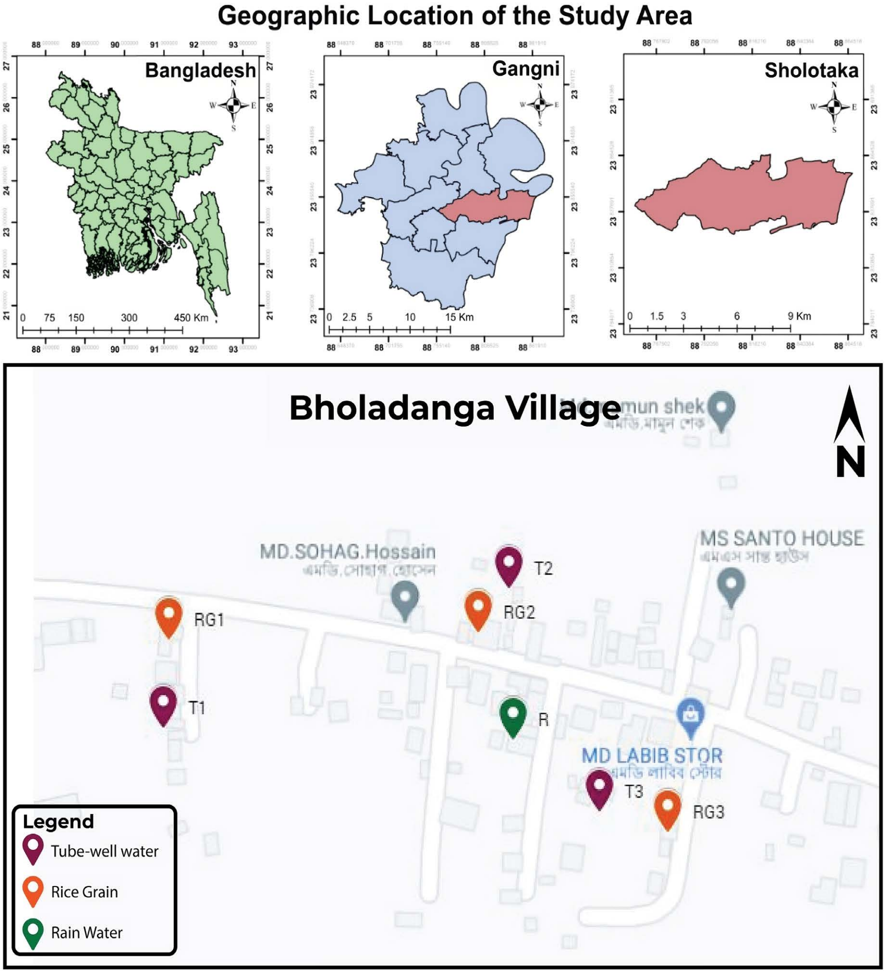

Figure 1. Location map of the study area.

Table 1. Status and identification coding of collected samples.

Samples Name	Sample size	Sample ID	Status
Rice Grain	03	RG1 RG2 RG3	Raw rice grain collected from three different fields
Tubewell water	03	T1 T2 T3	Water collected from three household tube wells
Rainwater	01	R	Collected from a common point among the household
Cooked rice with tube well water	03	CRT1	Prepared sample using RG1 and T1
		CRT2	Prepared sample using RG2 and T2
		CRT3	Prepared sample using RG3 and T3

Continued

Cooked rice with rainwater	03	CRR1	Prepared sample using RG1 and R
		CRR2	Prepared sample using RG2 and R
		CRR3	Prepared sample using RG3 and R

Airborne contamination was averted by wrapping samples in plastic bags. Deionized water was utilized to wash the rice grain samples. Samples that had been dewatered were oven-dried at 65˚C (Rahman et al., 2011). The samples were homogenized by grinding and appropriately labelled before being sealed in sealed polyethylene bags and stored at room temperature for arsenic testing. Six later-prepared cooked rice samples were studied. Each sample had a 1:2 cooking water-to-rice grain ratio, prepared by cooking 250 grams of rice grain in 500 mL of tube well water and harvesting rainwater separately. Rice was traditionally cooked to remove gruel (O'Neill et al., 2013). The traditionally cooked rice samples were then dried in an oven at 65˚C for 48 hours without washing (Rahman et al., 2011). The samples were homogenized through grinding, tagged, and packed in airtight polyethylene bags after being dried and cooled in a desiccator. They were then stored at room temperature for additional arsenic analysis. To complete the sample collection, preparation, and preservation for further arsenic analysis, the necessary apparatus and reagents are listed in **Table 2**.

Table 2. Apparatus and reagents for arsenic analysis.

Apparatus	Reagents	Reference
Plastic bottles, Polyethene bags, Hotplate, Glass beaker, Measuring Cylinder (20 mL), Test tube, HG-AAS instrument, Volumetric flask, Funnel, Whatman-41, and 42 filter paper	Conc. Nitric acid, Sulfuric acid, Perchloric acid, Sodium borohydride, Sodium Hydroxide and Hydrochloric acid	(Baird et al., 2017)

2.3. Sample Digestion

Water and rice samples were digested by using the USEPA method-3050B (Environmental Protection Agency, 1996; Kimbrough & Wakakuwa, 1989). Sample digestion and arsenic analysis were conducted in the Arsenic Center (Jashore), under the Asia Arsenic Network, Japan.

2.4. Arsenic Analysis

The arsenic level in the samples was tested by the HG-AAS method using a Shimadzu model AA7000 (Japan) Atomic Absorption Spectrophotometer. The hydride generation technique (HG-AAS) is commonly used within special analysis. This method is based on the development of hydride generation from analyte which is first reduced to hydride in the liquid state and consequently converted into the vapor state which is further atomized in an atomic absorption spectrometer. During analysis, the instruments were calibrated using a reference standard solution for arsenic concentration analysis.

2.5. Estimated Daily Intake (EDI)

Estimated Daily Intake (EDI) quantifies the daily intake of a contaminant (like arsenic) per unit of body weight through food or water consumption. The formula for EDI calculation is

$$\text{EDI} = \frac{\text{C} \times \text{IR}}{\text{BW}};$$

Where C represents the Concentration of arsenic in cooked rice (μg/kg), IR denotes the Ingestion rate of the food (kg/day) and BW stands for body weight of the individual (kg) (Liao et al., 2018).

Pierce et al. (2010) reported average BMI trends in rural Bangladesh using data from the Health Effects of Arsenic Longitudinal Study. The findings highlight low BMI values for a large portion of the population, corresponding to body weights close to 60 kg. A study by (Islam et al., 2017a) noted that rice consumption rates ranged significantly by age and region, with average daily intake values aligning with approximately 420 g/day for adults.

2.6. Target Hazard Quotient (THQ)

THQ is used to assess the non-carcinogenic health risk from a contaminant based on the ratio of the estimated intake to the reference dose. The THQ can be measured by following formulae, $THQ = \frac{EDI}{RfD}$; Where EDI represents estimated daily intake and RfD is the reference dose. According to the U.S. Environmental Protection Agency (EPA), The RfD for inorganic arsenic is 0.3 μg/kg/day. This value is based on non-cancer health effects, particularly skin lesions (Dong et al., 2016).

2.7. Lifetime Cancer Risk (LCR)

LCR estimates the probability of developing cancer over a lifetime due to contaminant exposure. To measure LCR, the following formulae is used.

$\text{LCR} = \text{EDI} \times \text{SF}$; where SF is the slope factor of As (μg/kg/d), used to assess carcinogenic risks, is 1.5 per mg/kg/day or 0.0015 per μg/kg/day, obtained from the USEPA which is commonly applied in risk assessment scenarios (Brown & Fan, 1994).

2.8. Statistical Analysis

Data obtained from the laboratory were organized in an Excel sheet, and analysis was done using Microsoft Excel 2013. The results were presented as descriptive statistics in the form of tables and graphs. A Study area map was drawn using R GIS-10.0. The experimental data obtained was compared with the Standard guidelines. The flow chart for the methodology adopted is given in **Figure 2**.

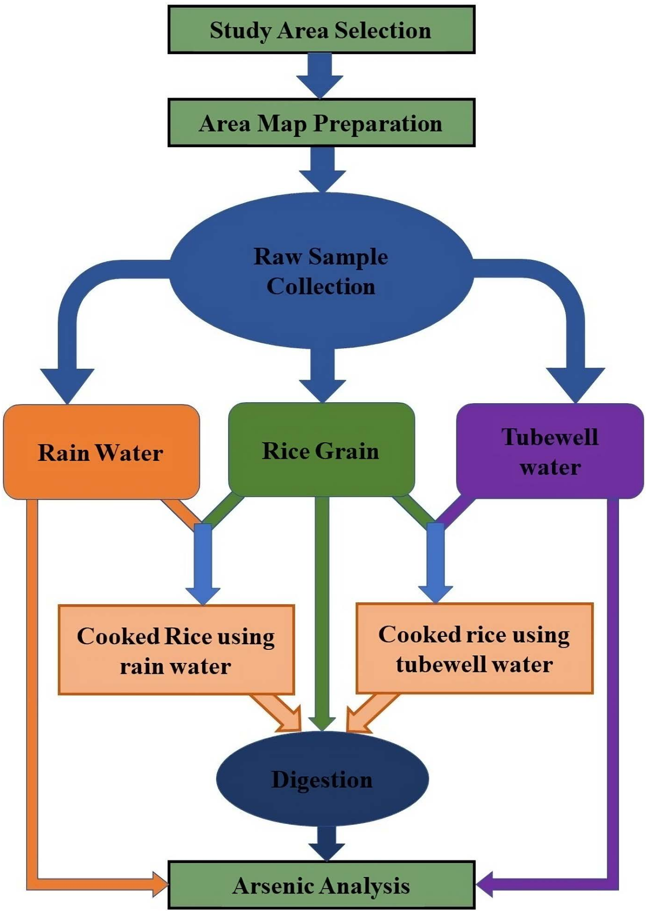

Figure 2. Flowchart of the methodology.

3. Results and Discussion

3.1. Arsenic Concentration in Tubewell Water and Rainwater

Arsenic concentration in tubewell water and rainwater is represented in Table 3. From the table, it is observed that Arsenic concentration in the rainwater sample consistently displays 0 mg/l indicating the absence of detectable arsenic in this sample. In the case of 3 tube well water samples, T1, T2, and T3 exhibit varying arsenic concentrations, with mean values of 0.53 ± 0.003 mg/l, 0.31 ± 0.003 mg/l, and 0.65 ± 0.002 mg/l, respectively. Among the three tubewell samples, T3 samples have the highest level of arsenic (As) compared to others. (T3 > T1 > T2).

Table 3. Arsenic concentration in rainwater and tubewell water samples.

Rainwater (R)	Tubewell water				WHO Standard	BD Standard
		T1	T2	T3		
0	Mean ± SD	0.53 ± 0.003	0.31 ± 0.003	0.65 ± 0.002	0.01	0.05
	Range	0.527 - 0.532	0.307 - 0.312	0.648 - 0.652		

Note: Data is the means of three replications and units are in mg/l.

Arsenic contents in tubewell water samples differ significantly from drinking water standards. All three tubewell water samples have arsenic levels surpassing the WHO guideline of 0.01 mg/l and Bangladesh threshold of 0.05 mg/l, suggesting substantial contamination (Chakraborti et al., 2010). The difference between measured arsenic levels and drinking water standards shows a major water safety threat. Enduring exposure to high arsenic concentrations increases the risk of different health issues (**Table 3**).

3.2. Arsenic Concentration in Rice grain and Cooked Rice

Arsenic concentrations in rice grain and cooked rice samples are presented in **Table 4**, which illustrates the impact of cooking water sources on arsenic accumulation in cooked rice. The table highlights significant differences in arsenic levels between raw rice grains and cooked rice samples. The raw rice grain samples exhibited varying arsenic concentrations, with RG1 showing a mean of 0.607 ± 0.007 mg/kg, RG2 at 0.458 ± 0.008 mg/kg, and RG3 at 0.7145 ± 0.001 mg/kg. Among the three rice grain samples, RG3 demonstrated the highest arsenic level, followed by RG1 and RG2, indicating the order of accumulation as RG3 > RG1 > RG2 (**Table 4**).

Table 4. Arsenic concentration (mg/kg) in rice grain and cooked rice samples.

Samples	Sample ID	Mean± SD	Range
Rice Grain (03)	RG1	0.607 ± 0.007	0.599 - 0.612
	RG2	0.458 ± 0.008	0.449 - 0.465
	RG3	0.715 ± 0.001	0.714 - 0.716
Cooked rice with tube well water (03)	CRT1	0.651 ± 0.007	0.643 - 0.657
	CRT2	0.484 ± 0.004	0.475 - 0.489
	CRT3	0.781 ± 0.001	0.780 - 0.781
Cooked rice with rain water (03)	CRR1	0.602 ± 0.007	0.594 - 0.608
	CRR2	0.439 ± 0.007	0.432 - 0.446
	CRR3	0.705 ± 0.001	0.704 - 0.706

Note: Data is the average of three replications.

The concentration of arsenic in cooked rice sample CRT1 prepared using RG1 and T1, was found to be 0.651 ± 0.007 mg/kg. Similarly, the arsenic level in cooked rice sample CRT2, made from RG2 and T2, was 0.484 ± 0.004 mg/kg. In the case of cooked rice sample CRT3, which was prepared using RG3 and T3, the arsenic concentration measured 0.781 ± 0.001 mg/kg. Among the three cooked rice samples prepared with tubewell water, CRT3 exhibited the highest arsenic concentration, followed by CRT1 and CRT2, in the order CRT3 > CRT1 > CRT2. These findings demonstrate that the level of arsenic in cooked rice varies by water source. In contrast, cooked rice samples prepared with rainwater CRR1, CRR2, and CRR3 had mean arsenic concentrations of 0.602 ± 0.007 mg/kg, 0.439 ± 0.007 mg/kg, and 0.705 ± 0.001 mg/kg, respectively (**Table**

4). CRR3 > CRR1 > CRR2 were the arsenic levels in these samples. These results suggest that the type of cooking water used significantly influences the arsenic concentration of rice.

3.3. Arsenic Concentrations in Rice Samples and Food Safety Standards

Arsenic concentrations must be compared to food safety standards set by the Codex Alimentarius Commission, Bangladeshi regulations, and the FDA when determining the safety of rice. **Figure 3** shows this comparison. Arsenic level for food, many organizations have guidelines. Bangladesh, the Codex Alimentarius Commission, and the FDA set limits of 0.2, 0.3, and 0.01 mg/kg. All samples have arsenic levels above FDA (0.01 mg/kg), Bangladesh (0.3 mg/kg), and Codex Alimentarius Commission thresholds (Singh, 2018).

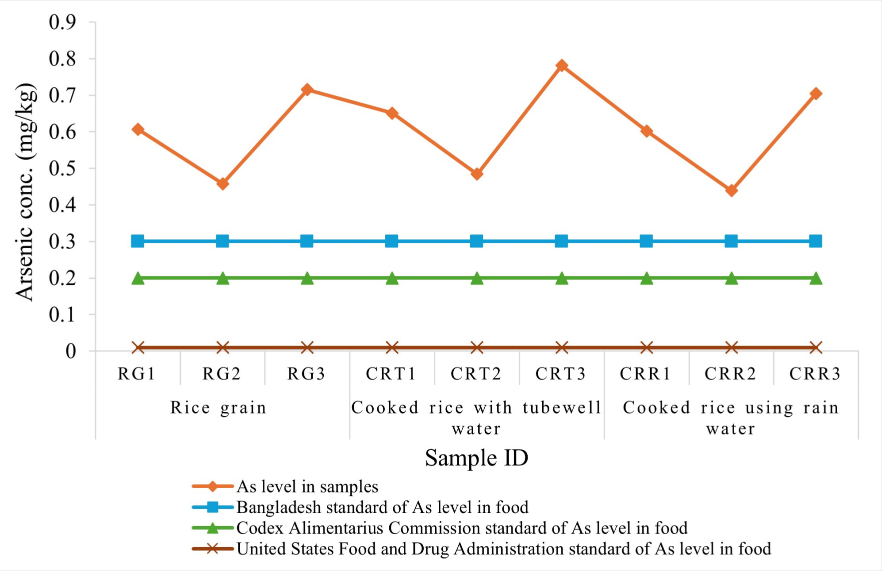

Figure 3. Arsenic level comparison in rice grain and cooked rice samples with food safety standards.

Rainwater for cooking has the potential to minimize arsenic levels compared to tubewell water for both raw and cooked rice. However, the concentration of arsenic in cooked rice prepared with rainwater still fails to meet the acceptable limits established by the Codex Alimentarius Commission, Bangladesh, and the FDA for maximum allowable arsenic levels in food. This is largely owing to the higher arsenic levels present in the rice grains, which result from irrigation with arsenic-contaminated water. When cooked, rice grains absorb various elements from the cooking water, leading to elevated arsenic concentrations. Data indicate that rice cooked with tubewell water has higher arsenic levels than that cooked with rainwater, highlighting the impact of water sources on arsenic content. The findings underscore the dietary health risks associated with arsenic exposure. Given the significant deviation from the stringent FDA requirement, rice with elevated arsenic levels poses a serious health risk to populations consuming it.

3.4. Comparison of Arsenic Concentrations among Samples

Figure 4 displays the arsenic concentrations among various samples, including rice grains and cooked rice prepared with tubewell water and rainwater, excluding the tubewell and rainwater samples themselves. The figure indicates that the arsenic levels in cooked rice prepared with tubewell water were higher than those in the rice grain samples. In contrast, the rice grains exhibited higher arsenic concentrations than cooked rice samples made with rainwater. The transmission of arsenic from cooking water to rice shows how water quality affects staple food arsenic accumulation.

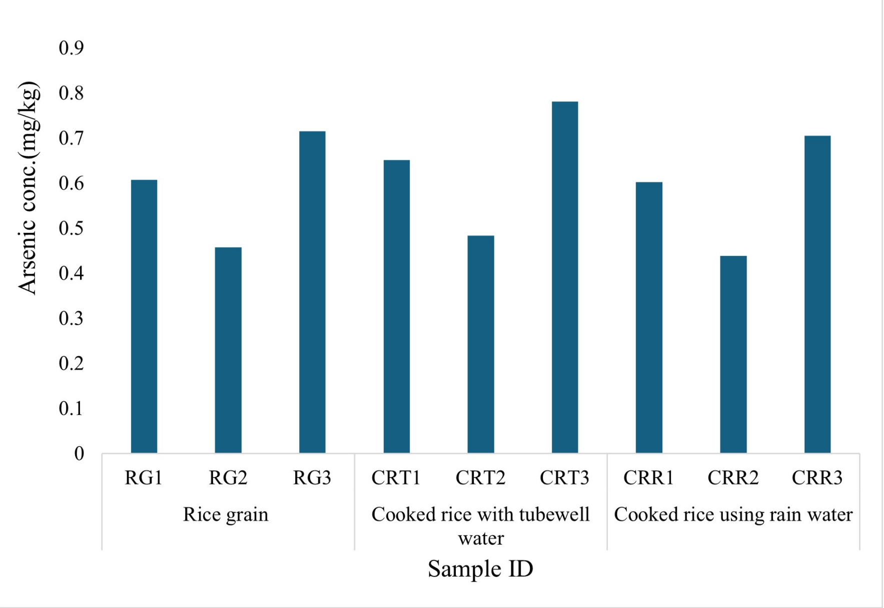

Figure 4. Comparison of arsenic concentration among samples.

Cooking rice samples with tubewell water resulted in higher arsenic concentrations than in raw rice grain samples, indicating significant arsenic accumulation from the tubewell water. The arsenic contents in the cooked rice samples (CRT1, CRT2, and CRT3) made using tubewell water were 7.25%, 5.68%, and 9.23% higher, respectively, than those in the raw rice grain samples RG1, RG2, and RG3. A considerable transfer of arsenic from cooking water to rice grains was found by Bae et al. (2002). Rice is capable of assimilating arsenic throughout the cooking process. The arsenic levels in the raw rice samples RG1, RG2, and RG3 were 0.82%, 4.15%, and 1.39% lower, respectively, in the rainwater-cooked rice samples CRR1, CRR2, and CRR3. Cooked rice has far less arsenic because rainwater has no arsenic. Although rainwater has been demonstrated to be effective in reducing arsenic levels during cooking, it is important to recognize its limitations in eliminating arsenic from raw rice grain. Rice grain samples cooked in tubewell water versus rainwater had different arsenic levels. Arsenic levels fell by 7.53% in CRR1 compared to CRT1. CRR3 declined 9.73% more than CRT3, whereas CRR2 declined 9.29% relative to CRT2. These data suggest that rainwater reduces arsenic better than tubewell water when cooked. Even with this decrease, rainwater can infect raw rice with arsenic. Instead of tubewell water-cooked rice, rainwater-cooked rice has less arsenic (O'Neill et al., 2013). Even if rainwater reduces arsenic contents, rice processing should include other mitigation procedures to improve food quality and reduce health hazards (Helmreich & Horn, 2009). How much arsenic rice absorbs depends on cooking time, water quality, and procedures (Garnier et al., 2010; Sengupta et al., 2006). Carefully choosing cooking water and methods will effectively reduce arsenic exposures when cooking rice, as their arsenic level can vary. In the study area, rainwater harvesting has emerged as a promising method to reduce arsenic exposure. However, ensuring its long-term sustainability requires addressing challenges related to water quality and storage. Decontamination methods such as boiling, chlorination, and filtration are essential to ensure rainwater safety. Chlorination, in particular, is effective against microbial contamination if used with appropriate dosages (Sharma et al., 2014). Regarding storage practices, rainwater should be kept in covered, UV-resistant tanks made from food-grade materials to prevent contamination. Regular cleaning of tanks and collection surfaces is also critical to maintaining water quality (Helmreich & Horn, 2009). In the context of climate change, large-scale, community-based RWH systems should be implemented to ensure resilience against changing precipitation patterns. These systems can store excess rainwater during the monsoon season for use in dry periods (O'Neill et al., 2013). By integrating these measures, rainwater harvesting can serve as a sustainable mitigation strategy, reducing arsenic exposure while ensuring water availability for cooking and drinking.

3.5. Health Risk

Table 5 shows the values of EDI, THQ for inorganic arsenic from cooked rice and lifetime cancer risk. The EDI values ranged from 3.07 to 5.47 μg/kg body weight/day. The THQ values calculated for the six cooked rice samples, ranging from 10.2 to 18.2 μg/kg/day, represent an estimate of the potential non-carcinogenic risk from arsenic exposure due to rice consumption. The THQ is a commonly used metric in risk assessments to evaluate the likelihood of adverse health effects arising from chronic exposure to a toxic substance like arsenic. A THQ greater than 1.0 indicates a potential for health risks, meaning the exposure may exceed the safe level for human health. The arsenic exposure from rice in CRT1 is 15.2 times higher than the reference dose, suggesting a significant potential risk for non-carcinogenic effects. Similarly, CRT2 shows a THQ of 11.3, indicating a considerable health risk. CRT3 with a THQ of 18.2, represents the highest level of non-carcinogenic risk among the samples. CRR1 and CRR3 with THQs of 14.0 and 16.5 respectively, show a similar level of concern for public health. Lastly, CRR2, with a THQ of 10.2, is the lowest of the six, but still indicates a potential non-carcinogenic risk.

Table 5. Estimated daily intake for inorganic arsenic and lifetime cancer risk from cooked rice.

Sample ID	Arsenic concentration (μg/kg)	EDI (μg/kg body weight/day)	THQ (μg/kg/day)	LCR (μg/kg/day)	LCR (%)
CRT1	651	4.56	15.2	0.00684	0.684
CRT2	484	3.39	11.3	0.00509	0.509
CRT3	781	5.47	18.2	0.00821	0.821
CRR1	602	4.21	14	0.00632	0.632
CRR2	439	3.07	10.2	0.00461	0.461
CRR3	705	4.94	16.5	0.00741	0.741

The Lifetime Cancer Risk (LCR) values derived for the six rice samples in this study, ranging from 0.00461 to 0.00821, represent the estimated risk of developing cancer over a lifetime due to arsenic exposure through rice consumption. These percentages values ranged from 0.461% to 0.821%. While these percentages may seem relatively small, they significantly exceed the threshold for acceptable cancer risk, as defined by the U.S. Environmental Protection Agency (EPA). The EPA considers a cancer risk of 1 in 1,000,000 (0.0001) to 1 in 10,000 (0.01) as a threshold of concern for environmental exposures. Risks above this range, particularly those exceeding 1 in 10,000, indicate a need for intervention or mitigation measures (EPA, 1996). In this case, the calculated LCR values ranged from 0.00461 to 0.00821, are much higher than the EPA's threshold of 0.01%. For instance, an LCR of 0.00684 (or 0.684%) represents a cancer risk that is 68 times greater than the 1 in 10,000 threshold, which is a significant public health concern.

4. Conclusion

The arsenic contamination of rice grains, rainwater, tubewell water, and cooked rice was investigated in Bholadanga village, Sholotaka Union, Gangni Upazila, Meherpur. The underlying hypothesis posited that rice cooked with rainwater would contain lower levels of arsenic compared to rice cooked with tubewell water. The findings confirmed this hypothesis, demonstrating that the choice of water source significantly impacts arsenic levels in cooked rice. Specifically, rice prepared using rainwater exhibited markedly lower arsenic concentrations than that cooked with tubewell water. This relationship underscores the importance of water sources in arsenic accumulation during cooking, suggesting that harvested rainwater may be a safer option for cooking in the studied region. The study further revealed that rice cooked with tubewell water poses significant health risks. Health risk assessments indicated that the estimated daily intake (EDI) values for cooked rice samples exceeded safe limits. Target hazard quotient (THQ) values confirmed a considerable non-carcinogenic risk, with some samples demonstrating exposure levels over 18 times the acceptable threshold. Lifetime cancer risk (LCR) values significantly exceeded the U.S. Environmental Protection Agency's threshold of 0.01%, indicating a heightened probability of developing cancer from arsenic exposure over a lifetime. Utilizing alternative water sources with lower contamination levels for food preparation can potentially mitigate health risks associated with arsenic exposure for populations that heavily rely on rice. These findings emphasize the necessity of considering water sources in food preparation, particularly in areas affected by arsenic contamination. The study revealed that using collected rainwater could reduce arsenic intake through rice consumption, thereby enhancing public health and mitigating the health risks associated with this critical food source. The study suggests collecting rainwater and using it for cooking purposes in arsenic-contaminated areas for public health and food safety.

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Conflicts of interest

There are no conflicts of interest between the authors.

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