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***Research article***

# Risk assessment of arsenic exposure from commercially available rice, vegetables, and fish in Brahmanbaria, Bangladesh

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ABSTRACT

Arsenic contamination in staple foods is a major public health concern in Bangladesh. This study aimed to comprehensively assess dietary arsenic exposure through commercially available rice, vegetables, and fish collected from local markets in Brahmanbaria District, Bangladesh. Market-based purposive sampling was employed to collect 20 rice, 48 vegetable, and 20 fish samples from multiple vendor stalls across local markets. Samples were analyzed for total arsenic content using HG-AAS. Statistical analyses were performed in R software (version 4.5.1), where mean ± SE was calculated using the descriptive statistics function. Health risks were evaluated through Target Hazard Quotient (THQ) analysis. Arsenic concentrations in rice ranged from 0.047 ± 0.010 mg/kg (Bayek) to 0.112 ± 0.022 mg/kg (Sultanpur), with the highest levels in Sultanpur, Gopinathpur, and Mulogram. Vegetables varied from 0.032 ± 0.004 mg/kg (tomato, Mogra) to 0.823 ± 0.149 mg/kg (amaranth, Gopinathpur), often exceeding the FAO/WHO limit of 0.1 mg/kg, particularly in leafy greens. Fish levels ranged from 0.054 ± 0.014 mg/kg (Mogra) to 0.410 ± 0.095 mg/kg (Gopinathpur), with several above the 0.1 mg/kg guideline. THQ analysis indicated rice posed the greatest chronic risk (THQ > 1), followed by vegetables, with fish contributing a smaller but notable hazard. The co-occurrence of elevated arsenic in staple foods indicates cumulative dietary exposure risks. Key limitations include moderate sample size and absence of speciation analysis. Future studies should address speciation, biomonitoring, and broader spatiotemporal sampling to refine exposure estimates. This study provides baseline data to guide food safety surveillance and public health interventions in arsenic-affected regions.

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## 1. INTRODUCTION

Arsenic contamination is one of the most severe environmental health crises in Bangladesh, affecting millions of individuals who are exposed to it through both direct and indirect pathways. Although the primary concern has historically been the ingestion of arsenic-contaminated groundwater used for drinking, increasing attention has shifted toward food as a significant exposure route, especially in regions with documented groundwater contamination (Ahmed et al., 2006; Das et al., 2004; Khaleda et al., 2025; Smith et al., 2000).

Among the most prominent dietary sources of arsenic are rice, vegetables, and fish—staple components of the Bangladeshi diet. Rice, which forms the dietary base for a large segment of the population, is highly efficient in absorbing arsenic from irrigation water and soil due to its cultivation in flooded conditions that enhance arsenic mobility and uptake (Khaleda et al., 2025; Meharg and Rahman, 2003). Studies have shown that Bangladeshi rice can contain arsenic levels well above the international safety limits, contributing significantly to total dietary arsenic intake (Mondal and Polya, 2008). Similarly, vegetables cultivated in contaminated soils or irrigated with arsenic-laden water can accumulate the toxic element in edible tissues, posing additional dietary risks (Alam et al., 2003; Wang et al., 2013; Williams et al., 2006). Furthermore, fish—especially those from freshwater systems exposed to arsenic through runoff and aquaculture—can bioaccumulate inorganic arsenic species, which are considered more toxic than organic forms (Bhattacharya et al., 2011; Rahman et al., 2014).

In Bangladesh, the integration of agriculture and aquaculture with contaminated water sources heightens the likelihood of arsenic entry into the food chain. The Brahmanbaria district, located in the eastern part of the country, has reported groundwater arsenic concentrations exceeding the WHO guideline value of 10 µg/L in several areas (DPHE and JICA, 2010). Given the district's reliance on groundwater for both irrigation and aquaculture, and its dependence on local markets for food supply, it becomes imperative to investigate arsenic levels in commonly consumed foods sourced from these markets.

Despite growing awareness of dietary arsenic exposure, most existing studies have focused on direct water exposure or have generalized dietary risks without district-level assessments. There is a critical gap in localized, market-based dietary exposure assessments, particularly in semi-urban districts like Brahmanbaria, where food production and consumption are deeply interconnected with the local environment. A comprehensive evaluation of arsenic in market-sourced food items in this region can inform public health authorities, consumers, and policymakers about potential dietary risks and guide the implementation of mitigation strategies such as water treatment, alternative irrigation practices, and food safety monitoring.

To date, a growing body of evidence has linked the consumption of arsenic-contaminated food to serious health consequences. Chronic exposure has been particularly associated with hepatotoxicity and nephrotoxicity, manifesting as liver and kidney dysfunction. Moreover, prolonged arsenic intake may contribute to cardiovascular complications by disrupting endothelial function, increasing oxidative stress, and promoting inflammation. These findings underscore the significant public health implications of dietary arsenic exposure, especially in regions with known contamination risks (Khaleda et al., 2025).

Our research question was to what extent are commonly consumed food items-specifically rice, vegetables, and fish-sourced from local markets in the Brahmanbaria district contaminated with arsenic, and what are the potential health risks associated with this dietary exposure? This study aimed to evaluate naturally occurring arsenic contamination in widely consumed food commodities rather than relying on food artificially spiked in a controlled laboratory setting. By focusing on rice, vegetables, and fish directly obtained from local markets, we sought to reflect real-world exposure scenarios representative of daily dietary intake among the population in an arsenic-affected district of Bangladesh.

To the best of our knowledge, this is among the first studies in Brahmanbaria to conduct a comprehensive, market-based arsenic risk assessment of multiple food groups using established public health models such as Estimated Daily Intake (EDI) and Target Hazard Quotient (THQ). Through this approach, we aimed not only to quantify the contamination levels in key dietary staples but also to estimate potential human health risks associated with chronic exposure. This research offers ecologically relevant insights into how environmental arsenic contamination infiltrates the food supply chain and may contribute to long-term health effects. Additionally, the findings are expected to inform targeted interventions, strengthen food safety surveillance, and raise public awareness in regions where both agriculture and aquaculture rely heavily on arsenic-affected water sources.

## 2. MATERIALS AND METHODS

### Study area

This cross-sectional study was conducted in the Brahmanbaria district, situated in the eastern region of Bangladesh (approximately 24.0°N latitude and 91.1°E longitude), an area previously documented for elevated groundwater arsenic contamination (DPHE and JICA, 2010). To reflect regional food consumption practices, food samples were collected from major local markets across three upazilas: Brahmanbaria Sadar, Kasba, and Akhaura. These marketplaces serve as primary food supply hubs for the local population and represent a cross-section of the district's dietary sourcing patterns (Figure 1).

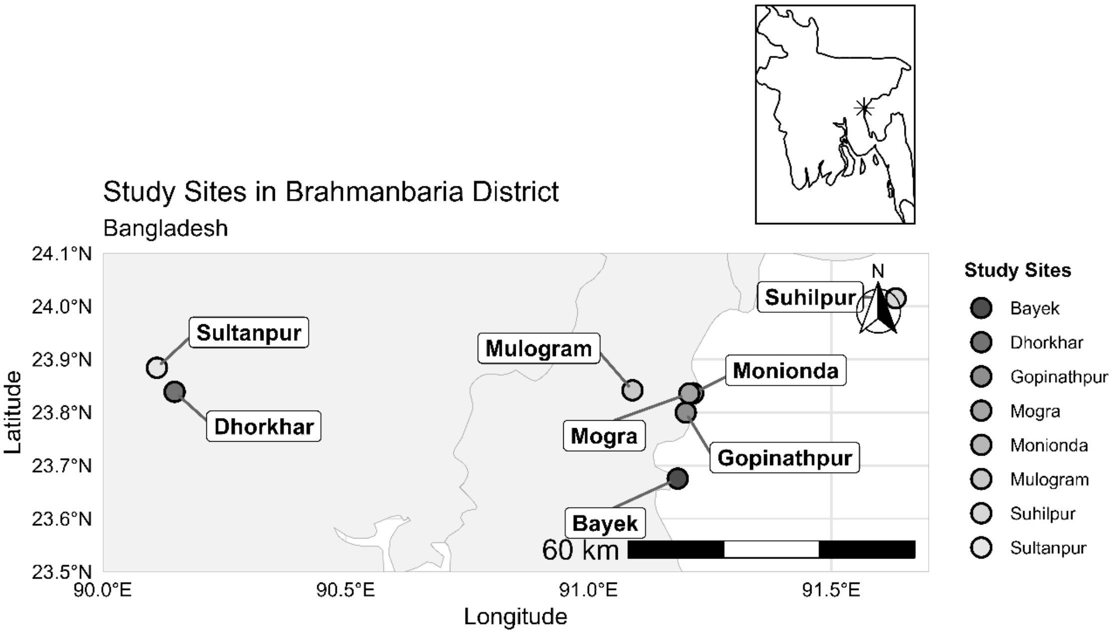


Figure 1. Map showing the geographic distribution of the study areas within Brahmanbaria District, Bangladesh. These locations were selected for the collection of dietary (rice, vegetables, fish) samples to assess arsenic contamination and evaluate public health risks associated with market-sourced exposure pathways.

### Sample collection and categorization

A total of 88 food samples were purposively collected during December 2024 to February 2025, targeting three major dietary groups. Twenty rice samples, including both parboiled and non-parboiled varieties, were collected from local rice vendors (10 vendor stalls). Forty-eight vegetable samples from 20 vendor stalls were also collected, representing a variety of edible plant types such as leafy greens (e.g., amaranth, spinach), root vegetables (e.g., potatoes, carrots), and fruiting vegetables (e.g., brinjal, tomato). Additionally, twenty freshwater fish samples were obtained from wet markets (10 vendor stalls), comprising widely consumed species of Pangas fish (*Pangasius hypophthalmus)*. All samples were collected in sterile polyethylene bags, labeled with relevant details, and transported to the laboratory in cooled conditions to maintain sample integrity.

### Sample preparation and digestion

In this study, fish, rice, and vegetable samples were collected from various local markets in the Brahmanbaria district to assess dietary exposure to arsenic. Upon collection, the samples were stored in clean polyethylene zip-lock bags and swiftly transported to the laboratory to minimize degradation and contamination. In the laboratory, all food samples underwent standard preparation procedures. Rice and vegetable samples were initially washed thoroughly with tap water for five minutes, followed by rinsing with deionized water to eliminate surface impurities. The cleaned samples were blotted with filter paper and oven-dried at 60 °C for 24 hours until constant weight was achieved. The dried materials were finely ground using a carnelian mortar and pestle, and the powdered samples were rinsed with 5 mL of deionized water and methanol to remove any residual contaminants. Fish samples were prepared by dissecting edible muscle tissue, which was then rinsed, air-dried, and homogenized using a mortar and pestle.

For arsenic analysis, sample digestion was carried out using a wet acid digestion method. In the procedure, 0.25 g of each powdered sample was digested using a combination of 1 mL perchloric acid ($HClO_4$), 1.5 mL sulfuric acid ($H_2SO_4$), and 4 mL nitric acid ($HNO_3$). Digestion was conducted in Teflon beakers on a hot plate at 100–120 °C within a fume hood until the samples were fully dissolved into a clear solution. The digested mixtures were filtered using Whatman No. 42 filter paper into 25 mL volumetric flasks and diluted to the mark with deionized water. The final solutions were stored in acid-washed polyethylene bottles at 4 °C before instrumental analysis of arsenic concentrations.

### Arsenic quantification

The concentration of arsenic in food samples was quantified using Atomic Absorption Spectrophotometry (AAS) equipped with a Hydride Generation System (HGAAS), which is particularly effective for detecting low levels of inorganic arsenic species. Several quality assurance and quality control (QA/QC) measures were followed to ensure data accuracy. Calibration was carried out using certified standard arsenic solutions obtained from Merck (Germany). Reagent blanks were included in each digestion batch to detect contamination. Recovery tests were conducted on spiked samples, with acceptable recovery values ranging from 85% to 115%. Additionally, 10% of the total samples were randomly selected for duplicate analysis. The Limit of Detection (LOD) for arsenic was 0.01 mg/kg. The arsenic concentrations were measured in milligrams per kilogram (mg/kg).

### Data analysis and health risk assessment

Data analysis was performed using Microsoft Excel 2021 and R software (version 4.5.1). Descriptive statistics were calculated for each food group, including mean, standard error of the mean (SE), and range. Arsenic concentrations were compared to national and international safety thresholds: 0.2 mg/kg for rice, 0.1 mg/kg for vegetables, and 1.0 mg/kg for fish, based on standards from BSTI and the Codex Alimentarius (FAO/WHO).

### Estimated daily intake (EDI)

The Estimated Daily Intake (EDI) of arsenic from each food category was calculated using the formula: $EDI = (C \times IR) / BW$, where C is the mean arsenic concentration (mg/kg), IR is the ingestion rate of the food (kg/day), and BW is the average adult body weight, assumed to be 60 kg. Dietary intake rates were based on national consumption estimates: 0.4 kg/day for rice, 0.2 kg/day for vegetables, and 0.05 kg/day for fish.

### Target hazard quotient (THQ)

To assess non-carcinogenic health risks from dietary arsenic exposure, the Target Hazard Quotient (THQ) was calculated using the formula: $THQ = EDI / RfD$, where the Reference Dose (RfD) for arsenic was 0.0003 mg/kg/day, as recommended by the U.S. Environmental Protection Agency (USEPA, 2012). A THQ value below 1 indicates negligible risk, while values equal to or exceeding 1 suggest potential health hazards. To evaluate cumulative exposure across all food categories, the Total THQ (TTHQ) was calculated by summing the THQ values for rice, vegetables, and fish.

## 3. RESULTS

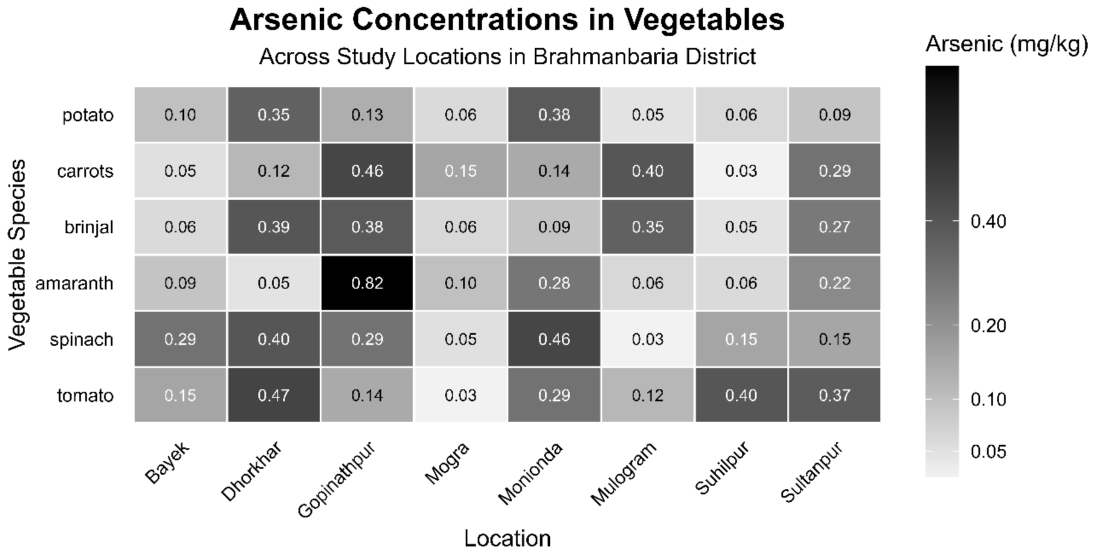
### Arsenic concentration in rice grains

We found that rice grains from three areas - Sultanpur, Gopinathpur, and Mulogram - contained the highest levels of arsenic compared to grains from other areas. The highest concentration of arsenic was recorded in Sultanpur (0.112 ± 0.022 mg/kg), and the lowest was recorded in Bayek (0.047 ± 0.010 mg/kg).

The mean concentration of arsenic in rice grains was 0.111 ± 0.030 mg/kg for Gopinathpur, 0.047 ± 0.010 mg/kg for Bayek, 0.111 ± 0.022 mg/kg for Mulogram, 0.071 ± 0.005 mg/kg for Moniondo, 0.049 ± 0.012 mg/kg for Mogra, 0.092 ± 0.005 mg/kg for Dorkhar, 0.112 ± 0.022 mg/kg for Sultanpur, and 0.062 ± 0.013 mg/kg for Suhilpur. These values indicate the mean concentration of arsenic in the rice grains from each area, with the standard error of the mean (SE) representing the precision of the estimate (Table 1).

### Arsenic accumulation in vegetable samples

In this study, arsenic concentrations were assessed in six commonly consumed vegetables—amaranth, brinjal, carrots, potato, spinach, and tomato—collected from local markets in Brahmanbaria district. The arsenic levels varied across both vegetable types and sampling sites, ranging from 0.032 ± 0.004 mg/kg (tomato from Mogra) to 0.823 ± 0.149 mg/kg (amaranth from Gopinathpur). Leafy vegetables such as amaranth and spinach consistently showed higher arsenic accumulation, especially in locations like Gopinathpur, Dhorkhar, and Monionda. In contrast, samples from Bayek and Mogra generally had lower levels, with most values below 0.15 mg/kg (**Figure 2**).



| | Bayek | Dhorkhar | Gopinathpur | Mogra | Monionda | Mulogram | Suhilpur | Sultanpur |
|---|---|---|---|---|---|---|---|---|
| potato | 0.10 | 0.35 | 0.13 | 0.06 | 0.38 | 0.05 | 0.06 | 0.09 |
| carrots | 0.05 | 0.12 | 0.46 | 0.15 | 0.14 | 0.40 | 0.03 | 0.29 |
| brinjal | 0.06 | 0.39 | 0.38 | 0.06 | 0.09 | 0.35 | 0.05 | 0.27 |
| amaranth | 0.09 | 0.05 | 0.82 | 0.10 | 0.28 | 0.06 | 0.06 | 0.22 |
| spinach | 0.29 | 0.40 | 0.29 | 0.05 | 0.46 | 0.03 | 0.15 | 0.15 |
| tomato | 0.15 | 0.47 | 0.14 | 0.03 | 0.29 | 0.12 | 0.40 | 0.37 |

Figure 2. Heatmap illustrating the spatial distribution of arsenic concentrations (mg/kg) in vegetable samples collected from different study areas in Brahmanbaria District. Arsenic levels range from a minimum of 0.03 mg/kg to a maximum of 0.82 mg/kg.

### Arsenic accumulation in fish

Fish samples collected from local markets in Brahmanbaria district exhibited varying levels of arsenic contamination, with concentrations ranging from 0.054 ± 0.014 mg/kg to 0.410 ± 0.095 mg/kg. The lowest arsenic levels were recorded in samples from Mogra (0.054 ± 0.014 mg/kg) and Bayek (0.059 ± 0.006 mg/kg), while the highest levels were found in Gopinathpur

(0.410 ± 0.095 mg/kg) and Mulogram (0.240 ± 0.093 mg/kg). These findings highlight the spatial variability in fish contamination, which reflects the aquatic environment, feeding habits, and bioaccumulation patterns of different fish species (**Table 1**).

### Comparative assessment of arsenic concentration and health risks via market-sourced foods

The present study assessed arsenic concentrations in commonly consumed food items—rice, vegetables, and fish—collected from local markets in Brahmanbaria District and evaluated their associated health risks using Target Hazard Quotients (THQs). The findings are illustrated in two key comparative plots: (i) mean ± SE arsenic concentrations versus established safety standards and (ii) THQ values for each food group (**Table 2**).

### Arsenic concentration relative to food safety standards

As shown in **Figure 3**, mean arsenic concentrations in rice (0.176 ± 0.025 mg/kg) and vegetables (0.149 ± 0.026 mg/kg) were higher than the corresponding recommended safety limits, while fish (0.103 ± 0.057 mg/kg) showed comparatively lower levels.

Table 1. The mean concentrations of arsenic in fish and rice samples collected from eight different study locations in Brahmanbaria, Bangladesh. The arsenic levels are expressed in milligrams per kilogram (mg/kg) and are accompanied by the standard error of the mean (SE), which indicates the variability of the measurements within each location.

| Location | Fish | Rice |
|---|---|---|
| Bayek | 0.197 ± 0.123 | 0.047 ± 0.010 |
| Dhorkhar | 0.085 ± 0.011 | 0.092 ± 0.005 |
| Gopinathpur | 0.197 ± 0.077 | 0.111 ± 0.030 |
| Mogra | 0.076 ± 0.004 | 0.049 ± 0.012 |
| Monionda | 0.082 ± 0.006 | 0.071 ± 0.005 |
| Mulogram | 0.212 ± 0.094 | 0.111 ± 0.010 |
| Suhilpur | 0.092 ± 0.011 | 0.062 ± 0.013 |
| Sultanpur | 0.205 ± 0.079 | 0.112 ± 0.022 |

Table 2. Arsenic concentration (Mean ± SE), Estimated Daily Intake (EDI), and Target Hazard Quotient (THQ) for rice, vegetables, and fish samples collected from Brahmanbaria, Bangladesh. The values reflect spatial variations in dietary arsenic exposure and associated non-carcinogenic health risks. THQ values ≥1 indicate a potential health concern.

| Food | Mean ± SE | EDI | THQ |
|---|---|---|---|
| **Fish** | 0.082 ± 0.032 | 0.00007 | 0.942 |
| **Rice** | 0.188 ± 0.026 | 0.00052 | 1.823 |
| **Vegetables** | 0.165 ± 0.009 | 0.00027 | 2.092 |

### Target hazard quotient (THQ)

Figure 4 presents the THQ values calculated for rice, vegetables, and fish. Rice exhibited the highest THQ (>1), followed by vegetables, while fish had a comparatively lower value.

### Integrated risk perspective

Taken together, Figures 3 and 4 provide an overview of arsenic concentrations in staple foods relative to safety limits, alongside their potential non-carcinogenic health risks as expressed by THQ values.

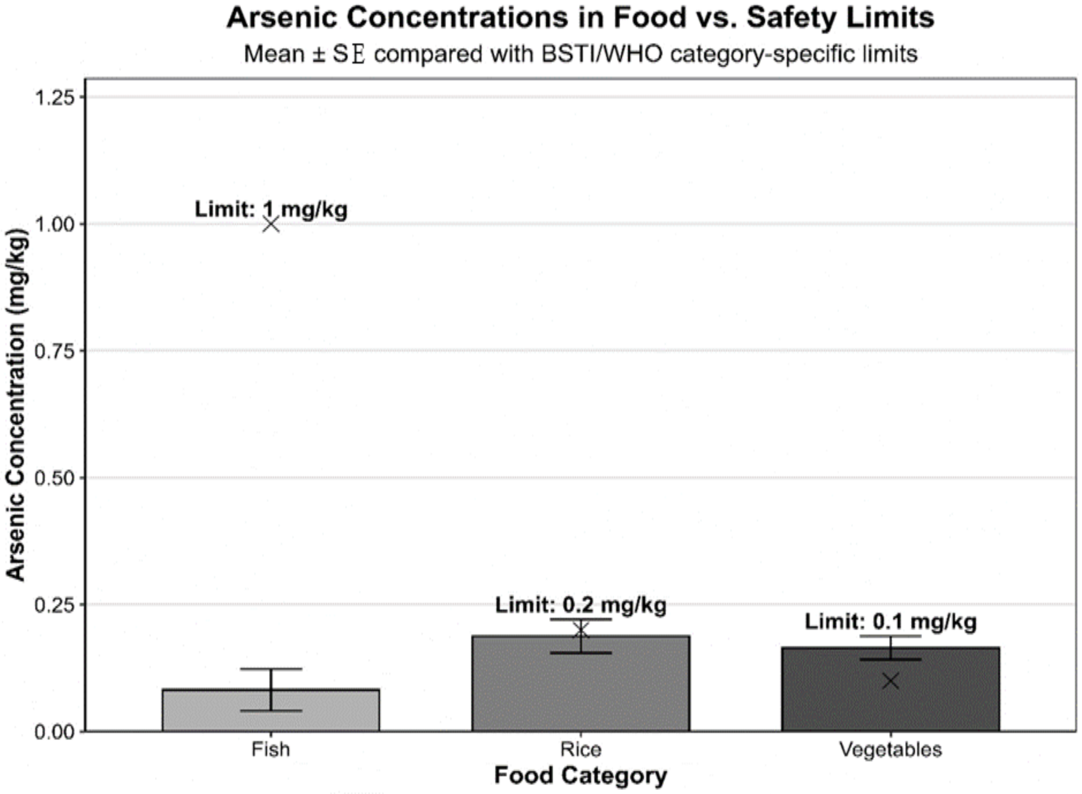


Figure 3. Mean ± SE values of arsenic concentrations in fish, rice, and vegetable samples collected from the study locations. The data indicates that arsenic levels in rice and vegetable samples are approaching or exceeding the recommended safety limits, whereas arsenic concentrations in fish samples remain within permissible thresholds.

## 4. DISCUSSION

Rice grains from Sultanpur, Gopinathpur, and Mulogram exhibited the highest arsenic concentrations, while Bayek and Mogra had the lowest. These findings align with studies in arsenic-affected regions of Bangladesh: Meharg and Rahman (2003) reported rice arsenic ranging from 0.05 to 0.40 mg/kg, and Islam et al. (2004) reported 0.05–0.15 mg/kg. Compared to Williams et al. (2006), whose range was 0.08–0.20 mg/kg, many of our samples were lower, suggesting variations in sourcing or improved irrigation practices. The relatively lower concentrations in Bayek and Mogra indicate possible regional differences in arsenic exposure or more effective water management strategies. Overall, continued arsenic presence in market rice, with some locations exceeding safety thresholds, underscores the importance of routine monitoring and informed sourcing.

Vegetables showed considerable variation in arsenic content, with leafy types such as amaranth and spinach consistently accumulating higher levels, particularly in Gopinathpur, Dhorkhar, and Monionda. These results are consistent with Alam et al. (2003), who reported arsenic ranging 0.01–2.39 mg/kg in vegetables, especially leafy greens, and with Roychowdhury et al. (2002), who observed elevated arsenic in brinjal, tomato, and potato. Many vegetable samples in this study exceeded the FAO/WHO (2001) recommended limit of 0.1 mg/kg, reflecting potential health risks. The observed spatial and species-specific differences likely result from environmental and agricultural factors such as soil contamination and irrigation practices (Rahman et al., 2009).

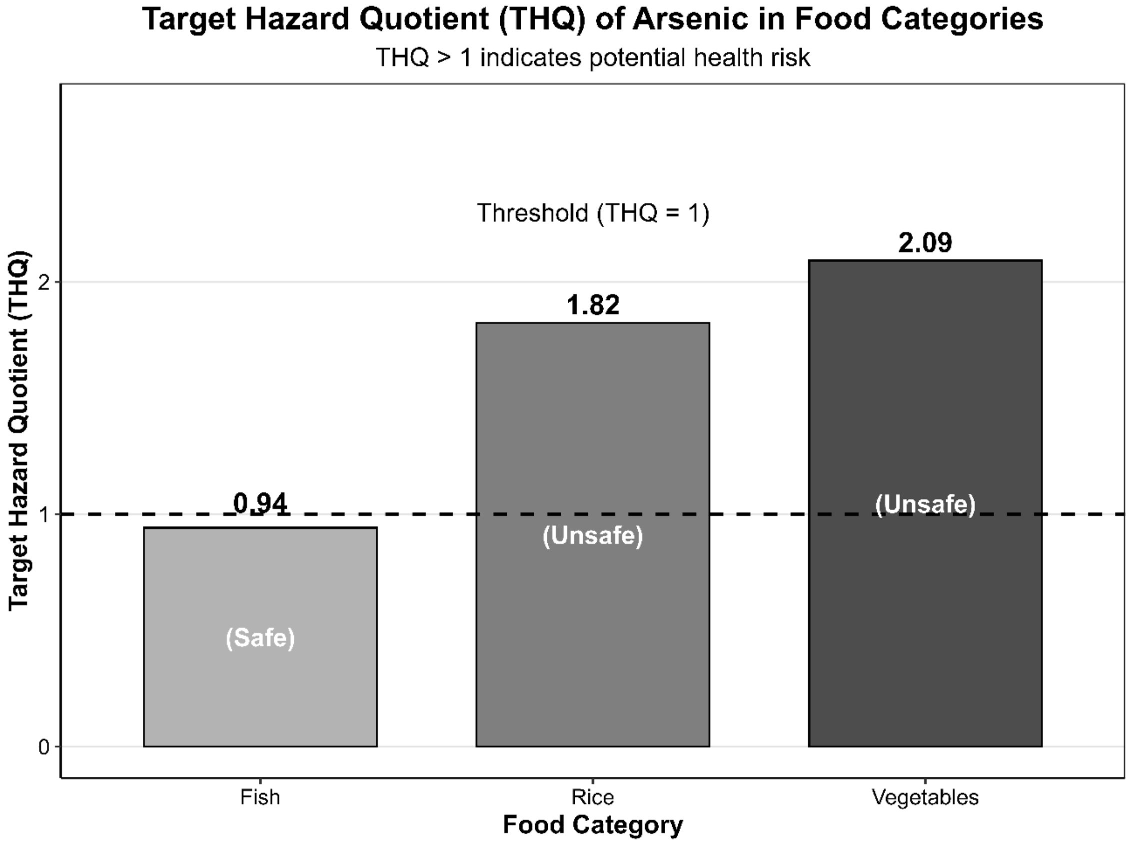


Figure 4. Target Hazard Quotient (THQ) values indicating the potential health risks associated with arsenic exposure from fish, rice, and vegetable samples collected from the study locations. A THQ value greater than 1 suggests a potential non-carcinogenic health risk. The results show that rice and vegetable samples exceed the safety threshold, rendering them unsafe for human consumption, while fish samples approach the threshold but remain within the acceptable limit.

Fish samples displayed variable arsenic levels, with lowest concentrations in Mogra and Bayek, and highest in Gopinathpur and Mulogram. Rahman et al. (2013) reported similar ranges (0.04–0.63 mg/kg) in commonly consumed Bangladeshi fish, and Saha and Ali (2007) reported 0.02–0.41 mg/kg, highlighting bioaccumulation in species like Pangasius and Tilapia. Some fish in our study exceeded 0.2 mg/kg, considered potentially hazardous for long-term consumption (Rahman et al., 2002). Although all samples were below the FAO/WHO provisional limit of 1 mg/kg, chronic exposure to even low levels can bioaccumulate, posing serious long-term health risks (Khaleda et al., 2025).

The comparative assessment of rice, vegetables, and fish using mean arsenic concentrations and Target Hazard Quotients (THQs) provides a comprehensive view of dietary exposure. Figure 3 shows that mean arsenic levels in rice (0.176 ± 0.025 mg/kg) and vegetables (0.149 ± 0.026 mg/kg) exceeded recommended limits (FAO/WHO, 2011), whereas fish (0.103 ± 0.057 mg/kg) remained below WHO's maximum limit for aquatic products (WHO, 1993). Even at lower levels, prolonged consumption contributes to cumulative exposure, highlighting the need for ongoing monitoring.

Figure 4 illustrates THQ values, indicating potential non-carcinogenic health risks from long-term exposure (USEPA, 2000). Rice had the highest THQ (>1), confirming its role as the primary dietary source of arsenic in the region. Vegetables had moderately elevated THQ, and fish contributed a lower but notable risk. This pattern reflects local consumption habits, where rice is eaten in large amounts daily. The predominance of bioavailable inorganic arsenic species in freshwater fish may intensify the health impact despite lower concentrations (Rahman et al., 2013). Interpreting concentration data alongside THQs underscores the integrated risk perspective: even foods within or near safety thresholds can collectively pose significant chronic health risks, especially for low-income and rural populations reliant on local foods.

The findings of this study underscore the need for comprehensive strategies to mitigate dietary arsenic exposure in Bangladesh. Routine monitoring of arsenic in staple foods—including rice, vegetables, and fish—at both production and market levels is essential to identify high-risk areas. The promotion of low-arsenic crop varieties, combined with the adoption of safe irrigation practices such as alternate wetting and drying in rice cultivation, can effectively reduce arsenic accumulation in food products. Public awareness initiatives should inform consumers, particularly in rural and low-income communities, about the risks of cumulative arsenic exposure and encourage dietary diversification to minimize intake from highly contaminated sources. Additionally, community-level interventions, including soil remediation and controlled aquaculture practices, can help lower arsenic uptake in vegetables and fish. Integrating human biomonitoring programs alongside environmental assessments will provide a more accurate evaluation of population-level exposure and enable targeted policy decisions to protect vulnerable groups, including children and pregnant women. Collectively, these measures offer a holistic, evidence-based framework for reducing chronic health risks associated with dietary arsenic in Bangladesh.

To support public health, future research should focus on arsenic speciation to distinguish toxic inorganic arsenic from less harmful organic forms. Biomonitoring in human samples (urine, hair, nails) and expanded spatiotemporal sampling can refine exposure assessment. Integrating dietary and socioeconomic data will help identify vulnerable groups, such as children and low-income households. Promoting low-arsenic crop varieties, safe irrigation, and labeling arsenic content in foods are essential steps to reduce long-term dietary exposure. Overall, these strategies will strengthen food safety and protect public health in arsenic-affected regions of Bangladesh and South Asia.

While these results provide critical evidence, certain limitations must be considered. The relatively small sample size, driven by resource constraints, may limit the broader applicability of the findings. Seasonal and geographic variability in arsenic levels, along with the absence of detailed individual dietary data, restrict the precision of exposure estimates. Additionally, this study measured total arsenic content without speciation analysis, an important factor since inorganic arsenic species pose the greatest toxicological risk.

## 4. CONCLUSION

This study delivers vital insights into dietary arsenic exposure from rice, vegetables, and fish sold in local markets of Brahmanbaria District, Bangladesh. Our findings reveal that arsenic concentrations in rice and vegetables frequently exceed the safety thresholds set by the World Health Organization (WHO) and the Bangladesh Standards and Testing Institution (BSTI), highlighting significant public health concerns. Although arsenic levels in fish generally remained within permissible limits, the cumulative risk—expressed through elevated Target Hazard Quotient (THQ) values—signals potential chronic health effects, particularly linked to rice and vegetable consumption.

This research lays a strong foundation for understanding localized dietary arsenic exposure and underscores the urgent need for systematic, routine food safety monitoring in Bangladesh. The evidence calls for coordinated multidisciplinary efforts among public health officials, environmental regulators, and food safety authorities to mitigate risk. Future investigations should prioritize larger-scale sampling, seasonal and spatial assessments, and detailed arsenic speciation to refine risk characterization and inform targeted interventions. Ultimately, protecting vulnerable populations from chronic arsenic exposure through food will require integrated policies that combine science, public awareness, and sustainable agricultural practices.

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