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Demographic and socioeconomic determinants of urinary arsenic concentration for elementary school children in Bangladesh

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Abstract

Background: Arsenic (As) is a toxic element that can lead to various health issues in humans. The primary exposure to As is through the consumption of water contaminated with high As levels, particularly in Bangladesh. Previous studies have shown that urinary arsenic (UAs) concentration can reflect As exposure and metabolism in individuals. However, little is known about how other factors, such as age, sex, and socioeconomic status, may affect UAs concentrations in children.

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Ethics approval and consent to participate
Ethical approval was obtained from Columbia University IRB and Bangladesh Medical Research Council Ethical Review Committee, Columbia University Protocol Approval # IRBAAAD0429 (Y1M01), BMRC Protocol Approval # BMRC/ERC/2007–2010/333. All of the participants agreed to voluntarily join the study and subsequently sign the informed consent forms.

CRediT authorship contribution statement
Raisa Sara: Writing – original draft, Methodology, Formal analysis, Conceptualization, Writing – review & editing. **Khalid M. Khan:** Writing – review & editing, Data curation, Conceptualization, Funding acquisition. **Shelbin Mattathil:** Writing – original draft. **Munachimso Nwankwo:** Writing – original draft. **Mohammad Aminul Islam:** Writing – review & editing. **Faruque Parvez:** Data curation, Funding acquisition.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The use of Generative AI and AI-assisted technologies in scientific writing
During the preparation of this work the authors used Microsoft Bing and Paperpal to improve readability and language of some parts of the paper. The use of these technologies complied with the terms of use of the relevant tool or technology of KeAi. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Objective: This study aimed to investigate the influence of factors such as age, sex, and socioeconomic status on UAs concentrations in children, in addition to the impact of drinking water arsenic (WAs) levels.

Methods: We conducted our study on elementary school-going children aged 8–11 years from rural Araihazar in Bangladesh. We measured UAs (available for a subset of 391 children) and WAs levels and collected information on demographic and socioeconomic characteristics. We employed regression analysis and *t*-tests to analyze the data.

Results: Our findings revealed that younger children ($\beta = 197.95$, 95% confidence interval [CI]: 111.97 to 283.94), female children ($\beta = 93.95$, 95% CI: 8.49 to 179.40), and children with less educated fathers ($\beta = 138.03$, 95% CI: 26.47 to 249.58) had higher UAs levels, particularly when they consumed water with high As content.

Conclusion: The study concludes that children's As exposure and UAs concentration may vary depending on their age, sex, and socioeconomic status. Therefore, these factors should be considered when assessing the health risks associated with As.

Keywords

Water arsenic; Rural children; Socioeconomic factors; Bangladesh

1. Introduction

Arsenic (As) in drinking water is a global environmental health concern because hundreds of millions of people are chronically exposed to levels of As exceeding the World Health Organization safety standard level of 10 μg/L.[1, 2] Bangladesh is one of the countries facing significant repercussions, with well-documented connections between the consumption of arsenic-contaminated drinking water and mortality rates attributed to both all-cause and chronic diseases.[3–5] About 35–77 million people in Bangladesh have been drinking water with high As concentrations since the 1970s.[4, 6–8] Rural areas in Bangladesh, receive groundwater contaminated with As from household wells for cooking and drinking. As determined by the Bangladesh standard, a "safe" drinking water source in rural Bangladesh is a well that has an As concentration level below 50 μg/L because other sources are likely to be contaminated with waterborne pathogens.[9] In addition to contaminated drinking water, environmental factors and diet have been identified as sources of As exposure in developing countries. Specifically, in Southeast Asian countries including Bangladesh, rice and rice products are a staple source of energy but remain one of the main sources of As exposure. Chronic As exposure from these sources increases the risk of cancer, skin lesions, cardiovascular disease, chronic kidney disease, obesity, maternal and fetal complications, metabolic syndrome, and dysbiosis.[10, 11] Children exposed to As are also at a higher risk of intestinal colonization with antibiotic resistant organisms, poor cognitive function and neurodevelopmental deficits.[12–17]

To address this pressing health issue in Bangladesh and beyond, various national and international mitigation strategies have been implemented in recent years. An effective approach to reduce As exposure through drinking water in Bangladesh has involved testing millions of wells across the country and communicating the risk of As exposure to rural residents. Consequently, 100,000 deep community wells have been installed across the country under the Bangladesh Arsenic Mitigation Water Supply Program and other related projects.[18] Other efforts to mitigate the effects of high As exposure include communication across 56 districts to raise awareness among rural people.[19] Agencies including the United Nations Children's Fund, the Department of Public Health Engineering, the Bangladesh governmental institution for provision of drinking water, and a few non-governmental organizations (NGOs) such as NGO Forum and BRAC. Bangladesh have also made attempts to educate people via printed materials and public service announcements.[12, 20] In spite of these efforts to raise awareness, As associated health problems remain high throughout the country.[21–23]

Despite the availability of low-As wells within walking distance, studies have shown that a large number of villagers persist in drinking water from their own high-As household and community wells (e.g., wells in schools, mosques, community clinics etc.).[24–28] Since rural residents, including children, are exposed to multiple wells at the same time, a biomarker of As (e.g., urinary As, blood As, nail As) may more accurately represent chronic As exposure than measuring drinking water As concentration. Studies have shown that urinary As concentration is a good indicator of recent As exposure in both environmental and occupational settings.[29] Urinary As (UAs) has been documented since 2000 by the Health Effect of Arsenic Longitudinal Study (HEALS) as a strong predictor of the risk of skin lesions.[30] To effectively reduce As exposure in low-income rural populations in Bangladesh and other comparable populations across the world, it is important to evaluate the potential social determinants of As exposure. Only a few studies have investigated the social risk factors associated with arsenic exposure. A study conducted in Northern Chile investigated the potential association between socioeconomic status (SES) and arsenic-exposure related disease, with a specific focus on type 2 diabetes, revealed that lower SES is an important risk factor for environmentally induced diseases.[31] In a separate study examining the link between SES and risk for As-related skin lesions, the results indicated an elevated risk of skin lesions among individuals who were non-land owners.[32] The study also observed a correlation between higher levels of well water As (WAs) and UAs. However, there is a lack of information from Bangladesh, despite its population being among those most exposed to arsenic through natural contamination of drinking water. In this study, we aimed to address this knowledge gap by analyzing data from a prospective As intervention study conducted in Bangladesh.[33] Our goal was to determine whether age, sex, and SES including parental education, predict UAs concentrations in children which is a reliable biomarker of chronic As exposure from drinking water.

Unlike earlier studies that have largely concentrated on the correlation between WAs levels in drinking water and UAs concentration, this study adopts a more comprehensive approach. Our study approach is novel since we thoroughly investigated how demographic and socioeconomic factors predict UAs levels (a biomarker of As exposure) with a particular emphasis on children, a vulnerable group that has not been thoroughly investigated in the past.

2. Materials and methods

2.1. Study area and recruitment

The data used in this study was originally collected from an elementary school-based educational intervention study on children.[33] Elementary education comprises of grades 1 to 5. Participants were recruited from Haizadi, Uchitpur, and Khagkanda, which were the rural administrative units randomly selected from a total of 12 units in Araihazar adjacent to the HEALS study area.[34] The study was conducted in Araihazar to leverage the field setting established by the HEALS study funded by a National Institute of Health (NIH) superfund grant. The sociodemographic, groundwater and geographic characteristics of Araihazar were reasonably good representations of other rural areas in Bangladesh. The families residing in these villages receive groundwater from a household well that is used for drinking and cooking. Participation was limited to one child per family. If multiple children were eligible in one family, the older child was approached to be recruited. Inclusion criteria limited the cohort to children between the ages of 8–11 years old who had regular school attendance, no known physical disabilities, and were enrolled in an age-appropriate grade level. The final cohort consisted of 773 children. In this study, we only use the baseline data collected before the implementation of the school intervention.

2.2. Study approach

Ethical approval was obtained from the Institutional Review Boards at Columbia University Medical Center and the Bangladesh Medical Research Council. The study team approached the parents of the 773 eligible children (mostly mothers) and all of them eventually agreed to voluntarily join the study and subsequently sign the informed consent forms. The field staff also obtained assent from the children. Sociodemographic information, including level of parental education and occupation, home construction characteristics, and access to television media, was collected between March and October of 2008 through structured parental interviews. Following these interviews, water was collected from the household and school wells used by the participating children to test for WAs on site using the Hach EZ As kit (product No. 2822800).[35, 36] Urine samples were collected from a subset of 391 children, who were included in a specific educational intervention group defined elsewhere.[33] All children took a 15-item As knowledge quiz.

2.3. Well water measurement of As

Samples of well-water were collected in 20-ml polyethylene scintillation vials and then acidified using high-purity Optima HCl for at least 48 h prior to analysis to ensure re-dissolution of any iron oxides.[37] These samples were then diluted 1:10 in a solution spiked with 73 Ge and 74 Ge for internal drift correction.[38] High-resolution inductively coupled plasma mass spectrometry was then used to analyze the samples for As.[35] The limit of detection for this method was typically 0.2 μg/L. The long-term reproducibility of WAs measurements determined from consistency standards included with each run averaged 4% (1 sigma) in the 40–500 μg/L range. The two-step Hach EZ As kit was used for on-site field assays. The test involved mixing prepackaged sulfamic acid and zinc powder with 50 ml of the sample from the well-water. Arsine gas (AsH_3) was eventually produced from this mixture. This gas is entrained with H_2 bubbles emanating from the acidified sample and trapped by a strip of paper impregnated with mercuric bromide.[35] As seen in a previous study, this method may underestimate As concentration within the range of 50–100 μg/L, thus recommending a procedure modification that would double the reaction time from 20 to 40 min.[35] Following the conclusion of the 40 min of reaction time, we observed the color intensity of the orange-brown circle on the strip and compared it to a reference scale of various colors corresponding to As concentrations of 0, 10, 25, 50, 100, 250, and 500 μg/L.

2.4. Urinary measurement of As

With the assistance of the participants' parents at their homes, we collected spot urine samples from the children. These samples were collected in 50-ml acid-washed polypropylene tubes and kept in portable coolers. Within six hours of urine collection, the samples were frozen at −20 °C and shipped to Columbia University Trace Metal Core laboratory on dry ice. UAs concentrations were measured by graphite furnace atomic absorption spectrophotometry using a PerkinElmer Analyst 600 system.[39] The detection limit for UAs was 2 μg/L and no samples below the limit of detection were identified. The inter-precision and intra-precision coefficients of variation were reported to be 4.2% and 4.1%, respectively. The laboratory, where UAs was analyzed participated in a quality control program coordinated by the Quebec Toxicology Center, Quebec, Canada. During the study period, intraclass correlation coefficients between our laboratory's values and samples calibrated at the Quebec Toxicology Center laboratory were 0.99. UAs levels were then adjusted for creatine concentrations (dilution factors), and a colorimetric method based on Jaffe's reaction was used to analyze levels.[40]

2.5. As knowledge assessment

The 15-item quiz mentioned above was administered to participants as both pre- and postintervention phases. Each correct answer warranted 1 point for the child. Points were then summated to create a quiz summary score that ranged from 0 to 15 for each participant. Initially, 20 quiz questions were pre-tested in a group of 10 children between age 8 and 10 prior to the study to evaluate cultural suitability and age appropriateness. Questions answered correctly by at least half of the children were shortlisted. In the next step, a focus group was arranged with four teachers from four different schools to further evaluate cultural suitability of the questions and the recommendations of the teachers were incorporated to make further modifications of the quiz questions. Topics that were included on this quiz included potential health effects that may develop due to As exposure, presence of As in environmental media, time required to produce symptoms in As-exposed individuals, types of As-exposure related skin lesions, color codes (green/red) to mark low- and high-As wells, methods for removal of As from drinking water, interventions for arsenicosis patients, and maintenance of low-As wells. We assigned a child as having high As related knowledge if they answered at least 8 out of 15 quiz questions correctly.

2.6. Statistical analysis

All statistical analyses were conducted using Stata 17 (StataCorp LLC, College Station, TX). Summary statistics were computed to describe the sample characteristic. We presented the summary statistics for all 773 children as well as the subset of 391 children with information on their UAs and presented any statistical difference between the full sample and the sub-sample. Using a *t*-test for continuous variables and chi-square test for categorical variables. Normality tests were conducted on continuous variables to assess data skewness, and log-transformations were applied to skewed distributions. We performed multiple regression analyses with heteroskedasticity-robust standard errors. We conducted the regression analysis with and without controlling for village level fixed effects, which accounted for any geographic characteristics that did not change over time and were common to children living in the same village. The main outcome variable for our analysis was urinary arsenic adjusted for creatinine (UAsCr) and the As related knowledge score. We also conducted sub-group analyses to compare the mean UAsCr levels in children, considering various demographic and socioeconomic factors. This was done separately for children with low and high WAs exposure. To evaluate the equality of these means, we implemented a two-sample *t*-test across the demographic and socioeconomic categories. This evaluation was independently conducted for children within the low and high WAs exposure groups. Low WAs were defined as water As concentrations below 50 μg/L, and high WAs were defined as water As concentrations greater than or equal to 50 μg/L.

To capture the demographic and socioeconomic factors, we have variables for parental education, household condition and income source as well as the age and gender of the child. For father's and mother's education, we constructed binary variables that take a value of one if they have more than elementary level education which is more than 5 years of formal education. The variable for household income source is also a binary variable that takes a value of one if the main source of household income is agriculture and zero otherwise. We also constructed a household condition score using information on household building materials for the floor, walls and roof as well as the ownership of radio and television. A higher score for each variable indicated better building materials for the house. We performed exploratory factor analysis to identify and compute composite scores for our aggregate index for the household condition where a higher score indicated better household condition. We defined household condition as poor if the composite score was below zero and was identified as non-poor if the household condition score was greater than or equal zero.

3. Results

3.1. Sample characteristics

The descriptive statistics for the sample characteristics are presented in Table 1. Our sample consisted of 773 school aged children between age 8 and 11 years, which we identified as the "full sample". The urinary measurement of As was conducted for a subset of 391 children out of these 773, and we referred to these children as the "sub-sample". There were no 11-year-old children in the sub-sample who provided urine sample for UAs measurement. Therefore, the children in the sub-sample were within the age range of 8 to 10 years. We compared different outcome variables, child and household characteristics between the "full sample" and "sub-sample" children to demonstrate if the study sample was substantially different from the subset (Table 1). After analysis, the "sub-sample" and the "full sample" for most of the variables did not differ significantly. The manganese level in drinking water was significantly lower in the sub-sample compared to the full sample. The children in the

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sub-sample were slightly older while their heights were marginally lower. In the sub-sample, about 20% of the fathers had more than elementary school education while the number is 13% for the mothers. About 18% of the households reported agriculture as their source of income and about 8% of the households were identified as non-poor according to our definition.

3.2. Regression analysis

We estimated a linear regression model of UAsCr and As related knowledge as a function of father's education, mother's education, household income source, household condition, age, weight, height, and sex of the child (Table 2).

The coefficient on father's education and child's age were negative and statistically significant at the 5% level across all specifications. This indicated that children whose fathers have more than an elementary education and older children have lower UAsCr. The coefficients for mother's education, household income source, poverty status, weight, height, and sex were not statistically significant, indicating a lack of association between these variables and UAsCr.

We performed the same analysis for an outcome variable that measured the level of knowledge about As exposure and health consequences among children. Knowledge level did not seem to differ by parent's education level or household conditions. However, we observed higher knowledge for older and taller children while there was no difference by weight or sex. Furthermore, as the WAs level increased, As knowledge decreased while no such association is observed for water manganese level.

3.3. Sub-group analysis

We also presented the mean level of UAsCr for children by their WAs exposure and different demographic and socioeconomic sub-groups in Figs. 1 and 2. We categorized WAs levels into low and high levels as defined before. As expected, we observed that children who consumed water with higher As level (≥ 50 μg/L) have higher UAsCr on average than those who consumed water with lower As level (< 50 μg/L). This indicated that water was a major source of As exposure for children in this region.

We investigated if the mean UAsCr level of children varied by age and sex for children living with high and low WAs exposure. We found that the mean UAsCr level for younger children was higher than the older children (Fig. 1A). Among children who were exposed to low WAs, the mean UAsCr level was found to be statistically significantly higher for 8 and 9 years olds compared to those aged 10 years (β = 49.92, 95% confidence interval [*CI*]: 8.77 to 91.06) (here "β" indicates the difference in the means of the two groups under comparison). For children with high WAs exposure, younger children aged 8 years have a higher mean UAsCr level compared to the children aged 9 and 10 years (β = 197.95, 95% *CI*: 111.97 to 283.94). We also explored the differences in the mean UAsCr levels by sex (Fig. 1B). While we did not observe any significant difference in the mean UAsCr levels by sex in children with low WAs exposure, we found that female children exposed to higher WAs levels have a higher mean UAsCr level relative to male children (β = 93.95, 95% *CI*: 8.49 to 179.40).

Further, we explored whether the level of As knowledge among children was associated with their UAsCr level. We did not find any significant difference in the mean UAsCr levels of children by their level of As related knowledge (Fig. 1C).

The figures depict the mean urinary arsenic adjusted for creatinine levels corresponding to various child characteristics, segregated by low and high water arsenic levels. The value displayed on each bar indicates the mean urinary arsenic adjusted for creatinine level, while the number within the bar signifies the sample size of that particular subgroup. The error bar represents the 95% confidence interval of the mean.

We also investigated whether children with high or low levels of WAs exposure impacted by parental education. We found that the mean UAsCr level was similar between children with parents who have more and less than elementary school education in areas with low WAs exposure (Fig. 2A and 2B). This indicated that the parent's education level may not be a significant predictor of As exposure in areas with low As contamination. However, for areas with high WAs exposure, there was a significant difference in the mean UAsCr level between children with fathers who have lower than elementary education and those with fathers who have more than elementary education (Fig. 2A). Specifically, children with fathers who have more than elementary education had a lower mean UAsCr level ($\beta = -138.03$, 95% *CI*: −249.58 to −26.47). The difference was not observed by mother's level of education (Fig. 2B). We did not find any significant difference in mean UAsCr levels by the household source of income and poverty level of the household as shown in Fig. 2C and Fig. 2D.

4. Discussion

UAs concentration is a commonly used biomarker of As exposure, as it reflects the total intake of As from all sources and the metabolism of As in the body. Several studies have explored the relationship between WAs exposure and UAs concentration in different populations consistently revealing a positive correlation between the two variables.[41–43] Our study's results further validate this finding, as we observe that children who primarily consume drinking water with elevated As levels exhibit higher UAs levels compared to those with low WAs exposure.

In our study we explored the relationship between the UAs in school-aged children and their individual and household characteristics. We found that younger, female children with fathers having less than elementary education were more likely to have higher UAs levels accounting for geographic variation. Notably, these associations are most pronounced among children exposed to high levels of WAs. A distinctive aspect of our study compared to others in the literature is that even after accounting for WAs exposure, the relationship between these individual and household characteristics and UAs level remains significant. This suggests that these factors influence UAs levels through channels other than high WAs exposure.

Age has been shown to be a statistically significant predictor of UAs in previous studies.[44–46] In the US, a one year increase in age was found to be associated with a 5.2% decrease

(95% *CI*: 6.9% to −3.6%) in total UAs concentration for children between the age of 6 and 17 years.[44] Negative association between As methylation and age for children aged 7–11 years was also found in Yaqui Valley, Mexico.[45] UAsCr was found to decrease with increasing age in Matlab, Bangladesh when compared across children, adolescents and adults.[46] Our finding on the relationship between age and UAs concentration suggests that with each additional year in age, there is an associated decrease of 7.2% in the UAsCr level, relative to the mean in our sample (we calculated this using the regression coefficient on the age variable in Table 2 Column 3 and compared it with the mean UAs level in the sample.). This is in line with previous studies in the literature indicating that younger children may be more susceptible to As exposure.

Gender differences may influence exposure patterns and subsequent UAs levels. In Iran, girls aged 6–11 years had higher UAs than boys in the same age group.[47] Sociocultural factors can influence the types of activities children engage in and the environments they are exposed to. For example, if certain gender roles or occupations involve greater exposure to As sources, such as through specific chores or activities, it could result in differential levels of As in the body. Girls are more likely to engage in excessive household chores than boys.[48] The same pattern is observed in the context of Bangladesh.[49] We only observed the difference in UAs levels by sex for children exposed to high WAs suggesting more frequent contact of female children with As contaminated water. Nutrition is also an important predictor of As toxicity.[50–53] In Bangladesh, gender norms prescribe that females receive small meal portions and make sacrifices in food consumption so that male family members can eat more.[54] In our study, we found that girls had lower mean weight than boys (β =−0.67, 95% *CI*: −1.21 to −0.12). Poor nutrition could also make girls more susceptible to WAs exposure explaining the higher UAs level among female children.

Higher parental education and socioeconomic status may indirectly influence UAs levels.[47] We found that children's UAs level was negatively associated with father's education level but not with mother's education. One possible explanation is that father's education may reflect the socio-economic status of the household, which may affect the availability and affordability of preventive measures against As exposure. For example, households with more educated fathers may have more income and resources to purchase filtered water, access health care services, or buy supplements that can reduce As intake or enhance As excretion. However, we observe that father's education was associated with children's As toxicity even after taking the household condition into account. Moreover, father's education may also influence the awareness and knowledge of the health risks of As exposure and the adoption of protective behaviors, such as avoiding contaminated food or soil, washing hands before eating, or seeking medical help when symptoms occur.[55] While parents' education may affect their own As related knowledge, we did not find any association between parent's education level and child's knowledge on As. Overall, children of educated fathers have a lower the UAs concentration. This finding underscores the importance of education, particularly father's education, in mitigating the health effects of As exposure in high-risk areas.

In contrast, mother's education was not associated with children's UAs level in this context where most of the parents have less than elementary education. In this environment, mother's education may not have a significant impact on the household's socio-economic status or the child's exposure to As sources as mother's education may not translate into higher income or decision-making power in the household, especially if women face discrimination or barriers in the labor market or in the family. The observed pattern could potentially be influenced by the patriarchal culture in Bangladesh. Men of the household often have more influence over decisions related to resource allocation and opportunities, which might include aspects related to health and education.[56–58] We also did not find any association between UAs and household condition or household's source of income. These findings could inform policymakers on allocating resources for knowledge-based interventions to reduce arsenic exposure in communities. Targeting "decision-makers" within households may prove to be the most effective approach to achieve optimal outcomes.

To understand the broader issues surrounding this public health crisis, examinations of structural factors and socio-political context in rural Bangladesh with respect to WAs exposure may provide valuable information for public health practitioners and policy makers. WAs exposure is a pressing rural health issue in Bangladesh and several other South Asian counties affecting the livelihoods of millions of people. About 70% of the population lives in rural areas, where agriculture is the main economic activity. However, agriculture indirectly contributes to As exposure in rural Bangladesh, as irrigation with As-contaminated water can transfer As to crops and food.[59]

Furthermore, the As problem in rural Bangladesh may worsen due to the structural factors associated with climate change and human activities. For example, sea level rise may increase salinity intrusion into coastal aquifers, reducing the availability of fresh water.[60] Deforestation and agricultural intensification may increase soil erosion and sedimentation, affecting the quality and quantity of surface water sources. Seasonal weather shocks such as floods and droughts may also disrupt water supply and increase vulnerability to water-borne diseases.[61] All these factors eventually force people rely heavily on well water often contaminated with As.

Moreover, rural areas suffer from multiple problems such as poverty, inequality, underdevelopment, and environmental degradation. These factors limit the access and affordability of safe water for many rural people, especially those who are poor, marginalized, or discriminated against. For instance, women and ethnic minorities may face barriers to switch to safe wells or collect rainwater due to their low mobility or decision-making power.[62] Additionally, the rural water supply system is inadequate and inefficient to meet the demand and quality standards of the rural population. There is a lack of coordination and accountability among different actors and agencies involved in As mitigation. Corruption and rent-seeking may also hinder the effective delivery and maintenance of water services.[63]

The findings from our study are important from a structural and socio-political point of view because they reveal the unequal distribution of WAs exposure among children in rural Bangladesh. They shed light on the impact of structural factors on urinary As highlighting the need for targeted policy interventions to address these issues from both public health and socio-political perspectives. They underscore the importance of clean water access, education, and gender-sensitive approaches in addressing As exposure in vulnerable communities.

Policies could focus on improving education, particularly in rural areas, and providing resources for safer water options. They also highlight the need for special attention to more vulnerable groups such as younger children, females, and those with less educated parents.

These findings also raise questions about social justice and equity in health. The fact that some groups are more affected by As exposure than others points to systemic inequities that need to be addressed. Policy-makers should consider these structural factors when designing interventions to ensure they are reaching those most at risk.

In terms of global health, this study contributes to understanding the factors influencing As exposure levels in children, particularly in regions with high natural contamination of drinking water like Bangladesh. Furthermore, findings from this study can inform evidence-based policies and interventions to mitigate As exposure and its associated health risks in vulnerable populations, contributing to improved global health outcomes.

5. Limitations

This study has several methodological limitations. Firstly, our analysis using cross-sectional data which in the absence of an experiment does not account for potential endogeneity or reverse causality between child's UAs and the child's socio-demographic characteristics. Secondly, some responses in our data were self-reported which may be subjected to social-desirability or recall bias. Finally, because this study was conducted in a rural setting of a developing country, it remains unknown how generalizable the reported findings are to other places across the world, particularly in urban communities or in As-affected populations in developed countries.

6. Conclusions

This study demonstrated that UAs concentrations in children are influenced by age, sex, and socioeconomic factors especially father's education, in addition to WAs levels. It highlights that younger children, female children, and children with less educated fathers had higher UAs levels, especially when consuming water with elevated As content. While WAs levels are crucial, this research recognizes that other factors could also predict As exposure in low-income communities in a developing country setting. These non-water-related social determinants of health add depth to our understanding of arsenic exposure and highlight that children's vulnerability to arsenic exposure varies based on these factors.

By identifying the most vulnerable sub-groups of children, the most important sources of As exposure, and a reliable biomarker of As exposure, this study can inform policy makers what factors would require special consideration while designing As exposure mitigation programs for school children. For example, policy makers can prioritize screening and providing safe water sources, nutritional supplements, or chelation therapy to younger, female, and low-SES children. Moreover, the study can assist policy makers in assessing the economic and social impacts of As exposure in children and in addressing the environmental justice issues related to As contamination, such as whether socio-economically disadvantaged children bear a higher burden of As poisoning. Findings of our study will help develop As-related clinical trials and intervention programs that are aimed to reduce As exposure and toxicity in vulnerable sub-populations in Bangladesh and other South and Southeast Asian countries.

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Availability of data and materials

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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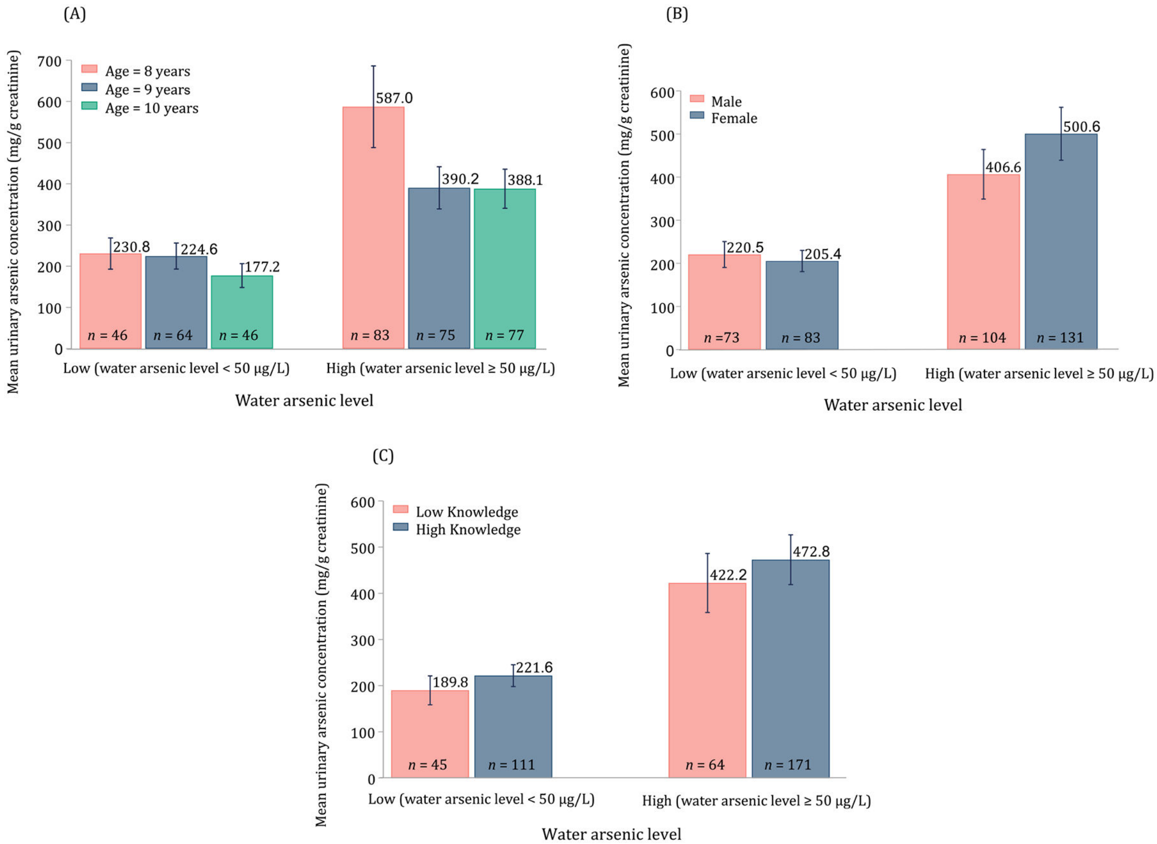

Fig. 1.

Comparison of mean urinary arsenic levels in children by age (A), sex (B) and arsenic related knowledge (C), stratified by arsenic levels in drinking water.

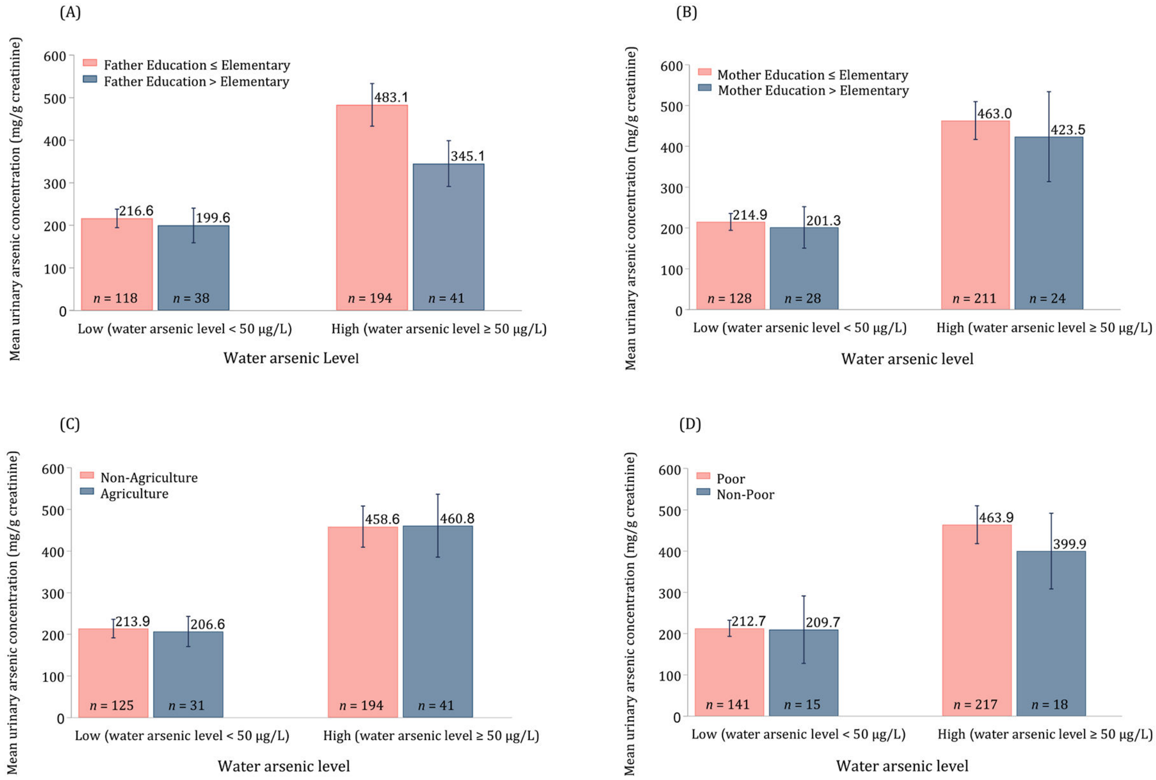

Fig. 2.

Comparison of mean urinary arsenic levels in children by parental and household characteristics, stratified by arsenic levels in drinking water. (A) Father education; (B) Mother education; (C) Source of income; (D) Poverty level.

Note: The figures depict the mean urinary arsenic adjusted for creatinine levels corresponding to various household characteristics, segregated by low and high water arsenic levels. The value displayed on each bar indicates the mean urinary arsenic adjusted for creatinine level, while the number within the bar signifies the sample size of that particular subgroup. The error bar represents the 95% confidence interval of the mean.

Table 1

Descriptive statistics on the characteristics of the participants.

Characteristics	**Sub-sample**[※] **(*n* = 391)**	**Full sample**[†] **(*n* = 773)**	***P*** [‡]
Urine Arsenic concentration (mg/g creatinine)	360.63 ± 294.72	360.63 ± 294.72	-
Water Arsenic (μg/L)	104.35 ± 127.09	119.3 ± 149.55	0.326
Water Manganese (mg/L)	1.21 ± 0.83	1.37 ± 0.84	0.001
Height (cm)	127.09 ± 8.0	128.3 ± 7.69	0.011
Weight (kg)	23.17 ± 3.91	23.51 ± 3.86	0.129
Arsenic knowledge (score)			
Total score < 8	109 (27.9)	227 (29.4)	0.596
Total score ≥ 8	282 (72.1)	546 (70.6)	
Age (years)			
8	129 (33.0)	298 (38.6)	0.033
9	139 (35.5)	284 (36.7)	
10	123 (31.5)	188 (24.3)	
11	0 (0.0)	3 (0.4)	
Female	214 (54.7)	417 (53.9)	0.799
Father's education more than elementary level	79 (20.2)	176 (22.8)	0.318
Mother's education more than elementary level	52 (13.3)	119 (15.4)	0.340
Main income source is agriculture	72 (18.4)	152 (19.7)	0.610
Non-poor	33 (8.4)	85 (11.0)	0.172

Values are expressed as mean ± standard deviation for continuous variables and *n* (%) for categorical variables. Variables indicating father's and mother's education, household income source, non-poor household condition and female are binary variables taking a value of one when the condition specified in the variable name is fulfilled. All other variables are in their original measured units. For the variable "Urine arsenic concentration (mg/g creatinine)" the sample size in both full- and sub-sample is 391.

[※] The final cohort of all children selected for the study.

[†] The subset of the full sample selected for the UAs measurement.

The *P*-values for group differences between the sub-sample and the full sample are reported using a *t*-test for continuous variables and chi-square test for categorical variables. Continuous variables are log-transformed prior to performing the *t*-test. -: Not applicable.

Table 2

Determinants of urine arsenic concentration and arsenic related knowledge among children.

Variables	Urine arsenic concentration (mg/g creatinine)									Arsenic related knowledge (total score)								
	Model 1			Model 2			Model 3			Model 4			Model 5			Model 6		
	β ± *SE*	*t*	*P*	*β* ± *SE*	*t*	*P*	*β* ± *SE*	*t*	*P*	*β* ± *SE*	*t*	*P*	*β* ± *SE*	*t*	*P*	*β* ± *SE*	*t*	*P*
Father's education more than elementary level	−79.08 ± 26.14	−3.02	0.003	−69.09 ± 25.82	−2.68	0.008	−47.29 ± 18.99	−2.49	0.013	−0.11 ± 0.26	−0.42	0.678	−0.09 ± 0.26	−0.35	0.727	−0.11 ± 0.26	−0.43	0.666
Mother's education more than elementary level	−34.05 ± 38.67	−0.88	0.379	12.99 ± 40.34	0.32	0.748	3.58 ± 27.54	0.13	0.897	0.48 ± 0.29	1.66	0.097	0.17 ± 0.30	0.59	0.558	0.18 ± 0.30	0.6	0.550
Main income source is agriculture	−2.11 ± 31.76	−0.07	0.947	−34.96 ± 32.31	−1.08	0.280	−45.02 ± 27.55	−1.63	0.103	0.13 ± 0.24	0.53	0.599	0.09 ± 0.25	0.37	0.712	0.08 ± 0.25	0.32	0.749
Household condition score	12.44 ± 15.04	0.83	0.409	−15.56 ± 16.53	−0.94	0.347	−2.94 ± 13.34	−0.22	0.826	0.17 ± 0.12	1.46	0.144	0.12 ± 0.12	0.98	0.328	0.13 ± 0.12	1.05	0.292
Age (years)	−73.29 ± 23.21	−3.16	0.002	−40.37 ± 17.94	−2.25	0.025	−25.77 ± 12.70	−2.03	0.043	0.50 ± 0.13	3.96	< 0.001	0.80 ± 0.14	5.87	< 0.001	0.81 ± 0.14	5.87	< 0.001
Height (cm)	2.14 ± 3.30	0.65	0.517	4.70 ± 3.06	1.54	0.126	2.24 ± 2.60	0.86	0.389	0.07 ± 0.02	2.90	0.004	0.05 ± 0.02	2.04	0.042	0.05 ± 0.02	2.05	0.041
Weight (kg)	−3.30 ± 6.44	−0.51	0.609	−10.78 ± 5.80	−1.86	0.064	−10.14 ± 5.57	−1.82	0.070	−0.01 ± 0.05	−0.30	0.766	−0.01 ± 0.05	−0.28	0.782	−0.01 ± 0.05	−0.26	0.795
Female	49.31 ± 29.00	1.70	0.090	35.41 ± 27.02	1.31	0.191	23.61 ± 21.91	1.08	0.282	0.10 ± 0.19	0.55	0.582	0.10 ± 0.19	0.52	0.604	0.13 ± 0.19	0.70	0.484
Water arsenic level	–	–	–	–	–	–	1.38 ± 0.29	4.84	< 0.001	–	–	–	–	–	–	−0.00 ± 0.00	−2.38	0.018
Water manganese level	–	–	–	–	–	–	−7.23 ± 19.94	−0.36	0.717	–	–	–	–	–	–	0.15 ± 0.13	1.12	0.261
Constant	818.09 ± 328.71	2.49	0.013	373.75 ± 283.40	1.32	0.188	410.36 ± 233.92	1.75	0.080	−4.10 ± 2.21	−1.86	0.064	−4.41 ± 2.26	−1.95	0.052	−4.51 ± 2.26	−1.99	0.047
Observations	391	–	–	391	–	–	391	–	–	773	–	–	772	–	–	772	–	–
R^2	0.067	–	–	0.297	–	–	0.553	–	–	0.077	–	–	0.160	–	–	0.168	–	–
Number of villages	15	–	–	15	–	–	15	–	–	27	–	–	27	–	–	27	–	–
Village fixed effects	No	–	–	Yes	–	–	Yes	–	–	No	–	–	Yes	–	–	Yes	–	–

β: Estimated regression coefficient, *SE*: Standard error. Variables indicating father's and mother's education, household main income source and female are binary variables taking a value of one when the condition specified in the variable name is fulfilled. Household condition score is the index constructed using exploratory factor analysis. All other variables are utilized in their original measured units. Model 1 and Model 4 include father's education, mother's education, main income source, household condition score, age, height, weight and gender of the child. Model 2 and Model 5 are extended to include village fixed effects or binary variables for each village to account for time invariant geographic characteristics at the village level. Model 3 and Model 6 additionally control for exposure to water arsenic and water manganese levels. -: Not applicable.