

# Does Arsenic-Contaminated Drinking Water Limit Early Childhood Development in Bangladesh?

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## Abstract

Arsenic contamination in shallow groundwater aquifers remains a major barrier to providing access to safe drinking water in Bangladesh. Chronic exposure to arsenic has been shown to cause serious health impacts, including various cancers, skin lesions, neurological damage, heart disease, and hypertension. Numerous epidemiological studies have shown cognitive impacts on memory, linguistic-abstract, attention, learning, and physical ability. The neurotoxic effects of arsenic could be particularly harmful for children during their critical growth periods and have impacts on early childhood development. This study uses cross-sectional data from the nationally representative 2012–13 Bangladesh Multiple Indicator Cluster Survey to investigate the effects of arsenic contamination in drinking water on early

childhood development outcomes in a sample of around 7,500 children ages 3–5 years. Early childhood development is measured in four skills domains: literacy-numeracy, physical, social-emotional, and learning using the Early Childhood Development Index. Arsenic contamination is measured in source drinking water at the cluster-level. After controlling for a range of demographic, social, and economic characteristics of households, the results show that arsenic contamination is significantly and negatively associated with the overall Early Childhood Development Index, on outcomes within the physical, social-emotional, and learning skills domains. Further, there is a clear dose-response relationship, where those children with exposure to higher concentrations of arsenic have worse developmental outcomes.

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# Does Arsenic-Contaminated Drinking Water Limit Early Childhood Development in Bangladesh?

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# 1. Introduction

Population exposure to inorganic arsenic through drinking water supply continues to be a public health issue across the world, from numerous regions of the Americas to Asia. Naturally occurring inorganic arsenic in groundwater has particularly overwhelmed Bangladesh, in what has been deemed the “largest mass poisoning of a population in history” (Smith et al., 2000). An estimated 35 million to 77 million Bangladeshis were chronically exposed to some level of arsenic through drinking water from 2000 to 2010 alone (Flanagan, et al., 2012). The exact mechanisms of the natural occurrence of arsenic in groundwater supply have been hypothesized and debated and can vary depending on hydrogeological and physiogeological contexts of regions in Bangladesh (Burgess, et al., 2010; Ravenscroft, et al., 2005). However, the presence of arsenic in drinking water supply and its effects on human health have been well documented since its discovery in well water in the early 1990s in Bangladesh. Though arsenic presents itself as colorless, odorless, and tasteless in drinking water, the heavy metal causes severe health impacts ranging from skin lesions to various deadly cancers and diseases (Ravenscroft, et al., 2009).

Similar to other heavy metals, such as lead, mercury, and manganese, arsenic can also penetrate the blood-brain barrier and have neurotoxic effects that may lead to irreversible neurological and cognitive damage. Numerous epidemiological studies have demonstrated adverse effects of arsenic on cognitive performance in both children and adults. For example, Wasserman et al. demonstrated in two separate studies that children exposed to low to moderate levels of arsenic had overall lower intellectual functioning among 10-year old and 6-year old Bangladeshi children (Wasserman, et al., 2004) (Wasserman, et al., 2007). A few studies additionally report the specific domains of cognitive function that are most impacted by arsenic in school-aged children including negative effects on memory, ability to focus and solve problems, sensory and motor function, and verbal and linguistic capability (Rosado, et al., 2007) (Asadullah & Chaudhury, 2008; Parvez, et al., 2011; Tsai, et al., 2003). Apart from the literal neurotoxic effect of arsenic poisoning, there are reasonable speculations on the indirect effect of arsenic poisoning on economic opportunities primarily acting through health status and cognitive abilities of victims. As such, those suffering from symptoms of arsenicosis have poorer health status and may subsequently have relatively poorer school or work attendance and performance. Victims may even be ostracized from public settings (Asadullah & Chaudhury, 2008). Murray and Sharmin, for example, observed that Bangladeshi children (aged 6-10 years) who drank arsenic-

contaminated water attended fewer days of school per year compared to those who drank arsenic-free water. The study further found that young adults (aged 19-21 years) who relied on arsenic-contaminated water had six months less schooling, on average, compared to their counterparts who drank arsenic-free water (Murray & Sharmin, 2015). On productivity, one study estimates that lowering the concentrations of retained arsenic among Bangladeshi prime-aged males to those levels found in unaffected countries would increase earnings by 9 percent (Pitt, et al., 2012).

Although there is significant evidence on the damaging effects of arsenic on cognitive function and educational attainment, the bulk of the literature notes these effects among adolescent-aged children and young adults, with relatively little focus on very young children. Yet, exposure to arsenic could be most harmful during the initial critical windows of growth when the developing brain is most sensitive (Rice and Barone, 2000; Kile, et al., 2016; von Ehrenstein, et al., 2007). Therefore, reduced cognitive and educational attainment in later childhood and adulthood could be an accumulative result of arsenic exposure during in utero and early childhood. Before a child even sets foot in school, he or she may already have vastly different cognitive abilities than his or her classmates, which may have significant implications for future individual health, education, and livelihood.

In this paper, we seek to measure the magnitude of the effect of varying levels of arsenic concentration in drinking water on early childhood development skillsets in children aged 3-5 using nationally representative household survey data. We ask: does arsenic exposure through drinking water lead to relatively poorer performance in skills related to healthy early childhood development? Such an effect would be consistent with evidence on the impact of arsenic poisoning on intellectual function and educational attainment and further motivate the prioritization of arsenic mitigation in Bangladesh for not only water and health policy, but also for early childhood development and education policy. We additionally attempt to determine the particular types of skills that arsenic poisoning can inhibit. We specifically examine the effects of arsenic on physical, social-emotional, literacy-numeracy, and learning skills domains and observe differences in effects experienced by the poor and non-poor.

We present an econometric analysis using cross-sectional data from the 2012-2013 Bangladesh Multiple Indicator Cluster Survey (MICS). To examine early childhood development, we analyze scores from the Early Childhood Development Index (ECDI), a novel 10-item module developed by UNICEF to monitor performance indicators for basic skills related to good early childhood development. In measuring childhood exposure to arsenic, we use MICS results from arsenic testing at a child's household water source used for drinking. We quantify arsenic exposure in three ways: 1) based on the WHO guideline for safe levels of arsenic for human consumption of less than 10 parts

per billion (ppb) of arsenic; 2) based on the Government of Bangladesh (GoB) standard of less than 50 ppb of arsenic; and 3) based on a combination of the WHO and GoB standards by categorizing three risk levels as low risk (0-10 ppb), medium risk (11-50 ppb), and high risk (51+ ppb). After controlling for a range of demographic, social, and economic characteristics of households, the results from the logit regression models show that arsenic contamination is significantly and negatively associated with the overall ECDI measurement, and specifically on outcomes within the physical, social-emotional, and learning skills domains. Further, there was a clear dose-response relationship, where those children with exposure to higher concentrations of arsenic had relatively worse developmental outcomes. Moreover, children from non-poor households significantly had better results on the EDCI than children from poor households when exposure status of arsenic was comparable. However, non-poor children who are exposed to arsenic had worse development outcomes than poor children who are not exposed.

The paper contributes to the literature on arsenic and cognitive development in three ways. One is that it specifically examines the developmental effects of arsenic poisoning in younger child populations. It also demonstrates a clear dose-response relationship and compares the effects based on both WHO and Bangladesh water quality standards. Finally, it utilizes a large nationally-representative sample size of around 7,500 children aged 3-5 and observes differences in poor and non-poor populations. The paper continues in four sections. Section 2 provides a background on arsenic contamination in drinking water in Bangladesh and summarizes evidence on arsenic's subsequent effects on health and cognition to corroborate why there could be a negative effect of arsenic on early childhood development skill domains. Next, section 3 describes the data used for the analysis and the methods for building the logistic regression models, and section 4 presents the results. Finally, section 5 discusses the findings and policy implications of the presented analysis.

## 2. Background: Arsenic contamination in Bangladesh and its effects on health and cognition

Arsenic poisoning from drinking water in Bangladesh was ironically an unintended consequence of campaigns that aimed to increase population access to safe and clean water. During the 1970s, international organizations and NGOs encouraged Bangladeshi households to stop drinking from surface water sources such as ponds, rivers, and lakes, which are highly susceptible to fecal and

industrial pollution that can lead to an array of water-borne and diarrheal diseases (Field, et al., 2011). Unlike surface water sources, groundwater sources are more protected from microbial contamination because they are not exposed in the open and are naturally filtered through bedrock and sediments. Millions of groundwater tubewells were thus installed throughout Bangladesh from the 1970s onwards (Smith, et al., 2000).

However, in the early 1990s, there were emerging signs that Bangladeshis primarily from rural areas were developing signs of arsenicosis, a common effect of prolonged arsenic poisoning marked by skin discolorations and lesions, cancers, blood vessel diseases, and other disorders (Smith, et al., 2000). After there was enough evidence to document the scale of the problem, a massive testing campaign was launched in 1998 to test tubewells for the presence of arsenic in areas with high incidence of reported arsenicosis. By 2005, the testing campaign resulted in millions of tubewells that were painted red to indicate that a tubewell exceeded the Bangladeshi standard arsenic concentration level of 50 ppb (Benear, et al., 2013). The most recent estimates indicate that about 25 percent of all tubewells across Bangladesh exceed the WHO recommended safe levels of arsenic at 20 ppb (Flanagan, et al., 2012).

Even with advancements in mitigation strategies, millions of Bangladeshis are still at risk for arsenic poisoning today from contaminated drinking water, soil, and crops (Flanagan, et al., 2012). The effect of arsenic poisoning on human health has long been established. Exposure to arsenic is associated with several dose-dependent illnesses, such as cancer of the lung and bladder, cardiovascular and pulmonary disease, and skin lesions (Smith et al., 1998; Sohel et al., 2009; Flanagan et al., 2012). Ingestion of arsenic has also been shown to contribute to poor pregnancy-related outcomes, including spontaneous abortion, low-birth weight, and other pregnancy complications (Kile, et al., 2014; Kile, et al., 2016). At an individual-level, the degree of toxicity of arsenic can depend on a person's general health, genetics, and diet (Anawar, et al., 2002; Karim, 2000). Population-wide studies in Bangladesh have found that hyperpigmentation and keratosis are the most diagnosed health effects of chronic arsenic poisoning followed by skin cancer and other internal cancers (Karim, 2000; Yu, et al., 2003). However, it is conjectured that arsenic contributes to other dysfunctions that are more difficult to diagnose or attribute solely to arsenic poisoning (Pitt, et al., 2012).

Neurological damage is perhaps one of the more hidden consequences of arsenic poisoning; yet there is growing research to indicate that there are significant population effects on cognitive dysfunction. One of the first epidemiological studies to note correlations between arsenic exposure and neurological damage in children is by authors Calderon et al. (2001). Using the Weschler

Intelligence Scale for Children (WISC), Calderon et al. demonstrate impairments in long-term memory and linguistic abstraction in Mexican children aged six to nine years old. Wasserman et al. (2004) and (2007) show similar neurologic consequences in Bangladeshi children. In a cross-sectional study of 10-year old children in Arhaizar, Bangladesh, it was found that those children exposed to arsenic levels greater than 50 ppb in drinking water tested worse on the WISC in Performance raw scores compared to those children exposed to less than 5.5 ppb arsenic in drinking water. Children in the highest quartile of arsenic exposure scored on average 10 points lower in Performance raw scores compared to the lowest quartile. The Performance score measured accuracy in picture completing, coding, block design, and maze tests, while arsenic exposure was measured by testing household water sources (Wasserman, et al., 2004). Later in 2007, a second study by Wasserman et al. implemented comparable intellectual functioning tests to a younger subset of children at age six. Although not as strong of an association as seen among 10-year old children, the authors saw a significant decline in raw scores dependent on a child's exposure to arsenic in well water (Wasserman, et al., 2007). These results complement an earlier study in Taiwan, China, which found strong negative correlations between well-water arsenic and similar Performance-type tests for older children (Tsai et al, 2003).

Additionally, Rosado et al. (2007) found a negative impact on memory and the ability to focus and solve problems among children aged 6-8, while Asadullah and Chaudhury (2008) showed that adolescent male Bangladeshi children who were exposed to arsenic at home had lower mathematics scores in school compared to those who had no contact with arsenic (Asadullah & Chaudhury, 2008). Most studies observing links between arsenic and cognitive function in children only examine children's current exposure status to arsenic. However, von Ehrenstein et al. consider in-utero arsenic exposure as well as present arsenic concentration exposure in children aged 5-15 years old in West Bengal. Again, using the WISC, the authors found a negative correlation between raw scores and current arsenic exposure status; however, they did not find a significant association between raw scores and arsenic exposure during pregnancy as hypothesized (von Ehrenstein et al., 2007).

Aside from intellectual functioning, there is strong evidence asserting other arsenic-related neurological impairments including motor disabilities. In a cross-sectional study of children aged 8-11 years old in rural Bangladesh, Parvez et al. observed impairments particularly in fine manual control and body coordination skills (Parvez et al., 2011), while Tseng et al. (2006) found impairments in motor and sensory nerve peripheral conduction. However, unlike this paper, these studies do not examine young children to observe effects in early childhood development.



## 3. Methodology

### 3.1 Data

We use cross-sectional data from the nationally representative 2012-13 Bangladesh Multiple Indicator Cluster Survey (MICS) to investigate the effect of arsenic contamination in drinking water on early childhood development outcomes in a sample of 7,502 children aged 3-5 years. The Bangladesh 2012-13 MICS is a nationally representative survey with health, nutrition, socio-economic, education, and housing characteristics indicators on women and children across urban and rural areas of the 7 divisions and 64 districts of Bangladesh. In answering our research question, we particularly examine indicators on arsenic contamination in household drinking water and early childhood development. The 2012-2013 MICS provides the latest nationally-representative data on household arsenic contamination and is the first to provide nationally-representative data on early childhood development skills domains.

To estimate arsenic exposure, we use the results from water quality testing conducted in the MICS. For the arsenic test, the MICS team randomly selected 5 households per cluster of 20 households and collected a water sample at the household's reported source point for drinking water. Arsenic was measured by the MICS team using the Arsenic Econo-Quick Test Kit (Industrial Test Systems, USA) and lab tests (UNICEF, 2015). Our main independent variables of interest are arsenic exposure from household drinking water wherein arsenic levels are constructed in three different ways. The first arsenic indicator variable is constructed as a binary variable, where the variable takes a value of 1 if the level of arsenic exceeds 10 ppb as per the WHO Drinking Water Quality Guidelines and takes a value of 0 otherwise. The second arsenic indicator variable is also constructed as a binary variable, where the variable takes a value of 1 if the level of arsenic exceeds 50 ppb as per the Bangladesh standard (UNICEF, 2015) and takes a value of 0 otherwise. The last arsenic indicator is an ordinal categorical variable using the following groups: low-risk (<10 ppb), medium-risk (11-50 ppb), and high-risk (>50 ppb). The categorical variable was constructed in order to examine a wide range of arsenic exposure to evaluate a dose-response relationship. It also provides a convenient variable to compare the WHO and Bangladesh national arsenic standards.

Early childhood development is estimated using results from the Early Childhood Development Index (ECDI), a novel monitoring tool created by UNICEF in 2007 to determine whether children

aged 3-5 years are developmentally on track. The index is based on a 10-item module on milestones a child is expected to reach by ages 3 and 4. Table 1 describes each item and how it fits into the four domains under study – literacy-numeracy, learning, physical, and social development. In this analysis, ECDI and each of the four domains are represented by binary variables, which take a value of 1 if the criteria in Table 1 are met. If a child is on track in 3 out of 4 domains, he or she is considered to be overall developmentally on track on the ECDI scale. In order to reflect this, a composite Early Childhood Development Index (ECDI) is constructed for every child such that the ECDI will take a value of 1 if a child meets at least three out of the four domains above.

### 3.2 Empirical strategy

Based on existing evidence, a negative correlation is expected between arsenic and early childhood development as measured by the ECDI and its four domains. Moreover, the association is expected to be stronger as the level of arsenic in drinking water increases. Logit regression analysis is used to estimate the association between arsenic contamination in drinking water and the combined ECDI and the four component domains, controlling for socio-economic and demographic factors that influence a child’s cognitive development. The following equation is estimated.

$$ECD_{ijk} = \alpha + \beta Child_{ijk} + Household_{jk} + WASH_{jk} + Arsenic_{jk} + Community_k + \varepsilon_{ijk} \quad (1)$$

Where  $ECD_{ijk}$  are the outcome variables of interest, which are: ECDI, literacy, physical, social and learning domains; and  $Child$ ,  $Household$ , and  $Community$  explanatory variables denote child, household and community characteristics. Arsenic exposure ( $Arsenic_{jk}$ ) is specified in three ways: (1) above 10 ppb; (2) above 50 ppb; and (3)  $x \leq 10$  ppb,  $10 < x \leq 50$  ppb, and  $x > 50$  ppb. To increase the sample size and improve robustness, the arsenic result from the tested household is applied to all households within the survey cluster.<sup>1</sup> This is based on the assumption that if a household water source is contaminated, then all households that use the same type of water source in the vicinity are likely to have similar levels of arsenic. Other explanatory variables in the three specifications include child’s age, child’s sex, whether he/she has ever been breastfed, maternal education, household location, household size, wealth quintile, type of sanitation facility, type of drinking water source, and water treatment. Breastfeeding (if a child has ever been breastfed) is included in the analysis to account for its impact on cognitive development and is expected to have a positive relationship with ECDI

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<sup>1</sup> Cluster is the primary sampling unit (PSU), which is composed of about 250 households from which 20 households are randomly sampled for the survey which (MICS, 2015).

performance based on past evidence (Quin et al., 2011). Likewise, maternal education is linked with early childhood development, specifically in relation to behavior and school performance (Carneiro 2007; Andrabi et al., 2009). Maternal education is represented by a variable comprising of three categories – no education, primary or lower education, and secondary or higher. On household wealth, several studies have shown that socioeconomic conditions are positively associated with cognitive development (pertaining to high IQ and language receptivity) and fewer behavioral problems (Duncan, 1994; Schady et al., 2014). In this analysis, household wealth quintiles are constructed using a principal component analysis, which accounts for ownership of durable goods, land, and animals. There is similar evidence indicating that access to both water and sanitation is crucial for proper cognitive development primarily through its effects on nutritional status and educational attainment (Bartram, 2006; Spears and Lamba, 2013; Adukia, 2016). The effect of water and sanitation is captured here through information on whether a household has access to an improved sanitation facility and improved water.<sup>1</sup> To account for water safety–related behaviors, this analysis also includes information on whether households use appropriate treatment methods such as boiling, adding bleach/chlorine, using a filter,<sup>2</sup> and solar disinfection to remove pathogens (MICS, 2015). Finally, a Huber-White matrix is used to correct standard errors for non-independent child observations at the household level (Zenger 1993; Liang and Zeger, 1993). District-effects were not added because arsenic exposure is strongly influenced by geography, meaning that only some districts are affected by arsenic. Instead, the analysis was done in a sub-sample of districts with reported arsenic issues. Similar results were found and can be given upon request. The three specifications of arsenic exposure are repeated to examine their relationship between overall ECDI performances and each of the four domains, separately.

### **3.3 Descriptive statistics**

Table 2 reports the summary statistics, giving the weighted mean values of the variables used in the logit model. About 65 percent of children aged 3-5 years are developmentally on track based on the Early Childhood Development Index (ECDI), suggesting that almost two-thirds of the child population meets at least three of the four domains. Of the four domains in the ECDI, literacy and numeracy standards are the least met, with only 21 percent of children being able to recognize words,

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<sup>2</sup> Filters have been shown to remove some arsenic from water (MICS, 2015).

letters of the alphabet, or numbers. Learning standards are met by 89 percent of children, while physical and social standards are met by 93 percent and 90 percent of children respectively.

When examining household arsenic exposure, about 27 percent of all children are exposed to arsenic based on the WHO standard of >10 ppb compared to 13 percent when using the Bangladesh standard of >50 ppb. About 73 percent, 14 percent, and 13 percent of children fall into the no-to-low risk, medium risk, and high risk exposure groups, respectively. Arsenic is most prevalent in water from tubewells. In contrast, less than 1 percent of households that use piped water and other sources are contaminated.<sup>3</sup> It should be noted that over 90 percent of the households in the sample use tubewells.

Figure 1 shows that arsenic risk levels are evenly distributed across wealth quintiles. This indicates that arsenic contamination is not influenced by wealth and affects households across all wealth quintiles. However, early childhood development performance does vary by wealth quintiles. When disaggregated by household wealth, more children are developmentally on track in Quintile 5 (76 percent) compared to Quintile 1 (62 percent). This trend is primarily driven by the literacy domain, where children from wealthier households perform better. In the other three domains, there is no clear difference between the number of children who are on track and those who are not across the different wealth quintiles.

## 4. Results

### 4.1 Overall ECDI

Table 3 presents the marginal effects from the logit model used to examine the relationship between ECDI and three specifications of arsenic exposure. After controlling for individual, household and community characteristics, the results from the logistic regression models report that arsenic exposure is significantly and negatively associated with the overall ECDI. Specifically, the presence of arsenic in drinking water above the WHO standard of greater than 10 ppb (specification 1) reduces the likelihood of being developmentally on-track by about 7 percentage points while the presence of arsenic above the Bangladesh standard of 50 ppb (specification 2) reduces the likelihood by about 11 percentage points. Based on specification (3) where the explanatory variable of interest is the intensity risk levels of arsenic in drinking water, the analysis further reveals that there is a clear dose-response

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<sup>3</sup> The piped water category includes piped into dwelling, piped into compound, yard or plot, piped to neighbor, and public tap/standpipe. Other sources include protected well, protected spring, unprotected well, unprotected spring, cart with small/tank drum, and surface water (river, stream, dam, lake).

relationship, where those children with exposure to higher concentrations of arsenic tend to have worse developmental outcomes. Medium-risk of arsenic concentration (between 11-50 ppb) reduces the chances of attaining overall child development by about 4 percentage points compared to the low risk group (0-10 ppb) while high concentration of arsenic (above 50 ppb) reduces this by about 12 percentage points compared to the low risk group.

The association between maternal education and ECDI is the highest with a 14 percentage point increase in ECDI performance if a child's mother has completed secondary education or higher compared to a mother with no education. The findings also indicate that female children are more likely to be developmentally on track compared to male children. Household characteristics and behavior such as improved sanitation and water treatment both increase the likelihood of being developmentally on track. Household wealth matters only if a household is in the topmost quintile, where the probability of being on track increases by 5 percentage points compared to the bottom quintile.

While the incidence of arsenic is nearly uniform across wealth quintiles as seen in Figure 1, its effects on early childhood development outcomes are considerably different when disaggregated by wealth quintiles. As an illustration, Figures 5 and 6 show the marginal impact of arsenic on overall ECDI for the B40 and T60 using the WHO and Bangladesh standards. Children living in households that consume arsenic contaminated water tend to perform relatively worse in meeting the ECDI regardless of whether they belong to the B40 or T60. In fact, children belonging to B40 households without arsenic appear to perform better than children in T60 households with arsenic indicating that the arsenic contamination more than offsets the advantages of belonging to a non-poor household. Similar patterns are reflected in the learning outcomes as well.

#### **4.2 Individual ECD domains**

Arsenic exposure has a strong negative association in three out of four domains – learning, physical, and social development. The effect of arsenic contamination on the child's achievement in the literacy domain was found to not be significant.

The likelihood of a child being literate at a very young age of three to five years is strongly associated with household wealth, maternal education, improved sanitation, water treatment, household size, and child's age (Table 4). Here, arsenic has no effect on literacy, regardless of what standard is used to define contamination. Though the bulk of the literature would suggest a strong effect on literacy, the reason for this result could be due to the fact that a very small proportion of children were found to be on track for literacy development, regardless of arsenic status. Only 21

percent of the total sample size met the literacy requirements (Table 2). Still, maternal education has the largest impact with a 12 percentage point increase in the likelihood of a child being literate if he or she has a mother who completed primary school or above, compared to a mother with no education. Having improved sanitation and treating water at home increase the probability of child literacy by 5 and 7 percentage points, respectively.

Arsenic contamination has a significant negative influence on a child's performance in the learning domain (Table 5). In the first two specifications, a shift from no contamination to some contamination leads to a 3 percentage point decrease in the likelihood of a child meeting the learning criteria. Factors that positively influence child learning include breastfeeding, age, maternal education, and household size. Improved sanitation has a small and significant impact with a 1 percent association. Breastfeeding has a substantial effect with a 5 percentage point increase in the likelihood of being on track in the learning domain.

Table 6 reports a negative association between physical development and arsenic contamination. The magnitude of the correlation increases from 2 percent in specification (1) to 3 percent in specification (2), indicating a greater negative impact on physical development at higher levels of contamination. Improved water has an unexpected negative association with physical development. This might be attributed to poor water quality despite improved coverage.

Finally, social development is also found to be negatively affected by arsenic contamination (Table 7). In specification (1), a shift from no arsenic to some contamination (WHO standard) leads to a 6 percentage point decrease in the likelihood of a child being on track for social development. The magnitude is greater (8 percentage points), when a Bangladesh standard is used in specification (2). This change is further illustrated in specification (3), where the association triples from a 3 percentage point decrease with medium exposure to a 9 percentage point decrease at high exposure, with no arsenic as the reference category. Other factors that play a role in social development include maternal education, child's age and sex. A female child is more likely to be socially developed compared to a male child. In addition, a mother's completion of primary education can lead to 3 percentage point increase in the probability of a child's social development, with no education as the base category.

## 5. Discussion

The results of this paper complement other findings from epidemiological studies on arsenic and cognitive development. This paper adds some noteworthy advancement to the literature base. One is that arsenic developmentally hinders children as young as age 3, highlighting the importance of

intervening in the early years. Second, it shows that children regardless of socio-economic status are at risk for effects of arsenic poisoning. Third, it reports a clear dose-response relationship, where increasing levels of arsenic increase the likelihood for developmental impairment. Finally, it confirms that children are sensitive to even small doses of arsenic that are less than the current Bangladeshi national standard of 50 ppb.

There are, however, limitations to this analysis that should be considered when interpreting the results. Some limitations surround the validity of how arsenic exposure is defined in the analysis. As reported in the methodology, arsenic was only tested randomly for 5 households per cluster in the original MICS data set. However, in order to increase the sample size, the result of the five arsenic test is applied to the rest of the households in that cluster. Although it is likely that households in close vicinity and with the same water source would have similar risks of arsenic exposure, it is still an assumption to believe all households in the same cluster would have the same arsenic concentration in their respective water sources. To reduce the impact from this assumption, households with dissimilar types of water sources from the tested household in the cluster were eliminated from the sample (i.e. if the tested household had a tube well, then households that had piped water in the cluster were not included in the sample). Yet, it is possible that even households with the same type of water source have different concentrations of arsenic levels.

Another limitation is the assumption that children's exposure to arsenic equates the concentration of arsenic in their household's water source. Although children aged 3-5 are most likely regularly drinking from their household's water source (i.e. are no longer breastfeeding), they could be consuming arsenic from other sources such as soil and food. The analysis also cannot account for past exposure such as from in utero or if a child lived in a different area. Biological specimens such as urine, toenails, or blood could have been a better proxy for actual exposure levels, but the data were limited in this regard.

The ECDI measurement also has some limitations. The ECDI is a mother-reported measurement of child development, which can introduce some bias. The ECDI may also not be able to capture the severity of disability, as mothers are only able to give yes or no responses. Nevertheless, the ECDI enables a better national-scale approximation of early childhood development than was previously possible. To our knowledge, only one other study utilizes the ECDI to measure population effects on child development (Miller, et al., 2015).

Additionally, as in the case of most cross-sectional analysis, attribution of causality can only be made with caution due to the non-temporal nature of the data set. However, since arsenic is a naturally

occurring substance and household adaptation to exposure especially through behavior change seems to be minimal, some claim of exogeneity and hence causality is plausible.

### *Responding to the arsenic crisis in Bangladesh*

Inorganic arsenic is released from sediment by biogeochemical processes and is found in higher concentrations at shallower depths of groundwater tables (Rice, 2000). There are few options for low-cost arsenic removal systems, and typically the most common mitigation strategy is simply switching to wells that have been tested as arsenic-free, which are typically deeper tubewells that are costlier to install (Chakraborti, 2010). Arsenic testing campaigns have some proven success for reducing population exposure to arsenic. Similar to other public health campaigns, education and awareness alone have been shown to be ineffective in motivating households to switch to arsenic-free improved water sources (Benneer, et al., 2013).

Nevertheless, it is essential that arsenic testing is coupled with assured availability of tested safe and improved water sources that households can access to avoid unintended negative consequences. The significance of this condition is illustrated in a study by Field et al. (2011), which evaluated unintended health consequences of massive arsenic testing and awareness campaigns. The study found that households living in high arsenic-prone areas post-2000 when there was significant public knowledge of arsenic had 27 percent higher rates of infant and child mortality compared to households living in unaffected areas of Bangladesh. The authors imply that the large abandonment of arsenic-contaminated wells after massive testing campaigns led to higher exposure to fecal-oral pathogens due to households switching to surface or other unimproved water sources that are typically perceived as arsenic-free (Field et al., 2011). The importance of safe and readily available arsenic-free sources is also demonstrated by two studies by George et al. (2012) and Opar et al. (2007), which both evaluated the effectiveness of arsenic testing and education interventions using randomized controlled trials. George et al. (2012) found that overall the intervention was effective in reducing urinary arsenic concentrations, where households would switch to arsenic-free improved water sources provided that they were closely available. Opar et al. (2007) also found that the distance to the nearest safe well also influenced a household's decision to switch to arsenic-free sources.

Areas that are highly prone to arsenic should be prioritized for arsenic mitigation. An extensive literature base indicates that not all segments of a population experience uniform advances in health status nor gains in life expectancy. One contributing factor for disparities in health status is disparities in environmental exposures. In any country, there are identifiable communities that experience higher levels of exposure to or greater impact from environmental contaminants. In the case of arsenic in



Bangladesh, the risk of arsenic contamination is primarily dependent on geography, where households living in some areas are more susceptible to arsenic contamination than others (UNICEF, 2015). Interestingly, exposure to arsenic does not seem to be dependent on one's socioeconomic status, despite available mitigating mechanisms including well-switching, regular testing, filtration, rain water harvesting, and installation of deeper tubewells (Rice, 2010). However, it would be expected that those without access to mitigation mechanisms are most likely those individuals from households with lower socio-economic status. The latest data from the 2012-2013 Multiple Indicator Cluster Survey (MICS) show that households across wealth quintiles have similar exposure levels to arsenic (UNICEF, 2015). Therefore, it is warranted that high-risk geographical areas of arsenic are instead prioritized for mitigation efforts.

In addition to prioritizing high-risk geographical areas, arsenic mitigation efforts should also be prioritized for expectant mothers and children. In recent years, the scientific community and policy makers have placed a strong emphasis on maternal and childhood interventions during the “first 1,000 days,” or simply the time period between a woman's pregnancy and her child's second birthday. Advocates for better nutrition have particularly embraced the “first 1,000 days” targeting strategy, claiming that investment in nutrition during this period is pivotal, as scientific evidence shows that the first years of a child's life build the biological architecture for healthy brain development, growth, and strong immunity (Miller et al., 2015). Investment in reducing environmental toxicities such as exposure to arsenic in the early years of child development may also be an essential intervention for improving long-term health, cognition, and productivity. Yet interventions for arsenic mitigation are not commonly targeted to expectant mothers and young children. For example, supporting water quality testing and installation of safe water sources in community health or conditional cash transfer programs could be good opportunities for targeting expectant mothers and children. Most studies observe cognitive impairment from arsenic exposure in school-aged and adolescent children; however, this study particularly sees this relationship in children as young as three years old. The study group was limited to children aged 3-5 due to the availability of data on cognitive development, but it is plausible that arsenic is damaging brain architecture at even younger ages. It is imperative that exposure to arsenic is eliminated at early ages when the brain is most vulnerable.

Based on the results already discussed in the paper, one last recommendation is for the Government of Bangladesh to revise its national water quality standards. Currently, the national drinking water standard of arsenic concentration in Bangladesh is greater than 50 ppb. However, since

2001, WHO and many other countries including the United States have adapted a more rigorous standard of greater than 10 ppb. The government and development actors in Bangladesh should adhere to more rigorous standards when testing and installing new water sources, as even small doses have a significant effect on child development.

**Table 1. 10-item module used to construct the ECDI (Source: MICS 2012-13 Report, Bangladesh)**

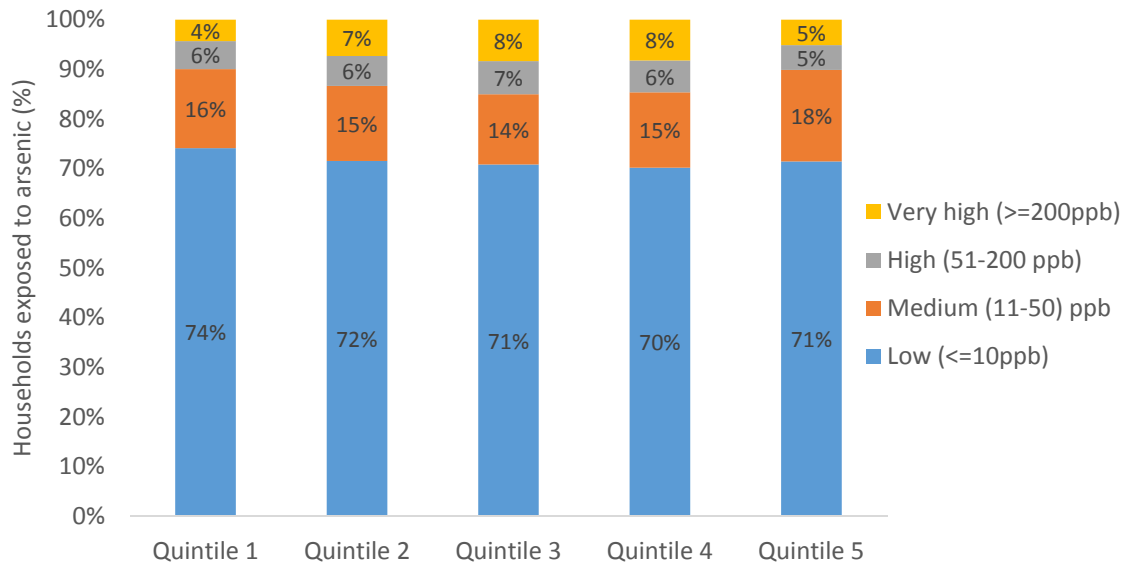
Domain	Component	Criteria for being on track
Literacy-numeracy	Identify at least ten letters of the alphabet	2/3 components must be true
	Read at least four simple and popular words	
	Name and recognize symbols of numbers 1 to 10	
Learning	Follow simple instructions	1/2 components must be true
	Carry out tasks independently	
Physical	Pick up a small object with two fingers	1/2 components must be true
	Healthy enough to play	
Social	Gets along well with other children	2/3 components must be true
	Does not kick, bite, or hit other children	
	Does not get distracted easily	
Overall EDCI	Literacy-numeracy	3/4 domains must be true
	Learning	
	Physical	
	Social	

**Table 2. Weighted sample mean values of variables in the logistic regression model**

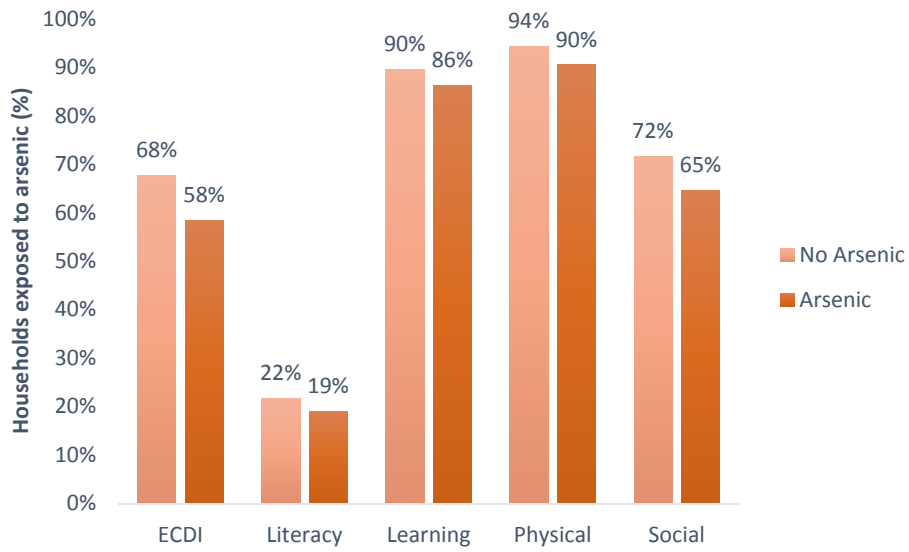
<b>Variable</b>	<b>Obs</b>	<b>Mean</b>	<b>Std. Dev.</b>	<b>Min</b>	<b>Max</b>
Early childhood development index	7,502	0.65	0.48	0	1
Literacy-numeracy	7,979	0.21	0.40	0	1
Learning	7,968	0.89	0.32	0	1
Physical development	7,906	0.93	0.25	0	1
Social development	7,693	0.70	0.46	0	1
Child ever breastfed	7,979	0.96	0.18	0	1
Child is female (Y=1)	7,979	0.48	0.50	0	1
Child's age (months)	7,979	47.50	7.01	35	59
Child's age, months (log)	7,979	3.85	0.15	4	4
Child's age squared, months (log)	7,979	7.70	0.30	7	8
Mother's education	7,979	0.69	0.66	0	2
Urban	7,979	0.19	0.39	0	1
Household size	7,979	5.54	2.47	2	25
Household size (log)	7,979	1.64	0.37	1	3
Wealth quintile	7,979	2.87	1.41	1	5
Improved sanitation	7,979	0.48	0.50	0	1
Improved water	7,979	0.98	0.14	0	1
Water treatment	7,979	0.05	0.22	0	1
Arsenic in source water (WHO, >10ppb)	7,979	0.27	0.44	0	1
Arsenic in source water (BD, >50ppb)	7,979	0.13	0.33	0	1
Arsenic in source water (11-50ppb)	7,979	0.14	0.35	0	1

**Note: The number of observations for the ECDI and four domains vary due to missing observations in the survey dataset**

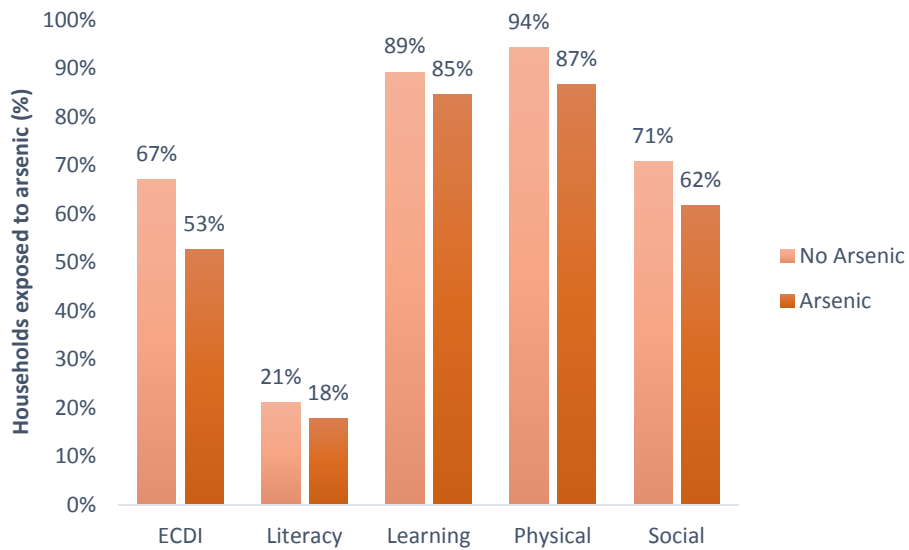
**Figure 1. Proportion of households with varying risk levels of arsenic, by wealth quintile**



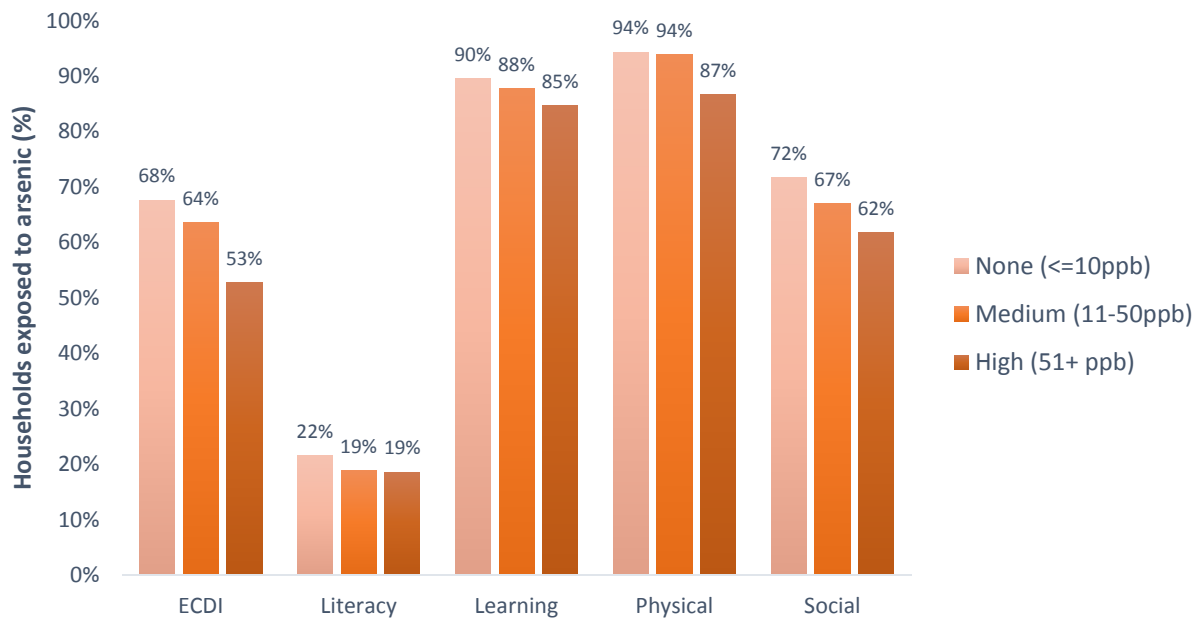
**Figure 2. ECDI rates by arsenic exposure (WHO Standard of >10ppb)**



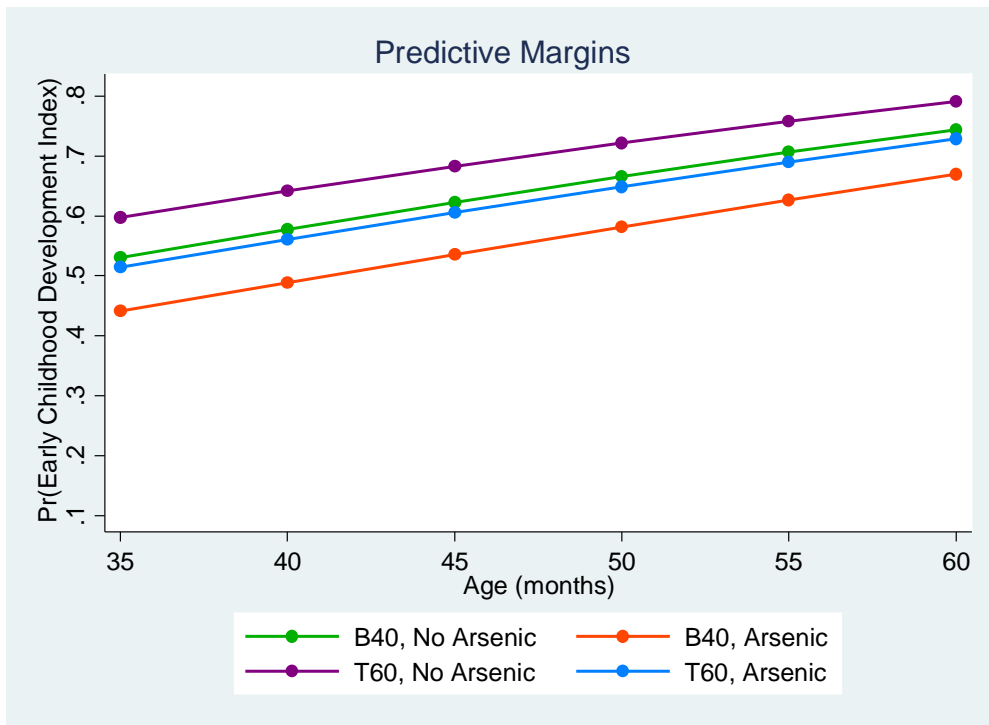
**Figure 3. ECDI rates by arsenic exposure (Bangladesh Standard of >50ppb)**



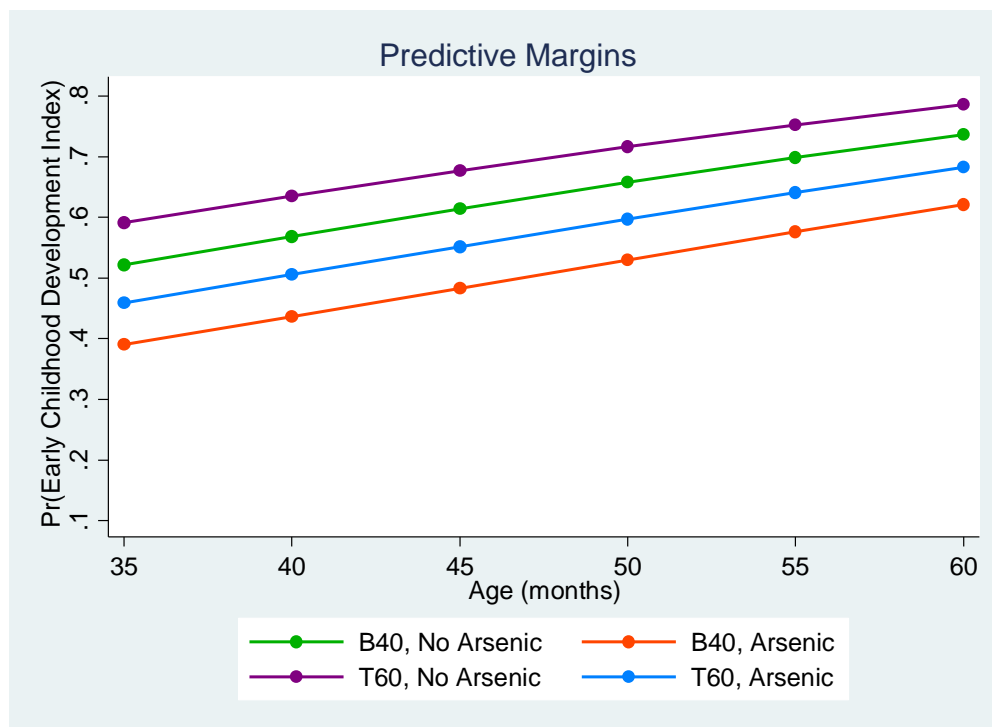
**Figure 4. ECDI rates by risk levels of arsenic**



**Figure 5. Predictive margins of overall ECDI performance and arsenic exposure (WHO Standard: >10ppb) by B40 and T60 wealth**



**Figure 6. Predictive margins of overall ECDI performance and arsenic exposure (Bangladesh Standard: >50ppb) by B40 and T60 wealth**



**Table 3. Correlates of overall ECDI performance including three-specifications of arsenic exposure (N=7,502 children aged 3-5 years)**

VARIABLES	(1)	(2)	(3)
	WHO	Bangladesh	Risk Levels
Child ever breastfed	0.0485 (0.0318)	0.0496 (0.0314)	0.0512 (0.0315)
Child is female	0.0429*** (0.0109)	0.0429*** (0.0109)	0.0428*** (0.0109)
Child's age (log)	0.394*** (0.0345)	0.393*** (0.0345)	0.393*** (0.0345)
Mother's education (primary/some secondary)	0.0698*** (0.0125)	0.0699*** (0.0125)	0.0693*** (0.0125)
Mother's education (secondary or higher)	0.143*** (0.0206)	0.145*** (0.0205)	0.143*** (0.0206)
Urban	0.0146 (0.0175)	0.0112 (0.0175)	0.0112 (0.0174)
Household size (log)	-0.0612*** (0.0160)	-0.0593*** (0.0160)	-0.0585*** (0.0159)
Quintile 2	-0.00568 (0.0163)	-0.00476 (0.0163)	-0.00462 (0.0163)
Quintile 3	-0.00695 (0.0171)	-0.00473 (0.0171)	-0.00479 (0.0171)
Quintile 4	0.0152 (0.0185)	0.0167 (0.0185)	0.0172 (0.0185)
Quintile 5	0.0532** (0.0232)	0.0508** (0.0232)	0.0524** (0.0232)



Improved sanitation	0.0376*** (0.0121)	0.0365*** (0.0121)	0.0373*** (0.0121)
Improved water	-0.0145 (0.0273)	-0.00456 (0.0265)	-0.00656 (0.0269)
Water treatment	0.0614* (0.0346)	0.0640* (0.0344)	0.0637* (0.0344)
Arsenic (WHO)	-0.0711*** (0.0136)		
Arsenic (BD)		-0.108*** (0.0176)	
Arsenic - medium (11-50 ppb)			-0.0357** (0.0181)
Arsenic - high (51+ ppb)			-0.119*** (0.0193)
Observations	7,502	7,502	7,502

Standard errors in parentheses  
\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Table 4. Correlates of child literacy-numeracy including three-specifications of arsenic exposure (N=7,979 children aged 3-5 years)**

VARIABLES	(1) WHO	(2) Bangladesh	(3) Risk Levels
Child ever breastfed	-0.0256 (0.0231)	-0.0251 (0.0231)	-0.0253 (0.0231)
Child is female	0.0157* (0.00814)	0.0157* (0.00814)	0.0157* (0.00814)
Child's age (log)	0.678*** (0.0344)	0.678*** (0.0344)	0.678*** (0.0344)
Mother's education (primary/some secondary)	0.117*** (0.00904)	0.116*** (0.00903)	0.116*** (0.00904)
Mother's education (secondary or higher)	0.235*** (0.0196)	0.234*** (0.0196)	0.235*** (0.0196)
Urban	0.0287** (0.0120)	0.0283** (0.0121)	0.0284** (0.0121)
Household size (log)	-0.0472*** (0.0121)	-0.0468*** (0.0121)	-0.0470*** (0.0121)
Quintile 2	0.0226* (0.0122)	0.0228* (0.0122)	0.0228* (0.0122)
Quintile 3	0.0401*** (0.0131)	0.0403*** (0.0131)	0.0403*** (0.0131)
Quintile 4	0.0754*** (0.0141)	0.0757*** (0.0142)	0.0757*** (0.0142)
Quintile 5	0.109*** (0.0178)	0.110*** (0.0177)	0.109*** (0.0177)

Improved sanitation	0.0450*** (0.00911)	0.0452*** (0.00911)	0.0451*** (0.00911)
Improved water	-0.00446 (0.0257)	-0.00388 (0.0258)	-0.00379 (0.0256)
Water treatment	0.0671*** (0.0204)	0.0674*** (0.0204)	0.0673*** (0.0204)
Arsenic (WHO)	0.00347 (0.0103)		
Arsenic (BD)		-0.00280 (0.0142)	
Arsenic - medium (11-50 ppb)			0.00720 (0.0130)
Arsenic - high (51+ ppb)			-0.00147 (0.0143)
Observations	7,979	7,979	7,979

Standard errors in parentheses  
\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Table 5. Correlates of child learning including three-specifications of arsenic exposure (N=7,968 children aged 3-5 years)**

VARIABLES	(1) WHO	(2) Bangladesh	(3) Risk Levels
Child ever breastfed	0.0463*** (0.0158)	0.0454*** (0.0157)	0.0467*** (0.0158)
Child is female	-0.00433 (0.00678)	-0.00443 (0.00678)	-0.00438 (0.00678)
Child's age (log)	0.127*** (0.0192)	0.126*** (0.0191)	0.126*** (0.0192)
Mother's education (primary/some secondary)	0.0203*** (0.00771)	0.0208*** (0.00778)	0.0203*** (0.00773)
Mother's education (secondary or higher)	0.0396*** (0.0123)	0.0415*** (0.0123)	0.0396*** (0.0123)
Urban	-0.00645 (0.0103)	-0.00676 (0.0104)	-0.00688 (0.0103)
Household size (log)	-0.0360*** (0.00957)	-0.0362*** (0.00960)	-0.0356*** (0.00960)
Quintile 2	-0.0300*** (0.00971)	-0.0302*** (0.00972)	-0.0299*** (0.00973)
Quintile 3	-0.0260** (0.0102)	-0.0260** (0.0102)	-0.0258** (0.0102)
Quintile 4	-0.0122 (0.0106)	-0.0124 (0.0105)	-0.0120 (0.0106)
Quintile 5	-0.00177 (0.0130)	-0.00350 (0.0131)	-0.00194 (0.0130)
Improved sanitation	0.0140*	0.0133*	0.0140*

	(0.00733)	(0.00731)	(0.00733)
Improved water	-0.0136	-0.0111	-0.0126
	(0.0178)	(0.0185)	(0.0179)
Water treatment	0.0379	0.0382	0.0382
	(0.0270)	(0.0271)	(0.0270)
Arsenic (WHO)	-0.0343***		
	(0.00791)		
Arsenic (BD)		-0.0330***	
		(0.00999)	
Arsenic - medium (11-50 ppb)			-0.0316***
			(0.0113)
Arsenic - high (51+ ppb)			-0.0424***
			(0.0123)
Observations	7,968	7,968	7,968

Standard errors in parentheses

\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Table 6. Correlates of child physical development including three-specifications of arsenic exposure (N=7,906 children aged 3-5 years)**

VARIABLES	(1) WHO	(2) Bangladesh	(3) Risk Levels
Child ever breastfed	0.0198 (0.0139)	0.0212 (0.0138)	0.0213 (0.0138)
Child is female	-0.00666 (0.00508)	-0.00675 (0.00507)	-0.00675 (0.00507)
Child's age (log)	0.0813*** (0.0177)	0.0802*** (0.0175)	0.0802*** (0.0175)
Mother's education (primary/some secondary)	0.00202 (0.00593)	0.00184 (0.00591)	0.00181 (0.00591)
Mother's education (secondary or higher)	0.00522 (0.0105)	0.00545 (0.0104)	0.00529 (0.0105)
Urban	-8.13e-05 (0.00881)	-0.00159 (0.00883)	-0.00160 (0.00882)
Household size (log)	-0.00373 (0.00729)	-0.00254 (0.00734)	-0.00250 (0.00735)
Quintile 2	-0.0131* (0.00716)	-0.0129* (0.00717)	-0.0128* (0.00717)
Quintile 3	-0.0156** (0.00747)	-0.0146** (0.00741)	-0.0145** (0.00741)
Quintile 4	-0.00832 (0.00800)	-0.00749 (0.00795)	-0.00745 (0.00796)
Quintile 5	-0.00967 (0.0108)	-0.0106 (0.0109)	-0.0104 (0.0110)
Improved sanitation	0.00888	0.00863	0.00868

	(0.00552)	(0.00552)	(0.00551)
Improved water	-0.0454**	-0.0417**	-0.0418**
	(0.0189)	(0.0188)	(0.0188)
Water treatment	0.00153	0.00228	0.00230
	(0.0163)	(0.0165)	(0.0165)
Arsenic (WHO)	-0.0187***		
	(0.00619)		
Arsenic (BD)		-0.0334***	
		(0.00780)	
Arsenic - medium (11-50 ppb)			-0.00224
			(0.00732)
Arsenic - high (51+ ppb)			-0.0418***
			(0.0116)
Observations	7,906	7,906	7,906

Standard errors in parentheses  
\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

**Table 7. Correlates of child social development including three-specifications of arsenic exposure (N=7,693 children aged 3-5 years)**

VARIABLES	(1) WHO	(2) Bangladesh	(3) Risk Levels
Child ever breastfed	-0.0114 (0.0296)	-0.0106 (0.0294)	-0.00921 (0.0295)
Child is female	0.0492*** (0.0107)	0.0493*** (0.0107)	0.0491*** (0.0107)
Child's age (log)	0.108*** (0.0355)	0.108*** (0.0356)	0.108*** (0.0355)
Mother's education (primary/some secondary)	0.0267** (0.0119)	0.0270** (0.0119)	0.0263** (0.0119)
Mother's education (secondary or higher)	0.0281 (0.0221)	0.0300 (0.0220)	0.0278 (0.0220)
Urban	0.0195 (0.0170)	0.0170 (0.0170)	0.0170 (0.0170)
Household size (log)	-0.00752 (0.0161)	-0.00597 (0.0161)	-0.00536 (0.0160)
Quintile 2	0.0177 (0.0159)	0.0186 (0.0159)	0.0186 (0.0159)
Quintile 3	0.00713 (0.0171)	0.00877 (0.0170)	0.00873 (0.0170)
Quintile 4	0.00147 (0.0182)	0.00269 (0.0182)	0.00307 (0.0182)
Quintile 5	0.0204 (0.0227)	0.0181 (0.0227)	0.0197 (0.0227)
Improved sanitation	0.00225	0.00155	0.00219

	(0.0121)	(0.0121)	(0.0121)
Improved water	0.0527*	0.0600**	0.0583**
	(0.0270)	(0.0264)	(0.0267)
Water treatment	0.0305	0.0327	0.0324
	(0.0313)	(0.0312)	(0.0312)
Arsenic (WHO)	-0.0581***		
	(0.0133)		
Arsenic (BD)		-0.0841***	
		(0.0171)	
Arsenic - medium (11-50 ppb)			-0.0323*
			(0.0178)
Arsenic - high (51+ ppb)			-0.0941***
			(0.0189)
Observations	7,693	7,693	7,693

Standard errors in parentheses  
\*\*\* p<0.01, \*\* p<0.05, \* p<0.1

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