Ground Water Arsenic and Education Attainment in Bangladesh

Michael P. Murray, Bates College

Raisa Sharmin, Bates College

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Abstract

A third of Bangladeshi children live in communities with unsafe, arsenic contaminated water. Fifty-seven percent of children in such communities are reported to drink from arsenic free sources, partly as a result of public health programs that identify contaminated wells and alert people to the risks of drinking from contaminated wells. Fixed-effects regressions reveal that the forty-three percent of boys who grow up in such communities and who are not reported to drink arsenic-free water, lose a half year of schooling to arsenic’s effects. Boys living in communities with unsafe water but reported to drink from arsenic-free sources do not suffer this adverse educational consequence. Estimated negative effects for girls are much smaller and statistically insignificant, which accords with others’ similar findings about arsenic’s differential impacts on cognitive development for Bangladeshi boys and girls. Public health measures that induce people to shift away from arsenic-contaminated wells not only improve health, but also build human capital.
1 Introduction

In 1987, clinicians reported Bangladesh’s first recognized cases of arsenic-caused skin lesions (Smith, et al., 2000). The arsenic came from tube wells that international agencies had been funding extensively since the 1970’s to end unhealthful reliance on surface water for drinking (Maddison, et al., 2005). Millions of Bangladeshis have become ill from these well-intentioned arsenic-laden wells (Akter and Ali, 2011).

Several authors review the extensive literature on the physical and social consequences of arsenic poisoning (most recently, Safiuddin et. al., 2011). The physical consequences can be dire, going far beyond skin lesions – Argos, et al. (2010) estimate that drinking groundwater containing arsenic in more than 150 parts per billion (ppb) causes almost a doubling of mortalities from all causes. Over 10% of Bangladeshi children live in communities in which the average tube’s well-water contains that much arsenic or more. Over a third of Bangladeshi children live in communities in which the average well’s water exceeds Bangladesh’s own safe water standard of 50ppb arsenic or less; two thirds live in communities in which the average well’s water exceeds the World Health Organization’s (WHO) standard of 10ppb.

Public health authorities’ interest in reducing households’ reliance on contaminated drinking water sources has been considerable. A literature about which public health strategies mitigate the effects of groundwater arsenic and which don’t has emerged (e.g. Bennear et al., 2013; Madajewicz, 2007; and Schoenfeld, 2005). One strategy widely used in Bangladesh couples clearly marking safe and unsafe wells with media campaigns that highlight the risks of drinking from arsenic-contaminated wells. Such two-pronged strategies can achieve little when there are few safe local sources of water, but in the many Bangladeshi neighborhoods with a mix
of safe and unsafe wells, a household alerted that its usual drinking-water source is contaminated can, in principle, shift to a safe well not far away (van Geen et al., 2003). Madajewicz has shown that one such public information campaign in Bangladesh increased by thirty-seven percent the probability that a Bangladeshi household initially using an unsafe well would shift its drinking-water source within one year. The private ownership of most wells impedes such shifts; costly negotiations with neighbors make shifts less likely. Moreover, shifting away from arsenic-contaminated water is not always an effective public health strategy; Howard et al. (2006) note that inducing households to avoid arsenic contaminated sources might lead them to replace arsenic with other water-borne contaminants (Howard et al. 2006); a return to drinking unhealthful surface water would often be a poor alternative to drinking from arsenic-contaminated tube wells. Good policies for grappling with groundwater arsenic must ensure that healthful water is available for households who want to make a change.

Carefully designed public health programs that induce households to use arsenic-uncontaminated water sources can reduce the adverse consequences of arsenic-contaminated ground-water. In this paper, we present evidence in support of this claim while shedding light on an overlooked consequence of drinking from arsenic-contaminated wells: reduced education attainment for those who grow up in drinking arsenic-contaminated water. The literature appears mute on arsenic’s effects on education attainment, though there is evidence of arsenic impairing cognitive capacities (Asadullah and Chaudhury, 2011, and Wasserman, 2007). Using a multivariate regression model, we estimate that by age 21, Bangladeshi boys who grow up drinking from “unsafe” wells, i.e. wells that exceed the Bangladeshi safe-water standard, lose at least a half year of education relative to boys who drink safe water.\(^1\) The potential health and

\(^1\) Bangladeshi males aged 23-25 averaged 7.59 years of education in 2005.
education attainment gains from inducing households to shift away from unsafe sources is reflected in our finding that that boys living in communities with on-average unsafe wells but who are reported to drink from arsenic-free sources do not suffer reduced education attainment. Our estimates of arsenic’s adverse effects for girls are much smaller than for boys, and generally not statistically significant, though they are uniformly negative.\(^2\) (Statistically insignificant but negative estimated effects of well-water arsenic for girls are consonant with Asadullah and Chaudhury’s finding of significant effects of arsenic on cognition for boys, but not for girls in Bangladesh. Those authors suggest boys’ greater drinking of water causes the differences. We find this explanation plausible.) Given our empirical results, we conclude that public health measures that induce a shift from unsafe to safe wells not only advance good health but also build human capital.

2 Data

We rely on two publicly available data sets: (i) the National Hydrochemical Survey (NHS) survey of wells conducted between 1998 and 2000 by the Department of Public Health Engineering of Bangladesh in consultation with the British Geological Survey (BGS and DPHE, 2001) and (ii) the 2006 Bangladesh Multiple Indicator Cluster Survey (MICS) round three that was carried out by the Bangladesh Bureau of Statistics and UNICEF.

The NHS provides chemical test results for 3534 boreholes from 61 of Bangladesh’s 64 districts. The NHS reports surveyed wells’ locations at the village level. We aggregate the arsenic levels to the sub-district level, the finest geographic detail available in the MICS data.

\(^2\) In our largest samples, girls aged 11-25, the estimated effect is a tenth of a year decrease in education attained; that estimate has a p-value of .102. We do not further report results for girls; the results are available from the authors.
Sub-districts in Bangladesh average about 150 sq. km., or 60 sq. miles. Districts average 2300 sq.km. or 890 sq. miles. We designate sub-districts with average well-water arsenic levels above Bangladesh’s 50ppb standard as “unsafe”; all other districts we designate “safe.” We must, of necessity, use the NHS data that are from 1998-2000; however, this is not debilitating because the natural hydrological traits of wells change little over time (van Geen et al., 2003) and policies have focused much more on households’ choices of which wells to use than on altering the wells themselves.

The MICS is a nationally representative randomly sampled household survey with a response rate of 92.5%. The MICS provides data on household socio-economic variables, including the head’s and each individual’s education attainment, local environment questions, such as proximity of the household to industrial pollution sources, and questions specifically about local well-water arsenic contamination.

3 Key Variables

This study focuses attention on four variables: (i) an individual’s years of education attained; (ii) the number of school days an individual attended in the past week; (iii) whether the sub-district in which an individual lived in 2005 was safe or unsafe; and (iv) whether an individual was reported by the survey respondent to drink from an arsenic-free source (which we shall refer to as “the individual drinks safely”). The NHS provides arsenic levels; the MICS provides the other three variables. The first two variables are integer valued; the second two are dummy variables.

Bangladeshi males 23-25 have generally completed their educations; they averaged 7.59 years of education in 2005. Primary school children averaged 5.3 out of 6 days of school per
week. The third of Bangladeshi children living in sub-districts with on-average unsafe well-water are, on average, exposed to arsenic levels of 145 ppb in their sub-district’s well-water. A probit model reveals that the probability of living in a community with on average unsafe water is unrelated to wealth or having more education (p-value = .53); a one standard deviation increase in wealth is associated with a 1.3 percentage point decline in the probability of living in a safe sub-district, and individuals living with a household head who at least competed secondary education are 2.5 percent more likely to live in safe water areas than are individuals living with household heads with less education (standard errors = .022 for each of these marginal effects).

Awareness of the arsenic problem is quite high. Ninety-three percent of respondents in sub-districts with on-average unsafe wells report having heard of the arsenic problem; seventy-three percent in sub-districts with on-average safe wells report having heard. Fifty-seven percent of youths living in unsafe sub-districts reportedly drink safely. Thirty-eight percent of individuals living in safe sub-districts reportedly drink safely. In general, both awareness of the arsenic problem and reported reliance on arsenic-free sources rise with the local level of arsenic in wells. This pattern is unsurprising since the government has focused its policy efforts on the most at-risk areas, and the greater the risk, the more reason for people to “spread the word” about the problem.

A probit model reveals that for males living in an unsafe sub-district, given education, an increase in household wealth of one standard deviation is associated with a 9.4 percentage point increase in the probability of drinking safely (standard error = .017), and, given wealth, 12.4 percent more of those who have completed secondary education drink safely compared to less-educated people (standard error = .022).
4 Control Variables

We construct five groups of control variables from the MICS data:

(1) Contamination awareness: survey respondents reported whether they had heard of the well-water arsenic problem.

(2) Wealth and income indicators: (i) the household’s $z$-score in the national distribution of wealth; (ii) the square of the household’s wealth $z$-score; (iii) the household head’s education level (seven categories); (iv) the mean wealth $z$-score across sampled households in the sub-district in which the individual lives; and (v) the standard deviation of wealth $z$-scores for sampled households in the sub-district in which the individual lives. We view the mean local wealth $z$-score as indicating local income opportunities that compete with school for individuals’ time.

(3) Local environs indicators: Whether the dwelling is: (i) in a flood-prone area; (ii) in a landslide-prone area; (iii) located near industrial pollution; and (iv) located near a garbage pile.

(4) Housing security indicators: (i) does the respondent report security from eviction; and (ii) is the household squatting.

(5) Fixed effects for the district where the household lives.

5 Sub-Samples

Choosing a sub-sample of individuals to study for arsenic’s effects on years of education requires judgment. Tube wells were far from ubiquitous in Bangladesh in the late 1970’s and early 1980’s. Schoenfeld (2005) reports some urban areas with under forty percent of households using tube wells in 1977, and clinical reports of physical effects did not begin until 1987 (Smith
et al., 2000). Thus, we do not know exactly which birth-cohorts were fully exposed to the groundwater arsenic levels measured in the NHS. Estimates of arsenic’s effects based upon individuals born before general use of tube wells will underestimate those effects, but estimates based upon individuals too young would miss the full effect of arsenic on education. We report estimates of well-water arsenic’s effects on education attainment for individuals in the MICS aged 19 through 21, i.e., born between 1984 and 1986. We choose 1984-1986 for several reasons. First, the period immediately precedes the first clinical reports of arsenic poisoning. Second, by age 19, seventy-nine percent of sample Bangladeshis have completed their educations, so by age 19, most of arsenic’s adverse effects have occurred. Third, estimates of arsenic’s effects for these cohorts are robust to adding individuals as young as 15 (suggesting that arsenic poisoning has its full effect on years of education by age 15), but decline with each older cohort added to the sample (which we attribute to less exposure to arsenic in the early 1980’s).

Until 2010, the Bangladeshi school system required school enrollment through grade V, which corresponds to ages 6 through 10. For boys aged 6-10, we examine whether drinking arsenic contaminated water affects school attendance.

6 Lack of an experiment and lack of panel data

Correlational models like ours do not offer the protection from bias that well-designed experiments can: in correlational models, omitted relevant variables can bias the results of an analysis. Our analysis requires particular attention to such biases because we do not have as rich an array of covariates available to us as we would wish. In particular, our data are a single cross-section, not a panel, of individuals. Consequently, we cannot track the dynamic determinants of education attainment. Our reliance on a cross-sectional correlational model is limited specifically
with respect to three classes of variables: economic, health, and policy variables. Here we attend briefly to the nature of the biases we risk by not having better measures of such variables.

To fully understand why an individual attains the schooling he or she does, one would favor a detailed examination of the individual’s economic circumstances over the course of the individual’s childhood. With only a single cross-section, we miss the fluctuations in households’ economic circumstances that affect education attainment. We observe a household’s wealth at a single moment of time, which provides only a partial picture of a household’s economic history. Because wealth fluctuates less over time than does income, observing a household’s wealth at one moment of time is more informative about the household’s economic circumstances over time than is observing the household’s current income. But wealth does, nonetheless, vary over time, and to the extent that wealth varied differentially across sub-districts with high and low levels of groundwater arsenic, our measures of arsenic’s effects on education attainment are biased. However, because we find that the level of wealth is uncorrelated with living in a high arsenic area, we think this potential bias not a particularly serious concern.

A potentially more serious concern is our lack of data about the non-arsenic related health status of individuals both over time and in the period we observe. If high levels of arsenic in groundwater are correlated with other health threats, such as malaria-carrying mosquitos, for which we have no measures, then our estimate of groundwater arsenic’s effect on education attainment will be biased. However, to the extent that individuals in a threatened area cannot avoid a specific health threat, both the estimated effect of arsenic contamination for those who drink arsenic contaminated water and the estimated effect for those in the same sub-district who drink from a safe source will be biased toward reduced education attainment. Thus, if such health threats are substantially correlated with groundwater arsenic contamination, we would expect to
see an effect of groundwater arsenic on education attainment for those who live in arsenic-unsafe sub-districts yet drink safely. As we shall report, this is not the case. The more substantial concern for our results are health threats that are avoidable, as we would expect that households which avoid unsafe water would also take measures like bed-nets to avoid diseases such as malaria. The question, then, is, “How correlated are arsenic contamination and such avoidable health threats?” We do have indicators of industrial pollution and garbage dumps in the vicinity of an individual’s home, but these are crude measures, so both avoidable environmental threats and avoidable ecological threats to health can cause biases in our results. Once again, we would be much more concerned about correlations between arsenic contamination and other health threats if living in arsenic contaminated sub-districts were correlated with the household head’s education or wealth.

The third class of variables for which time series data would be valuable are policy related variables. The effect of groundwater arsenic on residents of a sub-district is influenced by government policy. Moreover, government policy interventions are almost surely more intense in areas with the worst arsenic contamination. Both the extent of government policies in place during the childhoods of our observed individuals and the time path of those policies matter for the severity of groundwater arsenic’s effects. By focusing on 19 to 21 year olds born between 1984 and 1986, we capture the effects of groundwater arsenic averaged across the policy practices in place between 1984 and 2006.

Our reliance on a single cross-section risks yet another bias. An arsenic level measured at one moment in time likely mis-measures individuals’ long-run exposure to arsenic, which is the truly relevant exposure. Consequently, our estimates suffer some attenuation bias. Since arsenic levels in wells do not change much over time, attenuation bias arises chiefly from individuals not
always having lived in the sub-district in which they were observed in 2005. The more
individuals moved between childhood and 2005, the greater their contribution to such attenuation
bias. To reduce this bias we restrict the sample of 19-21 year olds to individuals who still lived
with their parent or grandparent when sampled; this shrinks the 19-21 sub-sample by 17 percent.

7 Results

In our regression models, we ask whether living in a sub-district with unsafe well-water
results in a lower number of years of education attained or in days of school attended in the past
week, and whether individuals in unsafe sub-districts who drink safely are affected differently by
the local arsenic levels. We expect that drinking unsafe water will have an adverse effect on
education attainment, but that living in an unsafe sub-district will have little effect if an
individual drinks safely. Thus, we expect “unsafe” to have a negative coefficient and its
interaction with “drinks safely” to have a positive coefficient of comparable magnitude.

We also include in our models all the control variables mentioned above, plus age. The
estimation procedure is fixed-effects regression, with fixed effects for the division within which
the sub-districts lie. We cluster observations by sub-district when computing robust standard
errors.

We first examine how groundwater arsenic affects years of education for individuals who
are between 19 and 21 years of age. The dependent variable is the years of education attained.
Table 1, Column 1 contains estimated coefficients for the dummy variable “unsafe” and for the
interaction of “unsafe” with the “drinks safely” dummy (with their robust, clustered standard
errors in parentheses). Males living in unsafe sub-districts, suffer a loss of one-half of a year of
education relative to males who live in safe sub-districts (the omitted category); males in
Table 1
Unsafe Water’s Effects on Boys’ Years of Education (19-21 year olds)
and Days of School Attended (6-10 year olds)

| Variable                        | Years of Education | Days of School Attended |
|---------------------------------|--------------------|-------------------------|
|                                 | 1                  | 2                       | 3            | 4            |
| **Regression:**                 |                    |                         |              |              |
| Unsafe Water                    | -.510\(^{\wedge}\) | -.578\(^{\wedge}\)     | -.120\(^{**}\) | -.172\(^{\wedge}\) |
|                                 | (.136)             | (.169)                  | (.054)       | (.068)       |
| Unsafe*Drink Safe               | .497\(^{\wedge}\)  | .499\(^{\wedge}\)      | .116\(^{**}\) | .114\(^{**}\) |
|                                 | (.139)             | (.139)                  | (.056)       | (.056)       |
| 10-50ppb Arsenic                | --                 | -.157                   | --           | -.054        |
|                                 |                    | (.152)                  |              | (.055)       |
| 10-50ppb*Drink Safe             | --                 | .125                    | --           | -.030        |
|                                 |                    | (.150)                  |              | (.052)       |
| **R\(^2\)**                     | .3241              | .3514                   | .0481        | .0450        |
| **# observations**              | 4511               | 4511                    | 14060        | 14060        |

**Regression:**

|                                 | 5                  | 6                        |
| **Arsenic Level**               |                    |                          |
|                                 | -.0026\(^{\wedge}\) | -.0004                   |
|                                 | (.0009)            | (.0003)                  |
| **Arsenic Level*Drink Safe**    | .0026\(^{\wedge}\) | .0002                    |
|                                 | (.0008)            | (.0003)                  |
| **R\(^2\)**                     | .3231              | .0479                    |
| **# observations**              | 4511               | 14060                    |

*statistically significant at .10 level.

**statistically significant at .05 level.

\(^{\wedge}\)statistically significant at .01 level.
unsafe-water sub-districts who drink safely experience no such deficit. To put arsenic’s effect in context, the household of the median boy drinking unsafe water has wealth in the 36th percentile. To increase expected years of education as much as shifting to safe water does, the household’s wealth would need to rise to the 50th percentile. Shifting to safe water has an appreciable effect on education attained.

Adding individuals as young as 15 to the sample hardly changes arsenic’s estimated effects. Apparently arsenic poisoning takes its education toll by age 15. Adding individuals as old as 25 cuts the estimated adverse effect to about three tenths of a year (but still confirms the finding of no adverse effect for those who drink safely). We attribute the lower estimate from using older individuals to lessened exposure to arsenic in the early 1980’s.

Appendix Table 1 reports estimates of the covariates’ coefficients. Each of the categories of control variables is collectively statistically significant. The local wealth variable has a statistically significant negative estimated coefficient, which we interpret as higher local wealth indicating better local income opportunities to compete with school for individuals’ time.

Drinking safely is correlated with father’s education. Consequently, one might worry that the estimated loss of years arises not from arsenic, but because particularly dim folks neither get as much education as others nor drink safely (the model has no control for an individual’s intelligence). A test of this worry’s validity is available because our probit model of the probability of living in a safe sub-district, which also lacked a control for individual’s intelligence, revealed no correlation between a safe sub-district location and father’s education, suggesting that across sub-districts, the mix of bright and dim individuals is much the same.

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3 Covariates’ estimated coefficients for the remaining regressions are available from the authors.
With similar mixes of bright and dim individuals across sub-districts, dropping the interaction term from the model would erase a spuriously observed arsenic effect. But if the effect is entirely real, the arsenic coefficient in the simplified model would be the average of arsenic’s zero effects on those who drink safely and its real effects on those who do not drink safely. Forty-three percent of individuals in unsafe districts drink safely; \(-0.512 \times 0.43 = 0.22\). The regression without an interaction term yields an average arsenic effect of 0.242 (standard error = 0.111). The estimated effect is not spurious.

Nearly two-thirds of Bangladeshi children face wells with average arsenic exceeding the stricter WHO standard, 10ppb. Table 1, Column 2 reports coefficient estimates for a regression which adds a dummy variable indicating an average local arsenic level between 10 and 50ppb, and an interaction between that dummy and the dummy for drinking safely. Compared to boys living in WHO-safe sub-districts, boys in Bangladesh-unsafe sub-districts who do not drink safely lose almost six-tenths of a year of education to arsenic’s effect; boys who drink safely lose nothing. The estimated effect of drinking from wells Bangladesh-safe but WHO-unsafe is negative and of non-trivial magnitude, but is quite imprecisely estimated.

We are not alone in imprecisely estimating arsenic’s effects at low levels. The National Research Council reports: “It is unclear what the shape of [arsenic’s] dose response curve [for cancer] is at low doses” (NRC, 2001, p.160). While we have chosen to emphasize differences in

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4 We had initially hoped to estimate a non-linear dose response function that would reveal the marginal effects of increased amounts of arsenic. However, splitting the arsenic levels into the five categories of Table 1 lost most signal in the noise. In two ways our data are not rich enough to support such an analysis. First, at lower levels, the standard errors are large enough to make us uncertain about differences in marginal effects at low levels. And second, sub-districts with high average levels of arsenic in their wells (say, greater than 165ppb) are located in districts containing very few sub-districts that have low levels of arsenic. Because of our limited variety of location–specific explanatory variables, we must rely on within-district variation to estimate
means across the Bangladesh and WHO thresholds, for its cost-benefit analyses the U.S. Environmental Protection Agency relies on a linear dose response function starting at zero because they “are currently unable to specify a safe threshold level” (EPA, 2001, p.6994). For Table 1, Columns 5 and 6 we replaced “unsafe” in our models with the average level of arsenic in a sub-district’s well-water to estimate such a linear dose response function for education outcomes. For an individual in an unsafe-water community who faces the mean level of arsenic for such communities (145ppb) the estimated linear effect of arsenic on years of education implies an arsenic induced loss of .37 years of education; the less parametrically estimated losses in Columns 1 and 2 lie within a 95% confidence interval around this estimate. We place more confidence in the less parametric estimates.

We see in primary school boys the roots of older boys’ reduced schooling due to arsenic. Columns 3 and 4 report regressions with the explanatory variables used for Columns 1 and 2, but with the dependent variable “days of school attended in the past week.” In Bangladesh’s 40 week school year, we estimate that boys drinking from unsafe water sources annually miss 4.8 to 6.9 more school days than do peers who drink safely. The estimated effect of arsenic levels between 10 and 50ppb is imprecisely measured and statistically insignificant.

For each of Table 1’s regressions, we fail to reject the null hypothesis of no adverse arsenic effects for boys who drink safely. Beyond confirming drinking safely’s efficacy, the like magnitudes and opposite signs of the effects for safe-drinkers and for others indicates that our estimates of arsenic’s adverse effects are not spuriously due to arsenic levels’ correlation with unsafe water’s effects. That variation is rather limited in districts that contain any high arsenic sub-districts.
omitted local conditions unless those conditions somehow affect boys who drink unsafely but do not affect boys who drink safely.

In sum, we find that drinking unsafe water impedes boys’ human capital accumulation in Bangladesh and that public health measures to shift drinking from unsafe to safe wells not only advance good health but also build human capital.
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Appendix Table 1
Regression 1’s Covariates’ Effects on Years of Education (19-21 year olds)

| Variable                          | Coef.     | Std. Err. | t     |
|-----------------------------------|-----------|-----------|-------|
| heard of arsenic prob.            | 0.559749  | 0.1176847 | 4.76  |
| age                              | 0.0863256 | 0.0517624 | 1.67  |
| head primary incomplete          | 0.2511068 | 0.12744   | 1.97  |
| head primary complete            | 0.8731088 | 0.1212886 | 7.20  |
| head some secondary              | 1.500308  | 0.1254925 | 11.96 |
| head secondary or more           | 2.491178  | 0.1389813 | 17.92 |
| head non-std. schooling          | -0.4992097| 0.7914837 | -0.63 |
| head educ missing                 | 0.0674144 | 0.8763467 | 0.08  |
| household wealth                  | 1.368785  | 0.0802983 | 17.05 |
| household wealth sqd.            | -0.1911339| 0.031282  | -6.11 |
| Mean subdistrict wealth          | -0.7981401| 0.25311   | -3.15 |
| StdDev subdistr wealth           | 0.2248109 | 0.3282781 | 0.68  |
| Floodprone                       | 0.2020512 | 0.1356002 | 1.49  |
| garbagepile                      | -0.0449738| 0.2863989 | -0.16 |
| landslide prone                  | -0.5445626| 0.7144153 | -0.76 |
| industrial pollution             | 1.321875  | 0.3087517 | 4.28  |
| safe from eviction               | 0.4493847 | 0.2030575 | 2.21  |
| squatter household               | -1.058756 | 0.6638271 | -1.59 |