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Poisoning the Mind:

Arsenic Contamination and Cognitive Achievement of Children

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Abstract

Bangladesh has experienced the largest mass poisoning of a population in history owing to contamination of groundwater with naturally occurring inorganic arsenic. Continuous drinking of such metal-contaminated water is highly cancerous; prolonged drinking of such water risks developing diseases in a span of just 5-10 years. Arsenicosis–intake of arsenic-contaminated drinking water–has implications for children's cognitive and psychological development. This study examines the effect of arsenicosis at school and at home on cognitive achievement of children in rural Bangladesh using recent nationally representative school survey data on students. Information on arsenic poisoning of the primary source of drinking water—tube wells—is used to ascertain arsenic exposure. The findings show an unambiguously negative and statistically significant correlation between mathematics score and arsenicosis at home, net of exposure at school. Split-sample analysis reveals that the effect is only specific to boys; for girls, the effect is negative but insignificant. Similar correlations are found for cognitive and non-cognitive outcomes such as subjective well-being, that is, a self-reported measure of life satisfaction (also a direct proxy for health status) of students and their performance in primary-standard mathematics. These correlations remain robust to controlling for school-level exposure.

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Poisoning the Mind: Arsenic Contamination and Cognitive Achievement of Children*

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"*Nobody sits beside me in school. They do not like to talk with me, and do not share books. Nobody likes to play with me in school. When I play, some children shout "don't touch her, don't play with her, she's got arsenic. I will not go to school.*"

> Taslima, aged 10, a girl who developed black spots on her palms and soles on schooling (Quoted in Hassan et al. / *Social Science & Medicine*, 2005).

1 Introduction

In the parlance of the World Health Organization, arsenic has been responsible for "the largest mass poisoning of a population in history". The victims are as many as 20 million Bangladeshis who have been drinking groundwater water contaminated with naturally occurring inorganic arsenic for nearly two decades (Rohde, 2005). Continuous drinking from arsenic-laced wells is highly cancerous and causes various other health disorders including birth complications. Lower doses of arsenic, consumed over years, can ultimately cause death. A low-cost solution to the problem is not <?> yet available in developing countries. No affordable technology exists that can either remove arsenic from drinking water or at least reduce it to a level at which it has no adverse effect on human well-being. Therefore, majority of the affected population continues to remain exposed to the crisis.

While the adverse effect of arseniosis on adult health is well-documented, little is known on the consequences of the catastrophic health crisis caused by drinking metal-contaminated groundwater for skill formation. For instance, children growing up in affected households are likely to be vulnerable to health shocks and hence have a poorer prospect for developing cognitive skills. Arsenic poisoning is also alleged to have created problems of exclusion for females at school and within the community and hence, has implications for their educational participation. This study therefore aims to test for the relationship between arsenicosis and child learning outcomes in Bangladesh. Most children are exposed to arsenic largely through fluid intake at home and in school. Therefore, we use primary data on test score for a large sample of secondary school students in rural Bangladesh and jointly investigate the effects of exposure to arsenicosis at home and school.

Bangladesh along with West Bengal (India) today constitutes the largest population in the world exposed to arsenic from drinking water. In both regions, children constitute nearly

50% of the affected population. Similar contamination of ground water with arsenic has occurred in Thailand, Nepal and Pakistan, and major problems have also been identified in some areas in China, Ghana, the USA, and South America (WHO, 2001; Misra, 2006). Therefore, it is hoped that our findings will inform government policies in other affected regions as well.

The remaining part of the paper is organized as follows. Section 2 elaborates on the study background. Section 3 discusses the data and sampling. The main results are reported in section 4. Section 5 concludes.

2 Background

2.1 Genesis of arsenicosis in Bangladesh

Tube wells are the single-most important source of fluid (drinking water) in Bangladesh. According to 2001 population census, 88% of rural households use tube wells as the main source of drinking water although the 1999-2000 Household Income and Expenditure Survey puts this figure to 95.7%. Nevertheless, usage of tube wells is relatively a recent phenomenon. Even in the early 1970s drinking from open water bodies was a common practice. However, surface water is often contaminated with bacteria and a major cause for waterborne diseases such as cholera, dysentery, typhoid, and diarrhoea. Unsurprisingly, these water-related illnesses in young children were the leading cause of morbidity and mortality. Therefore, for the past three decades, the government and various international organizations had promoted shallow (Tube) wells, as a course for safe drinking water from underground aquifers. Tube well construction strongly accelerated in the 1980s. Around 11 million tube wells were installed during the period, a vast majority being in private ownership (Geen et al, 2005). This initiative has helped control water-born diseases, but in many areas it has had the unintended side-effect of exposing the population to another health problem – toxic arsenic in ground water.

Pollution by arsenic occurs naturally through the dissolution of minerals and ores, and concentrations in groundwater in some areas are elevated as a result of erosion from local rocks (McArthur et al., 2001). The WHO maximum permissible level is less than 50 microgrammes per litre of arsenic. At the time of mass installation of tube wells in Bangladesh, during the 1980s, the aquifers were not tested for arsenic. Arsenic was first discovered in 1993. Realising seriousness of the crisis, a mass-detection campaign was undertaken during late 1990s. A systematic census of tube wells in suspected areas was followed by comprehensive awareness campaigns. As part of a multi-million dollar donor financed project, 5 million of the country's 11 million tube wells were tested in arsenic-prone areas. 1.4 million (or roughly 29 percent) were found to be contaminated (Rohde, 2005). According to government sources, there are 271 arsenic prone sub-districts (upazilas) in Bangladesh (BAMWSP, 2005) and 31% of all tube wells in affected regions have arsenic above WHO permissible level; a total of 32 million people drink from such tube wells (Chakraborti et al., 2004).

Arsenic toxicity has been recognized as an acute national problem. Intake of arsenic over the permissible level over a period of several years leaves a person at risk of developing arsenic related diseases. So far, 40,000-100,000 people have already developed visible pigmentation of skin, skin lesions, swollen limbs, warts, gangrene, and cancer) and/or invisible (damage to lungs, kidneys, and other internal organs; loss of feeling in the hands and legs). Prolonged exposure to inorganic arsenic can lead to hallucinations, agitation, emotional lability, memory loss, gangrene and skin as well as internal (lungs, bladder and kidneys) cancer (ATSDR, 2005).

There are a number of studies documenting the adverse effect of arsenicosis on physical wellbeing of adults. There is evidence that chronic arsenic exposure causes adverse pregnancy outcomes in terms of spontaneous abortion, still birth and pre-term birth rates (Ahmad et al. 2001). Ehrenstein et al. (2006) use primary data on 200 mothers from rural West Bengal and find that exposure to high concentrations of arsenic during pregnancy was associated with a six-fold increased risk of stillbirth after adjustment for potential confounders. Smith et al. (2006) find significant increases in mortality from lung cancer and bronchiectasis in persons with probable exposure to high concentrations of arsenic in drinking water *in utero* and early childhood. However, studies documenting costs of health care and inability of affected persons to engage in productive activities are missing.

2.2 Arsenicosis and children's development

For various reasons, arsenic exposure is a public health concern for children and infants as well. Newborns and infants are especially susceptible as arsenic may be passed from mother to child during pregnancy or through breastfeeding. Claudia et al. (2003) find that moderate arsenic exposures from drinking water during pregnancy leads to lower average birth weight. Children who are exposed to high levels of arsenic in their drinking water are seven to 12 times more likely to die of lung cancer and other lung diseases in young adulthood (Smith et al. 2006).

The existing health literature on children is however weak regarding the heterogeneity in the impact of arsenicosis. For adults, there is suggestive evidence that the symptoms of arsenicosis vary by an individual's demographic and socio-economic attributes. For instance, Hadi and Parveen (2004) studied the correlation between the prevalence of arsenicosis and various individual and household level factors such as age, sex, education and the economic status of the household[1]. Two findings are noteworthy here. First is the gender-differentiated impact -- the prevalence of arsenicosis was highest among middle-aged males[2] compared to their wives who drank water from the same source and who showed no visible signs of poisoning. A possible explanation for the gender difference in prevalence of arsenicosis is that males are more involved in physical activity and consume more fluid. Hence, they are more prone to suffer from Arsenicosis than females. Nonetheless, evidence from nation-wide data on arsenic patients is contradictory. According to Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP), there are about 38,000 arsenicosis patients people in 61 out of 64 districts in the country and most of the victims are women.

A second important finding emanating from Hadi and Parveen (2004) is the negative association between economic status and prevalence of arsenicosis. Poor people, who earn their living from physical labor, were found to drink more fluid than the non-poor. On the

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[1] The authors drew upon a dataset of 1654 individuals all of whom reside in a single village in South-west Bangladesh.

[2] The author argues that the first manifestation of arsenicosis occurs with a lag of 5–10 years (from initial exposure). The incubation period may vary with the amount of arsenic ingested, and the individual's nutritional and other immunity levels. This explains higher prevalence among old people than young people.

other hand, non-poor people are known to consume more nutritious food than poor people. Indeed there is evidence that nutritional deficiencies increase the susceptibility to arsenic health effects. Using data from West Bengal, Mitra et al. (2004) investigate whether dietary micro- and macronutrient intake alters the risk of arsenic-induced skin lesions, including alterations in skin pigmentation and keratoses. The authors conclude that low intake of calcium, animal protein, folate, and fiber may increase susceptibility to arsenic-caused skin lesions although the magnitude of increased risks related to these dietary deficiencies is small.

The findings discussed above have obvious implications for children's cognitive development. There are at least four reasons why educational development of children is likely to be hampered owing to exposure to arsenicosis. First, children who have continuously drank from Arsenic contaminated tube-wells are likely to have poorer health status and under-perform in schools compared to the peers who have grown up in arsenic unaffected households. Second, arsenicosis at home may cause adverse income shocks. Labor productivity of wage-earning adult members is likely to be reduced owing to declining health conditions. Given binding credit constrains in rural areas, such income shocks would have adverse effect on school participation and attainment.

Third, there is an emerging body of medical evidence documenting a direct impact of arsenic exposure on the intellectual development of children. A study in Mexico by Calderon et al. (2001) found that chronic malnutrition combined with exposure to arsenic influences verbal ability and long term memory. Arsenic concentration in urine was inversely correlated with verbal IQ, concepts factor (language), and knowledge factor (verbal comprehension and long-term memory). The negative effect of arsenicosis in verbal IQ scores remained even after accounting for nutritional status and other confounders. More recent research on arsenicosis and cognition also corroborates these findings. For example, Wasserman et al. (2004) concluded that exposure to arsenic in drinking water in Bangladesh was associated with reduced intellectual function in children[3]. Exposure was measured in terms of both well-water and urinary arsenic. Exposure to arsenic from drinking water was associated with

[3] Test instrument on intellectual function was drawn from the Wechsler Intelligence Scale for Children, version III.

reduced intellectual function after adjustment for socio-demographic covariates and water Mn. Children with arsenicosis (exposure to water arsenic at level above that prescribed by WHO) achieved significantly lower performance than did children with water arsenic levels below WHO limit. Interestingly, the association was generally stronger for well-water arsenic than for urinary arsenic[4].

Lastly, there is evidence that, when exposed to arsenic at early ages, children can develop visible symptoms such as pigmentation and arsenical skin lesions by the time they reach secondary school age[5]. Children with keratosis may become socially ostracised at school owing to the common belief that arsenicosis is contagious. If there are positive peer effects in classroom learning, affected children will be worse-off as arsenicosis would limit social interactions at school. Anecdotal evidence suggests that children with symptoms are often not sent to school in an effort to hide the problem and hence avoid such ostracism at school (Hassan et al., 2005).

School performance of children from affected households could be undermined for an additional reason. With nearly-complete awareness regarding the health implications of arsenicosis, affected households are increasingly seeking access to arsenic-free tube wells. Traditionally, children are sent to fetch water which cuts into study hours at home. If true, this would adversely affect school performance of children. However, the potential for this channel is a priori weak as arsenic contamination is highly irregular in a spatial sense. In many villages, unsafe tube wells are often near a safe well (Geen et al, 2005). Research on the choices of affected households suggests that a majority have managed to switch to arsenic free water wells after learning about the contaminated state of their own tube-wells. Using a large scale dataset on arsenic affected households in Araihazar district of Bangladesh, Madajewicz et al. (2005) find that 60% of the people whose wells were unsafe changed to another well within 12 months of receiving information by installing their own new well,

[4] However, evidence from extant epidemiological and public health literature is not conclusive enough owing to very small size of the sample. For example, Calderon et al. (2001) utilizes a sample of 80 children where only 41 were exposed to high levels of arsenic. Similarly, Wasserman, Liu et al. 2004 used data on a pool of 400 children aged between 9.5 and 10.5 years of which only 201-176 could be assessed for cognitive skills. The sample came from only one region of Bangladesh-- Araihazar.

[5] Upon examination of a large sample (N=5000) of children below 11 years of age from the affected Bangladeshi villages, Chakraborti et al. (2004) found Arsenical skin lesions in 6.1% of these children.

using a neighbor's well, or a community well. This mutes the potentially adverse effect of arsenicosis that operates via distorting time-allocation of school-going children between study and household chores.

3 Data and methodology

3.1 Sample and survey description

The data used in this paper have been collected in 2005 as part of a larger study to assess school quality in rural Bangladesh. The primary sampling unit of the survey was chosen to be unions[6]. To account for regional variation in school participation rate and so on, 60 unions were selected with proportional allocation from 6 divisions in the country. In the second step, for each sample union, a complete list of secondary schools in our sample unions was compiled. Using this list, all secondary educational institutes in each of the sample union were selected for data collection. In sum, a simple clustered sampling procedure was followed to select schools for the survey. All recognized schools and madrasas in each selected union were surveyed. In total, 321 schools and madrasas could be identified in the 60 unions (or school catchment areas). A detailed description of survey methodology and sampling is available in Asadullah, Caudhury and Dar (2007).

Two mathematics tests were administered on all students (both boys and girls) enrolled in grade 8 and present on the day of the survey. The first test was based on secondary-standard mathematics knowledge[7]. If there were two classrooms in grade 8, both were selected for participation in the math test. However, if any of the schools had more than two classrooms, only two were randomly selected. Once again, all students present on the day of the survey were interviewed. Given the cluster-based sampling, the survey led to a near-census of all secondary school going children (currently enrolled in grade 8 and present on the day of the survey) in the sample unions. The dataset contains a total of 321 schools and 8,475 students. Data on 5 schools were discarded, however, for poor quality and missing data problems.

[6] Union is an administrative unit bigger than a village but smaller than thana/upazila.

[7] The first test instrument was constructed by adopting 20 items previously used in the Trends in International Mathematics and Science Study (TIMSS), 1999. The second test instrument is based on primary school mathematics syllabus.

Each student taking the test was asked to answer a number of questions relating to their family and parental background. Detailed data on personal characteristics and the history of pre-secondary schooling (such as types of primary and pre-primary school attended) were also collected. For each school, the head teacher was interviewed to gather data on various aspects of the school including arsenic contamination of tube wells at school. If the head teacher was absent, the teacher-in-charge was interviewed. Additionally, school registers were accessed to collect data on student performance in school final examination in grade 7 in the previous year. This way, retrospectively, we collected data on 7-th grade final math, English and total test scores for all sample students.

To identify arsenic-affected children, we asked head-teachers and sample pupils whether tube wells at school and home were arsenic contaminated respectively. To be precise, we have used information on arsenic poisoning of the primary source of drinking water—tube wells--to ascertain arsenic exposure. This information has been gathered both at household-level and at school. This is because, children spend a substantial amount of their total time at school and a significant number of tube wells located in school compounds in the affected region are arsenic contaminated[8]. Therefore, we can simultaneously isolate arsenic affected and unaffected children at school and individual level.

Appendix Table 1 summarizes key variables of interest[9]. Our working sample therefore comprises of 7710 students for whom we have complete data on test score and arsenic contamination of tube wells at home. The main source of drinking water in 98% (316) of our sample schools is tube well. Of these, 30.22% (or 97 schools) are contaminated with arsenic. On the other hand, 13% of sample children belong to households with arsenic contaminated tube wells. In general, level of student achievement is very low in our sample. On average, students could correctly answer only 38% of secondary-standard math questions. When looking at test score by arsenic pollution status of tube well at home, we find that children from affected households have systematically lower math scores (both in secondary and primary-standard tests) and subjective well-being (happiness) (see Appendix Table 2). We

[8] Rosenborm (2004) in a study of arsenic contamination in 15 upazilas find that in 72% of all schools all wells exceeded the permissible concentration of arsenic.

[9] 13% of the actual sample observations were discarded due to missing data problem leading to a working simple of 7482 students.

are interested to see whether these differences in raw data prevail even when we account for various conventional determinants of school performance and subjective well being such as socio-economic condition of the family, personal attributes, schooling history and school attributes (including arsenic contamination status of tube wells at secondary school). This is explored in section 4 which reports results from multivariate regression models. The next section first describes the empirical strategy we follow to test the impact of arsenicosis at home.

3.2 Empirical framework

We are interested in investigating the effect of arsenicosis on cognitive achievement and psychological state of children enrolled in secondary schools. As mentioned earlier, the pollution is entirely natural (McArthur, 2006) and hence exposure to arsenic contaminated drinking water is exogenous. Nonetheless, mere exposure to polluted tube wells does not equally affect all children. Extent of the adversity depends on total intake of poisoned water. Fluid intake on the other hand varies by age, gender and amount of physical activities. Also children who grow up in poorer households are likely to have poor health status and more susceptive to arsenic-caused illness. Even in the case of equal fluid intake, impact may vary depending on previous nutritional status of the child (zinc which repairs skin damage?). Therefore, it's important to control for demographic and socio-economic attributes of the child. Therefore, we investigate the impact of arsenicosis on measures of cognitive outcomes and psychological well-being in the following regression framework:

$$T_i = H_i\alpha'_1 + A(h)_i\alpha'_2 + A(s)_s\alpha'_3 + S_s\alpha'_4 + S_i\alpha'_5 + \varepsilon_u + \varepsilon_s + \varepsilon_c + \varepsilon_i \qquad (1)$$

In equation (1), ε_u, ε_s and ε_c are union, school and classroom specific components of the error term respectively; ε_i is the idiosyncratic (student-specific) component of the error term. The following subscripts are applied throughout: *i* is for student, *c* is for class, *s* is for school and *u* is union of location. T_i is the test score of student *i* in class *c* (of grade 8) in school *s*; *A(h)* and *A(s)* are dummies for arsenic contamination of tube wells at home and school respectively so that the key parameters of interest are α_2 and α_3. *H* is a vector of controls for student- and family-background characteristics. Equation (1) is estimated using test performance of grade 8 students. The vector H controls for family factors such as paternal and maternal education and household assets. Other individual specific controls included in vector H are variables such as gender and age. Another vector with individual-specific attributes is S_i which account for past schooling background of the student as such type of the primary school attended, whether attended religious school for pre-primary schooling and a proxy for past achievement (measured by the class rank of the student in grade 7 final examination administered by the school in 2004). Inclusion of vector S_i -- proxies for pre-primary education, past school type and class rank in the regression -- yields a pseudo value-added specification of the production function to the extent these correlates proxy for past educational inputs. The vector S_s includes several school-specific controls such as land area, fraction of teachers being female, fraction of teachers being trained, mean educational attainment of teachers, log of total school expenditure and class size in grade 7.

Given the structure of the error term in equation (1), we can control for various types of unobservable factors by adopting a fixed-effects regression framework instead of a simple OLS model. First, we note that secondary school availability in rural Bangladesh varies significantly between unions so that control for union-specific unobservables accounts for geographic differences in access to schools[10]. This partially rules out selection into a given school purely for availability-related reasons. Additionally, this also accounts for non-random placement and/or finance of school facilities by the government. This is achieved by estimating equation (1) as (union) fixed-effects (UFE) regression and differencing out the term ε_u. In order to estimate the effect of household-level exposure net of school and classroom influences, however, we re-estimate equations (2) and (3) controlling for school and classroom fixed effects respectively:

$$T_i = H_i\beta'_1 + A(h)_i\beta'_2 + S_i\beta'_3 + S_s\beta'_4 + \varepsilon_c + u_i \quad (2)$$

$$T_i = H_i\gamma'_1 + Ah_i\gamma'_2 + S_i\gamma'_3 + \omega_i \quad (3)$$

In equations (1)-(3), we expect α_2 , β_2 and γ_2 to be negatively signed respectively. Significance of our estimates would indicate adverse impact of arsenic exposure on learning outcomes. As a robustness checks, we replace the dependent variable by test score in primary-standard

[10] For instance, the supply of rural public secondary schools only varies between unions in Bangladesh; there is no rural union with more than one public secondary school.

mathematics as an outcome variable. Second, we use data on subjective-well being[11] to form an additional dependent variable and examine the effect of arsenic exposure in drinking water. Next section reports the regression estimates of equation (1)-(3) using variety of outcome measures.

4 Results: Arsenic poisoning and student achievement

- **Key findings**

- Controlling for past school inputs, school characteristics (including arsenic poisoning of tube well at school) personal attributes and family background, we unambiguously find a negative and statistically significant correlation between mathematics score and arsenic contamination of water well at home (Table 1).

- Net of household-level exposure to arsenic poisoning, arsenic contamination of tube well at school has negative but statistically insignificant impact (Table 1).

    - Weak effect of arsenic poisoning at school is explained by the fact that children in rural Bangladesh switch from one school to another at the time of their transition from primary to secondary education. As a matter of fact, only 3% of the sample children attended the same school for primary education.

- Interaction of arsenic poisoning at home with gender variable indicates that boys from exposed households are significantly worse-off than girls. This finding seems consistent with the hypothesis that boys in rural areas consume more fluid than girls (as they're engaged in manual labor) and hence more likely to have greater intake of poisoned water (Table 1).

[11] There is a large number of empirical studies that have used subjective response data to model economic behaviour. For a review, see Tella and MacCulloch (2006).

- **Robustness**

    - The effect of household-level poisoning by arsenic is robust to control for school and classroom level unobservable determinant of learning.
        - To the extent students in a section attended same primary school, control for classroom FEs helps get rid of any effect of past exposure to arsenic contaminated water wells at primary school.

    - Similar correlations are found for cognitive and non-cognitive outcomes such as subjective well-being i.e. self-reported measure of life satisfaction (also a proxy for health status) of students (see Table 3) and their performance in primary-standard mathematics (see Table 2).

        - To the extent primary math skill is determined prior to enrolment in secondary grades, our finding of negative effect of arsenic exposure is arguably driven by adverse health effects due to arsenicosis.

- **Negative effect of arsenicosis - Health status or social ostracism?**

    - Control for school-fixed effects also provides a crude way to differentiate between the twin channels via which arsenic poisoning affects school performance, namely health status and social interactions. Children with visible signs of arsenicosis may be ostracized at school and traumatized. On the other hand, the effect could be purely owing to decline in health status. To the extent there are differences in norms (administrative rules and policies such as separate playground, common room for boys and girls) and dress-codes (full-length cover of the body only exposing eyes vs. head-scarf vs. traditional wear completely exposing arm and face) across schools, control for school fixed effects would purge the effect of social interactions of arsenicosis. As an indirect test of this proposition, we separately estimated the impact of arsenic exposure at home for the sample of madrasa and school students on secondary math score, controlling for school fixed-effects (regressions reported in Table 4). Indeed for the madrasas (which maintain strict dress code covering the whole body and disciplinary rules restricting social interactions at school), there is no statistically significant effect of arsenic poisoning at home. However, the effect is negative and statistically significant for school sample where children are not subjected to restrictions on dress code and have greater opportunity to ostracise someone on the basis of his/her physical/personal attributes. Similar results are obtained if we further control for classroom fixed-effects (regressions not reported).

5 Conclusion

Arsenic today threatens millions of people in Bangladesh, West Bengal, Thailand and elsewhere in the USA, China and South America. Although the health consequences of such natural disaster are well-documented, very little is known on the negative impact on children's developmental outcomes. We have drawn upon primary data on secondary school children of arsenic affected and unaffected households in Bangladesh, a country that has experienced the most severe form of arsenic poising to date.

We find a robust negative relationship between arsenicosis and test score. Given that health is an important input in educational production and children in arsenicosis-affected households have poorer health, this finding is unsurprising. Given the finding that cognitive development of children is negatively affected by arsenic, reducing exposure for this vulnerable group forms an important policy objective. We show that drinking water from a contaminated source at home is a significant route of exposure, net of school level exposure. Although arsenic poisoning of tube wells at school also serves as an additional route of exposure, for rampant school switching at the end of the primary cycle and lack of detailed data on pollution status of tube wells in primary school, we were unable to assess the actual impact of school level exposure – we have information on pollution status of current (secondary) school and only control for past school level exposure in an indirect manner (i.e. controls for various past schooling inputs that may be correlated with pollution status of primary school tube well). Knowledge of the relative effect of arsenicosis at home and school is important as policy makers may seek to target all places where children potentially drink water and hence target schools as well households in reducing exposure. However, if the adverse effect of exposure at home is larger, households may be targeted instead of schools. Future studies therefore should aim at collecting additional data on past exposure at all levels of schooling. Furthermore these studies should also involve collection of urine/blood samples from pupils to measure actual levels of arsenic exposure. Ideally these studies should involve randomized evaluations of arsenic decontamination of tube wells (or alternate provision of safe water) and impact on learning outcomes.

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Table 1: Determinants of student achievement [secondary math score in %]

	OLS	School FEs	Classroom FEs
Age	0.012	-0.003	-0.003
	(1.69)+	(0.53)	(0.51)
Age squared	-0.001	0.000	0.000
	(2.21)*	(0.10)	(0.06)
Home tube well arsenic poisoned	-0.012	-0.009	-0.009
	(1.82)+	(1.83)+	(1.78)+
Non Muslim	-0.004	-0.001	-0.002
	(0.58)	(0.21)	(0.31)
Female	-0.010	-0.017	-0.017
	(2.37)*	(5.50)**	(5.07)**
Father primary educated	-0.004	-0.003	-0.003
	(0.79)	(0.77)	(0.86)
Father secondary educated	0.002	0.005	0.005
	(0.27)	(1.06)	(1.11)
Father post-secondary educated	-0.000	0.012	0.013
	(0.07)	(2.67)**	(2.80)**
Mother primary educated	0.006	0.007	0.007
	(1.40)	(2.23)*	(2.19)*
Mother secondary educated	0.001	0.008	0.008
	(0.19)	(1.78)+	(1.89)+
Mother post-secondary educated	0.014	0.015	0.015
	(1.74)+	(2.63)**	(2.56)*
Household has a fan	0.003	0.007	0.006
	(0.68)	(1.83)+	(1.64)
Household has a TV	0.003	0.003	0.003
	(0.67)	(0.98)	(0.91)
Household has a radio	0.003	-0.001	-0.001
	(0.68)	(0.36)	(0.38)
House is pucca	0.004	-0.004	-0.002
	(0.64)	(0.79)	(0.53)
House is semi-pucca	0.004	-0.001	-0.001
	(0.70)	(0.25)	(0.14)
Travel time to school from home	-0.000	-0.000	-0.000
	(0.48)	(1.24)	(0.99)
Constant	0.220	0.357	0.433
	(3.12)**	(7.46)**	(9.85)**
Control for secondary school attributes?	Yes	No	No
Control for schooling history?	Yes	Yes	Yes
N	7710	7710	7710
R-squared	0.06	0.04	0.04

Note: Absolute value of t statistics in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. Each regression additionally contains dummies indicating tube well non-availability in school and at home, whether tube well at school is arsenic-contaminated and a set of 5 dummies indicating which day of the week the test was taken. OLS specification controls for Union FEs.

Table 2: Determinants of student achievement [primary math score in %]

	School FEs	Classroom FEs
Age	0.001	0.002
	(0.14)	(0.16)
Age squared	-0.000	-0.000
	(0.44)	(0.45)
Home tube well arsenic poisoned	-0.024	-0.023
	(2.51)*	(2.43)*
Non Muslim	-0.022	-0.024
	(2.32)*	(2.54)*
Female	-0.092	-0.091
	(15.66)**	(14.29)**
Father primary educated	0.004	0.004
	(0.63)	(0.53)
Father secondary educated	0.016	0.017
	(2.03)*	(2.16)*
Father post-secondary educated	0.015	0.015
	(1.72)+	(1.73)+
Mother primary educated	0.004	0.003
	(0.67)	(0.55)
Mother secondary educated	0.010	0.011
	(1.25)	(1.41)
Mother post-secondary educated	0.018	0.017
	(1.66)+	(1.58)
Household has a fan	0.018	0.018
	(2.61)**	(2.58)**
Household has a TV	0.003	0.003
	(0.40)	(0.40)
Household has a radio	0.004	0.005
	(0.83)	(0.93)
House is pucca	-0.002	-0.001
	(0.20)	(0.12)
House is semi-pucca	-0.008	-0.009
	(0.99)	(1.14)
Travel time to school from home	-0.000	-0.000
	(3.17)**	(2.86)**
Constant	0.791	0.874
	(8.86)**	(10.64)**
N	7710	7710
R-squared	0.07	0.06

Note: Absolute value of t statistics in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. Each regression additionally contains dummies indicating tube well non-availability in school and at home, whether tube well at school is arsenic-contaminated and a set of 5 dummies indicating which day of the week the test was taken. OLS specification controls for Union FEs.

Table 3: Determinants of happiness [dependent variable: 4=very happy; 1= very unhappy]

	OLS	School FEs	Classroom FEs
Age	-0.102	-0.063	-0.065
	(2.80)**	(1.77)+	(1.84)+
Age squared	0.003	0.001	0.001
	(2.32)*	(1.29)	(1.33)
Home tube well arsenic poisoned	-0.118	-0.100	-0.098
	(3.55)**	(2.98)**	(2.94)**
Non Muslim	0.016	0.018	0.017
	(0.47)	(0.52)	(0.49)
Female	0.167	0.172	0.186
	(7.94)**	(8.24)**	(8.21)**
Father primary educated	-0.040	-0.020	-0.022
	(1.54)	(0.80)	(0.87)
Father secondary educated	-0.011	0.030	0.032
	(0.37)	(1.04)	(1.10)
Father post-secondary educated	0.029	0.063	0.063
	(0.91)	(2.06)*	(2.08)*
Mother primary educated	0.038	0.024	0.022
	(1.65)+	(1.09)	(1.00)
Mother secondary educated	0.020	0.029	0.031
	(0.67)	(1.02)	(1.08)
Mother post-secondary educated	0.076	0.071	0.068
	(1.92)+	(1.88)+	(1.79)+
Household has a fan	0.005	0.043	0.042
	(0.19)	(1.77)+	(1.71)+
Household has a TV	0.147	0.127	0.125
	(6.04)**	(5.53)**	(5.48)**
Household has a radio	0.065	0.061	0.062
	(3.26)**	(3.23)**	(3.25)**
House is pucca	0.136	0.115	0.115
	(4.32)**	(3.80)**	(3.82)**
House is semi-pucca	0.100	0.087	0.082
	(3.49)**	(3.15)**	(2.98)**
Travel time to school from home	0.001	0.000	0.000
	(0.95)	(0.60)	(0.60)
Constant	4.599	3.442	3.399
	(12.81)**	(10.93)**	(11.68)**
N	7606	7606	7606
R-squared	0.05	0.04	0.04
Control for secondary school attributes?	Yes	No	No
Control for schooling history?	Yes	Yes	Yes

Note: Absolute value of t statistics in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. Each regression additionally contains dummies indicating tube well non-availability in school and at home, whether tube well at school is arsenic-contaminated and a set of 5 dummies indicating which day of the week the test was taken. OLS specification controls for Union FEs.

Table 4: Determinants of student achievement [primary math score in %] by school type (School Fixed-effects model)

	Madrasa	School
Age	0.004	0.052
	(0.71)	(1.54)
Age squared	-0.000	-0.002
	(0.79)	(1.66)+
Home tube well arsenic poisoned	0.001	-0.011
	(0.05)	(2.00)*
Non Muslim	-0.001	-0.002
	(0.02)	(0.32)
Female	-0.004	-0.021
	(0.51)	(5.73)**
Father primary educated	0.004	-0.005
	(0.42)	(1.16)
Father secondary educated	-0.001	0.005
	(0.07)	(1.13)
Father post-secondary educated	0.014	0.011
	(1.45)	(1.96)*
Mother primary educated	-0.003	0.009
	(0.37)	(2.49)*
Mother secondary educated	-0.014	0.013
	(1.56)	(2.60)**
Mother post-secondary educated	-0.031	0.024
	(2.79)**	(3.49)**
Household has a fan	0.003	0.007
	(0.44)	(1.72)+
Household has a TV	-0.013	0.007
	(1.64)	(1.68)+
Household has a radio	-0.000	-0.001
	(0.07)	(0.36)
House is pucca	0.007	-0.006
	(0.52)	(1.20)
House is semi-pucca	0.017	-0.004
	(1.67)+	(0.94)
Travel time to school from home	0.000	-0.000
	(0.68)	(1.70)+
Constant	0.700	-0.007
	(1.51)	(0.03)
Control for schooling history?	Yes	Yes
N	1526	6184
R-squared	0.03	0.05

Note: Absolute value of t statistics in parentheses. + significant at 10%; * significant at 5%; ** significant at 1%. Each regression additionally contains dummies indicating tube well non-availability in school and at home, whether tube well at school is arsenic-contaminated and a set of 5 dummies indicating which day of the week the test was taken. OLS specification controls for school FEs.

Appendix Table 1: Descriptive statistics

	Full sample		Boys		Girls	
Variable	Mean	SD	Mean	SD	Mean	SD
Outcomes						
% of mathematics answer correct [secondary standard]	0.38	0.20	0.38	0.19	0.37	0.21
% of mathematics answer correct [primary standard]	0.78	0.27	0.83	0.24	0.75	0.28
Happy [1=very unhappy; 4= very happy]	3.07	0.86	2.96	0.88	3.14	0.83
Personal attributes						
Age	13.23	0.95	13.34	1.07	13.16	0.85
Age, squared	175.82	29.76	178.97	37.99	173.85	22.95
Non Muslim*	0.12	0.33	0.12	0.33	0.12	0.33
Female*	0.61	0.49			1.00	0.00
Female*(Arsenic at home)						
Family background						
Travel time to school from home (in minutes)	22.48	18.68	21.45	16.85	23.14	19.72
Father primary educated*	0.33	0.47	0.33	0.47	0.33	0.47
Father secondary educated*	0.20	0.40	0.19	0.39	0.20	0.40
Father post-secondary educated*	0.23	0.42	0.25	0.43	0.22	0.42
Mother primary educated*	0.39	0.49	0.40	0.49	0.38	0.49
Mother secondary educated*	0.18	0.39	0.17	0.38	0.19	0.39
Mother post-secondary educated*	0.10	0.30	0.10	0.30	0.09	0.29
Household has a fan	0.36	0.48	0.38	0.49	0.35	0.48
Household has a tv	0.36	0.48	0.36	0.48	0.36	0.48
Household has a radio	0.58	0.49	0.57	0.49	0.58	0.49
House is pucca*	0.13	0.34	0.14	0.34	0.13	0.34
House is semi-pucca*	0.16	0.36	0.15	0.36	0.16	0.36
Home tube well arsenic poisoned	0.11	0.32	0.12	0.32	0.11	0.32
No tube well in the house	0.15	0.35	0.14	0.35	0.15	0.36
Schooling history						
Attended pre-primary (maktab) school in childhood*	0.62	0.49	0.56	0.50	0.65	0.48
Class rank in grade 7	22.19	21.70	20.52	20.53	23.24	22.33
Attended primary private school*	0.19	0.39	0.19	0.40	0.18	0.39
Attended primary madrasa*	0.05	0.21	0.06	0.24	0.04	0.19
Attended primary NGO school*	0.07	0.25	0.04	0.20	0.09	0.28
Attended primary grade in this school*	0.03	0.18	0.04	0.19	0.03	0.17
Secondary school attributes						
Class size	62.19	30.62	61.22	29.60	62.79	31.22
Distance to the nearest secondary school	3.76	1.09	3.79	1.10	3.75	1.08
School expenditure (in logs)	13.30	1.00	13.35	0.93	13.26	1.03
Years to recognition	8.09	11.74	8.58	11.81	7.78	11.68
Received best school award from the government*	0.12	0.32	0.13	0.33	0.11	0.32
Fraction of grade 8 teachers being female	0.12	0.13	0.10	0.11	0.14	0.14
Fraction of grade 8 teachers being trained	0.48	0.28	0.50	0.27	0.46	0.28
Madrasa*	0.20	0.40	0.21	0.40	0.19	0.39
Single sex school	0.16	0.37	0.03	0.16	0.25	0.43
School tube well arsenic poisoned	0.30	0.46	0.32	0.47	0.28	0.45
No tube well in school	0.02	0.12	0.01	0.11	0.02	0.13
N	7479		2881		4598	

Note: * indicates a dummy (1/0) variable. Omitted class for parental education variable is "never went to school". Base category for house type and primary school type is "kacha" and "government primary school" respectively.

Appendix Table 2: Descriptive statistics by arsenic exposure at home

	Home tube well arsenic poisoned		Home tube well arsenic free	
Variable	Mean	SD	Mean	SD
Outcomes				
% of mathematics answer correct [secondary standard]	0.36	0.18	0.38	0.20
% of mathematics answer correct [primary standard]	0.74	0.29	0.78	0.27
Happy [1=very unhappy; 4= very happy]	2.96	0.86	3.09	0.85
Personal attributes				
Age	13.07	0.92	13.25	0.95
Age, squared	171.79	24.93	176.35	30.30
Non Muslim*	0.13	0.33	0.12	0.33
Female*	0.60	0.49	0.62	0.49
Female*(Arsenic at home)				
Family background				
Travel time to school from home (in minutes)	23.07	18.97	22.41	18.65
Father primary educated*	0.34	0.47	0.33	0.47
Father secondary educated*	0.20	0.40	0.20	0.40
Father post-secondary educated*	0.19	0.39	0.24	0.43
Mother primary educated*	0.35	0.48	0.39	0.49
Mother secondary educated*	0.21	0.41	0.18	0.38
Mother post-secondary educated*	0.08	0.27	0.10	0.30
Household has a fan	0.31	0.46	0.37	0.48
Household has a tv	0.30	0.46	0.37	0.48
Household has a radio	0.53	0.50	0.58	0.49
House is pucca*	0.19	0.39	0.12	0.33
House is semi-pucca*	0.14	0.35	0.16	0.36
No tube well in the house	0	0	0.16	0.37
Schooling history				
Attended pre-primary (maktab) school in childhood*	0.55	0.50	0.63	0.48
Class rank in grade 7	22.82	21.36	22.11	21.74
Attended primary private school*	0.19	0.39	0.19	0.39
Attended primary madrasa*	0.06	0.24	0.05	0.21
Attended primary NGO school*	0.11	0.32	0.06	0.24
Attended primary grade in this school*	0.03	0.16	0.03	0.18
Secondary school attributes				
Class size	64.93	29.55	61.83	30.74
Distance to the nearest secondary school	3.65	1.23	3.78	1.07
School expenditure (in logs)	13.17	1.00	13.31	0.99
Years to recognition	6.97	9.79	8.23	11.96
Received best school award from the government*	0.08	0.27	0.12	0.33
Fraction of grade 8 teachers being female	0.13	0.13	0.12	0.13
Fraction of grade 8 teachers being trained	0.48	0.25	0.48	0.28
Madrasa*	0.20	0.40	0.19	0.40
Single sex school	0.23	0.42	0.15	0.36
School tube well arsenic poisoned	0.02	0.15	0.01	0.12
No tube well in school	0.49	0.50	0.27	0.44
N	860		6619	

Note: * indicates a dummy (1/0) variable. Omitted class for parental education variable is "never went to school". Base category for house type and primary school type is "kacha" and "government primary school" respectively.