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SHSU ECONOMICS WORKING PAPER

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## Abstract

This paper estimates the health costs of arsenic contamination of drinking water in Assam, India, where 0.72 million people are affected. Applying the Three Stage Least Square (3SLS) procedure to data collected through a primary survey of 355 households in 2013, it estimates three structural equations to determine health costs due to arsenic contamination. The estimates show that the annual health cost of a 1 microgram increase in arsenic concentration is about INR 4 per household. Furthermore, if the level of arsenic concentration is reduced to the safe limit of 50 microgram per liter, the annual welfare gain for a household is estimated to be INR 862 (USD 14). Projecting these figures to the entire arsenic-affected population of Assam, the annual health cost is estimated to be about INR 0.76 million (USD 0.01 million) and the welfare gain from reducing the level of arsenic concentration to the safe limit is estimated to be INR 153 million (USD 2.49 million).The results also indicate that these health costs and welfare gains vary significantly across different levels of arsenic concentration and across districts. Finally, the paper draws policy implications for providing safe drinking water in Assam.

*Keywords*: Arsenic contamination; health cost; welfare gains; averting expenditure; medical expenditure; Three Stage Least Square (3SLS); Household Production Function

*JEL Classifications*: I120; I130

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## 1. Introduction

Access to safe drinking water is a basic human right and the provision of adequate drinking water is an effective health intervention. Besides causing sickness and death, inadequate safe drinking water leads to poverty by increasing health cost, lowering school enrolment and work productivity, and reducing income (Ahmed et al., 2010). Contaminated drinking water is often considered a major health hazard in developing countries (WHO, 2007; Ahmed et al., 2010). It creates a set of menaces, affecting human health, economic development, and ecosystem function. Human sickness and death involve economic costs due to loss of workdays and wages, and also due to medical expenses. Healthcare costs associated with the treatment of pollution-induced diseases, preventive measures, disutility from reduced leisure due to illness, and changes in life expectancy are all economically quantifiable aspects of environmental health (Dasgupta, 2004). One of the sources of contamination is the presence of chemical arsenic in groundwater, which affects millions of people in many countries worldwide (Heikens et al., 2007; Kibria et al., 2010; Pearson et al., 2011; Thakur et al., 2013). According to the World Health Organization, 1.0 mg (milligram) of inorganic arsenic per day may cause skin diseases within a few years of first exposure (WHO, 1981). The U.S. Environmental Protection Agency (EPA) estimates that drinking of one liter of arsenic contaminated water (50 microgram [μg] / liter) per day could put as many as 13 persons per 1000 population at life risk from arsenicosis (Smith et al., 1992). Furthermore, the U.S. National Research Council (NRC) concludes that exposure to 50 μg /liter of arsenic could result in a combined cancer risk of 1 in 100 people (NRC, 1999).

Given these potential hazards, this paper intends to estimate the health costs due to arsenic contamination of drinking water in Assam, a state in the northeast region of India, where, according to a government report (GOA 2011), 0.72 million people (about 2.3 percent of the total population of the state) are affected by such contamination. The study uses the household production function (HPP) approach to estimate the health costs of arsenic-induced water pollution. It also estimates and compares health costs associated with different levels of arsenic concentration in drinking water. The cost calculations involve estimation of three simultaneous equations in three endogenous variables by the Three Stage Least Square (3SLS) estimation procedure. The estimates show that the monthly health cost of 1 μg increase in arsenic concentration in water is about INR 0.35 per household. Furthermore, if the level of arsenic concentration is reduced to the safe limit of 50μg/liter, the annual welfare gain for a household is estimated to be INR 862. Projecting these figures to the entire arsenic-affected population of Assam, the annual health cost is estimated to be about INR 0.76 million and the welfare gain from reducing the level of arsenic concentration to the safe limit is estimated to be INR 153 million. These estimates have implications for government policy on public health.

To the best of our knowledge, there are a limited number of studies (Ahmed et al., 2002; Roy et al., 2004; Roy, 2008; Khan, 2006; Khan and Haque, 2010) that estimate the economic costs of arsenic contamination of groundwater in Bangladesh and India. Our study is different from the earlier studies in two respects. First, in addition to estimating the health costs, it explores their relationship with the levels of contamination. No previous study examines the variations in health costs due to differences in the levels of arsenic concentration. Second, we believe, this is the first study that estimates the health costs due to arsenic contamination of water in Assam, one of the most affected states in India.

The paper is organized as follows: Section 2 discusses the extent of arsenic contamination of water. A brief review of the related literature is included in Section 3. The next section discusses the data and methodology used in this study. Section 5 presents the results and their analysis. Section 6 includes our concluding remarks and policy recommendations.

## 2. Extent of Arsenic Contamination of Water

Due to its significant toxicity, arsenic is a global concern as a pollutant of drinking as well as groundwater. High concentration of arsenic in groundwater has been reported for several countries (Mohan and Pittman, 2007; Jain and Singh, 2012). Globally, the worst cases have been reported from four countries in Asia. In order of the levels of arsenic concentration, these countries are: Bangladesh, India, China, and Taiwan. The groundwater arsenic poisoning in Bangladesh is regarded as one of the largest disasters or mass poisoning in the history of human civilization. According to various studies, between 77 and 100 million people are believed to be either drinking arsenic contaminated water or at risk of exposure on a daily basis (Kibria et al., 2010; Pearson et al., 2011; Abedin and Shaw, 2013).

The first case of arsenic contamination of water in India was reported in 1976 from Chandigarh (Thakur et al., 2013). Since then widespread contamination has been reported in groundwater from many parts of India (Figure 1) including West Bengal, Bihar, Chhattisgarh, Jharkhand, Uttar Pradesh, Bihar, Assam, Rajasthan, Punjab, Haryana, Himachal Pradesh, surrounding areas of New Delhi and the union territory of Chandigarh. Among them, the most severely contaminated state is West Bengal where 26 million people in 12 districts are affected (Chakraborti et al., 2004; Chakraborti et al., 2013; Thakur et al., 2013).

[Insert Figure 1]

Among the north eastern states, the highest level of arsenic contamination is found in Assam. According to the latest report by the Government of Assam (GOA, 2013), 19 out of 27 districts of the state are affected by arsenic. The concentration of arsenic in groundwater exceeds the permissible levels in several districts of Assam (GOA, 2011). Note that although the permissible limit of arsenic in drinking water is 10 μg/liter according to the World Health Organization (WHO) standards, it is set at 50 μg/liter by the Bureau of Indian Standards (BIS). Furthermore, Singh (2004) finds that the districts of Jorhat, Lakhimpur, Nalbari, and Nagaon have the maximum level of arsenic in groundwater. Since, according to the 2011 census report, more than 50% of the households in Assam use hand pumps to obtain their drinking water, a large proportion of the populations is likely to be exposed to arsenic contamination. In fact, according to the same report, access to safe drinking water in the state is less than the national average: the ratio for the state is only 9.2% against the all India average of about 32%. Also, the proportion of people having access to treated water sources is much lower and the proportion obtaining water from uncovered well is much higher for Assam than the average for all India (ORGCCI, 2011).

## 3. Related Literature

Although there have been a number of studies that examine the issue of arsenic contamination of water, the recent literature (Roychowdhury et al., 2002; Das et al., 2004; Norra et al., 2005; Huang et al., 2006; Rahman et al., 2007; Jakariya et al., 2007; Dahal et al., 2008; Bhattacharya et al., 2009 and 2010; Samal et al., 2011; Sanders et al., 2012; Halder et al., 2012; Santra et al., 2013) investigates the existence and effects of arsenic in soil, rice, fish, and vegetables as well. Some studies (Karim, 2000; Singh, 2004; Tornqvist et al., 2011; Chakraborti et al., 2013) specifically examine the health effects of arsenic in water. Rajasooriyar et al. (2013) and Navoni (2014) develop spatial maps of human health risk due to exposure to arsenic contamination of water in Sri Lanka and Argentina respectively. There are other studies (Shea, 2002; Opara et al., 2007; Chakraborti et al., 2013; Gani and Scrimgeour, 2014) that suggest specific actions to mitigate these health effects. Our study makes an attempt to assess health costs due arsenic contamination of drinking water in Assam.

Behavioral linkage methods (BLM) are used to assess health costs of water pollution. These methods are of two types: observed and hypothetical. The observed BLMs comprise HPP and hedonic price method (HPM). The hypothetical BLMs include contingent valuation method (CVM). Several researchers use CVM to find the willingness to pay (WTP) for safe water or for better and regular supply of water services (Chowdhury, 1999; Ahmed et al., 2002; Jalan et al., 2003; Maddison et al., 2005; Haq et al., 2007; Gunatilake and Tachiiri, 2012; Coster and Otufale, 2014; Khan et al., 2014). Ahmed et al., (2002) use CVM to assess household preferences and willingness to pay for arsenic-free drinking water. They find that although most respondents are aware of arsenic contamination in water, many of them are ignorant about its serious health effects. A lack of awareness affects the willingness to pay for safe and better drinking water facility (Jalan et al., 2003). Studies show that people are eager to switch to alternative safe water supply facility to avoid arsenic related health issues but sometimes have to use the arsenic contaminated water due to non-availability of an alternative source (Ahmed et al., 2002). This finding suggests that mitigation of arsenic related health problems require provision of alternative water sources. Since people seem to have a preference for government provision of water supply over community or individual level arsenic mitigation approach, the local government can play an important role (Coster and Otufale, 2014). Some studies (Chowdhury, 1999; Ahmed et al., 2002) further show that people are eager to pay for water supply facilities that provide safe and good quality water with no interruption. In some cases, however, the high connection cost appears to be a hindrance to government water supply coverage to the poor. Allowing payment of domestic connection cost in installment may ameliorate this situation (Gunatilake and Tachiiri, 2012). Education, exposure to mass media and income play a significant role in increasing people's WTP for safe drinking water (Ahmed et al., 2002; Haq et al., 2007; Khan et al., 2014). Thus paying for safe, better and regular water, people want to minimize the adverse effects of arsenic on health. Using CVM, Maddison et al. (2005) estimate annual health cost of arsenic contamination in tube well water in Bangladesh at USD 2.7 billion.

In contrast, very few studies use observed BLMs to estimate the health costs of arsenic contamination in water (Khan, 2006; Roy, 2007 and 2008; Khan and Haque, 2010). Using primary survey data of 878 households in Bangladesh, Khan (2006) estimates the total cost of illness as a result of exposure to arsenic between USD 9 million and USD 17 million per annum that accounts for nearly 0.6 percent of the annual income of the affected individuals. Khan and Haque (2010) estimate the annual cost of arsenic-related illness in Bangladesh, including mitigation expenses, at USD 51 per household using the 2010 price level. Based on a primary survey of 473 households in West Bengal, India, Roy (2008) finds that if the arsenic concentration is reduced to the safe limit of 50 μg/l, the benefits to each household would be INR 297 per month. Comparing this with the cost of supplying filtered piped water by the Kolkata Municipal Corporation to households, which is INR 127 ($3) per month per household, she concludes that it is economically feasible to invest in safe water and people are ready to pay for it.

# 4. Methodology and Data

## 4.1 Methodology

### *4.1.1 Theoretical Framework*

The study uses the household production function model framework (Freeman, 1993) to estimate the health cost due to arsenic contamination of water in Assam. This framework uses a household utility function of the following form:

$$U = U(X, L, S) \tag{1}$$

where $X$ denotes expenditures on all non-health goods, $L$ is the amount of leisure time and $S$ is the time spent being sick. The time spent being sick depends on exposure to pollution due to arsenic contamination ($p$), the acquired or mitigating activities such as medical treatment ($b$), stock of health capital ($h$), and stock of human capital measured by education ($e$). As in Roy (2008), the health production function is specified as:

$$S = s(p,b,h,e) \tag{2}$$

Furthermore, $p$ depends on the concentration of arsenic in water, $c$, and the extent of averting activity, $a$, undertaken by the household to avoid or reduce exposure to pollution. Thus,

$$p = p(c,a) \tag{3}$$

Substituting for $p$ in (2), we obtain:

$$S = s(c,a,b,h,e) \tag{4}$$

The household budget constraint is as follows:

$$I = I^* + [W \times (T - L - S)] = X + P_a.a + P_b.b \tag{5}$$

where $P_a$ is the price of averting activities, $P_b$ is the price of adaptive (medical) activities, $W$ is the wage rate, and $I^*$ is the non-wage income, and $T$ is total time. The household maximizes its utility (Eq. 1) subject to the given budget constraint (Eq. 5).

$$Maximize \quad G = U(X, L, S) + \lambda \left[I^* + W(T - L - S) - X - P_a.a - P_b.b\right] \tag{6}$$

The solution to this problem yields the demand functions for averting and mitigating activities (see Freeman, 1979 and Murty et al., 2003).

$$a^* = a^*(I^*, W, P_a, P_b, c, h, e) \tag{7}$$

$$b^* = b^*(I^*, W, P_a, P_b, c, h, e) \tag{8}$$

These functions represent the optimum quantities of averting and mitigating activities as functions of prices, income, arsenic concentration, health and human capital. Now, substituting for $a$ and $b$ in Eq. (6) with their optimal levels (as indicated by *) and using the first order utility maximization conditions with respect to $c$, we can derive the health cost as follows:

$$HC = W \frac{\partial s}{\partial c} + P_a \frac{\partial a^*}{\partial c} + P_b \frac{\partial b^*}{\partial c} - \frac{\frac{\partial u}{\partial s}\frac{\partial s}{\partial c}}{\lambda c} \tag{9}$$

Note that HC also represents marginal willingness to pay (*MWTP*) for improved health quality due to reduction in arsenic concentration of water. Further, $\lambda$ denotes the marginal utility of investment in averting and mitigating expenses to get rid of sickness. Now, taking total derivative of health production function in Eq. (4) with respect to arsenic concentration, we obtain the health effect due to arsenic contamination of drinking water.

$$\frac{ds}{dc} = \frac{\partial s}{\partial a^*}\frac{\partial a^*}{\partial c} + \frac{\partial s}{\partial b^*}\frac{\partial b^*}{\partial c} + \frac{\partial s}{\partial c} \tag{10}$$

Rearranging terms in (10),

$$\frac{\partial s}{\partial c} = \frac{ds}{dc} - \frac{\partial s}{\partial a^*}\frac{\partial a^*}{\partial c} - \frac{\partial s}{\partial b^*}\frac{\partial b^*}{\partial c} \tag{11}$$

Since the estimation of the last term in Eq. (9) (which measures disutility from sickness) is difficult, valuation studies often estimate the lower bound of the *MWTP* by eliminating it (Khan, 2006; Khan and Haque, 2010). Thus, eq. (9) becomes

$$HC = MWTP = W\frac{\partial s}{\partial c} + p_a\frac{\partial a^*}{\partial c} + p_b\frac{\partial b^*}{\partial c} \quad (12)$$

where *HC* or *MWTP* is the sum of costs due to work day loss, the adoption of averting and mitigating activities.

### *4.1.2 Empirical Model Specification*

Based on the theoretical model framework described above, we now outline an empirical strategy to estimate the health costs of arsenic contamination of water by calculating wage loss due to sick days, averting expenditure, and medical expenditure. This requires estimation of a system of three simultaneous equations in three endogenous variables: sick days, averting expenditure, and medical expenditure. The three stage least square (3SLS) estimation procedure is used. Rank and order conditions are used to determine that the system is neither under-identified nor over- identified (Gujrati, 1995). The three equations for our empirical estimation are specified as follows:

$$\begin{aligned} ln(sickday) &= \alpha_1 + \beta_{11}\, ln(familysize) + \beta_{12}\, ln(avertexp) + \beta_{13}\, ln(med\,exp) + \beta_{14}\, ln(arsenic) \\ &+ \beta_{15}\, ln(income) + \beta_{16} health + \varepsilon_{11} \end{aligned} \quad (13)$$

$$\begin{aligned} ln(avertexp) &= \alpha_2 + \beta_{21}\, ln(sickday) + \beta_{22}\, ln(med\,exp) + \beta_{23}\, ln(arsenic) + \beta_{24}\, ln(income) \\ &+ \beta_{25} aware + \varepsilon_{21} \end{aligned} \quad (14)$$

$$\begin{aligned} ln(med\,exp) &= \alpha_3 + \beta_{31}\, ln(age) + \beta_{32}\, ln(sickday) + \beta_{33}\, ln(avertexp) + \beta_{34}\, ln(arsenic) \\ &+ \beta_{35} + ln(income) + \beta_{36}\, ln(food\,exp) + \varepsilon_{31} \end{aligned} \quad (15)$$

where *sickday* is the number of sick days per household per month; *familysize* is the household size; *avertexp* is the monthly expenditure on averting activities; *medexp* is the monthly household expenditure on medical treatment; *arsenic* is the level of exposure to arsenic contamination; *income* is the total income of the household; *health* is the health status of the household; *aware* is a dummy variable that indicates the household awareness about the presence of arsenic in water; *age* is the age of the household head; and *foodexp* is the household expenditure on food. Appendix A includes a description of the variables and how the data are constructed.

In an alternative specification, we also include a district dummy to capture the effects of the district-specific factors on health costs. Furthermore, we include an interaction between arsenic concentration and the district dummy to examine if the effect of arsenic contamination of water on health costs varies across districts,

## 4.2 Data

The study area covers two arsenic affected districts of Assam: Jorhat and Nalbari. These two districts are among those with the highest number of arsenic affected population. The arsenic concentration ranges from 62.7 ppb (parts per billion; 1 ppb = 1 μg/liter) to 491 ppb in most habitations of Jorhat district, and from 58.4 ppb to 621 ppb in Nalbari district (GOA, 2011). These amounts exceed the BIS permissible limit. This study uses both primary and secondary data. The secondary data on the levels of arsenic concentration in different geographical locations of Jorhat and Nalbari district are obtained from the Public Health Engineering Department (PHED), Government of Assam. The primary data are collected through a sample survey of the households in the selected districts.

[Insert Table 1]

### *4.2.1 Survey Design*

The survey involves a multi-stage sampling procedure. In the first stage, two districts with large number of arsenic affected population have been selected. Figure 2 shows the two study districts of Assam. In the second stage, two Blocks, one from each district, have been selected based on the fact that they have the highest number of arsenic affected population within the respective districts. Thus, we choose Titabor Block of Jorhat district and Paschim Nalbari Block of Nalbari. Note that Titabor Block comprises 227 habitations (a habitation is a cluster of households) with an arsenic-affected population of 71,543 while Paschim Nalbari Block comprises 47 habitations with an arsenic-affected population of 18,887 (GOA 2011).In the third stage, six villages from each block have been chosen. The selection of the villages has been made according to three different levels of arsenic concentration: low (<100 ppb), medium (101-300 ppb), and high (>300 ppb). Thus, two villages each with high, medium or low arsenic concentration are selected. Finally, one habitation is selected from each village for the study. Household selection is made through random sampling. About 50% of the households in each habitation are sampled for the survey. A total of 175 households are selected from Titabor Block of Jorhat district. Similarly, 180 households are selected from Paschim Nalbari Block of Nalbari district. Thus, a total of 355 households are interviewed from the two districts.

[Insert Figure 2]

Data are collected using a semi-structured questionnaire during July-September 2013. The questionnaire used for interviewing households is divided into four sections. An attempt is made to obtain individual-level as well as household-level information. The first section deals with socio-economic details, including basic income-expenditure data. Information on household's demand for water quality is included in section two. The third section gives the sickness and medical treatment details of the family members. The fourth section contains awareness details, including questions regarding any arsenic-related awareness program conducted in the neighborhood. The questionnaire is translated into local language for better understanding by the respondents. These questions are adapted from Khan (2006) and Roy (2008) with some modifications to suite the local environment. The interview is conducted by the authors along with four data enumerators. About 1.5–2 hours are spent in collecting primary information from each household. Of these four data enumerators employed, two hold master's degree in economics and are trained in the terminology and the methodology used in the study. The other two data enumerators are from the survey area with some knowledge of arsenic contamination and thorough knowledge of the survey village. All four data enumerators are trained in the various aspects of the survey.

### *4.2.2 Household Characteristics*

Table 2 presents summary statistics of the data collected from primary and secondary sources on the variables that are included in our empirical model. This table shows that, on an average, the number of sick days is about 4 per household per month. The average averting expense for a household is about INR 39 per month while medical expenditure is about INR 115.

[Insert Table 2]

For about 68% of the households surveyed, the main source of water is hand pumps, of which some are community hand pumps and others are owned by the households. With about 18% of the households using deep tube wells, they are the second major source of water. The rest of the households use a variety of water sources including wells. In most cases, these sources do not go beyond the ground water level and, therefore, are exposed to arsenic contamination. Hand pumps with arsenic contamination of water are not usually marked RED to indicate that the water is unsafe for drinking (as required by government regulation). Note that people covered by the survey have been living in those places for more than 36 years. Thus, the residents who use hand pumps and deep tube wells are at high risk of being exposed to arsenic. In our survey, about 86% of households believe that arsenic is the major cause of their sickness. Nearly 5% of the people covered in the survey suffer from known arsenic-related diseases while many more unknowingly fall prey to such ailments. About 45% of these people suffer from gastrointestinal problem.

The survey finds that 85.5% of all respondents unaware of the presence of arsenic in the water they use either for drinking or for other purposes. This contradicts the findings of Ahmed et al. (2002) for Bangladesh. The average household averting expenditure is found to be higher than those reported by Khan (2006), Roy (2008) and Khan and Haque (2010). However, as Khan (2006) and Khan and Haque (2010) note, in Bangladesh, respondents are not involved much in averting activities due to their poor economic conditions. In contrast, the households in Roy's (2008) study travel less than households in our study to fetch arsenic free water and, as such, the average expenditure is lower.

Medical expenditure includes expenses on doctor's visit, clinical examination and medicine that are not provided by Public Health Center (PHC). Average medical expenditure accounts for only about 3% percent of total household expenditure. In Table 3, we present monthly average averting and medical expenditures, and number of sick days by three levels of arsenic concentration: low (below 100 ppb), medium (between 100 and 300 ppb) and high (above 300 ppb). The table shows that averting and medical expenditures as well as with the number of sick days increase with the level of arsenic concentration. Furthermore, averting expenditure is found to be positively related to the number of sick days. Although this seems counterintuitive, with no knowledge of the direction of causality, we can't comment on this.

[Insert Table 3]

## 5. Empirical Results and Discussion

In this section, we report the results from the 3SLS estimation of the system of equations as well as the health cost estimates for the baseline specification (13) – (15). Additionally, we report health cost estimates for different levels of arsenic concentration in water. Finally, we present health costs estimates for the two districts covered in our study separately, taking into account the fact that arsenic concentration affects the health costs components differently in these two districts.

### 5.1 Estimation of production and demand function

Table 4 presents the parameter estimates for the structural equations (13) – (15) in our baseline specification. The results for the sickday equation (Eq. 13) shows that exposure to arsenic has a positive impact on the number of sick days but the effect is statistically significant only at the 10% level. The estimated coefficient indicates that a 1% increase in arsenic exposure leads to a 9% increase in the number of sick days per household per month. The estimated coefficients are statistically significant for medical expenditure (at the 1% level), income (at the 10% level), and health status (at the 1% level). Higher medical expenditures are associated with more sick days. Further, households with higher income seem to have less sick days. Higher income may indicate that the households are more educated and, therefore, have higher level of awareness about health and hygiene.

[Insert Table 4]

For the averting expenditure equation (Eq. 14), the estimated coefficients for all but sick days and income are statistically significant at the conventional levels. Exposure to arsenic has a highly significant positive impact on averting expenditure. A one percent increase in arsenic exposure leads to 25 percent increase in such expenditure. Thus, the more a household is exposed to arsenic contamination, the higher is its spending on averting efforts. The signs of the estimated coefficients are consistent with prior expectations for all control variables. Sick days and awareness have significant positive effects while medical expenditure has a significant negative effect on averting expenditures.

For the medical expenditure equation (Eq. 15), the estimated coefficients are statistically significant and have the expected signs for all explanatory variables. Exposure to arsenic has a positive and statistically significant effect on medical expenditure: a one percent increase in arsenic exposure leads to a 26% increase in medical expenditure. Age of the household head, number of sick days, and income have significant positive effects while averting and food expenditure have significant negative effects on medical expenditure.

## 5.2 Estimation of the health costs

We now use the estimated coefficients of arsenic exposure in Eq. (13) – (15) (as reported in Table 5) to calculate the health cost as defined by Eq. 12. Note that the variables are in logarithm and, therefore, the estimated coefficients need to be appropriately adjusted to be consistent with Eq. (12). For example, $\frac{\partial s}{\partial c} = \widehat{\beta_{14}} \times \frac{s}{c}$ where we use the mean values of $s$ and $c$. The daily wage for a male person is assumed to be INR 120. This is the statutory minimum wage rate under the Mahatma Gandhi National Rural Employment Guarantee Scheme (MNREGS), a rural job guarantee scheme introduced in 2005. In order to be consistent with our estimates, we convert this into monthly wage by multiplying it by 30. Since men are the wage earners of the households surveyed, only the work days of the male members are taken into account to calculate the component of health cost that is due to lost wages. Furthermore, the averting expenditure and medical expenditure components are calculated by multiplying the adjusted coefficients from Eq. (14) and (15) by corresponding mean monthly expenditures per household. As Table 6 shows, the health cost of 1 μg increase in arsenic concentration in water is estimated to be INR 0.35 per month per household. This implies an annual cost of INR 4.29 per household.

[Insert Table 5]

These cost calculations can also be used to estimate welfare gain from reducing arsenic concentration to a safe desirable level. To do that, we use a scaling factor which, in our case, is the difference between the average level of arsenic concentration and the permissible level (i.e. 50 ppb). This difference is then multiplied by the cost estimated for 1 ppb of arsenic using Eq. (12). The result obtained from this exercise represents the health cost gain from reducing the arsenic level in water to the safe permissible limit. Our estimates show that the welfare gain for a household is INR 71.85 (USD 1.17, using average nominal exchange rate for July-September 2013) per month or INR 862.19 (USD 14.04) per year. We now project these figures to the arsenic-affected population of Assam. We divide the total number of arsenic-affected people (0.72 million) by the average size of the households (4.1 persons) to obtain an estimate of the number of arsenic-affected households and then multiply it by the estimated annual costs and welfare gain per household. The annual health cost for the entire affected population is estimated to be about INR 0.76 million (USD 0.01 million) and the welfare gain from reducing the level of arsenic concentration to the safe limit is estimated to be INR 152.7 million (USD 2.49 million).

It is useful to compare our findings with earlier studies of welfare gain from reduction in air and water pollution. The estimated welfare gain reported in this study is higher than Jalan et al. (2003) and Gupta (2006) but lower than Murty et al. (2003) and Roy (2008). Note that Jalan et al. (2003) consider only averting expenditure in the estimation of WTP for better drinking water facility while Gupta (2006) does not consider averting expenditure at all. In contrast, Murty *et al.* (2003) find the number of work days lost due to air pollution to be less but medical expenditure to be much higher than those reported for water contamination in our study. Further, the number of sick days and medical expenditure are higher in Roy's (2008) study than in the current study.

## 5.3 Variations in health costs by the levels of arsenic concentration

We also calculate health costs for high, medium and low concentration of arsenic in water. As shown in Table 4, high is defined as a level with arsenic concentration of above 300 μg, medium is with concentration between 100 and 300 μg and low is with less than 100 μg. The health cost estimation by different levels of arsenic concentration has important policy implications. Since these costs also reflect people's willingness to pay for safe drinking water, any evidence of significant differences by levels of concentration would suggest that a specific policy may not be uniformly effective across the state.

[Insert Table 6]

As Table 6 shows, the health costs of 1 μg increase in arsenic concentration for high, medium, and low arsenic levels are estimated to be Rs 0.60, INR 0.42 and INR 0.12 respectively per household per month. These cost estimates also imply that the monthly household welfare gains from reducing arsenic concentration to the safe permissible limit are INR 221.33, INR 86.74, and INR 1.43 respectively for high, medium, and low levels of current arsenic concentration in water. The equivalent annual gains are: INR 2656 (USD 43.25), INR 1041 (USD 16.95), and INR 17 (USD 0.28) respectively.

## 5.4 District-level variations in health-cost

Finally, we estimate an extended model that includes a district dummy (that takes the value 1 for the district of Nalbari and 0 for Jorhat) and an interaction between the district dummy and arsenic concentration in each of the three structural equations. By itself, the district dummy captures the differences in average sick days, averting and medical expenditures between the two districts. The interaction term is expected to capture the differences in the effect of arsenic concentration on sick days, averting and medical expenditures. Without reporting the detailed 3SLS estimation results, we note that the estimated coefficient for the district dummy is positive (but statistically insignificant) in the sick days equation, significant negative in the averting expenditure equation, and significant positive in the medical expenditure equation. The interaction term is negative but statically insignificant for sick days. In contrast, it is positive and significant for averting expenditure and negative and significant for medical expenditure. The signs and statistical significance of the estimated coefficients for other variables do not change although there are quantitative differences.

[Insert Table 7]

The separate health cost estimates for the two districts are reported in Table 7. Note that the average arsenic concentration level is substantially higher in Jorhat than in Nalbari. The health cost estimates based on the extended model reveal that the annual household health cost of a 1 μg increase in arsenic concentration is about 65% higher in Jorhat than in Nalbari (INR 6.10 in Jorhat against INR 3.70 in Nalbari). Similarly the annual welfare gain from reducing arsenic concentration to the safe permissible level is INR 1,351 (USD 22.00) in Jorhat while it is INR 634 (USD 10.32) in Nalbari.

Overall, we find evidence of significant differences in health costs of arsenic contamination by its level of concentration and by district. These findings are important for policies that are intended to provide safe drinking water to the rural population. While people in villages with high arsenic concentration may be willing to pay for safe drinking water others who face low health cost may not care for such measure.

## 6. Concluding Remarks

This paper estimates the health cost of arsenic contamination of drinking water in Assam, India, where 0.72 million people are affected. Applying the Three Stage Least Square (3SLS) procedure to data collected through a primary survey of 355 households in 2013, it estimates three structural equations to determine health costs due to arsenic contamination. The estimates show that the annual health cost of a 1 μg increase in arsenic concentration is about INR 4 per household. Furthermore, if the level of arsenic concentration is reduced to the safe limit of 50μg/liter, the annual welfare gain for a household is estimated to be INR 862. Projecting these figures to the entire arsenic-affected population of Assam, the annual health cost is estimated to be about INR 0.76 million and the welfare gain from reducing the level of arsenic concentration to the safe limit is estimated to be INR 153 million.

These results have important policy implications. In Assam, the supply of drinking water in urban areas is the responsibility of individual Municipal Board (MB) and Assam Urban Water Supply and Sewerage Board (AUWSB) which cover about 22 percent of total households. Drinking water in rural areas is managed by the Public Health Engineering Department (PHED), Government of Assam. At the non-governmental level, individuals, communities, and non-profit organizations establish water sources with either full or partial ownership. In urban areas, people pay a monthly fee for piped water though the quality of water is suspect due to many breakages and leakages of the old pipelines. In contrast, the payment for piped water is uncommon in rural areas and therefore it is difficult for private or community groups to facilitate drinking water. Consequently, PHED initiated a community initiative approach in 2006 under the National Rural Drinking Water Quality Monitoring and Surveillance Programme (NRDWQMSP). Under this approach, each village would have a water users committee that would charge INR50 to INR 150 as monthly fee from each household for providing safe drinking water. The exact fee would depend on the cost of operation for supplying clean water. The estimated average welfare gain from reducing the level of arsenic concentration to the safe limit, reported in this study, is within this suggested range of fees. In places with high arsenic concentration the estimated welfare gain far exceeds the maximum suggested fee. Thus, our findings suggest that it would be beneficial for the people in rural areas to take advantage of the water users committee under the NRDWQMSP. Since our findings also show that in places with low arsenic concentration, the welfare gain is negligible, the policy makers should take cognizance of these differences and incorporate some flexibility in their policies.

Finally, it should be recognized that our estimates of health costs and welfare gains are conservative at the best. These estimates are based on one-period health effects of arsenic contamination of drinking water. However, such contamination may have life-long impacts on health. If we consider these long-run effects, health costs as well as welfare gains of reducing water pollution will be much higher.

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# Appendix A

## Description of the variables

### *Endogenous variables*

Sick days (*sickday*): Number of sick days per household per month. Data are collected on the total number of sick days over a six month period prior to the survey and converted to monthly frequency to make them consistent with other variables.

Medical expenditure (*medexp*): Total monthly medical expenditure per household for treating all types of diseases (including arsenic-related). Data are for a six months period prior to the survey and were converted to monthly frequency.

Averting expenditure (*avertexp*): Total monthly expenditure on averting activities of a household. It is essentially the opportunity cost of the time each household spends in bringing arsenic free water. The monetary value of the distance travelled (in km) and the time spent in minutes per day by each household to fetch arsenic-free water is calculated. These values are then multiplied by 30 to obtain monthly averting expenditure.

### *Exogenous variables*

Age (*age*): Age of the head of a household.

Family size (*familysize*): Number of family members in each household

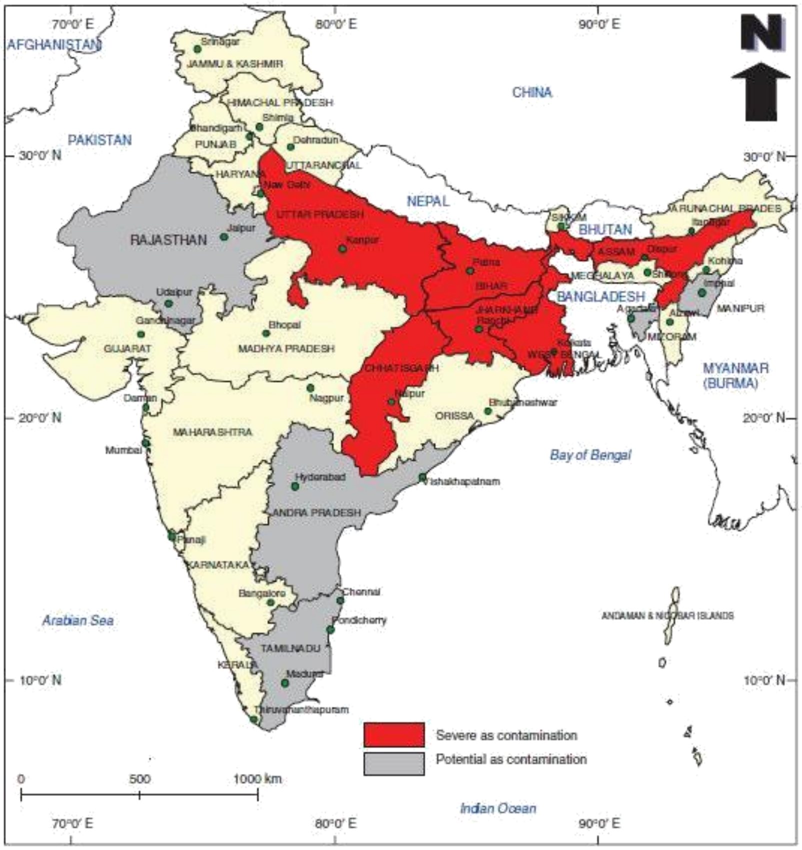
Exposure to arsenic (*arsenic*): Household's exposure to arsenic is the product of the quantity of drinking water consumption and the level of arsenic concentration in the area of the household. The information on arsenic concentration is obtained from PHED while the information on drinking water consumption is collected through the survey. The daily data on drinking water consumption are converted to monthly frequency.

Monthly income (*income*): Data on monthly household income are collected from the respondents.

Health status (*health*): Health status is an index that represents the health condition of the household members to carry out the normal activities during a month. It is calculated as 1 – (ratio of sick days to the total work days per household per month). The index value ranges from 0 to 1. A higher value indicates a better health status for the household. It is assumed that a person works for 6 days per week, which is common in rural areas. The number of total sick days for all members in each household during the six months period is collected through the survey. These numbers are converted to monthly frequency.

Awareness (*aware*): Awareness about arsenic contamination of water is a binary variable that takes the value of 1 if the head of the household is aware of arsenic and 0 otherwise.

Expenditure on food (*foodexp*): Monthly household expenditure on food items.




Source: Bhattacharya et al. 2011

**Figure 1**. The extent and severity of elevated concentration of arsenic in groundwater in India

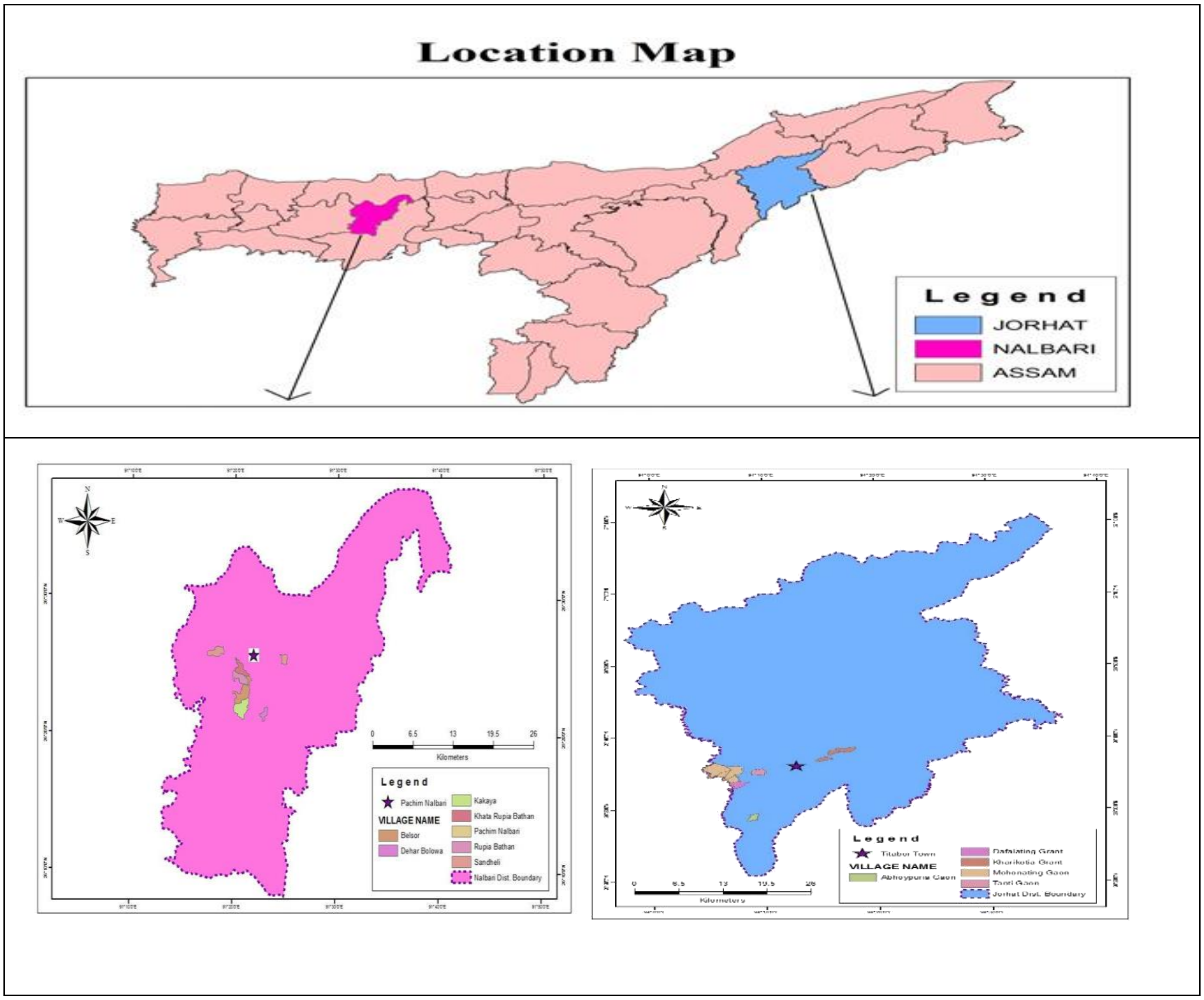



Figure 2. Survey districts of Assam

**Table 1** List of districts, blocks, and habitations covered in the study

| District | Block | Village | Habitation | Arsenic concentration (ppb) | Degree of arsenic | Households surveyed |
|---|---|---|---|---|---|---|
| Jorhat | Titabor | Mirigaon | Thengal Chuk | 491 | High | 41 |
| | | Khariakatia Gaon | Dhubi Chuk | 389.7 | High | 20 |
| | | Abhoypuria | Abhaypuria | 277.1 | Moderate | 29 |
| | | Tanti Gaon | Tanti Gaon | 238.4 | Moderate | 35 |
| | | Mohinating Grant | Bhakat Chuk | 62.7 | Low | 40 |
| | | Defalating Habi | Basa Bil | 63.6 | Low | 10 |
| Nalbari | Paschim Nalbari | Rupiabathan | Baishya Suba | 467 | High | 30 |
| | | Khata Rupiabathan | Kulbil Suba | 301.9 | High | 30 |
| | | Kakaya | Bayan Para | 262.6 | Moderate | 40 |
| | | Dehar Balowa | Mandir(1) | 221.3 | Moderate | 20 |
| | | Sandheli | Barman Suba | 58.4 | Low | 20 |
| | | Belsor | Ozapara | 62.1 | Low | 40 |
| Total | | | | | | 355 |

Source: PHED, Govt. of Assam, 2011

**Table 2** Summary statistics (Sample size = 355)

| | Minimum | Maximum | Mean | Std. Deviation |
|---|---|---|---|---|
| | (1) | (2) | (3) | (4) |
| Age | 24 | 80 | 46.6 | 9.6 |
| Monthly income | 1500 | 45000 | 7024.5 | 5069.5 |
| Monthly expenditure on food | 1000 | 8000 | 3156.3 | 1092.7 |
| Family size | 1 | 10 | 4.1 | 1.4 |
| Drinking water per day(liters) | 5 | 30 | 14.8 | 5.3 |
| Monthly averting expenditure(Rs) | 10 | 125 | 39.5 | 27.3 |
| Distance to collect safe water per month (km) | 0.20 | 5 | 1.3 | 1.4 |
| Time to collect safe water per day(minutes) | 12 | 45 | 21.9 | 15.5 |
| Sick days per month | 1 | 9 | 3.8 | 1.7 |
| Persons sick per month | 1 | 3 | 1.7 | 0.59 |
| Monthly medical expenditure(Rs) | 29 | 271 | 114.9 | 49.2 |
| Arsenic concentration level(µg/l) | 58.4 | 491 | 251 | 152.3 |
| Household exposure to arsenic(µg/l | 467.2 | 14730 | 3603.3 | 2533.7 |

Source: Authors' calculation from the survey data

**Table 3** Arsenic concentration level, averting and medical expenditures, and sick days per month

| Arsenic concentration level (ppb) | Monthly mean averting expenditure (INR) | Monthly mean medical expenditure (INR) | Number of sick days |
|---|---|---|---|
| | (1) | (2) | (3) |
| Low (below 100) | 28.7 | 66.3 | 2.1 |
| Medium (between 100 and 300) | 44.9 | 111.5 | 3.8 |
| High (above 300) | 43.7 | 162.5 | 5.5 |
| Total | 39.5 | 114.9 | 3.8 |

Source: Compiled from the primary survey data

**Table 4** 3SLS regression results

| Dependent variable: Sick days (Eq. 13) | | Dependent variable: Averting expenditure (Eq. 14) | | Dependent variable: Medical expenditure (Eq. 15) | |
|---|---|---|---|---|---|
| Variables | Estimated coefficient | Variables | Estimated coefficient | Variables | Estimated coefficient |
| Constant | 0.38<br>(0.55) | Constant | 3.40***<br>(0.70) | Constant | 1.12**<br>(0.49) |
| Family size (+) | 0.04<br>(0.04) | | | | |
| | | Sick days (+) | 0.16<br>(0.19) | Sick days (+) | 0.29***<br>(0.09) |
| Averting expenditure (-) | 0.06<br>(0.04) | | | Averting expenditure (-) | -0.10**<br>(0.03) |
| Medical expenditure (-) | 0.68***<br>(0.11) | Medical expenditure (-) | -0.54***<br>(0.21) | | |
| Arsenic exposure (+) | 0.09*<br>(0.05) | Arsenic exposure (+) | 0.25***<br>(0.07) | Arsenic exposure (+) | 0.26***<br>(0.04) |
| Income (-) | -0.05*<br>(0.03) | Income (+) | 0.02<br>(0.05) | Income (+) | 0.06**<br>(0.04) |
| Health status | -3.10***<br>(0.38) | | | | |
| | | Awareness (+) | 0.97***<br>(0.06) | | |
| | | | | Age (+) | 0.48***<br>(0.08) |
| | | | | Expenditure on food (-) | -0.11***<br>(0.04) |
| $R^2$ | 0.80 | $R^2$ | 0.68 | $R^2$ | 0.79 |
| Chi2 | 1239.95*** | Chi2 | 765.98*** | Chi2 | 1212.23*** |
| No. of observations | 355 | No. of observations | 355 | No. of observations | 355 |

Note: *** significant at the 1% level; ** significant at the 5% level; * significant at the 10% level. Standard errors are in parentheses.

**Table 5** Estimation of health costs and welfare gain

| Description | Values |
|---|---|
| Arsenic concentration level (μg) | 250.98 |
| Monthly household health costs of a 1 μg increase in arsenic concentration (INR) | 0.35 |
| Annual household health costs of a 1 μg increase in arsenic concentration (INR) | 4.29 |
| Monthly household welfare gain from reduction of arsenic concentration to the safe limit of 50 μg/l (INR) | 71.85 |
| Annual household welfare gain from reduction of arsenic concentration to the safe limit of 50 μg/l (INR) | 862.19 |
| Projected annual health costs of a 1 μg increase in arsenic concentration for the entire arsenic-affected population of Assam (millions of INR) | 0.76 |
| Projected annual welfare gain from reduction of arsenic concentration to the safe limit of 50 μg/l for the entire arsenic-affected population of Assam (millions of INR) | 152.7 |

Source: Authors' calculation

**Table 6** Estimation of health costs and welfare gain for different levels of arsenic concentration

| Description | Values | | |
|---|---|---|---|
| Level of arsenic concentration → | High | Medium | Low |
| | (1) | (2) | (3) |
| Arsenic concentration level (μg) | 421.42 | 252.50 | 61.78 |
| Monthly household health costs of a 1 μg increase in arsenic concentration (INR) | 0.60 | 0.42 | 0.12 |
| Annual household health costs of a 1 μg increase in arsenic concentration (INR) | 7.15 | 5.14 | 1.45 |
| Monthly household welfare gain from reduction of arsenic concentration to the safe limit of 50 μg/l (INR) | 221.33 | 86.74 | 1.43 |
| Annual household welfare gain from reduction of arsenic concentration to the safe limit of 50 μg/l (INR) | 2655.97 | 1040.88 | 17.12 |

Source: Authors' calculations

**Table 7** Estimation of health costs and welfare gain in Jorhat and Nalbari

| Description | Values | |
|---|---|---|
| Level of arsenic concentration → | Jorhat | Nalbari |
| | (1) | (2) |
| Arsenic concentration level (μg) | 271.38 | 221.14 |
| Monthly household health costs of a 1 μg increase in arsenic concentration (INR) | 0.51 | 0.31 |
| Annual household health costs of a 1 μg increase in arsenic concentration (INR) | 6.10 | 3.70 |
| Monthly household welfare gain from reduction of arsenic concentration to the safe limit of 50 μg/l (INR) | 112.59 | 52.82 |
| Annual household welfare gain from reduction of arsenic concentration to the safe limit of 50 μg/l (INR) | 1350.95 | 633.80 |

Source: Authors' calculation