Red wells or green wells and does it matter?
Examining households use of arsenic contaminated water in Bangladesh

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PRELIMINARY DRAFT

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1. Introduction

Bangladesh, along with Nepal and the state of West Bengal in India, is facing a health disaster of significant proportions because of arsenic contamination of groundwater aquifers. Bangladesh's has copious quantities of ground water, but the alluvial aquifers of the Ganges delta are polluted by naturally occurring arsenic (Nickson et al. 1998; Nordstrom 2002). Nearly 30 percent of all tube wells in the 258 *Upazilas* of Bangladesh are estimated to have arsenic content that exceeds the government's safety standards of 50 μg/liter.[2] Another 46% of wells exceed the safety standards maintained by the World Health Organization of 10 μg/liter (Caldewell et al. 2006). For Bangladesh, this means that an estimated 27 to 60 percent of its population is at risk from arsenic exposure (Smith, Lingas and Rahman, 2000).

Historically, Bangladesh has been a forerunner in South Asia in terms of providing its population with access to safe drinking water. Death due to cholera and diarrheal disease was successfully contained in the seventies and eighties by replacing existing sources of drinking water with tube wells, a strategy that was vigorously pursued by the Government of Bangladesh, UNICEF and other donors. Tube wells were dug to obtain clean water from 30 to 100 feet below the surface. This water did not have to be boiled and was free of many bacterial contaminants. Tube wells were cheap, could be installed close to homes and women found them extremely convenient. Notably, the expansion of tubewells occurred at a period when oral re-hydration treatment (ORT) was also widely distributed. While, there is evidence that ORT, more so than the availability of tube well water, was responsible for reduction in diarrheal mortality, tube wells grew rapidly as a dominant water source (Caldwell et al. 2006). As of 1997, some 97% of the rural population in Bangladesh obtained their drinking water from tubewells (Farouque and Alam 2002). Since the discovery of arsenic in ground water in 1993, Bangladesh has struggled once again with the problem of delivering safe water.

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Arsenic can cause numerous health problems ranging from skin lesions to cancer and cardio-vascular diseases. While many of the symptoms of arsenic appear over a long period of time, exposure at high concentrations can result in rapid onset of diseases. Because the presence of arsenic in water is impossible to detect through our normal senses and because of the lack of immediate health effects, it is not easy to convince households about the threats of arsenic.

Over the last decade, the Bangladesh government, donors and NGOs have run various health campaigns to inform people about the risks of arsenic. The government has tried to inform people about the presence of arsenic in drinking water sources through a binary color coding system. A green-colored tube-well is a safe one for collecting drinking and cooking water while a red-colored one is not. There are also door-to-door strategies and awareness programs undertaken by NGOs and information provided through the media. Nonetheless, either due to limited alternative sources of water or for other reasons, many households continue to use water from the unsafe tube-wells.

It is in this context, that this study examines arsenic exposure and people's responses in two upazilas in Bangladesh. We seek to understand if providing information on arsenic contamination is successful in reducing exposure. We also identify the costs of using arsenic contaminated water. The study attempts to answer three questions: a) do households reduce their use of contaminated water in response to information campaigns? b) do households that are able to reduce their exposure to red wells have specific characteristics, i.e. are they wealthy or have larger families, allowing them to find alternatives? And c) what are the costs to households of continuing to use red wells? We try to address these questions by examining the behavior of households that drink water from red (unsafe) and green (safe) wells. We assess how the probability of using red wells is affected by information and other household characteristics. We also examine medical expenditures and sick days that occur as a result of arsenic related symptoms. Examining these issues will allow for a better understanding of the impact of government and NGO activities and may enable the designing of better strategies.

A recent paper by Madajewicz *et al*. (2007) offers a careful analysis of the impact of information on health risks. This project was a joint effort by a large number of scientists and public health specialists in collaboration with professors from the University of Columbia and focused on one district in Bangladesh. Households were provided with information on the health consequences of drinking arsenic un-safe water and the results of a health exam. The study scientists were also able to run tests on 6500 wells in the district and inform households about the contamination in their wells. The same households were visited 6 to 12 months later to assess the effect of information. Household response to information campaign was quick and significant. Knowing that wells have an unsafe level of arsenic raised the probability that a household switches to a new alternate source of well within a year by 0.37. This switch was done despite a 15 fold (4.3 minutes per round trip) increase in the time spent collecting water from alternate sources. An interesting and very important finding from this study is that media communicated general information is as effective (in terms of awareness generation) as the expensive house-specific information provided to the study respondents. However, general media campaigns are less able to induce behavioral change and awareness does not necessarily lead to action.

Another study of relevance to our work is Jalan et al. (2003) on the determinants of water purification behavior among a country-wide sample of Indian respondents. Jalan et al (2003) treat schooling, media exposure and the presence of diarrhea as indicators of awareness of health risks. They ask how these indicators influence households to purify water. Using a large dataset, they find that each of these variables has a significant effect on home purification activities, independent of household characteristics such as wealth. For example, the probability of purification increases by 8% points if a female household member reads a newspaper at least once a week. The impact of education is also very significant.

Our study is not based on multiple surveys and control and treatment groups as found in Madajewicz at al. (2007) and is more along the lines of Jalan *et al.* (2009). However, like these other studies, we are interested in the role of education versus media versus government and NGO campaigns on water use behavior. The Columbia university study also established the cost of switching wells using information on time costs of collecting water from alternate sources. We attempt to estimate the costs or benefits of switching by looking at medical and related costs of time lost as a result of illness.

In the following sections, we first provide some background information on the extent of arsenic contamination in ground water in Bangladesh and health effects. We then discuss our study area and the data that we have to examine the impact of information on the use of red wells. Section 4 discusses our empirical estimation of the role of information. In section 5, we assess the costs of illness associated with arsenic contamination in Bangladesh. Our final section concludes and discusses next steps.

2. Background

Much of Bangladesh is a deltaic plain crisscrossed by rivers such as the Ganges, Brahmaputra, Megna and the Teesta. The country has a population of approximately 129 million inhabitants (Census 2001) making it the most densely populated country in the world. Bangladesh is also one of the least developed countries in the world, with a per capita GDP of US$ 444 in 2005 (BER, 2005). Nevertheless, Bangladesh has made significant strides in accelerating economic and human development. Access to clean water is a major development target of the government of Bangladesh. Until the discovery of arsenic, it was thought that ninety seven percent of households had access to clean water -- this number is now reduced to seventy four percent.[3]

Out of 4 million tube-wells installed in Bangladesh, 1.2 million are estimated to be contaminated with arsenic above safe standards (www.bamwsp.org). Fig. 1 shows the distribution of tube-wells with levels of arsenic monitored by the Department of Public Health Engineering of the Government of Bangladesh. The blue dots refer to tube-wells that have a concentration of arsenic of less than 0.5μg/liter, the red dots are tube-wells with a concentration of more than 50 μg/liter, the green dots are tube-wells with arsenic concentration between 0.5 to 4μg /liter and the peach dots represent concentration ranges from 4 to 50 μg/liter. What is startling is that the arsenic concentration level in 30-40 percent wells of the affected area is over the safe level of 50 μg/liter (World Bank, 2001).

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[3] http://lcgbangladesh.org/prsp/docs/257,2, An overview.

In terms of people affected, according to one estimate (DPHE 2005), there are some 38,380 *Arsenicosis* or other arsenic-affected patients in Bangladesh. However, this might be just the tip of the iceberg. For example, screening done by BAMWSP demonstrates that the figure might be as high as 1.1 cases of *Arsenicosis* per thousand people (World Bank, 2002). However, a recent country wide survey showed that some 7.9% of the sampled population drank arsenic contaminated water (Khan et al 2007). Thus, while there is clear information on the number of wells contaminated with un-safe levels of arsenic, there is more uncertainty regarding the exposed population.

The primary pathway to *Arsenicosis* is prolonged exposure through drinking arsenic-contaminated water.[4] It usually takes 5 to 20 years to develop. Because of the slow process, the evolution of the disease is divided into several stages. The primary stage includes *Melonosis*, *Keratosis*, *Conjunctivitis*, *Gastroenteritis*. The secondary stages includes diseases like *Lekonelanosis*, *Hyper-Keratosis*, Non-pitting *Edema*. In the tertiary stage, an *Arsenicosis* patient's physical condition deteriorates rapidly and the condition becomes irreversible. Gangrene of the distal organs or other parts of the body, cancer of the skin, lungs and urinary bladder and kidney and liver failure become manifest at this stage.

Numerous studies in Bangladesh have documented the health consequences of arsenic contamination. Smith, *et al*. (1999), for example, show arsenic contamination may be mainly responsible for bladder and lung cancer relative to other cancers. Chen and Ahsan (2004) estimate a doubling of lifetime mortality risk from liver, bladder and lung cancer in Bangladesh, because of arsenic exposure through drinking water. Rahman, Quamruzzaman and Dash (2000) estimate the incidence of *Arsenicosis* in children to be as high as 17 percent. In fact, the National Institute of Preventive and Social Medicine (NIPSOM), Bangladesh, estimates that 50 million people are at risk of developing *Arsenicosis*. According to NIPSOM, people who are already diagnosed with *Arsenicosis* are either in the primary or in the secondary stage and the number of such patients is increasing. Since symptoms of *Arsenicosis* develop over time, the number of cancer patients is expected to dramatically increase in the coming years.

Given the nature and the severity of the problem, the Government and other national and international institutions are engaged in providing aid to the people through technical and financial support for detection, research and mitigation projects. The World Bank, the Asian Development Bank and the Government of Bangladesh, with the help of many foreign governments, are working together on an investment plan worth 93.4 million dollars, for arsenic mitigation projects in Bangladesh. This investment, if successful, would eventually benefit nearly 24 million people (REF).

We note, however, that alternatives to drinking water from arsenic contaminated wells are limited. Not all wells are contaminated so well testing and switching is an important strategy. Dug wells that draw water from closer to the surface are another alternative. Deep tubewells that obtain water from over 150 meters below the ground are a good but expensive choice. There are also some household level technologies available but these are possibly less affordable.

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[4] Absorption of arsenic through the skin is minimal. Thus hand-washing, bathing, laundry, etc., with water containing arsenic do not pose human health risks.

3. Data and Study Area

The data for this paper comes from a survey of 5563 individuals from 878 households in two Upazillas (sub-districts) in 2005 (Khan 2007). The data was collected as part of a research project undertaken by one of the authors, Zakir H. Khan, and was sponsored by SANDEE. We are now re-using this data to specifically understand the impact of information and other variables on the how and why households continue to use red wells.

The study area, Upazillas Matlab and Laksman,[5] are located in the southeastern part of Bangladesh, which is the most arsenic prone region (see Fig. 1). Although the two Upazillas are located within a 50 km distance from each other, one of them, Matlab, is an area where health-related interventions are higher due to the presence of the International Centre for Diarrheal Diseases Research, Bangladesh. According to Department of Public Health Engineering (DPHE), nearly 0.16 per cent of Laksham's population is affected by Arsenicosis while 0.11 percent of the people in Matlab are affected. Only twenty four percent tube-wells in Matlab and thirty two percent tube-wells in Laksham are labeled safe (DPHE, 2005).

To identify households for our study, we first developed a sampling frame from a database provided by the DPHE. The DPHE database contained information on wells, location of wells and households using the wells. A two-step procedure was used to select the households. In the first stage, 900 tube wells were randomly chosen (450 from each Upazilla) from three Unions[6] in Matlab and four from Laksham. Since the same tube well is shared by several households, at the second stage, one household from each tube well user group was randomly selected from the DPHE database. The total number of households selected was 878.

The data collected for this study includes three general classes of information: a) household level information, eg. wealth, assets, sources of water and so on; b) health and demographic characteristics of individuals in the household (each enumerator was trained to identify different variants of Arsenicosis based on symptoms of arsenic diseases); and c) work days lost, income loss, sick days, and averting and mitigating activities both at household level and at the individual level. Avertive activities here refer to actions taken by households to avoid use of contaminated water. Mitigating activities refer to doctor and hospital visits.

Table 1 provides a brief summary of statistics at the individual and household level. The average household size in our study area is 6.3. If we examine the number of working members, households, have some 4.53 members over the age of 14. The average age of the individuals in the sample is 28 years and the male to female ratio is 1.28. Individuals in our sample have about five years of schooling on average. Women have approximately 1 year less education than men. Some 14% individuals over 7 years of age have no education; while 79% individuals have either primary or secondary education, and about 7% individuals have more than secondary education.

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[5] Matlab has a population of 445,607 and Laksham's population is 513,119 per the 1991 census.

[6] Administratively, Bangladesh is divided into several tiers: Division, District, Upazilla, Union, Ward and Village. Unions are the second tier of local government institutions.

To determine the wealth status of the household, we collected a list of 43 assets for each household. Of the 43 assets, 32 were household assets and the 11 productive assets. Using this list, a wealth index was developed that identifies for each household a number on a relative scale. The maximum value of the index is 100 and the minimum value is 0. We present the wealth distribution of the sampled households in Fig. 3. Ownership of radio and TV are important for understanding the role of information. Our data suggests that some 53% of households owned a radio while 23% owned a television.

So where did this exposure to arsenic come from? In order to understand this, we need to look at their sources of drinking water. Eighty five percent of the households indicated that they obtain their drinking water from tube wells. On average, these households had been using the same source of tubewell water for over 11 years. Less than 11% of households have access to deep tubewells (over 150 meters deep), which are generally arsenic free. Furthemore, over three quarters of all water sources are privately owned. Thus, our understanding is that over the last twenty or more years, households have drilled individual tubewells for themselves and use of public sources of water is limited. Very few households use surface water or get water from taps at home, less than 0.5 percent people use filters and only 0.2 percent use water from Arsenic Removal Plants. In the study area, a large number of tube wells (though not all) have been marked RED (unsafe for drinking) or GREEN (safe) by the government. However, survey data shows that 55 percent of households still drink water from RED-labeled tube wells. All of this clearly shows the extent of vulnerability of the local people to Arsenicosis.

4. The role of information

The first question we ask in this study is whether information campaigns reduce household exposure to arsenic contaminated water. Some 66% of households indicated that they were aware of the presence of arsenic in their wells. The main sources of arsenic related information (see Table 4) is through NGOs (42% of households) and the government (40%). Survey data also shows that 32 percent of households attended awareness programs organized by NGOs. In Bangladesh, NGOs cover nearly 50 percent of the rural population in terms of their activities. Thus, this number is not surprising. Households also got their information from media outlets such as radios and television. Some 14% of households got their information from TV or radio.

One of the questions we try to address in this paper is whether information available through the government, NGOs or the media has an impact on the household use of arsenic contaminated water. As previously noted, many wells in this area are painted red or green but households continue to use both kinds of wells. There are clearly various reasons why households continue to use contaminated ‘red’ wells. However, as Table 1 shows there are no systematic difference in terms of wealth or demographics between red well and green well users. Indicators such as household size, age, male female ratio and wealth do not vary much across people who imbibe from red wells versus green. Green well users are slightly more educated. We think the main reasons for why some households may use red versus green may be two-fold: a) geological i.e. because of their location some households have access to red wells; and b) behavioral – because of information available some households may have switched to green wells.

To examine this question of why some households use red wells versus green more carefully we ask what factors affect the probability of a household using a 'red' well. In particular, we ask if access to information in the form of TV or Radio, NGO awareness activities and information by the Department of Public Health have influenced the use of red wells. We are also interested in the role of education.

The model to assess what factors influence household use of red versus green wells is as follows:

$$Y_1 = \sum \beta_i X_i + \gamma_2 Y_2 + u_1 \qquad (1)$$

where, Y_1 is a binary variable (1 for drinking from red, 0 for drinking from green tubewells), X's are independent variables and Y_2 is the number of household members affected by arsenic in a household. We estimate equation 1 to assess the role of information on the probability of drinking from red wells.

Drinking from red wells is expected to be affected by household characteristics such as wealth, whether the household has access to other safe water or not, the number of adults in the household, which reflects its ability to carry water, and whether the well is privately or publicly owned. We hypothesize that wealth increases access to green wells, lack of alternative safe water increases the probability of drinking from a red well and the number of adults in the household decreases the probability of drinking from red wells. Whether the well is privately or publicly owned is an interesting variable. Our hypothesis is that if the household has access to a private well, it may be less reluctant to switch wells if it owns the well. If it doesn't own the well, the switch may be more like. Since we are not able to link household use with household specific ownership rights, we are unable to hypothesize on the sign of this variable.

The X variables in the above model include three information related indicator variables: a) whether the household obtained arsenic information from the government or DPHE (department of public health); b) whether the household obtained its information from the newspaper and c) whether the household obtained its arsenic information from NGOs. In the empirical estimation of Y_1 in equation (1), the marginal effects of these variables are ascertained relative to the default position of the households obtaining information from TV/radio. We do this because we partly want to assess whether the role of TV/radio is as important as more expensive information campaigns as suggested by the Madajawicz (2006) paper. We are also interested in the effect of education as these could be considered indicators of awareness of health risks (Jalan et al. 2003).

Following Jalan *et al.* (2009), we hypothesize that households are less likely to use red wells if they already have sick people in the household. As previously noted, some 19% of the households have a member who is sick with arsenicosis. We hypothesize that health shocks are likely to make the household more aware of sources and use of alternate water. However, the presence of arsenic patients in the household is itself dependent on drinking water from the red wells (Y_1). In order to remove this potential endogeneity in our model, we use a two-stage estimation. The number of arsenic affected people in a household is estimated in the first stage (eq. 2). This is estimated as negative binomial count data model because the dependent variable reflects the number of sick individuals in the household. In stage two, we then estimate the equation on drinking from red versus green wells as a logistic regression (eq 3) where $\hat{Y}_2$ is predicted from equation (2).

$$Y_2 = \sum \beta_i X_i + \sum \delta_j Z_j + u_2 \qquad (2)$$

$$Y_1 = \sum \beta_i X_i + \tilde{\gamma}_2 \hat{Y}_2 + u_1 \qquad (3)$$

In estimating the count data model of sick individuals, we introduce three instruments. These are: a) drinking from tube wells (a binary variable), b) age and gender of the household head, and c) years of use of the water from the same source. As Arsenicosis is linked to water from shallow tube-wells, we use drinking water from tube-wells as an instrument. Since the effect of arsenic depends on the level of arsenic in the human body and this accumulates slowly, we use number of years of use of drinking water from the same source as another instrument. Finally, the head of the household is an important decision maker. However, how he/she makes arsenic related decisions would likely be influenced by exposure to arsenic over the years. Further, exposure and understanding of health issues are not same for a male and female household heads. Considering this, we use an interaction term of age and gender of the household head as an additional instrument (1 for male and 0 for female that is interacted with age of the household head).

The results from the two-stage estimation are presented in Table 9. Columns 1 and 2 represent the basic probit equation without instrumenting for arsenic patients in the household. Column 1 presents the coefficient values and column 2 represents marginal effects. Columns 3 and 4 reflect the probit equation after instrumenting the number of arsenic patients. We restrict our discussion below to the marginal effects in column 4 – but we note that the results are rather robust across both models.

Both private ownership of tubewells and lack of access to water increase the probability of using a red well. The variation in wealth amongst these households is small, so the latter result is not surprising. Once we have controlled for lack of access to safe water, the number of adult members available to carry water is insignificant.

All the health risk awareness indicators have a significant and negative effect on exposure to arsenic related risks. All three information variables (news papers, government and NGO exposure) reduce the probability of a household using a red well relative to information obtained from radio and TV. Direct information by government and NGOs reduces the probability of drinking from red wells by 66% and 58% more than information obtained through radio/TV. This suggests that direct information from government and NGO workers has stronger behavioral effect than information provided by mass media.

Education plays an important role in reducing exposure to arsenic. Both education indicators have a significant negative effect on the probability of using red wells compared to illiteracy. These results are on par with Jalan *et al.* (2009), who find that education is significant in inducing behavioral change that reduces health risks. Table 9 shows that higher education has a stronger influence than education up to 10th grade.

If the household has more male members affected from arsenic compared to females, then this reduces the probability of using a red well. Thus, even though females may be the managers of water in the household, the likelihood of switching to clean water is higher if more male members are sick as a result of exposure. The coefficient on the number of arsenic affected household members is positive in the basic model but switches sign and is negative in the two-stage model. Thus, once we correct for endogeniety, it is clear that the number of arsenic patients in the household sends a signal and lowers the likelihood of using a red well. A household with one additional arsenic related patient is 45.7% more likely to switch from red to green wells

The Madagewicz et al (2007) study suggests that media campaigns are as effective as door to door campaigns in making households *aware* of arsenic contamination. However, they find that door-to-door campaigns are more successful in inducing behavioral change. Our analyses appears to back these results as they suggest that the probability of drinking from a red well is decreased by government and NGO campaigns relative to radio and TV campaigns. Very few people obtain arsenic information from newspapers (0.6% of the sampled households), so this is not such an effective strategy.

In general, however, our data and analysis suggest that providing information to households about arsenic contamination in wells – even if this information is very specific – is not sufficient. Fifty five percent of the wells used by the sample households were contaminated with arsenic at higher than safe levels; yet households continue to use these wells. Education and information campaigns do reduce use, but lack of access to alternate safe sources of water results in households exposing themselves to arsenic poisoning continuously.

5. Cost of Illness

About 5% of the individuals in our sample exhibited symptoms of arsenic poisoning.[7] A slightly larger percentage of women (6%) versus men (4.6%) had symptoms. Interestingly, Madajewicz *et al.* (2007) also found that some 6% of the sample population in nearby Araihazar district showed signs of arsenic impacts. In our sample, some 19% of households in the sample had at least one person sick from arsenic exposure.

Most of the individuals who suffered from some form of arsenic exposure were in the early stages of the disease. Some 34% of sick individuals exhibited signs of Kertosis or thickening of the palms and soles. Forty five to fifty percent of sick individuals also indicated that they had other symptoms of arsenic poisoning such as redness of the eye and gastro-intestinal problems. Between 2-3% of the population exhibited advanced conditions of arsenic poisoning (Khan 2007). Given that this is a late acting disease that can take 20 odd years to set in, the distribution of the disease is not surprising.

If we divide our sample into red well and green well users, we find that a small percentage of green well users are also sick from arsenic. This may be because they were previously exposed

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[7] 4 percent have black spots or *Melanosis*, 3 percent have thickening or roughness of palms and soles (*Keratosis*), 2 percent have redness in eyes or *Conjunctivitis*, 2 percent have inflammation of respiratory tract, 0.43 percent have swelling of the feet and legs, .068 percent suffer from liver and kidney failure.

and switched water sources over time. If we look at only red well users, 9% of the sample females show signs of arsenic contamination.

The next question we ask is what kind of a burden households bear as a result of exposure to arsenic contamination. Are households willing to pay to make the switch to clean water and to what extent are they already paying in the way of health costs and workdays lost? In order to address this question, we follow a simple health production function model to estimate health costs.

Following Freeman (1993), most health cost studies start with a utility maximizing individual, whose utility function is defined as:

$$U = U(X, L, S) \tag{4}$$

where, X represents a composite market goods, L denotes leisure, and S represents sickness or the health condition of the individual. The partial derivatives are expected to be $\frac{\partial U}{\partial X} \geq 0$, $\frac{\partial U}{\partial L} \geq 0$, and $\frac{\partial U}{\partial S} \leq 0$.

The individual's health is determined by her exposure to pollution (*P*), the actions she takes to reduce exposure or her avertive actions (*A*) and medical treatment taken to improve health (*M*). Thus, the sickness or health production function is given by:

$$S = S(A, M, P) \tag{5}$$

The individual's utility maximization problem therefore is:

$$\max \quad U(X, L, S(A, M,)) \tag{6}$$

Subject to

$$I + w(T - L) = X + p_a A + p_m M \tag{7}$$

where *I* is non-wage income, *T* is the total available time to the individual, p_a is the unit cost of avertive activities, p_m is the price or unit cost of medical treatment and X is treated as the numeraire with normalized price. The individual chooses *X*, *L*, *A* and *M* to maximize her utility.

The simultaneous solution to the first order conditions of this utility maximization problem establishes the demand for *X*, *L*, *M*, and *A*. For example, the demand functions for avertive activities (*A*) and medical treatment (*M*) would be:

$$A = A^* (I, w, p_a, p_m, P) \tag{8}$$

$$M = M^* (I, w, p_a, p_m, P) \tag{9}$$

Further, as Freeman (1993) shows, by maximizing (6), the individual's willingness to pay (MWTP) to reduce pollution can be deduced. This can be shown to equal the sum of four terms:

$$MWTP = w\frac{dS}{dP} + p_a\frac{\partial A}{\partial P} + p_m\frac{\partial M}{\partial P} - \frac{U_s}{\lambda}\frac{dS}{dp} \qquad (10)$$

Thus, the *MWTP* for health benefits from a reduction in pollution is the sum of the resulting reduction in the time costs of illness plus the costs of any avertive actions taken plus medical and treatment expenses plus the monetary equivalent of the disutility of illness.

Empirically, most health cost studies estimate the health production function *S*, along with the avertive actions (*A*) and mitigating activities (*M*) function to obtain the *MWTP*. The dis-utility of illness is difficult to capture and is most frequently ignored. Because the price of avertive actions and unit costs of medical treatment are difficult to establish, *A* and *M*, are usually estimated as expenditure functions. In our study, we estimate the sickness or dose-response function and the demand function for mitigating activities. Mitigation activities refer to actions undertaken to reduce the effects of arsenic related sickness and include medical expenses, fees paid to doctors or pharmacists, and travel costs. We do not have data to estimate averting costs.

Survey data shows that arsenic affected patients have very few sick days when they stop working and limited medical expenditures. Only 82 individuals out of more than 3260 individuals with some form of sickness reported workdays lost due to sickness. In the sample of 5563, only 88 reported medical expenditures related to arsenic, even though 296 suffered from arsenic-related diseases. Consequently, instead of using continuous data to estimate the dose response and mitigating functions, we use binary variables. Sickness takes the value of 1 if the individual reported arsenic-related sickness and 0 otherwise. Similarly, mitigating activities take the value 1 if an individual has any medical expenditure and zero otherwise. Using probit models, we estimate the probability of sickness and the probability of incurring mitigating expenditure due to exposure to arsenic.

A vector of independent variables is hypothesized to affect sickness and mitigating expenditures. These variables include: a) individual level information such as age measured in years, education and the gender of the individual; and b) a binary variable indicating the presence of arsenic in drinking water (which equals 1 if the tube well is labeled red or 0 if labeled green). Using a probit model, we determine the marginal effect due to a change in the source of drinking water (from red to green). The marginal effect measures the benefit of switching the source of water to a safe mode. The summary statistics of the variables used in the estimation of the dose-response and mitigating activities regressions are presented in Table 10. The estimated probit equations and the marginal effects are shown in Table 11[8].

Column 2 of Table 11 shows that the probability of sickness is associated with changes in age, and education. Since arsenic is a bio-accumulative element, the probability of *Arsenicosis* increases non-linearly up to 55 years for both men and women (see Fig. 3). Years of schooling is negatively associated with the probability of sickness. This reinforces our understanding that education is an indicator of health awareness; it may also be picking up some wealth effects. Each year of additional education reduces the probability of sickness by 0.27 percent. Finally,

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[8] We also estimated these two probit equations jointly and did not find any difference in the results.

the impact of switching from red to green sources of water reduces the probability of sickness by 4 percent, by far the largest gain in terms of reducing sickness.

Column 4 of Table 11 shows the marginal effects of the mitigating expenditures regression. The probability of incurring health expenditures increases by less than 1 percent if the water source changes from red to green. Age, as in the previous case, has a non-linear effect.

The next step is to estimate the willingness to pay of households for switching to cleaner water sources. We estimate the marginal willingness to pay in the following manner:

$$MWTP_i = w_i \times \overline{WDL_i} \times P_i(S \mid \Delta P) + \overline{M} \times P(M \mid \Delta P) \quad \text{..}(11)$$

$$= \qquad (A) \qquad + \qquad (B)$$

where P(S|ΔP) is the marginal effect or change in the probability of sickness (related to arsenic poisoning) for an individual due to changes in the level of arsenic poisoning, ΔP is expected changes in the dose of arsenic poisoning in water; *w* is average wage of the adult working population, $\overline{WDL}$ is the mean workdays lost, $\overline{M}$ is the mean mitigating expenditure per individual when he/she is affected with arsenic related diseases and *P(M|ΔP)* is the changes in the probability of incurring mitigating expenses due to changes in the level of exposure at the individual level. (A) measures the marginal impact in terms of income loss due to changes in the level of exposure to arsenic and (B) measures the marginal effect on mitigating expenditure due to changes in the exposure to arsenic poisoning.

Based on equation (11), and the coefficients from Table 11, we calculate the mean cost of illness for an individual to be Taka 171 per year, which is equivalent to Taka 1057 (US$ 18) per household per year. This measures annual willingness to pay for switching from red to green sources of water.

It is useful to compare our estimate of the benefits of switching with some other recent studies on willingness-to-pay (WTP) for clean water in Bangladesh. An earlier study by Ahmad *et al.*, (2002) estimates the WTP for safe water to be Taka 2831 per household per year. They use contingent valuation based on an understanding that households would have access to clean water either through home connections or stand posts. Madagewicz *et al.* (2007) estimate the lower bound for WTP based on an assessment of additional time taken to walk to alternative water sources. The implied WTP from their study is 90 Taka per month or Taka 1080 per household per year. For purely illustrative purposes, if we add our estimates of medical and sickness costs (Taka 1057) to avertive costs from Madagewicz *et al.* (1080 Taka), we obtain a total WTP for clean water of Taka 2137, which is very close to the estimates from Ahmad et al. (2002).

6. Conclusions

Our analyses of water use in two Upazillas in Bangladesh suggests that there is an important role for education and information campaigns in reducing exposure to arsenic contaminated water. We examined the probability of household use of red wells and find that government and NGO campaigns make a dent in reducing exposure to arsenic. These campaigns lead to a 66% and 58% decline in the probability of drinking from red wells, relative to more diffuse information from radio or television. These effects are independent of other variables that may affect the household choice to drink from red wells.

However, households continue to drink from red wells. Fifty five percent of our sample households indicated that they used red wells. This despite the fact that 66% of households indicated that they were aware of arsenic contamination of their main source of water. The lack of alternatives largely explains continued use of unsafe wells. Lack of access to safe water increased the chances of drinking from a red well by 68%.

Some 6% of our sampled individuals showed symptoms of arsceniosis. Most of patients exhibited early stages of the disease. While this number seems small, at the household level the burden of arsenic contamination is clearer since about 19% of households have at least one person sick from arsenic.

Households pay for their use of unsafe water by the sickness they experience. However, monetary payments in terms of wages lost or medical costs borne are somewhat limited. We estimated a lower bound to the costs household bear as a result of arsceniosis and find that this is Taka 1057 per household per year. These are not wealthy households, so could this be significant amount? Given, that the per capita GDP in Bangladesh in 2005 was $444, the health costs of arsenic exposure at a minimum amount to about 0.6% of annual household income. This percentage, however, is an under-estimate since income in these rural districts is likely to be lower than the Bangladeshi average and because we are only able to estimate the costs partially. The stress, the difficult choices households face, the general malaise from using bad water, and the costs of any avertive actions taken are not accounted for in our analyses.

Previous research (Khan 2007) suggests that there are technologies available to remove arsenic that cost less than 1000 taka per to buy and would cost about the same per year to maintain. Yet, households are not using these technologies. We don’t have a really good understanding of why this is the case. We are also unable to say for sure what factors lead to the actual switch from red wells to green wells. We do not have before and after information to answer this specific question. Finally, we have yet to ascertain the independent effect of different types of information awareness campaigns. Thus, there are several issues that require further analyses.

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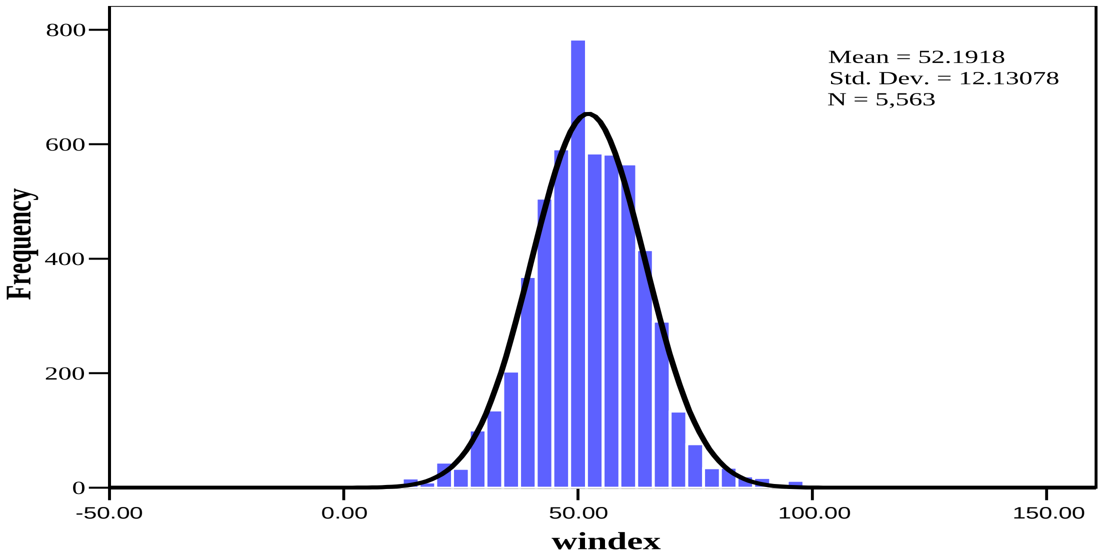
Figure 2: Wealth Index of the HH



Source: Survey 2005

Table 1: Household and individual level information

	Mean	Mean Red Well	Mean Green well
Household			
Household Size	6.33 (2.43)	6.41 (2.39)	6.24 (2.48)
Male/Female Ratio	1.28 (0.98)	1.33 (1.04)	1.22 (0.92)
Age of Household head (years)	52.8 (15.3)	53.8 (15.8)	51.5 (14.4)
Age (full sample)	27.49 (20.25)		
Percent of individuals over 7 illiterate	13.6 (17.9)	15.2 (19.5)	11.5 (15.7)
Percent individuals over 7 years with primary or secondary education	78.5 (20.7)	78.1 (21.3)	79.1 (20.1)
Education (years)	5.17 (4.15)		
Male (years)	5.6 (4.1)	5.44 (4.03)	5.82 (4.10)
Female (years)	4.8 (3.8)	4.6 (3.75)	4.98 (3.86)
Wealth	51.62 (12.4)	51.8 (12.9)	51.4 (11.7)
Radio ownership (%)	53.3 (49.9)	52.2 (50.0)	55.0 (49.8)
TV ownership (%)	27.1 (44.5)	26.8 (44.3)	27.7 (44.8)

Table 2: Presence of Arsenic Poisoning

	Mean	Mean Red Well	Mean Green well
Percent individuals with arsenic symptoms -Total	5.3 (22.4)	7.5 (26.2)	2.6 (16.0)
Male	4.6 (21.0)	6.4 (24.4)	2.4 (15.3)
Female	6.0 (23.8)	8.5 (27.9)	2.9 (16.8)
Percent households with at least 1 sick from arsenic	19%		

Table 3: Distribution of Arsenic Related Diseases among Sick Households

Different Arsenic Diseases	Arsenic-Related Diseases	Percent of Cases
Primary Stage	*Melanosis* or black spots in the body	8.6
	Keratosis or thickening of the palms and soles	34.3
	Redness of the eye or *Conjunctivitis*	58.6
	Inflammation of the respiratory system	45.7
	Gastrointestinal problem	46.4
Secondary Stage	Hypo-pigmentation or white spots	5.7
	Hyper-Keratosis or nodular growth	15
	Swelling of the feet and legs	12.1
	Peripheral Neuropathy	17.1
	Liver or kidney disorder	7.1
Tertiary or Final Stage	Gangrene of the distal organs	3.6
	Cancer of the skin, lung or urine	2.9
	Liver or kidney failure	2.1

Table 4: Drinking Water

	Households
Percent drink water from tubewell	85%
Average no. of years of drinking from tubewell, (among households that drink from tubewells)	11.45
Percent of all water sources owned by individual households	74%
Percent aware of arsenic in main source of water	66%
Percent drinking water from red wells	55%
Percent who follow some form of purification	18%
Percent Yes to averting technology	12%

Table 5: Sources of information about Arsenic

	Percent
DPHE	24.5
TV/Radio	14.6
Newspaper	0.59
Government	16.7
NGO	42.9
Other	0.24

Table 6: Reasons for drinking from red-wells (Among those who reported drink from red (n=485 HHs))

	No of HH	% of HH
Do not know the effect of drinking from Red-Wells	131	27.01
Safe or arsenic free source of water unavailable	230	47.42
Taste of the water is good	68	14.02
Shortage of money	27	5.57
Other	29	5.99

Table 7: Variable Description

No.	Variable Name	Description
1	Drink_red	Household drinks from red=1, 0 otherwise
2	Arsenic affected	Number of household members affected by Arsenic
3	Current owner	Well is owned by a Household = 1, 0 otherwise
4	No safe Water	Household does not have access to safe water = 1, 0 otherwise
5	WINDEX	Wealth Index
6	Adult	No. of adults greater than 14 years in household
7	News	Arsenic information obtained from news paper=1, 0 otherwise
8	Info_DPHE	Arsenic information obtained from DPHE, or government = 1, 0 otherwise
9	Info_NGO	Arsenic information obtained from NGOs=1, 0 otherwise
10	M_more	If the HH has more male members affected from arsenic compared to female = 1, 0 otherwise
11	Edu1_10	Percentage of household members with upto 10th grade education
12	Hedu	Percentage of household member with over 10th grade education
13	Tubewells	Household uses tubewell for drinking water=1; 0 otherwise
14	Age_Gender	Age*Gender (Male = 1) of household head
15	Yr_Use	Years of use of current sources of drinking water

Table 8: Summary Statistics of Variables Used in Information Regression

```
  Variable |       Obs        Mean    Std. Dev.       Min        Max
-------------+--------------------------------------------------------
drink_red_~r |       878    .5523918    .4975309         0          1
arsenic_af~d |       878    .3371298    .8884214         0         10
   cur_owner |       879    .7372014    .4404046         0          1
  nosafewater |       878    .2630979    .4405661         0          1
      WINDEX |       878    51.62301    12.40799         0        100
-------------+--------------------------------------------------------
       adult |       878    .5468653    .1830053         0          1
        news |       878    .0056948    .0752913         0          1
info_DPHE_~y |       878     .404328    .4910412         0          1
    info_NGO |       878    .4157175    .4931262         0          1
      m_more |       878    .9088838    .2879383         0          1
-------------+--------------------------------------------------------
     edu1_10 |       878    .7854417    .2072791         0          1
        hedu |       878    .0773063    .1530922         0          1
   tubewells |       879    .8430034    .3640047         0          1
age_gendea~H |       776    50.40722    19.09316         0        106
     yr_use1 |       877    11.23558    11.15522        .6        200
```

Table 9: Logistic regression (Dep Var: drink from red)

	(1) drink_red_~r	(2) drink_red_~r	(3) drink_red_~r	(4) drink_red_~r
cur_owner ~)	0.490*	0.0950*	0.857***	0.171**
	[0.220]	[0.0465]	[0.240]	[0.0529]
nosafewate~)	6.054***	0.607***	7.457***	0.689***
	[1.028]	[0.0339]	[1.154]	[0.0459]
WINDEX	0.000164	0.0000301	0.0121	0.00221
	[0.00663]	[0.00122]	[0.00745]	[0.00136]
adult	-1.085*	-0.199*	0.783	0.143
	[0.520]	[0.0980]	[1.061]	[0.196]
news (d)	-1.018	-0.227	-55.79**	-0.819***
	[1.203]	[0.299]	[17.21]	[0.0454]
info_DPHE_~)	-0.542	-0.102	-3.570***	-0.663***
	[0.428]	[0.0802]	[1.068]	[0.154]
info_NGO (d)	0.271	0.0491	-3.124*	-0.580**
	[0.411]	[0.0753]	[1.305]	[0.211]
m_more (d)	-0.228	-0.0397	-5.376***	-0.339***
	[0.323]	[0.0543]	[1.545]	[0.0755]
edu1_10	-0.358	-0.0657	-3.500**	-0.639**
	[0.593]	[0.109]	[1.211]	[0.246]
hedu	-1.385	-0.254	-8.313***	-1.518**
	[0.739]	[0.140]	[2.208]	[0.469]
arsenic_af~d	0.455**	0.0834*		
	[0.163]	[0.0350]		
ars_affecP			-2.504**	-0.457**
			[0.793]	[0.161]
N	878	878	775	775

Marginal effects; Standard errors in brackets
(d) for discrete change of dummy variable from 0 to 1
* p<0.05, ** p<0.01, *** p<0.001

Note:
Column 1: Basic model without instrumenting arsenic_affected. Column 2: Marginal effect of (column 1), column 3: coefficients from second stage regression where arsenic_affected is instrumented (Instuments used: tubewells age_gendear_HHH yr_use1).

Table 10: Summary Statistics: Dose-Response and Mitigating Costs Function

```
Variable |       Obs        Mean    Std. Dev.       Min        Max
-------------+--------------------------------------------------------
    sickness |      5562    .0532183    .2244886          0          1
medical_cost |      5562    280.0387    2469.751          0      80000
         age |      5556     27.5247    20.24126         .1        110
        age2 |      5556    1167.244    1589.166        .01      12100
   education |      5549    5.192067    3.958757          0         13
-------------+--------------------------------------------------------
        male |      5562    .5032362    .5000345          0          1
   drink_red |      5562     .558612    .4965974          0          1
```

Table 11: Estimation of the Sickness and Medical Expenditure Functions

```
----------------------------------------------------------------------------
                      (1)             (2)             (3)             (4)
                 sickness        sickness        med_cost        med_cost
----------------------------------------------------------------------------
age                0.0536***      0.00424***       0.0427***     0.000912***
                [0.00546]      [0.000404]       [0.00856]      [0.000166]

age2            -0.000488***   -0.0000386***    -0.000326***  -0.00000694***
              [0.0000649]    [0.00000493]     [0.0000937]    [0.00000187]

education        -0.0342***     -0.00271***      -0.0252*      -0.000538*
                [0.00815]      [0.000662]        [0.0128]      [0.000284]

male (d)          -0.108*       -0.00859*          0.0760         0.00162
                 [0.0614]       [0.00488]        [0.0985]       [0.00211]

drink_red ~)       0.517***       0.0397***        0.465***      0.00969***
                 [0.0665]       [0.00490]         [0.111]       [0.00231]
----------------------------------------------------------------------------
N                    5549            5549            5549            5549
----------------------------------------------------------------------------
 Standard errors in brackets
 (d) for discrete change of dummy variable from 0 to 1
* p<0.05, ** p<0.01, *** p<0.001
```