Evaluating Strategies to Reduce Arsenic Poisoning in South Asia: A View from the Social Sciences

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The World Health Organization has labeled the problem of arsenic contamination of groundwater in South Asia as "the largest mass poisoning in human history." Various technical solutions to the problem fall into one of two broad categories: (i) cleaning contaminated water before human consumption and (ii) encouraging people to switch to less contaminated water sources. In this paper, we review research on the behavioral, social, political, and economic factors that determine the field-level effectiveness of the suite of technical solutions and the complexities that arise when scaling such solutions to reach large numbers of people. We highlight the conceptual links between arsenic-mitigation policy interventions and other development projects in Bangladesh and elsewhere, as analyzed by development economists, that can shed light on the key social and behavioral mechanisms at play. We conclude by identifying the most promising policy interventions to counter the arsenic crisis in Bangladesh. We support a national well-testing program combined with interventions that address the key market failures (affordability, coordination failures, and elite and political capture of public funds) that currently prevent more deep-well construction in Bangladesh.

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I. Introduction

Much of the world's disease burden is due to environmental threats (Pruss-Ustun and Corvalan 2006). People often respond to environmental health risks by adopting technologies that reduce the risk (Pattanayak and Pfaff 2009). For example, people can invest in preventive health products such as bed nets to reduce

their risk of malaria or chlorine tablets to reduce the risk of acute gastrointestinal diseases like diarrhea. Arsenic contamination of drinking water is one such important challenge, and this paper describes the scope of that problem, technical solutions that can reduce contamination, and the design of policies to encourage widespread adoption of a solution that could effectively address this public health threat.

An estimated 45 million Bangladeshis consumed drinking water with arsenic concentration levels exceeding what is deemed dangerous to the human body according to a report published in 2009 (Bangladesh Bureau of Statistics and UNICEF 2011). The World Health Organization (WHO) referred to chronic exposure to arsenic from drinking well water in Bangladesh as "the largest mass poisoning of a population in history" (Smith, Lingas, and Rahman 2000). As a response, the government and various nongovernment organizations (NGOs) have implemented strategies to mitigate exposure to arsenic. Some of the initial attempts at arsenic mitigation focused on the technological aspects of arsenic removal. These efforts can only be successful to the extent that the technology is widely implemented by policy makers and/or adopted and used by households drinking contaminated water. Complexities in implementation, the political calculus of policy makers, coordination failures in the community, or simply household aversion to behavior change can undermine the promise of technically effective solutions.

Certain fields within social science, such as development economics and behavioral economics, have developed insights that can help us understand the sources of aversion to behavior change and the challenges of implementing technically effective solutions. For example, economic analysis can shed light on the reasons for low demand for point-of-use filters despite their apparent large benefits. Mechanism design can be used to overcome collective action failures. And randomized controlled trials and other techniques can be used to rigorously evaluate the effects of policy interventions and advise policy makers on the strategies that work best.

This paper analyzes the behavioral, economic, and institutional challenges of implementing arsenic mitigation interventions and identifies solutions that appear most promising according to the evidence base. The interventions we review fall under two broad classes of strategies: (i) either remove arsenic from contaminated water before it enters the human body or (ii) encourage consumers to switch to a different water source with a lower arsenic concentration. The paper also discusses the complexities of scaling up arsenic-mitigation interventions to address the needs of tens of millions of people.

This paper is organized as follows. Section II provides a background on the arsenic poisoning crisis in South Asia and other parts of the world. Section III discusses the two thematic behavioral strategies to reduce arsenic exposure, potential solutions that fall under these strategies, challenges in implementation,

and interventions that overcome those challenges backed by empirical evidence. Section IV discusses the complexities of scaling interventions that address the issue. Section V concludes with policy recommendations.

II. Background

Arsenic contamination is not unique to Bangladesh, but it is the most affected country in the world by far. Arsenic is naturally released into groundwater by Himalayan sediments. As a result, the groundwater in many countries in South and Southeast Asia (including India, Myanmar, Nepal, Pakistan, Cambodia, the Lao People's Democratic Republic, and Viet Nam) is contaminated to some degree (Ravenscroft, Brammer, and Richards 2009). Bangladesh is especially affected, with an estimated 45 million Bangladeshis consuming drinking water with arsenic concentration exceeding the WHO guideline of 10 micrograms per liter (Smedley and Kinniburgh 2002; Fendorf, Michael, and van Geen 2010).

There was a massive shift toward groundwater in Bangladesh in the 1970s and 1980s due to public health concerns about bacterial contamination of surface water sources. Excess infant mortality from diarrheal diseases, cholera, and other waterborne illnesses led governments, international donors, and NGOs to undertake massive programs promoting shallow tube-well installation across the country to reach aquifers free of pathogens.

The presence of arsenic in groundwater was first noted in the early 1980s in the geologically similar neighboring Indian state of West Bengal, when visible manifestations of the disease were identified and attributed to water from shallow tube wells (Chakraborty and Saha 1987). It was not until the late 1990s when the scale of the problem was fully understood, prompting massive public health action by the Government of Bangladesh and multinational organizations like the World Bank to test tube wells across the country (Dhar et al. 1997). By 2005, 1.4 million shallow wells with groundwater with an arsenic concentration above Bangladesh's drinking water standard of 50 micrograms per liter were painted red; another 3.5 million wells that were below the contamination threshold were painted green. Most tube wells have been replaced since then and very few were ever retested after the national testing campaign ended in 2005 (Ahmed et al. 2006, van Geen et al. 2016).

Some early efforts to mitigate the arsenic crisis focused on switching from groundwater to surface water from hand-dug wells, rainwater storage devices, and (filtered) pond and river water (Ahmad, Khan, and Haque 2018). Whereas switching to surface water sources can reduce arsenic consumption, it can also have the unintended consequence of increasing the risk of disease through fecal contamination (Lokuge et al. 2004, Howard et al. 2006, Johnston et al. 2014).

The health impacts of chronic arsenic exposure are severe (Vahter et al. 2010). It is estimated that 6% of total mortality in Bangladesh is due to chronic

exposure to arsenic (Flanagan et al. 2012). The main cause of the excess mortality is cardiovascular disease and not the types of cancer that researchers have linked to arsenic elsewhere (Smith, Lingas, and Rahman 2000; Chen et al. 2011). Chronic exposure has also been linked to increases in stillbirths, infant mortality, and motor and intellectual impairment of children (Wasserman et al. 2004, Parvez et al. 2011, Quansah et al. 2015).

Arsenic exposure negatively affects productivity. Pitt, Rosenzweig, and Hassan (2020) estimate that reducing Bangladeshi arsenic retention to United States levels would, on average, increase household income by 9% per male worker. Flanagan et al. (2012) estimate that arsenic-related mortality is expected to cost Bangladesh $12.5 billion from lost productivity over the next 20 years. The authors base this estimate on the productivity loss associated with deaths from the types of cancer known to be related to arsenic poisoning. However, this may be an underestimation because this economic loss does not account for health-care expenditures and other costs to society.

III. Strategies to Reduce Arsenic Consumption

Solutions that reduce arsenic in the water supply involve different categories of interventions as well as coordination between policy makers, implementers, communities, and end users. There are two broad strategies to address arsenic poisoning. The first is to clean the contaminated water before it enters the body by means of technological solutions like filtration systems. The second is to have people switch to clean sources of water by means of well testing and building low-arsenic deep tube wells. Both strategies require households to change their behavior. Barriers to a household's willingness to invest in preventive health products, coordination failures, and political economy factors are all challenges that must be addressed through careful policy design.

Removing arsenic from water or inducing people to switch to cleaner sources may require households to invest resources into buying water filters or installing deeper wells. Research by development economists in a variety of settings has found puzzlingly low rates of preventive health investments among poor households despite the long-run benefits (Kremer and Miguel 2007; Ashraf, Berry, and Shapiro 2010; Meredith et al. 2013). Factors such as liquidity constraints, information failures, peer effects, and intra-household conflicts over health are found to be responsible for the low demand (Brown, Mobarak, and Zelenska 2014). These barriers to technology adoption will be discussed in more detail in the following sections as they relate to specific arsenic mitigation approaches. We will highlight successful policy interventions that have managed to overcome such barriers in other settings.

Some solutions require community members to make collective decisions on the locations of clean water sources and to coordinate community contributions in cash, labor, and maintenance (Cocciolo, Habib, and Tompsett 2019). Failure to coordinate between group members, such as free riding, can hurt the long-run sustainability of community-based programs.

Public goods are sometimes delivered in a decentralized way where investments are delegated to local governments. For example, decisions about deep tube wells in Bangladesh—wells over 150 meters that are low in arsenic— are delegated to and financed by local governments. Decentralization of service delivery is thought to be efficient because local governments may have more accurate local information to better target services (World Bank 2003). However, taking a decentralized approach in rural communities with poverty, socioeconomic inequality, and a lack of political awareness can lead to distortions in targeting toward elites (Bardhan and Mookherjee 2000).

A.   Cleaning Up before It Enters the Body

Filtering methods to clean contaminated water was promoted by the National Arsenic Mitigation Policy in response to the discovery of arsenic in well water. Pond sand filters and small community slow sand filters were promoted because they could purify readily available surface water from ponds and rivers. However, support for sand filtration diminished because of the susceptibility to fecal contamination (Howard et al. 2006). Early efforts to remove the arsenic from groundwater using large arsenic removal plants were ineffective in reducing arsenic poisoning due to technical problems and poor maintenance (Hossain et al. 2005). Some household-level filtration devices may be effective, but demand for such products is low. Community filtration systems that serve large numbers of people are promising, provided that maintenance efforts are properly coordinated. This section will go over these options, their challenges, and recommendations.

1.   Point-of-Use Treatment

Point-of-use arsenic purification filters—such as SONO water filters, three-pitcher filters, and READ-F filters—have been shown to effectively reduce arsenic levels (Hussam and Munir 2007, Sutherland et al. 2002). However, field tests have found disappointing results on their adoption and usage (Johnston, Hanchett, and Khan 2010). One example is Sanchez et al. (2016), who provided households with READ-F filters—an easy-to-use device that filters arsenic from shallow well water—and encouraged their use over the 6-month duration of the intervention. Initially, participants showed a reduction in urinary arsenic levels, which is an objective indicator of intake and exposure. However, the benefits eroded over time

and arsenic in urine returned to preintervention levels by the end of the study period. After 1 year, 95% of the filters had been abandoned.

More research is needed to ascertain how much households are willing to pay for point-of-use filters for arsenic removal and how to encourage their use. Research on other water purification products have shown that demand has been low among poor households (Ahuja, Kremer, and Zwane 2010). In Ghana, for example, Berry, Fischer, and Guiteras (2019) measured the demand for Kosim water filters, which are effective at removing more than 99% of *E. coli* in trials. Their assessment found that households are willing to pay only 10%–15% of the cost of manufacturing and delivery. Similarly, Ahuja et al. (2010) found low willingness to pay for point-of-use chlorine treatment in Kenya when households were given coupons to redeem at local stores.

Liquidity constraints are cited as a key reason why demand for health products in developing countries is low despite their high benefits. People in poor rural areas may not have the liquidity necessary to pay large lump-sum costs for preventive health products. For example, SONO filters which remove arsenic through chemical reactions with iron, cost about $40 (Hussam and Munir 2007). High prices and the low willingness to pay suggest that price subsidies may be a sensible policy to increase the adoption of point-of-use filters. However— in addition to concerns about the fiscal capacity to provide subsidies—there are concerns that lower prices may affect how people value the product and subsequently use them. The psychological bias called the sunk cost fallacy posits that higher prices cause people to value a product more than if they got it free. Screening effects are when higher prices screen buyers who place a relatively high valuation on a product and thus would likely use it more than someone who is less willing to pay (Thaler 1980, Bagwell and Riordan 1991).

The Read-F filters used in Sanchez et al. (2016) were provided for free and the low usage they observe may lend support to concerns about sunk cost fallacy and screening effects. However, without observing adoption decisions under experimentally varied prices, this remains inconclusive. Field experiments that explicitly test for sunk cost fallacy and screening effects suggest that these concerns are unfounded (Ashraf, Berry, and Shapiro 2010).

Information failures may cause people to underestimate the true benefits of certain decisions from school choice or adopting new agricultural technology. Households may thus underinvest in preventive health decisions because they lack information about health risks (Somanathan 2010). There is some evidence that providing information about water quality increases adoption of water filters. In India, Jalan and Somanathan (2008) found that 45% of those surveyed did not equate contaminated water with diarrhea. The researchers tested the water and informed a randomly selected group of households about the contamination status and the various purification methods that are available. Households with contaminated water increased efforts to purify water before consumption once

they were informed. Information programs have also been designed for arsenic mitigation in Bangladesh and have proven to be highly effective in reducing consumption through inducing households to switch to cleaner wells (Madajewicz et al. 2007).

2.   Community Filtration Systems

Centralized community-based water treatment systems are an alternative to household point-of-use filters. These can supply arsenic-free water to around 100–200 families (German et al. 2019, Sarkar et al. 2010). Current units can produce up to 1 million liters of clean water before needing replacement (Sarkar et al. 2010). Community filtration systems have certain advantages over household filters. For example, arsenic levels are easier to monitor with centralized filtration systems because the tests only need to be administered at one community unit, instead of household filter units that are spread out. Centralized systems also make it easier to coordinate proper waste disposal compared to household filters (Johnston, Hanchett, and Khan 2010). However, the high cost and regular maintenance needs lead to concerns about long-run sustainability. This has led to concerns about the capacity of governments and NGOs to successfully deliver services.

Certain institutional arrangements in which community members organize funds and provide maintenance may address sustainability issues with rural water infrastructure. In such arrangements, village water committees collect small fees from villagers that contribute to the cost of maintenance. Maintenance itself is conducted by caretakers who are appointed by the committee. In some models, committees have little explicit public authority for revenue collection, but such cases do not show promising results. For example, Miguel and Gugerty (2005) report that 50% of borehole wells in Kenya that were maintained using a community-based maintenance model on a voluntary basis were inoperable by 2000. In rural Tanzania, free riding and a lack of coordinated maintenance decisions decreased the functionality rate of NGO-installed clean water pumps and consequently lowered rates of child survival and school attendance (O'Keeffe-O'Donovan 2019).

Clean water is a public good and maintaining it has positive externalities for other people in the community. If there are coordination failures and free riding, then it becomes difficult to maintain quality under community-based arrangements. Many community-level interventions experience coordination difficulties. One example is community toilets in India, where a study showed that one in six toilet seats was entirely nonusable (J-PAL 2012). Communal arrangements must be structured to ensure that incentives are correctly aligned, and the community can monitor its members (Duflo, Galiani, and Mobarak 2012).

Some evidence suggests that private contracting maintenance systems are an efficient way of maintaining water sources (Kremer et al. 2011). For point-of-source

chlorine dispensers in Kenya, Ahuja et al. (2010) found that paying contractors to maintain the system increased the level of maintenance significantly. Water collection fees can discourage free riding, leading to an increase in functionality (O'Keeffe-O'Donovan 2019). Current community-based filtration systems that charge user fees as low as $0.15–$0.30 a month and compensate unit caretakers have been found to be financially sustainable and lead to local job growth (German et al. 2019). Complementing a system with delivery services can also increase demand and revenue generation (Johnston, Hanchett, and Khan 2010; Sarkar et al. 2010; German et al. 2019).

B.   Switch to Groundwater That Is Already Low in Arsenic

The second strategy to mitigate arsenic poisoning is to encourage people to switch from a high-arsenic water source to a clean water source. Individuals choose their water source to maximize their welfare subject to the constraints they face and their information set. Consuming arsenic-contaminated water may be indicative of information failures or a lack of alternative clean water sources. For example, since arsenic levels in groundwater vary greatly over small distances, informing people of the status of their wells can induce them to switch to neighboring clean wells. Fortunately, concentrations of arsenic usually do not change over time, although some aquifers and wells need to be monitored more frequently than others (Fendorf, Michael, and van Geen 2010). Increasing a household's access to clean water by installing new low-arsenic deep tube wells is also a strategy worth considering.

1.   Information and Testing

People may drink from contaminated wells if they lack information about the arsenic concentration in their shallow well relative to other nearby wells. The distribution of arsenic in groundwater varies greatly, even over small distances and most owners live within walking distance of an uncontaminated well. Testing the groundwater concentration is therefore essential to provide the necessary information for people to switch (van Geen et al. 2002).

Arsenic tests are attractive because of the low cost to administer them. In previous interventions, the cost of a simple test was as low as $2.30, with the cost of supplies only amounting to $0.30 per test. Because of the large health consequences of chronic exposure to arsenic, simply providing information through arsenic tests can therefore be a highly cost-effective intervention as long as people respond to the new information. Evaluations show that providing test data to households, in some cases along with various forms of reinforcement, has induced between one-quarter and one-half of exposed households to stop using contaminated wells (Madajewicz et al. 2007, Bennear et al. 2013, Balasubramanya et al. 2014, Pfaff et al. 2017).

One issue with arsenic tests is how they should be provided and who should provide them. Public provision has not met the needs for testing. Recent estimates show that despite the national well-testing campaign between 2000 and 2005, at least one-half of the currently used tube wells in Bangladesh have never been tested for arsenic (van Geen et al. 2014, Jamil et al. 2019). National testing campaigns have not been repeated and most wells have by now been replaced and therefore were never tested.

Private testing may be a useful complement to public provision. The prospect of a private market for arsenic testing can induce local entrepreneurs to identify untested wells and market their services (Barnwal et al. 2017). Despite the low cost, poor households may not be able to afford arsenic test kits. An evaluation in the neighboring Indian state of Bihar shows that while demand for test kits is substantial, it is also highly price sensitive: the take-up level falls from 69% to 22% when cost increases from $0.16 to $0.80. This steeply downward-sloping demand curve is reminiscent of the elastic demand for other effective preventive health-care products such as insecticide-treated bed nets and deworming pills (Kremer and Miguel 2007, Cohen and Dupas 2010). Subsidizing testing kits may be efficient policy if encouraging initial usage helps neighbors learn about the value of testing and increases the demand for future testing. Barnwal et al. (2017) find that demand for test kits rose from 27% to 45% within 2 years of the initial subsidy campaign without any change in the nominal sales price.

Households will switch away from contaminated to cleaner wells after testing only if they know about the health consequences of arsenic in the first place. Interventions that combine tests with education about arsenic poisoning have been shown to increase switching (George et al. 2013, Chen et al. 2007, Pfaff et al. 2017). For example, Khan et al. (2015) found higher switching rates among children after an arsenic education curriculum designed to raise awareness of arsenic poisoning was administered in elementary schools in Araihazar, Bangladesh.

Tests are commonly provided by representatives from organizations outside of the village who leave once tests are administered, leaving little opportunity to reinforce that information. Training community members to deliver arsenic education concurrently with testing may be a more cost-effective way to monitor arsenic levels and reinforce information about health consequences. Such types of community health worker programs are a widely used intervention to improve the quality of health-care services—from health education to family planning and distribution of preventive care products—around the world. However, in one study, engaging community members did not decrease arsenic exposure any more than outside testers (George et al. 2012). Poor monitoring and a lack of incentives—common problems with other community health worker programs—may have been a reason why there was no difference. Providing monetary incentives to health workers, or better monitoring, may help improve performance and lead to better outcomes (Björkman et al. 2017, BenYishay and Mobarak 2019).

2.   Well-Sharing Arrangements

Many shallow wells are privately owned, and arsenic concentration levels vary between wells; therefore, exposure varies from household to household. Sharing arrangements between owners of clean shallow wells and owners of dirty wells can increase the proportion of the population consuming clean water. Such arrangements are possible in areas where houses are geographically close to one another and people interact on a regular basis, which is often the case in small village economies (Barnwal et al. 2017). However, households may not be willing to share with people outside their social network and low-income households may be less able to barter for access to a neighbor's clean well than households that are better off (Madajewicz et al. 2007). Social constraints may also be important determinants of water source usage (Mosler, Blochliger, and Inauen 2010; Inauen et al. 2013). Households with unsafe wells have also been found to purposefully conceal the results of the test, suggesting that social stigma could partially be to blame (although this could also be explained by concerns that the reveal would lower property value) (Barnwal et al. 2017).

These results suggest that we need to design mechanisms that are cognizant of such social constraints. For example, combining testing with a group commitment component where groups of households make a public commitment to their group before seeing test results—that if their well is tested and found clean, then they would promise to share water with those who have unclean wells—can address free riding and aversions to water sharing. If households are risk averse, then such a "risk-sharing contract" with ex ante commitments can improve joint welfare for the group of households and help to develop positive social norms about water sharing. Tarozzi et al. (2020) test this theory through a randomized controlled trial in Sonargaon, Bangladesh in which groups of buyers were offered tests and asked to sign an informal agreement about sharing water from their clean wells with those who had negative well-testing results. This form of soft commitment showed higher switching rates to clean water from dirty water among those who received a negative result compared to the treatment group where well tests were done at the individual level.

Public commitments have been shown to be effective in changing behavior, having been tested for other public health goals such as latrine adoption. For example, community-led total sanitation programs are an intervention aimed at changing social norms about open defecation by having communities pledge to become open-defecation-free. Bakhtiar, Guiteras, and Mobarak (2019) show that combining a form of a community-led total sanitation program, in which community members make public pledges in front of their neighbors, was effective in increasing the adoption of latrines when compared to private pledges and group-level financial incentives. In the context of arsenic, Inauen et al. (2014) show that public commitments enhance the effects of information on well switching.

3.   Installing Deeper Wells

In addition to well testing and well sharing, another promising approach is to install wells that reach deeper aquifers where arsenic concentrations are lower. In some areas, such aquifers are accessible at a depth of less than 90 meters and therefore reachable by local drillers using manual methods (Gelman et al. 2004). In one study area, many households switched to private intermediate-depth wells in response to early well testing in 2003 (Jamil et al. 2019). However, the cost of well construction increases linearly with well depth, and installation costs at this depth reach $200 per well. Estimates from blanket well tests in Araihazar, Bangladesh suggest that digging these expensive wells may still have positive net benefits since around 60,800 inhabitants experienced reduced exposure through this form of mitigation at an average cost of $28 per person.

Interventions to alleviate liquidity constraints may be necessary to help households afford the installation costs. In particular, providing microcredit to finance large purchases can enable households to invest and reap the long-run benefits. Credit provision can increase investments in preventive health. In India, providing access to microconsumer loans for insecticide-treated bed nets led to a large increase in uptake (Tarozzi et al. 2014). In Morocco, providing households access to credit to purchase a home water connection from a local water utility company led to 69% of households buying a connection, compared to just 10% in a control group (Devoto et al. 2012). In Cambodia, microloans significantly increased the willingness to pay for household latrines by 45 percentage points compared to a control group without the option to finance (BenYishay et al. 2017).

If there are learning externalities, then subsidies can induce others to subsequently adopt. Understanding the social dynamics of demand is useful to target subsidies efficiently. For example, targeting well subsidies to certain groups, such as highly influential people in a social network or people of lower socioeconomic status, can lead to greater subsequent adoption if neighbors learn more about the benefits and costs of the new technology, or by changing social norms. Social learning appears to have been important for nontraditional cookstove adoption in Bangladesh, where households made inferences about the new stoves based on information from people in their social network (Miller and Mobarak 2015). It was also relevant for hygienic latrines in Bangladesh (Guiteras, Levinsohn, and Mobarak 2019).

Deep tube wells that are deeper than 150 meters are more consistently low in arsenic but beyond the financial reach of most households. A deep tube well, when properly located, can meet the needs of several hundred villagers for years while requiring little maintenance (van Geen et al. 2003). Over 200,000 deep wells were installed as of 2007 by both NGOs and the Government of Bangladesh (Department of Public Health Engineering and Japan International Cooperation Agency 2009). Despite their engineering promise, the installation costs, inclusive of labor and

materials, can reach up to $850, which is beyond what most rural households can afford (Ravenscroft et al. 2014). Private deep wells therefore do not seem to be a feasible solution absent financial support or encouraging community members to pool their resources to jointly invest and share the well water. Khan et al. (2014) find that households are willing to pay on average 5% of their disposable annual household income for a communal deep-well fund. Variation in willingness to pay across households implies that one needs to solve a complicated problem to determine how much each member should be asked to contribute.

There are nontrivial challenges to successfully coordinating investments across households. Cocciolo, Habib, and Tompsett (2019) found that in a community-based program where members collectively made funding, location, and maintenance decisions for deep tube wells, larger groups led to fewer households participating in community meetings and less time spent deliberating over source location. In addition, they found that fewer households contributed to the cost of installation. As a result, larger groups saw smaller increases in the use of deep wells compared to smaller groups. More empirical evidence is needed about the drivers of collective action failure and on how community networks change as interventions scale.

The choice of where to place deep wells creates important complexities. Over half of the deep wells that have been installed by governments and NGOs were sited in areas where the prevalence of contaminated shallow wells is modest (Department of Public Health Engineering and Japan International Cooperation Agency 2009, van Geen et al. 2016). Households in heavily affected areas live too far from installed deep wells, beyond the 100–150-meter walking distance that previous studies have found to be the maximum that members of rural Bangladeshi households are willing to walk to fetch water (van Geen et al. 2003, Opar et al. 2007). From a blanket survey of all wells across Araihazar, van Geen et al. (2016) find that less than one-third of arsenic-contaminated shallow wells are located within walking distance (100 meters) of at least one of the 915 deep or intermediate-depth wells in the study area. If deep wells had been more evenly distributed, the percentage of shallow wells covered could have increased to 74%. Even when the engineering and financing constraints are addressed, there still appears to be some issue with the spatial distribution of deep-well placement (Figure 1).

One possible explanation for this inefficient deep-well placement is elite capture of this valuable public resource. Local government officials in Bangladesh have large discretionary authority over the siting of deep wells. In Araihazar, a subdistrict where much arsenic research has been conducted, the central government allocated funds to local government officials to install 50–100 deep wells each year over a decade. The location of a well is determined on the basis of input from the bureaucrat in charge of the subdistrict (Upazila Nirbahi officer), the senior local government official (Upazila Parishad chairman) who is directly elected, and the 12 Union Parishad chairmen who are also elected (van Geen et al. 2016). This

Figure 1.   **Clustering of Deep Wells**
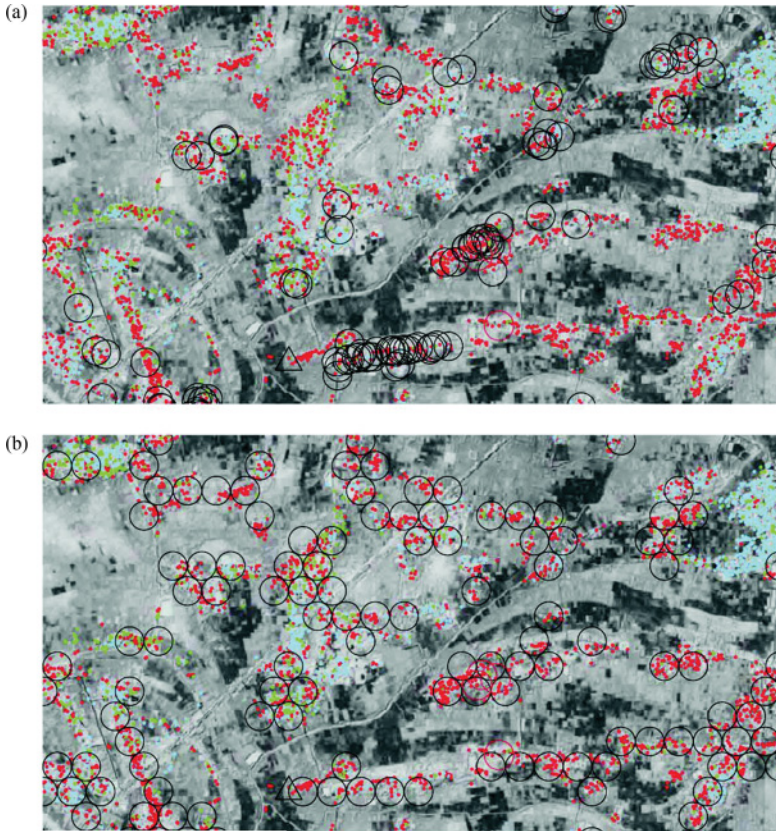
Notes: Panel (a) shows the overlapping circles with a radius of 100 meters around installed deep wells and shows that 29% of contaminated well (red) were within 100 meters of a deep well. Panel (b) shows the optimal placement of a subset of the wells from a regular-spaced grid.
Source: van Geen, Alexander, Kazi Matin Ahmed, E.B. Ahmed, and Imtiaz Choudhury. 2016. "Inequitable Allocation of Deep Community Wells for Reducing Arsenic Exposure in Bangladesh." *Journal of Water Sanitation and Hygiene for Development* 6 (1): 142–50.

decentralization of deep-well provision can be prone to elite capture, in which wells are preferentially targeted toward political, social, or economic elites in the community.

Evidence of elite capture of deep-well placement has mounted. In 2017, Human Rights Watch accumulated anecdotal evidence based on village interviews that politicians were preferentially placing wells near political supporters (Human Rights Watch 2016). Van Geen et al. (2016) report that about one-third of deep wells were placed in inaccessible locations such as inside the compounds of private households. Madajewicz et al. (2017) find that a community participation intervention that was designed to limit the influence of elites led to an increase in clean water access. Finally, Mobarak, van Geen, and Mangoubi (2019) investigated

the extent of elite capture by combining geospatial data on well placement and newly collected geocoded data on the location of political and economic elites. The authors find strong evidence that local politicians are more likely to have deep wells built near them during periods when their political party is in power. This form of elite capture accounts for about one-fifth of the inefficient spatial allocation of deep wells.

IV. Complexities of Scaling Policy Interventions

Large-scale public health problems such as arsenic poisoning across Bangladesh require scalable solutions. Implementing the strategies discussed in this article—treating contaminated groundwater or switching to low arsenic groundwater—is challenging and complexities may arise when going from a project in one district to a nationwide policy. As a program scales, for example, there may be spillover effects on nonbeneficiaries, friends and neighbors, and markets; political reactions from voters and governments; macroeconomic, growth, and welfare impacts; as well as concerns about the external validity of small-scale pilot results (Davis and Mobarak 2020).

Interventions may have spillover effects onto neighboring households or communities, interact with social networks, and affect market prices and wages. For example, the more that people use filters, purchase well test kits, or engage in well-sharing arrangements, the more attractive these behaviors may become to other members in a social network. The installation of more deep wells or community filtration systems in a given area could increase demand for spare parts, tools, and skilled labor, leading to positive spillovers in maintenance costs and better functionality. If people are less exposed to arsenic, they may become more productive employees, leading to more employment opportunities and higher wages in the community. More research on spillover effects can inform policy makers on unintended costs and benefits that can remain hidden in small-scale programs. This can motivate cost-effective intervention designs. For example, subsidies for test kits or filters may only need to be provided to a subset of households if demand for such products is interlinked between households, thus lowering the cost of the program substantially.

People may also adapt and react to policies in ways that can produce unintended effects. Some of those consequences might be negative. For example, Field, Glennerster, and Hussam (2011) hypothesize that the widespread switching to surface water after the discovery of arsenic in 1994 might have led to higher exposure to fecal–oral pathogens, which in turn increased infant and child mortality. On the other hand, people may also adapt in ways that produce unintended benefits. Keskin, Shastry, and Willis (2017) show that mothers react to arsenic exposure risk by increasing the propensity and the duration of breastfeeding, which provides infants some measure of protection against arsenic contamination, and this in turn

reduces infant mortality. The effects of any arsenic mitigation policies at scale will be inclusive of such adaptation and behavioral responses. For comprehensive policy evaluation, it is important for social scientists to provide rigorous analysis on these types of questions.

As an arsenic mitigation program scales up, it may change the behaviors of politicians and policy makers in response to the program. For example, if politicians have control of discretionary funding of deep wells, they may choose to install more in their home areas to gain votes or target placement near other politicians to gain political supporters. If funding for wells is externally funded by international NGOs, programs could erode political accountability if leaders claim credit for successful programs (Deaton 2013). On the other hand, externally funded programs may elicit political or financial support, as found in the case of externally funded sanitation programs in Bangladesh (Guiteras and Mobarak 2016). Research has already shown that political factors have led to inefficient deep-well placement in Bangladesh through elite capture. More research is needed on how best to address these political influences. For example, research on community participation in deep-well placement that imposed rules designed to limit the appropriation of projects by elites effectively expanded access to clean water sources (Madajewicz et al. 2017).

Changes in individual behavior induced by a program can, at scale, have macro-level impacts. Large-scale interventions that reduce arsenic consumption could boost human capital and labor productivity, which can lead to long-run growth. However, macroeconomic models often require parameters to properly predict macro-level impacts. Rigorous evidence from randomized controlled trials can help calibrate these models to more accurately determine these impacts in the medium to long run, and even simulate alternative policy scenarios. Net welfare impacts are also important when evaluating a program but are difficult to measure without modeling. For example, people may experience nonmonetary disutility by walking a longer distance to a communal deep well as they may be more vulnerable to crime if they must walk far and/or at night. Modeling can be used to answer normative questions about welfare trade-offs that are important for policy decisions.

Social science research aspires to generate evidence that policy makers can use to scale promising programs. Even if the research discussed above produced internally valid estimates of the policies studied at pilot scale, there are open questions about how programs would work outside the context of those evaluations. Replication studies and subsequent meta-analyses will be useful to aggregate results from different contexts.

V. Policy Recommendations

There are trade-offs in expanding access to clean water through well testing versus installing deeper, more expensive low-arsenic wells. Jamil et al. (2019)

Figure 2.   **Cost-Effectiveness of Different Interventions**
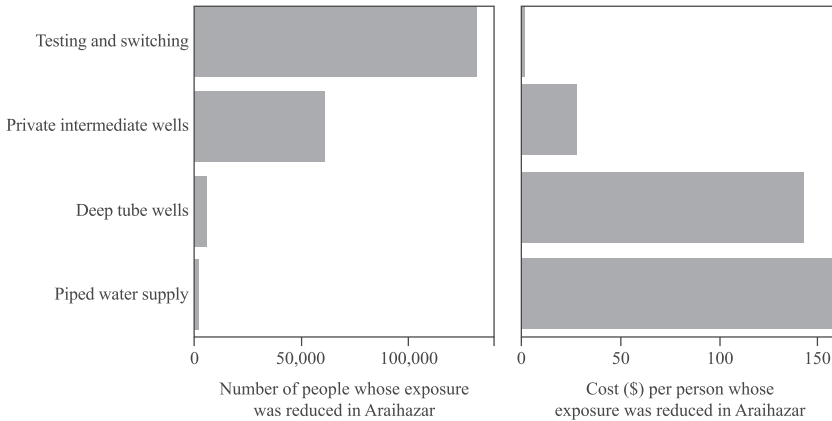
Note: This figure shows the number of people whose exposure was reduced in Araihazar, Bangladesh compared to the cost per person of each type of intervention.
Source: Jamil, Nadia, Huan Feng, Kazi Ahmed, Imtiaz Choudhury, Prabhat Barnwal, and Alexander van Geen. 2019. "Effectiveness of Different Approaches to Arsenic Mitigation over 18 Years in Araihazar, Bangladesh: Implications for National Policy." *Environmental Science and Technology* 53 (10): 5596–604.

conducted a cost-effectiveness analysis of alternative strategies in a particular area and found that free nationwide well testing would be the most cost-effective way of reducing exposure (Figure 2). Well testing alone reduced the exposed population in their study area of Araihazar in the short term by an estimated 130,000 people. The next most effective way was installing private intermediate-depth wells, which lowered exposure for 60,000 people at a cost of $30 per person. In contrast, installation of deep tube wells and piped-water supply systems by the government reduced the exposure of little more than 7,000 inhabitants at a cost of $150 per person (see Table on Comparison of Interventions). These numbers are a strong argument in favor of free well testing.

Simply providing test results addresses an information failure, which has been found to be a major impediment to the adoption of preventive health technologies in a variety of contexts. Informing people about the level of arsenic they are exposed to bolsters their demand for alternative sources of water. Therefore, well tests must precede investments in alternative sources in order to maximize the effectiveness of testing.

If well testing were complemented with interventions that make private intermediate-depth wells more affordable, such as with subsidies or microcredit, it could induce adoption and reduce exposure. A national database of well locations with test results can help policy makers target subsidies to areas with a high density of contaminated shallow wells. Designing subsidies that encourage sharing private intermediate-depth wells with neighbors can also increase the coverage.

Comparison of Interventions

Mitigation Method	Araihazar Activity	Exposed Population Reached	Exposure Proportion Reduced	Exposed Population Reduced	Cost per Govt/NGO ($)	Total Cost Govt/NGO ($)	Cost per Household ($)	Total Cost Household ($)	Total Cost per Exposure Reduced ($)
Testing and switching	48,800 wells tested (21,300 safe)	220,000	60%	132,000	2.5	122,000			1
Private intermediate wells	8,450 intermediate wells installed (7,610 safe)	67,600	90%	60,800			200	1,690,000	28
Deep tube wells	916 deep wells installed (907 safe)	51,200	10%	5,120	800	733,000			143
Piped water supply	312 connections installed (312 safe)	2,180	100%	2,180	250,000	250,000	300[a]	93,600	158

NGO = nongovernment organization.

Notes: [a] 10 years at $2.50/month. This table presents comparisons of the effectiveness and costs of various forms of arsenic mitigation conducted in Araihazar, Bangladesh.

Source: Jamil, Nadia, Huan Feng, Kazi Ahmed, Imtiaz Choudhury, Prabhat Barnwal, and Alexander van Geen. 2019. "Effectiveness of Different Approaches to Arsenic Mitigation over 18 Years in Araihazar, Bangladesh: Implications for National Policy." *Environmental Science and Technology* 53 (10): 5596–604.

Although Jamil et al. (2019) find that deep-well construction is much less cost-effective, the analysis by Mobarak, van Geen, and Mangoubi (2019) suggests that much of that is due to inefficient placement and elite capture. Deep wells are often forcibly "privatized" by politicians to use as a personal resource. This prevents other households from gaining access to clean water, even after expensive deep-well construction. Institutional reform that limits the discretion of public officials to site deep wells as they please would increase the efficiency of public funds that are deployed for well construction. Increasing either voter awareness or national government supervision of local politicians might put pressure on politicians to distribute deep wells in a fairer and more efficient way. We think that combining a national well-testing program with policy interventions that address these market failures currently preventing deep-well construction is required to properly address this massive health crisis in Bangladesh.

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