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Addressing Arsenic Poisoning in South Asia

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In Brief:

About 100 million people in Bangladesh and in the nearby Indian state of West Bengal are exposed to very high levels of naturally occurring arsenic in groundwater, which is their main source of drinking water. The World Health Organization recommends a maximum contaminant limit (MCL) for arsenic in drinking water of 10 μg/liter; in some areas of Bangladesh arsenic levels are as high as 800 μg/liter. This has rightly been called the largest case of mass poisoning in the history of mankind. Recent research indicates that chronic arsenic exposure is the underlying cause of about 20 percent of adult deaths in Bangladesh. Despite 20 years of public knowledge about arsenic-bearing drinking water in rural West Bengal and Bangladesh, as of 2006 less than 1 percent of the exposed population had access to arsenic-remediated drinking water. Our own field visits during 2008-2012 indicate that the situation has not changed much in recent years. To meet this challenge requires both effective technology and sensitivity to social dynamics. A technology invented in Berkeley for affordable and reliable arsenic remediation of ground water has been successfully tested in a community in West Bengal, and steps towards its successful establishment and social acceptance are under way by engaging local government, nonprofits, and local community and opinion leaders.

Key Concepts:

- The largest mass poisoning in the history of mankind is affecting about 70 million people in rural West Bengal and Bangladesh, with highly toxic levels of naturally occurring arsenic in their drinking water. These are among the poorest people on the planet, with little access to technology or formal education, and weak infrastructures and institutions.
- Adverse health consequences of chronic arsenic exposure include a variety of cancers, cardiovascular disease, gangrenes leading to amputations, neuropathy, and a reduced IQ in children exposed to arsenic. About 20 percent of adult deaths in Bangladesh are attributed to consequences of chronic arsenic exposure.
- Scientists in Berkeley have invented a technology “ECAR” that removes arsenic from typical arsenic-contaminated groundwater at an affordable price (estimated about US$ 0.004 per liter) and can operate with an intermittent power supply. These scientists are working with social and engineering scientists from Jadavpur University, Kolkata, and Kandi Raj College, Murshidabad (both in India), to undertake technology maturation, including its social embedding among relevant stakeholders and indigenization.
- New technologies, even if technically robust and economically affordable, don’t operate in isolation. To be successful, they have to be socially embedded with planned and deliberate engagement with various stakeholders. Building trust with and feedback from these stakeholders is critical to the success of the eventual final product or service.
- This paper describes the above process for ECAR as it progresses through successive field trials and technology maturation, as well as moves forward through the deliberate engagement with various stakeholders to prepare the grounds for its success in the real world and for moving toward large-scale implementation.

Independent researchers detected arsenic in the groundwater of West Bengal as early as 1983. In the arsenic-affected areas, people continue to substantially rely on this groundwater for drinking and irrigation. Arsenic enters the groundwater from naturally occurring arsenic-bearing sediments in the surrounding rock, though the details of the mechanism by which arsenic becomes mobile in water is still being discussed in the scientific literature. A third of West Bengal's population is at an elevated health risk from arsenic exposure. Studies have revealed that over half of West Bengal's districts contain arsenic-polluted wells, with new water samples continuing to reveal more aquifers with arsenic concentrations above 50 micrograms (μg)/liter.

Public demand for arsenic-safe water has emerged through various forms of public grievances and social conflicts between local inhabitants and the government. Local communities have staged mass deputations to the government officials and expressed their strong dissatisfaction through various methods including hunger strikes, rallies, and even boycotting of government campaigns for polio vaccination. Media often report on serious adverse health effects and deaths in the populace from arsenic while economists like Professor Joyashree Roy of the Global Change Program at Jadavpur University have initiated high-profile research projects on the cost of arsenic to West Bengal.

The state government's response has been limited. In 1983, the administration created a technical committee to better understand the science and suggest solutions. It took almost a decade for the government to then create the Arsenic Task Force, with the goal of installing arsenic-filtration systems at all arsenic-contaminated tube wells. Per official headcount statistics 59 percent of the population as of 2007 has been provided access to arsenic-safe technological installations—however the reality is otherwise. According to our survey data, almost 95 percent of newly installed arsenic treatment units are defunct within six months of installation due to inadequate or inappropriate social placement of the technology. Typically, private companies and non-governmental organization (NGO) operators were contracted for a fixed period to undertake replacement of arsenic filters and general upkeep. However, when their contracts expired the systems broke down and became defunct.

The government has responded to the crisis with alternative strategies, such as pressurized piped-water systems or deep aquifer tube wells, that bypass the need to access arsenic-contaminated shallow aquifers for water. Piped water and deep-aquifer tube well projects are commonly more costly and time-consuming to execute. Another major problem is that of perspective; users continue to be seen as "beneficiaries," not as customers, and integration with social practice —one of the core insights of the last few decades of development studies—is thrown by the wayside. The result is that most of the affected population must choose their drinking water from either the local arsenic-bearing tube wells or unevenly distributed, and scarce, deep tube wells.

Innovations that Engage the Community

Yet, despite the systemic failure to provide arsenic-safe drinking water in West Bengal and Bangladesh, there have been some innovations that reveal the strategies for success. One such tool is Electrochemical Arsenic Remediation (ECAR). ECAR technology was invented at Lawrence Berkeley National Laboratory and is being developed by the University of California-Berkeley. ECAR uses a small electric current to generate an arsenic sorbent *in situ* within contaminated groundwater. The only consumables required are ordinary mild steel plates and low voltage (< 3 volts) electricity—the latter can be supplied from the grid, solar PV panels, or batteries.

ECAR technology has many advantages over other low-cost arsenic removal methods such as chemical co-precipitation with ferric salts and filtration through activated alumina or granular iron-based adsorbent media. These advantages include the simplicity of inputs, very low maintenance (electrodes can be cleaned by automatically reversing the current direction during operation), high effectiveness (even in the presence of arsenic-III, which is more difficult to remove), and low overheads. The estimated operating cost of ECAR for removing 500 μg/liter arsenic from real groundwater to below 10 μg/liter is about 1 paisa (US$0.0002) per liter. We estimate that after including capital amortization, salaries of relevant personnel for maintenance, operations, and management, periodic arsenic testing of treated water, and business overheads and margins, the final price would be about 20 paise (US$0.004) per liter.

Inventing a robust, effective, simple-to-operate, and locally affordable technology is only the first of many steps toward successful implementation. Other steps include efforts to transfer technical knowledge and scientific capacity to local institutions. One crucial development was to replicate the ECAR unit indigenously at Jadavpur University in Kolkata. In 2011, this prototype was successfully field tested by the Jadavpur University scientific team in collaboration with Berkeley.

A concurrent challenge was to embed the units in local communities. For some time, schools in India have been identified as centers for introducing a range of poverty-reducing measures. By providing schools with arsenic-safe water-access installations to deliver arsenic-safe water to children and others (e.g., teachers and staff), knowledge of how the ECAR device works can be publicly demonstrated and seeded throughout the community. The provisions of safe water would have a natural alliance with other school programs, such as the midday meal, for promoting community wellbeing.

Amirabad High Madrasah, a school in the Murshidabad district of West Bengal, was selected as the test-pilot school. In December 2010 a pilot test of a 100-liter ECAR prototype, built and brought in from Berkeley, was successfully conducted in partnership with an NGO ("BAJS-Amirabad") founded and operating in the village of Amirabad, which helped to both select the school and manage the school's and community's expectations and provide the interface with local government.

The final necessary technical step was to work out what to do with the arsenic-bearing waste removed from the water. All arsenic removal technologies produce arsenic-laden sludge or waste that must be safely disposed of. The amount of wet sludge collected per 100-liter batch is approximately 0.4 liters, and the expected amount of dry sludge even less, for initial arsenic concentrations of between 600 and 3000 μg/liter in real groundwater. Previous studies suggested that leaching of arsenic from the sludge may occur in a landfill or hazardous waste burial site; therefore, we sought an alternative method for disposal by casting the waste material in concrete blocks for use in roadways (thereby also suggesting a business model for the waste's collection). Initial tests have been very promising.

Getting Back to Basics

From the experiments in West Bengal several principles for the scaling up of this and other remediation technologies can be discerned. These include:

1. The technology must be robust.
By this we mean that the inventors and innovators must apply the constraint that the technology will perform its intended task under stressful and difficult environmental and operating conditions encountered in the field (such as power blackouts and brownouts, dust, ambient heat and humidity, and being serviced by individuals with little formal technical training, under weak regulation and missing markets). This constraint of robustness must be applied right from the early stages of conceptualization and idea generation so we don't end up in a blind alley. Implied in this statement is the desire that the technology must perform at a level that is expected for first-world inhabitants. In other words, we should apply our best knowledge and creativity to ensure that we do not provide a lower service level to the poor people in the developing countries, by assuming that it would be "good enough" for them.

2. The technology must be locally affordable and culturally acceptable.
This is essential to ensure a financially viable technology in the long run. Only locally affordable technology will allow a sustainable solution that does not require continuous infusion of external subsidy or cash to keep it operational and make it available to millions of people. Furthermore, the technology must not run counter to local culture. In the ideal case, the invention will be adopted, without compromising its technical performance, to suit the culture and habits of the end users, and the inventors will not need to push to change the culture or even daily habits for the invention to work.

3. The invention and innovation must be scalable.
In business language, "scalability" means the ability for the invention to be replicated and delivered to millions or even hundreds of millions of end users. Many inventions that we now take for granted have gone through this process successfully, and many other inventions could not go to scale and ended up as only curiosities. For an invention to go to scale, its bare cost must be at least four to five times lower than its perceived monetary value to the end user. Only then is there a business case to be made for mobilizing finance capital, which is essential for large-scale production and delivery of the innovative product or service. We note that there are other aspects of the scalability constraint. The invention must not rely on some unique material that is in short supply, it must not produce waste products that are difficult to dispose of, and it must not cause environmental damage that will be unacceptable when deployed on scale. If used on scale, the innovation must not have foreseeable unacceptable consequences in economic or social spheres.

It Takes a Community To Build a Well

ECAR is a promising technology for arsenic remediation in poor rural parts of South Asia. It is technically highly effective in reducing arsenic and has a locally affordable cost per liter; the technology has very few moving parts; it is easy to operate and maintain and uses indigenous materials; no toxic or corrosive chemicals are required for any media-regeneration; and the bound arsenic in the (small amount of) resulting sludge is easy to immobilize.

The technology must be effective, robust, affordable, and scalable -- but the real secret lies in how the technology is seeded within a local community. Technical innovation of ECAR, supplemented by social engineering, forms the core of our model of technology maturation, field trials, stakeholder engagement, social embedding, and transfer to licensees for scale-up. The technology and the approach for its social embedding are likely to be useful in other countries in the region (e.g., Nepal, Bangladesh, Cambodia, Vietnam) affected with natural arsenic contamination of groundwater.

It's still early days in West Bengal, but the hope is that social innovations like the use of schools can be scalable by local governments in order to stop this entirely preventable scourge of Bengali and Indian families.

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