Battling 'the largest mass poisoning in history'

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Many wells dug in Bangladesh in the 1970s and 1980s to provide clean drinking water were later found to be highly contaminated with arsenic. Credit: David Funkhouser

International health experts have called it the largest mass poisoning in history, and it is still underway. Some 100 million people in southeast Asia have been drinking from shallow wells originally drilled to provide germ-free water; but many turned out to be contaminated with naturally occurring arsenic.

Despite efforts to understand the natural processes at work, and provide safer water, many are still being poisoned, due to scant resources, poor information at local levels, and the sheer numbers of people and wells involved. The result: a slow-burning epidemic of heart disease, cancers, lung problems and compromised child development.

Researchers at Columbia University's Lamont-Doherty Earth Observatory and the Mailman School of Public Health have been on the front lines of the issue since 2000. They are currently leading a wide range of initiatives, including long-term health programs, continued drilling of safer wells, education and continuing investigations into the geology of arsenic contamination.

Arsenic is of course a classic poison known since antiquity. Inert, and thus harmless, traces of the element are locked into many rocks and sediments across the world. But starting in the 1990s, studies by scientists at Lamont and elsewhere have shown that under certain natural conditions, these may release the arsenic into drinking-water aquifers. Altogether, it is now estimated that some 140 million people in 70 nations are exposed to unsafe levels of arsenic in well water.

Southeast Asia—Bangladesh in particular—is ground zero. About 97 percent of Bangladesh's rural population depends on millions of modest community and private wells. Nearly all water there is carried by hand, and most people live within 100 meters of one. By 1999, it was shown that half were contaminated. Some 33 million to 77 million Bangladeshis, or as much as half the current populace, have been exposed. The results: according to one 2012 Lamont study, one in 18 adult deaths can be attributed to arsenic. A 2014 Mailman study says the figure could actually be one in five. Many millions more are drinking from unsafe wells in India, Pakistan, Nepal, Cambodia, Myanmar and Vietnam.

Other countries with widespread problems include China, Mongolia, Chile, Argentina, Mexico and the United States. Some 43 million Americans depend on mostly unregulated private wells; testing has shown that nearly 7 percent contain unsafe levels. According to the

Environmental Protection Agency, 500 utilities in the U.S. provide drinking water with unsafe levels of arsenic. But determining how many people are getting too much arsenic in their water is difficult, according to a 2014 study conducted in part by the Columbia Water Center.

A success, then trouble

Before wells became common in Bangladesh and other southeast Asian countries, most rural people had to drink sewage-laced surface waters. In the 1960s and 1970s, the United Nations began systematically installing shallow wells in Bangladesh and other countries to provide safer water. It was a huge success; infectious diseases dropped, and other organizations, along with many communities and private parties, installed many more shallow wells. These were simple, narrow boreholes cased with plastic pipes, generally reaching down less than 30 meters. By the mid-1990s, 10 million were in use in Bangladesh alone.

Deep wells in villages around Jessore, in western Bangladesh, are showing high levels of arsenic, unlike in most areas of the country. Researchers are trying to find out why. Credit: David Funkhouser

The first signs of trouble appeared in southwestern India in the 1980s, when large numbers of people started turning up with previously unseen skin lesions. These were recognized as signs of advanced arsenic poisoning, eventually traced back to the wells. By 1993-1994, health authorities recognized the problem in Bangladesh, on a much wider scale. By 1996-97, testing showed many wells were drawing up arsenic at 10 to 100 times accepted safe levels.

The problem caught entire countries unawares in part because arsenic is a stealthy poison. Ailments often take decades of chronic exposure to show up. Studies by researchers at Mailman and other institutions have linked it most strongly to cardiovascular disease, and cancers of the skin, lung and bladder. Mailman researchers have also linked arsenic to reduced IQ in children—a finding confirmed last year among schoolchildren in the U.S. state of Maine who have been exposed to levels only a tenth those studied in Bangladesh. There is also good evidence for many other cancers, increased stillbirths, diabetes, neurological impairments and immune ailments.

"No organ system goes untouched," said pharmacologist Joseph Graziano, a leading arsenic expert and Earth Institute professor at Mailman who oversees Columbia's work on the issue.

For a long time, the U.S. Environmental Protection Agency set the maximum allowable concentration of arsenic in public water supplies at 50 parts per billion, but due to health studies, in 2000 this was lowered to 10 parts per billion. The World Health Organization now also recommends this standard. But in Maine, the recent research showed that just 5 parts per billion shaved several points off children's IQs. There may in fact be no safe level, say many experts. Bangladesh's own official "safe" level is still 50 parts per billion—and that is routinely exceeded in nearly a third of the country's wells, according to a 2015 government report.

The long latency period for arsenic-related diseases means that Bangladesh's burden of illness will probably continue to climb in coming years, no matter what is done now, said Graziano. In Chile and Taiwan, where authorities recognized the problem early and took action, mortality from cancer began to decline only after 20-some years.

Bangladesh and the other heavily affected southeast Asian countries have one factor in common: Much of their landmasses rest on vast piles of sediments eroded out of the Himalayas and dumped into river deltas.

Many of these sediments contain arsenic, stuck to rusty iron-oxide particles, where it can't do any harm. But studies by Lamont scientists and others show that the arsenic often can get into groundwater when organic compounds from plant matter percolate through shallow zones, where bacteria break them down. The decay process uses up dissolved oxygen in the water, and when the oxygen runs out, the bacteria eventually turn to the iron oxides for oxygen. This reaction sets the arsenic loose, to be dissolved in the water.

In Bangladesh, the younger, shallower sediments, laid down in the last 5,000 years, are the most hazardous. Safer water lies deeper, among sediments more than 12,000 years old at some 150 meters, where apparently the arsenic has already been depleted. Unfortunately, it costs as little as $100 to drill a shallow well, but a much deeper well can cost 10 or 20 times more.

Since 2005, internationally funded drilling of some 200,000 deeper wells probably reduced exposure for many people. But given the numbers exposed, this leaves a long way to go.

Kazi Matin Ahmed, a hydrogeologist at the University of Dhaka who has been overseeing the Bangladesh research, expresses quiet frustration at the situation. "We've been working on it 20 years now," he said. "We should not have anyone exposed to arsenic anywhere. But millions are still exposed."

According to the World Health Organization, the number of Bangladeshis drinking from wells exceeding the 50 parts per billion national standard has dropped by about 40 percent. But a 2012 study of Bangladeshi wells led by Lamont-Doherty researcher Sara Flanagan says that some 20 million Bangladeshis are still drinking water above that level, and 5 million are drinking water above 200 parts per billion. That does not count another 25 million or so drinking water above the internationally accepted standard of 10 parts per billion.

Part of the problem: Even if people live near safe wells, they may not be aware; and even when they are, they may not switch. International agencies in the last decade have labeled many wells, but often, ratings placards have fallen off. In one study area cited by Flanagan, vigorous public-education efforts over a two-year period increased the proportion of people drinking from safe wells by a few points. But in a control area, the proportion actually dropped; this was due not only to fading memories, but the fact that people continued to install new, inexpensive wells whose status is unknown.

According to a 2013 study led by Lamont's Alexander van Geen, the number of tubewells in the Araihazar district, just east of the capital of Dhaka, doubled from 2001-2012. Yet to compound the problem, there is evidence, says van Geen, that some newly drilled safe wells tend to cluster in politically favored districts, not according to need.

Rapid urbanization and expansion of intensive irrigation are also exacerbating the problem. Massive deep groundwater pumping to feed the municipal water supply of Dhaka (population 15 million and growing fast) appears to be pulling water in from neighboring, shallower aquifers. It is feared that this process—happening around other fast-growing cities as well—could eventually draw water from contaminated shallow aquifers into safe deep ones.

A 2014 study led by van Geen shows this may already be happening outside the booming city of Hanoi. There, pumping has moved water from a contaminated aquifer in the suburbs more than a mile toward the more populated center. The movement of arsenic itself seems to be slowed down by natural buffering processes, but it may already be moving in, and could become a problem in Hanoi and elsewhere within decades, says van Geen.

The rapid expansion of deep pumping for crop irrigation may pose an even more serious threat; farming uses much more water, and such pumps are proliferating across India, Bangladesh and other countries. In addition, rice irrigated with tainted groundwater takes up the element. Arsenic has also been shown to lower rice production—in Bangladesh, maybe 6 percent a year, according to unpublished Lamont research.

A legacy of chronic disease

The Columbia efforts began in 2000 around Araihazar, a highly polluted area. It started with testing of 6,000 wells serving some 70,000 people, and the opening of a clinic to conduct long-term health-monitoring of 12,000 people using the wells.

The researchers have since tested and labeled more than 50,000 wells, and the health monitoring study has expanded to include 35,000 residents. It is the largest longitudinal study of its kind, and has yielded many of the key results about the toxicity of arsenic. The clinic has since evolved into a four-building complex that also delivers basic health services and dentistry to the area. Employing 125 people, it has accumulated an arsenal of diagnostic tools—X-ray, EKG and ultrasound machines, and sophisticated equipment to test blood and take DNA samples. A dispensary hands out medicines at half-price. Workers at the clinic and back at the project offices in Dhaka compile reams of data for study, some of which goes into a new national registry of chronic diseases.

Dozens of people stop by each day with their health concerns.

"Diabetes and hypertension are high here," said Tariqul Islam, the clinic's director. Out of the 35,000 participants in the long-term study, he said, more than 3,000 have diabetes, and more than 6,000 have hypertension. These could be tied to arsenic—but also to other problems such as diet, cooking smoke and cigarettes.

In the nearby village of Panch Baria, Tariqul visited with members of the extended Khondaker family, 27 of whom have health issues related to arsenic poisoning. Nasima, wife of the hamlet's head man, said four family members have died from cancer, and her sister-in-law has lung cancer. A relative showed the mottled skin on his chest, and another family member showed bumps and lesions on his hands– typical signs of arsenic poisoning. The clinic has enrolled 22 family members in a clinic trial to see if doses of Vitamin E and selenium can help alleviate symptoms. Another trial has shown that folic acid can help some people reduce the amount of arsenic held in their bodies.

The Khondaker family and many of their neighbors now drink from a clean well donated by Columbia, and nearly two-thirds of the people in the long-term health study now use safe wells, Tariqul said. The rest have been given filters to remove arsenic. But filters are not a good long-term solution, because of cost and problems with maintenance, he said.

Among other things, Lamont has developed some simple tools to speed tests and cataloging of wells, including cheap, easy-to-use field water-sampling kits, and cell-phone technology to register results to a central database in Dhaka.

Most recently, in a study area just north of Araihazar, in conjunction with the government, researchers started a pilot program in which well owners can get a quick test for the equivalent of just 58 cents; the fee is subsidized by the project. A previous study in India showed that people were willing to pay such a nominal amount. If the experiment is successful here, it will be expanded to other areas.

Every 18 to 24 months, workers from the Araihazar clinic fan out to survey families involved in the long-term health study and update their conditions. When someone dies, they visit the home to interview the next of kin about the circumstances. In rural Bangladesh, 80 percent of deaths occur at home with no medical attention, so these "verbal autopsies" contribute valuable data about chronic diseases and the long-term effects of arsenic poisoning.

The clinic organizes village meetings to pass on information about arsenic and its symptoms, and to reinforce the importance of testing and using clean wells. Programs in public schools teach youngsters about avoiding arsenic in drinking water—and there is evidence the students have carried the lessons home to their elders.

"The best thing is, our education and prevention efforts have led to a 28 percent reduction in the arsenic blood level of our subjects," said Graziano.

"Our participants [now] have this knowledge regarding chronic diseases, the relationship to arsenic, the relationship to smoking, the relationship to cooking (smoke)," said Tariqul. He hopes the clinic's influence on study participants and their families "will act as a catalyst for the larger community" to promote healthier habits.

What's going on underground

In the meantime, geologists and hydrologists from Columbia and other institutions are traveling around Bangladesh, testing sediments to better understand the source of the problem.

Brian Mailloux, an environmental scientist from Barnard College, and Tyler Ellis from the Lamont-Doherty Earth Observatory traveled to Bangladesh in January 2015 to retest wells at several sites in the countryside outside Dhaka. Joining them was a team from Bangladesh, including Imtiaz Chadoury and Illias Mahmud from Dhaka University, and scientist Edwin Gnanaprakasam, from the University of Manchester in England.

On a visit to the village of Bari Kandi, 25 kilometers east of Dhaka, the team tapped into eight test wells dug to varying depths to help researchers track how arsenic may be moving underground. The site is one of several set up a decade ago that are periodically retested. They want to find out how arsenic gets into the water, and whether the problem is getting worse or better over time.

Mailloux and Ellis filled bottles with water samples, used filters to separate out carbon from the soil and started running tests with a makeshift field lab set up on a table borrowed from villagers. "I spend a lot of time looking at what carbon [the bacteria] are eating," Mailloux said. "Are they eating carbon from the sediment or are they eating carbon coming in from the water? If you can understand what carbon they're utilizing, you can better understand how the arsenic's getting released."

Skin lesions are one obvious sign of arsenic poisoning, which can have many long-term effects, including heart disease, cancers and respiratory problems. Credit: David Funkhouser

Meanwhile, a local crew set up a hand-levered, bamboo well-drilling rig and started driving a pipe into the ground, down through the layers with high arsenic concentrations. Every five meters, they pulled back the pipe and extracted a sample of dense gray sediment for Gnanaprakasam, who will use DNA sampling to identify which bacteria transform arsenic into a soluble form and release it into the groundwater. Working at another borrowed table, he set up a portable "clean" lab—a large bubble of clear plastic inflated with nitrogen, which creates a relatively oxygen-free environment that helps preserve the bacteria. Using glove-like inserts, he scraped samples into small vials for later testing.

To the west, across the broad Padma River (in India, the river is called the Ganges) near the city of Faridpur, van Geen and some colleagues are working with farmers to reduce arsenic contamination in their rice crops. The scientists want to see if simply replacing some of the topsoil contaminated by arsenic-laced irrigation water can help.

On a cool, foggy morning in January, van Geen and his team fanned out along narrow, muddy dikes that delineated a checkerboard of rice fields. Irrigation ditches channel water from pump houses out into the flat expanse of fields. The stages of planting were on view all around. A man wrestled a power tiller through a muddy field; a worker with a hoe clawed open a ditch to flood a field; barefoot men dressed in lungi, the traditional sarong, stooped down, ankle deep in water, rapidly poking rice seedlings into the soil.

The researchers headed to a plot they have chosen for testing. They mapped out a corner near the spot where irrigation water enters the field, where arsenic concentrations should be high; and then boxed off a second corner far across the field, where arsenic has likely dissipated. The farmer who tills these fields is one of several who have agreed to swap topsoil between the two plots, to see if they can improve yields.

Van Geen and Brittany Huhmann, a PhD student from MIT, crouched down and pushed a metal cylinder into the test plot to grab a sample of the rich soil. Huhmann then used an X-ray fluorescence machine, a handheld device that looks like a large glue gun, to measure arsenic and other minerals in the soil.

Meanwhile, Lamont researcher Benjamin Bostick and Bangladeshi assistant Anjal Uddin stepped into muddy fields to tap a foot-long gray pipe into the soil and grab more samples to study soil chemistry. Bostick is training Anjal to continue sampling through the season to track arsenic concentrations in the soil and how much gets taken up into the rice.

Van Geen hopes that by finding a way to increase rice yields, he can convince farmers not to pump more irrigation water from deeper wells. The fear is that drawing large amounts of water from the deeper, cleaner aquifer, will cause contaminated water from shallower layers to sink to that deeper level—and contaminate the source of clean drinking water.

But farmers will need some economic incentive to do that. Ruiwen Lee, a PhD student at Columbia's School of International and Public Affairs, came along in January to conduct surveys of farmers to understand the economics of the rice crop and see what would induce farmers to change their practices. She worked with local researcher Abdur Rahim to refine the survey, and he took over the work after she returned to New York.

Looking for leaks

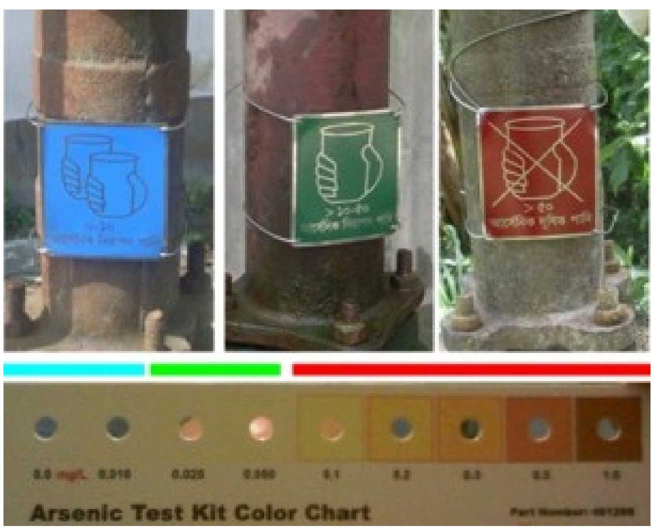
Arsenic in Bangladesh resides in the sediments washed down from the Himalayas by rivers like the Brahmaputra and Ganges over many thousands of years. Water pumped up for irrigation is affecting rice crops. Credit: David Funkhouser

After the work in Faridpur last January, van Geen led a crew southwest to Jessore, near the border with India, for another experiment. Tests have shown that some deeper wells—supposedly dug to the safe aquifer level—have become contaminated with arsenic.

Working with Mahfuz Kahn, a Bangladeshi studying at the University of Delaware, and student Abir Zaman, van Geen lowered a special camera down suspect wells to look for broken pipe. The camera, on a measured tether, also tells them how deep the well is—and whether the drillers went as deep as needed to find clean water.

They then deliberately salted the wells; when they came back the next day, salinity readings told them if freshwater was leaking in somewhere—a possible source of contamination.

Van Geen reported recently that the wells tested in Bangladesh have been properly drilled—and that the tests have confirmed that there is indeed contaminated water in the deeper wells in some areas. Radiocarbon dating revealed that the water there is younger than elsewhere at similar depths around the country—a possible clue to the source of higher arsenic levels.



Labels help villagers identify wells with safe water. The World Health Organization standard is no more than 10 parts per billion of arsenic (blue); the Bangladesh standard is currently 50 ppb (green).

Van Geen and his team have extended the well-testing work into the Indian state of West Bengal as well.

Researchers from many other institutions are involved with Columbia in the health and earth-sciences research, including the University of Chicago, Massachusetts Institute of Technology, the University of Delaware, the University of Dhaka and Texas A&M University. The Columbia researchers also have ongoing related studies in eastern India, Myanmar, Cambodia, Vietnam and the U.S. states of Maine and Illinois. Funding for the hydrological studies and the health research comes primarily from the National Institute of Environmental Health Science Superfund Research Program and the National Science Foundation.

Some 35,000 residents in Araihazar, including members of this family, are enrolled in a long-term study that tracks chronic diseases and other problems to better understand the impact of arsenic poisoning. Credit: David Funkhouser

"We first learned of arsenic in water in 1993, and we didn't know anything about arsenic at the time," said Kazi Matin. "This came as a shock to us. This project came along and gave us opportunity to go deep into the problem." He said the research has helped inform government actions in Bangladesh. "It has findings that will help people in other parts of the world," he added.

An update: Joseph Graziano reports that tremors from last spring's earthquake in Nepal heavily damaged one of the main buildings housing the Araihazar clinic. None were injured, but the building had to be abandoned; the clinic is using temporary quarters until a new center can be prepared in a newly constructed apartment building nearby.

Provided by Columbia University