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TWO NOBLE TRUTHS

--*Ashok Gadgil*

The furious young schoolteacher stormed right up to me. My six-foot-one-inch frame loomed over his short and skinny physique, but his anger made me take a step back. I was shocked to discover it was directed at me! The year was 2000 and I was deep in rural Bangladesh to visit one of the severely arsenic-affected villages to see the tragedy first hand. I hoped to understand the context of the problem and seek feasible solutions.

"You!" He fumed indignantly, "You have a return air ticket! You are here just to watch our misery and take photos," he almost shouted. "What choice do I have if the only water we get has high arsenic? I'm already showing signs of arsenic poisoning!" He put his arm next to mine, our skin was the same color but his was mottled with arsenic sores. "My future is limited, my health will soon fail, I will have trouble getting married and won't live to see my children grow up. And you! You too started out from nearby Bombay, but you've managed to go to the US. Now, you'll soon fly back! What have I done to deserve being trapped here, like this?" I was taken aback with the outburst. He was right to be furious at this injustice of fate, and I was left without an adequate answer. There was nothing I could do for him right then, all I could say was, "It could have been me in your place." In my mind, I resolved to do something about this; though nothing can be done about fate, surely, science and innovation could at least outwit arsenic!

That year, 2000, the top one billion people (that included me) in the world earned 78% of the world's income, and the bottom one billion people (that included the Bangladeshi schoolteacher) earned 2% of the world's income. The disparity in research spending is likely much larger; non-fatal problems of the top billion attract substantially more research funding than the life-threatening problems of the poorest billion – probably by many orders of magnitude.

My path to facing a furious, arsenic-scarred Bangladeshi schoolteacher had an unusual trajectory. In 1973, I came to Berkeley from India to pursue a doctorate in physics, and a whole new world opened up. In India I was a classic math and physics "nerd," getting thrilled with the Dedekind cut and Special Relativity in the 8th grade, delving into Richard Feynman lectures in high school, and getting a perfect 990 in the Physics GRE as a sophomore in college.

However, several events right after my arrival in Berkeley made me question the research trajectory that I had set on. In 1973 and again 1975, the U.S. was shaken by the oil shocks – for the first time there were long lines of cars at gas stations. Suddenly, the seemingly assured upward arc of American prosperity and indefinite economic growth seemed to falter.

Even so, America seemed shockingly affluent relative to India. I had always thought representations of the U.S. lifestyles in Indian movie theaters were a romantic exaggeration, typical of Bollywood fare. On arrival however, reality sank in: everyone had a phone (back then, we Indians had to pay a hefty fee and wait 10 years to get one), almost everyone had a car and a separate detached house (unthinkable for most Indians), and Americans were putting more fertilizer on their front lawns than India used for all its agriculture! When my American friends offered to drive me to see the nearby Oakland slums, I was even more amazed: the houses all had reliable electricity, 24/7 running water, flush toilets and phones, with paved roads in the front. "My" slum dwellers back in Bombay were living in rags, in illegally built bamboo-and-tarp shelters or under bridges, with no amenities.

This juxtaposition spurred me to start learning about India's poverty, developmental economics, industrial policy, and the political economy of development and underdevelopment. I also started wondering whether doing theoretical physics, with no practical applications in sight, would be the best way to help my countrymen. On top of that, in 1975, Mrs. Indira Gandhi declared an internal "state of emergency" on questionable grounds. The government suspended basic human rights, censored the press, launched forced sterilization campaigns and jailed political dissidents. This made me question the relevance of my fascination with pure physics all the more. What did I really want to do? What was really worth doing? To which area of inquiry should I apply my mind?

Ultimately, I decided to transition my studies towards a more pragmatic applied physics, and started studying under Professor Arthur Rosenfeld who had just switched from a brilliant career in experimental particle physics to a new area: energy efficiency for the U.S. I began my doctoral research with his group at the Lawrence Berkeley National Lab, just up the hill from UC Berkeley. My intention was to complete my Ph.D. at UC Berkeley and return to India to apply my knowledge to addressing the energy crisis which seemed to threaten getting the majority ever out of poverty.

Soon after finishing my doctorate in Physics my (Indian) wife and I returned to India with our 8-month-old daughter, with no plans to look back. I initiated research in India on energy efficiency and renewable energy at the then fledgling Tata Energy Research Institute (TERI). However, after some five years of TERI's rapid growth, I realized that my scientific aspirations no longer matched where TERI was headed. After unsuccessfully seeking another research position in India, I finally made the difficult decision to leave India and return to Berkeley with my family, now with two daughters.

Though my plans to remain in India did not succeed, my experience working there was invaluable. I gained first-hand insight on how technically sound solutions can fail in the real world unless they take into account the societal context. I saw the profound limitations in Indian infrastructure and institutions that had not been obvious when I was a student.

One of my first projects on return to LBNL was an attempt to address India's chronic battle with power shortages. Blackouts plagued most cities and industries, even as electricity was wasted in inefficient end use technologies; light bulbs are better at warming the air than lighting a room. The Indian power grid served many households whose lighting demands at night overwhelmed system's capacity and led to blackouts. The majority of these households were also too poor to afford efficient compact fluorescent lamps (CFLs). It seemed a Catch 22: the grid's capacity was inadequate to light up so many millions of inefficient bulbs. Meanwhile, these same millions of families were so poor they qualified for "lifeline" electricity rates that lost money for the power companies.

I realized that if the utilities could subsidize CFLs for their poorest customers, we'll have a win-win-win. I refined this idea and published several papers on its applications. In 1991, our attempts to implement the project in India succumbed to institutional politicking. Still, we persisted and succeeded brilliantly first in Mexico, then Poland, and then in several other countries. My work with energy efficiency and lighting had a useful lesson: lateral thinking can sometimes offer elegant solutions to complex problems

My work on CFLs and power outages was spurred by my distress with India's energy inefficiency, and the imperceptible pace of adopting innovations in technology and policy to address it. Nearly all of this research was on my own time, while I conducted formally funded research, published papers, and so on during my "day job". In this day job, I led work in Berkeley applying computational fluid dynamics to address the problem of indoor radon in the U.S. Indoor radon was then killing about 12,000 people in the U.S., mostly with lung cancer, and the challenges were to first find out quantitatively how radon got into homes, and second, how to effectively and energy-efficiently mitigate the indoor radon. This project was my first real foray into public health.

I had long noted the relatively high prevalence of waterborne diseases in India compared to their near-absence in the US. For that matter, my young daughters often suffered a bout or two of diarrhea every time my family visited India. I began to realize that while my generally healthy daughters bounced back, there were many children their age who never would. On one visit, my mother revealed that she had lost five nieces and nephews (cousins I never knew) to diarrheal death in their infancies.

Back in the 1990s, waterborne diarrheal diseases annually killed an estimated 4 million worldwide-- mostly children under age five. About half the deaths were in South Asia. Somewhere, infrastructure development and institutional motivations had failed India's children.

While pursuing other research threads, I started to collect and send relevant publications on drinking water disinfection to my scientist colleagues in India, suggesting they explore affordable and effective ways to produce drinking water from raw water. UV-disinfection appeared particularly promising at first sight. However, the reasons my colleagues offered for inaction were similar to mine: they were paid to do something else! They had to write the next journal paper, or author the next proposal, or review a manuscript, or whatever was the task *du jour*. The situation changed dramatically for me with convergence of two events in 1993. Art

Rosenfeld, my former thesis adviser, asked me to provide guidance to a Masters thesis research for a mechanical engineering student, and in exchange offered summer salary for the student to work with me to assess costs and effectiveness of drinking water disinfection with UV light. We discovered that for as little as just half a US cent, we could a disinfect a thousand liters of clear water with UV light. So, under ideal conditions, the *annual* cost of disinfecting one person's drinking water (daily 10 liters) would be a less than two cents US!

All that summer, I painstakingly incubated bacteria in water samples for my research on top of my home water heater. Meanwhile, another bacteria that was susceptible to my UV invention was barreling unchecked through South Asia. This outbreak of a mutant strain of "Bengal Cholera" started in India and spread to Bangladesh and Thailand, killing tens of thousands of people month after month. I remember feeling horrified the first time I read the details of death by cholera. I was elated that I might have a solution to stop such an outbreak but devastated that this time around, it was too late. I vowed then that I would relentlessly pursue the UV water disinfection idea until I got it right – it must function effectively, affordably, and robustly in remote parts of the developing world.

My early UV disinfection research was done at the Lawrence Berkeley National Laboratory (LBNL), one of the most prestigious of the US National Labs. All of this work was initially done on my own time, time stolen from family and sleep. In the National Labs, scientists are funded only by project; there is no core funding (or supported time) at the personal level to explore other research ideas, unlike for tenured faculty at a university. My colleagues generously helped by lending lab space and equipment, but I struggled for consumables and supplies.

In 1991, I won the Pew Fellowship in Environment and Resources for my work on energy efficient lighting for poor communities in India. I was thrilled to discover that the award included a no-strings-attached research grant -- which I immediately devoted to my UV disinfection work. Still, I knew I'd need more support. My initial requests for funding to more than 50 foundations were all refused or ignored. My lucky break came when some of my friends decided to vouch for scientific integrity and the promise of this project to a couple of foundations who provided modest support. LBNL's proximity to UC Berkeley attracted several engineering grad students to join the project as volunteers.

My second lucky break was through Steve Witkowski, a program manager at USAID, who saw the potential importance of a breakthrough in UV water disinfection. He defied institutional skeptics and naysayers to support my work with modest but steady funding. We held "Stop Cholera" workshops in Washington DC and Bhubaneswar, (Orissa, India) to get feedback from a diverse audience about any potential drawbacks in our evolving design and to network with potential supporters. I was always a bit incredulous that such a simple, elegant design had not yet been tried; I worried that there was some fundamental flaw in our design that I had missed. I put my concerns to Sam Pitroda, the former head of India's Technology Mission for Drinking Water. Sam not only reassured me that this was a new approach to water purification, but also offered his wholehearted support and suggested key Indian government contacts.

The principle behind UVWaterworks (the name of our UV disinfector), was to make it a fail safe technology that could provide clean water for the poorest communities in the developing world. This meant that UVWaterworks had to be highly effective, very low maintenance, of nominal cost and robust enough to withstand harsh environments. This would take cycles of research, design, and testing – far beyond my personal capacity or finances. Just as this challenge seemed insurmountable, two dedicated researchers offered to move to Berkeley and work on this project full time and for free! Edas Kazakevicious, a young physicist from Lithuania, won a George Soros Fellowship from Central European University in Budapest; David Greene was a fresh graduate from Rice University. With this infusion of energy, we raced through design refinements and successive cycles of field testing, feedback, and redesign in India, Mexico, and South Africa.

As my employers, the University of California and Lawrence Berkeley National Lab own the patent for UVWaterworks; they licensed the technology to a California startup, WaterHealth International (www.waterhealth.com), in 1996 and launched it into the real world. In that same year, this invention won the Discover Award for the Best Environmental Invention of the year, and also the Popular Science Magazine's "Best of What's New" award. Both awards brought a burst of publicity and enthusiasm for the newly formed WaterHealth.

Based on user feedback, we sacrificed some efficiency to make the UVWaterworks compact and light. We also designed it to have a huge (300%) overdoes of UV energy to overcome possible snags in field operations. So, the cost of disinfection alone climbed from 0.5 cents to 5 cents US per tonne of water. It is still 6000 times more energy efficient than disinfection by boiling water over a biomass cookstove.

From the inception of UVWaterworks, I wanted to help address water-borne disease in Africa. One day, I was feeling a bit down, struggling with balancing home and work and fund raising and research. I felt a big pleasant surprise when NRDC's Peter Miller walked up to me and said "Great! You have such an energy efficient water disinfector, let's see how to get it tested in Africa!" Through him I learned of the Lily of the Valley hospice near Durban, South Africa, for abandoned HIV-positive infants, established by a retired white Afrikaner farmer and his wife. Their only water supply was from a bore well that tapped a groundwater aquifer. Tragically, this water was badly contaminated from nearby pit toilets. About half the infants admitted to the hospice emerged HIV-free and were moved to orphanages. The other half were loved and cared for until they died. Heartbreaking though it was, I realized there was still something I could do. We installed a UVWaterworks unit at the hospice to provide safe drinking water for the infants. Suddenly, diarrheal disease declined precipitously, offering a better quality of life even for their brief childhoods. Michael Apted's award winning 1999 documentary "Me and Isaac Newton" followed our work at Lily of the Valley hospice.

WaterHealth now offers a micro water-utility with the necessary physical and social infrastructure for each village to have it's own safe drinking water supply. The water treatment technology is housed in a small structure on community land near the village's original raw water supply (often a local pond or river). These WaterHealth Centers collaborate with local non-profit organizations to provide essential community education in public health and hygiene. The turn-key package includes financing from a bank, and construction, operation and maintenance by WaterHealth. The village council (a locally elected body) owns the WaterHealth Center. The costs are recovered by selling affordable, safe drinking water to the local community. Prices will vary depending on factor costs at various times and places, but affordability is one of the key tenets of the WaterHealth model. In 2007, the prices in Eastern Andhra Pradesh in India were about 2 cents US per 10 liters of potable water, 140 times cheaper than the local price of bottled drinking water. By end of 2008, WaterHealth had 300 of these micro water-utilities either in operation or at various stages of construction, with a service capacity for more than a million villagers.

In 2005, I visited India's first fully functioning WaterHealth Center in Bomminapadu, a remote village outside Vijayawada, in Eastern Andhra Pradesh. Then, we had just hired a thin, quiet man named Venkanna as our Center technician. Up till then, he had been struggling to find work and was on the verge of leaving the village to expand his search. He told me this job had been a lifeline; he had been deeply unhappy at the thought of leaving behind his family and community to find work. "This job has changed my entire outlook!" he crowed. I met Venkanna again in 2008 – now a beaming and confident man. Over the past three years he had risen to supervise a cluster of eleven WaterHealth Centers!

By end of 2008, WaterHealth employed several hundred people in India, serving safe drinking water to more than a million rural villagers. In my estimation, WaterHealth was now preventing some 200 infant diarrheal deaths per year. I was visiting one of "our" villages when a mother thrust her chubby infant into my arms. Looking down at his smiling face, I realized that what had been just a spark in my mind way back in 1993 had come a long way. That same year, Irena Selena released "FLOW," an award-winning documentary about water that includes a segment about WaterHealth's work in Andhra Pradesh.

Though UVWaterworks has been demonstrably effective in addressing some water-borne illness in the developing world, there are other problems beyond its scope. The horrific arsenic contamination in Bangladesh, for instance, has been well-recognized for over a decade, but we've made little progress in reducing its impact. More than 50 million people are affected by arsenicosis in Bangladesh and the neighboring Indian state of West Bengal, in what is rightly called the largest case of mass poisoning in history. That encounter with the furious schoolteacher remains with me even today; since then (in 2000), I've invented two novel methods of arsenic remediation – both are technically effective, robust and affordable, but are still in early stages of field testing (you can learn more at http://arsenic.lbl.gov).

On one site visit to West Bengal, I decided to visit some unsuccessful projects to remove arsenic from water to learn what mistakes to avoid. In every case, the science had not failed, but the scientists had. They had overlooked the needs of the community and set up technologies that were too expensive, complex, or delicate for the rural environment. We faced a harrowing scene: many villagers in Murshidabad district had amputated limbs from arsenic-induced gangrene, family members who had died from arsenic-induced cancers and tales of spiraling from poverty to destitution, and a loss of even hope. In reality, much of this suffering might have been prevented, and can still be prevented.

I thought back to that angry schoolteacher I'd met in the year 2000. He was right to be angry. Arsenic in groundwater is an act of nature, but its presence in drinking water is an act of human society. Our collective failures in addressing arsenic in groundwater are not an accident or some act of fate. They reflect an uncomfortable truth about institutional priorities but simultaneously reflect an opportunity to change the world for the better. My way of making a difference has been through science, and two additional noble truths sustain me in my work. One is to always remember my humanity and the second is to always move forward with optimism; the humanity makes me care, and the optimism makes me keep trying.
