The Subir & Malini Chowdhury Center for Bangladesh Studies

at the Institute for South Asia Studies
University of California at Berkeley

Bangladesh Research Notes

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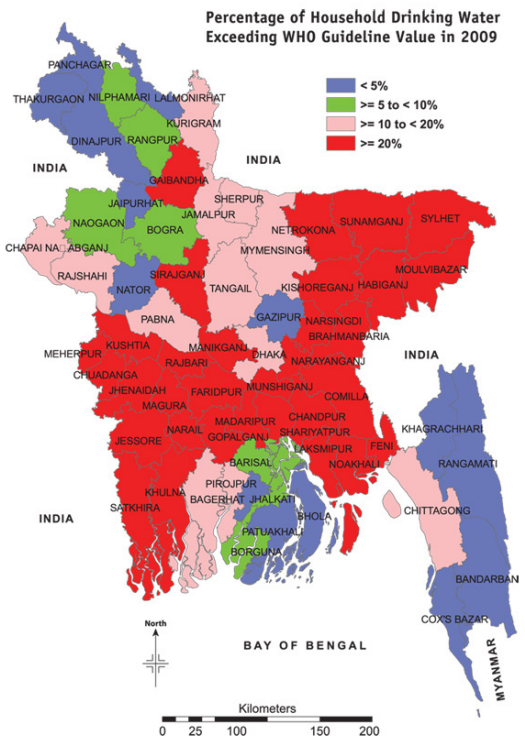
ENGINEERING FOR CHANGE

PROVIDING ARSENIC & FLOURIDE-FREE SAFE DRINKING WATER IN BANGLADESH, INDIA AND VICINITY BY INVENTING AFFORDABLE AND SUSTAINABLE TECHNOLOGIES

Ashok Gadgil
Professor of Civil & Environmental Engineering; Senior Faculty Scientist and Former Director of the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory, University of California, Berkeley

According to the World Health Organization 200 million people worldwide are exposed to toxic concentrations of naturally occurring arsenic in groundwater supplies, the vast majority living in rural Bangladesh and India (West Bengal, Bihar). Other arsenic-affected areas are found in Vietnam, Thailand, Argentina, Chile, Mexico, China and the United States. The chronic ingestion of arsenic in the body causes skin lesions, gangrene, multiple types of cancer, cardiovascular diseases, reduced IQ in children, neuropathy and premature death. Over 60 million people in Bangladesh and West Bengal (India) drink groundwater contaminated with naturally occurring arsenic. Although the WHO's recommended maximum limit for arsenic in drinking water is 10 parts per billion (ppb), the arsenic levels in groundwater used for drinking can exceed 1000 ppb. Forty thousand people in Bangladesh are already showing signs of arsenic poisoning, in what is rightly called the largest case of mass poisoning in history. A recent 10-year long cohort study published in The Lancet showed that 1 in 5 of all adult deaths in Bangladesh are now due to arsenic.

High concentrations of naturally occurring fluorides are another threat to public health affecting nearly 200 million people worldwide. Fluoride is naturally present in water. In small quantities, it is beneficial but when concentration exceeds WHO's permissible limit of 1.5 mg per liter (with a target of between 0.8 and 1.2 to maximize benefits and minimize harmful effects), it can cause severe health repercussions, including anemia due to poor nutrient absorption, mottling of tooth enamel (dental fluorosis), and severe bone deformities in children (skeletal fluorosis). In India, over 66 million people are at risk of developing fluorosis and face large and adverse social, economic, and health repercussions. Particularly in the newest Indian state created in June 2014, Telangana, the Nalgonda District offers an appropriate site to study this global development challenge because the problem there is severe, long standing, and still largely unresolved. It is estimated that 10% (~0.35 million people) of the district population are affected by fluoride contamination and about 10,000 people are irreversibly crippled due to skeletal fluorosis. Despite awareness of the problem for over six decades, fluoride contamination in Nalgonda continues to persist due to lack of alternative water sources for the rural populations.



SUMMARY

OVER 200 MILLION PEOPLE GLOBALLY (AND 60 MILLION IN BANGLADESH & WEST BENGAL ALONE) DRINK GROUNDWATER CONTAMINATED WITH ARSENIC.

OVER 200 MILLION PEOPLE GLOBALLY (AND 66 MILLION IN INDIA ALONE) ARE AT RISK OF DEVELOPING FLUOROSIS

ASHOK GADGIL AND HIS LAB TEAM HAVE DEVELOPED TWO NOVEL APPROACHES TO SUSTAINABLY, EFFECTIVELY, AND AFFORDABLY REMOVE ARSENIC AND FLUORIDE FROM GROUNDWATER

THIS REPORT EXPLORES THE WORK AND CHALLENGE OF IMPLEMENTING SUCH TECHNOLOGIES

ASHOK GADGIL is Senior Faculty Scientist and former Director of the Environmental Energy Technologies Division at LBNL. Concurrently, Dr. Gadgil is the Andrew & Virginia Rudd Family Foundation Distinguished Professor of Safe Water and Sanitation in the Department of Civil and Environmental Engineering at UC Berkeley. In 2004-05, Dr. Gadgil was the MAP/Ming Visiting Professor in Civil and Environmental Engineering at Stanford. He received his B.Sc. degree in Physics from University of Mumbai, M.Sc. in Physics from IIT Kanpur, and Ph.D. in Physics from the University of California, Berkeley, in 1971, 1973, and 1979 respectively.

Dr. Gadgil has a long record of innovative solutions to problems in the developing world. He has pioneered the way to accelerate access to compact fluorescent lamps for poor households in developing countries; invented and commercialized a method to affordably disinfect drinking water for poor communities; designed, tested, and then found a way to build, field-test, and disseminate tens of thousands of fuel-efficient stoves to refugee women in Darfur; and invented and is currently field-testing an extremely low cost, robust, and technically reliable method to remove arsenic from

IT IS A WASTE OF TIME TO TRY TO SOLVE PROBLEMS IN A SMALL WAY. YOU NEED TO THINK ABOUT HOW TO GO TO SCALE AND MAKE LIVES BETTER FOR AT LEAST 10 MILLION PEOPLE
—Ashok Gadgil

Since 1999, Ashok Gadgil and his Berkeley Lab colleagues have been working on the enormous challenge of finding an effective, affordable and practical way to remove arsenic and fluoride from water in India and Bangladesh. Their goals has always been to design water treatment systems that are not only technically robust but cost effective and socially acceptable for poor rural communities that suffer from groundwater contamination. Therefore alongside the scientific and engineering development, the team is developing a business model for system implementation. This solution will take into account economic costs/benefits, social acceptability, affordability, and sustainability.

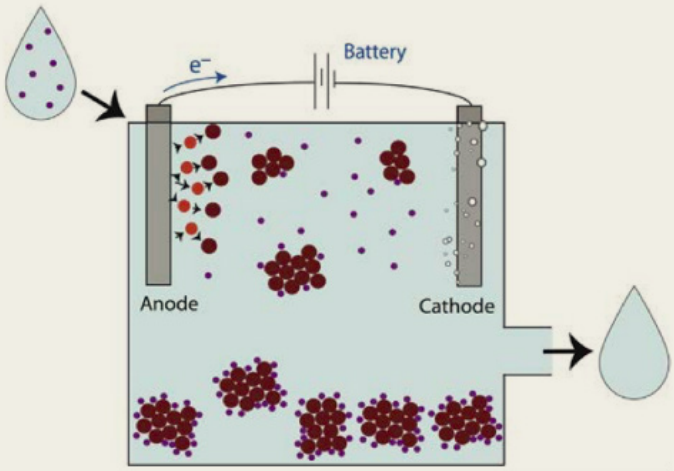
For arsenic remediation, they have developed an affordable and effective technology, referred to as ELECTROCHEMICAL ARSENIC REMEDIATION (ECAR). For fluoride remediation, they are investigating BAUXITE as a potential sustainable fluoride removal method with lower material, energy, and carbon costs.

ELECTRO-CHEMICAL ARSENIC REMEDIATION (ECAR)

In ECAR, electricity is used to continuously dissolve an iron electrode, forming a type of rust in the water. Arsenic in the water binds to the rust particles, which can then be removed. The rust particles are created electrochemically at the time of use, eliminating the need for a costly supply chain. In addition, electrochemical processes resulting from the use of electricity greatly enhance the arsenic removal capacity (i.e. arsenic removed per unit iron input) relative to the common chemical methods of arsenic removal.

The only inputs required for ECAR treatment are ordinary mild steel plate electrodes and low voltage (< 10 V) power source.

After years of proving the effectiveness of ECAR in the lab the Gadgil team scaled up to a 600 L pilot plant in West Bengal. After verification that this system met all necessary standards the team scaled again to a 2,000 L plant capable of producing 10,000 L/day. Since April 11th 2016 this plant has been producing clean, safe water that meets all Indian drinking water standards.



The arsenic removal mechanism in ECAR. Iron (Fe) from the anode dissolves into solution, forming rust. The rust forms complexes with arsenic in solution through adsorption to the rust surface, or precipitation into a new iron-arsenic solid. The arsenic-laden rust complexes are then filtered or settled out of the water.

A vital feature of ECAR technology is that it is cost effective for the poor, rural communities that need them. The estimated operating cost of ECAR is $0.83-$1.04 /m3 (amortized capital plus consumables). Including the estimated cost of civil works, equipment capital, maintenance, salaries for operators, management, overheads, quality control costs, and profit margin, the final

price of arsenic-free water is roughly $.02/L (which is equivalent to 1 Indian Rupee or 1.2 Bangladeshi Taka).

ECAR 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 include:

- Higher adsorption capacity due to the much larger surface area of newly precipitated nano-scale particles
- Ability to oxidize and effectively remove As[III]
- No need to backwash media, (since media are removed by precipitation)
- Low maintenance needs (electrodes can be cleaned by automatically reversing the current direction during operation)
- Strong pH buffering ability (no need for pH adjustment)
- No need to import, manufacture, deliver, or handle media or chemical additives
- Very low production of waste sludge
- Amenability to automation

ECAR HAS BEEN LABORATORY TESTED USING GROUNDWATER WITH RELEVANT LEVELS OF PHOSPHATE AND SILICATE FOR GROUNDWATER IN THE BENGAL REGION. ECAR HAS ALSO BEEN TESTED USING REAL GROUNDWATER SAMPLED FROM ARSENIC-CONTAMINATED WELLS IN WESTERN AND CENTRAL BANGLADESH, WEST BENGAL (INDIA), AND CENTRAL CAMBODIA. IN ALL CASES, ECAR WAS ABLE TO REDUCE ARSENIC TO < 10 PPB, AND IN MOST CASES TO < 5 PPB.

UC Berkeley PhD candidate Siva Bandaru takes samples in the field, West Bengal, India.

ECAR operates at low voltages (< 10 V in real groundwater), easing electrical safety issues. Power can be supplied using grid, battery, or solar photovoltaic sources. The semi-batch process allows for electricity interruptions, and the equipment can be made robust against voltage surges, sags, and spikes. Arsenic-remediated water can be pumped and stored into an elevated delivery tank, preventing water supply disruptions during electricity outages.

The optimal scale for ECAR technology is a community scale (500 - 3000 people). This is because the burden of maintenance, operation, arsenic monitoring, electricity supply, and quality control are spread over the full customer base; these burdens do not decrease proportionately as the technology is scaled to a household. ECAR technology itself can be built for a single household, or even smaller units, and could be powered with a D-Cell battery. The unit price increases significantly with smaller size.

THE ARSENIC TEAM

UC BERKELEY

ASHOK GADGIL *Principal Investigator*
SUSAN AMROSE *Lead Scientist*
SIVA RAMA BANDARU *Researcher*
CAROLINE DELAIRE *Researcher*
KATE BODEN *Researcher*
DANA HERNANDEZ *Researcher*
PRASENJIT PAUL *Researcher*

JADAVPUR UNIVERSITY

JOYASHREE ROY *Principal Investigator*
SHYAMASREE DASGUPTA *Researcher*
ABHISEK ROY *Researcher*

Bio contd.

drinking water in Bangladesh and nearby regions.

Dr. Gadgil is the recipient of numerous awards and honors. In 1991 he was named a Pew Fellow in Conservation and the Environment for his work on energy efficiency. In 1996 he received the Discover Award for the most significant environmental invention of the year, and also the Popular Science "Best of What's New" award, both for his water disinfector. In 2002, he won the World Technology Award for Energy. In 2001 he was one of the 35 top American inventors featured in the book "Inventing Modern America", published by MIT Press. In 2004, he was won the "Tech Laureate" award from the San Jose Museum of Science and Technology, and in 2006 the Chicago Museum of Science and Industry named him as one of the exemplars of the "Spirit of Leonardo da Vinci in modern America." In 2007 he received the "Breakthrough Award" from Popular Mechanics for the Berkeley-Darfur Stove. In 2009 he won the prestigious Heinz Award, which cites him for research, innovation, and humanism. Dr. Gadgil received the European Inventor Award in 2012 for the most significant invention in the Non-European Category from all non-European countries (for UVWaterworks). Also in 2012 he was awarded the Zayed Future Energy Prize in recognition of his achievements in innovation, leadership, long-term vision, and impact in renewable energy and sustainability.

THE NOVELTY OF ECAR

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

THE BOUND ARSENIC IN THE (SMALL AMOUNT OF) RESULTING SLUDGE IS EASY TO IMMOBILIZE

THE TECHNOLOGY IS EFFECTIVE, ROBUST, AFFORDABLE, AND SCALABLE

IT OPERATES AT LOW VOLTAGES AND CAN BE POWERED BY GRID, BATTERY, OR SOLAR PHOTOVOLTAIC SOURCES

The most recent success of the ECAR team is four consecutive months of operating their 2,000 L pilot plant during the summer of 2016. Once automated this plant will have a throughput of 10,000 L/day, the first of its size and scope. Weekly water analysis performed by UCB and two independent Nationally Accredited Board Laboratories in India confirm that the plant's product water is always below the 10 ppb WHO limit. Located on a school premise in the rural outskirts of Kolkata, West Bengal, this plant serves the needs of 3,000 students and families in the community.

Pictured here is the full 2,000 litre ECAR pilot plant at Dhapdhapi High School, West Bengal. Social & engineering sciences are both equally critical in successful deployment of each unit.

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.

ECAR TREATMENT CONSISTENTLY REDUCES HIGH CONCENTRATIONS OF ARSENIC >500 PPB TO BELOW THE WHO LIMIT OF 10 PPB IN DRINKING WATER

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.

The pilot plant in West Bengal is still in its early days, but the hope for the future is that the lessons and successes learned there will transfer and scale to the rest of the world; forever putting an end to this entirely preventable mass poisoning.

ECAR team & Dhapdhapi school staff Summer 2016

HOW THE INSTITUTE FOR SOUTH ASIA STUDIES HELPS

IN SUMMER OF 2016, WE SENT TO BANGLADESH AND INDIA, UC BERKELEY STUDENT WAHEED BAKSH SHEIKH TO STUDY ECAR FOR ITS SUITABILITY AND RAPID ADOPTION IN BANGLADESH

BAUXITE: A LOW-COST WATER DEFLUORIDATION TECHNIQUE FOR INDIA

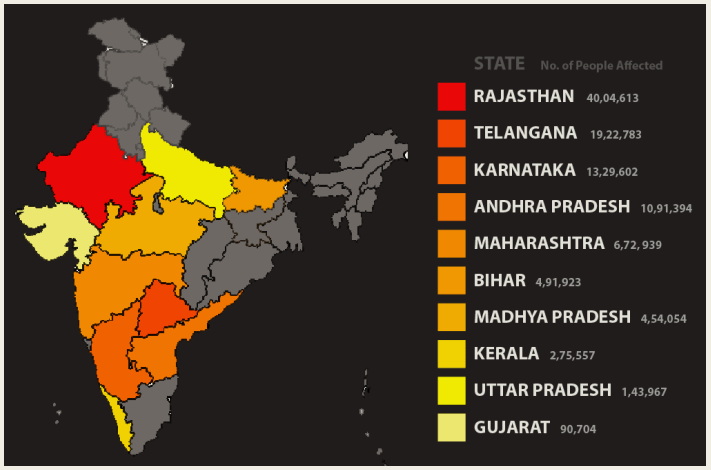
Globally, 200 million people are at risk of developing crippling deformities (e.g. fluorosis) by drinking groundwater contaminated with toxic levels of naturally occurring fluoride. Researchers in the Gadgil lab propose to use raw bauxite, an aluminum-rich ore, for reasons enlisted in the box on right, to remediate groundwater fluoride through a community-scale batch absorption process. Eliminating the costly and wasteful process of refining bauxite into activated alumina – a commonly utilized defluoridation approach, has the potential to reduce the annual per capita cost of treated water significantly, from $50/person/year to ~$1/person/year.

GADGIL LAB'S NOVEL DEFLUORIDATION TECHNOLOGY HAS THE POTENTIAL TO BE LOCALLY SOURCED AND AFFORDABLE, HIGHLY EFFECTIVE, CULTURALLY APPROPRIATE, TECHNICALLY FEASIBLE AND ROBUST IN A RURAL SETTING, AND REQUIRES MINIMAL MANPOWER TO OPERATE AND MAINTAIN THE SYSTEM

Although many defluoridation technologies have been proven to be effective in labs, few have been distributed in the field and even fewer appear to be sustainable long-term. There is a pressing need to develop a more sustainable adsorbent method with lower material, energy, and carbon costs.

Skeletal fluorosis patients in Nalgonda (Photo: Katya Cherukumilli)

Excess fluoride intake is detrimental. Thus, Gadgil lab is developing a novel defluoridation technology using raw bauxite, the raw material for producing alumina and aluminum, as a potential sustainable fluoride removal method. Their novel technique eliminates the costly, wasteful, and unnecessary processes of refining bauxite into higher-end products and has the potential to be (a) locally available and affordable, (b) highly effective at removing a wide range of fluoride concentrations, (c) culturally appropriate, (d) technically feasible and robust in a rural setting, and (e) operated and maintained with minimal manpower.



Indian States with most number of people with fluorosis. Image credit: Manoj Manduva, 03/9/2015, www.Factly.com

Many previous studies on the use of bauxite for defluoridation have relied on energy- intensive processes like calcination to thermally activate its surface or on chemically intensive processes to increase the purity of the bauxite ore.

THE NOVELTY OF BAUXITE

IT IS LOCALLY AVAILABLE, AFFORDABLE & CULTURALLY APPROPRIATE

IT CAN BE HIGHLY EFFECTIVE AT REMOVING A WIDE RANGE OF FLUORIDE CONCENTRATIONS

IT CAN BE TECHNICALLY FEASIBLE AND ROBUST IN A RURAL SETTING AND CAN BE OPERATED AND MAINTAINED WITH MINIMAL MANPOWER

USING BAUXITE FOR TREATMENT DOES NOT NEGATIVELY IMPACT WATER QUALITY BECAUSE IT LEAVES NO RESIDUAL HARMFUL CHEMICALS IN THE WATER

GADGIL LAB'S TEAM LEAD'S INITIAL LAB RESULTS SHOW THAT A DOSE OF RAW BAUXITE OF 4 TO 20 G/L (VARIANT BASED ON THE SOURCE OF BAUXITE) CAN SUFFICIENTLY REMEDIATE 10 MG/L FLUORIDE CONCENTRATIONS TO BELOW THE WHO LIMIT OF 1.5 MG/L

DEALING WITH FLUOROSIS

FLUOROSIS IS AN ENDEMIC DISEASE PREVALENT IN 20 STATES OUT OF THE 35 STATES AND UNION TERRITORIES OF THE INDIAN REPUBLIC

EXCESS FLUORIDE INTAKE IS DETRIMENTAL TO TEETH AND BONES, CAUSING CONDITIONS SUCH AS DENTAL AND SKELETAL FLUOROSIS

DENTAL FLUOROSIS INVOLVES DISCOLORATION AND WEAKENING OF TEETH WHILE THE SKELETAL CONDITION MAY LEAD TO ARTHRITIS AND OSTEOPOROSIS

PEOPLE WHO RELY ON GROUNDWATER ARE AT GREATER RISK

IN SOME PLACES THE FLUORIDE CONCENTRATION CAN EXCEED THE WHO-MCL BY EIGHT TIMES

AN ADSORPTION-BASED DEFLUORIDATION TREATMENT METHOD APPEARS TO BE THE MOST PROMISING IN TERMS OF COST AND EFFECTIVENESS

THE FLUORIDE TEAM

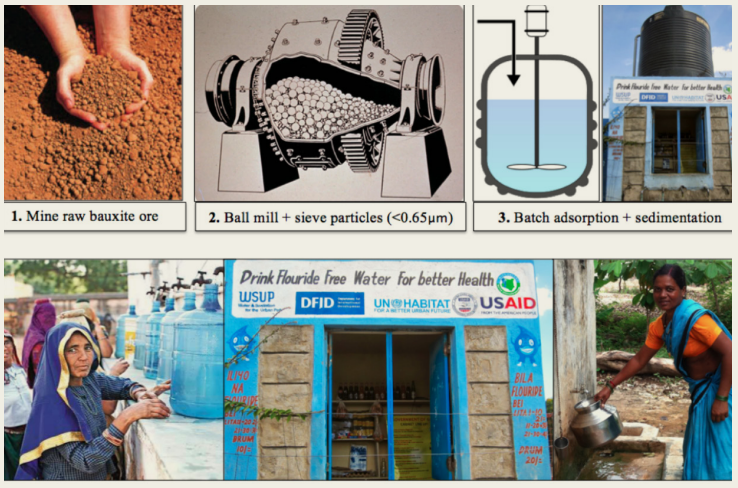
UC BERKELEY

ASHOK GADGIL
Principal Investigator

KATYA CHERUKUMILLI
Ph.D Candidate & Lead Researcher

To avoid the costs associated with the high energy and chemical digestion steps, the Gadgil Lab method is exploring the use of raw or mildly-activated bauxite in a batch adsorption. In particular, because adsorption is a physical-chemical process that is greatly dependent on surface area, their approach uses a novel (and cheap) technique to crush the raw bauxite ore to small particle sizes (<10um) using the well-known industrial ball milling process.

Based on global market costs for bauxite and activated alumina ($30/ton vs. $1500/ton), the WHO daily per capita water needs for drinking/cooking (7.5 L/ day/ person), a high initial fluoride concentration of 10 mg/L, and assuming that the two adsorbents have similar adsorption capacities, the estimated annual per capita cost of defluoridated water treated with bauxite (~ $1/person year) is much lower than the cost with activated alumina (~$50/person year). Unless the mass of bauxite required is 50 times greater than the required mass of activated alumina, the cost of treatment is always significantly lower for bauxite.



Gadgil Lab's Novel Approach

In addition to the dramatic cost-reduction potential of this novel technology in comparison to other Al-based methods, India has the 5th largest bauxite deposit (19000 million tons) in the world and neighboring states to Telengana (Andhra Pradesh and Orissa) account for almost two thirds of the country's bauxite deposits.

Because bauxite is the primary ore source of aluminum metal production, which is environmentally and socially costly, many mining sites in coastal Andhra Pradesh currently face large opposition from local tribal and environmental groups. The Gadgil Lab method will not contribute to the toxic and polluting processes associated with aluminum manufacturing factories, which is the basis of the locals' opposition.

HOW THE INSTITUTE FOR SOUTH ASIA STUDIES HELPS

IN 2013 WE AWARDED A RESEARCH GRANT (VIA MAHARAJ KAUL RESEARCH FELLOWSHIP) TO GADGIL LAB GRADUATE STUDENT KATYA CHERUKUMILLI THAT GOT HER FIELDWORK STARTED IN HER RESEARCH FOR INEXPENSIVE WAYS TO ADDRESS FLUORIDE IN DRINKING WATER.

IT TAKES A COMMUNITY

Many household and community-scale arsenic or fluoride treatment units have been deployed and quickly abandoned because they were not maintained, repaired, accepted, or affordable. Such remediation technologies must be evaluated based on their ability to perform within a sustainable and scalable implementation model that addresses these challenges, and not just for their ability to treat water. From the experiments in West Bengal several principles for the scaling up of these and other remediation technologies can be discerned. These include:

Rajesh Kumar Singh/Associated Press

THE TECHNOLOGY MUST BE ROBUST

This means 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 in order to not 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 developing countries, by assuming that it would be "good enough" for them.

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.

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 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. Other scalability constraints for the technology is that it 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.

THIS RESEARCH REPORT USED SOURCES AND INFORMATION FROM DOCUMENTS, PAPERS, GRANT APPLICATIONS, AND PREVIOUS RESEARCH DONE BY THE GADGIL LAB AT UC BERKELEY.

FURTHER DETAILS ON THESE AS WELL AS OTHER RESEARCH ONGOING AT GADGIL LAB PLEASE VISIT

GADGILLAB.BERKELEY.EDU

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. HIGHLY EFFECTIVE IN RELEVANT AND DIVERSE GROUNDWATER COMPOSITIONS
2. ROBUST IN THE FIELD EVEN WHEN OPERATED WITH MINIMAL AND LOW-SKILLED MAINTENANCE
3. LOW COST ENOUGH FOR CLEAN WATER TO BE LOCALLY AFFORDABLE WITH NECESSARY BUSINESS MARGINS
4. SUSTAINABLE WITH MINIMAL SUPPLY-CHAIN COMPLEXITY
5. OPERABLE WITH MINIMAL RISK TO SAFETY AND THE ENVIRONMENT
6. CULTURALLY ACCEPTABLE TO THE LOCAL POPULATION

The Subir & Malini Chowdhury Center for Bangladesh Studies, at the Institute for South Asia Studies (ISAS) at UC Berkeley champions the study of Bangladesh's cultures, peoples and history. The first of its kind in the US, the Center's mission is to create an innovative model combining research, scholarships, the promotion of art and culture, and the building of ties between institutions in Bangladesh and the University of California.

Bangladesh Research Notes is published by the Chowdhury Center to promote dialogue and exchange between scholars who work in inter-disciplinary fields related to Bangladesh, as well as to convey to the wider public the variety of exciting projects going on at Berkeley. Bangladesh Research Notes are available at chowdhury-center.berkeley.edu/research.

— READ MORE ABOUT GADGIL LAB AND THEIR ONGOING PROJECTS

• COOKSTOVE PROJECTS:

About three billion of the world's population cooks their food indoors using open fires or rudimentary cookstoves. Indoor burning of solid fuels releases toxic pollutants including particulate matter and carbon monoxide. These harmful cooking practices cause an estimated 4 million premature deaths annually. Learn how Dr. Ashok Gadgil and his team have designed, tested, and evaluated improved cookstoves
http://gadgillab.berkeley.edu/research/energy/cookstoves/

• LIFE CYCLE ASSESSMENT:

Life cycle assessment (LCA) is an approach for assessing industrial systems. LCA provides a complete view of a system's life cycle, and this view is used to calculate the system's overall impact allowing for an improved focus on optimization efforts. LCA is unique from other types of assessments because it includes all the processes in the life cycle (cradle-to-grave) beginning when materials are extracted from the Earth and ending when materials are returned to the Earth.Learn more about what Gadgil Lab is doing to assess the life cycle impact of technologies
http://gadgillab.berkeley.edu/research/energy/life-cycle-assessment/

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