IDEAS Competition
Cover Sheet

Project Name: Innovative Drinking Water Technology for Bangladesh, West Bengal and Nepal

Team Members:

Name	e.mail	MIT affiliation
Tommy Ngai	ngait@mit.edu	Full time student
Debu Sen	debusen30@hotmail.com	Non-affiliated
Heather Lukacs	lukacs@mit.edu	Full time student

PrimaryContact:

Name: Tommy Ngai MIT ID#: 929793707
Address: 550 Memorial Drive Phone #: (617) 225-9154
Apt 12D3
Cambridge, MA 02139

Project Summary (100- 150 words):

Arsenic and pathogens are two of the most significant drinking water concerns in the developing countries. While much of the current research effort by the scientific community focuses on independent treatment for arsenic and pathogens; the drinking water in Bangladesh, Eastern India (West Bengal), and Nepal are contaminated with both arsenic and pathogens. In addition, many of these treatment systems are inappropriate in a number of ways. As a result, people have not choice but to continue to drink contaminated water, leading to horrible health consequences. Our innovate drinking water treatment design not only treats both contaminants simultaneously, but is also technically, socially, and economically appropriate.

Innovative Drinking Water Treatment Technology for Bangladesh, West Bengal, and Nepal

by
Tommy Ngai
Debu Sen
Heather Lukacs

submitted for
2002 IDEAS Competition
Final Application

April 26, 2002

Table of Content

Innovative Drinking Water Treatment Technology for Bangladesh, West Bengal, and Nepal

A. Introduction

Arsenic and pathogens are two of the most significant drinking water concerns in the developing countries. While much of the current research effort by the scientific community focuses on independent treatment for arsenic and pathogens; the drinking water in Bangladesh, Eastern India (West Bengal), and Nepal are contaminated with both arsenic and pathogens. In addition, many of these treatment systems are inappropriate in a number of ways. As a result, people have not choice but to continue to drink contaminated water, leading to horrible health consequences. Our innovate drinking water treatment design not only treats both contaminants simultaneously, but is also technically, socially, and economically appropriate.

B. Background

The most recent UNICEF statistics shows 1.7 billion people in the world do not have access to safe drinking water. Of these 1.7 billion people, over 100 million lives in rural Bangladesh, Eastern India (West Bengal), and Nepal. Refer to figure 1 for a map showing these countries. In these developing countries, two of the most significant contaminants in the drinking water are arsenic and pathogens[1].

Fig 1. Map of Asia showing Bangladesh, India, and Nepal

Arsenic has been long known as a poison. Exposure to arsenic via drinking water initially causes skin diseases such as pigmentation (dark and light spots on the skin) and arsenicosis (hardening of skin on hands and feets). Later, cancer of the skin, lungs, bladder, and kidney may occur[2]. Unfortunately, there is no cure for these diseases. Both the World Health Organization (WHO) and the U.S. Environmental Protection Agency (USEPA) have classified arsenic as carcinogen. In many parts of Bangladesh and West Bengal, the arsenic level in the groundwater can be over 100 times higher than the WHO and EPA guidelines[3] of 10 μg/L.

Pathogens, such as bacteria, viruses, protozoa and helminths, are the most common water-related problem in the developing countries, causing diarrhoea, intestinal worm, trachoma, schistosomiasis, cholera, amebiasis, giardiasis, stunting and other diseases[4].. At any given time, about half of the population in Bangladesh, India and Nepal are suffering from these diseases. Modern medication and health services are usually too costly to be widely available in the rural areas. Table 1 shows some health statistics of these three countries[5].

Table 1. Selected health statistics for Bangladesh, India and Nepal (WorldBank,2002)

	Bangladesh	India	Nepal
Rural population (million)	100	700	20
Infant mortality (per 1000 live birth)	60	69	74
Under 5 mortality (per 1000 live birth)	83	88	105
Moderate to severe stunting (% of pop)	45	46	54
Life expectancy	62	63	59

Target group

Although the entire population of these countries needs safe drinking water, our target group is the rural population, where the need for safe drinking water is the greatest. In urban centers, some forms of drinking water treatment facilities may exist. These facilities provide part of the urban population with "purified" water from piped municipal distribution system. However, this is certainly not the case in the rural area, where modern water treatment facilities are seldomly found. Many in the rural area depend on tubewells for their daily water needs. A high percentage of the tubewell water is contaminated with arsenic and/or pathogens.

Existing Solutions for Rural Populations

Many tubewell treatment or household scale solutions appropriate for rural populations in developing countries for arsenic removal and pathogen removal currently exist. Each technology has its advantages and drawbacks. A few of these technologies are discussed below. For arsenic, treatment technologies include coagulation & precipitation, simple aeration, activated alumina, and 3-Kalshi/3-gagri with iron filings. For pathogens, treatment technologies include chlorine disinfection, ceramic filter, boiling, and slow sand filtration. Table 2a and 2b compares the advantages and drawbacks of these technologies.

Table 2a. Comparison of some arsenic removal technologies:

	Brief Description	Advantages	Drawbacks
Coagulation & Precipitation	• Add iron chloride powder to water in a pot/bucket • Stir and wait for the sludge to settle • Decant the water and dispose the sludge	• High arsenic removal rate if properly operated	• Iron chloride not locally available • Time consuming and complicated operating procedures
Simple aeration	• Let water sit in a bucket for a day • Remove the settled sludge	• Simple to operate • Cheap	• Poor arsenic removal rate • Easily contaminated by bacteria and viruses
Activated Alumina	• Pass contaminated water through a column of activated alumina	• Excellent arsenic removal rate	• Expensive (up to US$2000) • Alumina not widely available
3-Kolshi Iron Filings	• Pass water through a bucket of iron filings (scrap iron) • Collect water at bottom of bucket	• Iron filing widely available • Excellent arsenic removal rate • Cheap	• Treated water contains high iron • Clogging

Table 2b. Comparison of some pathogen removal technologies

	Brief Description	Advantages	Drawbacks
Chlorine Disinfection	• Add chlorine solution to water • Stir and wait for chlorine to inactive pathogens	• High pathogen removal rate if properly operated	• Chlorine solution not locally available • Time consuming and complicated operating procedures
Ceramic Filter	• Water passes through a ceramic filter • Filter removes pathogens	• Simple to operate • Cheap	• Very low flowrate • Recontamination if filter not properly maintained
Boiling	• Boil water	• Excellent pathogens removal • Simple	• Time consuming • Fuel can be expensive
Slow Sand Filtration	• Pass water through a sand bed by gravity • Biofilm in sand bed removes pathogens	• Excellent pathogens removal • High flowrate • Minimal maintenance	• Need 2-3 weeks startup time to grow the biofilm layer

C. Innovation

While much of the current research effort by the scientific community focuses on independent treatment for arsenic and pathogens; the drinking water in Bangladesh, Eastern India (West Bengal), and Nepal are frequently contaminated with both arsenic and pathogens. Therefore, an appropriate technology should be one that can remove both arsenic and pathogens simultaneously. In addition to technical performance, the technology must also be socially appropriate and economical.

The design

My design combines the strengths of two promising technologies for arsenic and pathogens while minimizes the deficiencies in each technology:

1. *Three Kalshi/Three-Gagri Iron Filings technology*[6]
   - developed, tested and used in Bangladesh, also tested in Nepal;
   - various studies showed 95-99% arsenic removal[7]
   - potential problems include high iron in treated water, clogging and bacteria growth
2. *Slow Sand Filtration modified for intermittent household use (i.e. Biosand Filter)*
   - developed Dr. David Manz, of the University of Alberta, Canada,
   - effective removal of pathogens, iron, colour, odor, turbidity of over 99%[8]
   - very high flowrate (20L/hour), no problem with clogging

The combined-filter design consists of a concrete biosand filter as shown in Figure 2, with added iron filings on top of the diffuser. See Figures 3 and 4 for a view of the diffuser. Figure 5 shows some iron filings. Refer to Figure 6 for a schematic diagram showing the major parts of the combined-filter. The construction of the combined-filter is simple. First, a concrete mold is built, with a plastic pipe connected to the bottom. Gravel, coarse sand and fine sand are placed in the concrete mold. Then, a square diffuser is constructed. It can be made of wood and metal as shown in Figure 3 and 4, or any other available material that is strong enough to hold a kilogram of iron. Iron filings (i.e. iron scrap) are then added on top of the diffuser. Finally, the filter is capped with a cover that can be made with any available material. Arsenic and pathogen contaminated water must be poured into the filter. In about two weeks, a biofilm layer will be fully grown in the fine sand layer. The combined-filter is now ready for use. During its use, almost no maintenance is required. The iron filings can last for years. The biofilm will continue to be active as long as the filter is used. The plastic pipe and concrete may need inspection for cracks and leaks.

Cost

Currently, a micro-enterprise run by Durga Bahadur Ale in Nawalparasi, Nepal is charging 2000 Nepali Rupees per biosand filter, or about US$27. The cost of our combined-filter should be about the same, because the additional iron can be very cheap (~US$7 per ton). However, we believe the price of constructing our system can be dramatically lowered to between US$5 to 10. It is because the required materials are available locally and cheaply. The labor cost can be competitively reduced when more people know the construction method.

Fig 3. Top view of the Biosand filter showing the water diffuser

Fig 4. The water diffuser can be removed

Fig 2. An existing Biosand filter in Nepal

Fig 5. Iron Filings

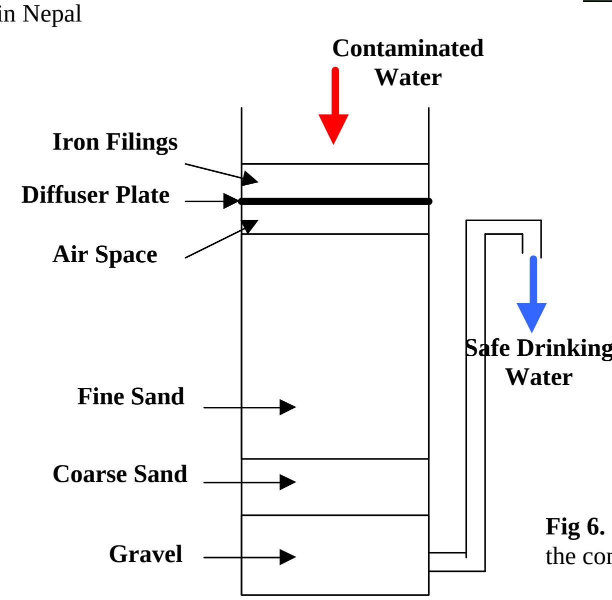

Fig 6. A schematic diagram of the combined-filter

Theory and Operation

Raw water with arsenic and pathogens contamination is poured into the filter. Water percolates through the iron filings. Some iron is dissolved in the water as a result. Then, the dissolved iron forms precipitates upon contact with air. Iron precipitates are excellent adsorbent for arsenic. The iron precipitates are trapped on top of the fine sand layer. Arsenic is thus removed from the water. The pathogens contaminated water then passes through the fine sand layer. The fine sand layer contains a biofilm, which removes the pathogens from the water. The arsenic-free and pathogen-free water can then be collected at the tap.

Advantages of the design

1. *Innovative*
   - Both arsenic and pathogens are removed simultaneously and effectively; a rarity among existing technologies.
   - A combined treatment system saves time and effort over two separate treatment systems.
   - Combines the strengths of existing technologies while minimizes their weaknesses. For example, iron filings technology has excellent arsenic removal rate, but has problems of high iron concentration and potential bacteria growth in the treated water. The slow sand filtration can remove over 99% iron and bacteria in water.
2. *Economical*
   - The construction cost is very low, and the operation and maintenance (O&M) cost is minimal; thus highly affordable to the rural population. Some of the existing technologies can have high capital cost, such as activated alumina, or high O&M cost, such as coagulation & precipitation.
   - No energy requirement. Save fuel costs, as oppose to boiling water.
   - The combined-filter is durable, and can last for years.
3. *Safe*
   - The treated water can meet WHO water quality guidelines for arsenic, pathogens, iron, turbidity. Other existing technologies such as simple aeration cannot effectively remove contaminants.
   - All the construction material and filter material are non-toxic, as opposed to the dangerous chlorine solution
4. *Socially appropriate*
   - All the material (e.g. iron filings, concrete, sand, plastic tube..) are made and available locally; thus more reliable and sustainable than imported materials such as chlorine solution or iron chloride.
   - Creates valuable local employment
5. *User-Friendly*
   - The high flowrate of up to 20L/hour not only provides time savings, but is sufficient to provide a household's daily cooking and drinking needs of 40-50L/day. This high flowrate is very favorable compared to many current technologies, such as ceramic filter, which has a flowrate of about 1-2L/day.

• Simple setup, operation, and maintenance; proper usage can be easily achieved by women and children who performed most of the water duties.
• The filter is designed for intermittent use instead of continuous use. This is very convenient for household use.
• No need to purchase additional items during its use, as opposed to the need to purchase iron chloride or chlorine solution. This not only eliminates hassles to the people, but also eliminates the risk of these additional items not available.
• No energy requirement. Can be operated everywhere. It is particularly important for many rural areas where electricity is unavailable and fuel is not widely available.

D. Implementation

Implementation Plan
The implementation goals of the project are as follows:

- Find a feasible and effective solution to remove arsenic and pathogens from water from technical, social and economic point of views
- Bring the product to local NGOs in public health for review and assessment
- Modify the product based on suggestions by the authorities and the local people
- Introduce the product to the markets with the assistance of local businesses

Work to date
A prototype has been built and tested in the laboratory. This prototype uses a plastic biosand filter, as shown in Figure 7 and 8, instead of a concrete filter. The rest of the construction details are identical to the design as mentioned above. Water from the Charles River was collected on April 23, 2002. The Charles River water contains high level of total and fecal coliforms, which are indicators of pathogen contamination. The Charles water is mixed with water from a well in Salem, NH that contains extremely high level of arsenic. The mixed water is tested in the combined-filter system. The filter was tested two times. Table 3 shows the average test results. Figure 9 shows the raw water and the treated water. The system's technical performance is exceptionally high, with arsenic and iron below the WHO guideline of 10 μg/L and 0.3 mg/L. The total coliform removal is also very good. Better coliform removal can be achieved when the biofilm is fully grown. More laboratory testing and investigation is recommended. Test for other water quality parameters such as pH, turbidity, and hardness should also be done to ensure the treated water meets all drinking water objectives.

Table 3. Average treatment performance of the combined-filter

	Raw Water	Treated Water	% Removal
Total Coliform (cfu/100mL)	3000	285	90.5
Total Arsenic (μg/L)	150	< 5	> 96.7
Total Iron (mg/L)	0.4	< 0.1	> 75

Figure 8. Top view of the combined-filter

Figure 7. A prototype combined-filter

Figure 9. Comparison of raw water (left) and treated water (right)

Scope of work in the next phase

There are two options to proceed to the next phase: First, a business based on the new design can be developed. Second, this technology can be offered to NGOs working in this field to serve the affected people in Bangladesh, West Bengal, and Nepal. Each strategy calls for a distinct track of work.

We believe that our design can make the greatest impact in the second option, which is collaboration with local NGOs. Local NGOs are chosen as partners because local NGOs are more effective and flexible than government agencies. We will contact some NGOs in each of the three countries. Appropriate NGOs will be selected based on factors such as their established reputation, staff experience, interest in our design, commitment level, community relationships, and availability of staff. Our role will be advisors to help them implement the project for the greater benefits of the community. We will describe our design in details, including the theory behind the design, choice of material, construction methods, quality assurance, proper operation, and maintenance. Some of their staff will be trained. Then, pilot studies will be established in various villages. Our filter will be built and operated in selected households by the NGO staffs. The NGO staffs will also monitor the performance of the filter for 3 to 6 months. Feedbacks from the community users will be gathered and analyzed. The design of our filter will be modified based on the community feedbacks in order to better satisfy their needs. After the design has been proven to be suitable to the community, massive implementation may follow. We will hold training classes for all individuals who want to learn to construct our water treatment systems. Then, individual households can either build a treatment system by themselves, or contact these trained builders to build for them. Because a large number of people will know how to build our system, the cost of building such a system will become competitive. It is not a trade secret.

Besides a need to collaborate with local NGOs, we also need to find a funding source. The funding source is necessary to setup pilot studies. We intend to sell our innovative water treatment system at cost to the users, instead of a heavy subsidy. The reason is that it promotes the economic sustainability of this project. The users also have a sense of ownership of their filters because they paid for it, leading to better operation and maintenance.

Timeline
Table 4 shows a summary of a timeline outlining major steps in the implementation of this water project:

Table 4. Timeline showing major steps in our project implementation

Feb - May 2002	• Complete technical experiments and work
Jun - Jul 2002	• Travel to Bangladesh, India, and Nepal to contact local NGOs, public health officials, and to understand the local conditions • Begin discussions with stakeholders, local NGOs, public health officials, World Bank project mangers
Aug 2002	• Identify NGOs to implement projects • Plan for pilot studies
Sep 2002	• Training of NGO staffs • Identify funding sources • Begin pilot studies
Oct - Nov 2002	• Advisory role for the NGO • Look out for new opportunities, new partners
Dec and after	• Evaluate pilot studies • Modify design if necessary • Plan for massive implementation

Challenges
Challenges until now are mostly in the design phase, such as how to best select technologies to treat both arsenic and pathogens simultaneously and effectively. Many of these challenges are already solved given the exceptional arsenic and pathogen removal results on our prototype. Our next set of challenges will be outside the laboratory. Examples of these challenges are:

- To establish good relationships with some local NGOs
- To convince the stakeholders to try our innovative design
- To find investors to fund the project
- To get international agencies like the WHO and World bank staff to work with us

They are external forces and require business savvy and confidence to meet them. We are confident that we have the skills and experience to face them successfully.

Support Network

Establishing a support network is crucial to the success of our project implementation. We have made preliminary contacts with the local professionals, community members and embassies in the USA for further contacts and assistance. The response so far has been encouraging. We also have contacts with some local agencies such as ENPHO and IBS in Nepal, and OCETA in Bangladesh. A brief description of these organizations is followed:

1. Environmental and Public Health Organization (ENPHO)
    - NGO located in Kathmandu, Nepal
    - Contact person: Roshan R. Shrestha
    - Has a fully equipped lab performing arsenic test for Nepal tubewell water
    - Design and evaluate various arsenic treatment technologies such as arsenic treatment plants (these plants didn't work)
    - Have trained staff to build, test, and implement new technologies
2. International Buddist Society (IBS)
    - NGO located in Lumbini, Nepal
    - Contact person: Bhikkhu Maitri
    - Currently contracting out biosand to a micro-enterprise run by Durga Bahadur Ale
    - Considering to construct biosand filters on their own, to eliminate the cost of middleman
3. Ontario Centre for Environmental Technology Advancement (OCETA)
    - A Canadian non-profit agency located in Toronto, with main office in Dhaka, Bangladesh
    - Contact person: Roy Boerschke
    - Established the Environmental Technology Verification – Arsenic Mitigation (ETV-AM) program with the Government of Bangladesh to assess arsenic mitigation technologies based upon a rigorous performance criterion, followed by verification under conditions of actual use

E. Impact

There are two levels of impacts. The primary impacts are related to health benefits. The secondary impacts are other external benefits such as time saving.

Primary impacts
More than 100 million people living rural Bangladesh, West Bengal, and Nepal can potentially enjoy the improved health benefits resulting from a successful implementation of our innovative water treatment system. Better health contributes to higher quality of life. People live happier. Less stress will be placed on health and medical facilities. Less sickness also results in greater worker productivity, leading to overall economic growth of society. In addition, the prevention of arsenic poisoning will lead to greater family cohesion. Currently, some women who show signs skin diseases due to arsenic poisoning are excommunicated from their family. Divorce and rejection for marriage has become a major social problem[9]. Furthermore, the access to safe drinking water can lower the need to buy expensive bottled water for many households.

Secondary effects
One of the secondary effects is time saving for women who fetch most of the water for their household. Women can save time because they no longer need to travel a far distance to collect better quality water. With our innovate design that can treat both arsenic and pathogens; nearby water source can be used even if the quality is worse.

F. Budget for implementation

(1). Further testing and refining of our design	$ 500
(2). Presentations and brochures	$ 500
(3). Travel expenses	$6000
(4). Communications/phone calls	$ 500
(5). Setup pilot studies/Legal costs	$2000
(5). Contingencies	$ 500
Total	$10,000

G. Conclusion

Access to adequate drinking water is not only a basic human right, but also has considerable health and economic benefits to households and individuals. Our innovate drinking water treatment design not only treat both arsenic and pathogens simultaneously, but is also technically, socially, and economically appropriate.

H. Biographies

Tommy Ngai is a Master of Engineering student in the Civil and Environmental Engineering Department. He is currently taking classes in Groundwater Remediation, and Water and Sanitation Planning in Developing Countries. He traveled to Nepal in January 2002 to study the arsenic contamination situation, and to field test the appropriateness of an arsenic removal technology. His interest in searching for a practical solution for the arsenic problem began with his undergraduate project on arsenic removal in Bangladesh groundwater. He is informed of various existing arsenic treatment technologies and their strengths/weaknesses.

Heather Lukacs is a Master of Engineering student in the Civil and Environmental Engineering Department. Her expertise is in environmental microbiology and sustainable development. She studied the fate of fecal coliform in combined sewer overflow for her undergraduate thesis. She traveled to Nepal in January 2002 to evaluate the performance and appropriateness of Biosand filter to remove pathogens. She is highly experienced in the construction and operation of a Biosand filter. In addition to her technical proficiency, she is a currently a professional whitewater rafting guide and trip leader.

Debu Sen is trained as an economist focusing on educational planning and entrepreneurship development. He received his doctorate in educational planning from Harvard University. He had worked in the Massachusetts Government, the World Bank, and Harvard University (as a consultant). He cofounded iDL systems, an internet based software company in Cambridge. He is also engaged in community services through non-profit organizations in India. His interest in drinking water issues originates from his concern for his fellow Indian population.

I. Reference

1 UNICEF statistics Feb 2002. Access on April 25, 2002. Available: www.unicef.org

2 Nepal Red Cross Society "Research on Arsenic Contamination in the Groundwater of Terai Nepal." Final Report. Sep 2000.

3 World Health Organization. "United Nations Synthesis Report on Arsenic in Drinking Water." Internet. Feb 28, 2002. Available: http://www.who.int/water_sanitation_health/Arsenic/ArsenicUNRep1.htm

4 UNICEF water and sanitation database. Access on April 25, 2002. Available: www.unicef.org

5 World Bank Indicator Database April 2002. Accessed on April 25, 2002. Available: www.worldbank.org

6 Munir et al. "Evaluation of Performance of Sono 3-Kolshi Filter", Technologies for Arsenic Removal from Drinking Water, page 171-189, May 2001

7 Lackovic, J.A., N.P. Nikolaidis and G.M. Dobbs. Inorganic arsenic removal by zero-valent iron. Environmental Engineering Science, 17(1):29-39. 2000.

8 Lee, T. "Biosand Household Filter Project in Nepal." MIT Master of Engineering Thesis. May 2000.

9 Maskey, A. "Arsenic Contamination" ENPHO 10th Anniversary Report, page 40-41. 2001.