Biosand Filters for Water Decontamination in Rural Chinese Communities
Progress Report

Faculty Advisor: Dr. Jose Alfaro (Assistant Professor, School of Natural Resources)
Faculty Co-advisor: Dr. Steven Wright (Professor, School of Engineering)
Team Members: Whitney Johnson (MS, School of Natural Resources, team point of contact); Sibu Kuruvilla (Ph.D., School of Engineering, 2nd point of contact); Rashmi Krishnan (MS, School of Natural Resources); Zu Dienle Tan (MS, School of Natural Resources); Nicholas Jansen (BA, College of Literature, Science and the Arts, Program in the Environment)
Partner organizations: Sustainability Without Borders, Rural Intercultural Student Exchange (RISE, Beijing)

Abstract: Project scope and associated outcomes/impacts

High levels of arsenic in the groundwater in China are a major public health concern. In addition to a fairly widespread volume of naturally occurring arsenic-contaminated well-water across China, a significant amount of arsenic is contributed by anthropogenic actions like rapid industrialization, weak environmental policies and poor planning. Cases of chronic arsenicosis have been found in eight provinces in mainland China, including Shanxi. The highest: arsenic levels in drinking water lie between 0.05 and 2 mg/L, dangerously higher than the WHO-recommended level of 0.01 mg/L (Mukherjee et al., 2006). Rodriguez-Lado et al (2013) estimate that close to 20 million people are at risk of being affected by the consumption of arsenic-contaminated groundwater in China.

Biosand Filters (BSF) are low-cost, low maintenance, point-of-use filters that are built out of locally available materials. The Arsenic Biosand Filter (ABSF) is a version of the BSF that is designed to remove arsenic and pathogen present in the groundwater.

At the University of Michigan, we built a prototype of an ABSF design with the intent of replicating the contamination and filtration scenario in Shanxi, testing our filter and further optimizing our design. At Pingyao - Shanxi, we worked with our student partner organization, the Rural Inter-cultural Student Exchange (RISE) group from Tsinghua University and a student group from the Taiyuan University of Technology to implement another design variant of the ABSF in a village. We successfully built 43 ABSFs in individual households, and initial performance tests showed that the ABSFs were able to remove up to 87% of arsenic, relative to the arsenic content of the inflowing water, while minimizing the turbidity of the water.

Ongoing and future work entails the periodic testing of the filters' performance to ensure arsenic removal is stable and continuously available. Further, we are interested in creating a dynamic flow setup to reduce labor intensity of using the ABSF and further automate the system. Additionally, we are currently researching the extent of arsenic contamination in other communities to explore regions we can expand our work to.

Progress and achievements accomplished to date

Phase one (May – July 2015): Building and testing at the University of Michigan

- Bought and prepared materials:
  o 2 buckets, pipe fittings – drilled holes for pipe attachments and aeration
  o Brick Chips, Fine Sand (filtered through 1mm sieve), Coarse Sand (between 2-3 mm), Iron filings, Activated Carbon – washed sand until turbidity was visibly lower, allowed iron filings to rust by soaking them in water
- Built a single filter based on the design below (Design 1) consisting of an Arsenic Removal Unit and a Pathogen Removal Unit
- Purchased arsenic and arsenic test kit, but did not perform tests due to time constraints
DOW SUSTAINABILITY FELLOWS
UNIVERSITY OF MICHIGAN

- Results: Flow rate - 46L/h, pre and post - filtration arsenic levels - N/A
- Design 1 is an experimental design proposed by RISE and was NOT implemented in Shanxi. RISE has found that Design 2 has a high arsenic removal rate through prior field work, hence this design was chosen for Shanxi. As part of future work, we will replicate Design 2 and optimize it to control the outflow rate between units and include a tap at the outlet.


Phase two (August 2015): Building and implementation at Liangjiabao, Pingyao - Shanxi

The team was a total of 13 students comprising of members from SWB, RISE and students from Taiyuan University of Technology. The latter have previously collaborated with RISE in implementing BSFs in other parts of Shanxi. They ensure smooth communication with the community by contributing local and indigenous knowledge that is invaluable to this community-centric project. RISE has technical expertise along with a long-standing association with the point-of-contact in the community. SWB’s understanding of the complex interactions between appropriate technologies and community development in addition to being a culturally and academically diverse team makes us a key asset to this project.

The village of Liangjiabao has a population of approximately 3000. Tests results from several water samples show that the arsenic level in the groundwater is above 0.1 mg/L. The water has a distinct odour and some residents have reported the presence of worms in their water. All households in the community have water taps that are connected to a common water tower into which groundwater is pumped.
RISE’s point-of-contact in the community provided us with a workshop in his home. His occupation is carpentry and construction, so he was able to source and prepare the raw materials for us (coarse sand, fine sand, small stones, large stones). On top of accessing our materials from here, we used his house to store equipment. We then divided ourselves into sub-teams of 3-4 persons and installed these filters separately at each house. RISE members instructed maintenance procedures to all households and provided them with a maintenance manual. Orders for the filters were placed with the point-of-contact and payments were made to him as well.

<table>
<thead>
<tr>
<th>Average household size:</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occupation:</td>
<td>Mostly farmers with another source of income (family business or hold other occupations like masonry or carpentry). Corn is the main crop cultivated.</td>
</tr>
<tr>
<td>Previous experience with filtration:</td>
<td>All households boil their tap water before using it for drinking or cooking. A few households had experimented using ceramic filters with an activated carbon core, but soon found that it was not effective. High technology filters are available but cost around 2000-3000 yuan (~312-470 USD), which is generally out of reach for the villagers, except for the very affluent families (approximately 1 in 100 households).</td>
</tr>
<tr>
<td>Expectations from the filter:</td>
<td>Households expect to filter enough water for cooking and drinking for all members daily (30 – 40 litres per day).</td>
</tr>
<tr>
<td>Experience with BSFs:</td>
<td>All the households were either family friends or relatives of RISE’s point-of-contact in the community and were familiar with the appearance and working of the ABSF since the point-of-contact has one at his residence. None of them showed any hesitation towards using the filtered water. However, a few households were uncomfortable with the murky appearance of water inside the filter before it underwent filtration.</td>
</tr>
</tbody>
</table>

Table 1. Summary of community characteristics based on SWB’s interaction with 43 households

Notes from the Field

- The filters were constructed according to Design 2
- Materials required for each filter:
  - Two buckets of capacities 36 and 68 litres each, pipe fittings, diffuser plates
  - Big Stones, Small Stones, Coarse Sand, Fine Sand, Rusted Iron Nails
- Both sets of stones needed to be washed at least 3 – 4 times, while the coarse sand was to be washed 4 – 5 times. The iron nails were coated in machine oil to prevent rusting, which required washing at least 3 times with hot soapy water. Construction of a single filter uses between 350 – 400 litres of water (a conservative estimate).
- Time required for washing and assembly: 2 – 3 hours
- Price of one filter: 260 yuan (40 USD)
- Expected life: Unknown, as this is also an experimental design and depends on the rate of adsorption of arsenic by ferric hydroxide (rust). Once the rust has fully adsorbed the arsenic, the layer of iron nails will need replacement.
- The installed filters had a maximum flow rate of 61 L/h, a minimum of 18 L/h and an average of 39.2 L/h. The maximum recommended flow rate is 50 L/h (RISE, 2012). Post-filtration arsenic levels were measured only for three filters and they were 0.013 (87% arsenic removal), 0.049 (51%) and 0.052 mg/L (48%) respectively.
Design 2: Built at Liangjiabao - Shaxxi, August 2015

Chart 1. Histogram of flow rates of 43 installed ABSFs. Data for some filters is missing and will be collected when the next team visits Liangjiabao.
Table 2. Summary of project progress

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Status</th>
<th>Funds utilized ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) Build two biosand filters. Test how effective they are considering: removal of toxins, ease of use, integration, cost, and projected lifespan in controlled settings and in the field.</td>
<td>Built a single filter on campus and did not test it due to time and logistical constraints. We found the flow rate of the filter to be 46 L/h.</td>
<td>$633.26</td>
</tr>
<tr>
<td>2) Propose improvements to filter systems including: integration, ease of use, delivered water quality. Build filters in China with RISE</td>
<td>Built 43 filters in China and are now ready to propose improvements based on Design 2.</td>
<td>$0 (funded by our student organization, RISE, and villagers)</td>
</tr>
<tr>
<td>3) Survey community needs for water filtration, implement optimal filter design in China, and work with RISE and community members to measure filter efficacy.</td>
<td>Implemented RISE's tried and tested design, surveyed community needs and determined pathways for future work based on the current system followed.</td>
<td>$0</td>
</tr>
</tbody>
</table>

Future Work

Based on our ground work on campus and our field work in China, we have outlined three project objective paths for future work. At 50% of the proposed budget, we will follow Objective Path 1 alone.

Objective Path 1: Optimize the current system of working and design a continuous sand filter

Manufacturing a product without an optimized system can be a highly inefficient process. Running out of sieved sand, underestimating quantities of material required, making extra trips to the workshop and using excess quantities of water are easily avoidable hiccups in the process. We propose applying a systems optimization approach to the production pathway of the ABSF – from obtaining raw material to assembling the filter. We will identify production variables (for example, the quantity of water used during construction or man-hours available for sieving sand) and establish a dependable protocol that RISE may follow in order to build these filters more efficiently. We will also consider manufacturing methods alternative to the ones currently used and pick the one that seems most appropriate and least wasteful. In addition, we plan to work on improving the current design (Design 2) of the filter and design a prototype continuous sand filter that can remove arsenic.

Objective Path 2: Social Network Analysis – Identify central individuals in other target communities across Shanxi

RISE's point-of-contact in the village is indispensable to the success of the Biosand Filter project. In addition to creating a make-shift workshop for RISE, he facilitates easy material sourcing by identifying the cheapest and most reliable vendors, advertises and promotes the technology by informing his family friends and relatives about the BSF, provides additional manpower, collects orders and payments from community members and receives maintenance requests and complaints from them.

From the viewpoint of social network theory, he appears to be a node with high degree centrality and a high clustering coefficient. Previous and current research shows that identifying central individuals in a network aids in effective dissemination of information and successful diffusion of innovations (Melkas and Harmaskorpi, 2012; Rogers, 2003). Knowing who is central to a network enables policymakers and development-oriented organizations to target the right individuals so as to effectively spread information.

We propose to visit up to 5 communities similar to Liangjiabao at risk of arsenicosis in Shanxi and administer surveys by employing an existing diffusion model like the 'gossip' model (Banerjee, Chandrasekhar, Duflo & Jackson, 2014) to identify central individuals in the network. This will be useful information to RISE and the Shanxi Department of Environmental Protection. We will standardize our survey so that it can be used in similar scenarios anywhere in the world.
**Objective Path 3:** Design a source filtration system that will remove arsenic from the groundwater in the community’s water tower

Although the BSF is commonly accepted as a low-cost filtration option, all the households we visited appeared particularly affluent. Less than 10% of the 3000 people living in Liangjiabao currently have access to arsenic-free drinking water. We propose to design a source filtration system that can treat the groundwater pumped into the community water tower and to develop a financing mechanism that will allow the entire community to gain access to safe drinking water without the barrier of unaffordability. We will collaborate with the Shanxi Department of Environmental Protection, the Pingyao Municipal Government, RISE, Taiyuan University of Technology and AguaClara on this project pathway to design an appropriate treatment technology for the community.

AguaClara is a pioneer in designing and implementing gravity-powered community-scale water treatment plants using locally available materials for communities in Honduras with an existing water distribution system. Their designs are developed by engineering students at Cornell University and they are currently working on two pilot projects in East India.

<table>
<thead>
<tr>
<th>Dates</th>
<th>Project Objective/s</th>
<th>Metric of Success</th>
<th>Expected Expenses</th>
</tr>
</thead>
</table>
| September - November ‘15 | • Rebuild the ABSF according to Design 2  
• Submit water sample and PVC from China for analysis  
• Identify target communities  
• Research successful diffusion models, preferably tested in East and South-East Asia  
• Reach out to AguaClara and discuss the possibility of a partnership  
• Propose the project to the Shanxi Department of Environmental Protection and Pingyao Municipal Government | • Assess physical reproducibility of ABSF Design 2, focusing on source and quality of raw materials  
• Quantify levels of arsenic, pathogens, and other inorganic contaminants in water samples transported back from China. We will use high precision chemistry instrumentation in order to evaluate presence of contaminants exhaustively.  
• Understand basics of network theory and how diffusion models work  
• Evaluate the diffusion models and shortlist the one most appropriate for the target communities  
• Arrange for a training session with AguaClara in November and discuss the possibility of a site visit to one of their community water treatment plants in February  
• Note expectations from partners and communicate project deliverables to them | • Work-study wages $15/hr for 5 team members - $1500  
• Materials for ABSF (Fine Sand, Coarse Sand, Iron Nails, Small Stones, Big Stones) - $500  
• External expertise (special analysis by UM Chemistry department): Mass spectrometry, liquid chromatography - $1000  
• Work-study wages for 5 team members - $1500  
• $0 |
| November - December ‘15 | • Conduct tests on the ABSF  
• Establish 2 – 3 alternative manufacturing methods (example - shipping finished materials to households with instructions for assembly and maintenance) | • Measure flow rates and arsenic removal capability to ensure Design 2 has been reproduced.  
• Deconstruct building process required – from raw materials to completed filter – and | • Work-study wages for 5 team members - $1500  
• Testing equipment (Arsenic test strips, pathogen test kit) - $1000 |
<table>
<thead>
<tr>
<th>January – March ’16</th>
<th>March – May ’16</th>
</tr>
</thead>
</table>
| Identify production variables in all alternative methods to be considered  
Design surveys and questionnaires for the communities based on the diffusion model  
Visit the AguaClara center at Cornell University  
Attend a training session with AguaClara  
Develop a mathematical model of the system for each method and present the alternatives to RISE  
Draft a design for the continuous sand filter  
Develop a framework for data collection and analysis  
Hire a translator  
Collaborate with RISE and Taiyuan University students to draft a design and develop a budget for the treatment facility  
Visit one of AguaClara’s community project sites  
Present a sensitivity analysis of production variables from the models  
Establish a feasible design for continuous flow ABSF that can reproduce filtration rates of Design 2 while also reducing labor-intensive construction and operation steps  
Test the questionnaire and survey by checking for communication errors during translation and back-translation  
Informally present the initial design and budget to the Shanxi Department of Environmental Protection and Pingyao Municipal Government  
Compare the efficacy and appropriateness of the drafted design to the implemented one  
Assess the community’s satisfaction with the filtration system  
Build a prototype filter, test and optimize the design  
Present the final design to RISE  
Revise the survey, questionnaire and framework  
Pre-travel logistics – necessary permits and | Successfully fabricate a continuous flow ABSF  
Measure requirements for water source, flow rate of new design, and filtration capacity  
Determine lifetime of continuous flow filter and added constraints  
Evaluate feasibility and potential for implementation  
Work-study wages for 5 team members - $1500  
Raw materials and building equipment for one continuous sand filter - $1000  
Work-study wages for 5 team members - $900 |
| - Work-study wages for 5 team members - $1200  
- Travel to AguaClara’s design office for 5 people - $1500  
- Training charges for 5 people - $1500 |
<table>
<thead>
<tr>
<th>DOW SUSTAINABILITY FELLOWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNIVERSITY OF MICHIGAN</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>May – July '16</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Travel to China and implement continuous sand filters with RISE</td>
</tr>
<tr>
<td>• Administer surveys in communities</td>
</tr>
<tr>
<td>• Present the final design, budget, and financing scheme to the Shanxi Department of Environmental Protection, Pingyao Municipal Government, and the community with RISE and Taiyuan University students</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>August '16</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Analyze the data collected with consultation from U-M CSCAR and present results to RISE</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>through discussions with RISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Share the questionnaire and survey with RISE and receive feedback on expected receptivity in the communities</td>
</tr>
<tr>
<td>• Prepare a final design of the filtration system</td>
</tr>
<tr>
<td>• Ensure that the costs per household lie within the household's willingness-to-pay based on published research</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Permit and approval fees - $1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work-study wages for 5 team members - $900</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Objective Path 1 Total ($)</th>
<th>19,500.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objective Path 2 Total ($)</td>
<td>9,500.00</td>
</tr>
<tr>
<td>Objective Path 3 Total ($)</td>
<td>9,400.00</td>
</tr>
<tr>
<td>Grand Total ($)</td>
<td>38,400.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Travel for 5 people - $6000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lodging and food for 5 people in China ($35/day) (15 days) - $4000</td>
</tr>
<tr>
<td>Survey costs - Translators, local guide, equipment, stationery, incentive allowance - $3000</td>
</tr>
<tr>
<td>Work-study wages for 5 team members - $500</td>
</tr>
</tbody>
</table>
Gaps in Skillset

- **Continuousflow design expertise:** The team recognizes that the development of a continuous flow sand filter is an advancement to the technological complexity of the ABSFs as is. Despite the difficulty we anticipate with the redesigning of the system, we are confident in our abilities to establish such a system through the varied expertise we bring from our different backgrounds. Nevertheless, the added process of motorized pumping, flow rate regulation, reservoir maintenance, etc. will require significant technical expertise. Therefore, we will seek guidance from our current co-advisor, Dr. Steve Wright from the Civil Engineering department, who has an established record of building automated systems for projects centered around resource scarcity, sustainability, and sanitation. We believe that with his mentorship, combined with our technical capabilities, we will be able to achieve a successful continuous flow filter.

- **Public Health Expertise:** A second gap in our skillset that we recognize is the lack of a public health expert to analyze the implications of our filters, in terms of both health needs and health impacts in the community. It would be ideal to have someone on the team that is capable of studying the various characteristics of the environment we are working in - such as health policies, health education, and population health issues. To address this, we plan to reach out to the School of Public Health to find graduate students that are engaging in global health, health policy, or health behavior to be a part of our team and contribute to this piece, which is relatively lacking at the moment.

- **Socio-economical expertise:** Understanding the social and economic environments of a community we work in is instrumental in determining the adoption potential and sustainability of our filters. For example, we noticed that the financial situations of the Shanxi households we worked in varied very differently from one another - some would likely be considered very poor, while others were affluent enough to have two flat-screen televisions. We hypothesize that the adoption of our filters and the overall impact that they have will be highly affected by the economics of the villages (and individual households) that we work with. It would be interesting and likely necessary to establish a relationship between socioeconomic factors and our project, so we will seek a team member that is well versed in performing community economic analysis, such as someone from the business school, international studies, or another global development-related field.

References
Appendix

Figure 1: Sieved fine sand

Figure 2: Rusted iron nails

Figure 3: Layer of brick chips in the pathogen removal unit

Figure 4: Complete pathogen removal unit

Figure 5: Completed ABSF with water flowing at 46 L/hr built on UM campus.

Appendix A. Stages of building ABSF according to Design 1 on campus

Fig 6. Completed ABSF (Design 2) built in Shanxi province at Household No. 4.

Fig 7. ABSF built in Shanxi province for a family at Household No. 40.

Appendix B. Pictures from our field work at Liangjiabao