BEAR in Cambodia

Final report

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1 Executive Summary

This paper was written to document a field trip to Cambodia in Summer 2008, where a recently developed technology that removes arsenic from groundwater was brought to the field for the first time. The « Berkeley Electrocoagulation Arsenic Remediation » (BEAR) is based on a process using the electro-coagulation of iron to effectively bind arsenic at a very low cost, hence its high potential among the low-income, rural populations that are most affected by the arsenic issue. While hundreds of millions worldwide are at risk of being exposed, poor and rural areas are especially exposed due to the lack of centralized treatment infrastructure and the higher water consumption linked to manual labor. Yet there is no technical solution to solve the issue in an effective and responsible way, unless its technical efficiency and economical sustainability can be observed on the field. Therefore, the focus of the 2008 field trip in Cambodia was to

(1) demonstrate the technical efficiency of the prototype to decrease the arsenic concentration of highly contaminated Cambodian water to an acceptable level;

(2) establish a preliminary assessment of the local demand by talking to local villagers and

(3) establish contact and gain advice from interested and competent local Non Governmental Organizations on the potential of a future implementation of the technology in Cambodia.

The technical trial of the prototype was very conclusive, as concentrations ranging between 100 ppb and 1000+ppb, were reduced to outlet concentrations below the WHO standards of 10 ppb on nine different water sources. Furthermore, an experimental optimization of the BEAR process in Cambodia led to the successful treatment of highly contaminated (1000ppb As) sources at a flow rate of 30 liters per hour with no outlet mixing. If an outlet mixing step is introduced, the flow rate can be increased to 60 or 90 liters per hour for mixing times of 20 and 30 minutes respectively. All these results are more advantageous than obtained during the laboratory trials in the US in April 2008. Energy Wise, the electricity requirement of the BEAR electrodes ranges between 0.04 and 0.21 Wh/l, depending on the chosen flow rate. Therefore, if the use of a 12V 32Ah battery as a primary source is assumed, one fully loaded battery can treat a volume of 3046 liters (at 30 liters/hour) of contaminated water. If a mixing step is added, the treated volume increases to 9137 liters. However, additional energy must then be provided for the required 20 minute mixing. The first element that was sought by assessing the local demand was to identify water use patterns. In rural Cambodia, there is a strong cultural habit of using rainwater as a primary water source. This habit has been observed, the visited household mentioned as reasons its gratuity, ease of access, apparent purity and the fact that they simply liked the taste. Therefore, source switching must be the primary arsenic remediation strategy to be applied in Cambodia. However, almost all households mentioned at least one additional water source that was required for dry season supply, which hints the usefulness of an alternative arsenic remediation strategy. In the lack of rain or available surface water, the price of untreated water ranges between 0.5 and 0.75USD/m^3. The price of « pure », bottled water ranges between 12.5 and 18.75USD/m^3. However, the willingness to pay for removing arsenic alone is virtually zero because there are already several other options available. Thus, if the BEAR technology ever were to be launched in such an area, it is vital that the product sold would be completely pure water, safe to drink, and not only arsenic-free groundwater that requires the households to further filter it at home, in order to compete with the bottled water prices mentioned above. Particularly, iron, turbidity and pathogen removal have been mentioned as key parameters of acceptability.

Finally, local Non Governmental Organizations were contacted with the aim of gains valuable advice and insight on local market conditions and possible implementation strategies, as well as to potentially establish valuable partnerships for long term collaboration. The key takeaways from these meetings have been the importance of catering to local tastes and preferences, providing safe water instead of just arsenic-free water, paying attention to aesthetics to raise the willingness to pay, utilizing community-based marketing techniques to build awareness, recruiting local investors to mitigate risk, and involving the communities to develop a sense of pride and ownership. While treating surface water is the preferred method of addressing arsenic contamination, using BEAR with groundwater may become a more feasible option as surface water sources become increasingly polluted chemically. Before proceeding with an extended technical trial, BEAR needs to identify an appropriate community and local partner. It would be useful to use the piloting period to test out different business models and price points and demonstrate the success of the BEAR technology to private investors.

2 Introduction

This paper documents a demand assessment and technical field trial in Cambodia of an innovative technology to address the issue of groundwater arsenic poisoning. The strategy is based on a device that physically removes arsenic from water through electro-coagulation. The prototype has been designed and assembled in Spring 2008 at the University of California at Berkeley and showed promising laboratory results both in terms of removal efficiency and projected operational costs. Thus, in partnership with a RDI Cambodia[1], the present project seeks both to tests the efficiency of the device on natural arsenic contaminated Cambodian groundwater, and to explore the possibility of a sustainable implementation of the system among Cambodian communities.

3 The issue of arsenic

Arsenic in drinking water is a major public health problem threatening the lives of over 140 million people worldwide (Beck 2007), leading to what has been aptly called "the largest mass poisoning of a population in history (Smith 2000). Primary drinking water supplies in Argentina, Chile, Mexico, China, Hungary, Cambodia, Vietnam, West Bengal (India), Bangladesh and areas of the United Stated are contaminated with up to 1000-4000 ppb of arsenic due to the underlying arsenic rich geological strata which exceed the World Health Organization standards maximum permissible exposure of 10 ppb by hundreds of times.

Prolonged exposure to arsenic, a colorless, tasteless, and odorless poison with no immediate effects, is devastating to the poor. Symptoms of arsenic poisoning can include weakness, lethargy and fatigue that hinder work, painful bloody coughing that can be misdiagnosed as tuberculosis, uncontrollable tremors, numbness and chronic pain (Chowdhury et al., 2000), along with cancers of the skin, lungs, bladder, urinary tract, and kidney and ultimately, death. Poor nutrition, common in the midst of poverty, is known to exacerbate its toxic effects, especially in children (Rahman et al., 2005). Increased health costs, loss of productivity and income, and social exclusion can be perilous to a family at subsistence-level living. We estimate the welfare costs of exposure to arsenic in drinking water are estimated to be US $248 per household per year, based on a study in India (Roy, 2005) – a crippling burden on yearly income for those making US $1-2 per day. While methods to prevent arsenicosis have been successfully developed, few of these solutions have been adapted and made affordable to the communities affected most by this often overlooked disease.

[1] Resource Development International (RDI) is a local non governmental organization seeking to provide Cambodians with access to safe drinking water.

Indeed, while in urban areas, centralized water supply systems allow straightforward monitoring and control of arsenic level; the arsenic contamination issue is a rural problem, where water supply typically consists of many small groundwater sources. Moreover, as evidences have shown in Bangladesh (WHO 2006), due to nutritional status, and greater consumption of water during work, the impact of arsenic exposure is especially marked among the poorest households. Harmful exposure to high arsenic levels mainly occurs through drinking water consumption, as contact through skin exposure or irrigated crops is believed to have a fairly limited impact. Arsenic is thus primarily a rural drinking water issue, mostly targeting the poorest. The results yield to a fatal chronic disease, whose only possible treatment strategy is to avoid further exposure to arsenic in drinking water.

In Cambodia, decades of war have postponed to the 1990's the installation of the numerous pump wells that are currently in use on arsenic contaminated aquifers. Therefore, a catastrophe similar to what is currently happening in Bangladesh (where the pumpwells were mostly installed in the 1970's-1980's) can be expected in Cambodia in a few decades if no measures are taken. Currently, an estimated 2 million people are at risk (Buschmann 2007) in Cambodia. However, a real opportunity to change the situation if something is done early. Thus, the expected outcome of this project is a viable and reliable solution to reduce human exposure to this deadly poison through drinking water and halt the tragedy.

4 Drawbacks of current safe water options

There is no traditional technology in Cambodia capable of removing arsenic. Safe water approaches being tried or considered suitable fall into two primary categories: switching to alternative arsenic-free water sources and remediation of arsenic contaminated sources. The former category includes treatment of surface waters (e.g. pond sand filters or shallow dugwells), and rainwater harvesting. However, while the use of surface water presents its own challenges, such as the need for pathogen control, and the quality of collected rainwater depends highly on available storage techniques, rainwater harvesting relies on the storage of uncontrollable rain occurences, whose water might be short of the minerals needed by the human body.

The latter category, arsenic remediation, includes systems that have been deployed in Asia such as he Sono 3-Kolshi filter, Kanchan filter (MIT) and the SORAS method (ETH Zurich). Each safe water option varies in capital and recurring costs, levels of maintenance, water quality, water flow rate, social acceptability, and other external factors. These arsenic remediation technologies have been primarily employed as chemical adsorbents in point-of-use systems, placing the burden of maintenance and operation on the end-user. Such systems have been plagued by high abandonment rates after a short time (Ahmad et al., 2003; Hoque et al., 2004; Vergara, 2007) due to difficult operation and maintenance, lack of time to devote to maintenance, and low cultural acceptability. In addition, consumable chemical adsorbents have limited effectiveness in removing arsenic-III (Bhattacharya et al., 2002) and generate non-trivial amounts of hazardous waste.

Although several laboratory and field technologies exist to remove arsenic from water, most technologies have not yet successfully been implemented on a wide scale because of prohibitively high costs, maintenance or scalability challenges. However, it is our opinion that all of these failures also occurred because the local awareness of the real importance of the problem has been overestimated. Although the problem is claimed to be acknowledged, we have some doubt on the real consent of these poor and struggling rural households to produce the effort required by these strategies to mitigate a non-short term affecting poison. Understandably enough, mere instant survival would be argued to be of higher importance.

Therefore, in addition to being technically efficient and locally implementable in terms of supply chains and resources, the real challenge is to design an economically viable solution given the low willingness to pay described above. This can only be done by significant improvements on two parallel axes. The local demand should be raised through efficient education and information leading to an increase in the value attributed to arsenic free water, and the offer should be improved by producing low cost solution meeting the Poor's scarce resources. While the first axis is left to local institutions and health workers, the Berkeley Electrocoagulation Arsenic Remediation project strives to progress on the second axis.

5 The BEAR solution

The Berkeley Electrocoagulation Arsenic Remediation project was launched in 2008 as a student term project in the frame of "Design for Sustainable Communities", a graduate course offered by the Energy and Resource Group (ERG) of the University of Califonia at Berkeley. The project is mentored by Dr Ashok Gadgil, himself inventor of several low cost technological solutions for poverty alleviation. The early phase of the project, conducted in Berkeley in Spring 2008 had the objective of adapting a laboratory technology, researched by Susan Amrose at the Lawrence Berkeley National Laboratory (LBNL), to a field context through the design of an adapted, adaptable and robust flow prototype.

5.1 Technology

The prototype is based on the release and coagulation of Iron ions in water submitted to an electric field, forming arsenic binding corrosion products, which bind arsenic ions and are subsequently mechanically removed. The technology is traditionally used in the removal of heavy metals in waste water, but was recently adapted to treat arsenic contaminated groundwater with its specific ionic composition and the required low output concentrations. The technology involves three consecutive processes that involve an electrochemical phase, a mixing phase and a filtration phase.

The efficiency of the LBNL batch technology in laboratory settings are promising, as arsenic concentrations as high as 600 ppb are reduced to values under the World Health Organization standards (10 ppb) on synthesized Bangladeshi groundwater. This high efficiency can likely be linked to the oxidation of all the arsenic species in an easily adsorbable species in the presence of an electrical current on one part, and to the high specific surface of the electrochemical coagulate on the other.

5.2 Implementation

In order to ensure sustainable clean water access, a new dissemination model is needed. In nearby India, WaterHealth International (http://waterhealth.com) has supervised the building of small community Safe Water Centers to sell clean water at a profit for 1 rupee (~ 2.5¢ US) per 10 liters, a price affordable to the poor. A community-based model removes the barriers that plague point-of-use systems, relieving the end-user of the burdens of set-up, quality-assurance, operation, and maintenance. Modest profits on the treating water can attract business investment making the model rapidly scalable, while fully recovering the initial investment as well as the cost of electricity, maintenance and operation and ensuring that local villagers continue to have stake in successfully operating the technology. WaterHealth centers have enjoyed great success in a region where water has traditionally been free and available near the household (similar to the household tubewells of Cambodia). They have opened more than 200 centers over the last two years, each serving 6000 residents, with expansion projects in other developing countries. The centers also provide incentives for entrepreneurship – WaterHealth has found that independent businesses develop near centers to deliver water door to door. This service is offered for twice the retail cost, still affordable at 4¢ per 10 liters, and is utilized by the poor who are willing to pay for the time-savings. The informal local distribution market completes the turnkey solution, which frees women and children from the burden of transporting the clean water from the centers themselves, as they are often traditionally in charge of fetching water. WaterHealth Safe Water Centers demonstrate the feasibility of a for-profit community scale business model in Bangladesh. In light of the barriers that plague point-of-use systems, a community Safe Water Center is a promising way to sustain clean water access long term.

Overall, the electro-coagulation technology is technically adapted for use in a community Safe Water Center:

- Unlike certain chemical adsorbents, which require a manufacturing plant and supply chain, electro-coagulation requires only iron in the form of mild steel, which is readily available in Cambodia and can be replenished in one shipment per year (~ 635 kg per year could provide 10 l of clean water/day to 6000 people).
- Adsorbents requiring manufacture (such as LBNL's promising ARUBA technology) also ask for a large capital investment at startup, whereas electro-coagulation units are modular and scalable, allowing small pilot projects to be sustainable on their own or replicated for scale-up.
- Electro-coagulation is extremely effective, capable of reliably reducing the arsenic level in water to below the World Health Organization limit of 10 ppb, ensuring the same standards in developing countries as are enjoyed in the United States.
- Waste produced is low at 60-120 grams per person per year and easily pacified on-site through burial in a small limestone or brick-lined pit.

The major design tradeoff for all of these benefits is the requirement of electricity. Nevertheless, WaterHealth has shown that water treatment centers using a modest amount of electricity can be installed, operated and maintained with full cost recovery in a rural area (through a grid, generator, standard 12V car battery, or photovoltaic source). The total cost of operation, assuming the electricity source is a photovoltaic panel, is estimated to add up to 0.1¢ to 1¢ per day and person.

6 Project outline

As previously mentioned, the goals of the present project are twofold:

1) To test the technical efficiency of the BEAR device to remove arsenic species from Cambodian groundwater to acceptable levels. This goal involves adapting and optimizing the parameters of the process to the local groundwater conditions.

2) To assess the possibility of an economically and socially sustainable dissemination and implementation of the technology that is adapted to the local context and aimed at improving the livelihood in rural Cambodian communities.

To reach these goals, three main axis of research are considered in this report:

a) A field technical trial on the BEAR prototype, whereby ground water is sampled from several highly contaminated Cambodian sources, and tested on the prototype in order to observe its behavior in a field setting. For logistical reasons, these tests were conducted in a local research laboratory, using a constant current power supply.

b) A demand survey is administered to a limited number of households surrounding the sampling sites in order to contemplate the possibility of a financially sustainable and locally adapted, future implementation of the prototype, once fully developed.

c) Contacts and discussions with relevant NGOs are organized, in order to integrate their priceless local experience and knowledge on the implementation and dissemination of water treatment and distribution devices among rural Cambodian communities.

7 Technology technical trial

As mentioned in the previous section, the first type of research was of a technical nature: to assess and optimize the efficiency of the technology on the specific setting of Cambodian groundwater. Specifically, the BEAR technology will be applied on arsenic contaminated groundwater sampled from nine sources in three different villages. All selected sources are equipped with a pump and have been either observed or suspected by RDI to be located on contaminated aquifers, where high levels of arsenic are expected. Methodologically, the project consists of a sequence of the six successive stages that are described in the following sections, while the full procedures are given in Appendix A.

The main findings resulting from the technical trial of BEAR in Cambodia are the following:

- Arsenic is present in Cambodian groundwater in very high concentrations (above 1000ppb), as well as several potentially interfering ions, such as iron and chloride.

- Presumably due to the high iron concentration naturally present in Cambodian groundwater, a decrease of the arsenic concentration is observed during storage in presence of oxygen.

- The BEAR prototype reduced the arsenic concentration of nine different ground water sources from inlet concentrations ranging between 100 ppb and 1000+ppb, to outlet concentrations below the WHO standards of 10 ppb. This performance was obtained with a set flow rate of 18 liters per hour and did not require any outlet mixing.

- An experimental optimization of the BEAR process in Cambodia led to the successful treatment of highly contaminated (1000ppb As) sources at a flow rate of 30 liters per hours. If an outlet mixing step is introduced, the flow rate can be increased to 60 or 90 liters per hours for mixing times of 20 and 30 minutes respectively. All these results are more advantageous than obtained during the laboratory trials in the US in April 2008.

- The energy consumption of the BEAR electrodes ranges between 0.04 and 0.21 Wh/l, depending on the chosen flow rate. If the use of a 12V 32Ah battery as a primary source is assumed, one fully loaded battery can treat a volume of 3046 liters (at 30 liters/hour). If a mixing step is added, the treated volume increases to 9137 liters. However, additional energy must then be provided for the required 20 minute mixing.

- Several design improvement possibilities to both the sushi cartridge and the rest of the prototype are suggested.

7.1 Source selection

Based on geographical maps showing arsenic concentrations in various parts of Cambodia and previous study done by RDI, we chose to sample water from the three communes Preak Russei, Dei Edth, Preak Aeng based on the following criteria:

(a) The level of the arsenic concentration in the ground water,

(b) the presence of an Arsenicosis outbreak (as is the case in Preak Russei),

(c) accessibility,

(d) availability of well data collected by RDI.

Next, based on the well characterization previously conducted by the laboratory staff, we selected three tube wells in each of these regions. Table 1 displays an overview of the sampling sources and selection criteria.

Preak Aeng Commune, Kien Svey district, Kandal Province

Well designation	Selection criteria
PA1	Random selection
PA2	Random selection
PA3	Random selection

Preak Russei village, Kompong Kong Commune, Kaoh Thum District, Kandal Province

Well designation	Selection criteria
PR1	As level, number of users
PR2	As, Nitrate, Cl and F levels
PR3	As and Fe levels, number of users

Dei Edth village and Commune, Kien Svey District, Kandal Province

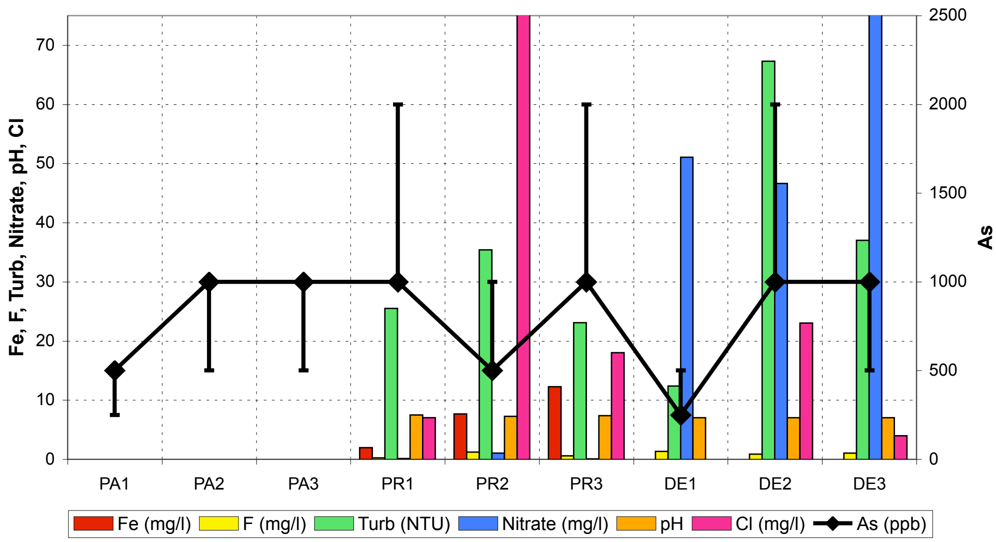
Well designation	Selection criteria
DE1	As and F levels
DE2	As, Cl and turbidity levels, number of users
DE3	As and nitrate levels

Table 1: Selection criteria for the tested wells.

7.2 Sources characterization

In the frame of a large scale ground water survey campaign that was run in 2005-2006, the sampled sources in all locations except Preak Aeng had previously been characterized by RDI for principle ions and parameters such as Fe, F, Cl, turbidity, nitrate and hardness. According to local experts from RDI, negligible seasonal variations of these parameters can be expected in the underground water of the considered regions.

The RDI characterized parameters for Preak Russey and Dei Edth are displayed in figure 1. The arsenic level measured by our team while sampling is given in the same graph, completed by qualitative remarks regarding the aspect and testing history of the sources.



Batch	PA1	PA2	PA3	PR1	PR2	PR3	DE1	DE2	DE3
As (ppb)	500	1000	1000	1000	500	1000	250	1000	1000
Fe (mg/l)				1.93	7.65	12.24	0	0	0
F (mg/l)				0.25	1.2	0.6	1.3	0.85	1.05
Turb (NTU)				25.5	35.4	23.1	12.4	67.3	37
Nitrate (mg/l)				0.1232	1.056	0.0792	51.04	46.64	92.4
Hardness				90	198	162	161	394	376
pH				7.5	7.23	7.37	7	7	7
Cl (mg/l)				7	211	18	0	23	4

Figure 1: Dissolved ion characterization for each of the selected wells.

High ion content: One can notice the extremely high level of arsenic in all tested sources, which are all more than one level of magnitude above the WHO standards. Furthermore, high levels of ions such as iron, fluoride, hardness (carbonate) and chloride are observed and might influence the electrocoagulation process by affecting the electrode surface state (Cl), its corrosion kinetics (F and carbonate) and the iron dosing of the solution (Fe).

Arsenic testing history: On the nine sampled wells, four were already red painted (indicating a tested high level of arsenic), two were positively tested but not painted, and three had never been tested. Among the three untested well, one was used daily as a drinking water source.

Visual Aspect: The turbidity of all sources was very low (qualitative observation). However, as water from the Dei Edth sources was uncolored, a light red color was observed in most of Preak Russey and Preak Aeng sources, presumably due to the presence of iron.

Families served: Most wells were family-owned in Dei Edth and Preak Aeng. Yet in the more remote and less well-off village of Preak Russey, all the wells were shared between more than five households.

7.3 Storage

Water sampling sessions were conducted by the authors between July 2nd and July 11th, 2008 in the communities. The sampled water was stored in 30 liters water bottles made of translucent plastic (presumably Polyethilene or Polypropylene) for about three weeks. Thus, the presence of oxygen and light slightly modified the physico-chemical setting of the stored ground water, influencing parameters such as the pH, dissolved oxygen (DO), conductivity, and even the arsenic concentration.

The effect of the changes that took place within the considered batches during the three weeks period between their sampling and their use are displayed in figure 2, where the mean values on all batches are shown.

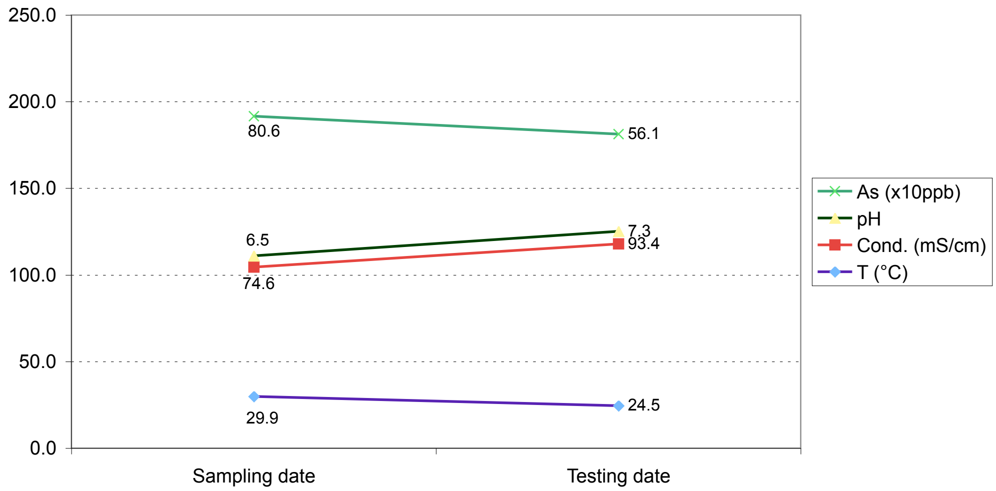


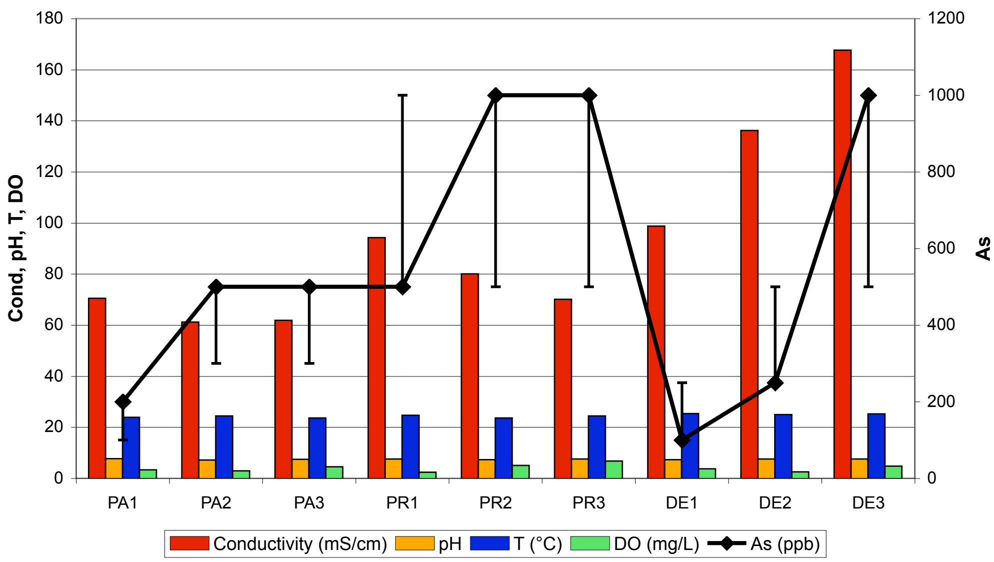
Figure 2: Evolution of the samples between sampling and BEAR testing (about 3 weeks).

The increase of pH and conductivity is linked to the diverse reduction-oxidation reactions that took place in the batches, due to the increased presence of oxygen and light. Such reaction may be organic (photosynthesis and respiration of algae) and inorganic (oxidation of the dissolved iron), both of which increased the turbidity and the particle content of the batches.

The decrease of arsenic can be explained by the oxidation of the naturally present dissolved iron. The coagulation of the oxidized iron then forms rust particles on which the arsenic may sorb, in a similar mechanism to that is applied through the BEAR technology. As a matter of fact, one may infer that in the presence of high levels of naturally occurring dissolved iron, high concentrations of arsenic may be decreased through extended storage in the presence of oxygen. However, a mean arsenic concentration superior to 500 ppb was still obtained among the nine considered batches after a tree week storage period, which demonstrates the need of an engineered process such as the BEAR technology to speed up the reaction.

7.4 BEAR inlet batches characterization

Experiments on a BEAR prototype brought in from the US have been conducted by the authors between August 6th and August 8th, 2008 at the RDI laboratory in Cambodia. The previously collected groundwater samples were flowed through the prototype with the expectation of strongly reducing their arsenic concentration. However, due to the storage effects mentioned above, the characterization of the main physical parameters of the collected ground water batches had to be measured immediately before being flown through the BEAR prototype. The conductivity, pH, temperature, DO and arsenic concentration of the nine different batches on August 6th, 2008 are displayed in figure 3.



Batch	PA1	PA2	PA3	PR1	PR2	PR3	DE1	DE2	DE3
Conductivity (mS/cm)	70.5	61.2	61.8	94.3	80	70.1	98.8	136.2	167.6
pH	7.705	7.18	7.44	7.51	7.345	7.63	7.33	7.585	7.6
T (°C)	23.9	24.4	23.6	24.7	23.66	24.45	25.3	24.9	25.2
DO (mg/L)	3.34	2.92	4.5	2.35	5	6.75	3.7	2.52	4.72
As (ppb)	200	500	500	500	1000	1000	100	250	1000

Figure 3: Testing parameters on August 6th, 2008.

General observations: Despite the storage effect, the slightly basic nature of the arsenic containing water, the low DO and the still high arsenic content can be noted.

Visual aspect: A slightly turbid and reddish aspect is observed on all samples, even the ones that were not turbid when sampled. Furthermore, suspended red-brown algae growth is noticed in most samples, as wells as the appearance of thick black particles (about 1mm diameter). However, the top of the storage recipient, where the BEAR inlet water was collected, was always clear due to the effect of settling and decantation.

7.5 Proof of concept

Figure 4: The BEAR filter.

In order to establish a proof of concept of the BEAR technology on Cambodian groundwater, all nine batches were flowed through the prototype and their inlet and outlet arsenic concentration monitored using a Quick Test® kit, whose accuracy was verified by the testing of standards. The applied operational parameters such as the flow rate, electrical current and mixing time were first chosen on the basis of the experiments previously conducted at Lawrence Berkeley National Laboratory (April 2008) on synthetic Bangladeshi groundwater. However, experimental adjustments had to be made to these parameters in order to fit the specific setting of Cambodian groundwater.

The operational parameters used for the BEAR proof of concept experiments in Cambodia are displayed in table 2, while the inlet and outlet arsenic concentration of the nine batches flown through the prototype are shown in figure 5.

	Optimal LBNL April 2008	**Cambodia P.o.C** August 2008
Current [A]	1	1.106
Current density [mA/cm2]	0.96	1.06
Flow rate [l/h]	16	18
Dosing [C/l]	248.9	221.2
Mixing time [min]	30	0
Filtration	0.45 um, vacuum	11um, gravity

Table 2: Parameters used for the proof of concept BEAR runs.

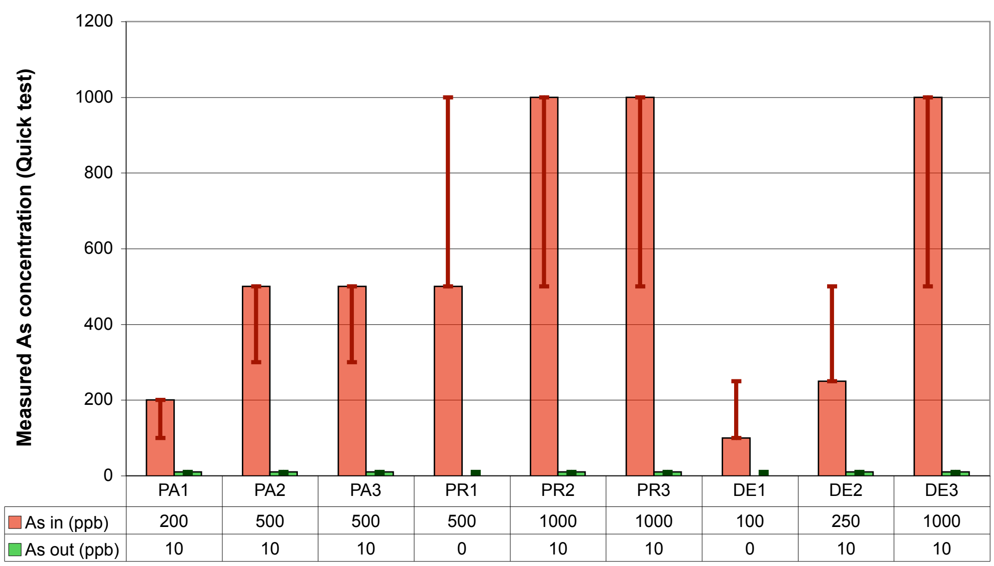


Figure 5: Inlet and outlet arsenic concentration in the proof of concept BEAR run.

Operational parameters: The more liberal parameters that are here applied (i.e. the higher flow rate, the absence of mixing time and the use of a simpler filtration option) hint to the fact that the prototype seems to behave more efficiently in the field laboratory on Cambodian water, than in the LBNL laboratory on Bangladeshi synthetic water. This statement will be further explored in the next section.

Proof of concept: The result of the experiment on the nine groundwater batches shows that the BEAR technology is efficient in reducing very high concentrations of arsenic to a levels that are below WHO standards. This was performed with more liberal operational parameters than expected, and on all nine of the relatively diverse water sources, in terms of provenance and ionic composition.

Residual Iron: However, given the importance of the iron content of the filtered water in terms of acceptability (see section 8.4), and knowing the high initial iron content and the switch to a coarser filtering solution, a deeper analysis of the iron content of the outlet samples would be advisable.

7.6 Technical Optimization

Finally, given the promising results of the proof of concept experiment described above, an experimental optimization has been performed, whereby further combinations of flow rate and mixing time have been tested. The scatter plot in figure 6 gives a complete overview of the BEAR prototype's performance with the several parameter combinations attempted. All the optimization experiments were conducted on Dei Edth (mostly DE3) sources because of their accessibility.

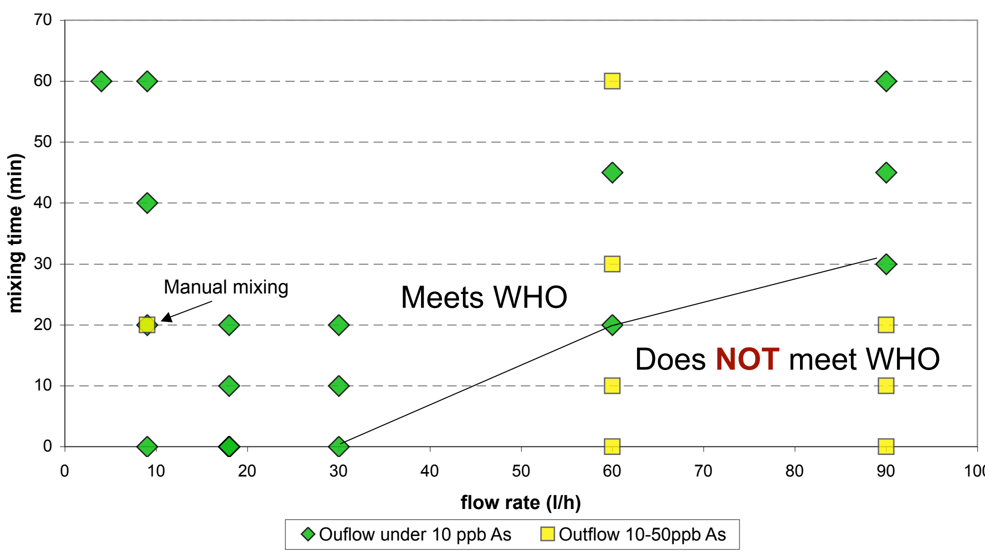


Figure 6: The BEAR filter performance using various combinations of flow rate and mixing time.

Compliance with Bangladeshi standards: All the experiments yielded to outflows with arsenic concentrations below the Bangladeshi standard of 50 ppb, even with flow rates as high as 90 l/h and zero minutes of mixing. This is of interest because Bangladesh is another possible target area for the implementation of the BEAR technology.

Compliance with WHO standards: However, if the WHO standard of 10 ppb or less is sought, a line of optimal combinations can be observed (gray line on the graph). All results with lower mixing time or higher flow rate are not compliant to WHO standards.

Economic Optimalization: Three of the experimented combinations of parameters seem to be optimal: (A) 30 l/h flow rate with no mixing time, (B) 60 l/h flow rate and 20 minutes mixing, (C) 90 l/h flow rate and 60 minute mixing. An economic optimization would be the logical next step to locate the optimal couple of parameters along the line of technical solutions formed by these three results.

Manual mixing: A 20 minute manual mixing (flipping of the bottle every 30 seconds) has been attempted on a 10 liters per hour flow rate BEAR outlet. However the result did not meet the WHO standards, while the same experiment with regular mixing (magnetic stirrer) did meet these standards. Thus in addition to the quantity, the quality of mixing seems to affect the efficiency of the BEAR process.

7.7 Dismantling – Long term use observation

The BEAR experiments in Cambodia required an estimated total of 100 liters of water to be flown through the working prototype, unevenly spread on a total period of 47 days between July 3rd 2008 and August 18th 2008. At the end of this period of use, two observations can be made:

Energy use: The potential drop between the electrodes was monitored on all BEAR experiments. The mean value of the steady state voltage on the sixteen collected values is 3.42 V (standard deviation 0.82). Considering the constant 1.106 A of current provided, the total required power is estimated at 3.78W. From this result, several energy consumptions estimations can be made, as a function of the chosen flow rate. Furthermore, if the assumption is made that the BEAR filter is operated on a 12V 32Ah car battery, the treated water volume per battery can be estimated. These estimations are given in table 3. However, it is important to mention that the additional energy linked to the mixing step must be taken into account as well in a further economic optimization of the process.

Energy (Wh/l)	Liters per battery	Remarks
0.210140	1827.353193	Proof of Concept Flowrate, no mixing required
0.126084	3045.588655	Optimal flowrate, no mixing required
0.063042	6091.177310	Optimal flowrate, 20 min mix required
0.042028	9136.765966	Optimal flowrate, 30 min mix required

Table 3: Energy use of the BEAR dosing step.

Electrode wearing: In order to observe the effect of the electro-coagulation process on the electrode surface after the treatment of the estimated volume of 100 liters, the sushi cartridge was unrolled and observed.

Two qualitative observation on its aspect are to be mentioned:

- First there is a preferential wearing of the iron at the electrode junction, which eventually resulted in the ripping of one electrode (see figure 7). This preferential wearing can be linked to an inadequate geometry of the electrode which led to preferential corrosion inside the junction angle.

Figure 7: Ripped electrode due to corrosion.

- Secondly, a preferential corrosion was also noticed right behind the plastic mesh, which eventually formed small holes on the electrode surface (see figure 8). This preferential wearing may be linked to a flow effect, whereby the slower flow in these zone led to a higher concentration of dissolved iron, and thus a higher conductivity. This local higher conductivity of the water may then have locally led to a higher current density behind the plastic mesh and thus a preferential corrosion.

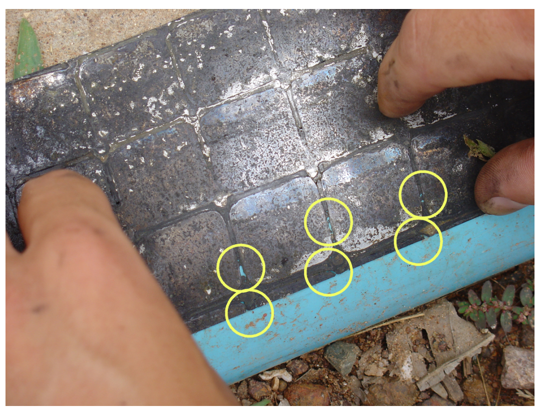


Figure 8: The location of several holes in the iron sheet due to corrosion.

7.8 Conclusion – Design recommendations

The main findings of this technical trial have been summarized in the introduction. In addition, several design recommendations can be thought of. These recommendations were deduced from experience gained on the treatment of 100 liters of source water in Cambodia and concern the Sushi cartridge, the BEAR prototype and its integration in a global water treatment system.

7.8.1 Sushi Cartridge

(i) *The replacement of the HDPE transparent plastic layer by mesh layers.* The plastic layer is fragile and its failure would make the device unusable by creating a short circuit. A logical solution would be to replace it by two layers of plastic mesh, similar to those already in place between the electrodes. However, this would also increase the active electrode area and would require the adaptation of the electrode geometry and/or the electrical current.

(ii) *The replacement of the built-in electrode junction by a soldered wire.* As mentioned in the preceding section, small holes on the electrodes right behind the plastic mesh, and preferential wearing of the iron at the electrode junction were noticed. Both issues may result in an open circuit on the electrode. This issue may be dealt with by soldering a longitudinal non corroding metal wire on the electrode, insuring the distribution of the current despite the holes on the electrode. Furthermore, using the wire instead of the electrode "ears" as junctions would prevent their ripping off and avoid the presence of a weak point.

7.8.2 BEAR Prototype

(i) *Improvement of the vent system.* The current vent system consists of a screw on the electrode top, which operation is not really practical in a field laboratory. Additionally, gas has been observed to build up inside the prototype in prolonged use. This corrosion product (presumably a mix between O2 and H2) may be explosive and is thus dangerous in contact of the spark-prone electrode. An efficient vent system must be introduced, either in the design or the operation procedure of the system.

(ii) *Draining of the prototype cap.* Due to pipe leaks or the prototype filling process, water tends to build up on the prototype cap, right between the junctions of the two functioning electrodes. A drainage grove carved in the cap would thus be a welcomed feature of the next design iteration.

(iii) *Outlet flush.* Thick rust particles tend to build up in the prototype outlet system and might clog it in long term use. An efficient flushing system must thus be introduced in both the design and the use procedure of the system.

(iv) *Wider pipes.* Finally, the piping currently used seem to be right enough for a 90 liters per hour flow rate. If a higher flow rate is sought in further iterations of the prototype, wider piping is thus advisable.

7.8.3 System Integration

(i) *Outlet mixing process.* As mentioned above, results have shown that the outlet mixing step can be suppressed from the BEAR process. However, adding a mixing step can be applied as a trade off needed to increase the flow rate, and an economic optimization is necessary to determine the final operation parameters.

If the mixing step is kept, experience shows that the technique of manually flipping the recipient every 30 seconds is inadequate. Therefore the quality of mixing seems to be an critical parameter as well. One solution could be to add a built-in mixing device to the existing prototype, as a second sushi in series behind the first one. This new sushi will not be electrically connected and not made of conductive materials and would exclusively provide mixing.

(ii) *Filtration process.* All successful experiment were conducted using a standard Whatman #1 filter. Therefore, the use of a series of standard cartridge filters may be considered.

(iii) *Integration in a global treatment system.* In the current state of development, the integration of the BEAR prototype to a classic small scale water filtration plant (similar to the process used by the NGO "1001 Fontaines" in Cambodia) may be considered. The final treatment process consisting of (1) a settling phase (2) a sand filter phase (3) the BEAR prototype (4) a series of cartridge filters (5) a UV disinfection device, yielding to safe and affordable water for local communities.

8 Community assessment

8.1 Goals

The second axis of research consisted in a small-scale community survey with the goal of assessing the villagers' drinking water preferences, their available water sources and the existing economical competition to a possible installation of a community safe water center including a BEAR unit to remove arsenic.

However, as the filter hasn't yet completed its design phase, there was little benefit in attempting to collect a statistically representative set of data on possible implementation areas – nor did we have the human resources for such an effort. Instead, we decided to concentrate on a handful of surveys, conducted personally by one of our team members with the support of a native Khmer speaker for both translation and cultural sensitivity of our questions.

Through these rather informal interviews, as well as the comments of our Khmer staff who is personally involved in drinking water research[2], we aimed to obtain location-specific inputs that might escape the mind of an university student only vaguely familiar with the living situation and the daily challenges of Cambodia's rural population. Hopefully, these considerations will influence the next design iterations and lead to a more adapted and more people-oriented arsenic filter and also provide signposts for a more thorough study of this interesting market at a later point of time.

8.2 Process

A first draft of the household questionnaire was written in Berkeley (see households 1 to 5 in Appendix B, page 11) and then used for the interviews done in Preak Russei, the first of the three communes visited.

However, we quickly realized that we had underestimated the group dynamics of a Khmer neighborhood curiously gathering beneath a traditional stilt house at the sight of foreigners.

Our plan of isolating the head of each household were given up when we realized that the interactions between the chitchatting villagers, all eager to give their own opinion and anecdotes, might be far more resourceful to our development process than the rigid lines of a predefined (and rather complicated) survey. Also, several questions regarding

Figure 9: Interviewing in Preak Russei.

[2]Both of our local staff were working for RDI Cambodia.

their use of electricity as well as their arsenic awareness turned out to be far too specific for the present stage of the project.

Consequently, we redesigned the whole survey and shortened it from six pages to only one – including only questions related to the present drinking water sources and their preferences among them, combined with a few complementing remarks on road accessibility, wealth and electricity alimentation of the village. These observations were taken directly by the Cambodian translator and ourselves, thus avoiding to ask culturally sensitive (as well as potentially unreliable) questions on the household income. Furthermore, as far as the methodology goes, we decided to aim rather to gather as many neighbors as possible than to interview two households separately. The filled out survey form would then be only one part of the assessment, completed by the villagers' remarks that we'd note on a separate sheet of paper. Hoping thus to have access not only to the facts but also the rationale behind their drinking water choices, this modified survey then became the basis for our interviews in Dei Edth and Preak Aeng.

Figure 10: Interviewing in Preak Aeng.

Unfortunately however, it turned out that both remaining villages were far more individualistic and hardly any neighbor took interest in our being there. Consequently, the group discussion on the questions didn't turn out as rich as we had hoped. Nevertheless, the new survey design turned out to be efficient and more simple at collecting the information relevant to our research. And since the wells too were individualistically owned, we still stuck with the resolution of doing only one survey for each well visited.

The complete survey forms, including observations and comments, are attached in Appendix B starting with page 40.

8.3 Community description

As described in section 7.1, the communes visited were Preak Russei, Dei Edth and Preak Aeng, all three in the Kandal province in central Cambodia.

All three of these provinces are characterized by a high concentration of arsenic in the ground water (around 1000 ppb) but differ on a certain number of other relevant aspects:

Preak Russei has seen cases of an Arsenicosis outbreak and, as a response, undergone intensive sensibilisation and relief efforts by RDI which has led to source switching as described in section 4. The tube wells still present are used almost exclusively for cooking, cleaning and doing laundry, which is presumed to present a lower risk of Arsenicosis (WHO 2008).

It is a rather poor community which is difficult to access (the car ride from the capital Phnom Penh takes three to four hours across mud roads and involves an adventurous ferry ride across the Ton Le Touch river). Most households, and literally all that were interviewed, are not connected to an electricity grid. Instead, they possess a 12V car battery which they regularly bring to a charging station in the village center.

Dei Edth has yet been spared from an Arsenicosis outbreak, at least for what is known so far. Several wells in the commune have already been tested for arsenic contamination and are no longer being used for drinking.

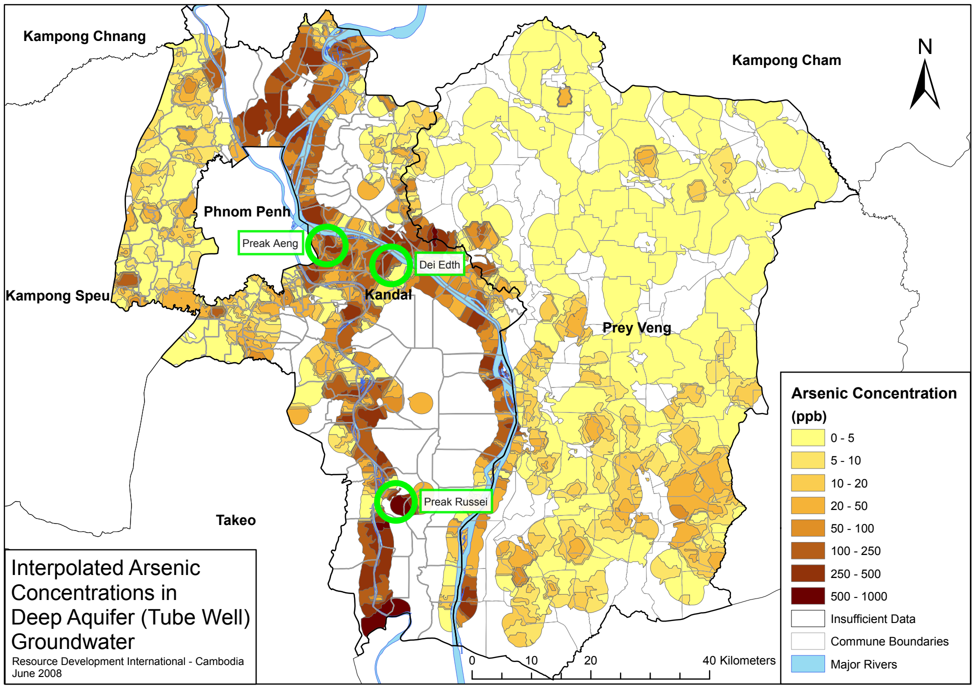


Figure 11: The location of the three communes visited, as well as the general arsenic concentrations found in the groundwater in the Kandal province. (RDI Cambodia)

Situated next to the National Highway N°1, the commune is easily accessible by car and less than an hour away from Phnom Penh. However, the level of wealth seems to be distributed quite unevenly in this commune and the households interviewed represent that dispersion, with only one being connected to an electricity grid and the remaining ones recharging their car battery as in Preak Russei.

Preak Aeng doesn't seem to have observed a case of Arsenicosis, either. Even closer to the capital than Dei Edth but further off from the highway, this commune has decent road access, although a four-wheeler or a motorbike is required for the last kilometers. Our khmer staff classified the village wealth as *medium* in all three surveyed households, and quite a few households are connected to an electricity grid.

This is also the only place where we found families actually drinking the tube well water – an observation that might have been distorted by the fact that we only visited communes where RDI had already been and, consequently, many wells had already been tested and people had at least a basic notion of the dangers linked to arsenic.

8.4 Results

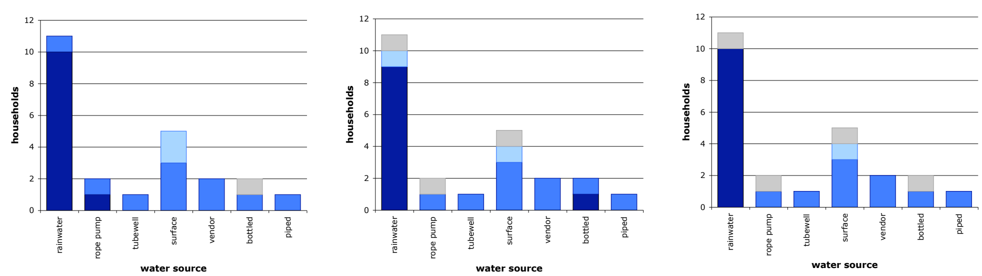
8.4.1 Drinking water preferences

If there was one main observation to make, it would be about the Cambodians' overwhelming preference for rainwater. Not only is it free, clear and falling right on their own roof, it also comes directly from the sky and is thus perceived as safe and pure. Some have their entire house surrounded by traditional water jars (each containing about 200 liters) to store the precious liquid all the way through the dry season.

It might be as a result of the easy access to rainwater combined with its relative optical purity in comparison with the mostly brown rivers that have made it the number one water source for much of Cambodia's rural population.

To verify this hypothesis, we asked villagers to classify their different water sources according to convenience, taste and color. However, after listening to the villagers repetitively putting rainwater on top of every single category without giving it any further thought, our translators often shrugged, commenting that "they simply like rainwater". It seems that generations of rain water consumption have left its trace in the culture so that people today have simply grown accustomed to its taste, appearance and odor. In every category, it has become the ideal.

Such an observation isn't absurd, after all, most people prefer a certain type of drinking water, and it is most often the one they've grown up with. Tap water in another country, although it might be safe and pure, is rarely as attractive as the one used at home. And the situation was similar in Bangladesh 30 years ago when UNICEF installed thousands of hand pumps for a population accustomed to rainwater, and had to launch substantial promotion programs to promote the switching of drinking water sources [Jakariya, 2007]. It might be partly for these efforts that the arsenic crisis is currently more present in Bangladesh – Cambodians are yet relying largely on rain and surface water; although that, of course, also has its specific problems.



(a) based on convenience **(b)** based on taste **(c)** based on color

Figure 12: The interviewees preferences over their drinking water sources. (Dark blue represents the amount of villagers who mentioned the sources as first, medium blue as second, light blue as third choice and gray the ones with no classification available.)

In more detail, figure 12 shows both the amount of households that were using each drinking water source (i.e. all eleven households use to drink rainwater for at least some months of the year, but only one has access to piped water) as well as their classification of these sources according to the three criteria *convenience*, *taste* and *color*.

The graphs show that with the exception of one household in Preak Aeng with extensive rainwater storage (16 traditional jars of about 200l each), all families rely on at least one additional water source during the dry season. It can also be seen that only one of the interviewed households is using his tube well as a drinking water source.

Since arsenic prevention work has been done in all villages, we may thus conclude that in these areas, source switching presently seems to be an okay strategy.

Furthermore, the different criteria show that while rainwater is certainly the overall favorite, there are households who find the rope pump more convenient (possibly due to the fact that no storage is required) or the taste of bottled and tube well water more appealing (maybe because the more expensive bottled water is seen as superior by the interviewed teenage boy). Upon questioning the same young interviewee about his unique preference for tube well water, he replies that it tastes almost like bottled water while rainwater has quite an unique taste to it. This observation opens an interesting area for further exploration: May it be that there is already a change in attitude on the way, similar to the one observed in Bangladesh 10 years ago? Does the younger generation, who has grown up with the advertisement of mass-produced drinking water bottles and tube wells in their back yard, do they now prefer this novel source of drinking water?

Of course, one single such observation is not enough to conclude on a general trend, but it would be interesting to verify, at a later point of this project, whether such a change can be found in larger parts of the country.

8.5 Drinking water cost

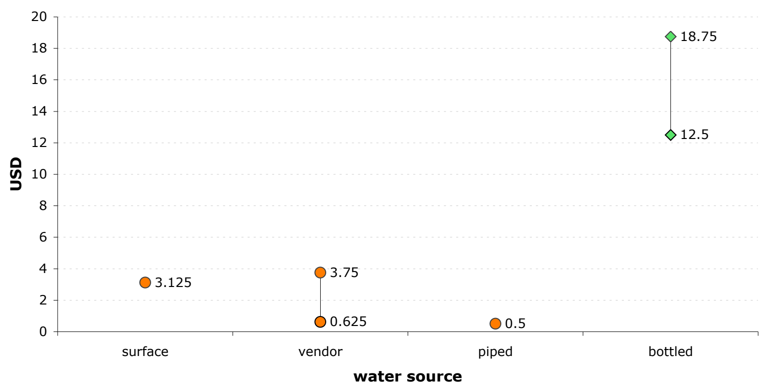


Figure 13: The cost of a cubic meter of water. (Orange dots represent unpurified water sources, green rhomboids stand for safe drinking water.)

Another part of the survey aimed to obtain some rough estimates for the cost of available drinking water sources, summarized in figure 13. The data comes from villager information and does not include setup costs linked to storage jars, pumps or well drilling. As a result, rainwater, rope pump and tube well water were looked at as 'free' water sources and left out of figure 13. Since access to surface water, jar filling by a vendor and the use of a piped water system all offered untreated water of some sort, those prices have to be compared separately from bottled water which is safe to be drunk directly. Hence, the interviewed households are used to an access of $1m^3$ (1000l) of untreated water for a cost between 0.5 and 3.75 US Dollars, while they pay between 12.5 and 18.75 USD for the same amount of purified drinking water. Once sufficient tests have been run on the BEAR filter to forecast its operating (and retail) cost, those figures should be compared against these present cost estimates.

In order to correctly estimate these running costs of the BEAR filter system, one will need estimates of the electricity cost in this country. Without pretending to be representative, the numbers in figure 14 may give a hint of this cost factor.

As described in section 8.2, the survey forms were completed by our own observations and remarks. Among them is the comment of several villagers that would like to drink treated

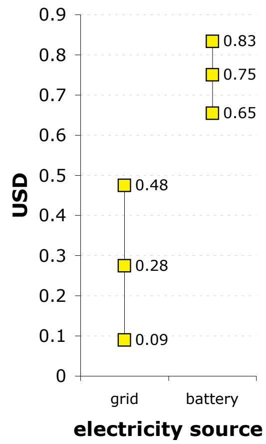


Figure 14: The cost of one kWh of electricity.

piped water but are unable to do so because of its relatively high cost – their preference for rainwater may, after all, not be solely by free choice but by necessity.

Also, the willingness to pay for arsenic free water is virtually zero because there are already several other options available. Thus, if the BEAR technology ever were to be launched in such an area, it is vital that the product sold would be completely pure water, safe to drink, and not only arsenic-free groundwater that requires the households to further filter it at home.

Concerning the present point-of-use treatment that villagers apply to their drinking water before consumption, the most frequently used method consists in boiling the water, some use the Ceramic Water Purifier[3] (especially where it had been provided for little or no cost by a NGO) and a few still apply no treatment at all.

A few small businesses have already been set up to provide water all year round: In Preak Russei, RDI helped installing a community water supply plant with a mini-grid and in Dei Edth, villagers mentioned a water vendor down the road who they call during the dry season to fill up their water jars with untreated river water.

In Preak Aeng, the well water seems to have a particularly high iron content, much to the dislike of the villagers. One elderly woman observed that when the water is stored the whole day, it tends to turn red – and so do the clothes she washes with it. Also, when used for cooking, this water makes her food less delicious, she mentions. Another woman made the same observation and now uses a sand filter even for her laundry water in order to lower its iron content. – That being said, taking out the iron from the water might be a very welcome, valuable side effect from the BEAR process, potentially raising the willingness to pay above the required threshold.

As mentioned before, the full information on the survey results can be found in Appendix B, starting with page 40.

8.6 Implementation recommendations

The lessons learned during these village interviews may add some valuable signposts to the further journey of the BEAR technology, namely:

[3] http://www.rdic.org/waterfiltrationsystems.htm

Alternative water sources. For most parts of Cambodia, there are alternatives to ground water, mainly rain- or surface water from a nearby river. One valuable advantage of ground water is its more reliable availability as well as a certain steadiness in its quality – rain falls only during some months of the year and surface water is easily polluted by bathing villagers, laundry activities and (more and more) pesticides from farming. Another important issue is the lack of minerals in rainwater, as will be specified in section 9.2.

However, it is vital to assess the potential of treating these other water sources and weigh it against the possible benefits of the BEAR solution. New is not always better, and the traditional water sources may, with better treatment and monitoring, provide a viable alternative.

Water preference. Further increasing the importance of the above comment, the majority of the Cambodians are currently used to rainwater consumption, and a certain reluctancy to switching water sources is to expect. Such consumer preferences must be included in a thorough comparison between different safe water options.

However, as part of the research, one may try to look for a possible shift in preference according to the age of the villagers interviewed. With tube wells being present since the 1990s, and bottled water ads being all over the country, it is possible that the younger generation is more open to ground water than their parents.

Iron reduction. Anybody working on arsenic reduction will at some point note the extremely low willingness to pay. Indeed, a colorless, tasteless, and odorless poison with no immediate effects is not seen as an important threat by villagers who are daily fighting for survival. Thus, the presence of a secondary effect, valuable to the locals, may well decide over the success or failure of the remediation strategy.

Our surveys show that the iron content is particularly felt by consumers in at least one of the three communes visited, where villagers already have strategies in place to counter its effects on clothes, food and pans. By simultaneously lowering the iron content, the BEAR technology might thus have better odds in this place. Since the high iron levels may equally have a positive impact on the efficiency of the BEAR process, such high-iron regions might be ideal for a first generation of BEAR water centers.

Cooperation with existing businesses and organizations. As there is little use in reinventing the wheel, we strongly encourage further researchers in this project to seek the feedback from local NGOs and cooperate with existing businesses. Not only is it confusing to the villagers to be instructed every few years to use another water source[4], it is also a waste of local resources and knowledge to rely solely on outside teams.

9 Market Considerations and Implementation Strategies

9.1 Goals and Process

While conducting technical trials and community surveys, the team also identified and scheduled meetings with local institutions in order to gain valuable advice and insight on local market conditions and possible implementation strategies. This component of field work was

[4] In certain areas, after generations of surface and rainwater consumption, villagers were first offered untreated ground water through the UNICEF tube well installation. Then an NGO such as RDI came to warn them of the dangers of Arsenic and – due to a lack of alternatives – advised them to switch to filtering rain and surface water. And now maybe, researchers will soon try to convince them to buy arsenic-free ground water.

crucial for gathering information about local market conditions and possible implementation strategies, as well as bringing the prototype into contact with local demand, including potential investors and dissemination agencies. The physical interaction of BEAR members with local institutions also made it possible to establish, strengthen, and expand partnerships for longer-term collaboration in the future.

9.2 Lessons Learned from Local Institutions

BEAR met with four reputable non-governmental organizations (NGOs) in Cambodia, including RDIC, to learn about considerations and best practices for the launch and sustainable operation of rural safe water centers in partnership with the local communities. The meetings also often included a site visit component, to demonstrate the operation of rural water centers at the ground level. The organizations interviewed by the team are profiled in the section below.

Additionally, the team attended a monthly Water and Sanitation meeting hosted by the Ministry of Rural Development to meet other local institutions, learn about relevant government initiatives, and develop a sense of the current local situation regarding water quality and sanitation.

9.2.1 Ressource Development International – Cambodia

Resource Development International-Cambodia (RDIC), based in the Kandal Province of Cambodia, is part of an international 501(c)(3) non-profit organization. RDIC's strategy is based on a holistic approach, where projects in several complementary areas are conducted simultaneously to improve the livelihood of Cambodian communities. Such projects are as diverse as water testing and water filter manufacturing, adapted farming, health worker training and large-scale health education through radio and television broadcasting. With a well-equipped modern laboratory and strong logistic resources, they are considered to be leaders in arsenic testing in Cambodia (Engineers Without Borders-Australia website) and strive to research appropriate technologies and promote education to serve the Cambodian people. "The core of [their approach] is based on relationships with the Cambodian people" (RDIC website). After a decade of fruitful collaboration and community work, they are well integrated in the Cambodian culture.

The meeting with RDIC Country Director Mickey Sampson gave insight into the local arsenic situation. Several cases of arsenicosis have been recorded in isolated villages, and the severity seems to be correlated with the inaccessibility of the village. Since most responses to arsenic contamination in Cambodia have been emergency reactions, the predominant strategy has been source switching to alternative water sources, such as surface water and rain water, combined with point-of-use (POU) treatment, such as the Ceramic Water Purifier (CWP) or boiling. However, Dr. Sampson fears that pesticide contamination from agriculture will increasingly threaten the quality of surface water sources and necessitate a rural treatment plant, either for disinfecting surface water or for removing arsenic from groundwater. There could be an increasing need for reliable and cheap arsenic removal technologies in regions where surface water is unavailable or too heavily contaminated. Dr. Sampson also noted that existing commercial beverage and bottled water companies may eventually want to license arsenic-removal technologies, as their source surface water could become contaminated through agricultural and industrial pollution.

A rural water center has a responsibility to provide safe water, so even a groundwater treatment plant should include precautionary disinfection because pathogens may still be present, depending on the quality of well installation. The BEAR team was able to visit one of the water disinfection centers established by RDIC but managed by two local community members. In RDIC's experience, chlorination has been shown to be the most effective while still remaining acceptable to the public, over decantation, flocculation, and ultraviolet (UV) which raise the possibility of recontamination. UV disinfection would be fairly straightforward to provide at a treatment plant that uses the BEAR method, though, because both methods require a small amount of electricity that could be provided with a small solar panel or car battery. A water treatment or distribution center must also meet regulatory requirements of the Ministry of Industry, Mines, and Energy (MINE). Unfortunately, due to corruption, MINE approval can still be purchased at this time.

RDIC also warned that the villages chosen to be surveyed by the BEAR team may not be representative of the local demand, as NGOs have saturated them will free or highly subsidized filters, rope pumps, and treated piped water systems. In reality, many villages have already show that they are willing to pay for treated piped water, piped water with POU treatment, or bottled water. There is growing public awareness of the link between drinking contaminated surface water and contracting diarrheal diseases and between drinking arsenic-contaminated groundwater and contracting arsenicosis, yet aesthetically clear bottled water that was advertised as microbiologically safe but arsenic-contaminated was still able to be sold. It is unclear whether irrigation with arsenic-contaminated water can be harmful to human health, as plant uptake varies greatly. According to RDIC, local taste preferences favor surface water over groundwater because people do not like the taste and feeling of iron-laden water. Therefore, there may be a great opportunity to address demand for safe water with an acceptable taste by coupling arsenic removal and biological disinfection with the removal of principal ions affecting water taste and texture, all at a competitive price.

In addition to treatment efficacy and cultural acceptability, proper distribution is critical for the success of any rural water center. There are tradeoffs between delivery of bottled water and installing pipes, depending on the density of the community, and the balance will likely be tipped further as gas prices rise. Recommended next steps for the BEAR team include investigating water source alternatives at each village, gathering more data on taste and convenience preferences, determining the cost of currently available bottled or piped water to set as a competitive price target, and identifying ions that affect water taste and methods of ion removal.

9.2.2 International Development Enterprises

International Development Enterprises (IDE) is a non-profit NGO that applies market-based approaches to poverty reduction in several countries. Established in 1994, the Cambodian branch of IDE is based in the city of Phnom Penh and is mostly active in the fields of agriculture, water and sanitation, to alleviate poverty in rural Cambodia. Through their market-based strategy, "IDE helps to build profitable enterprises and value chains that deliver sustainable social and economic benefits to the rural poor, enabling them to increase production and improve their quality of life" (IDE website). IDE has expertise in identifying pro-poor market opportunities through value chain analysis, the establishment of supply chains to serve the poor at affordable prices, as well as micro and small enterprise development to better serve rural markets. IDE's knowledge of local markets and experience with feasibility assessments has lead to the efficient implementation of many successful projects, including the CWP.

Country Director Michael Roberts and his intern met with BEAR to share the experience IDE gained from working in arsenic-affected communities and leveraging the market to disseminate appropriate technologies. Arsenic hotspots in Cambodia are typically found near rivers and deltas, where it is also less expensive to drill shallow wells. The close proximity to the river is correlated with a higher level of prosperity and accessibility, which translates to more infrastructure development and more awareness of water-related health risks. This means that an estimated 80% of arsenic-affected communities may already have access to electricity and willing to pay for arsenic removal or alternative safe water sources. The existing electricity source could facilitate the implementation of the BEAR treatment system and also offer an opportunity for BEAR to partner with the local grid provider or entrepreneurs with car batteries. Other possible partnerships include delivery personnel and health workers, who already travel from household to household in rural areas. Where electricity is not available, Roberts suggested looking into biomass in addition to solar, as solar can be expensive, and collaborating with the Association of Electricity Providers, a network of thousands of providers in Cambodia.

To assist with the BEAR demand assessment, IDE provided a demand assessment for sanitary latrines as an example and also reviewed a draft of the BEAR community survey. General comments were that the questions should be randomized and not be too complex. Additionally, the price people are currently paying for water serves as a useful benchmark, so IDE recommended contacting the Phnom Penh Water Authority and the water provider of the Kien Svay commune to find out current tariffs for treated piped water.

Roberts emphasized that behavior is a key issue and people often look for the lowest initial cost rather than the best value, so community-based systems deal better with higher capital cost and complex maintenance and disposal issues. In IDE's experience, a prototype costing $900, the BEAR estimate at the time, is not out of reach for a water vending business. Bundling services with water purification have many advantages, by increasing revenue for the business and adding value to its consumers. IDE recommended four key considerations for any business: design simplicity, social marketing (including television and radio), convenient distribution, and presentation aesthetics (of the buildings and containers). Next steps include reducing the cost of the system, running a one-year pilot with donor support to figure out the details of how the business will operate, and linking to local microfinance organizations and entrepreneurs. A successful model BEAR could follow is the MIREP project, which implemented small-scale water treatment plants with piped distribution for villages of 400-500 families at approximately $75,000 per village. The multi-step process consisted of a technology study, plant design, bid request via advertisements in the newspaper to reach local entrepreneurs, selection of entrepreneurs for implementation based on financing plan and level of personal investment, low interest loans to support the local entrepreneurs, installment of the plant, and sustainable operation of the plant supported by tariffs.

Additionally, one BEAR team member had an opportunity to speak with the founder of IDE International, Paul Polak, during a summit at the Massachusetts Institute of Technology. Polak recommended setting up miniature water center pilots in different communities and selling at different price points to get more accurate information about the willingness to pay, as survey data can be biased. Also, in light of the rising cost of transportation, Polak believes community water centers should be more decentralized, with up to 3 per community depending on density. The cost of distributing to greater distances and the cost of building and operating a new center should be compared.

9.2.3 Groupe de Recherche et d'Échanges Technologiques

Groupe de Recherche et d'Échanges Technologiques (GRET), known in English as the Research and Technological Exchange Group, is the not-for-profit constituent of a hybrid social-commercial venture. Created 30 years ago, GRET is a professional solidarity and international cooperation association with offices in Africa, Asia, Latin America, and Europe. GRET aims to contribute to sustainable, fair development and alleviate poverty and structural inequalities. GRET designs and implements field projects, provides expertise, conducts studies, assessments and applied research, and runs information and exchange networks to increase the incomes of rural and urban populations, reduce their vulnerability, improve their access to quality infrastructures and services, and develop their ability to be heard. The organization places considerable emphasis on experience capitalization and communication for development, in particular through its publications.

The meeting with GRET provided useful information about how to conduct effective surveys. GRET suggested avoiding focus groups in favor of surveys for individual households, to prevent peer pressure from influencing answers. Khmer staff could be recruited and trained to become survey administrators, instead of translators, to reduce misinterpretation and ensure the household members are not distracted or influenced by the presence of a foreigner. Training locals also has the advantage of scalability to survey up to hundreds of households. Other important measures for conducting successful surveys include limiting the survey to one hour maximum per household and considering the time of day that is most convenient to survey households, as some residents may prefer taking naps in the early afternoon. It is also helpful to obtain support, such as a memorandum of understanding, from the chief and committee of the village or commune before conducting any surveys.

To bring a technology to market, GRET proposed piloting the technology in the most affected communities to show results that can attract private sector investors. The staff at GRET emphasized the importance of impact-maximizing and risk reduction approaches that typically include a local co-investor, since a reputable organization can assist local entrepreneurs with receiving lower interest loans from banks. Recruiting local entrepreneurs to run the pilot is an effective way to share risk and capitalize on local expertise. In GRET's experience, it is better to select entrepreneurs with less capital because they tend to be less corrupted, more invested in the project, and trainable. To establish such a partnership, a detailed business plan needs to be advertised in local media and venues showing how the enterprise would earn income, how long it would take to recover costs, what quality control procedures would be in place, and how the enterprise would be scaled in terms of production capacity and coverage area.

9.2.4 1001 Fontaines Pour Demain

1001 Fontaines Pour Demain (1001), known in English as 1001 Fountains for Tomorrow, is an award-winning French non-governmental organization with the mission of "enabling small isolated communities to fulfill their needs for drinking water by themselves and without any specific infrastructure or skills" (1001 website). 1001 uses a structured purification process with standardized treatment units powered by solar energy to provide clean drinking water in safely-sealed bottles. One of 1001's greatest strengths is harnessing local participation, and the organization has developed several novel and effective methods to engage the communities in which they work and encourage the residents to share in the investment and operation of the water centers.

During an interview with the BEAR team, 1001 co-founder Lo Chay provided many interesting ideas for fostering community ownership and cooperative management of a safe water center. The first step is to identify an appropriate community by talking to the chief and elected officials to determine if the community has over 800 households with a 5-6 km radius, there is an untreated water source but no safe water source, there is sufficient road access, and the community members are willing to participate. 1001 looks for community members that boil water before drinking because they tend to be more health conscious, aware of water issues, and willing to pay for treated water. Often, another local NGO, such as Buddhism for Development or Institut de Technologie Cambodge (ITC), is recruited to utilize existing local contacts during the community identification process.

Once communities are identified, the next step is to commence a technical trial of the treatment technology, with 3-4 units operating under different business models, such as private ownership, community ownership, and co-operative models. The most successful model can then be scaled to the rest of the country. 1001 is now partnering with local communities to establish water centers under a franchise model. The plan is to scale to 60 operating units in 3 communes by 2010, with the target of establishing 200 units eventually. The community is responsible for finding land for the water center, identifying potential staff with writing and calculation skills, and partial investment in the treatment plant building. The staff are responsible for operation only and do not contribute any personal investment initially, so the community retains ownership of the building. 1001 provides the treatment and disinfection unit and is responsible for staff training and assisting with regulation and marketing. The first year of operation is a trial period, where the community is reimbursed for any losses. The community water center becomes autonomous during second year of operation, though 1001 still offers support with water quality assurance, maintenance, and acquiring spare parts. Water quality is checked by sending a sample into the city for testing every 3 months. A small royalty fee is paid to 1001 for access to branding, maintenance, and quality control.

To promote the water centers, 1001 organizes an opening ceremony and cinema night for the community. A humorous animated film has been developed in the local language for this purpose. An entertainer may also be hired to sell water. Chay noted that bottle aesthetics have been especially important for promotion. A well-designed bottle appears clean to customers, increasing the willingness to pay as well as the pride associated with purchasing bottled water. 1001 brands the bottles with its logo, to build trust and awareness. The strongest form of promotion in 1001's experience has been word of mouth.

Chay also shared details on the ground operation of a typical water center. Households purchase bottles initially, which are then collected, returned to the center, cleaned, refilled with treated water, and resealed with a heat sealer. The bottle lids are attached to pumps, designed so that households cannot pour water back into the bottles and re-contaminate them. Many households are also time conscious and opt to pay more to have the bottles delivered to their door or call ahead to reorder water for a pick-up time of their choice. Additional temporary workers are hired during the dry season to assist with deliveries. 1001 warns against providing piped water because of recontamination concerns with cheap infrastructure. Chlorine may need to be added to ensure water quality with piped distribution, requiring a change in the local taste and mindset. While staff salary can be either fixed or variable with sales volume, 1001 emphasized the importance of differentiating roles and pay grades. A higher paid "chief" position would make it clear who was accountable for operation of the center.

The water centers are financed through a combination of private investors, donors, and joint investments with the communities. 1001 has also established a strong corporate partnership with Dannon for additional support. Interest rates in Cambodia can often reach up to 30%. While 1001 does not currently recover costs, Chay explained that it would be possible to do so using their model in a densely populated country with higher living standards and wages, such as Bangladesh. The cost of water center is currently about $10,000. As mentioned earlier, 1001 provides the treatment equipment while the community invests approximately $2,000 in the building. To begin operation, the center also needs a bike and cart, typically around $800, and 600 bottles, which are about $2.60 each. Electricity for the UV disinfection unit is provided via batteries charged by solar panels from the Khmer Solar Co., which offers ? square meter solar panels for $400 with a 25 year guarantee. Operating costs have been around $6-8 per cubic meter of treated water, to cover the cost of treatment, transportation, and salaries.

Chay also took the BEAR team on a site visit to a water center in the Watamim Commune, which gave more insight into the local context. Cambodia is mostly governed through the decentralized system of communes. While groundwater quality is more consistent, most people still prefer to use surface water in the dry season and rainwater in the wet season, the latter of which has no minerals. The local taste is especially adverse to hardness, because it leaves a residue after boiling and looks suspicious. However, these patterns may change as agricultural runoffs add trace organics to surface water and air pollution deposits on rooftops contaminate rainwater. The center at Watamim is operating under a co-operative model, where a society of community members invested in the building and receive a percentage of profits after a fee is paid to 1001; the remaining profits go toward staff salaries. The building was simple but clean, with three separate rooms for different activities: one room for pre-treatment (including flocculation, sedimentation, and filtration with sand or alum), another room for disinfection (using UV and cartridge filters of progressively smaller sizes) along with bottle filling and sealing, and the last room for bottle washing and storage. The community watched and protected the building, agreeing to be held responsible in the case of a robbery. The untreated water source was a nearby river, brought to the center with a gasoline-powered pump. A gross-seller was responsible for delivering water and also brought bottles to the market. Chay mentioned that future centers would fold deliveries into normal operation and staff duties instead of contracting out to a gross-seller.

The Water and Sanitation (WatSan) meeting occurs every month at Ministry of Rural Development and provides a forum for various governmental departments, non-profits, and NGOs to share ideas and collaborate on future projects. At the meeting that BEAR attended, participating local organizations included RDI and GRET. From the discussion, it was made clear that the government depends heavily on the resources and work of non-profits and NGOs to drive improvements in access to and quality of water and sanitation. The government is currently focused on developing a map and database of local organizations and projects, in an attempt to quantify total impacts and ensure there are no overlapping efforts. On a more disappointing note, BEAR learned that organizations often bribe the government in order to gain support for a project or win a public contract. Overall, the WatSan meeting was a good way to gather information about the local context, institutions, and potential partners.

9.3 Synthesis and Recommendations

All organizations found ways to work with the financial and distributional challenges of rural Cambodia. The key takeaways from the meetings with experienced NGOs have been the importance of catering to local tastes and preferences, providing safe water instead of just arsenic-free water, paying attention to aesthetics to raise the willingness to pay, utilizing community-based marketing techniques to build awareness, recruiting local investors to mitigate risk, and involving the communities to develop a sense of pride and ownership. While treating surface water is the preferred method of addressing arsenic contamination, using BEAR with groundwater may become a more feasible option as surface water sources become increasingly polluted. Before proceeding with a technical trial, BEAR needs to identify an appropriate community and local partner. It would be useful to use the piloting period to test out different business models and price points and demonstrate the success of the BEAR technology to private investors.

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Appendices

A: Procedures

<u>BEAR IN CAMBODIA: SUMMER 2008 COMMUNITY ASSESSMENT PROTOCOL</u>

Before visit:

- Have the survey double-translated (English to Khmer to English)
- Brief the translator on the questions and procedure. If possible, the same translator for all surveys to maintain consistency.
- Select 3 accessible target villages in which arsenic levels exceeding 150 ppb have been monitored in the majority of the pump wells. Collect the following village data:
    - Approximate community population size and distribution
    - Demographics if possible
    - Access to grid electricity
    - Approximate distance to nearest province capital
    - Approximate distance to nearest paved road
    - Approximate distance to nearest health facility
    - Approximate distance to RDI
    - *Should we also make note of potential partners for promotion, like radio stations and schools?*
- Contact the local village chief/health worker/school leader/village development committee and set up an appointment for the morning of the visit.
- Select 3 contaminated wells (>150 ppb) that are monitored by RDI, have high levels of Si, HCO_3, or P, have low levels of Fe, and are geographically dispersed in the community. Label each well, collect well information:
    - GPS
    - Is the well painted?
    - Mean and seasonal variation in As, Si, HCO_3, P, Fe, turbidity, and E. coli when available

Village visit:

1. Introduction interview (1 hour)

Meet with village chief and/or health workers and village development committee

- Introduce ourselves, explain the purpose of the interviews and testing, the expected benefits of the research solutions, what we want to know and why
- Share the 3 selected wells and ask the leader to select 2 households that use each well for interviews (approximately 30 minutes each)
- Find out when the leader believes the head of household and spouse of the selected households will available for interviews (<u>arrange tasks 2a, 2b, 2c accordingly)</u>
- Thank the leader and with permission, document the meeting by taking photos afterwards

2a. Well #1: ARUBA Testing, Household Surveys, Water Collection (1.5 hours)

Split the team into 2 groups

- ARUBA testing
  - P1 and P2 will perform the ARUBA testing (see ARUBA testing procedure)
  - P1 and P2 will also perform AAS field tests before and after ARUBA treatment for each test *(I thought Kristin asked us to do this? It's not in their procedure…)*
  - P1 and P2 will collect pH, DO and T of ARUBA treated samples *(I moved this from the water collection procedure)*
- Household surveys (2 at approximately 30 minutes each)
  - P3 will talk (give introduction, ask questions, thank the interviewees)
  - RDI staff will translate
  - P4 will take notes
  - Thank the interviewee and with permission, document the interview by taking photos afterwards
- Water collection
  - P3 and P4 will get the pH, DO and T probes from P1 and P2
  - P3 and P4 will collect BEAR water samples (see BEAR water collection procedure)
  - P3 and P4 will return the pH, DO and T probes to P1 and P2
  - P3 and P4 will bring BEAR water samples back to the car

2b. Well #2: ARUBA Testing, Household Surveys, Water Collection (1.5 hours)
Repeat process.

2c. Well #3: ARUBA Testing, Household Surveys, Water Collection (1.5 hours)
Repeat process.

BEAR WATER COLLECTION PROCEDURE

Objective: Collect and characterize 20 liters of As contaminated water for each of the 3 selected community wells

Equipment:
3 Capped 20 liter water jars
DO, pH, T probes
Arsenic field AAS test
Lab notebook
Masking tape
Sharpies

Procedure (at each well):

1. Record date and time, well location, and any observations in lab notebook
2. Make sure the well has been pumped for at least 5 minutes
3. Measure and record pH, DO and T in lab notebook
4. Perform As field test
5. Fill 20 liter jar <u>up to the top</u> and cap it ASAP
6. Label the sample and bring it back to the car

BEAR IN CAMBODIA: SUMMER 2008 LABORATORY PROTOCOL

Materials (minimum amounts)

- 33 QT containers (and additional equipment for QT)
- 34 AAS containers
- 2 1 L beakers (to collect water as it flows through Sushi)
- Vacuum filter and hose
- 2 Erlenmeyer flasks with funnels and vacuum attachments
- 21 0.45 μm filters
- 2 stirrers
- Power supply (either galvanostat or 12 V battery + Wasabi), electrical connections
- pH and DO meters
- Multimeter
- Bucket, sushi
- Screwdriver (cross)

Sushi start-up protocol

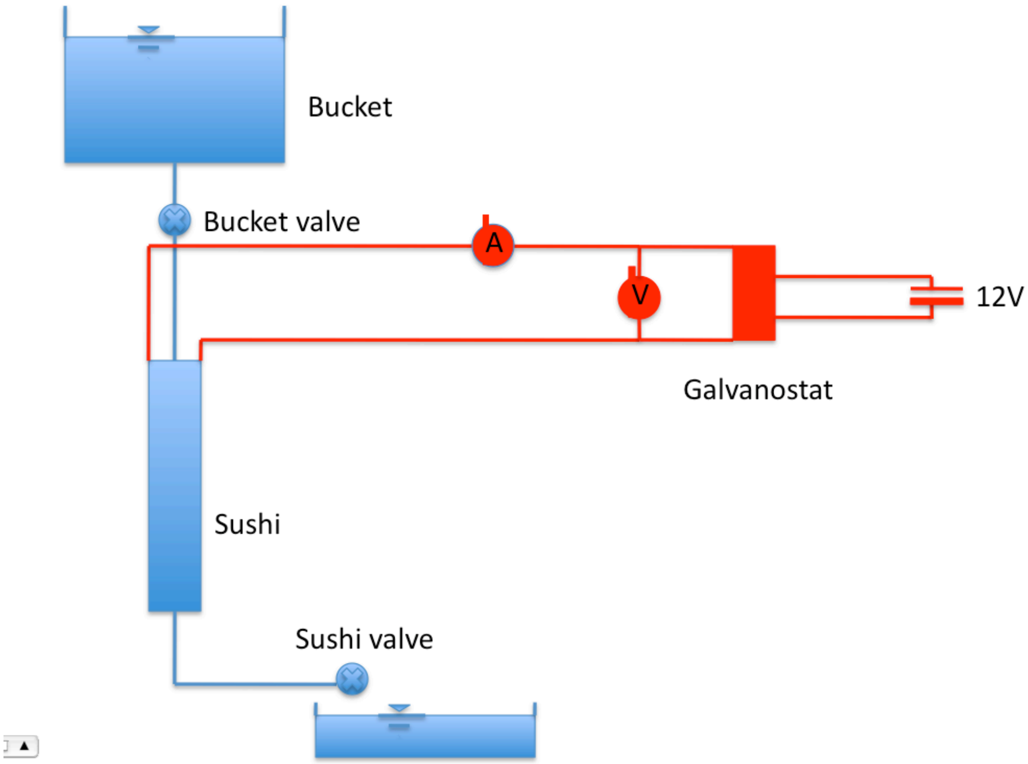
Preliminary checks:

- The electrodes don't touch. Short circuit check: ohm-meter indicates > 100kΩ
- The fishing wire is inserted in the sealing groves
- The bucket and prototype are stable
- Both valves (bucket and sushi) are closed
- The vent screw on the sushi box is opened.
- Check the polarity of the electric connection to the 12V battery
- The electrode seals must always be unscrewed before opening the sushi, in order not to rip the electrodes off.

Perform the following before proceeding with any of the following parts:

1. Fill the bucket with at least 4 liters of untreated water.
2. Open the bucket valve and let the sushi fill with water. Let as much air as possible escape.
3. Close the sushi vent screw.
4. Secure electrical connections (on dry electrodes). CHECK POLARITY
5. Set flow rate: *slightly* open the sushi valve and measure the time needed to fill a 50 mL beaker. Do not close the valve.
6. Turn the electricity on so that it corresponds to 1.1 mA/cm^2, knowing that the effective electrode area is 1006cm2; measure voltage.
7. Allow at least 3 liters to flow in order to reach steady state.
8. Proceed to the sampling described below (do not forget to regularly measure the voltage). Assign one person to ensure that the water level in the bucket is always around 2 liters ± 0.5 liters by gradually filling in the remaining untreated water (when there is no more water, just let the level decrease).

Lab Setup



Electrode geometry

	mm	in
L	1397	55
W	90	3.5
T	5	0.2
Diam	90	3.5
	cm2	
Area	1257.3	
Effective area	1005.84	

Part 1: Proof-of-concept

Perform the following for each of the 9 batches of water collected from the field:

1. Collect 1 QT and 1 AAS sample from the untreated water.
2. Measure the pH and DO of the untreated water.
3. Run the water through the Sushi prototype under the following conditions (determine corresponding current and flow rate):
    a. $i = 1.1$ mA/cm^2
    b. $q = 300$ C/L
4. Collect 250 mL of water after 1 L of water has flowed through the prototype.
5. Stir the treated water for 40 minutes.
6. Vacuum filter the treated water using a 0.45 μm filter.
7. Collect 1 QT and 1 AAS sample from the treated water.
8. Perform QT and submit AAS sample for lab analysis.

→ 18 QT and 18 AAS samples

Part 2: Dosing

Perform the following for each of the 2 batches of water selected for dosing testing:

9. Collect 1 QT and 1 AAS sample from the untreated water.
10. Measure the pH and DO of the untreated water.
11. Run the water through the Sushi prototype under the following conditions (determine corresponding current and flow rate):
    a. $i = 1.1$ mA/cm^2
    b. $q = 250$ C/L
12. Collect 250 mL of water after 1 L of water has flowed through the prototype.
13. Stir the treated water for 40 minutes.
14. Vacuum filter the treated water using a 0.45 μm filter.
15. Collect 1 QT and 1 AAS sample from the treated water.
16. Perform QT and submit AAS sample for lab analysis.
17. Repeat steps 11 through 16 using q = 200, 150, and 100 C/L.

→ 10 QT and 10 AAS samples

Part 3: Current density

Perform the following for the batch of water selected for current density testing:

18. Collect 1 QT and 1 AAS sample from the untreated water.
19. Measure the pH and DO of the untreated water.
20. Run the water through the Sushi prototype under the following conditions (determine corresponding current and flow rate):
    a. $i > 1.1$ mA/cm^2
    b. q = selected in Part 3

21. Collect 250 mL of water after 1 L of water has flowed through the prototype.
22. Stir the treated water for 40 minutes.
23. Vacuum filter the treated water using a 0.45 μm filter.
24. Collect 1 QT and 1 AAS sample from the treated water.
25. Perform QT and submit AAS sample for lab analysis.
26. Repeat steps 20 through 25 using another value of *i* that is greater than 1.1 mA/cm^2, and 2 values of *i* that are less than 1.1 mA/cm^2. Note that flow rates will change in order to maintain a constant *q*.

→ 5 QT and 5 AAS samples

Total samples: 33 QT and 33 AAS samples, + 1 blank sample for AAS

B: Survey

Informed Consent Form:

We are investigating the feasibility of a community-based treatment center to remove arsenic from groundwater. We intend to ask questions about health, water supply, and socio-economic status in relation to your village. The whole process should take 20-30 minutes.

The choice to take part is entirely yours and you are free to stop at any point. If there is a question you do not wish to answer then you don't have to. All this information will be kept confidential as much as possible. Your name and address will not appear anywhere in the write up of this project.

Verbal Agreement:

The above description was read/translated to me by **< *Name Of Translator* >** who explained to me anything that I did not understand and answered all of my questions. I voluntarily agree to participate in this research.

Household Survey #1 in PreakRussei
7/2 @ 1:20pm to 1:50pm
BEAR: Jessica, Michele
RDI: Samrach

Survey Information

Date	02/07/08	Time	13:20 to 13:50
Village Code	PR	Household #	☒ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Interviewers	Jessica, Michele	Translator	Sam
Documenters	Jessica, Michele	Interviewee Information	Age: ☐ 20-35 ☐ 36-50 ☒ 50+ Gender: ☐ M ☒ F

Socio Economic

No.	Question	Answer
Q1	How many people live in your house, including you? What is everyone's age?	1_____ Under 12 1_____ 12 to 20 2_____ 20 to 50 2_____ Over 50 6_____ Total # living in household
Q2	What is your occupation?	Rice farmer
Q3	What was your cash income from all household members and from all sources in the past 12 months?	☐ $0-300 ☐ $301-600 ☐ $601-900 ☒ $901 & above (Note: This is a sensitive question, especially when it is asked in front of other villagers, so it is difficult to get a straight answer. The family would not give a number so Sam guessed based on their answers. Other assets noticed at this household were a corrugated metal sheet on half of the roof, a TV, a battery, 1 cow, which could have belonged to the neighbor, and 1 rope pump, which was provided by RDI at no cost. The floors were packed dirt and there were no latrines.) ☒ Poor ☐ Medium ☐ Rich
Q4	How much money did your household spend buying food last month?	$107.14 (15000R/d * 30d/mo * $1/4200R)
Q5	What else do you remember your household buying during the last month? *(Cigarettes? Clothes?)*	Doesn't remember
Q6	How long did it take your household to go to the market last time? On average?	_____ minutes last time _____ minutes on average The seller comes to her house

Electricity

No.	Question	Answer
Q7	Is there electricity/electrical appliances your house?	☒ Yes *(Continue on to **Q8**)* ☐ No *(Skip to **Q19**)* (Note: To the villagers, having electricity implies being connected to the grid.)
The following questions are for households **with electricity**:		
Q8	How many hours of electricity did	_____ hours

	your household use last week?	Unclear how many hours but use ~6 days/week (each battery charge lasts 2 days; battery charged 3 times most weeks with some variance because it is expensive)
Q9	What did your household use electricity for last week?	TV, lamp
Q10	How much did your household pay for electricity last month?	$5.14/month (1800R/charge * 3 charge/wk * 4 wk/mo * $1/4200R)
Q11	Are you (personally) satisfied with the current electricity supply? Why?	☐ Yes ☒ No Why? Sam says that it is a common mindset to always want something better than what one currently has.
Q12	What is your electricity source? *(Please show me your source)*	☒ Battery *(Continue on to **Q13**)* ☐ Local electric network *(Skip to **Water Behavior**)* ☐ Other (specify) ___________ *(Skip to **Water Behavior**)*
The following questions are for households that use a **battery**:		
Q13	Is the source a self-owned car battery?	☒ Yes *(Continue on to **Q14**)*

		☐ No *(Skip to **Q17**)*
The following questions are for households that use a **self-owned battery**:		
Q14	How often did you reload your car battery last week?	3 times/week
Q15	How far is the charging station?	200 meters
Q16	How much did you pay last time to recharge your car battery?	$0.43 (1800R * $1/4200R) Price depends on battery size: 40: 1600R 50: 1800R 70: 2200R *(Skip to **Water Behavior**)*
The following questions are for households that use **another person's battery**:		
Q17	How far is the battery you are using?	______ meters
Q18	How often did you go to the battery last month?	☐ Once a one week ☐ Twice a month ☐ Once a month *(Skip to **Water Behavior**)*
The following questions are for households **without electricity**:		

Q19	Why doesn't your household have electricity?	No power line available in the village
Q20	Would your household want to have electricity tomorrow if it cost <u>*$1*</u> per week? *(Replace with $2, 3$, …, $7)*	Max willingness to pay: ☐ $0 ☐ $1 ☐ $2 ☐ $3 ☐ $4 ☐ $5 ☐ $6 ☐ $7
Q21	At this price, would your household regularly carry a car battery to a charging station near the village head's house? *(Note distance to village head's house)*	☐ Yes ☐ No Distance to village head's house: _____ meters
Q22	What would your household use electricity for?	

Water Behavior

No.	Question	Answer
Q23	During the **<u>wet season</u>**, how does your household get drinking water, how often does your household use each source and how much does your household pay?	*Source* *Cost* <u>x</u>__ % Rainwater __________ (used ~1day/wk) <u>x</u>__ % Surface water __________ (5 min walk, available 1-2 mo/yr) ___ % Tube well __________ ___ % Water vendor __________ ___ % Bottled water __________ ___ % Piped water __________ <u>x</u>__ % Other __________ (Rope pump, used ~6 days/wk) *100 % Total*
Q24	During the **<u>dry season</u>**, how does your household get drinking water, how often does your household use each source and how much does your household pay?	*Source* *Cost* ___ % Rainwater __________ ___ % Surface water __________ ___ % Tube well __________ ___ % Water vendor __________ ___ % Bottled water __________ ___ % Piped water __________ <u>100</u> % Other (rope pump) __________ *100 % Total*
Q25	The last time your household fetched water, how long did the roundtrip take? On average?	___ minutes last roundtrip ___ minutes on average
Q26	How many times did your household fetch water last week? On average?	___ trips per week ___ trips on average
Q27	Who collected the water for your household yesterday? On average?	Yesterday: <u>Daughter</u> On average: <u>Son-in-law</u>

Arsenic Awareness

No.	Question	Answer

Q28	Have you heard of arsenic?	☒ Yes *(Continue on to **Q31**)* ☐ No *(**End** survey)*
The following questions are for interviewees that have **heard of arsenic**:		
Q29	How did you hear of it? *(Check all that apply)*	☒ NGO ☐ Commune Council ☐ Village Development Committee ☐ Health Center ☐ Village Health Worker ☐ Other villagers ☐ Other (specify) ________________
Q30	Are you aware of arsenic-free water sources near here? If so, are you using the arsenic-free sources?	☒ Aware ☐ Not aware (Piped water next to house) | ☒ Using ☐ Not using
Q31	Would you walk to a free surface safe drinking water source <u>*5 min*</u> away? *(Replace with 10, 15, 20)*	Max willingness to walk: ☐ 5 min ☐ 10 min ☐ 15 min ☐ 20 min
Q32	Would you walk to a free underground safe drinking water source <u>*5 min*</u> away? *(Replace with 10, 15, 20)*	Max willingness to walk: ☐ 5 min ☐ 10 min ☐ 15 min ☐ 20 min
Q33	Would you pay <u>*1000 R*</u> per week for an unlimited amount of safe drinking water for your household from a standpipe near the village head's house? *(Replace with 2000, 3000,…,6000)* *(Note distance to village head's house)*	Max willingness to pay: ☐ 1000 R ☐ 2000 R ☐ 3000 R ☐ 4000 R ☐ 5000 R ☐ 6000 R Distance to village head's house: _____ meters
Q34	Would you pay <u>*2000 R*</u> per week to have safe drinking water delivered to your home? *(Replace with 3000,43000,…,6000)*	Max willingness to pay: ☐ 2000 R ☐ 4000 R ☐ 6000 R ☐ 8000 R ☐ 10000 R
Q35	Are you aware of any diseases caused by arsenic? If so, what diseases?	☐ None/Don't Know *(**End** survey)* ☒ List of diseases: <u>Bumpy skin</u>
The following questions are for interviewees **aware of diseases caused by arsenic**:		
Q36	Does anyone in your household have symptoms of these diseases?	☒ Yes *(Continue on to **Q37**)* ☐ No *(**End** survey)*
Q37	What are the symptoms and who is suffering from them?	Who: <u>Neighbor's son (11 yrs)</u> Symptoms: <u>Bumpy skin on stomach</u>

Notes:

- Context:
    - Tube well being sampled was installed 7 years ago (hand pump replaced in 2005)
    - Switched away from tube well 2 years ago after NGO warned the village about arsenic
    - Before RDI marked the well, 20-30 households drank from the red-painted tube well PR01
    - Households in the village are no longer using the red-painted tube wells for drinking (only for washing)
    - Rope pump and tube well are located right next to the home

- Red paint on tube well is already coming off
- Household behavior:
  - Household off the grid and also poor—unclear if family would pay additional money for electricity if they already have a battery
  - Occasionally drink unfiltered surface water
  - Prefer to drink treated piped water because it is perceived as trustworthy, but they cannot pay for it
- Interview logistics:
  - About 35 people were watching this interview, which may have affected the answers (especially for the income question) because of neighbor dynamics and jealousy
  - Everyone nearby the interviewed house gathers around so it may be difficult to interview 2 separate households per well

Household Survey #2 in PreakRussei
7/2 @ 2:50pm to 3:20pm
BEAR: Jessica, Michele
RDI: Samrach

SURVEY INFORMATION

Date	02/07/08	Time	14:50 to 15:20
Village Code	PR	Household #	☐ 1 ☒ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6
Interviewers	Jessica, John, Marc, Michele	Translator	Sam
Documenters	Michele	Interviewee Information	Age: ☐ 20-35 ☒ 36-50 ☐ 50+ Gender: ☐ M ☒ F

SOCIO ECONOMIC

No.	Question	Answer
Q1	How many people live in your house, including you? What is everyone's age?	1_____ Under 12 0_____ 12 to 20 3_____ 20 to 50 0_____ Over 50 4_____ Total # living in household
Q2	What is your occupation?	Farmer during ½ the year
Q3	What was your cash income from all household members and from all sources in the past 12 months?	☒ $0-300 ☐ $301-600 ☐ $601-900 ☐ $901 & above (The daughter living in town may send money back but it is not counted here) ☒ Poor ☐ Medium ☐ Rich

Q4	How much money did your household spend buying food last month?	$35.71 (5000R/d * 30d/mo * $1/4200R)
Q5	What else do you remember your household buying during the last month? *(Cigarettes? Clothes?)*	Nothing
Q6	How long did it take your household to go to the market last time? On average?	_____ minutes last time _____ minutes on average The seller comes to her house

ELECTRICITY

No.	Question	Answer
Q7	Is there electricity/an electrical appliance in your house?	☑ Yes *(Continue on to **Q8**)* ☐ No *(Skip to **Q19**)* (Note: To the villagers, having electricity implies being connected to the grid.)
The following questions are for households **with electricity**:		
Q8	How many hours of electricity did your household use last week?	21 hours
Q9	What did your household use electricity for last week?	lamp
Q10	How much did your household pay for electricity last month?	$4.19/month (2200R/charge * 2 charge/wk * 4 wk/mo * $1/4200R)
Q11	Are you (personally) satisfied with the current electricity supply? Why?	☐ Yes ☑ No Why? It is too expensive.
Q12	What is your electricity source? *(Please show me your source)*	☑ Battery *(Continue on to **Q13**)* ☐ Local electric network *(Skip to **Water Behavior**)* ☐ Other (specify) ___________ *(Skip to **Water Behavior**)*
The following questions are for households that use a **battery**:		
Q13	Is the source a self-owned car battery?	☑ Yes *(Continue on to **Q14**)* ☐ No *(Skip to **Q17**)*
The following questions are for households that use a **self-owned battery**:		
Q14	How often did you reload your car battery last week?	2 times/week
Q15	How far is the charging station?	1000 meters
Q16	How much did you pay last time to recharge your car battery?	$0.52 (2200R * $1/4200R) Price depends on battery size:

		40: 1600R 50: 1800R 70: 2200R *(Skip to* ***Water Behavior****)*
The following questions are for households that use **another person's battery**:		
Q17	How far is the battery you are using?	______ meters
Q18	How often did you go to the battery last month?	□ Once a one week □ Twice a month □ Once a month *(Skip to* ***Water Behavior****)*
The following questions are for households **without electricity**:		
Q19	Why doesn't your household have electricity?	No power line available in the village
Q20	Would your household want to have electricity tomorrow if it cost <u>*$1*</u> per week? *(Replace with $2, 3$, …, $7)*	Max willingness to pay: □ $0 □ $1 □ $2 □ $3 □ $4 □ $5 □ $6 □ $7
Q21	At this price, would your household regularly carry a car battery to a charging station near the village head's house? *(Note distance to village head's house)*	□ Yes □ No Distance to village head's house:

		_____ meters
Q22	What would your household use electricity for?	

WATER BEHAVIOR

No.	Question	Answer
Q23	During the **<u>wet season</u>**, how does your household get drinking water, how often does your household use each source and how much does your household pay?	*Source* *Cost* <u>x</u>__ % Rainwater __________ (first preference) <u>x</u>__ % Surface water __________ (last choice) ___ % Tube well __________ ___ % Water vendor __________ ___ % Bottled water __________ ___ % Piped water __________ <u>X</u>__ % Other __________ (rope pump is second preference) *100 % Total*
Q24	During the **<u>dry season</u>**, how does your household get drinking water, how often does your household use each source and how much does your household pay?	*Source* *Cost* ___ % Rainwater __________ <u>100</u> % Surface water <u><<$0.01/liter</u> (untreated surface water costs 1500R to pump into rain water jar and is stored up to 10 days and drunken directly)

		___ % Tube well ________ ___ % Water vendor ________ ___ % Bottled water ________ ___ % Piped water ________ ___ % Other ________ *100 % Total* (Note: Sources left over from wet season are used in dry season until they run out)
Q25	The last time your household fetched water, how long did the roundtrip take? On average?	10 minutes last roundtrip (last year) ___ minutes on average (very rare—only during wet season when both other options run out, 30L collected each time, time includes walking and boating)
Q26	How many times did your household fetch water last week? On average?	___ trips per week ___ trips on average
Q27	Who collected the water for your household yesterday? On average?	Yesterday: ________ On average: Interviewee

ARSENIC AWARENESS

No.	Question	Answer
Q28	Have you heard of arsenic?	☑ Yes *(Continue on to **Q31**)* ☐ No *(**End** survey)*
The following questions are for interviewees that have **heard of arsenic**:		

Q29	How did you hear of it? *(Check all that apply)*	☑ NGO ☐ Commune Council ☐ Village Development Committee ☐ Health Center ☐ Village Health Worker ☐ Other villagers ☑ Other (specify) Government	
Q30	Are you aware of any health impacts from drinking or consuming arsenic?	☑ Yes (specify) bumpy skin, foot lesions ☐ No (No one in household has arsenicosis symptoms, but neighbors do)	
Q31	Are you aware of arsenic-free water sources near here? If so, are you using the arsenic-free sources?	☑ Aware ☐ Not aware (Rain water and rope pump next to house)	☑ Using ☐ Not using

Notes:

- Context:
  - NGOs and government have been coming to this village since first arsenic case in 2006
  - Used to use neighbors tube well PR01, but it was already covered
  - The samples are collected from a different well than PR01
  - There is a rope pump in front of the house (provided by RDI for free), but it may run out during dry season
- Household behavior:
  - Car battery is too old for TV, used for lamp only
  - Unwilling to pay for arsenic free water because they already get it for free

Household Survey #3 in PreakRussei
7/2 @ 3:43pm to 4:10pm
BEAR: Jessica
RDI: Samrach

Survey Information

Date	*02/07/08*	Time	15:43 to 14:10
Village Code	PR	Household #	☐ 1 ☐ 2 ☒ 3 ☐ 4 ☐ 5 ☐ 6
Interviewers	Jessica	Translator	Sam
Documenters	Jessica	Interviewee Information	Age: ☐ 20-35 ☐ 36-50 ☒ 50+ Gender: ☐ M ☒ F

Socio Economic

No.	Question	Answer
Q1	How many people live in your house, including you? What is everyone's age?	0_____ Under 12 0_____ 12 to 20 3_____ 20 to 50 2_____ Over 50 5_____ Total # living in household
Q2	What is your occupation?	Rice farmer
Q3	What was your cash income from all household members and from all sources in the past 12 months?	☐ $0-300 ☐ $301-600 ☐ $601-900 ☐ $901 & above (Too sensitive of a question) ☒ Poor ☐ Medium ☐ Rich
Q4	How much money did your household spend buying food last month?	$71.42 (10000R/d * 30d/mo * $1/4200R)
Q5	What else do you remember your household buying during the last month? *(Cigarettes? Clothes?)*	
Q6	How long did it take your household to go to the market last time? On average?	_____ minutes last time _____ minutes on average The seller comes to her house

Electricity

No.	Question	Answer
Q7	Is there electricity/an electrical appliance in your house?	☒ Yes *(Continue on to **Q8**)* ☐ No *(Skip to **Q19**)* (Note: To the villagers, having electricity implies being connected to the grid.)
The following questions are for households **with electricity**:		
Q8	How many hours of electricity did your household use last week?	24.5 hours (3.5 hr/day*7day/wk)
Q9	What did your household use electricity for last week?	TV, lamp
Q10	How much did your household pay for electricity last month?	$3.43/month (1800R/charge * 2 charge/wk * 4 wk/mo * $1/4200R)

Q11	Are you (personally) satisfied with the current electricity supply? Why?	☐ Yes ☐ No Why? They prefer a direct power line to their home.
Q12	What is your electricity source? *(Please show me your source)*	☐ Battery *(Continue on to **Q13**)* ☐ Local electric network *(Skip to **Water Behavior**)* ☐ Other (specify) ____________ *(Skip to **Water Behavior**)*
The following questions are for households that use a **battery**:		
Q13	Is the source a self-owned car battery?	☐ Yes *(Continue on to **Q14**)* ☐ No *(Skip to **Q17**)*
The following questions are for households that use a **self-owned battery**:		
Q14	How often did you reload your car battery last week?	2 times/week
Q15	How far is the charging station?	1000 meters
Q16	How much did you pay last time to recharge your car battery?	$0.43 (1800R * $1/4200R) Price depends on battery size:
		40: 1600R 50: 1800R 70: 2200R *(Skip to **Water Behavior**)*
The following questions are for households that use **another person's battery**:		
Q17	How far is the battery you are using?	______ meters
Q18	How often did you go to the battery last month?	☐ Once a one week ☐ Twice a month ☐ Once a month *(Skip to **Water Behavior**)*
The following questions are for households **without electricity**:		
Q19	Why doesn't your household have electricity?	No power line available in the village
Q20	Would your household want to have electricity tomorrow if it cost $1 per week? *(Replace with $2, 3$, …, $7)*	Max willingness to pay: ☐ $0 ☐ $1 ☐ $2 ☐ $3 ☐ $4 ☐ $5 ☐ $6 ☐ $7
Q21	At this price, would your household regularly carry a car battery to a charging station near the village head's house? *(Note distance to village head's house)*	☐ Yes ☐ No Distance to village head's house:

		_____ meters
Q22	What would your household use electricity for?	

WATER BEHAVIOR

No.	Question	Answer
Q23	During the **wet season**, how does your household get drinking water, how often does your household use each source and how much does your household pay?	*Source* *Cost* x__ % Rainwater __________ (first preference because it is perceived as clean) x__ % Surface water __________ (second preference, gas costs 5500R/L and half liter is used for transport) ___ % Tube well __________ ___ % Water vendor __________ ___ % Bottled water __________ ___ % Piped water __________ ___ % Other __________ *100 % Total*
Q24	During the **dry season**, how does your household get drinking water, how often does your household use each source and how much does your household pay?	*Source* *Cost* ___ % Rainwater __________ ___ % Surface water __________ ___ % Tube well __________ ___ % Water vendor __________ ___ % Bottled water __________ ___ % Piped water __________ x__ % Other (storage) __________ *100 % Total*
Q25	The last time your household fetched water, how long did the roundtrip take? On average?	___ minutes last roundtrip 30 minutes on average (for surface water including pumping time, although sometimes it takes longer if a car or motorbike runs over the pipes and they need to be reconnected)
Q26	How many times did your household fetch water last week? On average?	___ trips per week ___ trips on average
Q27	Who collected the water for your household yesterday? On average?	Yesterday: __________ On average: Husband Son (if husband is busy)

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ARSENIC AWARENESS

No.	Question	Answer
Q28	Have you heard of arsenic?	☐ Yes *(Continue on to **Q31**)* ☐ No *(**End** survey)*
The following questions are for interviewees that have **heard of arsenic**:		
Q29	How did you hear of it? *(Check all that apply)*	☐ NGO ☐ Commune Council

		☐ Village Development Committee ☐ Health Center ☐ Village Health Worker ☐ Other villagers ☐ Other (specify) _______________	
Q30	Are you aware of arsenic-free water sources near here? If so, are you using the arsenic-free sources?	☒ Aware ☐ Not aware (surface water 80m from house)	☒ Using ☐ Not using
Q31	Would you walk to a free surface safe drinking water source <u>*5 min*</u> away? *(Replace with 10, 15, 20)*	Max willingness to walk: ☐ 5 min ☐ 10 min ☐ 15 min ☐ 20 min	
Q32	Would you walk to a free underground safe drinking water source <u>*5 min*</u> away? *(Replace with 10, 15, 20)*	Max willingness to walk: ☐ 5 min ☐ 10 min ☐ 15 min ☐ 20 min	
Q33	Would you pay <u>*1000 R*</u> per week for an unlimited amount of safe drinking water for your household from a standpipe near the village head's house? *(Replace with 2000, 3000,…,6000)* *(Note distance to village head's house)*	Max willingness to pay: ☐ 1000 R ☐ 2000 R ☐ 3000 R ☐ 4000 R ☐ 5000 R ☐ 6000 R Distance to village head's house: _____ meters	

Q34	Would you pay <u>*2000 R*</u> per week to have safe drinking water delivered to your home? *(Replace with 3000,43000,…,6000)*	Max willingness to pay: ☐ 2000 R ☐ 4000 R ☐ 6000 R ☐ 8000 R ☐ 10000 R
Q35	Are you aware of any diseases caused by arsenic? If so, what diseases?	☐ None/Don't Know *(**End** survey)* ☒ List of diseases: <u>(interviewee didn't specify)</u>
The following questions are for interviewees **aware of diseases caused by arsenic**:		
Q36	Does anyone in your household have symptoms of these diseases?	☒ Yes *(Continue on to **Q37**)* ☐ No *(**End** survey)*
Q37	What are the symptoms and who is suffering from them?	Who: <u>Husband</u> Symptoms: <u>Bumpy skin on stomach</u>

No.	Question	Answer
Q28	Have you heard of arsenic?	☒ Yes *(Continue on to **Q31**)* ☐ No *(**End** survey)*
The following questions are for interviewees that have **heard of arsenic**:		
Q29	How did you hear of it? *(Check all that apply)*	☒ NGO ☐ Commune Council ☐ Village Development Committee ☐ Health Center

		☐ Village Health Worker ☐ Other villagers ☐ Other (specify) ________________	
Q30	Are you aware of arsenic-free water sources near here? If so, are you using the arsenic-free sources?	☒ Aware ☐ Not aware (Piped water next to house)	☒ Using ☐ Not using
Q31	Would you walk to a free surface safe drinking water source <u>*5 min*</u> away? *(Replace with 10, 15, 20)*	Max willingness to walk: ☐ 5 min ☐ 10 min ☐ 15 min ☐ 20 min	
Q32	Would you walk to a free underground safe drinking water source <u>*5 min*</u> away? *(Replace with 10, 15, 20)*	Max willingness to walk: ☐ 5 min ☐ 10 min ☐ 15 min ☐ 20 min	
Q33	Would you pay <u>*1000 R*</u> per week for an unlimited amount of safe drinking water for your household from a standpipe near the village head's house? *(Replace with 2000, 3000,…,6000)* *(Note distance to village head's house)*	Max willingness to pay: ☐ 1000 R ☐ 2000 R ☐ 3000 R ☐ 4000 R ☐ 5000 R ☐ 6000 R Distance to village head's house: _____ meters	
Q34	Would you pay <u>*2000 R*</u> per week to have safe drinking water delivered to your home?	Max willingness to pay: ☐ 2000 R ☐ 4000 R ☐ 6000 R	

	(Replace with 3000,43000,…,6000)	☐ 8000 R ☐ 10000 R
Q35	Are you aware of any diseases caused by arsenic? If so, what diseases?	☐ None/Don't Know (***End** survey)* ☒ List of diseases: <u>Bumpy skin</u>
The following questions are for interviewees **aware of diseases caused by arsenic**:		
Q36	Does anyone in your household have symptoms of these diseases?	☒ Yes *(Continue on to **Q37**)* ☐ No *(**End** survey)*
Q37	What are the symptoms and who is suffering from them?	Who: <u>Neighbor's son (11 yrs)</u> Symptoms: <u>Bumpy skin on stomach</u>

Notes:
- Context:
  - RDI came after they heard about arsenicosis breakout in village and brought pictures of symptoms to educate the people, the husband of this household noticed his belly matched the pictures so he got his family to stop drinking from the tube well PR02
  - RDI tried to put in treated piped water w/ cost sharing but was rejected by families (difficult to do arsenic removal business or arsenic-free water business because there are already arsenic-free water sources available at no cost that people perceive as clean)
- Household behavior:
  - Ceramic water purifier is used to treat all water before drinking
- Interview logistics:
  - Husband joined interview and also contributed to answers

Household Survey #4 in PreakRussei
7/2 @ 4:23pm to 4:34pm
BEAR: Jessica
RDI: Samrach

SURVEY INFORMATION

Date	*02/07/08*	Time	16:23 to 16:34
Village Code	PR	Household #	☐ 1 ☐ 2 ☐ 3 ☒ 4 ☐ 5 ☐ 6
Interviewers	Jessica	Translator	Sam
Documenters	Jessica	Interviewee Information	Age: ☒ 20-35 ☐ 36-50 ☐ 50+ Gender: ☐ M ☒ F

SOCIO ECONOMIC

No.	Question	Answer
Q1	How many people live in your house, including you? What is everyone's age?	1_____ Under 12 0_____ 12 to 20 2_____ 20 to 50 0_____ Over 50 3_____ Total # living in household
Q2	What is your occupation?	Housewife
Q3	What was your cash income from all household members and from all sources in the past 12 months?	☐ $0-300 ☐ $301-600 ☐ $601-900 ☐ $901 & above (Too sensitive of a question) ☒ Poor ☐ Medium ☐ Rich
Q4	How much money did your household spend buying food last month?	$71.42 (10000R/d * 30d/mo * $1/4200R)
Q5	What else do you remember your household buying during the last month? *(Cigarettes? Clothes?)*	2 piglets at 200,000R/each
Q6	How long did it take your household to go to the market last time? On average?	_____ minutes last time _____ minutes on average The seller comes to her house

ELECTRICITY

No.	Question	Answer
Q7	Is there electricity/electrical appliances your house?	☒ Yes *(Continue on to **Q8**)* ☐ No *(Skip to **Q19**)* (Note: To the villagers, having electricity implies being connected to the grid.)
The following questions are for households **with electricity**:		
Q8	How many hours of electricity did your household use last week?	14___ hours (2 hr/day * 7 day/wk)
Q9	What did your household use electricity for last week?	TV, lamp
Q10	How much did your household pay for electricity last month?	$4.57/month (1600R/charge * 3 charge/wk * 4 wk/mo * $1/4200R)

Q11	Are you (personally) satisfied with the current electricity supply? Why?	☐ Yes ☒ No Why? Feel that they need a power line and would like a businessman to run a power line to their house
Q12	What is your electricity source? *(Please show me your source)*	☒ Battery *(Continue on to **Q13**)* ☐ Local electric network *(Skip to **Water Behavior**)* ☐ Other (specify) ____________ *(Skip to **Water Behavior**)*
The following questions are for households that use a **battery**:		
Q13	Is the source a self-owned car battery?	☒ Yes *(Continue on to **Q14**)* ☐ No *(Skip to **Q17**)*
The following questions are for households that use a **self-owned battery**:		
Q14	How often did you reload your car battery last week?	3 times/week
Q15	How far is the charging station?	1500 meters
Q16	How much did you pay last time to recharge your car battery?	$0.38 (1600R * $1/4200R)
		Price depends on battery size: 40: 1600R 50: 1800R 70: 2200R *(Skip to **Water Behavior**)*
The following questions are for households that use **another person's battery**:		
Q17	How far is the battery you are using?	______ meters
Q18	How often did you go to the battery last month?	☐ Once a one week ☐ Twice a month ☐ Once a month *(Skip to **Water Behavior**)*
The following questions are for households **without electricity**:		
Q19	Why doesn't your household have electricity?	No power line available in the village
Q20	Would your household want to have electricity tomorrow if it cost *$1* per week? *(Replace with $2, 3$, …, $7)*	Max willingness to pay: ☐ $0 ☐ $1 ☐ $2 ☐ $3 ☐ $4 ☐ $5 ☐ $6 ☐ $7
Q21	At this price, would your household regularly carry a car battery to a charging station near the village head's house?	☐ Yes ☐ No

	(Note distance to village head's house)	Distance to village head's house: _____ meters
Q22	What would your household use electricity for?	

WATER BEHAVIOR

No.	Question	Answer
Q23	During the **wet season**, how does your household get drinking water, how often does your household use each source and how much does your household pay?	*Source* — *Cost* x__ % Rainwater __________ (preferred and perceived as very pure because it "falls from the sky") x__ % Surface water __________ (2500R/jar) ___ % Tube well __________ ___ % Water vendor __________ ___ % Bottled water __________ ___ % Piped water __________ ___ % Other __________ *100 % Total*
Q24	During the **dry season**, how does your household get drinking water, how often does your household use each source and how much does your household pay?	*Source* — *Cost* ___ % Rainwater __________ ___ % Surface water __________ ___ % Tube well __________ ___ % Water vendor __________ ___ % Bottled water __________ ___ % Piped water __________ 100 % Other (open well) __________ *100 % Total*
Q25	The last time your household fetched water, how long did the roundtrip take? On average?	___ minutes last roundtrip 30 minutes on average (dry season)
Q26	How many times did your household fetch water last week? On average?	___ trips per week ___ trips on average
Q27	Who collected the water for your household yesterday? On average?	Yesterday: _________ On average: _________

ARSENIC AWARENESS

No.	Question	Answer
Q28	Have you heard of arsenic?	☐ Yes *(Continue on to **Q31**)* ☐ No *(**End** survey)*
The following questions are for interviewees that have **heard of arsenic**:		
Q29	How did you hear of it? *(Check all that apply)*	☐ NGO ☐ Commune Council ☐ Village Development Committee ☐ Health Center ☐ Village Health Worker ☐ Other villagers

		☐ Other (specify) ________	
Q30	Are you aware of any health impacts from drinking or consuming arsenic?	☒ Yes (specify) bumpy skin ☐ No (No one in household has arsenicosis symptoms)	
Q31	Are you aware of arsenic-free water sources near here? If so, are you using the arsenic-free sources?	☒ Aware ☐ Not aware (Rain water next to house)	☒ Using ☐ Not using

Notes:

- Context:
  - RDI installed a rope pump here but it has no water, even in rainy season
- Household behavior:
  - Household wants power line but it is unclear how much they would pay for it (currently using a ThunderLite NS 40L 12V 32Ah battery)
- Interview logistics:
  - Income question was very sensitive

Household Survey #5 in PreakRussei
7/2 @ 5:00pm to 5:12pm
BEAR: Jessica
RDI: Samrach

SURVEY INFORMATION

Date	*02/07/08*	Time	17:00 to 17:12
Village Code	PR	Household #	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☒ 5 ☐ 6
Interviewers	Jessica	Translator	Sam
Documenters	Jessica	Interviewee Information	Age: ☐ 20-35 ☒ 36-50 ☐ 50+ Gender: ☐ M ☒ F

SOCIO ECONOMIC

No.	Question	Answer
Q1	How many people live in your house, including you? What is everyone's age?	2_____ Under 12 2_____ 12 to 20 1_____ 20 to 50 0_____ Over 50 5_____ Total # living in household
Q2	What is your occupation?	Housewife (looking for employment, owns a female cow and breeds cows part time by splitting calves with the owner of the bull)
Q3	What was your cash income from all household members and from all sources in the past 12 months?	☐ $0-300 ☐ $301-600 ☐ $601-900 ☐ $901 & above (Too sensitive of a question and there are also 2 children working in town who may

		be sending money home but it is not recorded here) ☒Poor ☐ Medium ☐ Rich
Q4	How much money did your household spend buying food last month?	$57.14 (8000R/d * 30d/mo * $1/4200R)
Q5	What else do you remember your household buying during the last month? *(Cigarettes? Clothes?)*	Nothing
Q6	How long did it take your household to go to the market last time? On average?	_____ minutes last time _____ minutes on average The seller comes to her house

ELECTRICITY

No.	Question	Answer
Q7	Is there electricity/electrical appliances your house?	☒ Yes *(Continue on to **Q8**)* ☐ No *(Skip to **Q19**)* (Note: To the villagers, having electricity implies being connected to the grid.)
The following questions are for households **with electricity**:		
Q8	How many hours of electricity did your household use last week?	7___ hours (1 hr/day * 7 day/wk)
Q9	What did your household use electricity for last week?	Lamp
Q10	How much did your household pay for electricity last month?	$3.05/month (1600R/charge * 2 charge/wk * 4 wk/mo * $1/4200R)
Q11	Are you (personally) satisfied with the current electricity supply? Why?	☐ Yes ☒ No Why? Feel that it is too expensive and they do not have enough money
Q12	What is your electricity source? *(Please show me your source)*	☒ Battery *(Continue on to **Q13**)* ☐ Local electric network *(Skip to **Water Behavior**)* ☐ Other (specify) ____________ *(Skip to **Water Behavior**)*
The following questions are for households that use a **battery**:		
Q13	Is the source a self-owned car battery?	☒ Yes *(Continue on to **Q14**)* ☐ No *(Skip to **Q17**)*
The following questions are for households that use a **self-owned battery**:		
Q14	How often did you reload your car battery last week?	2 times/week
Q15	How far is the charging station?	500 meters

Q16	How much did you pay last time to recharge your car battery?	$0.38 (1600R * $1/4200R) Price depends on battery size: 40: 1600R 50: 1800R 70: 2200R *(Skip to **Water Behavior**)*
The following questions are for households that use **another person's battery**:		
Q17	How far is the battery you are using?	______ meters
Q18	How often did you go to the battery last month?	□ Once a one week □ Twice a month □ Once a month *(Skip to **Water Behavior**)*
The following questions are for households **without electricity**:		
Q19	Why doesn't your household have electricity?	No power line available in the village
Q20	Would your household want to have electricity tomorrow if it cost *$1* per week? *(Replace with $2, 3$, …, $7)*	Max willingness to pay: □ $0 □ $1 □ $2 □ $3 □ $4 □ $5 □ $6 □ $7
Q21	At this price, would your household regularly carry a car battery to a charging station near the village head's house? *(Note distance to village head's house)*	□ Yes □ No Distance to village head's house: _____ meters
Q22	What would your household use electricity for?	

WATER BEHAVIOR

No.	Question	Answer	
Q23	During the **wet season**, how does your household get drinking water, how often does your household use each source and how much does your household pay?	*Source* x__ % Rainwater (preferred out of habit) x__ % Surface water ___ % Tube well ___ % Water vendor ___ % Bottled water ___ % Piped water ___ % Other *100 % Total*	*Cost* __________ __________ __________ __________ __________ __________ __________
Q24	During the **dry season**, how does your household get drinking water, how often does your household use each source and how much does your household pay?	*Source* ___ % Rainwater 100 % Surface water (very turbid)	*Cost* __________ __________

		___ % Tube well ________ ___ % Water vendor ________ ___ % Bottled water ________ ___ % Piped water ________ ___ % Other ________ *100 % Total*
Q25	The last time your household fetched water, how long did the roundtrip take? On average?	___ minutes last roundtrip 10 minutes on average
Q26	How many times did your household fetch water last week? On average?	___ trips per week ___ trips on average
Q27	Who collected the water for your household yesterday? On average?	Yesterday: ________ On average: Interviewee

ARSENIC AWARENESS

No.	Question	Answer
Q28	Have you heard of arsenic?	☒ Yes *(Continue on to **Q31**)* ☐ No *(**End** survey)*
The following questions are for interviewees that have **heard of arsenic**:		
Q29	How did you hear of it? *(Check all that apply)*	☒ NGO ☐ Commune Council ☐ Village Development Committee ☐ Health Center ☐ Village Health Worker ☐ Other villagers ☐ Other (specify) ________
Q30	Are you aware of any health impacts from drinking or consuming arsenic?	☒ Yes (specify) Unsure of what it causes, just heard from someone that it has bad effects ☐ No
Q31	Are you aware of arsenic-free water sources near here? If so, are you using the arsenic-free sources?	☒ Aware ☐ Not aware (Rain water next to house) ☒ Using ☐ Not using

Notes:

- Context:
  - Household used to use tube well PR03
  - Husband died 1 year ago, leaving 2 young children and 2 children working in town
  - Very unhappy with NGO piped water system that was recently installed and does not use it
    - Worker came to install but she did not have an additional 16000R to extend the pipe all the way to the rain water storage jars
    - She would have had enough money in two days
    - Worker could not wait and installed the pipe part way
    - She thinks the pipe is too far away and inconvenient to use
- Household behavior:
  - Ceramic water purifier is used to treat all water before drinking
- Interview logistics:
  - Income question was very sensitive

Date: JUL 04, 2008 **Time:** 10:10 **to** 10:40 **Village:** Popeal Khael **Interviewer:** Michèle Itten **Translator:** Sam **Documenter:** Deborah Cheng

No.	Question	Answer					
Q1	Village Accessibility *(closest paved road, rivers)*	☐ Poor *(closest paved road:* 500m,	☐ Medium	☒ Good *closest river:* wetland at 20m *)*			
Q2	Village Wealth	☐ Poor	☐ Medium	☒ Good			
Q3	Electricity	☒ grid, cost: 1100 R/kWh		☐ battery, cost:			
Q4	Where do you get *drinking water* during the **wet season**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		1 Rainwater No of jars: 5	free	boiled for kids only	1	1	1
		Surface Water					
		Tube Well					
		Rope Pump					
		Open Wells					
		Water Vendor					
		Bottled Water					
	(Order by preference)	Piped Water					
		other:					
Q5	Where do you get *drinking water* during the **dry season**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		1 Rainwater	free	boiled for kids only	1	1	1
		Surface Water					
		Tube Well					
		Rope Pump					
		Open Wells					
		Water Vendor					
		2 Bottled Water	1500 R per 20l	none	2	2	2
		Piped Water					
		other:					

Date: JUL 04, 2008 **Time:** 10:10 **to** 10:40 **Village:** Popeal Khan **Interviewer:** Michèle Itten **Translator:** Sam **Documenter:** Deborah Cheng

Comments and Observations:

- People present:
  - 1 woman, well owner, head of a household of 2 adults and 4 kids (below 16 years of age)
  - 1 man, neighbor, head of a household of 5 adults and 5 kids (below 16 years of age)
- When ordering the sources by preference, both mention that they *"just like rainwater"*. To them, it is purer even than bottled water because it falls from the sky.
- They store rainwater in traditional jars for a long time, even through the dry season. According to them, this storage has no influence on the taste of the water.
- With their 5 traditional jars, the woman's household usually has enough water to cover their needs in the dry season. Only very rarely, she buys bottled water.
- The neighbor owns 9 traditional jars, but due to his bigger household size, he is required to buy about 30 jugs of bottled water every year.
- The arsenic-contaminated hand pump is used for bathing only.

Date: JUL 04, 2008 **Time:** 13:20 **to** 13:35 **Village:** Dei Edth **Interviewer:** Michèle Itten **Translator:** Sam **Documenter:** Deborah Cheng

No.	Question	Answer					
Q1	Village Accessibility *(closest paved road, rivers)*	☐ Poor *(closest paved road:*	☐ Medium 10m,	☒ Good *closest river:* far)			
Q2	Village Wealth	☐ Poor	☒ Medium	☐ Good			
Q3	Electricity	☐ grid, cost:		☒ battery, cost: (no information)			
Q4	Where do you get *drinking water* during the **<u>wet season</u>**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		1 Rainwater No of jars: 6	free	boiled	1	1	1
		Surface Water					
		Tube Well					
		Rope Pump					
		Open Wells					
		Water Vendor					
		Bottled Water					
	(Order by preference)	Piped Water					
		other:					
Q5	Where do you get *drinking water* during the **<u>dry season</u>**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		Rainwater					
		Surface Water					
		Tube Well					
		Rope Pump					
		Open Wells					
		1 Water Vendor	3000 R per jar	boiled	2	2	2
		Bottled Water					
		Piped Water					
		other:					

Date: JUL 04, 2008 **Time:** 13:20 **to** 13:35 **Village:** Dei Edth **Interviewer:** Michèle Itten **Translator:** Sam **Documenter:** Deborah Cheng

Comments and Observations:

- People present:
  - 2 elderly women and 2 young women: well owner and neighbors
  - household in question consists of 3 adults and 4 children (below 16 years of age)
- During the dry season, a water vendor fills their 6 traditional jars with river water.
- One year after they dug their hand pump (in 2000), people came to test the water. They never drank from it since.
- Either way, they prefer rainwater to any other source: It is free, it tastes better and it is clearer.

Date: JUL 04, 2008 **Time:** 13:55 **to** 14:10 **Village:** Dei Edth **Interviewer:** Michèle Itten **Translator:** Sam **Documenter:** Deborah Cheng

No.	Question	Answer					
Q1	Village Accessibility *(closest paved road, rivers)*	☐ Poor *(closest paved road:*	☐ Medium 10m,	☒ Good *closest river:* far *)*			
Q2	Village Wealth	☒ Poor	☒ Medium	☐ Good			
Q3	Electricity	☐ grid, cost:		☒ battery, cost: (no information)			
Q4	Where do you get *drinking water* during the **wet season**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		1 Rainwater No of jars: ??	free	boiled	1	1	1
		Surface Water					
		Tube Well					
		Rope Pump					
		Open Wells					
		2 Water Vendor	500 R per jar	boiled	2	2	2
		Bottled Water					
65	*(Order by preference)*	Piped Water					
		other:					
Q5	Where do you get *drinking water* during the **dry season**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		Rainwater					
		Surface Water					
		Tube Well					
		Rope Pump					
		Open Wells					
		1 Water Vendor	500 R per jar	boiled	1	1	1
		Bottled Water					
		Piped Water					
		other:					

Date: JUL 04, 2008 **Time:** 13:55 **to** 14:10 **Village:** Dei Edth **Interviewer:** Michèle Itten **Translator:** Sam **Documenter:** Deborah Cheng

Comments and Observations:

- People present:
  - 1 elderly man, well owner, head of a household of 5 adults and 3 children (below 16 years of age)
- The hand pump has not yet been tested on Arsenic concentration since its installation one year ago. Nevertheless, it is used for washing only – the household drinks rainwater (when available) or surface water (from water vendor) because they don't like the flavor of ground water. Also, he mentions that rainwater has the better color than ground water; it is *"whiter"*.
- When we find a high Arsenic contamination (500 to 1000 ppb), Sam further stresses the importance of not using the tube well water for drinking purposes.
- In order to have his jars refilled, he walks to the water vendor (500m down the road) and orders him to come.

Date: JUL 11, 2008 **Time:** 10:50 **to** 11:10 **Village:** Chung Preak **Interviewer:** Michèle Itten **Translator:** Laing Shun **Documenter:** Michèle Itten

No.	Question	Answer					
Q1	Village Accessibility *(closest paved road, rivers)*	☐ Poor *(closest paved road:* 1 km,	☐ Medium	☒ Good *closest river:* 2 km *)*			
Q2	Village Wealth	☐ Poor	☒ Medium	☐ Good			
Q3	Electricity	☒ grid, cost: 1900 R/kWh		☐ battery, cost:			
Q4	Where do you get *drinking water* during the **<u>wet season</u>**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		1 Rainwater No of jars: 16	free	boiled	1	1	1
		Surface Water					
		Tube Well					
		Rope Pump					
		Open Wells					
		Water Vendor					
		Bottled Water					
	(Order by preference)	Piped Water					
		other:					
Q5	Where do you get *drinking water* during the **<u>dry season</u>**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		1 Rainwater	free	boiled	1	1	1
		Surface Water					
		Tube Well					
		Rope Pump					
		Open Wells					
		Water Vendor					
		Bottled Water					
		Piped Water					
		other:					

Date: JUL 11, 2008 **Time:** 10:50 **to** 11:10 **Village:** Chung Preak **Interviewer:** Michèle Itten **Translator:** Laing Shun **Documenter:** Michèle Itten

Comments and Observations:

- People present:
  - 1 elderly woman, tube well owner, living in the house next door with her granddaughter (below 16 years of age).
    One year ago, her daughter's family built a house by the tube well. This new house however is connected to a piped water system at the price of around 1800 R per cubic meter.
- The well was built in 1982 and used by many people before the lady moved here four years ago. She had never used it for drinking purposes, but still has made some observation regarding its water quality:
  - When the well water is stored the whole day, it gets red – and so do the clothes that she washes in that water.
  - When she uses the well water for cooking, her food is less delicious.
- Although the local translator (Laing Shun) estimates the village wealth to be average, she notes that there are many new buildings in the area because people sell their land.

Date: JUL 11, 2008 **Time:** 11:50 **to** 12:00 **Village:** Metapheap **Interviewer:** Michèle Itten **Translator:** Laing Shun **Documenter:** Michèle Itten

No.	Question	Answer					
Q1	Village Accessibility *(closest paved road, rivers)*	☐ Poor *(closest paved road:* ~ 200m,	☒ Medium	☐ Good *closest river:* 3 km *)*			
Q2	Village Wealth	☐ Poor	☒ Medium	☐ Good			
Q3	Electricity	☒ grid, cost: 360 R/kWh		☐ battery, cost:			
Q4	Where do you get *drinking water* during the **wet season**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		1 Rainwater No of jars: 3	free	sometimes boiled	1	3	1
		Surface Water					
		Tube Well					
		Rope Pump					
		Open Wells					
		Water Vendor					
		Bottled Water					
	(Order by preference)	Piped Water					
		other:					
Q5	Where do you get *drinking water* during the **dry season**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		Rainwater					
		Surface Water					
		1 Tube Well		always boiled	2	2	2
		Rope Pump					
		Open Wells					
		Water Vendor					
		2 Bottled Water	1000 R per 20l	none	?	1	?
		Piped Water					
		other:					

Date: JUL 11, 2008 **Time:** 11:50 **to** 12:00 **Village:** Metapheap **Interviewer:** Michèle Itten **Translator:** Laing Shun **Documenter:** Michèle Itten

Comments and Observations:

- People present:
  - 1 boy, later joined by his younger sister. Both live in the household of five people consisting of two adults and three children. Two older siblings work and live in Phnom Penh.
- The tube well was built in 2003 when the family moved here. It is around 40m deep and hasn't been tested for Arsenic contamination yet. By consequence, the family regularly drinks from it during the dry season (after boiling the water). If, during that season, they run out of boiled water, they go to buy a 20l-jar of bottled water.
- After we test the water and find a high Arsenic contamination (500 to 1000 ppb), Laing Shun advises the family to stop drinking it and switch to rainwater storage whenever possible.
- Interestingly, this boy is the only one interviewed who prefers the taste of ground water. Upon questioning, he explains that it tastes the most similar to bottled water, and that rainwater has a different smell. May it be that this is a general trend in water preferences throughout the country?

Date: JUL 11, 2008 **Time:** 15:00 **to** 15:25 **Village:** Toul Tachan **Interviewer:** Michèle Itten **Translator:** Laing Shun **Documenter:** Michèle Itten

No.	Question	Answer					
Q1	Village Accessibility *(closest paved road, rivers)*	☐ Poor ☒ Medium ☐ Good *(closest paved road:* (no information), *closest river:* (no information) *)*					
Q2	Village Wealth	☐ Poor ☒ Medium ☐ Good					
Q3	Electricity	☐ grid, cost: ☒ battery, cost: 2000 R each, lasts longer than a week					
Q4	Where do you get *drinking water* during the **wet season**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		1 Rainwater No of jars: 2	free	boiled	1	1	1
		Surface Water					
		Tube Well					
		Rope Pump					
		Open Wells					
		Water Vendor					
		Bottled Water					
	(Order by preference)	2 Piped Water	2000 R / m^3	boiled	2	2	2
		other:					
Q5	Where do you get *drinking water* during the **dry season**?	*Source*	*Cost*	*Treatment*	*Convenience*	*Taste*	*Color*
		Rainwater					
		Surface Water					
		Tube Well					
		Rope Pump					
		Open Wells					
		Water Vendor					
		Bottled Water					
		1 Piped Water	2000 R / m^3	boiled	2	2	2
		other:					

Date: JUL 11, 2008 **Time:** 15:00 **to** 15:25 **Village:** Toul Tachan **Interviewer:** Michèle Itten **Translator:** Laing Shun **Documenter:** Michèle Itten

Comments and Observations:

- People present:
  - 1 elderly woman, well owner, head of a household of five, including 4 children (up to 20 years of age).
  - 1 young woman, probably her daughter, who speaks some English.
- The well was built in 1998 and has a depth of 33m. It is regularly used as a drinking water source. It has been tested on Arsenic three months ago by another research group who came to test the Kanchan filter who now installed five filters for research purposes and offered the family two additional ones for private use. Although nobody specifically warned them of the dangers of directly drinking the well water, and even though the results of their research are not yet available to them, the women remember being advised to start filtering their well water with the Kanchan technology.
  However, because the research results are not out yet, the family is not sure whether the filtering process really turns the water safe for drinking.
- Also three months ago, they connected their house to a piped water system for an initial cost of 70 USD and a recurring cost of 2000 R per cubic meter. As the main reason for this decision, they mention the difficulty of taking water from the tube well, but deny any causal connection with the filter installation.
- With this new water source in place, the tube well water is now used mainly for laundry. However, the women realized that the *"clothes become bad"* with repeated well water washing. Their solution to this problem is to use the Kanchan filter without the nail layer, as a mere sand filter to take out the iron from their laundry water.
- Also, they recall that when they used to boil the well water, the iron regularly stuck to the pan, making even that treatment difficult.
- Conclusion: Taking out the iron might turn out to be a very welcome, valuable side-effect of the BEAR process!

C: Sampling codes

Khmer Bear Sample list

Series	Label				Quick Test Result ([ppb As])
	Source	Date	BEAR flowrate (ml/min)	BEAR mixing time (minutes)	
BATCH	PA1B	Aug.07	N/A	N/A	100-200
BATCH	PA2B	Aug.07	N/A	N/A	300-500
BATCH	PA3B	Aug.07	N/A	N/A	300-500
BATCH	PR1	Aug.07	N/A	N/A	1000-500
BATCH	PR2	Aug.07	N/A	N/A	500-1000
BATCH	PR3	Aug.07	N/A	N/A	500-1000
BATCH	DE1	Aug.07	N/A	N/A	100-250
BATCH	DE2	Aug.07	N/A	N/A	500-250
BATCH	DE3	Aug.07	N/A	N/A	500-1000
P. o. C	PA1B	Aug.07	300	0	0-10
P. o. C	PA2B	Aug.06	300	0	0-10
P. o. C	PA3B	Aug.06	300	0	0-10
P. o. C	PR1	Aug.07	300	0	10-0
P. o. C	PR2	Aug.07	300	0	0-10
P. o. C	PR3	Aug.07	300	0	0-10
P. o. C	DE1	Aug.06	300	0	10-0
P. o. C	DE2	Aug.06	300	0	0-10
P. o. C	DE3	Aug.06	300	0	0-10
Optimization	DE1	Aug.08	1500	0	10-25
Optimization	DE1	Aug.08	1500	10	10-25
Optimization	DE1	Aug.08	1500	20	25-10
Optimization	DE1	Aug.08	1500	30	10-0
Optimization	DE2	Aug.08	1000	0	25-10
Optimization	DE2	Aug.08	1000	10	10-25
Optimization	DE2	Aug.08	1000	20	10-0
Optimization	DE2	Aug.08	1000	30	10-25
Optimization	DE2	Aug.08	500	0	0-10

D: Recommendation List

Sushi Cartridge.

(i) *The replacement of the HDPE transparent plastic layer by mesh layers.* The plastic layer is fragile and its failure would make the device unusable by creating a short circuit. A logical solution would be to replace it by two layers of plastic mesh, similar to those already in place between the electrodes. However, this would also increase the active electrode area and would require the adaptation of the electrode geometry and/or the electrical current.

(ii) *The replacement of the built-in electrode junction by a soldered wire.* As mentioned in the preceding section, small holes on the electrodes right behind the plastic mesh, and preferential wearing of the iron at the electrode junction were noticed. Both issues may result in an open circuit on the electrode. This issue may be dealt with by soldering a longitudinal non corroding metal wire on the electrode, insuring the distribution of the current despite the holes on the electrode. Furthermore, using the wire instead of the electrode "ears" as junctions would prevent their ripping off and avoid the presence of a weak point.

BEAR Prototype.

(i) *Improvement of the vent system.*

The current vent system consists of a screw on the electrode top, which operation is not really practical in a field laboratory. Additionally, gas has been observed to build up inside the prototype in prolonged use. This corrosion product (presumably a mix between O2 and H2) may be explosive and is thus dangerous in contact of the spark-prone electrode. An efficient vent system must be introduced, either in the design or the operation procedure of the system.

(ii) *Draining of the prototype cap.*

Due to pipe leaks or the prototype filling process, water tends to build up on the prototype cap, right between the junctions of the two functioning electrodes. A drainage grove carved in the cap would thus be a welcomed feature of the next design iteration.

(iii) *Outlet flush.*

Thick rust particles tend to build up in the prototype outlet system and might clog it in long term use. An efficient flushing system must thus be introduced in both the design and the use procedure of the system.

(iv) *Wider pipes.*

Finally, the piping currently used seem to be right enough for a 90 liters per hour flow rate. If a higher flow rate is sought in further iterations of the prototype, wider piping is thus advisable.

System Integration.

(i) *Outlet mixing process.*

As mentioned above, results have shown that the outlet mixing step can be suppressed from the BEAR process. However, adding a mixing step can be applied as a trade off needed to increase the flow rate, and an economic optimization is necessary to determine the final operation parameters.

If the mixing step is kept, experience shows that the technique of manually flipping the recipient every 30 seconds is inadequate. Therefore the quality of mixing seems to be an critical parameter as well. One solution could be to add a built-in mixing device to the existing prototype, as a second sushi in series behind the first one. This new sushi will not be electrically connected and not made of conductive materials and would exclusively provide mixing.

(ii) *Filtration process.*

All successful experiment were conducted using a standard Whatman #1 filter. Therefore, the use of a series of standard cartridge filters may be considered.

(iii) *Integration in a global treatment system.*

In the current state of development, the integration of the BEAR prototype to a classic small scale water filtration plant (similar to the process used by the NGO "1001 Fontaines" in Cambodia) may be considered. The final treatment process consisting of (1) a settling phase (2) a sand filter phase (3) the BEAR prototype (4) a series of cartridge filters (5) a UV disinfection device, yielding to safe and affordable water for local communities.

Business implementation.

(i) *Alternative water sources.*

For most parts of Cambodia, there are alternatives to ground water, mainly rain- or surface water from a nearby river. One valuable advantage of ground water is its more reliable availability as well as a certain steadiness in its quality – rain falls only during some months of the year and presents a lack of minerals, while surface water is easily polluted by bathing villagers, laundry activities and (more and more) pesticides from farming.

However, it is vital to assess the potential of treating these other water sources and weigh it against the possible benefits of the BEAR solution. New is not always better, and the traditional water sources may, with better treatment and monitoring, provide a viable alternative.

(ii) *Water preference.*

Further increasing the importance of the above comment, the majority of the Cambodians are currently used to rainwater consumption, and a certain reluctancy to switching water sources is to expect. Such consumer preferences must be included in a thorough comparison between different safe water options.

However, as part of the research, one may try to look for a possible shift in preference according to the age of the villagers interviewed. With tube wells being present since the 1990s, and bottled water ads being all over the country, it is possible that the younger generation is more open to ground water than their parents.

(iii) *Regions with high iron concentration.*

Anybody working on arsenic reduction will at some point note the extremely low willingness to pay. Indeed, a colorless, tasteless, and odorless poison with no immediate effects is not seen as an important threat by villagers who are daily fighting for survival.

Thus, the presence of a secondary effect, valuable to the locals, may well decide over the success or failure of the remediation strategy.

Our surveys show that the iron content is particularly felt by consumers in at least one of the three communes visited and villagers already have strategies in place to counter its effects on clothes, food and pans. By simultaneously lowering the iron content, the BEAR technology might thus have better odds in this place. Since the high iron levels may equally have a positive impact on the efficiency of the BEAR process, such high-iron regions might be ideal for a first generation of BEAR water centers.

(iv) *Cooperation with existing businesses and organizations.*

As there is little use in reinventing the wheel, we strongly encourage further researchers in this project to seek the feedback from local NGOs and cooperate with existing businesses. Not only is it confusing to the villagers to be instructed every few years to use another water source[5], it is also a waste of local resources and knowledge to rely solely on outside teams.

Insight from local NGOs.

(i) *Local tastes and preferences.*

It is important to cater to local tastes and cultural preferences in order to provide a socially acceptable product in which people are willing to invest their time and money. Removing iron ions, which impart an earthen taste and color to the water that is disliked by many locals, may make treated groundwater a more viable alternative. Paying attention to details such as water clarity and taste, bottle aesthetics, and the attractiveness and cleanliness of the water center building will not only raise the willingness to pay, but also bring pride and prestige to the households utilizing the services and encourage adoption by others.

(ii) *Water quality.*

Although shallow tubewells generally are pathogenically safe, several NGOs working in water have cautioned that biological contamination is still possible, depending on the quality of well installation. Beyond removing arsenic, the team will need to ensure that the treated water is safe for drinking. A disinfection unit combined with regular testing can help maintain water quality in accordance with the standards of the Ministry of Industry, Mines, and Energy.

(iii) *Infrastructure and operation.*

A promising finding has been the increasing availability and affordability of electricity in isolated, rural villages. Appropriately sized photovoltaic panels can provide enough electricity to power a motorized pump, mechanical mixing and filtration, arsenic removal through electrochemistry, as well as UV disinfection. After selecting the proper equipment scale and building location, staff training will be a crucial component of operational success. Instituting a head staff position with higher salary will help delineate who is ultimately responsible for the operation of the center. The optimal distribution method will depend heavily on the density of the community, and could involve the installation of a piped network or door-to-door delivery of bottles.

[5] In certain areas, after generations of surface and rainwater consumption, villagers were first offered untreated ground water through the UNICEF tube well installation. Then an NGO such as RDI came to warn them of the dangers of Arsenic and – due to a lack of alternatives – advised them to switch to filtering rain and surface water. And now maybe, researchers will soon try to convince them to buy arsenic-free ground water.

(iv) *Promotion.*

In response to the traditional lack of awareness about the correlation between water quality and health, several NGOs have piloted effective and creative campaigns to educate rural communities about the importance of drinking from arsenic-free safe water sources. The best way to leverage the work that has already been done would be to partner with a local institution that is actively involved in the region of implementation. The BEAR team can build trust and presence faster by utilizing a local partner's existing contacts with village leaders and proven community-based marketing techniques, such as videos and karaoke. Fostering community involvement is important to long-term sustainability because it develops sense of co-ownership.

(v) *Financing and risk mitigation.*

Before proceeding with a technical trial, BEAR needs to identify an appropriate community and local partner. It would be useful to use the piloting period to test out different business models and price points and demonstrate the success of the ECAR technology to private investors. During the interviews, the team was also highly encouraged to seek out local co-investors in addition to traditional funders. Local entrepreneurs can help mitigate the risk of implementation by providing local expertise and contributing their own capital; additionally, local entrepreneurs may also face fewer barriers in encouraging community participation.

(vi) *External influences.*

Finally, a number of external environmental and economic factors are also becoming increasingly important to any growing water business. Rising gas prices present great challenges to water delivery and disposal of arsenic-laden waste. The nature of current safe water alternatives and competing water services may also be on the brink of change. While treating surface water is the preferred method of addressing arsenic contamination, treated groundwater may become a more consistent and feasible option as surface water sources become increasingly polluted through heavy agricultural activities.