In-home methods for water purification in rural Ecuador

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Abstract
The Tufts University student chapter of Engineers Without Borders (EWB) is working in El Cristal, a rural community in northern Ecuador, to improve the quality of the community’s water supply as part of a greater effort to increase the overall health of the community. During the summer of 2010 a student group traveled to El Cristal to assess the performance of the community’s slow sand filter. In addition to bettering the existing filtration system, the travel team educated the community on supplemental water purification methods. These supplemental methods include: boiling, in-home bio-sand filtration, in-home chlorination, and SODIS treatment. While in El Cristal the team tested each of these methods and found that each was successful in removing fecal coliform and E. Coli, but in varying degrees. Chlorination, boiling, and SODIS removed 100% of the total coliform whereas the bio-sand filter, operating below optimum conditions, reduced the bacteria concentration by a factor of 2.5. This paper documents the community’s reactions to these purification methods and the feasibility of each method in El Cristal.

Keywords
Rural water purification
Total coliform
E. Coli
Boiling
Bio-sand filtration
SODIS treatment
Chlorination
Ecuador

Background
In August of 2006 Tufts EWB traveled to Ecuador to work with a local NGO (Fundación Brethren y Unida) and the community of El Cristal to investigate the potential for providing a potable water supply for the community. In August of 2007 students returned to El Cristal and performed preliminary water quality tests to determine the level of fecal coliform and E. coli contamination. The students also built a bio-sand filter for one family in hopes that other families would be able to model the filter and use it as a sustainable alternative that would replace other more costly options. After Tufts EWB left, the community leaders took the results from the water quality tests to the local government and successfully received a grant for the construction of a slow sand filter [1].
Three Tufts students returned to El Cristal in January of 2008 to measure seasonal variation in water quality and found that the slow sand filter was under construction but still not operational. In August of 2010 five students and one professor traveled to El Cristal to evaluate the functionality of the filter and to present the community with four supplementary methods of water purification: boiling, in-home bio-sand filtration, in-home chlorination, and solar water disinfection (SODIS.) During this trip the students found that 1) the community’s water supply was still heavily contaminated with fecal coliform, 2) the community’s slow sand filter was not effective in removing bacteria, and 3) community reactions were mixed about the use of supplemental treatment methods.

Boiling water is one of the oldest and most commonly known methods for in-home water purification. If executed correctly, it is also considered the most effective method of disinfecting water of bacterial and viral contamination [2]. Many sources disagree on the amount of time water must be boiled to effectively kill all waterborne pathogens. However, the World Health Organization claims that once water begins to boil it has exceeded the thermal conditions in which pathogens can survive [3]. This trusted method is used all over the world in fully developed countries when primary disinfectant methods fail.

Biosand filtration is a method that has been utilized around the world for 150 years [4]. It is a small in-home replicate of a large slow sand filter. Water is flushed through a sand-filled chamber where it is disinfected by both mechanical trapping and bioremoval. As water flows through the voids between the granules of sand, influent solid particles are trapped. Many bacteria bond to larger particles within the contaminated water; thus trapping particles serves as an effective method for bacterial removal. The main mechanism for purification of water within a biosand filter relies on bacterial removal that occurs in a biologically active layer known as the schmutzdecke. This layer, which forms at the sand-water interface, is composed of algae, protozoa, invertebrates and other biomaterials that accumulate over time [5]. These bacteria work to eliminate and kill organic matter and pathogens that contaminate the water. Once sand is added to a biosand filter, either after construction or cleaning, it takes about 22 days to form a productive schmutzdecke, and the effectiveness increases exponentially over time [6]. After about 33 days biosand filters prove to be 99% effective in bacteria removal [6].

Chlorination is widely used in municipal water supplies as a method for water treatment. In the United States, the rate of waterborne illnesses dramatically decreased after the introduction of water chlorination in 1908 [7]. When chlorine is added to a water supply the chemical breaks through the bacterial cell wall and kills the organism, thus acting as a disinfectant. In larger water distribution systems, chlorine is introduced as a gas which can be a very dangerous procedure without proper control or training. However, most of the potential dangers in using gaseous chlorine can be avoided by using aqueous chlorine instead. As a result, in-home chlorination has proven a viable method for rural water treatment in many countries [8].

SODIS, short for “solar water disinfection,” is a purification method that was developed by the Swiss Federal Institute of Aquatic Sciences and Technology. The sun’s long-wave ultraviolet rays have the ability to kill bacteria, viruses and parasites in water [9]. If water is placed in clear PET bottles (bottles made of polyethylene terephthalate) and put outside for direct sun exposure...
for six hours, the sun’s ultra violet rays disinfect the water [9]. SODIS is not dependent on ambient temperature, rain or altitude; however the process is less efficient when there is cloud cover. In atmospheric conditions of more than 50% cloud cover, the bottle must be left out for 48 hours to ensure complete purification [9]. SODIS is recommended for volumes of water less than ten liters with turbidity of less than 30 NTU [3]. Many successful SODIS projects have been conducted in Ecuador as a result of the high UV radiation exposure due to its proximity to the equator.

This paper documents the results of the tests conducted to demonstrate these supplemental methods to the community.

**Methodology**

For testing the in-home water purification methods in El Cristal, Tufts EWB used tap water from a single household that proved to be highly contaminated with coliform (in concentrations of more than 760 colonies per 100mL) to test each method. The water from each treatment method was tested for both fecal coliform and E. coli. To measure bacterial content of the water samples, 100mL of the sample was filtered through a coliscan membrane filter apparatus onto 47mm gridded white 0.45um filter paper. The filter paper was removed and placed in a petridish containing Millipore m-ColiBlue24 Broth. The cultures were then incubated in a HACH portable incubator for 24 hours at 35°C. Between sample filtrations the apparatus was rinsed with sterilized water. Specific procedures for water treatment using each supplemental method are listed below and were followed during sampling unless noted in the results section:

- **Boiling-**
  1) Bring tap water to a boil in a pot over the stove for 2-3 minutes
  2) Use clean cup with a handle to remove water for drinking, cooking and dishwashing
  3) Rinse lid of pot with boiled water using cup
  4) Place cup upside down on top of lid for future use
  5) Never let cup handle or hands come in contact with the inside of the pot or the purified water

- **Bio-sand-** The biosand filter that was constructed by Tufts EWB on the August 2008 trip was used for testing. This biosand filter was constructed using a 50L bucket with a lid, a diffuser basin, PVC pipes and fittings, a gasket, 20L of fine sand (D<1mm), 4L of coarse sand (D=3-6mm) and 6L of gravel (D=6-15mm). For construction a hole was drilled 2” from the bottom of the bucket for the outlet. Teflon tape and a rubber gasket sealed the PVC piping to the bucket. The outlet pipe was assembled using the gasket and union. 40 evenly distributed holes were punctured in the plastic diffuser basin using a heated sewing needle. The sand and gravel was sieved and washed before being added to the filter. The sediments were added in order of decreasing grain size with the sediments with the largest diameter at the bottom [1].
  1) Pour water into the diffuser basin and cover the biosand filter with the bucket lid. Place catch bucket under filter nozzle to collect filtered water.
  2) Expect water from filter to be fully purified 22 days after construction or cleaning
3) Use biosand filter frequently to avoid water discoloration. Run water through system daily and scrape sediments from surface as needed.

- Chlorination-
  1) Add three drops of Clorox per liter of water in a container
  2) Invert, let sit for half an hour before drinking, cooking or dishwashing

- SODIS
  1) Fill PET bottle with water
  2) Place on roof for at least six hours during day light
  3) Replace bottles when they become scratched or deformed

Results

Table 1: Results of water quality tests after each method of filtration as compared to initial bacteria concentrations

<table>
<thead>
<tr>
<th>Sample</th>
<th>General coliform (cfu/100mL)</th>
<th>E. coli (cfu/100mL)</th>
<th>Total coliform (cfu/100mL)</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tap Water</td>
<td>110</td>
<td>657</td>
<td>767</td>
<td>1</td>
</tr>
<tr>
<td>Boiled Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Bio-Sand Filter Water</td>
<td>44</td>
<td>260</td>
<td>303</td>
<td>2</td>
</tr>
<tr>
<td>Chlorinated Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>SODIS treated Water</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Boiling, chlorination and SODIS all proved to be feasible and successful forms of removal of total coliform from contaminated water in El Cristal. The bio-sand filter had only been running for two days at the time of testing which is not adequate time for a schmutzdecke to form. The standard time for this biolayer to form is 22 or more days. The filter was able to reduce the bacteria concentration by a factor of 2.5, even though the filter was not working at full potential at the time of testing. This removal can be attributed to physical particle removal by filtering since it is probable that no biolayer had formed.

Discussion

The most important factor in evaluating water purification interventions in rural communities is assessing social, economic, and behavioral situations of the community [10]. Presenting a community with a seemingly viable solution for water purification will not prove successful if the limitations of the community are not considered in the design of the treatment mechanism. Factors such as the community’s fiscal capacity, technical and scientific knowledge, and social practice must be considered in the installation of such a system. If a water purification method is not convenient or viable for a household, it is unlikely that the household will use that method.
When Tufts EWB completed testing of the four supplemental purification methods, each process was demonstrated to the community in an open meeting. The community was able to clearly identify the need for alternate forms of water purification. Community members understood the importance of clean water, as demonstrated by their attendance at this open meeting, the questions they posed, and their willingness to pay for clean water. The community was able to draw the connection between clean water and digestive health. This is particularly important in successfully introducing a new and sustainable practice for water purification in a rural setting.

**Social Considerations**
Each of the four supplemental treatment methods that were tested in El Cristal has pros and cons when the social and economic situations are considered:

**Boiling**, if done correctly, is very easy and efficient. Although the process does not take long, it is inherently not desirable for immediate drinking purposes because of its elevated temperature after the disinfection process. Also, boiling water can be very expensive for households that do not have biogas systems or other alternative ways to heat their water [2]. By comparing the community health surveys taken in El Cristal in 2008 and 2010, more families are boiling water: in 2008 15% reported boiling water and in 2010 47% reported boiling water. Some families said that their children did not like the taste of boiled water so they stopped boiling.

**Biosand filtration** proved the most difficult and unsustainable solution. The community did not embrace the biosand filtration from 2008 to 2010 and it was hard for the one family who had a biosand filter to maintain the proper usage procedures over a long period of time. Although the initial start up cost of a biosand filter is minimal (less than $2), there is a significant educational component needed to maintain the filter. The biosand filter was able to successfully remove contamination by a factor of 2.5 most likely as a result of physical filtration and removal of larger organic particles. Many biologic contaminants cling to these particles, and therefore can be removed as the particles are removed.

**Chlorination** is very effective in removing bacteria but it gives the water an unpleasant taste and smell. This method is the easiest in terms of labor, but also has a relatively high monetary cost. From estimations based on the price of Clorox in the neighboring towns of El Cristal it would cost a family of five $1 a month to purify their drinking, cooking and dishwashing water (assuming that 1/5 of their water consumption goes to these purposes—a reasonable estimate considering most of their water consumption is dedicated to agricultural purposes). In El Cristal, this cost might be too expensive for many families. However, during the community meeting one woman got up and encouraged all the other community members to taste the sample of chlorinated water to prove that it was not too unpalatable to drink. This demonstrated the community’s interest in using chlorination and their understanding that changes needed to be made in terms of water purification.

**SODIS** has a lot of potential for water purification in Ecuador. It is very simple and very effective, and although it takes over six hours to purify, it is recommended that one uses the cooled, treated water from the previous day to make the cycle continuous. The community did not seem to understand this purification method when it was presented to them. They did not
trust that the sun’s rays have the power to remove bacteria because the sun’s rays are not tangible or visible.

Relation to Engineering Education
During this trip to El Cristal, the students gained an understanding of the importance of social perspective and ethical engineering practices. The implementation of a project of this nature, as well as any engineering design project, will not be successful if only technical feasibility is considered. By identifying the effects of the socioeconomic issues and rural development procedures on the community’s attitude and expectations toward water supply and sanitation, the success of a project inherently increases [11]. In El Cristal, the formation of a trusting relationship between the university and the community facilitated the process of understanding the social and economic situation of the community.

Student-powered sustainable engineering projects such as this one are beneficial in many ways: 1) students contribute to the engineering community by researching the plausibility of implementing known purification methods in rural situations, 2) community members and students are able to interact and develop personal connections with each other while gaining perspective about different cultures, and 3) students gain hands-on experience using engineering principles and processes that are learned in the class room, and are forced to make ethical decisions about “real-world” engineering situations.

In terms of engineering education, student trips such as this one far surpass classroom and laboratory experiences in terms of ability to instill the importance of engineering ethics in students and to empower them that they have the ability and knowledge base to provide viable solutions to “real-world” problems. The students have the opportunity to share their knowledge about water resources and sanitation with a community to ensure the sustainability of the project and further develop the idea of life-long learning.

Conclusions

The current water supply in El Cristal is heavily contaminated with both fecal coliform and *E. Coli*. This presents a significant problem to the community members in terms of digestive and overall health. While Tufts designs a solution to increase the efficiency and performance of the community’s slow sand filter, these four methods of supplemental water purification were presented to the community for the interim. When done properly, boiling, chlorination and SODIS proved effective in removing 100% of the bacteria from the contaminated water. Biosand filtration only reduced the bacteria content of the water by a factor of 2.5; however the filter was not functioning at full potential when tested due to inherent difficulties in operating and maintaining the system. Based on community response, chlorination and boiling seemed to be the most suitable methods of supplemental water purification for El Cristal. Many of the community members showed initiative in mobilizing their fellow community members to adopt these methods of purification and ensure safer, potable drinking water in hopes of bettering community health.
References


