The Road to Clean Water

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1 Abstract

The global water crisis is one of the most important issues in modern society. Drinking water is often filled with contaminants that cause illnesses, and millions of people go without clean water every day. In order to combat this issue, residents of developing countries need help, support, and effective water systems designed by engineers. A prototype water purification system has been developed that could be implemented in the village of Nueva Santa Caterina Ixtahuacan, Guatemala, to provide the residents with easy access to clean water. This prototype effectively purified the water by decreasing the turbidity, and removing bacteria as well as other contaminants with 80% volume efficiency.

2 Introduction

2.1 Global Water Crisis
In developed countries around the world, clean water is an amenity that is often taken for granted. At the same time, millions in developing countries suffer from the lack of a fundamental need: clean water. More than one in six people worldwide don’t have access to improved water sources [1]. Many need to walk miles to collect water infested with bacteria and parasites that cause illnesses and sometimes death [2]. Moreover, around the world, 2.5 billion people live without basic sanitation. This leads to diseases like diarrhea, cholera, and typhoid. Eighty eight percent of diarrheal deaths are caused by lack of sanitation, unclean drinking water, and lack of water for hygiene purposes [1]. Organizations like Engineers without Borders-USA are working to provide sanitation and distribution of water to developing countries to prevent these illnesses and deaths.

2.2 Case Study in Guatemala
EWB-USA works to provide sustainable solutions to a variety of technical challenges in developing countries around the world. In Nueva Santa Caterina Ixtahuacan of Guatemala, the Rutgers University Student Chapter of EWB-USA took five trips to provide essential clean water supplies to the community. The engineers took three assessment trips to the community in the span of two years, collecting data in order to build an effective water distribution system that best suits the culture of the community. By inspecting the qualities of existing water supplies and health of the community, they came up with three alternatives, and offered them to the community’s Water Committee in order to choose a solution that they deemed most suitable. Of the three, the committee decided to amplify the existing distribution system and then later implement a disinfection system. EWB-USA worked
closely with the water committee to make and finalize plans. Also, they initiated public outreach and education to promote awareness of the importance of clean water, so that the community would be able to sustain its own water supplies in the future. Then, they finalized the planning process and began the installation of the system during two implementation trips. Currently, another implementation trip is being planned to finalize the project by installing a filter to the system [3].

2.3 Goal
The goal of this project is to develop a prototype of an effective water filtration system for this community in Guatemala. Following the systemic approach of the EWB-USA in NSCI, feasible ways to implement the prototype will be explored. Also, the culture of the communities will be taken into consideration so that the system will not violate the social norms and that the communities will eventually become self-sustainable.

3 Background

3.1 Current Conditions in NSCI
The village of Nueva Santa Caterina Ixtahuacan, Guatemala is located about five miles away from the nearest water source. The 5000 residents of the village spend valuable time every day attempting to obtain water and disinfect it, usually by boiling. Boiling does not remove all contaminants, and some of the water is lost via evaporation. The village, a government relocation planned town, was provided with a water pump and a pipeline; yet, this infrastructure has decayed and some pumps have failed due to the lack of maintenance and general wear. There is currently no purification process, which means that villagers have access to the water but the water still contains harmful bacteria. A water purification system needs to be implemented to efficiently filter out all contaminants from the water.

3.2 Water Filtration and Distribution Process
The water purification process is composed of four steps: aeration, clarification, filtration and disinfection. Aeration purifies water by exposing it to air and providing turbulence, removing dissolved gases and oxidizing or reducing molecules like carbon dioxide and iron. For example, in rivers and lakes, natural aeration results from the flowing of water. In industrial settings, structures such as water fall aerators, which provide turbulence to the body of water using gravity, and air diffusion aerators, which pump air into the water, are used as effective aeration systems. Clarification includes a sequence of three sub-steps: coagulation, flocculation, and sedimentation. The coagulation is the neutralization of ions dissolved in water so that they will no longer be attracted to polar water molecules. These neutral particles stick together rather than staying suspended in polar water, and form solid clumps known as agglomerations. The formation of agglomerations is known as flocculation. Finally, sedimentation occurs when the agglomerations sink to the bottom of the water. The next step, filtration, removes suspended particles, undesirable chemicals, and biological contaminants from the water[4]. There are many different types of filters that remove solids from water. One often-used example is a mixed-media filter, in which a variety of media are used to catch the solids as the water flows through. The media are sorted by size, so that larger, coarser particles are at the top of the bed and smaller, finer particles are at the bottom. This effectively catches the solids in the water by size, because the suspended particles come in contact with the media and get caught. The coarser materials remove
larger particles, while the finer materials remove smaller particles. Gravity filters are a commonly used kind of filter, because no pumps are required to filter the water [5]. Lastly, the water will be disinfected. The disinfection process ensures that all pathogens are removed via chemical treatments, such as chlorine [6].

4 Design and Development

4.1 Materials and Costs
A variety of materials were needed to build the prototype water filter. Water testing kits were used to test the water at different stages of filtration for contaminants like pH, alkalinity, hardness, iron content, and nitrates/nitrites. The materials used to build the actual filter included two storage containers, two sizes of PVC pipe, PVC pipe couplings and elbows, epoxy, caulk, large and small wood screws, chlorinating granules, alum, a safety knife, two acrylic sheets, funnels, plywood, steel wool, and a saw. Also, coarse sand, small pebbles, and larger pebbles were purchased for filtration media. In addition to these materials, fine sand, duct tape, and other tools necessary to build the filter were acquired and used.

4.2 Design and Motivation
The prototype water filter is a gravity-fed, mixed-media filter that follows the design shown in Figure 1. The water first goes through aeration, where the water cascades down shelves as the coagulant is mixed in (Figure 2). The aeration unit was built as a box with five sides of plywood, and one side of acrylic sheet. It was put together with wood screws and sealed with caulk. The aerating shelves were also screwed in. In the top of the unit, there is a hole to pour the contaminated water and a funnel to add the coagulant, alum. Alum was used as the coagulant because it is cheap, safe, and a salt that will be able to neutralize ions. Then, the water is drained into a holding tank, where the agglomerations deposit at the bottom (Figure 3). Next, the water is fed into a chlorination tank where chlorine is added and mixed in through a funnel (Figure 3). When chlorine is added to the water, it breaks into a few chemical compounds including hypochlorous acid and hypochlorite ion. The reaction between those two is called the “free chlorine” reaction. They attack microorganisms and bacteria in the water by attacking lipids and enzymes[9]. This was also built from plywood and acrylic sheet, with cascading shelves. Finally, the water is fed into the filter where it passes through stones, pebbles, coarse sand, and fine sand (Figure 5).
Construction and optimization of this prototype was done by trial and error. Between cutting all of the materials to size and actually putting them together, it turned out to be more work than we initially thought. Cutting the acrylic sheet did not work with the safety knife, so it had to be brought back to Lowes to be cut to size. A lot of the wood pieces weren’t perfect squares or rectangles, so they didn’t fit together perfectly. Another challenge was screwing the angled shelves in the aeration and chlorination units, as shown in Figure 2 and Figure 3. Referring to those pictures, caulk was used to seal all of the gaps to make the system watertight. Then, in order for the water in the holding tank to be able to flow out of the container through the PVC pipe efficiently, a slanted path was created using duct tape as, shown in Figure 4. Finally, separate parts were put together, following the design shown in Figure 2. During first few trials, we noticed many water leakages, especially in the aeration and disinfection units and the pipelines. We resealed those units with caulk and reinforced them with duct tape. The final system is shown in Figure 6.
5 Testing the Prototype

5.1 Initial Water Tests- Prior to Purification

To best represent the water from Guatemala, water was collected from a small pond next to the Raritan River in New Brunswick, NJ. Multiple tests were conducted on the water to determine the qualities and contaminants present in it. The first tested pH, along with the levels of Alkalinity, Chlorine, Hardness, Iron, Copper, Nitrates and Nitrites. The data from this test is shown in Table 1.

<table>
<thead>
<tr>
<th>TEST</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.5 – safe</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>240 – high</td>
</tr>
<tr>
<td>Chlorine</td>
<td>0 – safe</td>
</tr>
<tr>
<td>Hardness</td>
<td>280 – harder</td>
</tr>
<tr>
<td>Iron</td>
<td>0 – low</td>
</tr>
<tr>
<td>Copper</td>
<td>0 – safe</td>
</tr>
<tr>
<td>Nitrates</td>
<td>0 – safe</td>
</tr>
<tr>
<td>Nitrites</td>
<td>0 – safe</td>
</tr>
</tbody>
</table>

These results show that the pond water is safe in 6 out of 8 aspects of this test. In addition, a bacteria test was performed. This test took 48 hours and determined if the water contains harmful bacteria, particularly *E. coli*. The test came out yellow (left side of Figure 8), which indicated that the water contained those harmful pathogens. Before purification, the water had a high level of turbidity, which is the measure of the amount of suspended solids in water. The water before purification is shown in Figure 7.
5.2 Results

One gallon of contaminated water was poured into the purification system and about 80% of the purified water was collected, which translated to 80% efficiency. The whole process took forty-five minutes. The tests that were performed before running the water through the system were repeated; results for all but the bacteria test are in Table 2. The bacteria test came out purple, which meant that no harmful bacteria were present in the water after purification (right side of Figure 8). Also, the turbidity was lowered dramatically, shown in Figure 9.

Table 2

<table>
<thead>
<tr>
<th>TEST</th>
<th>RESULT</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>5 – caution</td>
</tr>
<tr>
<td>Alkalinity</td>
<td>40 – low</td>
</tr>
<tr>
<td>Chlorine</td>
<td>1 - safe</td>
</tr>
<tr>
<td>Hardness</td>
<td>250 - harder</td>
</tr>
<tr>
<td>Iron</td>
<td>0 - low</td>
</tr>
<tr>
<td>Copper</td>
<td>0 - safe</td>
</tr>
<tr>
<td>Nitrites</td>
<td>0 - safe</td>
</tr>
<tr>
<td>Nitrates</td>
<td>0 - safe</td>
</tr>
</tbody>
</table>

6 Analysis of Results

The water purification system prototype succeeded in most of the target areas, but left some to be improved.

Alkalinity, which determines the ability of a solution to neutralize acid, was lowered after purification. Hardness was also lowered, showing that the system was effective in removing some of the mineral content. This is good for pipes and other equipment used in a water system. It is important for water to be “softer” when a system is implemented, so it doesn’t decay as fast.

Compared to the previous result, the pH value of the purified water went from 7.5 to 5, which was a little too acidic for drinking water. The main cause of this occurrence was chlorine, which was added as the disinfectant that formed hypochlorous acid in water. This also explained a slight rising of the chlorine value.

In order to make the system more effective, a less concentrated solution of chlorine should be added so that the pH does not go into the acidic range. The pH of drinking water should preferably be between 6.5 and 7.5. Also, the efficiency of the system should be improved. In our test, about 80% of the water put in came out. This means that water leaked out and was absorbed into the wood and the sand. In a system in Guatemala, the yield would need to be optimized. A final area for improvement was the time taken to run the process. 45 minutes were required to purify just a gallon of water, which was inefficient and would prevent many villagers from accessing the purified water.
7 Application

7.1 How to Scale to a Larger System
The prototype alone will not be sufficient for actual implementation of the water filter and effective usage by the community. In order to adequately meet the community’s needs, it will be built in a scale proportional to the size of the population. Instead of using plywood for the aeration structure, the system will be built so that contaminated water from existing water sources will flow into a water tank made with sturdy, inexpensive cement. Other structures for storage, disinfection, and final filtration will use rigid water tanks, rather than plastic containers. The coagulant will be added to the gravity-effective waterfall aerators in the same way as in our prototype, but it will be made sure that the community is provided with inexpensive, accessible, and effective supplies of coagulant so that the system will be sustainable. The disinfectant will also be implemented in the same way as the coagulant. Finally, the filtration structure will be built using easily accessible stones, pebbles, or sand of the area.

7.2 How to implement in Guatemala while taking into consideration cultural and environmental impacts
Aside from mechanical aspects of implementation of our prototype to the communities in Guatemala, we explored effective methods for the water purification system to successfully be “assimilated” into the communities. It was noted that there has been a lack of education of the townspeople about the importance of clean water [3]. Difficulties with this include language barriers and lack of education. Thus, before actually building the structures, we will organize a committee dedicated to informing people of the hazards of consuming contaminated water and encouraging them to practice safe habits. The committee will consist of both engineers and community leaders, who, as part of the community themselves, will be able to educate other townspeople more effectively. They will also be responsible for sustaining the filtration system by re-supplying coagulant and disinfectant, and by regularly cleaning the water filter. After the implementation of the water purification system, the committee will take “preventive risk management,” [7] precluding contamination of the drinking-water by running water quality testing. The water system will be placed inside the town preferably in a public area, where everyone can get clean water. By shortening the distance people have to travel to obtain clean water, these people will have more time to contribute to the community and support their families through means including farming, education, and other tasks.

8 Conclusion
Through this project, a water purification system has been built that successfully treats contaminated water. It was capable of decreasing alkalinity and hardness, while killing pathogenic bacteria. In order to implement this in Guatemala, it would have to be improved to treat water at a faster rate. The prototype cost about $200, so finding the cost of a larger system would require a scaling factor proportional to the population of Nueva Santa Caterina Ixtahuacan.

Providing clean water to developing countries like Guatemala will not only support healthier communities but also boost their economies. Data shows that developing countries with access to clean water showed average Gross Domestic Product growth of 3.7%, compared to 0.1% of other developing countries without the same access. The primary explanation for this occurrence is the decoupling of economies of poor
countries from the annual amount of rainfall by providing constant water supplies. This enables them to concentrate on meeting other urgent needs such as farming to provide food, educating children, and taking care of them [8]. If water systems like this are implemented in communities around the world, global health will improve and economies will flourish.

9 Acknowledgements

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10 Resources


