Water Purification Solution for Akumadan, Ghana through BioSand Filtration

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The Ohio State University
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B. List of Frequently Used Terms and Abbreviations

- CAWST: Center for Affordable Water and Sanitation Technology
- CFU: Colony Forming Units
- E. coli: Escherichia coli
- MPN: Most Probable Number
- ONDA: Offinso North District Association
- PVC: Polyvinyl Chloride
- SOW: Scope of Work
- UV: Ultraviolet

C. Executive Summary

Ghana is one of many countries that overall has a large population of people who do not have reliable access to clean drinking water. The village of Akumadan in the Offinso North District of Ghana is one example of this. In this specific village, it has been identified that the water used for drinking and everyday activities has significant concentrations of nitrates and e. coli present. A high nitrate concentration in drinking water can cause newborns to become ill and if left untreated, they could die. Nitrates have similar effects on expecting mothers. The consumption of E. coli can cause loss of appetite, fever and diarrhea. If these symptoms are left untreated the person can become dehydrated and eventually die. This project’s main focus is to create an effective filtration device for the water in Akumadan. To solve this problem, a BioSand Filter has been created to reduce the number of E. coli bacterium in the water. The filter consists of three separate layers and with a growing fourth layer. This includes layers are two small layers
of gravel and a large layer of sand. The fourth layer that will eventually develop is a biological layer that consists of bacterium.

D. Background and Introduction

a. Challenges/Goals of the Project
The main goal of this project is to purify the drinking water the villagers obtain from the water depot and wells. In order to do this, contaminants such as nitrates and E. coli must be removed from the water to make it safe for consumption. After research, it was decided a BioSand filter would be most effective in this community. A prototype of this filter was constructed and tested to prepare for implementation of BioSand filters in Ghana. Along with the filter, education materials and plans have been made to educate the villagers on using the filter, maintaining the filter, and informing them of ways the water can become contaminated even after filtration.

b. Needs Assessment
A list of materials was kept throughout the prototyping process and was used when packing for Ghana. A list was taken to Ghana that said exactly what needed to be purchase in country and how much of each item was needed. The group also needed to finalize the testing methods for in country. While implementing the BioSand filter in Ghana, the group must teach the villagers how to repeat the construction procedure and how to maintain a BioSand filter in order to keep it running at maximum effectiveness.

c. Customer/In-Country Partners
The customers are the villagers of Akumadan that are governed by ONDA, as well as the villagers in Yawtokrom.

E. Achievements

a. Scope of Work
It is estimated that more than nine million Ghanaians lack access to clean water. In the village of Akumadan this is no different. Villagers collect their water from a depot that is fed by an underground springs or from streams and carry it back to their residence. The villagers also use bore hole wells to collect water, many of which are contaminated. It is known that the water in this depot contains dangerous concentrations of both E. coli and nitrates, which can be harmful to the human body if consumed. The villagers currently lack a way to filter out these contaminants.

Completed:
To begin, a project proposal was developed and submitted for approval. After approval, a Gantt chart was constructed to help create deadlines and assure the project team was on track for prototyping, testing, and in-country implementation. Each member did their own research to find different ways to purify the water. Once
everyone did sufficient research, each member presented their findings to the group. The team discussed the positives and negatives of each of the different filter types and decided on a BioSand filter. After the decision was made, more research was done to determine specifics about how to build the filter. Prototyping began after materials were purchased.

In order to fully test the accuracy and efficiency of the filter, gaining access to E. coli was essential. Several professors were contacted in order to acquire access to E. coli. Professor Pradhan from the Microbiology Department at Ohio State was able to provide the E. coli strain and a location for testing. The prototype was tested and data was collected for flow rate and reduction of E. coli concentration.

**In Country Accomplishments:**
While in country two BioSand filters were built with the help of ONDA staff and engineers. The first filter was constructed in the ONDA Annex office to serve as a model BioSand filter to teach the staff about the construction process and help them with recreating the filters in the future. The second filter was constructed at ONDA and finally assembled in the village of Yawtokrom where it will be used by the local villagers. The team also left both the ONDA staff and the villages with education documents on how to clean the filter, how to use the filter, and left ONDA with specific construction manuals. Throughout the building process, the team included ONDA staff to learn about the filter to increase its sustainability.

**b. Deliverables:**
The main deliverable of this project is the BioSand filter itself. While in country, the group constructed two BioSand filters. One BioSand filter was constructed at the ONDA annex office and left as a model for future replication. Another filter was constructed and delivered to the village of Yawtokrom. During the construction of the first filter, the team enlisted the help of ONDA staff members to learn about the construction process in order to replicate the filter in the future. The team also left ONDA with laminated education documents on how to clean the filter, how to use the filter, and general questions about the filter. Additionally, ONDA was left with two copies of the Construction Manual and a copy of the CAWST BioSand manual. During the final construction of the second filter, which was completed in the village of Yawtokrom, the group tried to explain the components of the filter to the villagers as it was constructed. This was achieved through the use of a manual as well as a physical demonstration of each part of the filter as it was built in the village. ONDA member Andy Bediako also assisted the group education by translating our demonstration in Twi. Additionally, the group left the villagers with instructions on how to use the filter and how to maintain the filter. These documents are attached in Appendix IV and Appendix V. Lastly, the group left the villagers with a clean water container with a spigot to store the filtered water in as well as a washing station with
soap to encourage the villagers to clean their containers after collecting dirty water.

c. **Plan for End User Involvement/Training**
The end user was given several packets of information as a source of education about the BioSand filter so that it can be maintained in the future. A user manual was provided to ONDA that contained information regarding the construction of the BioSand filter. The ONDA staff was included in building process of the filter alongside of the group for hands on experience. A second piece of information was also given to ONDA, as well as the villagers of Yawtokrom, describing how to maintain and clean the filter and how to keep it running at maximum effectiveness.

d. **Plan for Sustainability and Ownership**
The ONDA staff and the villagers were involved with the building and assembling of each of the BioSand filters. ONDA gained hands on experience of the construction of the first filter in their own office as well as helped with the assembly of the second filter in the village. An instruction manual was also provided to them (Appendix IV) as well as separate handouts on how to use and maintain the filter. Also, all of the materials used for the filter were purchased in country in order to make sure the filter was repeatable for the ONDA.

**F. Research and Development**

a. **Background Research**
Multiple filtration types were considered when deciding on an appropriate filter type for those in Akumadan including ceramic filtration, solar pasteurization, UV filtration, and BioSand filtration. Ultimately, BioSand filtration was decided on as the optimal technology to be used in Ghana.

UV filtration uses ultraviolet light, found between visible light and x-rays on the electromagnetic spectrum, as a source of energy to disinfect water. Ultraviolet energy works by attacking microorganisms and changing their DNA and RNA so that they are unable to reproduce. UV filtration is beneficial because of its ease and effectiveness; it can kill 99.9 percent of bacteria. UV systems are cost effective and easy to maintain. The water must be pre-filtered to contain only particles under a size of five microns (“UV Water Purification”). During research, the team was unable to find easy access to UV light bulbs in country, which made this option impractical for long-term sustainability in Ghana.

Ceramic filtration uses porous ceramic material to filter out bacteria and other contaminants. The filters are typically made using fine sawdust, ground rice husks, and other fine materials to give a porosity that should be less than one micrometer. The
benefits to ceramic filtration include that it is portable, inexpensive, and low maintenance. According to a study performed in Cambodia, the ceramic filters were extremely effective. Compared to unfiltered water there was an average of 98 percent less E. coli in water put through the ceramic filters. The filters can be made with materials found in country. With proper care, the filters can last over five years; however, one of the largest issues found was people did not continue to use the filters or the filters broke after they had been implemented in country (Brown). In addition to these drawbacks, the filters have very low flow rates: typically, about one to three liters per hour (“Ceramic Filtration”).

Solar pasteurization kills or deactivates bacteria and other pathogens by heating the water to sixty-five degrees Celsius for six minutes. There are multiple designs currently produced that utilize pasteurization including Aquapaks, solar puddles, and solar cookers. Aquapaks are for personal filtration while solar puddles and solar cookers can be used for multiple people (Andreatta). Solar pasteurization is typically inexpensive and systems can be made from materials found in country. An important factor in deciding whether or not to use pasteurization was the weather in Ghana. The average amount of sunlight varies from about four and a half hours in July to about eight hours in November. Of the daylight hours, it is sunny about fifty-four percent of the time ("Sunshine & Daylight Hours in Accra, Ghana"). This limits the time that people would be able to use the filter and makes it impractical as a continuous reliable source of filtration.

BioSand filtration is a multi-layer filtration system that uses different sizes of gravel and sand to filter. The bottom layer is known as the drainage level and is the largest gravel ranging from six to twelve millimeters in diameter. Its purpose is to keep the separation gravel from blocking the outlet. The next layer up is called the separation gravel. It stops the sand from sinking and clogging the outlet and is from 0.7 to six millimeters in diameter. The largest and most important layer is the sand, which must be less than 0.7 millimeters in size (“BioSand Filter Construction Manual”). On top of these layers, a biological layer forms consisting of the bacteria present in the contaminated water. The biological layer builds over time and the filter becomes more effective in removing increasingly more pathogens as it grows. There are four main ways that the filter works to remove pathogens: mechanical trapping, predation, adsorption, and natural death (“BioSand Filter Construction Manual”).

A diffuser layer is important component in a Biofilter to ensure that there is not a disturbance of the Biolayer while pouring water into the filter. Studies have shown that the holes should be three millimeters in diameter and three centimeters apart from one another (“Ngai”).

Eventually, the biological layer becomes too thick and prevents flow in the filter.
When this occurs, the filter must be cleaned. For a more detailed explanation of the maintenance and construction of a BioSand filter, refer to the education components of this report found in Appendix IV and V.

Limiting factors of BioSand filters are the flow rate and the necessary resting period between uses. CAWST recommends, in their construction manual to use the filter between one and four times each day. The resting period after filtering is approximately one hour to 48 hours and is important because it allows oxygen to reach the Biolayer and keeps it alive. The filter has many factors that can affect how effective the filter is including the materials used, the turbidity of the water, and how well the filter is maintained. There have been slightly different results for effectiveness in a laboratory versus in the field. In the laboratory up to 98.5 percent of bacteria, 70 to greater than 99 percent of viruses, and greater than 99.9 percent of protozoa were filtered. In the field, there was not as much available data; however, there was a removal of 87.9 to 98.5 percent of bacteria (“BioSand Filter Construction Manual”).

b. Representation

During research for the BioSand filter design, some preliminary sketches were created to represent the filter prototype and the final design in Ghana. Some additional sketches were made in country as well to aid in construction.

This first sketch depicts the major components of the filter and its proportions as given in the CAWST manual. These proportions include the drainage gravel, the separation gravel, the filtration sand, the standing water layer, the 2 cm gap, and the water reservoir. The layers of the prototype and final design were changed in proportion to this design based on the size of each container used. The 4 to 6 cm standing water layer and 5 cm gap needed to be held constant for each design.

The sizes of the sand and gravel are a very important component of the filter. In order to get the correct sizes, three sieves should be used: a 6 mm, a 1 mm, and a 0.7 mm. The picture below shows each layer of the filter with the corresponding sizes of gravel or sand that pass through the sieves or remains trapped by them.
The prototype filter was to be constructed from three 5 gallon buckets. The sketch depicts the total height of this design and also the correct orientation for the buckets to fit together. The middle bucket was inverted to make a tight seal because the buckets diameter changed slightly from top to bottom. The in country design was instead created from one container for a more robust filter.

Another major component of the filter is the diffuser plate which controls the initial flow of water into the filter. This plate required handles that allow it to be removed for maintenance. The sketch below depicts two options for lifting the plate, either with a hooks or full metal handles.

Several components of the filter vary with the size of the filter. One such component is the bottom PVC system, which is created after making several measurements as outlined in the construction section. This sketch was created to show that two 25 cm pipes needed to be cut for the assembly with the lengths of the PVC caps, elbows, tee, and male adapter factored in.
c. Gantt Charts

![Water Filtration Semester Schedule]

Develop Team Agreement
Develop Project Proposal
Independent research of filtration options
Decide source vs POU filtration
Further research into boiand vs solar pasturization
Decide filtration and initial prototype design
Research biosand materials for prototyping
Primary shopping day for materials
Build prototype
Gain access to E. Coli
Draft documentation
Draft education materials
Revise and finalize documentation/education
Testing
Pre-trip presentation
In Ghana
Complete Post Trip report
Post-trip presentation
Water Filtration Schedule in Ghana

- 26-Dec: Travel from Columbus to Ghana
- 28-Dec: Purchase materials in Kumasi and meeting with ONDA
- 30-Dec: Purchase materials in Techiman
- 1-Jan: Purchase gravel from rock quarry in Kumasi
- 1-Jan: Construction of First Filter
- 3-Jan: Assembly of First Filter
- 5-Jan: Construction of Second Filter
- 7-Jan: Delivery & Assembly of Second Filter to Yawtokrum
- 9-Jan: Travel from Ghana to Columbus
- 11-Jan: Update on completion status
d. Prototyping Details
The BioSand filter prototype was 105 cm tall and 30 cm in diameter. The filters built in Ghana will be similar dimensions. Three five-gallon buckets were used to create the filter prototype container. The top two buckets had the bottoms cut out of them and they were sealed together using silicon glue and then taped on the outside of the container. The diffuser plate was created from a sheet of galvanized metal that was cut to fit inside the circular bucket and 3mm holes were drilled every 2.5 cm to let water through. Nylon brackets for the diffuser plate to sit on were drilled through the bucket at 2 centimeters above the desired height of the standing water.

A system of $\frac{1}{2}$” PVC was constructed to collect the water from the bottom of the filter and raise it to an accessible height to be collected in a bucket. In the bottom of the filter, a “U” shaped assembly of PVC had $\frac{1}{8}$” holes drilled into it to collect the filtered water. The PVC piping then went outside the bucket and up the side to the same height as where the standing water will be inside the filter (pressure will push water out until the water level is the same as inside the filter). The PVC piping was constructed on the outside of the bucket so it would not disrupt the consistency of the gravel and sand layers inside the filter. All PVC components were sealed using standard PVC primer and cement.

The gravel and sand used in the prototype were sorted using sieve sets borrowed from the Civil Engineering Department at Ohio State. Other tools needed, such as power drills and hammers, were borrowed from the Multidisciplinary Capstone Lab at Ohio State located in Smith Lab. The prototype was primarily constructed in Smith Lab, but the final assembly was done in a Microbiology Lab where the prototype was also tested. All materials used in the prototype were purchased at a Lowes in Columbus, Ohio. The prototype took approximately 10 hours to build including shopping for materials and trial and error for design changes and cost $73.43. Pictures of the prototyping process are in Appendix II. The document in Appendix V details more exactly the design and measurements for the prototype as it is the construction manual for BioSand filters and the prototype differed from what was implemented in country.

e. Testing Procedures
The prototype was tested in a Microbiology Laboratory at Ohio State using water contaminated with E. coli. The E. coli was provided through the Department of Microbiology and Professor Madhura Pradhan. Four rounds of testing were performed over the span of fourteen days. Round one of testing was on day one, round two was on day two, round three was on day five, and round four was on day fourteen. Measurements were taken for flow rate during testing. Additionally, the data on the concentration of E. coli in the water before and after filtration was collected two ways; using the Colilert 10mL tubes Test and traditional plating. The testing procedures and collection of results were done with assistance from Professor Pradhan.
Each round of testing put 12 L of contaminated water through the filter prototype. In the first two rounds of testing, water that had an $8 \times 10^3$ CFU/mL concentration E. coli was put through the filter. This concentration was chosen based on a report that evaluated E. coli levels in Tamle, Ghana (Stauber). In the last two rounds of testing, water that had a $2.9 \times 10^7$ CFU/mL concentration of E. coli was put through the filter because the previous concentration was not detectable with the test used. Each round of contaminated water was prepared by adding concentrated E. coli culture to 12 L of tap water. The table below details the preparation of the four rounds of water.

<table>
<thead>
<tr>
<th>Testing Round</th>
<th>Concentration of E. coli Culture (CFU/mL)</th>
<th>Volume of E. coli Culture added to water (mL)</th>
<th>Concentration of E. coli in water (CFU/mL)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$9.6 \times 10^7$</td>
<td>0.10</td>
<td>$8 \times 10^3$</td>
</tr>
<tr>
<td>2</td>
<td>$9.6 \times 10^7$</td>
<td>0.10</td>
<td>$8 \times 10^3$</td>
</tr>
<tr>
<td>3</td>
<td>$1.4 \times 10^{10}$</td>
<td>25</td>
<td>$2.9 \times 10^7$</td>
</tr>
<tr>
<td>4</td>
<td>$4 \times 10^9$</td>
<td>87</td>
<td>$2.9 \times 10^7$</td>
</tr>
</tbody>
</table>

Colilert testing kits, provided by Professor Pradhan, were used to compare the concentration of E. coli present in the water before and after filtration for all four rounds of testing. Five Colilert 10 mL tubes were filled with contaminated water before filtration and five tubes were filled after filtration for each round. The tubes were then incubated for 24 hours at 35°C. When the Colilert tubes were observed after 24 hours of incubation, the color of the fluid in each tube was documented. If the tube was clear, Colilert states that less than 2 CFU/100 mL of E. coli is present in that tube. If the tube is yellow, there are more than 2 CFU/100 mL present in that tube. Calculations were then performed in regards to the number of tubes that were yellow vs clear to calculate the MPN of coliforms after filtration for the round of testing.

Only for round four of testing, the water was also plated on agar petri dishes (also provided by Professor Pradhan) before and after filtration. Two small samples of contaminated water before filtration were diluted to $2.9 \times 10^3$ CFU/mL (diluted $10^4$ fold) and $2.9 \times 10^2$ CFU/mL (diluted $10^5$ fold) and .1 mL of each was plated individually.

After filtration two samples of water were diluted identically (one diluted $10^4$ fold and one diluted $10^5$ fold) to get two samples of comparable concentration and they were plated separately. All plates were incubated for 24 hours at 35°C. When the plates from round four were observed after 24 hours on incubation, the number of colonies on each plate were counted and recorded.

Flow rate measurements were taken by measuring the volume of water coming out of the filter prototype for either 1 or 1.5 minutes and were collected during testing rounds two, three, and four.
f. **Testing Results**

The table below reports the results from testing rounds one, three, and four. Unfortunately, the results from testing round two could not be collected 24 hours after filtration due to limited availability of the Microbiology Lab so there is no data reported below from that round. The associated concentration of E. coli based on the number of positive tubes out of 5 comes from the Colilert manual. The calculation of percent reduction of E. coli concentration comes from assuming the water before filtration only had a concentration of 16 MPN/100 mL. The actual concentration of E. coli in the water before filtration was likely higher than that, so the percentage reported is the minimum reduction percentage possible. Pictures of the Colilert results from round two and three of testing are in Appendix III.

**Table 2: Results from Colilert 10 mL Test.**

<table>
<thead>
<tr>
<th>Testing Round</th>
<th>Water Before Filtration</th>
<th>Water After Filtration</th>
<th>Percent Reduction of E. coli concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number of Positive Tubes</td>
<td>Associated concentration of E. coli (MPN/100 mL)</td>
<td>Number of Positive Tubes</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>&lt; 2</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>&gt; 16</td>
<td>2</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>&gt; 16</td>
<td>3</td>
</tr>
</tbody>
</table>

Zero tubes turned yellow even before filtration in round one. Because of this, the concentration of E. Coli in the contaminated water was increased significantly using Professor Pradhan’s suggestions for testing rounds three and four. The table below details the results of plating .1 mL of two different dilutions of the water both before and after filtration, during round four of testing. The numbers of E. coli colonies were less after filtration in both cases.

**Table 3: Results from plating round four of testing.**

<table>
<thead>
<tr>
<th>Dilution amount from water in or out of filter</th>
<th>Number of colonies observed on plate colonies observed on plate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dilution amount from water in or out of filter</td>
<td>Before filtration</td>
</tr>
<tr>
<td>10,000 fold</td>
<td>187</td>
</tr>
<tr>
<td>100,000 fold</td>
<td>4</td>
</tr>
</tbody>
</table>


Table 4 below details the results of the flow rate measurements and calculations for the filtration prototype. The collection of water to measure flow rate was taken soon after the water was poured in the filter for each round of testing while the water was still flowing steadily.

<table>
<thead>
<tr>
<th>Testing Round</th>
<th>Time (min)</th>
<th>Volume of Water (mL)</th>
<th>Flow Rate (mL/min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>1.5</td>
<td>350</td>
<td>233</td>
</tr>
<tr>
<td>3</td>
<td>1.0</td>
<td>250</td>
<td>250</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>400</td>
<td>267</td>
</tr>
</tbody>
</table>

**Table 4: Flow Rate Results.**

g. *Evaluation of Results*

The results of the Colilert prototype testing showed that there was a reduction in E. coli based on the before filtration testing compared to the after filtration testing. These tests were completed before the Biolayer had formed as water was only run through for one day prior to testing each time. The plate testing was inconclusive due to the inconsistencies, especially in the before filtration samples. There was not enough testing time to determine exactly what the cause of error in the plating results was. One possibility was that less than $10^{-3}$ mL of the actual sample both before and after was being plated. This is an incredibly small volume to represent the total volume of 12 L. The concentration of E. coli is not perfectly homogenous so a very small representative sample can render inaccurate and flawed results.

The results of the E. coli tests found from prototyping are not necessarily reflective of how effective the filter will be in country. The Biolayer had two days of bacteria water run through it and then there was a two-day break from not having access to the lab over the weekend. There was then contaminated water run through the filter for two days before having a six day break from bacteria water due to Thanksgiving break. Contaminated water was run through one day after this. CAWST recommends that the user does not go more than 48 hours without running water through the filter because a period longer than that can kill the Biolayer making the filter less efficient. In addition to the issues with breaks, the filter becomes more efficient over time as the Biolayer develops. The group did not have the time frame necessary to build up the Biolayer.
The flow rates found with our prototype were slower than the ideal. The suggested flow rate from CAWST is 350 to 400 milliliters per minute. To fix this issue for the in-country filters, the group needs to clean the sand more thoroughly. It is also possible that the larger sand layer implemented in the prototype also resulted in a slower flow rate. The sand layer could also be reduced to match the same ratios as CAWST.

h. Cost Analysis
The project has a total budget of $500 dollars for the duration. One prototype was created during the pre-departure period of the project. The costs during the prototyping phase added up to be $73.43. A breakdown of each item that was purchased can be seen in Table 1 in Appendix I. This cost left a remaining budget of $426.57 to be used in country.

G. In Country Implementation
a. Design Details
In Ghana, the BioSand filter was constructed from a single bucket that was 99 cm tall and had a diameter that varied from 30 cm to 50 cm. The outside container was a heavy duty blue plastic with curved walls and a removable lid. The diffuser plate was created from a sheet of galvanized metal that was cut to fit inside the circular bucket and 3mm holes were drilled every 2.5 cm to let water through. Due to the changing diameter of the container, the diffuser plate had to be constructed in three different pieces. The inside metal disc was constructed small enough to fit through the opening of the container to be removed for maintenance. The other portion of the diffuser plate were two half circles that fit together to create a permanent rim that was fixed to the side of the container using metal brackets 2 cm above the desired height for the standing water layer. Pictures of the redesigned diffuser plate are shown in both Appendix IV and Appendix V.

The PVC system for the BioSand filter was constructed the same as the PVC system for the prototype. The only design change was the threaded elbow on the outside of the container was changed to a slip elbow and the adapter pieces were changed to a single male adapter attached to a single female adapter which had a slip end that could be connected to the slip elbow with a small piece of PVC pipe.

The gravel used in the BioSand filter was donated from a granite quarry in Kumasi and was sorted using sieve sets borrowed from ONDA. The separating gravel was then hand sorted to remove any additional large pieces that could not be sieved out with the sieves available. The sand for the filter was donated from a construction site located in Akumadan. The sand was first washed to remove dirt and debris. The sand was then dried in the sun and sieved using flour sieves purchased in the Akumadan market.

The tools needed, such as power drills and hammers, were brought to Ghana from Columbus. One BioSand filter was constructed in the ONDA Annex to serve as a model BioSand filter while another filter was constructed and delivered to the village of Yawtokrum. The document in Appendix V details more exactly the design and measurements for the prototype.
as well as the BioSand filter constructed in Ghana as it is the construction manual for BioSand filters.

Throughout the filter construction phase, there were many unforeseen obstacles that were encountered. The outside container purchased for filter curved in at the top and the bottom. The curve in at the top meant that the design for the diffuser plate had to be changed. Instead of just a plate, the group designed a rim. Another unforeseen difficulty was due to the curve at the bottom. The curve caused the PVC construction at the bottom inside of the barrel to point upwards. To fix this problem, a plumber melted the barrel over a fire at his shop near ONDA and used a wooden paddle to flatten that section of the barrel. Because of the issues with the curvature in the barrel. It is recommended to use a container that has a consistent diameter with flat walls.

The biggest obstacle was creating a leak-free seal. In both of the filters that were constructed, there was an issue with getting a good seal on the bottom hole where the thread came through the barrel. Multiple different solutions were attempted. Sealant tape was used with O-rings in the first attempt. This resulted in a significant leak. Plumber’s putty was then added around the threads and outside of the hole. The resulted in a successful seal for the first evening that the filter was filled with gravel and sand. When the group returned in the morning, there was water all over the floor from a leak that had started. Epoxy was then used both inside and out of the filter around the hole. This proved to be successful until the filter was moved for transport to the village and then it began to leak. The final solution was to melt plastic completely around the PVC and this was done by the same plumber that melted the barrel to fix the curvature issue. This past the initial leak test, but when taken to the village and tested, there was still a very minor leak. It is recommended that any future groups use a different outside container to avoid some of these seal issues.

b. In Country Testing
In Ghana, the team constructed two filters at the ONDA Annex. The first filter was kept at the Annex and was built to be a working model for ONDA Staff when reproducing the design. The first filter was built completely before the second filter was started. This was so that obstacles and issues that arose during construction could be addressed and resolved before the second filter was begun. Both filters were built as a collaboration and partnership with ONDA staff including Jonas, Fuseini, Isaac, and Bernard. The team had multiple meetings and discussions at the beginning of the trip to solidify the end goals of our project and explain the filter design. Educational materials created by the team were provided to ONDA. This included a 40 page, explicitly detailed manual that outline exactly how to create or reproduce a BioSand filter. The manual was used purposefully as both filters were built to reinforce understanding of the construction process.

Education was also done as the filter was assembled in Yawtokrum. The basics of what the filter does and how to operate and maintain it were explained in both English and Twi. Two laminated informational sheets were left in the village regarding the use and upkeep of the BioSand filter.

The seal between the bottom of the container and the PVC outlet tube was tested many times before delivery to Yawtokrum. To test it, about 70 gallons of water were poured inside the
filter. The first time this was done, the filter had only been sealed with epoxy and it seemed to not leak. However as soon as the container was tipped forward to increase pressure, it did begin leaking. Plastic was then melted around the junction and the seal was retested. This time it appeared to be effectively sealed however the filter may have still had a small leak (observed when assembling in Yawtokrum).

In Ghana, Coliplate kits were used to test water quality. These kits give the user a most probable number (MPN) of coliforms in the water indicated by the number of wells that turn blue. In Ghana temperatures, these plates yielded accurate results in 48 hours of sitting in a dark place. This method was used because there was not an incubation box available to speed up the process. These kits also can indicate the MPN for specifically E. coli bacteria by placing the plate under an ultraviolet light. An ultraviolet light was brought from the United States and left at ONDA to assist in future testing. These kits were acquired by the team by contacting Kim Schiefer at Bluewater Biosciences Inc., a contact provided by Bob Campbell who has prior experience in water testing with ONDA. He emphasized the test was practical and easy to use in Ghana. Twenty-four testing kits were bought for $150 and taken to Ghana.

In Ghana, Fuseini shared that ONDA still had Coliplate kits brought by Bob Campbell few months ago. However, there was concern that the plates had expired due to their long-term storage at high temperatures. To test if they had expired, every water sample was plated using both an old test kit and a new test kit, then compared. It was determined that the old plates had expired when an orange color was observed in the wells and the results from these plates did not correlate at all with the new plates.

Two different samples of water were tested in Ghana. The first was water from a well in Akumadan. This water was used during construction of the first filter and also to test leakage of the second filter. After 48 hours, the plate was observed and 23 wells were identified as blue correlating to the water containing 69 MPN. The second sample was from water that came out of the filter during the final stages of construction so it was originally from the well also but had been used during filter assembly. Every single well on this plate turned blue indicating that the concentration of coliforms was greater than 2,424 MPN. All of these wells glowed under ultraviolet light as well indicating the presence of specifically E. coli coliforms.

c. Evaluation of Results
Limited water testing data was collected primarily due to time constraints. The main focus of the trip was to complete two filters and because of leakage problems there was not a significant amount of time with a functioning filter that we could use to test water. Also because the Coliplates took 48 hours to yield results the OSU team was only able to observe samples plated Tuesday. The well sample reported above was actually plated Wednesday and Isaac communicated the results via Whatsapp. Testing needs to be continued by ONDA and future teams at OSU because this group was not able to actually test the efficacy of the constructed filters and observe if they were removing bacteria like the prototype in the United States did.

The Coliplate tests that Bob Campbell brought had expired due to high temperatures. Because of this, ONDA was instructed to store the new testing plates (left behind by the student team) in a cooler place, possibly a refrigerator or somewhere with air conditioning.
This will allow the tests to remain viable for a long period of time as water testing is continued in the future.

There was more bacteria in the water that came out of the filter during construction than originally in the well. One explanation for this is that the rocks and sand inside the filter were washed but in contaminated water. This problem will resolve quickly as water is continuously poured through the filter daily and the bacteria will wash out or be deprived from oxygen and die. This is why CAWST advises that the first sample of water through the filter is not consumed.

The shape of the outside container caused multiple problems with the filter design throughout the construction phase that were not present while prototyping before the trip. The first of which was the shape of the diffuser plate. Where the diffuser plate needs to be located in the filter had a wider diameter than the opening at the top of the container. Since the plate needs to be removed for maintenance, this caused an issue. The plate was redesigned to include a permanent rim that was sealed to the filter wall and had an inset disc that could be removed for maintenance. The shape of the container and the material it was made from presented many problems for getting a good seal between the PVC and the container. An issue with the curved walls at the bottom of the filter did not allow the PVC to properly seal to the bucket. To remedy this problem the containers were taken to a plumber who flattened out the bottom side of the container to provide a flat sealing surface. Even with a flat side, the plastic of the bucket was not a good surface to seal to. After trying O-rings, plumber’s putty, and epoxy, the team eventually got the best possible seal by melting plastic around the PVC pipe on the outside of the container.

During the two weeks in Ghana, the team addressed every objective. The team was able to construct two filters in country. The first filter was constructed in the ONDA Annex to serve as a model BioSand filter to be recreated. Though the first filter did leak, the team left the ONDA staff with instructions on how to repair the filter or rebuild the filter from scratch. The second BioSand filter was built and delivered it to the village of Yawtokrum.

A key component of the project was making sure it was sustainable in country. To make this possible, the group made sure that all materials were purchased in country and that several members of ONDA were well educated on the filter. This included sitting down with many ONDA staff members like Honorable Kojo, Fuseini, and Isaac and reviewing the manual. They also helped in the building of the filter. This was to ensure that multiple ONDA people understood the construction of the filter. Two manuals with detailed instructions were left behind at ONDA so that more filters could be created in the future.

Implementation in the village was carefully done to also allow for sustainability. Filling the filter with the layers of gravel and sand were done with the villagers watching. A detailed description of the filter was explained to the villagers both in English and Twi. This consisted of explaining how the filter worked, the maintenance of the filter, and the few restrictions the filter has, such as the pause period. Pamphlets were left with the villagers that described both how to use the filter and the monthly maintenance the filter requires.

While speaking with Honorable Kojo, it was decided that ownership would be addressed by assigning a few people of the village to maintain and clean the filter. The team also spoke
with Kojo about assigning an ONDA person to take ownership of the filter project and to help produce more filters for other villages in the future.

d. **Cost Analysis**
The in-country parts for the filters were purchased from various different market shops in Kumasi, Techiman, and Akumadan. A total of $234.06 was spent in-country. This cost was broken down between the cost to implement two filters, research and development costs incurred in country, and sunk costs such as tarps and shovels to start the construction process. The total cost to implement one BioSand filter in Ghana was $77.10, with two being created for a cost of $154.20. Table 2 in Appendix I shows the breakdown of the cost to build one BioSand filter. The research and development costs in country amounted to $66.97 and the sunk costs for the project totaled $12.89. These cost breakdowns are detailed in Table 3 of Appendix I. The team also brought many tools to Ghana, estimated at a cost of $281.37, which should be taken into account for replication costs. The list of tools and prices is shown in Table 4 in Appendix I. A complete list of the cost and amount of each item purchased in country can be found in Table 5 in Appendix I. The final total spent for the entire project including all research and development costs along with testing kits was $457.49.

H. **Conclusions**
During the two weeks in Ghana, two BioSand filters were constructed and presented to ONDA, as mentioned in the list of deliverables. The first filter was constructed in the ONDA Annex to serve as a model BioSand filter to be recreated. The second filter was also constructed and delivered it to the village of Yawtokrum. The overall cost to create one BioSand filter was found to be $77.10. This cost does not take into account the $281.37 in tools that were brought to Ghana from Columbus and used during the construction process. However, $12.89 was dedicated to startup costs that will allow ONDA to produce more filters. Additionally, extra materials were left to be used for future filter construction. All of the materials used in the BioSand filters were purchased in Ghana to allow for a sustainable filter. Education documents and multiple construction manuals were also created and delivered to both the ONDA staff as well as the villagers to promote the proper usage and maintenance of the BioSand filters.

The BioSand filter is an appropriate technology to solve the issue of contaminated water in the Offinso North District. The filter can be constructed from completely local materials, allowing for easy maintenance and upkeep. The local materials also make the filter more sustainable if something were to break. The filter is also low maintenance and can be used with little instruction. At $77.10, the filter created was expensive to be implemented in a single household, but by being implemented in a community, it is much more manageable. ONDA and the villages also have budgets set aside to invest in clean water solutions, making the replication and expansion of BioSand filters more feasible.

I. **Recommendations**
We strongly urge future Ohio State groups working to implement additional water filters in Ghana to continue with our design and improve on it. One of our central goals was introducing a new technology to ONDA that can be feasibly reproduced at a relatively low cost, since many of the villages in the Offinso North District have a crucial need for clean
drinking water.

Guidelines for the design have been given throughout this report and also in the construction manual that was created, which focuses on a plastic BioSand filter constructed from materials entirely within Ghana. The CAWST manual is another great resource for BioSand filters, although it is not specific to Ghana and focuses on a concrete filter design. The following section contains several suggestions for future work with this filter (all items are important, regardless of order). Keep in mind to communicate with ONDA members to ensure that these suggestions are both feasible and desired.

1. One of the largest recommendations is to ensure that the container used for the filter has completely straight walls. Our container used in country had slight curves on the top and bottom. The bottom curve caused the largest issue, making it very difficult to create a sealed PVC connection that runs through the container, and this resulted in a filter leak. The PVC system was screwed into the wall of the container using a male and female adapter with an O-ring, although a tight connection required a flat surface. This curved surface also caused the bottom PVC assembly to stick up at an angle inside the filter, which creates a need for a larger drainage gravel layer on the bottom.

The curve on the top of the container also created a large problem for the diffuser plate. This plate is meant to encompass the entire filter diameter as well as be removable. Because our container diameter varied towards the top, our diffuser plate was much more complicated to build. Don’t forget the other filter requirements including one that is non-transparent, has a removable lid, and one that will not rust (plastic or concrete). If a suitable container with an opening or lid is very difficult to find, cutting the top of a container and designing a custom made lid could be investigated.

We recommend coordinating with ONDA members to locate the most suitable container before travelling to Ghana, as this is very important and might take a lot of time to find. Feedback such as pictures, measurements, and the price of different containers found near in the the Offinso North District would be beneficial. We also strongly recommend to use a one-piece container for both the prototype and in-country design, as the three bucket design used in our prototype was difficult to seal.
Some examples of alternate containers found in country:

Descriptions of alternate containers on previous page from left to right (1-4):
1. Found in Cape Coast, smaller than #3
2. Found in ONDA annex building, no removable top (would need to be cut and lid built)
3. Found at ONDA annex building. Isaac says widely available. Large.
4. 30 cm diameter PVC. Not found on our trip, though Andy says is available. Requires flat bottom and removable lid (PVC cap). Much more narrow than others.

2. Different types and shapes of containers should be researched. A square container would make it easier to build the diffuser plate, because it is difficult to cut the sheet metal into a perfect circle. If the circle diffuser plate is not cut precisely, water will flow around its edges and disproportionately disturb the sand underneath. It might be worthwhile to find a hard plastic or polymer for the diffuser plate instead of sheet metal as well.

The BioSand filter is scalable; larger designs can be made. Research should be done on how the container diameter effects filter components such as the filter effectiveness, the flow rate, and load capacity (the amount of water that can be added at one time). A larger diameter filter will be more expensive and require more sand and rock, but could possibly have worthwhile advantages such as a faster flow rate, and a larger load capacity. These properties should be investigated in order to build the most appropriate filter.

ONDA and Honorable Kojo expressed interest in larger filter designs. While the filter design shown was meant for a few families at most, it was given for a whole village. Some ONDA members also had some interest in at the source filters, although we suspect such filtration systems would need to be very large, much more expensive, and require more difficult maintenance. The BioSand filter specifically cannot be used continuously because of its needed rest period in between loads of water, which gives the Biolayer time to consume bacteria and
time for some oxygen to diffuse through the 5 cm of standing water for Biolayer growth. Our team decided that point of use filtration is more feasible to implement for its lower cost, with a greater potential for ownership and maintenance if used by one or a few families as intended.

Concrete filters like in the CAWST design could also be investigated for possible advantages. Our team decided that a plastic filter would be sufficiently robust and much easier to build.

3. Variations in the PVC pipeline system should be investigated, as the leak between the PVC system and filter container was a large and recurring challenge. Even a small leak in the BioSand filter can largely decrease its effectiveness, because the standing water layer of 4 to 6 cm needs to be maintained. The team ruled out a pipeline system that runs up through the filter because of the possibility of disrupting the sand layers, although the extent of this disruption was not thoroughly researched. If such a design has low effect on filter effectiveness or flow rate, it might be worthwhile to have a pipeline system that does not leave the container until its final vertical height is reached. A leak at this height would be located at the top of the standing water, where any possible leakage would not drain the standing water. There is also less pressure at the top of the filter where leakage or possible container wear would be minimized. Improvements on the connection through the filter (with the male and female adapter, an O-ring, and a carefully drilled hole) should also be investigated. These suggestions as well as a flat container should eliminate any leakage problem.

It might be worthwhile to also investigate a variation on the bottom of the internal PVC system. It is possible that having more than two perforated pipes could increase the flow rate, although we suspect the sand layer is the limiting factor of flow rate. Additional perforated pipes might be a more appropriate option for a larger filter design.

4. One thing that was very helpful for purchasing materials in Ghana was printing out images of each material we needed for both the ONDA driver helping us and also for storeowners. We used our Bill of Materials in the construction manual portion of the report. The locations of every material purchased there are also included in the report.

5. Sieving and drying sand for the filter takes a lot of time. We left behind a blue tarp for drying sand and also a few sieves. Inquire whether these are still available. Several ONDA members were not aware of where sieve sets could be purchased, whereas ONDA member Rahmat quickly showed us sieves that women use for flour that were very cheap and quite suitable for 1 mm or 0.7 mm sieves (we did not measure exactly). It might be worthwhile to investigate building custom sieves in Ghana that are larger or more robust, made from metal mesh and a wooden frame, which are both available near the ONDA building in Akumadan. Our team also left behind several buckets for holding and
transporting sand and rock. Remember to see whether more are needed when purchasing materials.

6. We strongly recommend planning more time to do extensive testing of the BioSand filter for both the prototype and final filters in country. Acquiring data for how well the filters remove bacteria is not only crucial for creating more safe drinking water for the region, but also for how well ONDA accepts the filter design and whether they will take steps to replicate them.

7. We also recommend doing more research on tests themselves and on testing results. Our in-country tests were called Coliplate from BlueWater Sciences Inc. More information on these (and prototype testing at Ohio State) are provided in the Testing section of this report. These tests were used based on a suggestion from Bob Campbell, who used these tests in the Offinso North District in 2014 with ONDA member Fuseini. They are simple to use, require no dilutions, and give quantitative data on the concentration of coliforms in water in MPN numbers (which indicate the presence of pathogens) and also the concentration of E. Coli if a U.V. light is used (our group left a UV light with ONDA in the annex building). These tests can be purchased from Bluewater for $11 each via telephone, although our team acquired a large discount after explaining what they would be used for. Our team liked using these tests, but researching different tests for better prices or better usability might be beneficial—although the Coliplate tests are now familiar to several members at ONDA.

Our recommendation for testing results is extensively researching the implications of the Coliplate test results in MPN (which is common among water tests). The only data we have found is such that recommends an MPN of 0 for drinking water (from WHO and the EPA). One result we found in a well near ONDA showed an MPN of 69. What does this number really indicate? How likely are people to get sick from drinking water with this amount of coliforms? What about with 10, or 100, or 1000 MPN? For these water tests to be maximally beneficial for people in the Offinso North District, these questions should be looked into. According to ONDA, they have made efforts to educate people on which water sources are contaminated and which are not, and it seems that the more knowledge we can share with them on the issue can have some very real impact on the health of the locals in this region of Ghana.

8. Here we will make a list of which ONDA members witnessed or helped with which portions of our project planning and construction specifically. We hope this can be beneficial for future work in the district.

- Andy Bediako (Andy) was our main communication before travelling. He responds very quickly over WhatsApp and knows written English very well. He helped us with various questions including what ONDA thought of the filter design and confirmed that each of the materials we needed for our filter could be found nearby.

- Tenkorang Isaac (Isaac) helped us find both sand and gravel for our filter, and he also witnessed how the Coliplate tests worked. We went through a lot of the design of the filter with Isaac using our manual, and he indicated he could serve as one of the main engineers for replicating these water filters in the future.
• Mahadi Annor (Also known by “Chief Driver”) was our main person for shopping the markets and looking for materials. He was very knowledgeable and good at bargaining prices. Be sure to give him or whatever driver images of what you need before driving to the market.

• Honorable Kojo (Kojo) is who you want to talk to about plans for the filter (from both the OSU and ONDA sides). He decided what village our second filer would go to (Yawtokrom) and gave us background on the village. As he is the chief of ONDA, he will be very helpful throughout the entire trip. We sat down and had multiple meetings with him to discuss both broad and specific project goals. Kojo is very friendly and personable.

• Fuseini Mumuni (Fuseini) is in the department of Environmental Health and one of the main engineers of water quality. He has had practice in the past with the Coliplate tests, and also helped us with various construction of our filter including part of the PVC system. Fuseini will likely be one of the main players for the water filter in the future.

• Rahmat Ndego (Rahmat) was very resourceful for general questions and also a lot of background on Ghana. She also helped us find our sieves for the sand and likely knows where metal mesh can be found. She was also there with us during a majority of the construction process (although was not involved in much of the technical construction).

• Gamfi Benard (Benard) was there for a lot of the construction process, as well as using the Coliplate tests and precisely filing the filter with sand and gravel. He was a key player in troubleshooting problems with the filter and was very eager to help.

9. The final suggestion is to have good communication with ONDA members to keep ONDA involved with your project. Make sure to ask questions as well as feedback and suggestions. Meeting the needs of people is done best by listening to them. Make sure to speak clearly and deliberately and confirm ideas (and ask for confirmation) for all ideas and plans that are communicated with one another.

Ensure that what you are doing is meeting the wants and needs of Kojo, ONDA, and the villages you will be visiting. We have been advised that there is a budget with ONDA for water purification, and Kojo, Isaac, and Andy have expressed interest in replicating the water filters. In order for these plans to be executed, it will take strong organization and a thorough understanding of the filter by multiple ONDA members. The construction of these filters is labor intensive and someone will need to take the initiative and maybe get village involvement for things like washing and sieving sand and gravel. We recommend to really pinpoint 2 or 3 individuals in ONDA who can spearhead becoming experts in the planning, construction, and replication of water filters (if these designs are indeed found to be most suitable and approved by Kojo and ONDA). Likely members include Isaac, Fuseini, and Benard.

10. Finally we invite you to reach out and email members of this engineering team for any questions regarding our experience with the BioSand filter in Ghana. We hope that work can
continue to be made here to help increase the health and wellbeing of some of those in great need of clean drinking water.

J. References


K. Acknowledgements

We would like to thank Roger Dzwonczyk and Mariant Gutierrez-Soto for their continuous support throughout the semester and teaching us the important aspects of designing a technology for a developing country. Thank you to Andrews (Andy) Bediako, Honorable Kojo Appiah-Kubi, and Fuseini Mumuni for being our in-country contacts and answering questions that we had throughout the design process of our project. Additionally we would like to thank Isaac Tenkorang and Bernard Gamfi for dedicating a lot of their time to our project throughout our two weeks in Ghana. We would like to show our gratitude to Nana for providing us with information about the culture of Ghana and helping to get us in contact with our in-country partners. We would like to show our appreciation to Professor Madhura Pradhan and the Microbiology Department at the Ohio State University for providing us with access to E. coli to test our prototype with and for guiding us through the testing period of our project. We thank Leslie Callahan for her help in obtaining our visas and preparing us for travel to Ghana. Without the support of each of these individuals our project would not be possible.
## Appendix I: Project Cost Analysis

Table 1: Itemized List of Items Purchased for Prototyping in the United States.

<table>
<thead>
<tr>
<th>Item</th>
<th>Product #</th>
<th>Purchase Location</th>
<th>Individual Cost</th>
<th>Quantity</th>
<th>Total Cost (before tax)</th>
<th>Total Cost (after tax)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 Gallon Bucket</td>
<td>4853</td>
<td>Lowes</td>
<td>$2.19</td>
<td>2</td>
<td>$4.38</td>
<td>$4.71</td>
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<td>5 Gallon Bucket</td>
<td>4853</td>
<td>Lowes</td>
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<td>$14.90</td>
<td>$15.94</td>
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<td>5 Gallon Bucket Lid</td>
<td>276477</td>
<td>Lowes</td>
<td>$0.93</td>
<td>2</td>
<td>$1.86</td>
<td>$1.99</td>
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<tr>
<td>5 Gallon Bucket Lid</td>
<td>276477</td>
<td>Lowes</td>
<td>$1.27</td>
<td>2</td>
<td>$2.54</td>
<td>$2.72</td>
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<tr>
<td>Germicidal Bleach</td>
<td>150275</td>
<td>Lowes</td>
<td>$3.98</td>
<td>1</td>
<td>$3.98</td>
<td>$4.26</td>
</tr>
<tr>
<td>PVC Primer/Paint Set</td>
<td>452387</td>
<td>Lowes</td>
<td>$5.90</td>
<td>1</td>
<td>$5.90</td>
<td>$6.34</td>
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<td>1/2 in x 5 ft SCH40 Pipe</td>
<td>23967</td>
<td>Lowes</td>
<td>$0.93</td>
<td>1</td>
<td>$0.93</td>
<td>$1.00</td>
</tr>
<tr>
<td>1/2 in x 5 ft SCH40 Pipe</td>
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<td>$1.27</td>
<td>1</td>
<td>$1.27</td>
<td>$1.36</td>
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<td>1/2 in PVC SCH 40 Tee</td>
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<td>Lowes</td>
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<td>$0.42</td>
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<tr>
<td>1/2 in PVC SCH 40 90 deg Slip Elbow</td>
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<td>2</td>
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<td>$0.41</td>
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<tr>
<td>1/2 in PVC SCH 40 90 deg Slip Elbow w/ opp side outside threaded</td>
<td>22691</td>
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<td>$0.55</td>
<td>1</td>
<td>$0.55</td>
<td>$0.59</td>
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<tr>
<td>1/2 in PVC SCH 40 90 deg Slip Elbow w/ opp side inside threaded</td>
<td>23935</td>
<td>Lowes</td>
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<td>1/2 in PVC SCH 40 cap</td>
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<td>1/2 in SCH40 PVC extender</td>
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<td>1/8 in Hex Titanium Bit</td>
<td>280453</td>
<td>Lowes</td>
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<td>$2.71</td>
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<tr>
<td>50 lb Play Sand</td>
<td>10392</td>
<td>Lowes</td>
<td>$2.84</td>
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<td>$2.84</td>
<td>$3.04</td>
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<td>50 lb Play Sand</td>
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<td>Lowes</td>
<td>$3.85</td>
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<td>Item Description</td>
<td>Code</td>
<td>Store</td>
<td>Unit Price</td>
<td>Qty</td>
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<td>------------------------------------------</td>
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<td>--------</td>
<td>------------</td>
<td>-----</td>
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<tr>
<td>12 in x 18 in 26Ga Plt</td>
<td>44487</td>
<td>Lowes</td>
<td>$3.67</td>
<td>1</td>
<td>$3.67</td>
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</tr>
<tr>
<td>0.5 cu ft River Pebbles</td>
<td>4697</td>
<td>Lowes</td>
<td>$2.19</td>
<td>1</td>
<td>$2.19</td>
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</tr>
<tr>
<td>0.5 cu ft Pea Gravel</td>
<td>745402</td>
<td>Lowes</td>
<td>$2.57</td>
<td>1</td>
<td>$2.57</td>
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</tr>
<tr>
<td>Stan 4-ct 3/4 in Znc Braces</td>
<td>315714</td>
<td>Lowes</td>
<td>$1.97</td>
<td>1</td>
<td>$1.97</td>
<td></td>
</tr>
<tr>
<td>Nyln Hex Nut #8-32 ct-4</td>
<td>138980</td>
<td>Lowes</td>
<td>$0.68</td>
<td>1</td>
<td>$0.68</td>
<td></td>
</tr>
<tr>
<td>Nyln Ft Wshrs #8 ct-4</td>
<td>139061</td>
<td>Lowes</td>
<td>$0.56</td>
<td>1</td>
<td>$0.56</td>
<td></td>
</tr>
<tr>
<td>Nyln Wing Nut #10-24</td>
<td>138997</td>
<td>Lowes</td>
<td>$0.68</td>
<td>2</td>
<td>$1.36</td>
<td></td>
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<tr>
<td>#10-24x1/2 in Nyln Ms</td>
<td>139000</td>
<td>Lowes</td>
<td>$0.56</td>
<td>2</td>
<td>$1.12</td>
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</tr>
<tr>
<td></td>
<td></td>
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<td></td>
<td><strong>Total</strong></td>
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<td></td>
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<td><strong>$73.43</strong></td>
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Table 2: Itemized list of items purchased for implementation of one BioSand Filter.

<table>
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<tr>
<th>Item</th>
<th>Purchase Date</th>
<th>Purchase Location</th>
<th>Individual Cost</th>
<th>Quantity</th>
<th>Total Cost</th>
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<tr>
<td>Implementation of One BioSand Filter</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>90˚ Slip Elbow</td>
<td>12/28/2015</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>1 GH¢</td>
<td>5</td>
<td>5 GH¢</td>
</tr>
<tr>
<td>½” Valve Socket</td>
<td>12/28/2015</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>1 GH¢</td>
<td>1</td>
<td>1 GH¢</td>
</tr>
<tr>
<td>½” K2 PVC</td>
<td>12/28/2015</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>1 GH¢</td>
<td>1</td>
<td>1 GH¢</td>
</tr>
<tr>
<td>½” End Cap</td>
<td>12/28/2015</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>1 GH¢</td>
<td>2</td>
<td>2 GH¢</td>
</tr>
<tr>
<td>½” PVC Tee</td>
<td>12/28/2015</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>1 GH¢</td>
<td>1</td>
<td>1 GH¢</td>
</tr>
<tr>
<td>½” PVC Tap</td>
<td>12/28/2015</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>15 GH¢</td>
<td>1</td>
<td>12 GH¢</td>
</tr>
<tr>
<td>½” 10 ft section PVC</td>
<td>12/28/2015</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>7.50 GH¢</td>
<td>1</td>
<td>7.5 GH¢</td>
</tr>
<tr>
<td>1 mm Square Plate</td>
<td>12/29/2015</td>
<td>Aspet-A Compant (Techiman)</td>
<td>38 GH¢</td>
<td>1</td>
<td>9.5 GH¢</td>
</tr>
<tr>
<td>PVC Socket</td>
<td>12/29/2015</td>
<td>Techiman Market</td>
<td>3 GH¢</td>
<td>1</td>
<td>3 GH¢</td>
</tr>
<tr>
<td>Outside Container</td>
<td>12/29/2015</td>
<td>Techiman Market</td>
<td>70 GH¢</td>
<td>1</td>
<td>70 GH¢</td>
</tr>
<tr>
<td>PVC Sealant Tape</td>
<td>12/29/2015</td>
<td>Techiman Market</td>
<td>2 GH¢</td>
<td>1</td>
<td>2 GH¢</td>
</tr>
<tr>
<td>Screw, Nut, Washer (4)</td>
<td>12/30/2015</td>
<td>Techiman Market</td>
<td>3 GH¢</td>
<td>1</td>
<td>3 GH¢</td>
</tr>
<tr>
<td>O-Rings (4)</td>
<td>12/30/2015</td>
<td>Techiman Market</td>
<td>1 GH¢</td>
<td>1</td>
<td>1 GH¢</td>
</tr>
<tr>
<td>Wire</td>
<td>12/30/2015</td>
<td>Techiman Market</td>
<td>12 GH¢</td>
<td>1</td>
<td>12 GH¢</td>
</tr>
<tr>
<td>Brackets</td>
<td>12/30/2015</td>
<td>Techiman Market</td>
<td>10 GH¢</td>
<td>4</td>
<td>40 GH¢</td>
</tr>
<tr>
<td>Drainage and Separating Gravel</td>
<td>12/30/2015</td>
<td>Kumasi Quarry</td>
<td>Donated</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Epoxy</td>
<td>1/6/2015</td>
<td>Techiman</td>
<td>10 GH¢</td>
<td>1</td>
<td>10 GH¢</td>
</tr>
<tr>
<td>Melt Plastic Container</td>
<td>1/7/2015</td>
<td>Akumadan</td>
<td>20 GH¢</td>
<td>1</td>
<td>20 GH¢</td>
</tr>
<tr>
<td>1/2 inch backstop</td>
<td>1/4/2016</td>
<td>Techiman</td>
<td>3 GH¢</td>
<td>1</td>
<td>3 GH¢</td>
</tr>
<tr>
<td>Clean Water Containers</td>
<td>1/4/2016</td>
<td>Techiman</td>
<td>40 GH¢</td>
<td>1</td>
<td>40 GH¢</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Total:</td>
<td></td>
<td></td>
<td>293 GH¢</td>
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**Table 3:** Itemized list of items purchased for additional research and development and implementation in Ghana.

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<th>Item</th>
<th>Purchase Date</th>
<th>Purchase Location</th>
<th>Individual Cost</th>
<th>Quantity</th>
<th>Total Cost</th>
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<tr>
<td><strong>Sunk Costs for BioSand Filter Implementation</strong></td>
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<td></td>
</tr>
<tr>
<td>Tape Measures</td>
<td>12/28/15</td>
<td>Kumasi Market</td>
<td>7 GH¢</td>
<td>2</td>
<td>14 GH¢</td>
</tr>
<tr>
<td>Clear Container</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>5 GH¢</td>
<td>1</td>
<td>5 GH¢</td>
</tr>
<tr>
<td>Tarp</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>60 GH¢</td>
<td>1</td>
<td>60 GH¢</td>
</tr>
<tr>
<td>Shovels</td>
<td>12/31/15</td>
<td>Akumadan</td>
<td>30 GH¢</td>
<td>2</td>
<td>60 GH¢</td>
</tr>
<tr>
<td>Sieves Set of Two</td>
<td>1/4/16</td>
<td>Akumadan</td>
<td>5 GH¢</td>
<td>1</td>
<td>5 GH¢</td>
</tr>
<tr>
<td>Jug of Soap</td>
<td>1/4/16</td>
<td>Melcom Techiman Store</td>
<td>35 GH¢</td>
<td>1</td>
<td>35 GH¢</td>
</tr>
<tr>
<td>Soap</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>1.50 GH¢</td>
<td>1</td>
<td>1.5 GH¢</td>
</tr>
<tr>
<td>Washing Station Container</td>
<td>1/4/16</td>
<td>Techiman Market</td>
<td>4 GH¢</td>
<td>1</td>
<td>4 GH¢</td>
</tr>
<tr>
<td>8 Plastic Buckets</td>
<td>12/29/15</td>
<td>Techiman Market</td>
<td>140 GH¢</td>
<td>4</td>
<td>70 GH¢</td>
</tr>
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<td><strong>Total:</strong></td>
<td></td>
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<td>254.50 GH¢</td>
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<td><strong>In Country Research and Development Costs</strong></td>
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<td>66.97</td>
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<tr>
<td>½” PVC Tap</td>
<td>12/28/15</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>15 GH¢</td>
<td>2</td>
<td>30 GH¢</td>
</tr>
<tr>
<td>Jerry Can</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>5 GH¢</td>
<td>2</td>
<td>10 GH¢</td>
</tr>
<tr>
<td>Extra PVC</td>
<td>1/4/16</td>
<td>Techiman Market</td>
<td>9 GH¢</td>
<td>1</td>
<td>9 GH¢</td>
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<td><strong>Total:</strong></td>
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<td><strong>In Country Testing Costs</strong></td>
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<td>Coliplate Tests</td>
<td>12/9/15</td>
<td>Bluewater Testing (Canada)</td>
<td>N/A</td>
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<td>$150</td>
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<td>$150.00</td>
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<tr>
<td>Item</td>
<td>Quantity</td>
<td>Total Cost</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>-----------------------------------------------</td>
<td>----------</td>
<td>------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sharpie</td>
<td>4</td>
<td>$6.39</td>
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<td></td>
<td></td>
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<tr>
<td>Metal Shears</td>
<td>1</td>
<td>$9.50</td>
<td></td>
<td></td>
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<td>Plumbers and Electrical Hole Saw Kit</td>
<td>1</td>
<td>$134.99</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>(7/8” drill bit needed)</td>
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</tr>
<tr>
<td>Power Drill</td>
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<td>$49.00</td>
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<tr>
<td>Assorted Drill Bits</td>
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<td>$29.99</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Small Hammer</td>
<td>1</td>
<td>$9.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Center Punch</td>
<td>1</td>
<td>$9.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utility Knife</td>
<td>1</td>
<td>$8.50</td>
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<td></td>
<td></td>
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<tr>
<td>Electrical Tape</td>
<td>1</td>
<td>$5.00</td>
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<tr>
<td>Silicone Sealant</td>
<td>1</td>
<td>$3.00</td>
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<td>Calculator</td>
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<td>$2.00</td>
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<td>Hand Saw</td>
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<td>$15.00</td>
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<td><strong>Total:</strong></td>
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Table 5: Itemized list of items purchased for implementation in Ghana.

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<tr>
<th>Item</th>
<th>Purchase Date</th>
<th>Purchase Location</th>
<th>Individual Cost</th>
<th>Quantity</th>
<th>Comments</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>90˚ Slip Elbow</td>
<td>12/28/15</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>1 GH¢</td>
<td>10</td>
<td>Need to be smooth on inside</td>
<td>10 GH¢</td>
</tr>
<tr>
<td>½” Valve Socket</td>
<td>12/28/15</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>1 GH¢</td>
<td>2</td>
<td></td>
<td>2 GH¢</td>
</tr>
<tr>
<td>½” K2 PVC</td>
<td>12/28/15</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>1 GH¢</td>
<td>2</td>
<td></td>
<td>2 GH¢</td>
</tr>
<tr>
<td>½” End Cap</td>
<td>12/28/15</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>1 GH¢</td>
<td>4</td>
<td></td>
<td>4 GH¢</td>
</tr>
<tr>
<td>½” PVC Tee</td>
<td>12/28/15</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>1 GH¢</td>
<td>2</td>
<td></td>
<td>2 GH¢</td>
</tr>
<tr>
<td>½” PVC Tap</td>
<td>12/28/15</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>15 GH¢</td>
<td>2</td>
<td></td>
<td>30 GH¢</td>
</tr>
<tr>
<td>½” 10 ft section PVC</td>
<td>12/28/15</td>
<td>God’s Power Hardware ENT (Kumasi)</td>
<td>7.50 GH¢</td>
<td>2</td>
<td></td>
<td>15 GH¢</td>
</tr>
<tr>
<td>Tape Measures</td>
<td>12/28/15</td>
<td>Kumasi Market</td>
<td>7 GH¢</td>
<td>2</td>
<td></td>
<td>14 GH¢</td>
</tr>
<tr>
<td>1 mm Square Plate</td>
<td>12/29/15</td>
<td>Aspet-A Comapant (Techiman)</td>
<td>38 GH¢</td>
<td>1</td>
<td>4 ft by 4 ft galvanized metal</td>
<td>38 GH¢</td>
</tr>
<tr>
<td>8 Plastic Buckets</td>
<td>12/29/15</td>
<td>Techiman Market</td>
<td>140 GH¢</td>
<td>8</td>
<td>2 big, 2 medium, 4 small with lids</td>
<td>140 GH¢</td>
</tr>
<tr>
<td>Outside Container</td>
<td>12/29/15</td>
<td>Techiman Market</td>
<td>70 GH¢</td>
<td>2</td>
<td></td>
<td>140 GH¢</td>
</tr>
<tr>
<td>Item</td>
<td>Date</td>
<td>Location</td>
<td>Price</td>
<td>Quantity</td>
<td>Total</td>
<td></td>
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<td>------------</td>
<td>-------------------</td>
<td>--------</td>
<td>----------</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>PVC Sealant Tape</td>
<td>12/29/15</td>
<td>Techiman Market</td>
<td>2 GH¢</td>
<td>1</td>
<td>2 GH¢</td>
<td></td>
</tr>
<tr>
<td>Screw, Nut, Washer (4)</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>3 GH¢</td>
<td>1</td>
<td>3 GH¢</td>
<td></td>
</tr>
<tr>
<td>O-Rings (4)</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>1 GH¢</td>
<td>1</td>
<td>1 GH¢</td>
<td></td>
</tr>
<tr>
<td>Jerry Can</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>5 GH¢</td>
<td>2</td>
<td>10 GH¢</td>
<td></td>
</tr>
<tr>
<td>Soap</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>1.50 GH¢</td>
<td>1</td>
<td>1.50 GH¢</td>
<td></td>
</tr>
<tr>
<td>Clear Container</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>5 GH¢</td>
<td>1</td>
<td>5 GH¢</td>
<td></td>
</tr>
<tr>
<td>Tarp</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>60 GH¢</td>
<td>1</td>
<td>60 GH¢</td>
<td></td>
</tr>
<tr>
<td>Wire</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>12 GH¢</td>
<td>1</td>
<td>12 GH¢</td>
<td></td>
</tr>
<tr>
<td>Brackets</td>
<td>12/30/15</td>
<td>Techiman Market</td>
<td>10 GH¢</td>
<td>4</td>
<td>40 GH¢</td>
<td></td>
</tr>
<tr>
<td>Drainage and Separating Gravel</td>
<td>12/30/15</td>
<td>Kumasi Quarry</td>
<td>5 GH¢</td>
<td>1</td>
<td>5 GH¢</td>
<td></td>
</tr>
<tr>
<td>Shovels</td>
<td>12/31/15</td>
<td>Akumadan</td>
<td>30 GH¢</td>
<td>2</td>
<td>60 GH¢</td>
<td></td>
</tr>
<tr>
<td>Sieves Set of Two</td>
<td>1/4/16</td>
<td>Akumadan</td>
<td>5 GH¢</td>
<td>1</td>
<td>5 GH¢</td>
<td></td>
</tr>
<tr>
<td>Flatten Bucket</td>
<td>1/4/16</td>
<td>Akumadan</td>
<td>ONDA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Washing Station Container</td>
<td>1/4/16</td>
<td>Techiman</td>
<td>4 GH¢</td>
<td>1</td>
<td>4 GH¢</td>
<td></td>
</tr>
<tr>
<td>Clean Water Containers</td>
<td>1/4/16</td>
<td>Techiman</td>
<td>40 GH¢</td>
<td>2</td>
<td>80 GH¢</td>
<td></td>
</tr>
<tr>
<td>Jug of Soap</td>
<td>1/4/16</td>
<td>Melcom Techiman Store</td>
<td>35 GH¢</td>
<td>1</td>
<td>35 GH¢</td>
<td></td>
</tr>
<tr>
<td>Epoxy</td>
<td>1/5/16</td>
<td>Techiman</td>
<td>10 GH¢</td>
<td>1</td>
<td>10 GH¢</td>
<td></td>
</tr>
<tr>
<td>Metal Taps</td>
<td>1/6/16</td>
<td>Kumasi</td>
<td>12 GH¢</td>
<td>2</td>
<td>24 GH¢</td>
<td></td>
</tr>
<tr>
<td>Melt Plastic Container</td>
<td>1/7/16</td>
<td>Akumadan</td>
<td>20 GH¢</td>
<td>1</td>
<td>20 GH¢</td>
<td></td>
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</tbody>
</table>
Appendix II: Prototyping Pictures

Figure 2.1: Diffuser Plate being cut.

Figure 2.2: Gravel being sieved.

Figure 2.3: PVC being cut with handsaw.

Figure 2.4: “U” shaped assembly of PVC placed in bottom of filter.

Figure 2.5: PVC assembly being attached to bottom bucket of filter.

Figure 2.6: Assembled BioSand filter prototype.
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Figure 3.1: Colilert results from round 2 of testing. The left 5 tubes (all yellow) are before filtration and the right 5 tubes (3 clear; 2 yellow) are after filtration.

Figure 3.2: Colilert results from round 3 of testing. The left 5 tubes (all yellow) are before filtration and the right 5 tubes (2 clear; 3 yellow) are after filtration.

NOTE: Yellow tubes indicate the presence of coliforms in the water.
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Figure 4.2: Gravel being sieved.

Figure 4.3: Diffuser Plate being drilled.

Figure 4.4: Diffuser Plate rim installed in container.

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BioSand Filter Construction and Maintenance Guide
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1. What is a BioSand Filter?

A BioSand filter, also known as a BSF, is a filtration system that makes dirty and contaminated water clean enough to drink. The BioSand filter uses sand and gravel to filter out pathogens like E. coli, viruses and sediments to make the water clean. A Biolayer forms on the top of the sand as more pathogens are poured into the filter. This manual provides instructions for the construction of a single family, at home BioSand filter. BioSand filters can be scaled up for filtering larger volumes of water for multiple families, but information regarding the effects of a larger filter are not presented.

1.1 How Does the Filter Work?

1. Pour a bucket of dirty water in the top of the filter, onto the plate. Water will start to flow out of the tube. Put the lid back on the filter to prevent other things from falling into the filter.

The filter should be filled between 1 and 4 times every day.

At each filling, enough water should be poured into the filter the fill the reservoir[1]. This amount varies by filter size.

2. The top empty space of the filter is called the reservoir. It holds the water that will pass through the filter. But, besides the standing water layer of the filter, water should NOT fill the reservoir fully to be stored for long periods of time [1].

When the reservoir is full, the water will come out of the tube the fastest, and will slow down as the reservoir empties.

3. It usually takes around 1 hour for the water to stop flowing.

4. After the water stops flowing, the filter must rest. The filter must rest for at least 1 hour before pouring more water in, but cannot remain unused for more than 48 hours.

This is called the Pause Period [1]. The optimum Pause Period is 6-12 hours.
1.2 What Does an Entire BioSand Filter Look Like?
### 1.3 What is a BioSand Filter Made of?

#### Hardware/Building Components [1]

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Filter Container</strong></td>
<td>The container is made out of plastic and is circular in shape. It holds the sand and gravel which filters the water. The container should NOT be transparent, and can be circular or square shaped.</td>
</tr>
<tr>
<td><strong>Lid</strong></td>
<td>The lid should be tight. It prevents contamination and keeps out unwanted pests and debris. The lid should remain closed at all times when water is not being poured into the filter.</td>
</tr>
<tr>
<td><strong>Diffuser Plate</strong></td>
<td>The diffuser plate catches the water poured into the BSF. It is a plate with small holes drilled in a uniform pattern so the water slowly drips through to the sand. The diffuser plate protects both the biolayer and the filtration sand from being damaged by water being poured into the filter.</td>
</tr>
<tr>
<td><strong>Outlet Tube</strong></td>
<td>Water that comes out of the outlet tube is safe to drink. The tube is made of PVC to ensure durability. <strong>Safe Storage</strong> A clean safe water storage container, with a lid, must be used to collect the water as it flows out of the outlet tube. A spigot installed on this container will help prevent recontamination of the clean water.</td>
</tr>
</tbody>
</table>

Original Images by CAWST
<table>
<thead>
<tr>
<th>Internal Components [1]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reservoir</strong></td>
</tr>
<tr>
<td>This is the top empty space in the filter where water is poured in.</td>
</tr>
<tr>
<td>The reservoir can be designed to hold the volume of water necessary for the user.</td>
</tr>
<tr>
<td><strong>Standing Water</strong></td>
</tr>
<tr>
<td>This is a layer of water about 4-6 cm tall that remains in the filter at all times, even after water has been poured through to be filtered.</td>
</tr>
<tr>
<td>The layer of standing water sits between the diffuser plate and the filtration sand.</td>
</tr>
<tr>
<td>The water protects the sand and provides oxygen for the biolayer, which allows it to grow and catch more pathogens when water is poured through. The water also keeps the biolayer wet, which is important because the biolayer will die if it dries out.</td>
</tr>
<tr>
<td><strong>Biolayer</strong></td>
</tr>
<tr>
<td>The biolayer is the top layer of sand (1-2 cm deep), where very small microbes live.</td>
</tr>
<tr>
<td>You cannot see the microbes but they perform an important job, eating the pathogens in the water that cause illnesses.</td>
</tr>
<tr>
<td><strong>Filtration Sand</strong></td>
</tr>
<tr>
<td>The sand inside the filter is the most important part. The sand removes almost all the pathogens and dirt from the water.</td>
</tr>
<tr>
<td>The sand must be prepared correctly for the filter to work. It must be the correct size and cannot be compacted.</td>
</tr>
</tbody>
</table>

Original Images by CAWST
1.3 What is a BioSand filter made of? (Cont’d)

<table>
<thead>
<tr>
<th>Internal Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Separation Gravel</td>
</tr>
<tr>
<td>The small gravel stops the sand from moving down and blocking the outlet tube. The gravel is important in order to create a stable base for the filtration sand.</td>
</tr>
<tr>
<td>Drainage Gravel</td>
</tr>
<tr>
<td>The large gravel stops the small gravel from moving and blocking the outlet tube. The large gravel is also important in creating a stable base for the filtration system. The large gravel is too big to get inside the outlet tube and block the flow of water.</td>
</tr>
</tbody>
</table>

1.4 What is the Biolayer?

The Biolayer is the most important part of the BioSand filter as it is what makes the water clean. The Biolayer is a small layer of microorganisms that live in the top layer of sand and eat the pathogens that are poured through the filter when dirty water is poured through.

The Biolayer is NOT…
- A green slime on top of the sand
- Visible to the naked eye

However, the Biolayer is still there and is very important. The filtration sand may turn a darker color from trapped particles, but this is not the Biolayer.
The growth of the Biolayer over time is shown below [1]

<table>
<thead>
<tr>
<th>Day</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day 1</td>
<td>The microbes that live in the water begin to live in the top layer of the sand as dirty water is poured through the filter.</td>
</tr>
<tr>
<td>Day 15</td>
<td>The more the filter is used, the more microbes grow in the Biolayer. The more microbes in the Biolayer result in cleaner water coming from the filter.</td>
</tr>
<tr>
<td>Day 30</td>
<td>At this point the Biolayer is full of microbes that are hungry. The microbes will then eat all of the pathogens in the dirty water poured into the filter.</td>
</tr>
</tbody>
</table>

The water from the filter CANNOT be used after the initial pouring of it through the filter. However, the water from the filter can be used for drinking before the 30-day mark while the Biolayer is growing, but the water must be disinfected [1].

Below is a graph that tracks the estimated growth of the Biolayer

Notice that the water may not be as good for a few days after the filter is cleaned. This is normal and does not mean that the filter is not working. The water will be very clean again a few days after cleaning the filter.
2. Common Facts and Questions about BioSand filters

1. How do BioSand filters clean water?
Water is cleaned by the sand. Contaminants get stuck in the sand (called “adsorption”) and accumulate near the top of the filter, where the Biolayer is formed, this contains bacteria that mechanically traps and consumes future bacteria (called “predation”).

2. How effective are BioSand filters?
While the Biolayer is the key component to removing pathogens, these filters [according to CAWST] will remove from 30% to 70% of pathogenic bacteria with sand alone through mechanical trapping and adsorption. With the Biolayer, an ideal filter will remove up to 99% of pathogens, most of the turbidity, almost all the protozoa and worms, and more than 70% of the viruses. How well the BioSand filter treats water is also affected by how it is built and maintained.

3. What if people still seem to be getting sick from the filtered water?
If this occurs before the filter has been used for about a month, it is likely because the Biolayer has not formed yet. Continue using the filter every day for it to become more effective. If the filter has been used every day for over 30 days, there are still more ways users can get sick from the filtered water.

This will likely happen if the same bucket is used for collecting water and for storing clean water. There should be a separate container for clean water and it should be covered with a lid. Cups and hands should not be put into the filtered water bucket, and the water should be poured out instead. A whole bucket of filtered water can be easily re-contaminated.

4. Why is the Pause Period necessary?
The pause period allows time for the micro-organisms in the Biolayer to consume the pathogens in the water. This should be a minimum of 1 hour. If the pause period is over 48 hours, many of the micro-organisms will eventually eat all of the nutrients and pathogens in the water and then die from starvation, and the filter will not work as well. A long pause period may also cause the standing water in the filter to evaporate, causing the Biolayer to dry out and die.

5. What is the purpose of the “standing water”?
The standing water keeps the Biolayer from drying out and dying. It also keeps the Biolayer from being disturbed by water drops hitting it when water is poured into the filter. The standing water should be at least 4 cm deep and no more than 6 cm, because oxygen still needs to get through the water and into the Biolayer for it to live.

6. Will the filter fill up with sediment from water poured in?
This can and should be prevented. Water with a lot of dirt and sediment should sit in its container for some time (up to 30 minutes) until these particles fall towards the bottom. The container or bucket should then be carefully poured so the sediment at the bottom stays.
The diffuser plate will also collect sediment (and possibly leaves and sticks) and should periodically be removed and cleaned with soap and water. The periodic “swirl and dump” maintenance (See Section 4.4.2 Swirl and Dump) should remove the remaining sediment that gets through.

8. How does the filtered water flow back up through the piping?
Pressure and gravity force the water to flow up through the tube and out the open end. The water will stop flowing when the water level in the container is at the same level as the top bend in the outlet tube.

9. What keeps bacteria from accumulating below the Biolayer (the “non-biological zone”)?
Pathogens below the Biolayer should die off due to a lack of nutrients and oxygen during the Pause Period.
3. How to Build a BioSand Filter

When constructing a BioSand filter it is important to pay attention to the materials being used in the process. The sand and gravel are especially important since they are what make the filter clean, but it is also important to choose the right container and PVC components to construct a working filter.

3.1 Bill of Materials

The following bill of materials details all of the components used to construct a BioSand filter.

A bill of materials detailing the specific materials used to construct your BioSand filter and the stores where the materials were purchased will also be provided.

<table>
<thead>
<tr>
<th>Container and Lid (circular or squared)</th>
<th>OR</th>
<th>Large PVC Pipe</th>
</tr>
</thead>
<tbody>
<tr>
<td>• About 30 cm diameter</td>
<td></td>
<td>• About 30 cm diameter</td>
</tr>
<tr>
<td>• About 1 m tall</td>
<td></td>
<td>• *requires an additional sealed flat bottom</td>
</tr>
<tr>
<td>• *Straight walls are required (no curvature)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Larger designs possible (the effectiveness of larger designs needs to be bid)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

PVC Pipe
-16mm (1/2 inch)
-Need length of at least 1.2 m/filter

Galvanized Steel sheet metal
-Plastic or polymer optional
-Need 300mm square (large enough for filter diameter)
Metal mesh for Sieve Sets+Lumber
- 12 mm mesh
- 6 mm mesh
- 0.7 mm mesh

OR Flour Sieve (found in Akumadan)

PVC Primer+Cement
-One set

PVC Tee, Slip (Slip=non threaded)
16mm or ½ inch
x1

PVC Cap
16mm or ½ inch
x2

PVC 90 degree slip elbow, slip
16mm or ½ inch
x5
PVC Female Adapter
female threaded
16mm or ½ inch
x1

PVC Male Adapter
male threaded
16mm or ½ inch
x1

O Ring
16mm or ½ inch
x1

Screw and nut
Nylon preferably
wing nut preferably
if not wing nut, washer needed
x4 needed

Small metal bracket
x4
Rock Quarry pebbles and sand
- Varying sizes needed
  - 0.7 mm filtration sand
  - 0.7 mm - 6 mm separating gravel
  - 6 mm - 12 mm drainage gravel
- See 3.52: Getting the Right Gravel
- In Wenchi district of OND, Ghana

Silicon Sealant
Waterproof, flexible

Zip Ties (Optional)
Not available in Ghana
Can be used for diffuser plate handles
3.2 Outside Container

The container is an important part of the BioSand filter as it holds all of the internal components which filter the water and make it safe to drink. The container will be a plastic drum. The drum can be any size suitable to provide the appropriate amount of water for the user.

However, depending on the height of the drum, the layers of the sand and gravel may need to be proportioned differently. It is recommended to have a narrow container (with at least a 30 cm diameter) as less sand will be needed to fill the filter. Information regarding how various filter sizes change the effectiveness should be researched if larger containers are considered.

It is very important that the filter walls are straight so the PVC system can be properly sealed to the container and the diffuser plate can be easily installed and removed. The container also should not be a clear plastic as the sunlight will affect the biolayer and may cause the filter to not work [1].

Shown below are pictures of a BioSand filter constructed of three 5 gallon buckets stacked on top of each other. The final BioSand filter had a 30.48 cm diameter (12 inch) and a final height of 105 cm.
In-Country Outside Container

In-Country, the BioSand filter was constructed out of one single container. The final BioSand filter had a varying diameter which caused difficulties during the construction process. At the smallest point the diameter was 38 cm, while at the largest point the diameter was 50 cm. The container had a final height of 99 cm.
In Country Recommendation:

Due to the changing shape of the outside container many problems arose during construction. For future implementation, we highly suggest finding a new container that has flat walls and a consistent size throughout. Additionally, the container can be made from concrete to reduce the problems with sealing plastic, or a smoother plastic should be chosen.

Shown below is a suggestion for a new container for the filter that we noticed while in Ghana. The container has flat walls, a consistent size, and is made from a smooth plastic that would better allow the PVC system to seal to it.
3.3 Diffuser Plate

The diffuser plate is an important part of the BioSand filter as it protects the Biolayer from getting damaged. The diffuser plate is located at the bottom of the reservoir, but above the Biolayer. The plate has holes drilled in it in a grid pattern that controls the flow of water into the filter when water is poured in the top. Without the diffuser plate, the Biolayer would be damaged and the filter would not make the water safe to drink [1].

The diffuser plate can be made of the following materials [1]:
- Galvanized sheet metal
- Plastic
- Concrete
- Acrylic Sheet

The diffuser plate used in this BioSand filter is made of Galvanized sheet metal, which prevents the metal from rusting when the water is poured over it.

A diffuser plate can be made from galvanized sheet metal using the following procedure:
1. The diffuser plate should be cut to tightly fit the circumference of the filter. There should not be any gaps between the plate and the edge of the container [1]. The plate can be cut with a metal saw or with metal shears.
2. A grid should be drawn on the plate with lines perpendicular to each other and spaced 2.5 cm apart [1].

3. **3 mm diameter holes** should be drilled into the sheet metal at each intersection of the grid lines [1]. A drill with a ⅛” bit can be used to drill the holes in the sheet metal. A hole punch should be used before drilling to make the holes cleaner.

4. Handles should be added to the diffuser plate to allow easy removal during the cleaning process. This can be done with various materials, as zip ties could not be found in Ghana.
In-Country Diffuser Plate

In-Country, the diffuser plate was more difficult to construct because the opening at the top of the container was smaller than the part of the container where the diffuser plate needed to be mounted.

As a solution, the diffuser plate was constructed in two parts:

1. A permanent rim fixed to the container

2. A removable inside plate that could fit out the opening at the top of the filter for maintenance
Procedure for the Rim:
1. Measure the diameter where the rim will be permanently fixed.
2. Using Cardboard, create a template of the inside diameter where the rim will be permanently fixed. The template should be made from two half circles that are a little larger than the halfway point so that they overlap when fitted into the filter.
3. The half-moons should be cut so that when the inside piece sits on the rim there was a 1 cm overlap on all sides of the inside plate.
   a. For example: if the rim diameter is 50 cm and the inside piece of the diffuser plate has a diameter of 34 cm, the rim should be cut to be 17 cm wide
      i. $50 - 34 = 16$ cm, but you want a 1 cm overlap, so the rim should be 17 cm wide

![Diagram of rim and inside piece](image)

4. Grid and draw holes in the two rim pieces using 3 mm holes with 2.5 cm spacing between them.
5. Epoxy the rim to the brackets of the filter once laid inside to ensure a permanent fit.
6. Seal the edges of the rim to the outside container using caulk or a silicon sealant.

Procedure for the Inside Diffuser Plate Piece:
1. Measure the opening of the filter container, make the template for the inside piece have a diameter 1 cm smaller than the opening to ensure the center piece can be easily removed.
2. Follow the instructions above for creating a diffuser plate.
Procedure to Mount Center Piece on Rim:
1. Lay the center diffuser piece on the rim.
2. Find the holes closest to the edge of the interior circle that will hold it in place.
3. Fold a zip tie in half and insert into a hole.
4. Loop another zip tie around the back and close the zip tie to prevent the tie from falling through the diffuser plate.

In country, various other materials could be used to create a securing device, as zip ties could not be found in Ghana.
3.4 PVC Pipeline System

The PVC pipeline system begins at the bottom of the filter, and will carry the filtered water out, up, and then back down for collection and drinking. The upwards component of the pipeline system is designed to allow for 5 cm of standing water at the top of the filter. When water is poured in the filter, it will continue to flow downwards and then up through the tube system (by pressure and gravity) until the water level reaches the highest bend in the outside PVC pipeline, where water will remain at that height.

The high bend in the PVC system must be positioned 5 cm above the top of the sand. Once in place, the sand can be adjusted up and down to ensure a standing water level of 5 cm.

The pipeline system is created using 16 mm (1/2 inch) PVC, with a total length approximately equal to the filter height, plus an additional length of twice the filter diameter. For the pipeline turns, five 90 degree elbow slip connectors are needed. The other parts needed are PVC primer and glue, one “o” ring, a female adapter, a male adapter, one slip tee joint, and 2 caps.

All materials are pictures in the bill of materials above.

Building the pipeline system:

1. After acquiring all the above materials, the 16 mm PVC pipe must be cut into several pieces. The internal portion of the system will look as pictured on the right, and this assembly will need to fit inside the bottom of the filter (as pictures above). You will need to calculate which lengths to make the two pieces of PVC pipe shown in the assembly.

2. To find the correct lengths, first measure the diameter of the bottom of the filter container. Then from top to bottom (as seen on the right), measure the length the tee joint connected to the elbow, plus the male adapter, (NOT including its threaded portion). Then measure the length of one cap.
3. In order to get the length of one of the pipes in the assembly on the right, the lengths that were measured for the tee, one elbow, the adapter, and one cap, should be subtracted from the diameter of the filter, or:

\[
\text{Length of Pipe} = \text{[diameter]} - \text{[length cap]} - \text{[length elbow]} - \text{[length tee]} - \text{[length adapter]}
\]

4. You will then need to account for the length that the pipe is inserted into the cap and elbow. These insertion lengths may be measured if the cap and elbow pieces have a grooved ring inside them (which controls the maximum amount the pipe can be inserted).

The grooved ring inside this PVC piece will dictate the insertion length.

If no groove is present, this length should be about 1.5 cm at each insertion, and results in an additional 3 cm needed for the length of each pipe. Two pipes need to be cut this length.

\[
\text{Length of one pipe inside the filter (need two):}
\]

\[
\text{Final Length of Pipe} = \text{[diameter]} - \text{[length cap]} - \text{[length elbow]} - \text{[length tee]} - \text{[length adapter]}
+\text{[insertion length elbow]} +\text{[insertion length cap]}
\]

5. Three additional smaller PVC pipe cuts will need to be made. These will be the connections between each side of the tee joint with the elbow joint, and between the tee and the adapter. These will be glued in place with the PVC cement.

Each piece should be about two of the insertion lengths found above, or near 3 cm each. Cut three of these pieces.
6. Holes must be drilled into the larger PVC pieces that were cut. The filtered water will be flowing through these two pipes, and out of the filter through the tee joint.

7. Clamp one of the pipes to hold steady for drilling holes (if clamp available). Obtain a drill and a 3 mm (⅛ in) drill bit. Drill these 3 mm holes in the pipes every 19 mm (¾ in) for each row. Drill multiple rows of the holes, with spacing about 19 mm between each row. A marker or pencil should be used to trace where the holes should be drilled first.

8. Drill these holes for both pipe pieces. The images below show what this process will look like. Be sure to clean out the plastic pieces inside each pipe that accumulate from drilling.

9. Now the inside PVC assembly can be put together. Obtain the PVC primer and cement to complete this.

10. Assemble the pieces as shown in the image on the right to create the internal portion (the image on the right does not show the male adapter, which should also be attached). Apply the primer to each end of each connection, and then add the cement on top. Read the container directions for best application. Allow the pipe system to dry the amount of time recommended on the containers before allowing water to flow through it.
11. Now the external pipeline system can be made and connected to this internal portion. Place the internal assembly into the bottom of the filter.

12. A hole needs to be drilled into the bottom of the filter. The internal and external portions of the pipeline system will be connected through this by the extender piece.

Obtain a 16 mm hole saw and the 16 mm connection for drilling. If an exact size is not available, start drilling holes with the closest size available, starting small first. The male adapter piece should be able to fit snugly through this hole. The connection process is described in step 13. With the internal assembly in place at the bottom of the filter, you should be able to trace the center of where the outlet of the PVC tee will be. The hole should be made at this same level.


14. With the internal assembly already inside the filter, screw the female adapter into the male adapter through the hole in the container, using an O-ring between the connection. This connection should be tightly screwed into the bucket. The elbow piece can then be attached to the non-threaded side of the female adapter, using a 3 cm PVC piece as shown in step 5. Ensure the elbow piece is facing upwards.

15. Now the vertical upwards pipe can be attached. The length of this pipe will need to be calculated so that the horizontal bend (the bottom of it) that is connected by another elbow piece, is the same height as where the standing water should be (5 cm above the sand level).

16. The sand level may need be adjusted after assembly of this entire outer piping system, ensuring that the water stops flowing 5 cm above the sand.

17. Attach this longer PVC pipe to the bottom joint with PVC primer and cement. Do the same for the top tee joint with this vertical piece, so that the end of the tee joint faces away from the filter. The horizontal connecting piece should be cut a certain length so that the connected outlet tube will be over the center of a water collection bucket underneath. This length will depend on the collection container used.
18. The final elbow and downward pipe can then be installed with PVC primer and cement. The final vertical piece (the outlet tube) can have varying length, depending on how the water will be collected. If PVC under ¼ inch is used, the water in the filter will flow until it reaches height of the end of the outlet tube (lower than the horizontal bend) due to a siphon effect.
3.5 Internal Components of the Filter

The sand and gravel that go into the BioSand filter are the most important parts of the filter as they are what cleans the water. The filtration sand and gravel must be prepared exactly as presented in order to build an effective filter [1]. The correct amounts to add can be found below in section 3.5.5 Proportions of the Materials.

Ensure that the drainage gravel completely covers the PVC assembly in the bottom of the filter so that the sand and separation gravel cannot fall into the piping below (with drilled rows of holes). Also be sure to adjust the height of the sand (after installing the entire PVC pipeline system) so that the water poured in will stop flowing at a height 5 cm above the sand.

In addition to the sand and gravel, and the PVC pipeline system that is installed as instructed above, the remaining internal components needed will be the brackets that hold up the diffuser plate.

Installing the diffuser plate brackets:

1. Obtain the 4 brackets, 4 wing nuts, and 4 screws. Nylon nut and screws are preferable because they will not rust. If a normal nut is used (rather than a wing nut) 4 washers should also be obtained.

2. The top of the brackets (where the diffuser plate will lie) should be positioned so that there is a 2 cm gap between the diffuser plate and standing water. Find the height at which the screws should be drilled into the bucket so that there is an appropriate gap.

3. Drill 4 holes at this height, each one 90 degrees from the other. It is very important these are located at the same height so the diffuser plate sits level on top. A small drill bit will need to be used so that the nylon screw will fit snugly through the bucket. It is best to start with a small drill bit, and increase sizes if they do not make a large enough hole. If metal screws are used, these can be drilled directly into the bucket.
4. Attach the brackets to the inside of the filter with the screw and nut. Ensure that the brackets are installed correctly so that the diffuser plate will be at the needed 2 cm height above the standing water. The diffuser plate can now be placed inside, and the installation of the internal component is complete.

3.5.1 Building a Sieve Set

In order to get the right size sand and gravel for the filter, the sourced material must be put through a specific series of sieves to size out the material. Below are instructions on how to build your own sieve set which can be reused in the construction of additional BioSand filters.

There are 3 sieve sizes that you will need [1]:
1. 12 mm sieve
2. 6 mm sieve
3. 0.7 mm sieve

A Wooden Frame Sieve Set can be created from the materials and procedure outlined below. This process only makes one sieve. To make the complete set of sieves needed to build a BioSand filter, the procedure would need to be repeated 3 times with the correct mesh sizes.

Materials:
- Pieces of Lumber
- Correct Mesh Size

Procedure:
1. Measure 2 pieces of lumber to be wider than the width of a wheelbarrow or container where the sieved material will be collected.
2. Measure out another 2 pieces of lumber the width of the wheelbarrow.
3. Screw the four pieces of lumber together so they are perpendicular and make a square, shown on the next page.
4. Once the square frame is screwed/nailed together, cut a piece of the correct size mesh to cover the opening and overlap some of the wood.

5. Screw or nail the mesh onto the wood frame. Make sure the mesh is securely attached since heavy rocks will be poured onto the mesh. The finished sieve will look similar to the one shown below.
**In-Country Sieve**

While in Ghana, we were able to locate some sieves in the Akumadan market, and did not have to construct our own. Additionally, ONDA had a few various sized sieves that were able to be used to sieve the Quarry dust purchased in Kumasi.

Shown below are the sieves we purchased to use for sieving sand, they were 1 mm sieves.

In order to sieve the separating gravel, we had a two-step sieving process. The separating gravel that was purchased was called quarry dust and was purchased from a granite quarry in Kumasi. First used a metal sieve ONDA had was used to remove the dust and small rocks. Then the remaining gravel was sieved by hand to pick out the pieces that looked too large. Those large pieces of gravel were added to the drainage gravel pile.
3.5.2 Getting the Right Gravel

In order to create an effective BioSand filter, it is important to get gravel and sand from the right place. Please source gravel and sand that fit the criteria outlined below [1].

- Get sand that has many different grain sizes
- Get clean sand that is free from other things like sticks, leaves, and salt
- When you squeeze a handful of dry sand it should not clump together
- The sand should NOT be contaminated with pathogens or microbes
- The sand should NOT be from an area used a lot by animals

The **BEST** place to get gravel and sand is to get **crushed rock** from a Quarry or Gravel Pit [1]

- Crushed rock has a good mixture of grain sizes
- Less likely to be contaminated with pathogens
- Quarry rock may be filled with large rock chunks or dust, but these will be sieved out

The next best place to get gravel and sand is from a Sand Quarry [1]

- Can get sand here, maybe gravel
- Not as clean, may already be contaminated with pathogens
Never Source Sand or Gravel from:
  ● The River
  ● The Beach

These sources contain contaminated sand and gravel which will make the water worse if they are used in the BioSand filter [1].

**In-Country Materials**

The drainage and separating gravel was purchased in country from a granite quarry located in Kumasi, Ghana.

For the drainage gravel, two sizes of rocks, 1/2 inch and 3/8 inch, and the two sizes of gravel were mixed together.

For the separating gravel, quarry dust was purchased from the granite quarry. The dust was sieved to remove small particles and then sieved again by hand to remove rocks that were too large.
The sand was donated in country from a job site Isaac Tenkorang was supervising. If using the same sand it is advised to wash the sand and dry it prior to sieving as about 50% of the volume of sand is lost while washing.

3.5.3 Sieving the Materials

In order to create a working BioSand filter, the crushed rock must be sieved and separated according to grain size and layered in the filter accordingly.

<table>
<thead>
<tr>
<th>Tools and Materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shovel</td>
</tr>
<tr>
<td>Tarps or plastic sheets</td>
</tr>
<tr>
<td>Sieves (3 sizes): 12 mm (1/2&quot;)</td>
</tr>
<tr>
<td>6 mm (1/4&quot;)</td>
</tr>
<tr>
<td>0.7 mm (0.03&quot;)</td>
</tr>
<tr>
<td>Gloves</td>
</tr>
<tr>
<td>Dust mask or scarf</td>
</tr>
<tr>
<td>Sand and gravel</td>
</tr>
</tbody>
</table>

Original Image by CAWST
Procedure [1]:
1. Lay a tarp on the ground. Make sure that when you sieve the material, the sand and gravel make it onto the tarp.
2. With two people holding the 12 mm sieve, pour the sand and gravel through the sieve. Throw away anything that does not fit through the 12 mm sieve, that rock is too big to go into the BioSand filter. (Pictured below)

![Original Image by CAWST](image1.png)

3. Pick up all the material that passed through the 12 mm sieve and now put that same material through the 6 mm sieve. Store all of the gravel that passed through the 12 mm sieve and sits on top of the 6 mm sieve in the 6-12 mm container or pile. This gravel is used for the drainage gravel inside the filter. (Pictured on the next page)

![Original Image by CAWST](image2.png)

4. Pick up all of the material that went through the 6 mm sieve and is sitting on the tarp and now put that same material through the 0.7 mm sieve. Store all of the gravel that stays on top of the 0.7 mm sieve and put it in the 0.7-6 mm container or storage pile. This gravel will be used for the separation gravel within the filter.

5. Pick up all of the material that went through the 0.7 mm sieve and is sitting on the tarp and put it into the 0.7 mm container or storage pile. This material will be used for the filtration sand in the filter. (Pictured on the next page)
A detailed schematic for what grain sizes of gravel should be used in what parts of the filter is provided on the next page.
Gravel Size Schematic

Recommended Sources:

1. Sieve 1: 12 mm (½")
   - Throw away rocks bigger than 12 mm (½")

2. Sieve 2: 6 mm (¼")
   - Store Drainage Gravel
     6 mm (¼") - 12 mm (¼")

3. Sieve 3: 0.7 mm (0.03") (#24 mesh)
   - Store Separating Gravel
     0.7 mm (0.03") - 6 mm (¼")

4. Store Filtration Sand
   ≤ 0.7 mm (0.03")

Filtration Sand
≤ 0.7 mm (0.03")

Separating Gravel
0.7 mm (0.03") - 6 mm (¼")

Drainage Gravel
6 mm (¼") - 12 mm (¼")
Tips for sieving the materials [1]:

- Only sieve **DRY** material, wet material will not go through the sieve.

  ![Dry material](image1.png)
  ![Wet material](image2.png)

- The sand must be **CLEAN** before it goes through the sieve, dirty sand will clog the sieve.

  ![Clean sand](image3.png)
  ![Dirty sand](image4.png)

- Do NOT pile too much material on top of the sieve, it will break the sieve.

  ![Too much material](image5.png)
  ![Correct amount](image6.png)

- Keep sieving until very little material falls through the sieve, you want the most material to pass through to use.

  ![Sieving until little material](image7.png)
  ![Material remaining](image8.png)

- Repair sieves when they break, make sure the holes are uniform. Do not use broken sieves to separate the material for inside the filter.

  ![Repair sieves](image9.png)
  ![Broken sieves](image10.png)

*** Wash the sand BEFORE sieving; 50% of the volume of sand is lost during the washing process ***

Original Images by CAWST
What to do with the material after it is sieved?

- Store the material in a place that it will stay **clean and dry** until it is needed to construct the BioSand filter.
- **Make sure to keep the piles of materials separated.** If the piles accidentally become mixed, the material will need to be sieved again before being used in the filter.
- Material can be stored in either a storage pile or a storage container.

You should have the following 3 piles:
1. Sand (<0.7 mm)
2. Separating Gravel (0.7 mm - 6 mm)
3. Drainage Gravel (6 mm - 12 mm)

Sample Storage Pile [1]:

> Piles of sand and gravel are separated by tall concrete walls
> Floor of storage area is concrete
> Storage area is covered

Sample Storage Container [1]:

> Storage container should be clean
> Storage container should have a lid
> Storage container should be airtight, and watertight and not have any holes
> Different sizes of gravel should be separated into different storage containers
> Storage containers should be labeled with the correct size of gravel inside
3.5.4 Cleaning the Material

Before assembling the BioSand filter, make sure that the internal materials are clean and dry. This is very important, as the sand and gravel are responsible for cleaning the water and making it safe to drink.

**Tools and Materials**

- Buckets
- Water and drain
- Rubber gloves (optional)
- Clear jar with lid
- Filtration sand (<0.7 mm)
- Separating gravel (0.7-6 mm)
- Drainage gravel (6-12 mm)

Original Image by CAWST

**Procedure for Cleaning the Gravel [1]:**

1. Place gravel in a bucket.
2. Fill the bucket half full with clean water.
3. Swirl the gravel in the water with your hand or a spoon.
4. Dump the water out of the bucket. Use your hand to hold the gravel in the bottom of the bucket. Pour the water down a drain or into some bushes.
5. Repeat until the water dumped out of the bucket is clear.
6. Store the clean gravel in a storage pile or storage container once it has been dried out.

Procedure for Cleaning the Filtration Sand [1]:

1. Place some filtration sand in a bucket. This is the sand that has passed through the 0.7 mm sieve.

2. Fill the bucket half full with clean water

3. Swirl the sand in the water with your hand or a spoon.

4. Dump the water out of the bucket. Use your hand to hold the sand in the bottom of the bucket. Pour the water down a drain or into some bushes.

5. Repeat the washing steps. Count how many times you have rinsed the sand.

6. Note: The water poured out of the bucket will not be clean and clear.

7. Perform a jar test (shown on the next page) to test how clean the sand is.
8. Store the clean gravel in a storage pile or storage container once it has been dried out.
The Jar Test [1]
After you have washed the sand 3 or 4 times, perform a jar test to see if the sand needs to be cleaned more.

1. Put some filtration sand in the bottom of a clear jar.

2. Fill the jar with water. Put the lid on tightly.

3. Shake the jar.

4. Stop shaking the jar and wait 4 seconds.

5. After waiting 4 seconds, look into the side of the jar.

If you cannot see the top of the sand, the sand is still too dirty. Keep washing the sand and perform another jar test after another 1 to 2 washes.

If you can see the top of the sand, but not clearly, the sand is the right cleanliness. Wash the rest of the sand the same number of times.

If the water is clear or almost clear and you can clearly see the top level of sand, the sand is too clean. Throw this sand away, it cannot be used in the filter. Start again, but wash the sand a fewer number of times before doing a jar test.
Check the Sand in a Filter

To make sure that the filtration sand will work in a BioSand filter and not clog the system, install the sand in a test filter first and check the flow rate [1].

1. Build one BioSand filter with the washed gravel and filtration sand.

2. Put the diffuser plate into the filter. Fill the filter with water.

3. Catch the water in a container with marked measurements on it. The container should hold at least 500 mL.

4. In order for the sand to work correctly, when water is poured through the filter you should be able to get 400 mL or less water in 1 minute. (You can also fill a 1 liter bottle, which should take 2 minutes and 30 seconds or longer to fill completely)

5. Compare the flow rate you get to the results below. Wash the filtration sand according to those results.

Results [1]:

<table>
<thead>
<tr>
<th>Too Fast! Wash Less</th>
<th>If the flow rate is over 450 mL per minute the sand has been washed too much and will not clean the water. Discard the sand wash the next batch less.</th>
</tr>
</thead>
<tbody>
<tr>
<td>400 mL/min Good</td>
<td>If the flow rate is about 400 mL per minute, the sand is cleaned the right amount. You can use this sand in the BioSand filters. Wash the rest of the sand the same number of times.</td>
</tr>
<tr>
<td>Too Slow! Wash More</td>
<td>If the flow rate is less than 300 mL per minute the useable water may come out too slowly for users. Try cleaning the sand a little bit more to improve its flow rate and make the filter more user friendly. You can still use this sand, it will clean the water well.</td>
</tr>
</tbody>
</table>
3.5.5 Proportions of the Materials

It is important when building a BioSand filter that the proportions of the gravel and the filtration sand are correct. This allows the filter to effectively clean the water and make it safe to drink.

Shown Below are the Heights of the Layers for a 87.3 cm tall BioSand filter
If your filter container is bigger or smaller, please adjust the proportions accordingly:
For example if your container was 120 cm tall, the layer heights would be as follows:

\[
\text{Reservoir Height} : \frac{15.8}{87.3} = \frac{x}{120} \rightarrow x = \frac{15.8 \times 120}{87.3} \rightarrow x = 21.7 \text{ cm}
\]

*Gap*: Always stays at 2 cm

*Standing Water*: Always stays at 4 to 6 cm

*Filtration Sand*: \[\frac{55}{87.3} = \frac{x}{120} \rightarrow x = \frac{55 \times 120}{87.3} \rightarrow x = 75.6 \text{ cm}\]

***Filtration Sand must have a minimum height of 55 cm***

*Separating Gravel*: \[\frac{5}{87.3} = \frac{x}{120} \rightarrow x = \frac{5 \times 120}{87.3} \rightarrow x = 6.9 \text{ cm}\]

***Separating Gravel should have a minimum height of 5 cm***

*Drainage Gravel*: \[\frac{5}{87.3} = \frac{x}{120} \rightarrow x = \frac{5 \times 120}{87.3} \rightarrow x = 6.9 \text{ cm}\]

***Drainage Gravel should have a minimum height of 5 cm***

It is recommended that the BioSand filter is no smaller than 87.3 cm tall and therefore the proportions should only be scaled up when constructing a larger BioSand filter.
In Country Proportions:

Shown Below are the heights of the layers for a 99 cm tall BioSand filter constructed with materials found in Ghana.

*** It is important to note that the filtration sand is the most important aspect of the filter and should not be less than a height of 55 cm. Also, the size of the reservoir can be adjusted based on the amount of water the filter needs to clean at a given time.
3.6 Assemble the BioSand filter

The following are the tools you will need before assembling your filter:

1. Compass
2. Protractor
3. Writing Material for writing on galvanized metal/PVC
4. Metal Shears
5. Plumbers and Electrical Hole Saw Kit
   a. 22 mm bit
6. Drill
   a. 19 mm drill bit for diffuser plate and bottom PVC
7. Small hammer
8. Center Punch (to start the holes in the diffuser plate)
9. Utility Knives
10. Electrical Tape
11. Silicon Caulking/Sealer (for mounting the diffuser rim)
12. Calculator for calculating proportions of sand and gravel
13. Hand saw to cut PVC
14. Tape measure
15. Clamp/Vice for holding PVC while drilling the rows of holes

A majority of the assembly process for a BioSand filter has been described above Section 3 as outlined here:

3.1 Bill of Materials ................................................. 10
3.2 Outside Container ............................................. 14
3.3 Diffuser Plate ................................................ 17
3.4 PVC pipeline system ......................................... 22
3.5 Internal Components of the Filter ......................... 27
   3.5.1 Building a Sieve Set .................................... 28
   3.5.2 Getting the Right Gravel ............................. 31
   3.5.3 Sieving the Materials ................................. 33
   3.5.4 Cleaning the Materials ................................ 39
   3.5.5 Proportions of Sand and Gravel .................. 43
To make the assembly process most efficient, the assembly should be performed in a particular order. Here is a Step-by Step Outline of the entire process:

**Step 1: Locate where the filter will be installed**
The filter should ideally be installed inside a home and away from sunlight. The ground will need to be level so that the filter can stay firmly in place. The filter should **never be moved** from this position.

**Step 2: Acquire all materials as outlined in 3.1 Bill of Materials**
Before beginning to create a BioSand filter, you should first ensure that all of the materials you need are available to purchase.

The first material you should buy is the filter container, because the amount of sand, gravel, and PVC length will depend on how large your container is exactly. Attempt to use the dimensions outlined in 3.2 Outside Container.

We recommend using 300 mm PVC pipe or another 300 mm plastic container for the container, rather than 5 gallon buckets. A PVC pipe will need a bottom sealed to it. If 5 gallon buckets are used, the bottoms need to be cut with pliers and sealed thoroughly with flexible and waterproof silicon. The 5 gallon bucket design is subject to leaking. You will need to ensure water flows through without any leaking.

Additionally, it is important that the outside container has flat walls and does not change in diameter or shape when moving through the filter. The change in diameter will cause multiple issues when trying to build and seal the filter.

Before purchasing materials, plan ahead whether you will be building multiple filters, and buy multiples of the materials as necessary. This will cut down travel time.

**Step 3: Sieve, clean, and dry the gravel and sand**
This should be performed next because the gravel and sand will need to dry before use in the filter. Refer to section 3.5.3, section 3.5.4, and section 3.5.5 for how to perform these steps. The sand and gravel are the most important part of the filter, and are essential to removing contaminants.

**Step 4: Build the PVC pipeline System**
The PVC pipeline should be built next because the cement used will need to dry before any further use. Refer to 3.4 PVC pipeline system. The entire pipeline system (internal and external) should be installed.

**Step 5: Diffuser Plate**
The diffuser plate can now be built as in Section 3.3 Diffuser Plate. This needs to be carefully cut so that water does not leak around the edges, and solely drips through the holes.
Step 6: Other Internal Components
Section 3.5 should be followed for the rest of inside filter. The brackets for the diffuser plate should be installed, and the diffuser plate should be tested on top.

It is also recommended to use a knife to horizontally score the inside of the container. This will prevent water from leaking around the sides of the sand and gravel layers. It is important these cuts are horizontal.

Step 7: Filling the filter with gravel and sand
*** It is very important to check that the container does not leak before filling it with material
Lines should be marked on a measuring stick to make filling the filter with sand and gravel easier. First put a stick or extra length of PVC in the filter and make sure it touches the bottom of the filter, the stick should also extend above the top of the filter. Mark a line where the top of the container is. The using a tape measure, measure from that line down the measuring stick to the depth of the drainage gravel. For example, if you need 5 cm of drainage gravel, measure 5 cm down from the top line and mark that line with a “D”. Repeat that process for the depth of separating gravel, now measuring 5 cm down from the “D” line. Mark the new line with “SG”. Finally, measure 55 cm down the stick from the “SG” mark and label this line “Sand”. After making the stick, pour about 25 liters of water into the filter before adding gravel to prevent air pockets from forming in the sand. Pour the drainage gravel into the filter, periodically checking the depth with the measuring stick. Once the “D” mark reaches the top of the filter, the gravel is 5cm deep and the next layer of material can be poured in. It is important to note that the drainage gravel needs to cover the draining pipe completely, and more can be poured to fulfill this. Next pour in the separation gravel until the “SG” mark reaches the top of the filter, and then add the sand until the “Sand” mark reaches the top of the filter. The water level should always be higher than the sand while it is being added.

The diffuser plate can now be installed, and water will need to be poured into the filter until a flow will occur.

Step 8: Check flow rate and standing water level
As explained at the bottom of Section 3.5.4, a certain flow rate will indicate whether the sand and gravel in the filter have been cleaned the right amount. The flow rate should be near 400mL/minute, and the sand should be washed more if the flow rate is faster. A faster flow rate indicates the filter might not be as it effective as it should. Water that is flowing out slower may not be favorable to the user (but the filter will still be effective).

If all of the above steps are completed successfully, the filter should be adequately assembled.

It is important that the BioSand filter is cleaned on a regular basis to ensure that the filter is still cleaning the water and making it safe to drink.

4.1 How to Correctly Use the BioSand filter [1]

1. Use the BioSand filter every day, each pouring fills the reservoir.
   ○ It is important that the filter is used at least once every day, however, you should wait one hour after water has stopped flowing out of the filter before pouring more water into the filter. This is the Pause Period, and it is important to have a Pause Period, as it keeps the Biolayer alive.
   ○ Do not go more than 2 days without using the BioSand filter. The Biolayer will die and the filter will not work anymore.
2. Always use water from the same source.
   ○ Water from different sources contains different contaminants and pathogens. The Biolayer will get used to eating certain pathogens and will survive better and clean the water better if it is fed water from the same source every day.
   ○ If you must change water sources, it is important to disinfect the water after it is filtered for the first few days until the BioSand filter gets used to the new source water.
3. Use the cleanest water possible in the filter.
   ○ Dirty, cloudy water makes it harder for the sand to remove pathogens and make the water safe to drink.
   ○ Dirty water also requires the BioSand filter to be cleaned more often.
4. Always store the clean, filtered water in a safe storage container and use as soon as possible.
   ○ Use a different container than the one used to collect the water in, and use the safe storage container only for clean water. The safe water container should NOT be used to collect the first water that is poured through the filter.
5. Always make sure the diffuser plate is in place before pouring water in.
   ○ Pouring water directly onto the sand will damage the Biolayer.
6. Always keep the lid on the filter.
   ○ The lid protects the filter from debris and more contaminants.
7. Never put chlorine in the filter.
   ○ To disinfect the water put chlorine in the storage container or disinfect the water using the SODIS method - lay bottles full of water in the sun for 6 hours.
8. Never attach anything to the outlet tube. Keep the outlet tube open.
   ○ Do not attach a hose or tap to the outlet tube.
9. Use the filter only for water.
   ○ Never pour anything else in the filter and do not store anything in the reservoir.
4.2 Why is it Important to Clean the BioSand filter?

It is important to clean the BioSand filter when needed because the water will only be as clean as the filter that is cleaning it. If there are pathogens and dirt on the diffuser plate or the outlet tube the clean water coming out of the filter will quickly become dirty again and will make you sick.

Also, when the inside of the filter become too dirty and clogged with particles the flow rate of clean water coming out of the filter will be too slow to be useful. When this happens, a Swirl and Dump cleaning procedure is needed to clean particles out of the sand and increase the flow rate [1].

4.3 How Often to Clean the BioSand filter?

The lid, diffuser plate, and outlet tube should all be cleaned once a week [1].

The BioSand filter itself should be cleaned with the Swirl and Dump procedure whenever the flow rate becomes too slow to get enough water out of the filter [1]. This can usually be done every few months, and the Swirl and Dump procedure can be repeated numerous times in a row to achieve the final desired flow rate.

4.4 How to Clean the BioSand filter?

There are two important parts to cleaning the BioSand filter [1]
    1. Wash the diffuser plate, lid, and clean the outside of the outlet tube.
    2. When the flow rate becomes too slow, perform a Swirl and Dump cleaning procedure to increase the flow rate again.
### 4.4.1 Cleaning the Parts of the Filter

<table>
<thead>
<tr>
<th>Part to Clean</th>
<th>Why Should it be Cleaned?</th>
<th>How Often Should it be Cleaned?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diffuser Plate</td>
<td>The diffuser plate will collect dirt and large particles. The dirt will not harm the water, but it will make it harder for the water to flow through the filter. Cleaning the dirt off will also prevent the dirt from clogging the sand [1].</td>
<td>Once a week</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The plate should be washed in warm, soapy clean (not filtered) water</td>
</tr>
<tr>
<td>Lid</td>
<td>The lid gets dirty when it is opened and closed so that water can be poured through the filter. If the lid is used to store things it should be cleaned [1].</td>
<td>Once a week</td>
</tr>
<tr>
<td></td>
<td></td>
<td>The plate should be washed in warm, soapy clean (not filtered) water</td>
</tr>
<tr>
<td>Outlet Tube</td>
<td>The outlet tube is the place where the clean, filtered water comes out of the filter. If the tube gets dirty, the water gets dirty again and you are no longer drinking clean water [1].</td>
<td>Once a week</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Wipe the outside of the outlet tube with a chlorine rag</td>
</tr>
<tr>
<td></td>
<td></td>
<td>If you do not have chlorine, wipe down with warm, soapy, clean (filtered) water</td>
</tr>
</tbody>
</table>

*** Chlorine should never be put inside the filter

Original Images by CAWST
### 4.4.2 Swirl and Dump

The Swirl and Dump is an important cleaning process that will unclog the top of the filter and make the clean water flow out of the filter more quickly [1]. This can be repeated multiple times until the desired flow rate is achieved.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>1.</strong> Take off the lid. Pour water into the BioSand filter until the water level is over the diffuser plate. Then remove the diffuser plate.</td>
<td></td>
</tr>
<tr>
<td><strong>2.</strong> Put your hand flat on the sand. Swirl the surface of the sand a few times, but do not dig your hand deep into the sand layer.</td>
<td></td>
</tr>
<tr>
<td><strong>3.</strong> Use a cup to scoop out the dirty water from the top of the filter. Make sure you only remove the water and not any of the layer of sand.</td>
<td></td>
</tr>
<tr>
<td><strong>4.</strong> Pour the dirty water down the drain or in some bushes. Do NOT use the water to water crops or anything you will eat.</td>
<td></td>
</tr>
</tbody>
</table>
5. Make the top layer of sand level and flat. Do **NOT** compact the sand or push down on it.

6. Wash the lid, diffuser plate, and outlet tube as shown above.

7. Put the diffuser plate back in the filter.

8. Wash your hands with warm, clean water and soap. The top layer of sand is very dirty and so your hands need to be cleaned.

9. Pour a bucket of water into the top of the filter.

   If the flow rate is still too slow repeat the Swirl and Dump procedure until the flow rate gets faster.

**Original Images by CAWST**
4.5 Where to Dispose of the Dirty Water?

After performing the Swirl and Dump procedure, the dirty water can be dumped outside on plants or down a drain.

Do Not:
- Use the dirty water for agriculture
- Drink the dirty water
- Wash with the dirty water

Do:
- Wash your hands with warm, clean water and soap after cleaning the BioSand filter
- Close the lid to the BioSand filter
5. How to Store Clean Water

Keeping the water that comes out of the filter clean is just as important as cleaning the water in the first place. If the filtered water comes into contact with contaminants again, then it is as if the water was not cleaned at all.

Important things to remember when storing clean water [1]:
1. Choose the right container to hold the clean water
2. Make sure the water container is clean before filtered water is stored in it
3. Do not allow anything to touch the clean water (ie. hands, cups, dippers)
4. Use the water as soon as possible, do not allow clean water to sit in the container for long periods of time

Choose a Safe Container to Hold the Clean Water

When choosing a container to hold clean water there are several conditions that should be met [1]:
- The container should have a tight fitting lid on it
- There should be a tap/spigot or narrow opening for water to be poured out
- The container should be easy to clean
- The container should be made of strong materials that will last for a long time
- The container should not be made of clear or transparent material to prevent the growth of algae in the clean water

Provided on the next page are examples of unsafe containers as well as safe containers that they should be replaced with:
Unsafe Containers  Safe Containers

No Lid  Tight Lid
Wide Opening  Tap

Original Image by CAWST

*** Clean Water Container used in Ghana
Make Sure the Container is Clean Before Use

Selecting the right container to hold the filtered water is only the first step in storing the clean water safely. Before the container can be used, it needs to be cleaned to ensure there are no contaminants living in the container.

The following steps should be followed to ensure that the container is clean [1]:

1. Wash your own hands with soap and clean water (treated water). Once your hands are clean, try not to touch anything other than the container that you will be cleaning.
2. Wash the inside and outside of the selected container with soap and treated water. Make sure to clean all parts of the container including the lid and any taps.

   The treated water can be water coming straight from an already working BioSand filter or water that has been boiled or treated in the sun for 6 hours.

3. Empty the soapy water through the tap in the container (if there is one) to ensure it is as clean as the inside of the container.
4. Rinse the container and all its parts using treated water.
5. Again, empty the water through the tap in the container (if there is one) to ensure the soap has been washed out of the container completely.
6. Let the container air dry. Do not dry the container with towels or fabric. The towels hold other contaminants that will make the container unsafe to use to store clean water.
7. Once the container is dry, wipe the container’s tap, or area where clean water will come out, with chlorine.
8. Put chlorine drops or tablets in the clean container and fill with treated water. Wait 30 minutes for the chlorine to clean the inside of the container.
9. Empty the chlorine water from the container through its tap, or narrow opening. This water can be consumed or can be dumped down a drain.

   Do not use this water to water plants as the chlorine will kill the plants.
Do Not Allow Anything to Touch the Clean Water

It is important that the clean water is removed from the container only by using the tap or by pouring the water out through a narrow opening.

If the container you choose does not have a tap on it, pour the water out through the opening, but be careful to make sure nothing falls into the container while the lid is off.

Original Image by CAWST
Cups, hands, and dippers all contain contaminants that will make the clean water dirty again. Cups and hands have pathogens on them that can contaminate the water again and make you sick if you drink it. Nothing should be put into the clean water and the lid should remain on the storage container except when clean water is being removed for use [1].

Use the Treated Water as Soon as Possible

It is important that the filtered water is used as soon as possible and does not remain in the storage container for long periods of time.

The longer the water sits in the storage container, the greater the risk of recontamination. It is best if the filtered water is used within 1 day of treating it [1].

Additionally, the water poured through the filter in the morning is the best quality water and should be used for drinking, while water poured through the filter later in the day should be used for cooking and washing things. It is still safe to drink, but will not be as clean as the morning water [1].

Also consider disinfecting the water after it comes out of the filter. The water can be disinfected using either by putting chlorine in the container, or by using the SODIS method. The SODIS method involves putting the filtered water into clear plastic bottles and laying them in the sun for 6 hours. The sunlight will kill any remaining pathogens in the filtered water [1].
6. What if the BioSand Filter Breaks?

1. What if the BioSand filter stops working?
   Did you move the filter? The BioSand filter cannot be moved once it has been assembled. The filter cannot be bumped, tipped, shaken, or moved as the gravel and sand layers will settle and prevent the water from filtering.

   If the filter has been moved, the sand and gravel needs to be removed from the filter and fresh sand and gravel need to be re-layered in a container that will not be moved.

   If the filter has not been moved, check to make sure that the horizontal PVC is even with the top of the standing water height, this is important for the flow of the water.

   If the filter still is not working, ensure that when layering the drainage gravel in the bottom of the filter, the drainage gravel needs to cover the PVC assembly in the bottom of the filter entirely. The drainage gravel is large enough that it prevents the separating gravel from blocking the holes in the PVC to allow water to flow out of the filter.

2. What if the BioSand filter has a leak?
   Stop using the BioSand filter Immediately. A leak will cause a mess and the filter will not work to clean the water. The BioSand filter should be taken apart, the leak should be sealed, and fresh gravel and sand should be re-layered into the fixed outside container.

3. What if the PVC connections start leaking?
   If the PVC connections begin leaking, the connections either need to be resealed with more PVC cement or a silicon sealer or the PVC needs to be taken out of the filter entirely and a new PVC assembly needs to be installed in the filter.

4. What if the lid becomes lost or broken?
   It is important that the filter has a lid to ensure no other contaminants fall into the filter. A new lid needs to be purchased or the old lid needs to be repaired. A lid should remain on the filter at all times when water is not being poured through the filter.
7. References and Additional Resources


Additional Resources:

The Ohio State University Engineering Education Service Learning
Roger Dzwonczyk: dzwonczyk.1@osu.edu

Center for Affordable Water and Sanitation Technology
www.cawst.org
Appendix VI: Supplemental Education Materials

HOW TO USE YOUR BIOSAND FILTER

It is important to use the BioSand filter correctly to make sure that the water coming out of the filter is clean and safe to drink.

IMPORTANT THINGS TO REMEMBER

Use the Filter Every Day:

- It is important that the filter is used at least once every day. However, you should wait one hour after water has stopped flowing out of the filter before pouring any additional water into the filter.
- Do NOT go more than 2 days without using the filter.

Always Pour Water from the Same Source:

- Water from different sources contains different contaminants and pathogens. The BioLayer cleans the water better if it is fed water from the same source every day.

Use the Cleanest Water Possible in the Filter:

- Dirty, cloudy water makes it harder for the sand to remove pathogens and makes the water safe to drink. Dirty water also requires the BioSand filter to be cleaned more often.

If using dirty water, let the water sit and the sediment settle before pouring into the filter. Remove any sticks or leaves from the water before pouring it into the BioSand filter.

Always Store Clean Water in a Safe Container:

- The container should be different than the one used to pour the water into the filter. The container should also have a lid and a tap on it. The water in the container should be used as soon as possible.

Always Make Sure the Diffuser Plate is in the Filter:

- If you pour the water directly on the BioLayer, the filter will be damaged and will not clean the water as well.

STEPS TO USING YOUR FILTER

1. Place a safe water storage container under the outlet tube of the BioSand filter.

2. Take off the lid. Fill the reservoir of the BioSand filter with dirty water. The water should not be too cloudy from sediment.

3. Put the lid back onto the BioSand filter while the water is filtering.

4. The water will take up to 1 hour to filter. After the water stops flowing, wait at least 1 hour before filling the reservoir again.

5. Put a lid on the safe water storage container to keep the water clean.
HOW TO CLEAN YOUR BIOSAND FILTER

It is important to clean the BioSand filter when needed because the water will only be as clean as the filter that is cleaning it. If there are pathogens and dirt on the diffuser plate or the outlet tube the clean water coming out of the filter will quickly become dirty again and will make you sick.

CLEAN ONCE A WEEK

Diffuser Plate:
Wash the plate in warm, soapy (not filtered) water

Lid:
Wash the lid in warm, soapy (not filtered) water

Outlet Tube:
Wipe the outside of the outlet tube with a chlorine rag

If you do not have chlorine, wipe down with warm, soapy, clean (filtered) water

***Chlorine should NEVER be put inside the filter***

CLEAN WHEN THE FLOW RATE IS SLOW

1. Take off the lid. Pour water into the BioSand filter until the water level is over the diffuser plate. Then remove the diffuser plate.

2. Put your hand flat on the sand. Swirl the surface of the sand a few times, but do not dig your hand deep into the sand layer.

3. Use a cup to scoop out the dirty water from the top of the filter. Make sure you only remove the water and not any of the layer of sand.

4. Pour the dirty water down the drain or in some bushes. Do NOT use the water to water crops or anything you will eat.

5. Make the top layer of sand level and flat. Do NOT compact the sand or push down on it.

6. Wash the lid, diffuser plate, and outlet tube as shown to the left.

7. Put the diffuser back in the filter when clean.

8. Wash your hands with warm, clean water and soap. The top layer of sand is very dirty and so your hands need to be cleaned.

9. Pour a bucket of water into the top of the filter.

If the flow rate is still too slow repeat the Swirl and Dump procedure until the flow rate gets faster.
Common Facts and Questions about BioSand Filters

1. How do BioSand filters clean water?
Water is cleaned by the sand. Contaminants get stuck in the sand (called “adsorption”) and accumulate near the top of the filter, where the Biolayer is formed, this contains bacteria that mechanically traps and consumes future bacteria (called “predation”).

2. How effective are BioSand filters?
While the Biolayer is the key component to removing pathogens, these filters [according to CAWST] will remove from 30% to 70% of pathogenic bacteria with sand alone through mechanical trapping and adsorption. With the Biolayer, an ideal filter will remove up to 99% of pathogens, most of the turbidity, almost all the protozoa and worms, and more than 70% of the viruses. How well the BioSand filter treats water is also affected by how it is built and maintained.

3. What if people still seem to be getting sick from the filtered water?
If this occurs before the filter has been used for about a month, it is likely because the Biolayer has not formed yet. Continue using the filter every day for it to become more effective. If the filter has been used every day for over 30 days, there are still more ways users can get sick from the filtered water.

This will likely happen if the same bucket is used for collecting water and for storing clean water. There should be a separate container for clean water and it should be covered with a lid. Cups and hands should not be put into the filtered water bucket, and the water should be poured out instead. A whole bucket of filtered water can be easily re-contaminated.

4. Why is the Pause Period necessary?
The pause period allows time for the micro-organisms in the Biolayer to consume the pathogens in the water. This should be a minimum of 1 hour. If the pause period is over 48 hours, many of the micro-organisms will eventually eat all of the nutrients and pathogens in the water and then die from starvation, and the filter will not work as well. A long pause period may also cause the standing water in the filter to evaporate, causing the Biolayer to dry out and die.

5. What is the purpose of the “standing water”?
The standing water keeps the Biolayer from drying out and dying. It also keeps the Biolayer from being disturbed by water drops hitting it when water is poured into the filter. The standing water should be at least 4 cm deep and no more than 6 cm, because oxygen still needs to get through the water and into the Biolayer for it to live.

6. Will the filter fill up with sediment from water poured in?
This can and should be prevented. Water with a lot of dirt and sediment should sit in its container for some time (up to 30 minutes) until these particles fall towards the bottom. The container or
bucket should then be carefully poured so the sediment at the bottom stays in the pouring container.

The diffuser plate will also collect sediment (and possibly leaves and sticks) and should periodically be removed and cleaned with soap and water. The periodic “swirl and dump” maintenance should remove the remaining sediment that gets through.

7. How does the filtered water flow back up through the piping?
Pressure and gravity force the water to flow up through the tube and out the open end. The water will stop flowing when the water level in the container is at the same level as the bend in the tube.

8. What keeps bacteria from accumulating below the Biolayer (the “non-biological zone”)?
Pathogens below the Biolayer should die off due to a lack of nutrients and oxygen during the pause period.
Appendix VII: Project Proposal

Stream Water Purification Proposal
Akumadan, Ghana
December 26-January 10
The Ohio State University
9/22/2015
**Identify the customer:** Offinso North District Assembly

**Team:** Stream Water Purification/Filtration

<table>
<thead>
<tr>
<th>Members</th>
<th>Roles</th>
<th>Major (Minor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rachel Teater</td>
<td>Team Leader and Meeting Facilitator</td>
<td>Biomedical Engineering (Humanitarian Engineering)</td>
</tr>
<tr>
<td>Rachel DuBois</td>
<td>Photographer, Videographer, Presentation Coordinator</td>
<td>Civil Engineering (Global Option in Engineering)</td>
</tr>
<tr>
<td>Josh Fuchs</td>
<td>Chief Communications Officer</td>
<td>Environmental Engineering</td>
</tr>
<tr>
<td>Alexis Uber</td>
<td>Primary Documenter</td>
<td>Chemical Engineering</td>
</tr>
<tr>
<td>Tori Wilson</td>
<td>Chief Financial Officer</td>
<td>Chemical Engineering</td>
</tr>
</tbody>
</table>

**Primary Contact:**

| Fuseini Mumuni | Environmental Health, Sanitation and Water Testing | Fuseinimuni59@gmail.com | 024 184 4460 |

**Definition of Terms:**

- E. Coli: *Escherichia Coli*
- ONDA: Offinso North District Assembly
- PVC: Polyvinyl Chloride
**Background:**

According to UNICEF in 2015, many people in Ghana do not have access to clean drinking water, where they have determined about 5 million Ghanaians still use water from unsafe sources. Contaminated water is linked to poor sanitation, sickness and disease, where UNICEF has found about 4,000 Ghanaian children die each year from diarrhea, even more die from pneumonia, and about 23% of Ghanaian children suffer from stunting or chronic malnutrition.  

1In 2011 a student group from the Ohio State University, *Ghana for Sustainable Change*, assessed the quality and access water across parts of the Offinso North District in Ghana, whereas about half of the water sources tested were found to contain high contamination, and a majority had at least some contamination.  

Further, the Offinso North District Assembly has identified three specific water sources in the Akumadan Frafraline region of the Offinso North District that are contaminated with nitrates and E. Coli.

**Problem statement:**

Residents in the Offinso North District of Ghana currently collect water from three streams as well as several borehole wells. This project is focused on the three streams that serve as water collection depots from underground springs. The villagers collect the water at the streams and transport the water back to their residence. During a 2015 assessment of the water sources, it was found that the three streams are contaminated with E. Coli and nitrates, making it unsafe to consume. Additionally, during flooding one of the streams becomes unavailable for water collection as well as becomes the site of Typhus outbreaks. One water collection depot is located at the bottom of a ridge in Akumadan Frafraline. There is currently a cistern in place that is not being used. The other two water collection depots do not have cisterns built currently.

**Goal of the project:**

Design and implement a large scale water filtration or water purification system that cleans the contaminated water at the source or develop a smaller scale water filtration system that can be implemented at the residences of multiple villagers. If a large scale water filtration system is designed, its implementation will be focused on the site where the cistern has already been constructed.

**Scope of work/specific objectives:**

- Design a water filtration or purification system that removes the E. Coli and Nitrates from the water of the stream located at the bottom of a ridge in Akumadan Frafraline
- Visual documentation will be created throughout design process
- The research and development, design, implementation and the purification process itself must be within the budget of $500
- The system must be built from parts available in Ghana
- The system must be low maintenance and easy to service
- The system must be durable and able to be continuously used
- Ensure that ONDA prepares the following prior to our arrival: cover the existing cistern in the stream, add valves on the PVC pipes emanating out, and redirect the water to the cistern

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1 From *WASH in Communities*. UNICEF.  http://www.unicef.org/ghana/wes.html  
2 From *Sanitation Mapping, Offinso North District, Ghana*. Kevin Buettner. Pg 3  
https://osu.app.box.com/s/d4wszqxt6wzf94wgn3b9ryuxe71mzvu8
Testing:
After researching filtration methods, a prototype of the initial design will be built. The prototype will undergo a number of tests to determine filtration effectiveness, system durability, and water flow rate. The testing parameters will be further defined as part of the research process before prototyping. Purification effectiveness will be tested using purchased water testing kits. The water will be tested for contaminants before entering the filter and after going through the filter. After the testing parameters have been specified, the team will be able to evaluate the percentage of the contaminants that are removed during the filtration process. The contaminant removal will be performed for both the prototype in the United States and for the design implemented in country.

Deliverables:
The main deliverable will be a filtration system. A document with proper maintenance and upkeep instructions will also be provided. A bill of materials will be provided with the filtration system. This will describe the parts in the system as well as where they were purchased.

Plan for partnering, end user involvement, training, and education:
In order to create a working community partnership, all knowledge about water filtration and hygiene that is learned during the course of the project will be shared with the community members. A user manual, maintenance guide, and bill of materials will be provided to the community to facilitate an easy understanding of the filtration system. Additionally, pictures will be implemented into the documentation when available to minimize the misunderstandings that can result from confusing wording. To provide additional training and education, the team will attempt to hold a meeting with community members to describe the functions of the filtration system and ask questions. The team will also attempt to understand and respect the cultural aspects in Ghana to create a better working relationship with community members and allow community members to take on a larger role in the project.

Plan for sustainability and ownership:
In order for the filtration system to remain sustainable, a majority of the system will be designed and built from materials that are readily available in Ghana. The available materials will make the maintenance of the system much simpler in case something breaks or malfunctions. In order to allow the residents in Akumadan to take ownership of the project by allowing the villagers to participate in the construction of the filtration system so that they can easily replicate the system and keep it maintained. Another way to promote ownership of the filtration system would be to advise Kojo to appoint a community representative to be in charge of monitoring the filtration system and ensuring the water is continually being cleaned.
Appendix VIII: Team Agreement

Stream Water Filtration/Purification
Team Agreement

Identifying the project:

- Term of contract: 9/14/2015-1/31/2016
- Team Members and contact info
  
  Rachel DuBois: (440) 822-9259 dubois.66@osu.edu
  
  Major: Civil Engineering
  
  Minor: Global Option in Engineering

  Josh Fuchs: (330) 312-3903 fuchs.75@osu.edu
  
  Major: Environmental Engineering

  Rachel Teater: (614) 949-1427 teater.16@osu.edu
  
  Major: Biomedical Engineering
  
  Minor: Humanitarian Engineering

  Alexis Uber: (330) 321-5247 uber.11@osu.edu
  
  Major: Chemical Engineering

  Tori Wilson: (614) 314-9424 wilson.2523@osu.edu
  
  Major: Chemical Engineering

Teamwork Criteria:

1. Team Leadership Roles:
   
   - Josh Fuchs: CCO (Chief Communications Officer)
   
   - Rachel DuBois: Photographer, Videographer and Presentation Coordinator
   
   - Rachel Teater: Team Leader and Meeting Facilitator
   
   - Alex Uber: Primary Documenter
   
   - Tori Wilson: CFO (Chief Financial Officer)/Accountant
2. Preferred Methods of Communication:
   - Email and phone communications with a Group Me for team members
   - Ghanaian communication using WhatsApp
   - Information will be stored on a Google Drive
   - Project timeline will be created and edited with Google Gantter

3. Meeting Guidelines:
   - At the end of each class, group members will establish what each person is expected to accomplish before the next class
   - Meetings will be scheduled at times when the majority of group members are available
   - All members will be on time to meetings and meetings will be scheduled using “When to Meet” online scheduler when necessary

4. Participation:
   - Group members will split tasks and documentation evenly amongst themselves
   - All members will put forth effort and complete tasks on time
   - Group members are expected to check rubrics and guidelines to ensure the problems are being addressed
   - Team members will not make statements that are not supported by facts and will make an honest effort to research when needed

5. Responsibilities:
   - Team Leader and Meeting Facilitator is responsible for scheduling meetings outside of class, creating project Gantt chart, taking meeting notes, and keeping meetings on task
   - The Chief Communications Officer will be in charge of communicating with Ghanaian contacts and anyone else involved in developing the project
   - The Chief Financial Officer and Accountant is responsible for recording project expenses and tracking project budget
The Photographer, Videographer, and Presentation Coordinator is responsible for assembling any digital presentations or other presentation aids required for the project and for pictorial documentation both in the United States and Ghana.

The Primary Documenter is responsible for assembling any written reports required for the project and submitting all deliverables.

6. Methods of evaluating and processing project ideas

- All project ideas will be considered equally.
- Use process of elimination to narrow down number of project ideas.
- Develop a non-bias ranking system to evaluate individual project ideas.
- Use approaches to decision making and problem solving/conflict resolution if necessary.
- Provide constructive criticism about the project idea not the person proposing the idea.

7. Approaches to conflict resolution:

- Conflicts will be resolved within the group and without gossiping to outside parties.
- Each team member will attempt to provide a solution to the conflict.
- All solutions will be considered equally as plausible resolutions to the problems.
- Each conflict will be evaluated on a flexible, case-to-case basis.
- For conflicts that cannot be resolved by the group members themselves, group will use an instructor as a mediator to solve the problem.

8. Approaches to problem solving:

- When problems arise, each teammate will be expected to communicate the problem with the rest of the team.
- The team will consider all ideas proposed to solving problems.
- After a solution has been decided on, the team will still be open minded to new ideas throughout the implementation if time allows.
9. Approaches to decision making

- Decisions will be discussed or communicated as a team
- If there is a problem making a final decision, the team will decide using the majority opinion, but also attempt to try multiple options if feasible

10. Signatures agreeing to the terms in this contract

Rachel DuBois

[Signature]
(9/14/15)

Josh Fuchs

[Signature]
(9/14/15)

Rachel Teater

[Signature]
(9/14/15)

Alexis Uber

(9/14/15)

Tori Wilson

[Signature]
(9/14/15)