Filtration and Disinfection of Water from Natural Reservoirs

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I. INTRODUCTION

The town of Marsabit is an outpost of urban civilization in the vast desert of northern Kenya. Marsabit is also home to a number of tribal communities who live outside the city. These tribal communities depend heavily on natural bodies of water such as lakes and ponds which are formed and replenished by the annual seasonal rainfall. However, the stagnant water in the lakes and pools, exposed to animal and avian contamination, poses a significant health and sanitation hazard for the tribal groups. Without proper treatment, the consumption of water has resulted in the prevalence of potentially fatal water borne diseases among the tribal communities. Thus, the primary objective of this project is to convert water from natural lakes/ponds into potable water safe for human consumption, in order to reduce the incidence of water-borne diseases among the tribal population.

II. BACKGROUND

Currently, the environment in Kenya is made up of a mostly desert terrain, unless there is the occasional flooding, which causes the farming land, especially sediments and dirt to enter the watering holes or lakes in their area. This is especially harmful because the community and their livestock are drinking directly from this water. Because of this, an experimental procedure to filter the water was created. The community was using the dirty water from the watering hole and lake as drinking and cooking water. When they cooked, the water could be boiled, which is sufficient to get rid of bacteria and viruses; however, they were not using any cleaning processes for their drinking water. Currently, they are being transported bottle water from Atlanta to use in order to avoid the unclean water there. This, however, is not feasible solution, which is why this filtration project is vital to developing a long-term solution to provide clean drinking and cooking water for their community.

Figure 1: Photo of Filtration and Disinfection Target Body of Water

The most optimal solution was to create a filtration prototype and process that could be easily replicated by the community using their materials, so there are no added costs. The materials used were items such as cotton cloth, sand, charcoal, gravel, pebbles (small and large rocks), buckets, etc. These are very basic materials that could be gathered easily in an underdeveloped society such as this one.

These materials were used because the model built had to be able to be replicated by the community, only materials that could be found in their environment were used. For example, soda bottles and buckets would be prevalent in their society, as would rocks, sand, and charcoal, given their desert-type terrain. It became clear that these would be the most effective materials utilized. Since pebbles and gravel can be used as a natural filter to eliminate large mud or dirt, the filters were built with them. In order to remove even smaller particles, smaller natural filters were needed as well. Sand became the most straightforward choice since it is abundant in the environment. Further research showed that charcoal allowed for even smaller particles to filter through. This is because sand and charcoal have very small pores that allow for water to seep through, but not any larger dirt particles. Finally, the filter needed to be exposed to a cloth material to serve as a final filter. Determining the type of cloth to use required research as to the material best suited as a filter. Research showed that material that was least pliable worked best because it would have the smallest pores and would not let in smaller particulates. Silk material was described as being ideal, and cotton as second. Since silk seemed to be less accessible for the community to acquire, cotton was used instead. It would be just as effective, but the material would cause the pores to stretch over time, allowing more particulates to pass through.

III. OBJECTIVES

Given the background of the community, its environment, finances, and surroundings, the most plentiful and reliable resources could be used. This meant the process must consist of materials that are found in the Kenyan environment, and would not be supplemented with any added costs or with a scarcity of a source. It also must provide comfort and ease to the community members, so the process must be feasible to conduct in an efficient and timely manner. The filter design must also maximize the water retention rate and eliminate all harmful substances in the unclean water, making it safe to drink. Most importantly, the final prototype and process must be 100% easily reproducible and repeatable for each family in the Kenyan community to reproduce.

Firstly, the harmful substances to be removed from the unclean water were narrowed down to three main components: particulates, bacteria, and viruses. In order to eliminate particulates, a filtration process must be used. This process must involve a design that can provide clear water, free of dirt and outside particles, by maximizing the water retention rate and minimizing the time of the filter process to go through.

Secondly, in order to eliminate bacteria and viruses, a disinfection process must be used. This process was used in the form of boiling. This process must be able to hold as much water as possible in large quantities and also be able to minimize the time required to completely boil the water. Lastly, there must be an effective way to cool the water because water exposed to the boiling or to sunlight may be required to be cooled before consumption. This must be done with a process to cool the largest possible quantity of water in the least amount of time. Each of these processes must be able to be measured quantitatively in order to obtain accurate and reputable results

IV. MATERIALS & METHODS

A. PART 1 – FILTRATION

A biofiltration process was investigated for the effective filtration of water containing solid particulates. A 1:4 mixture of dirt and water by mass was used as the filtration sample.

Four materials were considered for the construction of the biofilter - gravel/stones, sand, charcoal and cotton fabric. The materials are arranged in terms of decreasing particle size, in order to filter out larger particulates first and the smaller particles last. Gravel/sand form a layer with large pores, ideal for filtering out large particles or tiny animal and plant matter. Sand forms a layer with smaller pores, filtering out smaller particles in the sample. Ground charcoal, which has the smallest particle size, is expected to improve the filtration process by removing the smallest particles. Cotton fabric was used both as a filter and a barrier to prevent the sand and charcoal from leaking out of the filter.

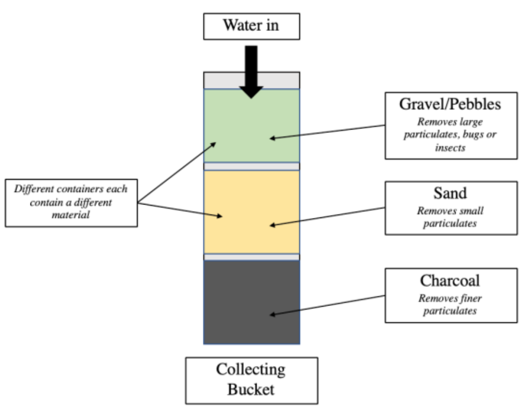
Figure 2: Small test filters with pebbles, sand and cloth (left), and pebbles, sand, charcoal and cloth (right) configurations

Filters of varying sizes and material configurations were used to compare the effectiveness of different materials in the filtration process. Small filters (made using 10 oz. styrofoam cups) were used to compare different material configurations, as shown in Figure 2. Larger filters (made using 24 oz. cups), as shown in Figure 2, were used to determine the effect of scaling on the filtration process. Other previous designs included large soda bottles (2 liters), which had a similar material configuration with large rocks on top, smaller pebbles in the middle, and cloth at the bottom.

Figure 3: Large test filters with pebbles, sand and cloth (left), and pebbles, sand, charcoal and cloth (right) configurations

Building the soda bottle configuration and tests required using three bottles and testing with only small pebbles, both small and large rocks, and both small and large rocks and a cloth supplement, respectively. It was also noted to pre-soak the cloth in the third filter to allow for best results. Each test of the measurement of the unclean water required the weight of dirt and water separately and then equally. After gathering the water, a timer was set as the water was poured through the filter. After all of the water seeped through the system, the remaining water was measured in order to calculate the water retention rate and the time was kept in check to decide whether the filter needed to perform faster or was standard.

Figure 4: Proposed biofilter design with removable containers



Finally, a larger filter was developed using different containers containing different filtration materials stacked to form a tower, as shown in Figure 3. Each container contains a different filtration material and is lined with cotton fabric at the bottom to prevent the material from leaking out of the holes made at the bottom of the containers to allow passage of water. The filter design offers multiple advantages. The filter design is highly scalable, allowing the user to filter large quantities of water in one run, as the filtration capacity can be increased by using larger containers or buckets. Furthermore, the design allows the user to remove the containers and easily rinse the filtered material to prevent accumulation of particulates in the filters.

Figure 5: Biofilter model with removable containers

B. PART 2 – DISINFECTION

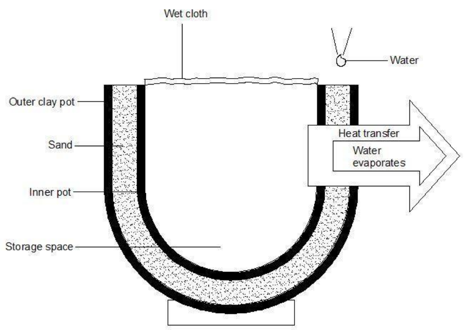
Thermal disinfection in the form of boiling was employed to disinfect the water after filtration. High temperatures have been found to eradicate most pathogenic microbes - bacteria and viruses - in infected water. Two samples of infected pond water (250 ml each) were heated until brought to a rapid boil, and allowed to boil for 3 minutes and 5 minutes respectively. A third sample (1000 ml) was also brought to a rapid boil and allowed to boil for 3 minutes. UV disinfection was also investigated as an alternate method of disinfection, which does not require fuel. Infected pond in a clear 500 ml PET bottle was exposed to sunlight was 6 hours. "Bacteria in Water" testing kits manufactured by *TestAssured* were used to detect the presence of bacteria in the water.

C. PART 3 – RAPID COOLING

The materials required to perform the cooling experiments are a small shovel, two 1-L pots to boil water in, access to water, ten pounds of sand, cloth (old t-shirt), and three earthenware clay pots – one large, one small and narrow, and one small and wide.

Boil two liters of water, one in each pot, simultaneously. After bringing the water to a quick boil, pour two pots of water into the small clay pots respectively. Leave one boiling water pot on the stove away from the heat source. Record the time elapsed for the water to become comfortable to the touch for each pot.

Figure 6: Zeer Pot Configuration



Refer to figure 6 above to construct a zeer pot, use the small wide clay pot. Now, record three more trials using the zeer pot on a countertop, be sure to cover the inner lip of the pot with a wet cloth. Next, find a spot outside to dig a hole deep and large enough to fit the zeer pot up to the bottom of its lip. Record five more trials with times required to comfortably rest one's finger in and times required for he water to become cooler than ambient temperature.

Figure 7: Newly Finished Zeer Pot

V. RESULTS & DISCUSSION

A. PART 1 – FILTRATION

The different test filters and their configurations have been summarized in Table 2. It may be noted that the first few runs with a new filter may show inconsistent results, as soluble particles within the filtration materials may dissolve in the water. The effect can be minimized by rinsing the filtration materials before use in the filter. All filters were able to successfully filter the sample of dirty water to produce a clear transparent filtrate. Filter B (Pebbles + sand + charcoal + cloth) was found to perform better than filter A which contained no charcoal. Filter A demonstrated a noticeable yellow coloration in the filtrate, which was reduced significantly on addition of a layer of charcoal. This is expected as the smaller particle size of the ground up charcoal can remove smaller particles from the sample.

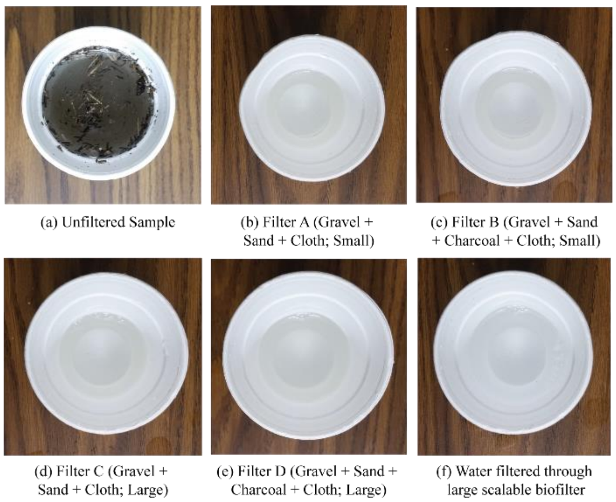
Filter C, which was a larger filter containing pebbles, sand and cloth, performed better than filter A, showing a very faint yellow coloration in the filtrate. A longer sand layer increases the residence time of the water in the filter, allowing more particulates to be filtered out. Therefore, longer filters can be used to boost the effectiveness of a biofilter. However, the larger filter D containing an additional layer of charcoal performed poorly, demonstrating a dark cloudy coloration in the filtrate. The coloration was found to disappear when the layer of charcoal was replaced by a new thoroughly rinsed batch of charcoal. This may be attributed to the presence of smaller particles, such as ash, which are picked up by the water and observed in the filtrate.

Table 1: Filter configuration with results

Filter	Configuration	Size	Results
A	Pebbles + Sand + Cloth	Small	Clear water with yellow coloration
B	Pebbles + Sand + Charcoal + Cloth	Small	Clear with less distinct coloration
C	Pebbles + Sand + Cloth	Large	Clear with very little coloration
D	Pebbles + Sand + Charcoal + Cloth	Large	Clear with some charcoal coloration

The best filtration results were obtained for the larger biofilter shown in Figure 4. The filter produced a clear transparent filtrate and no coloration was observed in the filtrate on filtration. The filter allowed a larger volume of water to be effectively filtered in one filtration run, and allowed easy access to different materials to be switched out for rinsing. The filtrate samples for different filter designs are shown in Figure 8.

Figure 8: Filtrate samples for different filter designs



It was important to consider that multiple design elements and processes were established before choosing the final filter design as the most effective. Beginning testing, different rock configurations were tested, such as the small pebbles, the combination of small and large pebbles, and the combination of cloth and small and large pebbles, to see the most effective results, as shown in Table 2. The results shown prove that the best combination consists of a combination of cloth and small and large pebbles. However, the water bottle design was not the most efficient for cleaning out the filter because repeated results gave less reliable results. This was because the top of the rocks had dirt saturated on them and the cloth had become unclean after using it through multiple trials. Cleaning the filter with the water bottle filter was difficult because of the bulky design. Along with that, it was also the least sturdy as more water filled the filter, so it would not work as a cohesive feature to maximize the amount of water for the process either.

Another aspect of the soda bottle design that proved ineffective was its inability to remove smaller particles from the unclean water. In order to combat this, smaller natural filters like sand or charcoal were introduced.

Table 2: Soda bottle filter configurations and results

Filter Configuration	*Water (g)*	*Dirt (g)*	*Combined water + dirt (mL)*	*Dirt stuck in filter*	*Total water + dirt collected in filter*	*Water filtered (mL)*	*Time to filter (min)*	*Condition of water quality*
Large rocks	197	50	247	7	-	-	>10 min	*Trial deemed as FAIL due to time constrictions
Small rocks	204	25	238	5	46	187	08:44.9	Thick brown water
Cloth on top, large rocks, small rocks	211	24	235	3	40	192	08:00.0	Lighter brown

*Note: Each configuration had article of cloth attached at the lip of the bottle and each piece of cloth was pre-saturated.
*Note: Water + dirt combination was not always equivalent to the separate water and dirt measurements.

B. PART 2 – DISINFECTION

The tested samples and their results are summarized in Table 2. Samples A and B boiled for 3 and 5 minutes respectively both demonstrated a lack of bacterial population after boiling. The result is consistent with literature, which recommends a 3-minute continuous boil for effective disinfection. A larger volume of water (Sample C) was also boiled for 3 minutes and showed a negative result when tested for bacteria. Consequently, the effect of total volume on the boil time can be demonstrated to be negligible. For effective disinfection, a boil time of 3 minutes or more regardless of the volume of infected water is thus recommended.

Figure 9: Photo of Bacteria tests; Left is the control, Middle is after 3 minutes boiling, right is after 5 minutes boiling

In figure 9 above, yellow indicates harmful bacteria and purple indicates negative bacterial presence. This further shown by table 3 below.

Table 3: Presence of bacteria after disinfection using boiling

Sample	*Volume, ml*	*Boiling time, min*	*Bacterial Presence Result*
A	250	3	negative
B	250	5	negative
C	1000	3	negative
Control	250	0	positive

C. PART 3 – RAPID COOLING

As seen in x, the zeer pot is extremely effective at rapidly cooling water. When placed in the ground, the pot is capable of cooling water to acceptable drinking temperature 80% faster than leaving it in the stove pot.

Table 4: Single Pot Cooling Times to Drinking Conditions

Trial	Volume	Stove Pot	Wide Clay Pot	Narrow Clay Pot
1	1 L	49:44 min	23:37 min	26:44 min
2	1 L	53:52 min	~	~

The inground zeer pot is effective because the water has a larger surface area to react with than in the stove pot, the earth's temperature is less than the ambient temperature, and the earth can absorb an unlimited amount of heat relative to the volume of boiled water.

Table 5: Outdoor, inground Zeer Pot temperatures to drinking conditions and below ambient temperature times

Trial	Volume	Drinkable	Below Ambient Temperature
1	1 L	10.02 min	18:11 min
2	1 L	9:48 min	16:09 min
3	1 L	10:12 min	16:49 min
4	1 L	9:13 min	17:35 min
5	1 L	9:01 min	17:23 min

VI. CONCLUSION & NEXT STEPS

As indicated in the results and discussion section, the experiments in this project yielded overwhelmingly positive results. The mechanical filters are very efficient and result in clear water with only slight coloration. The most effect mechanical filter is configuration C, which is the large – pebble, sand, cloth – filter. Boiling the water for disinfection completely killed all the harmful bacteria and viruses that could be tested for, which confirms literature on boiling for disinfection. The benefits of boiling also did not diminish with increasing volume. Zeer pots prove to be effective rapid coolers, they perform best when in the ground, constructed with the widest pots available.

Next steps for this project include scaling up the water filters from bowls to 5-liter buckets and designing a permanent apparatus that can be installed at the water source to continuously filter sediment.

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