Biosand Filter Performance: The Multi-Faceted Aspects of Poverty Observed in Sisit, Kenya

E. Davis Lacey[1], Laura W. Lackey[2]

Abstract – The purpose of this research endeavor was to examine how various technical, geographical, and socio-economic parameters affected biosand filter (BSF) performance in Sisit, Kenya. In 2010, Mercer students installed 25 BSFs throughout the village of Sisit. As part of the 2012 Mercer on Mission trip to Sisit, each previously installed filter's performance parameters (flow rate, % coliform removal, etc.) were compared to respective distances, populations, and levels of affluence. Analysis illustrated that the distance between a household and the community center is highly correlated to various aspects of BSF performance. A relationship was also shown to exist between a BSF's coliform removal efficiency and the distance between the associated household and water-collection point.

Keywords: Biosand filter, BSF, water quality.

INTRODUCTION

Since 1990, over 2 billion of the world's people have gained access to an improved source of drinking water. While such a statistic is worthy of celebration, there remain 783 million people without access to a safe source of water. Over 40% of those 783 million people live in sub-Saharan Africa, making the region the most severe case of disparity of clean water supplies in the world. Sub-Saharan Africa's rural population is more adversely affected by the water disparity than those who live in urban areas. As of 2010, 50.8% of sub-Saharan Africa's rural population lacked access to an improved water source, while only 16.8% of city-dwellers lived without improved water [1].

Mercer University sponsors various international study opportunities through its "Mercer on Mission" program. These opportunities allow students to use skills and knowledge obtained in the classroom to address specific issues related to poverty in the developing world. In response to the clean water disparity in rural sub-Saharan Africa, Mercer University commissioned one such service-learning opportunity to travel to the village of Sisit in northern Kenya. The object of the trip was to construct biosand filtration systems (BSFs) as a means to improve the quality of residential-use water.

In June of 2010, Mercer University students and faculty partnered with a local non-government organization (NGO), Africa Exchange, to construct 25 BSFs in Sisit, Kenya. Each filter was constructed with the members of a household that had expressed interest in receiving a BSF to the village's leadership council. In addition to constructing the BSFs, the Mercer team provided educational sessions addressing water safety, proper sanitation and handling techniques, and advice for BSF maintenance. When the team left the village at the end of the trip, all 25 filters were reported to be in good working order.

When a Mercer on Mission trip to Sisit was finalized for the summer of 2012, an objective to study the 25 pre-existing BSFs was established. Each BSF was to be investigated in relation to mechanical integrity (i.e. the durability and longevity of the filter over the two year period) and effective water treatment (i.e. the quality of the filter's effluent in comparison to the source water). In addition to observing each of the 25 BSFs, observations were made as to the relative affluence of each of the 25 households, so that relationships between BSF performance and

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relative affluence could be investigated. A GPS coordinate was also recorded for each household, so that potential relationships between geography and filter performance could be established.

TECHNICAL BACKGROUND

In support of the technical analysis performed in this study, a brief discussion regarding BSF performance parameters is provided. Figure 1 is a detailed schematic of the Mercer on Mission BSF:

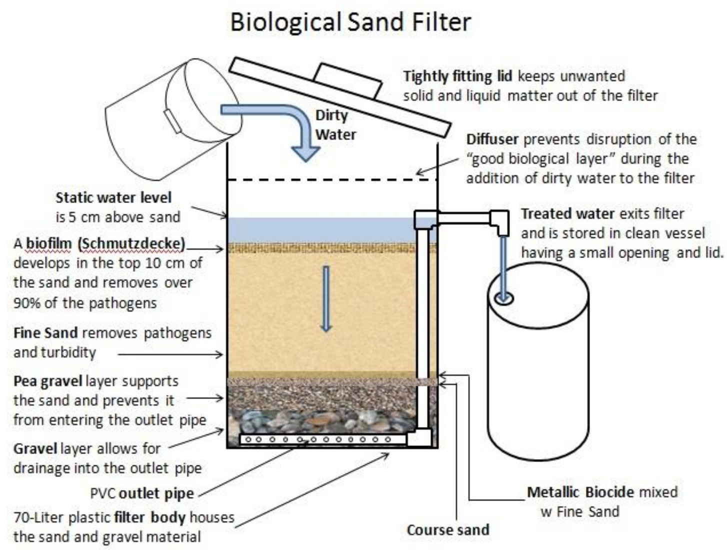

Figure 1. BSF schematic.

The BSFs contain the following components:

1. **A tightly fitting lid** prevents contamination by particles (dust, dirt, etc.) as well as unwanted photosynthetic biological growth. It also prevents unwanted pests from entering the BSF [2].
2. **A diffuser,** made by drilling holes into a plastic insert atop the filter, prevents the filtration sand from being overly disrupted. It also protects the biological layer that is located at the top of the sand layer [3].
3. **The biofilm,** also known as the schmutzdecke, develops in the top 10cm of the filter media. The schmutzdecke is formed in the initial period of BSF operation, and is comprised of the various forms of microscopic life that are removed from the filter's influent. The biofilm removes the majority of pathogens from the influent, and breaks down organic compounds into simple inorganic salts [4].
4. **Fine sand** makes up the majority of the BSF's filter media. It removes pathogens and suspended solids from the influent, thus reducing the turbidity of the water [5].
5. **A metallic biocide**, such as copper, supplements the pathogen removal of the porous sand medium.
6. **A layer of coarse sand** rests below the biocide.
7. **A layer of pea gravel** supports the sand medium. It also prevents the sand from entering and clogging the outlet pipe.
8. **A layer of large gravel** protects the drainage pipe. It also allows water to drain quickly into the drainage pipe.
9. **The PVC outlet pipe** is located on the bottom of the BSF. It is drilled with holes so that water can enter as it passes through the gravel layer.

Water is poured through the diffuser at the top of the filter. As the height of the water rises above the filter's outlet pipe, the hydraulic head pushes water through the sand medium, in accordance with Darcy's Law:

$$V = K \frac{dH}{dL} \quad (1)$$

V represents the Darcian velocity of the water through the sand, *K* represents the sand's hydraulic conductivity, and *dH/dL* represents the hydraulic gradient in the direction of the flow [6]. After the water passes through the filter medium, it reaches the outlet pipe. The pipe conveys the water from the gravel layer up along the side of the BSF. The peak flow rate of water from the BSF should ideally be around 1 L/min [7].

The outlet is located approximately 5 cm above the top of the sand layer. As water behaves according to Pascal's principle, the equilibrium water level of the BSF, which is achieved when water is neither entering nor exiting the BSF, rests 5 cm above the sand medium [8]. The purpose of this layer of standing water is twofold. Oxygen that diffuses through the standing water provides an oxygen source for the BSF's biological layer. Additionally, the standing water provides a reservoir of pathogens and organic matter to nourish the biological layer while the filter is not in use [9]. The Centre for Affordable Water and Sanitation Technology (CAWST) recommends that a pause of at least one hour be observed between uses of a BSF. To prevent depletion of the biological layer's nutrient supply, CAWST recommends that pauses between BSF usages be no longer than 48 hours [9].

With proper operation, BSFs remove pathogens very efficiently from water sources. Laboratory testing has indicated that BSFs can remove up to 96.5% of water-borne bacteria, 70 to 99% of viruses, over 99.9% of protozoa, and up to 100% of helminths [9].

The Mercer on Mission BSFs were constructed in SKYPLAST 70-liter plastic basins. A picture of one such BSF can be seen in Figure 2.

Figure 2. A BSF constructed by the Mercer on Mission team in Sisit, Kenya.

METHODOLOGY

The 2012 Mercer on Mission trip to Sisit, Kenya took place in June, 2012. The trip served two purposes, one of which was to continue to improve the quality of the village's drinking water. Through multiple trips to the village of Sisit, Mercer students and faculty have constructed multiple BSFs with numerous village-dwellers. During the course of the 2012 trip, 25 additional BSFs were constructed. Educational sessions on hygiene and sanitary water storage were also provided.

The second purpose of the trip was to observe, record, and analyze data from the 25 households in which BSFs were constructed in 2010. Because one of the existing BSFs could not be located, 24 households were observed. Three types of data were collected: technical data, geographical data, and socio-economic data. Technical data dealt strictly with the performance of the household's BSF. Geographical data collection involved recording the GPS coordinates for the location of each household, as well as those of the water collection points and the village's community center. Socio-economic data points included the population of each household, the relative affluence of each household, etc. These data points were collected so that relationships could be investigated between technical and non-technical factors.

Collecting Technical Data

Technical data points were collected by observing and investigating the BSF in each of the 24 households. First, qualitative analysis was performed by observing each BSF in detail. The diffuser of each BSF was checked for cracks and/or breaks; the outlet pipes were observed for leaks and bends; etc. After qualitatively analyzing each

BSF, and after asking permission from the head of each household, each BSF was filled to its top with source water. The hydraulic head was measured and, the BSF effluent volumetric flow rate was estimated using a graduated cylinder and stopwatch. Water samples were collected of each household's influent (stored water gathered from a water collection point), effluent (collected directly from the BSF outlet pipe), and stored water (collected and stored after BSF treatment).

Collecting Geographical Data

Through the use of a camera with GPS technology, the GPS coordinates of each household were collected. A picture of a note card with the name of the head of household (or family name) was taken near the front door of each house, so that the data could be easily archived. In the same manner, the GPS coordinates of the Sisit community center and various water collection points were also recorded.

Collecting Socio-Economic Data

Socio-economic data points were collected through a process called asset mapping. Individual or family-based interviews were used to gather and catalog the assets of each household [10]. Through conversations held with household members (often relying on the aid of a translator), population data was ascertained. This data included the number of people in each household who had experienced an illness within the past year. Information regarding each household's material assets was also gathered (i.e. livestock owned, possession of a cellular phone, etc.)

DATA COLLECTION

In order to compare the technical factors of BSF performance to geographical and socio-economic information, extensive data analysis was required. The following text describes how each technical, geographical, and socio-economic factor was evaluated.

Analyzing Technical Data

Each BSF was qualitatively investigated for damaged parts, missing parts, etc. To quantify these observations, an observational scale was applied for each household BSF. If a household had an ideal BSF (i.e. no missing/broken parts), it was given a score of "10." For households with less than ideal BSFs, 2 points were subtracted from the "ideal" score for every broken BSF component, and 4 points were subtracted for every missing BSF component. Additionally, 1 point was subtracted from the ideal score if the water storage container was broken, missing a lid, different from the standard storage can originally provided to the household, etc. This category of data was referred to as "mechanical integrity."

Measured flow rates were compared to the ideal BSF flow rate of 1 L/min using the percent difference comparison described in equation 2.

$$\text{"\% difference"} = \frac{1\frac{\text{L}}{\text{min}} - \text{actual BSF flow rate}}{1\ \text{L/min}} \tag{2}$$

If a measured BSF flow rate was within ±5% of the ideal BSF flow rate (1 L/min), the BSF was assigned an observational score of 10. If the BSF flow rate was within ±10% of the ideal flow rate, that household was awarded an observational score of 9. Each additional 10% difference in flow resulted in a one point deduction on the observational scale. This data set was referred to as "flow rate."

Coliforms were enumerated using a disposable plate counting method developed by Micrology Laboratories (www.micrologylabs.com); Coliscan Easygel medium was used. A 1 mL sample of inlet water and 5 mL samples of the effluent and storage can were plated and incubated for 24 hours. The total colony-forming units (CFU)/mL of each sample was determined by visually counting the number of colonies in each plate. An example of a post-incubated plate can be seen in Figure 3.

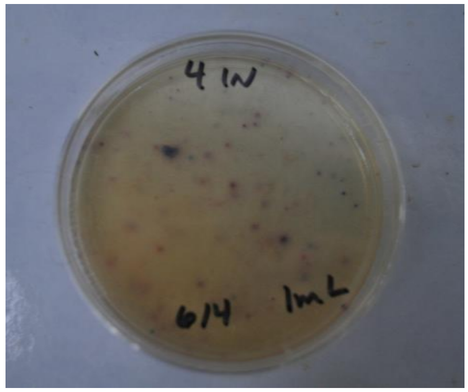

Figure 3. Plate count agar dish after 24 hours of incubation.

The % coliform removal of each BSF was determined by comparing the influent and effluent CFU counts through equation 3.

$$\%\ \text{coliform removal} = 100 - \frac{\text{effluent CFU/mL}}{\text{influent CFU/mL}} \times 100 \qquad (3)$$

This data set was referred to as "BSF % removal."

"Sanitary storage" was defined through the use of equation 4.

$$\%\ \text{coliform removal} = 100 - \frac{\text{storage can CFU/mL}}{\text{influent CFU/mL}} \times 100 \qquad (4)$$

The sanitary storage data was compared to the BSF % removal data. Ideally, the water in each household would be stored under sanitary conditions, meaning that little difference would be observed between the effluent CFU/mL data and the storage can CFU/mL data. An observational score of 10 was awarded to households that saw less than 5% difference between the results of equation 3 and equation 4. For households that did see a significant increase in the storage can CFU/mL data (as compared to the effluent CFU/mL data), 1 point was subtracted from the ideal observational score of 10 for each 5% difference (over and above 5% difference).

Analyzing Geographical Data

GPS coordinates of each household were recorded. GPS coordinates were also recorded for Sisit's community center (the location of the village's church/school and water collection tank), as well as each additional water collection point (namely, the Wei Wei river). These coordinates were archived into Google Earth; an overlay of the village of Sisit, with the recorded location of each household, the community center, and the water collection points, can be viewed in Figure 4.

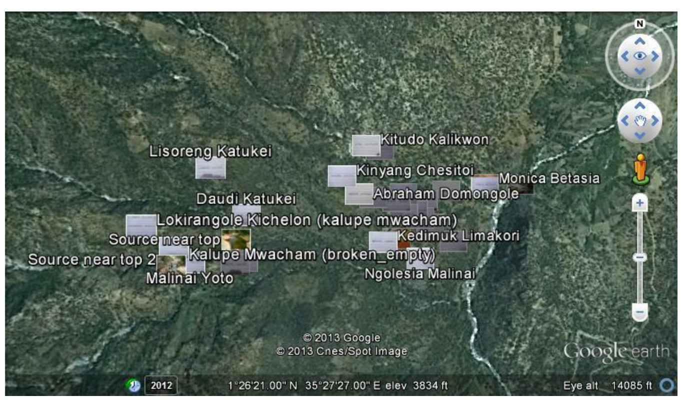

Figure 4. Google Earth overlay of the village of Sisit.

Using Google Earth's "ruler" tool, the straight line distances (in miles) from each household to the community center were calculated. Additionally, the straight line distances (in miles) from each household to the nearest water collection point were recorded.

Analyzing Socio-Economic Data

Socio-economic data was gathered from each household through a process called asset mapping. Each household self-reported information about household illness (i.e. how many household members had been ill over the past year) and the demand for filtered water (i.e. how many people regularly used the BSF). Additionally, through interviews and visual observations, information regarding each household's relative affluence was gathered. Because it relied heavily on subjective evaluation, each household's relative affluence was quantified rather simply. An observational score of "0" was assigned to households who lived without one or more basic needs being met. An observational score of "5" was assigned to households who had all basic needs met, but who had little or no extra "luxuries" (i.e. cellular phones, livestock, etc.) An observational score of "10" was assigned to households who lived in relative affluence: all needs were met, and the household possessed numerous luxuries (livestock, cellular phones, radios, etc.)

Results

A number of multi-faceted relationships were discovered among the data collected. One such relationship involved comparing the distance between BSFs and the nearest water collection point and the % coliform removal of the BSF. Out of the 24 households observed, % coliform removal data could only be produced for 17 BSFs. For 14 of those 17 BSFs, the distance to the collection point was determined. Results for these 14 BSFs were analyzed graphically in Figure 5, with the distance between the BSF and the water collection point plotted on the x-axis and the % coliform removal for the BSF plotted on the y-axis. An r^2 value of 0.66 was found, indicating a potential relationship between a household's distance to a source of water and the % coliform removal of the household's BSF. Figure 5 illustrates that as the distance to a household's water source increased, the % coliform removal of the household's BSF decreased. In an effort to elucidate this relationship, additional data will be collected and analyzed by future Mercer on Mission teams.

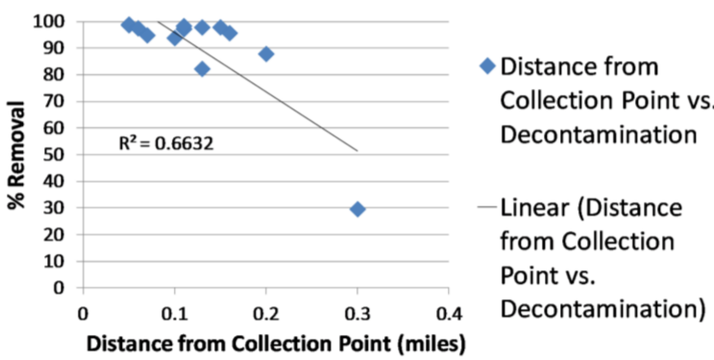

Figure 5. The potential relationship between distance from a water collection point (miles) and the % coliform removal of a BSF.

This relationship seems plausible, as the weight of the water collected by a villager is 18 kg (40 pounds) on average. A long distance between a household and a collection point would likely deter a villager from collecting water more than absolutely necessary, creating a greater likelihood that the household's BSF may be used at intervals that exceed the recommended pause time.

The factor which proved to have the largest impact on BSF effluent water quality in Sisit was the distance between a household and the community center. Of the 24 households observed, 12 were located within a 0.4 km (0.25 mi) straight line radius of the community center. Nine were located outside of that radius, and the locations of 3 could not be determined by GPS coordinates. The households containing BSFs were divided into two groups: those that were within the 0.25 mile radius of the community center, and those that were not. The data from the unidentifiable locations were omitted.

Based on the observational analysis (as described in the data analysis section), the average mechanical integrity of the BSFs located within 0.25 miles of the community center was found to be 6.1 out of 10. The average mechanical integrity of the BSFs outside of the defined radius was found to be 2.5 out of 10. The households located within the 0.25 mile radius from the community center also demonstrated more sanitary storage conditions than those outside of the radius. Within 0.25 miles of the community center, the average observational score for sanitary storage was 6.2; outside of the 0.25 mile radius, the observational score for sanitary storage was 2.5. Of the 7 BSFs that were found to be no longer functioning, only 1 belonged to a household within the 0.25 mile radius from the community center. These data are illustrated graphically in Figure 6.

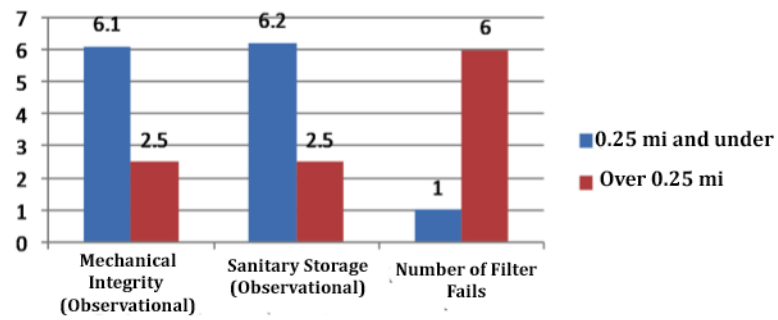

Figure 6. Technical data compared to distance from Sisit's community center.

Figure 7 provides a comparison of BSF % coliform removal to household distant to the community center. BSFs that belonged to households within the 0.25 mile radius from the community center had an average % coliform removal of 85.5. In contrast, those BSFs outside of the 0.25 mile radius averaged just 37.6 % coliform removal.

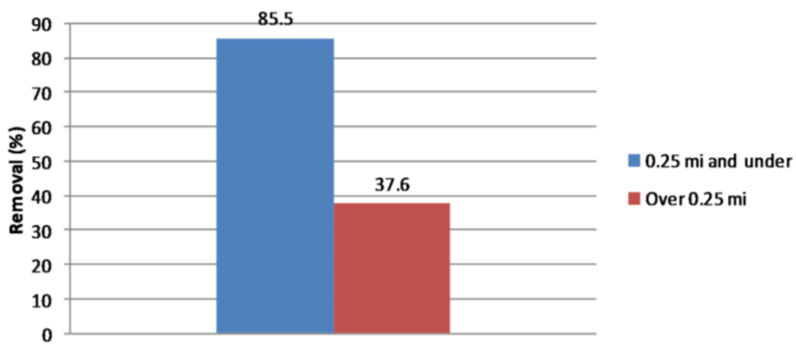

Figure 7. BSF % coliform removal compared to distance from the Sisit community center.

As shown in Figure 8, the average affluence of households within the 0.25 mile radius from the community center was 6.9 out of 10; by contrast, those outside of the 0.25 mile radius averaged just 4 out of 10 on the observational scale.

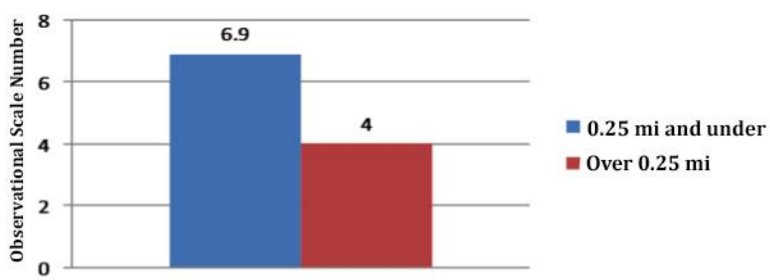

Figure 8. Average relative affluence (observational scale) compared to distance from Sisit's community center.

CONCLUSIONS AND RECOMMENDATIONS

Through examining the data collected from households in Sisit that had possessed a BSF for approximately two years, BSF performance was not found to be a one-dimensional, technical issue. While technical factors certainly are of utmost importance in designing solutions to address the developing world's clean water crisis, they are not necessarily the only factors to incorporate into a design. A strictly technical design could be easily engineered, but the data collected from Sisit highlights the need for a more holistic approach towards global poverty alleviation. Geographical ad socio-economic factors should also be considered.

Based on the analysis of the collected data, the factor which was shown to have the most impact on both affluence and BSF performance was the distance between a household and the central community. Such a conclusion testifies to the importance of community to residents of the developing world, and raises more questions than answers with regard to both the global water crisis and global poverty alleviation. Future work should be undertaken to determine what factors (if any) play into a household's location with respect to the center of community. Similar data should also be collected from other areas in the developing world, to determine if these findings are indicative of trends in locations other than Sisit, Kenya.

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