Global Livestock CRSP

The BioSand Filter for Improved Drinking Water Quality in High Risk Communities in the Njoro Watershed, Kenya

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Unsafe drinking and domestic water is a major community and public health concern in the River Njoro watershed. Low-cost household water treatment was identified as an intervention to address the problem, and the BioSand filter (BSF) was selected as the most sustainable and appropriate technology to develop for river-using households in the Njoro watershed. This brief summarizes results of a three-phase research program to develop and adapt the BioSand filter for local production and use, and test its effectiveness, acceptability, and health impacts with the population segment using river water for domestic and drinking in the Njoro and similar areas. Laboratory experiments showed sand grain size, residence time, and hydraulic loading rate have significant effects on the microbiological removal performance of the BSF. By adapting these design and operating parameters to better match local water source characteristics prior to local commercialization, performance can be significantly improved. In a six-month trial of the adapted local filter design with 30 rural and peri-urban households in the Njoro watershed, average removal performance matched controlled laboratory performance for indicator bacteria and viruses. The filters also demonstrated a very high level of user satisfaction and good evidence of commercial demand.

Background

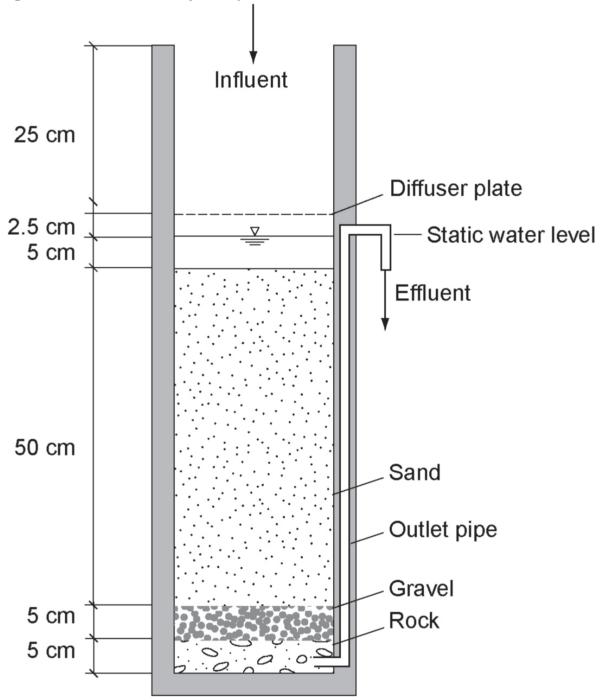
Access to safe, clean, and reliable domestic water supplies is unavailable for many households in the Njoro watershed, and emerged early in the SUMAWA project as a major community priority. The situation is similar across many rural and peri-urban communities in Kenya, where, according to the World Health Organization, less than half of households in 2004 had an improved water supply source within 15 minutes of home. Agricultural households are disproportionately affected, as they are located in dispersed and often remote communities where providing public water service is often prohibitively expensive. Consequently, over half of the households in the Njoro watershed fetch water for drinking and domestic use directly from watering points along the highly polluted River Njoro and Little Shuru Tributary, where domestic livestock are watered and many other domestic and small commercial water needs are met. Early investigations revealed recurrent outbreaks of typhoid and high rates of childhood diarrhea associated with drinking river water in the area.

To address the water-borne disease burden, low cost point-of-use (POU) household water treatment was identified as an intervention to improve domestic water quality for the population segment that depends on open polluted water sources. Review and screening of available technologies identified the BioSand filter (BSF) as best suited to conditions in the Njoro watershed (Tiwari and Jenkins 2008). A program to evaluate, adapt, and field test the BSF for use by high-risk households to treat polluted River water was launched in 2006 with the Nakuru District Ministry of Health's Public Health Division and the Civil and Environmental Engineering Departments of University of California, Davis (UCD) and Egerton University (EU).

The BSF is a slow sand filter modified to operate intermittently at household level, treating one 20-liter batch at a time. It is composed of a container, made of either plastic or concrete, which contains five centimeters (cm) of rock, five cm of gravel and a column of 50-60 cm of sand (Figure 1). Polluted water is poured into the top, flows down through the sand column by gravity and out the exit pipe where the treated water is collected. The BSF was selected for development application in the Njoro watershed on the basis of its robust design, ease of use, no recurring costs, low capital cost, high flow rate, and potential to treat turbid water.

Starting in 2006 under Phase I development, design and operating factors were tested in controlled laboratory experiments at UCD to evaluate and optimize the BSF's ability to remove bacteria, viruses and turbidity. Two different sand sizes, fine (0.17 millimeters-mm) and coarse (0.52 mm), and three maximum head space levels (10, 20 and 30 cm above the sand surface), were tested under both long (mean: 16 hours) and short (mean: five hours) batch residence time operation. Insights from Phase I research on filter design and operation were applied in the next phase of confirmatory testing at Egerton University (EU) labs in Kenya using locally constructed filters operated with River Njoro

Figure 1. Schematic of Kenyan BioSand Filter



water. Filter performance with different local sands and sizes was compared: processed fine (0.15 mm) sand from Kisumu (commercial granitic river sand), processed coarse (0.30 mm) Kisumu sand, and processed coarse (0.30 mm) locally mined porous volcanic pumice sand from the Njoro watershed. Other tests were also conducted to adapt best design and operating guidelines to local conditions.

Results from development testing at EU provided the basis for finalizing standards for commercial design, local construction, and household operation of the BSF for the last phase of field-testing undertaken in 2007. Final validation consisted of a six-month randomized controlled behavioral trial of the filters by households living in the upper and middle Njoro watershed who met a high risk profile for child diarrhea disease from drinking untreated river water established in earlier assessments. Of the 59 qualifying households enrolled in the trail, 30 were randomly assigned to receive and use the BSF. The remainder continued their normal water use practices. Filter performance in BSF households and drinking water quality in all 59 households were monitored monthly and BSF and control households compared. BSF users' perceptions, attitudes, and usage and maintenance practices were collected at three points during the trial. All households were given the opportunity to purchase the filter at a reduced price or have it removed at the end of the trial.

Major Findings

The BSF ability to remove bacteria, virus, and turbidity in water was evaluated in filter influent and effluent samples. Key findings from each research phase (I, II, and III) are presented in the following sections.

Phase I: Experimentation to Optimize Filter Design and Operation. Operating the filter with a pause of 12 to 24 hours (long residence time) between treatment of successive batches of water significantly improved the removal of bacteria, viruses and turbidity, irrespective of sand size or head level compared to no pause between successive batches (short residence time). Fecal coliform bacteria removal was significantly better for fine sand filters (+0.16 to 0.30 $\log_{10}$) and for lower head filters (+0.10 to 0.29 $\log_{10}$), independently of each other, under both long and short residence time operation, with the positive effects produced by fine sand and lower heads enhanced under long compared to short residence time operation. Fine sand and lower head also produced higher virus removals; however, the effects were considerably smaller (+0.05 to 0.10 $\log_{10}$) than those for bacteria and observed only under short residence time operation. Fine sand size resulted in slightly decreased turbidity removal under long residence time operation (-1.7% points) but showed no effect under short operation, while reducing head to 10 cm from 30 cm resulted in improved turbidity removal only under short residence time operation (+4.3% points). Irrespective of the filter's design configuration, Sacramento River water turbidity (spiked with raw sewage and MS2 coliphage - a virus that is parasitic and reproduces itself in bacteria), which ranged from five to 59 NTU (nephelometric turbidity unit to measure turbidity) over Phase I experiments, was always reduced to below three NTU under short residence time operation and to two NTU or below under long residence time operation, translating to average long and short operation turbidity reductions of 91% and 87%, respectively. Mean performance for the best BSF configuration (fine sand, 10 cm head) under long residence time operation and the worst configuration (coarse sand, 30 cm head) under short residence time operation is compared in Table 1.

Phase II: Confirmatory Testing of Local Filter Construction Materials and River Njoro Water. Testing at EU in Njoro, Kenya on the effects of local sand type and size was conducted for long (24-hour) residence time operation with the standard 30 cm head configuration. Results confirmed Phase I findings of significant improvement in bacterial removal by fine over coarse sand (1.30 $\log_{10}$ or 95% vs. 0.91 $\log_{10}$ or 88%), but found no significant difference between coarse Kisumu and coarse porous volcanic Njoro sand (0.91 $\log_{10}$ or 88% vs. 0.97 $\log_{10}$ or 89%). Turbidity and MS2 coliphage removals were not statistically different for the three sand configurations. Viral removal in the fine Kisumu sand filter averaged 0.81 log (84.5%), comparable to Phase I results for the same sand size under long residence time operation. River Njoro water is very turbid; levels averaged 133 NTU during lab testing. Turbidity removal in the Kenyan BSF filters was much worse than in Phase I at UCD, averaging only 39.3%, and filter effluent was never below 23.3 NTU. Analysis of the chemical composition of River Njoro water revealed its extreme chemical softness compared to surface waters globally; softness can reduce the BSF biofilm's ability to attract and remove suspended particles. When River Njoro water's hardness was artificially raised by calcium carbonate addition and filter performance re-tested, effluent turbidity was reduced to below five NTU, confirming the negative influence of Njoro water's extreme softness on BSF Njoro River turbidity removal. The fine Kisumu sand filters demonstrated comparable fecal coliform removal under eight and 24-hour pause time in further testing. Switching between highly turbid and polluted river water to cleaner and clear borehole groundwater in filter operation resulted in degraded groundwater quality and led to the decision to limit BSF operation to river water for Phase III.

Phase III: In-home BSF Performance and Drinking Water Improvement. Based on Phase I and II findings, fine Kisumu sand and a 30 cm head space container were selected for field validation in river-using households. BSF trial households were advised to only treat river water in the BSF, to allow eight hours of pause between batches for a maximum of 60 liters (three batches) treated per day, and to use water from the overnight batch (morning collection) for drinking. Local volcanic sand was too coarse to produce fine size sand, and the cost and complexity of chemical additives to raise hardness prohibitive for households to sustain. The standard 30 cm head space design, which handles a maximum of 20 liters, was selected because it retains full flexibility to operate the filter with higher or lower head by simply reducing the batch volume. Table 2 compares the performance from each phase of BSF development and testing, for the standardized fine sand 30 cm head filter design configuration. Over the six months of monitoring, fecal coliform and turbidity removal in the 30 household-operated BioSand filters (95% and 43%, respectively) was comparable to results obtained under controlled EU laboratory testing with River Njoro water (Table 2). Across trial homes, the bacterial quality of BSF treated river-sourced drinking water was greatly improved (average 39/100 ml) compared to control homes' untreated river-sourced drinking water (average 504/100 ml) and found to be comparable to that of public borehole groundwater-sourced drinking water (average 29/100 ml) in homes that occassionally used this improved source for drinking.

Table 1. Comparison of average performance of best (fine sand, 10 cm head, long operation) and worst (coarse sand, 30 cm head, short operation) filter design configuration and operation (CI – Confidence Interval).

Performance Outcome	**Best**	**Worst**	**Difference: Mean (95% CIs)**
Fecal Coliform removed (Log_{10})	1.83	1.08	0.75 (0.52, 0.97)
MS2 Coliphage Removed (Log_{10})	0.68	0.25	0.44 (0.20, 0.67)
Turbidity Removed (%)	92.4	86.4	6.0 points (2.5, 9.6)

Although the BSF did a relatively poor job of clarifying river water, BSF users considered the treated water to be better aesthetically than untreated water. Specifically, 97% reported better taste, 83% reported better smell, and 75% reported better appearance. Intervention households were able to easily incorporate BSF water treatment into daily routines, reported more than enough clean water production, and recommended the BSF to friends and neighbors. At the termination of the trial, 69% of control households and 90% of intervention households purchased the BSF at the reduced offer price (US $4.86 vs. US $22.91 commercial price).

Over half the trial households used rainwater and river water interchangeably as water sources in their BSF. This mixing did not degrade the quality of BSF effluent, and collected rainwater quality was improved through BSF treatment. BSF households reported a variety of health and non-health benefits from using the BSF, which motivated high levels of observed user satisfaction and post-trial purchase.

Table 2. Mean and standard deviation of BioSand filter performance under long operation for the fine sand 30 cm hydraulic head design configuration. [1]Operated with moderately turbid and hard Sacramento River water collected at West Sacramento City's Intake and spiked with raw sewage and MS2 virus coliphages.[2]Operated with highly turbid and extremely soft River Njoro water collected at Mary Joy and spiked with MS2 virus coliphages. [3]Operated with highly turbid and extremely soft River Njoro water collected at various water points by households.

Filter Performance		**Three Phases of BSF Development and Testing**		
Outcome	Indicator Measure	UC Davis Lab Experiment [1] (3 Filters)	Egerton U. Lab Testing [2] (2 Filters)	Household Trial [3] (30 Filters)
Bacteria Removal	Mean Log Fecal Coliforms removed (percent equivalent)	1.51 ± 0.36 (96.1%)	1.30 ± 0.40 (95.0%)	1.30 ± 0.95 (95.0%)
Virus Removal	Mean Log MS2 virus coliphages removed (percent equivalent)	0.81 ± 0.35 (84.5%)	0.81 ± (84.5%)	not tested
Turbidity Removal	Percent of NTU of Turbidity removed	88.5 %	39.3 %	43.2 %

Practical Implications

This research has demonstrated the Kenyan BSF design (Figure 1) significantly improves the microbial quality and safety of contaminated river and collected rainwater for drinking and domestic needs when operated by Kenyan households who depend on polluted surface sources and unsanitary collection and storage of roof-harvested rainwater. The standardized design and simple construction process are suitable for local commercial production by artisan masons in the Njoro and similar communities where access to improved sources is inadequate or lacking. Users found the BSF easy to operate and maintain and experienced a range of health and non-health consumer benefits (including reduced incidence of diarrhea and less time spent treating contaminated water), allowing households to quickly take up and sustain the practice of treating their river water. These findings provide strong justification for development investment to widely promote and market commercial Kenyan BioSand filters to at-risk rural segments in the Njoro and similar watersheds in Kenya.

The research also demonstrates the value of local investigative lab testing and adapting the BSF design and operating guidelines to accommodate differences in the turbidity and chemical composition of local waters, and household water switching behavior. Poorer households lacking improved water supplies often depend on relatively turbid and contaminated surface or shallow well water. The BSF was able to perform well for microbial removal under high turbidity conditions, but was shown to perform poorly in removing turbidity when the source water was chemically soft, without pre-treatment with a coagulant or source of artificial hardness, which make filter operation more costly and complicated for households. While the BSF greatly improved the safety of river and rainwater, by removing 95% of bacteria and 84% of viruses, a post-filtration disinfection step by pasteurization or chlorination (with cheap, widely available products like WaterGuard or AquaGuard, in Kenya) is recommended to guarantee safety.

Further Reading

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